Evaluation of key factors influencing a South African based electrical utility to utilise smart grid technologies for power quality management

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Abstract

With the ever-growing global drive to reduce carbon emission compelling the need to diversify Energy generation options, solar and wind renewable energy sources are the popular choices in South Africa. Since photo-voltaic sources are variable and injected by means of a solid-state interface, special consideration is needed, to control the frequency and have sufficient energy available during all load conditions. In addition, maintaining adequate levels of reliability and voltage quality to end users necessitates more sophisticated and intelligent network capabilities.

It is within this context that this dissertation seeks to examine the influence of smart grid on electrical network and explore its application by a South African power utility to facilitate the monitoring and improved management of power quality on distribution networks. Internationally, research trends indicate that the implementation of the smart grid on electricity network can and does lead to increased network reliability, energy efficiency, and improved power quality.

However, this theory has not been fully tested in South Africa and until recently, South Africa has mostly trailed the world in the adoption of smart grid technology. This lack of empirical evidence led to the primary research question: Does the use of smart grid technology on distribution networks provide opportunities to improve the management of power quality for a South African-based power utility?

Secondary research questions were formulated to adequately answer the stated primary research question and to achieve this, based on the problem statement, it was necessary to:

- Develop measures for the concepts power quality management and smart grid technologies;
- Determine the scope of the power quality management program in a South African-based power utility;
- Determine the extent to which South African-based power utilities can utilize smart grid technologies for their network operations;
- Identify themes, links, and patterns in the description of industry participants regarding their experiences and industry sensitivity to power quality issues and their views on smart grid technologies; and
- Formulate factors that influence a South African-based power utility's decision to use smart grid technologies for power quality management.

Based on the philosophy of pragmatism as the research paradigm, an empirical investigation comprised of both quantitative and qualitative studies were undertaken as part of mixed-methods research design. In the quantitative phase, a comprehensive literature study is used to describe the concepts of power quality management and smart grid technologies and thereafter a non-experimental, cross-sectional online mail survey is carried out using a structured questionnaire with the participation of South African power utilities who have a program to manage power quality of their electrical networks.

A proposed model and hypotheses are verified, using a single-stage descriptive analysis by cross-referencing with findings made from the literature study. The verification of the model supports the proposed hypothesis that smart grid technologies can be used to enhance the management of power quality on distribution networks for a South African-based power utility. To improve confidence of the findings and to ensure that the problem statement was appropriately addressed and to enable data triangulation to take place, it was necessary to develop a related instrument that was content and context specific.

To achieve this, a descriptive and explorative qualitative inquiry is undertaken by means of semi-structured interviews, to develop an in-depth description of seven individuals representing large industrial customers of power utilities in South Africa. Their reactions to interview questions were used to gauge the sensitivity of industry role-players to power quality issues and their views on smart grid technologies. Once the quantitative and qualitative data was interpreted, a SWOT analysis was performed on the research findings, to formulate suitable factors toward the implementation of smart grid technologies by a South African-based power utility.

The main conclusion drawn in the research is that if a South African utility were to implement smart grid technologies, it can enable them to improve the management of power quality. Other conclusions drawn include that larger utilities like Eskom and metropolitan utilities are in a better position with adequate resources and power quality expertise to effectively enhance the management of power quality through the use of smart grid technologies. Another conclusion was that regardless of the type of industry, voltage dip events experienced by the industries can interrupt productions and loss of income. It also emerged that power quality events may lead to severe complications for various industries, which power utilities may not be aware of. For instance: Chemical and Mining industries are susceptible to explosions and fires if an unplanned prolonged supply interruption occurs, posing a safety risk to workers.

Likewise, untreated and unsafe drinking water may flow into the pipelines if a power quality event were to cause power interruptions to the Water Pumping and Purification industries. Moreover, the following factors that influence a South African utility's decision to explore the use of smart grid technologies on distribution networks are identified:

- Power utilities can collaborate with research institutions and non-governmental institutions to develop smart grid pilot systems;
- Development of a microgrid system at a smaller scale is possible through government support;
- Utilities can be enabled to keep an efficient, automatic modernized electricity network;
- Utilities have an opportunity to acquire the intelligence to facilitate the integration of the technologies of renewable energy generation (solar and wind) into the distribution network, and maintain efficient voltage control capabilities;
- The benefit of advanced distribution automation can enable a South African utility to improve the monitoring of power quality and reliability of supply to the benefit of customers by proactively rerouting supply networks during times of power outages or severe voltage fluctuations; and
- Utilities can achieve a dynamic real-time decision and management of network parameters, and identification of system disturbances can also be enhanced through the smart grid on a SCADA system.

Finally, it is concluded that a need for synchronized measurement of power quality data in a wide area network exists for a South African utility, to allow comparison of PQ data measured at different network locations as though the measurement were all made by a single instrument. This phenomenon can be made possible by synchronization of the phasor measurement unit using a common time distribution such as the GPS. It is therefore recommended for power utilities in South Africa to consider the use of PQ instruments with precise time protocols that can allow synchronized data measurement such as phase angle variations across a wide area, which would be useful for comparison of PQ disturbances on smart grid implementation for distribution networks.

Keywords: Distribution networks, phasor measurement units, power quality, power quality management, smart grid technologies, and synchronized measurement of PQ

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When a person decides to undertake post-graduate studies ten years after qualification, as a prospective student, I understood that it would be a daunting task, necessitating hard work, commitment, perseverance and a great deal of self-discipline. What initially began as a routine investigation of a power quality complaint at Phokane municipality-Hartswater, transpired into a research discussion with my former undergraduate Lecturer and culminated with this research towards a Masters degree.

Having accumulated sufficient work experience accompanied by numerous technical reports into power quality investigations at work, I thought I was well prepared and knew what to expect. However, like many other researchers, I did not take into account, the daily program which was underpinned by its unusual challenges and frustrations associated with post-graduate study, while also being a fulltime employee, a husband and a father to my children. Needless to say, this turned out to be even more challenging than expected, attributable to my limitations as a person with visual impairment.

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List of Acronyms

ADA	Advance Distribution Automation
AMI	Advanced Metering Infrastructure
CVI	Content Validation Index
CVTs	Constant Voltage Transformers
DC	Direct Current
DG	Distributed Generation
DR	Demand Response
Dx	Distribution
DySCs	Dynamic Sag/Dips Correctors
ECSA	Engineering Council of South Africa
EMC	Electromagnetic Compatibility
FACTS	Flexible Alternating Current Transmission Systems
Fr	Frequency
GPS	Global Positioning System
GWh	Gigawatt Hour
ICT	Information and Communication Technologies
I-CVI	Item Content Validation Index
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
IoT	Internet of Things
IPPs	Independent Power Producers
ISO	International Organisation for Standardisation
JAWS	Job Access With Speech
LPU	Large Power Users
MW	Megawatt
NERSA	National Energy Regulator of South Africa
NMD	Notified Maximum Demand
OT	Operational Technology
PDC	Phasor Data Concentrator
PLC	Programmable Logic Controller
PMU	Phasor Measurement Unit
PoC	Point of Connection
PoD	Point of Delivery
PoS	Point of Supply

PQ	Power Quality
PQM	Power Quality Management
PU	Per Unit
PV	Photovoltaic
QoS	Quality of Supply
REIPPP	Renewable Energy Independent Power Producer Procurement Program
RTIC	Research Testing and Innovation Centre
SCADA	Supervisory Control and Data Acquisition
S-CVI	Scale Content Validation Index
SGT	Smart Grid Technology
STATCOM	Static Synchronous Compensator
SVC	Static Var Compensator
SWOT	Strengths, Weaknesses, Opportunities and Threats
TQM	Total Quality Management
UPS	Uninterruptable Power Supply
VSDs	Variable Speed Drives
WAM	Wide Area Measurement
WAN	Wide Area Network

1 Chapter 1 – An orientation to the study

1.1 A poetic approach to power quality

Jabu is an engineer at the Eskom's Distribution Division, based in the Free State operating unit. Part of his job outputs includes developing strategies to improve the technical performance of the electrical network. An electrical engineer by profession, Jabu is a registered professional engineer with the Engineering Council of South Africa (ECSA) and his area of specialization is in electrical power quality. A few years ago, while at home, he came across some power quality events which he sought to describe poetically, as narrated below:

One day he woke up and suddenly realized that something wrong was going on. It was a wonderful bright morning, but since it was a winter morning, he did not expect to see any sunshine that early. He felt he was missing something when he realized that the alarm clock had not gone on. Seems too late! He jumped off the bed and watched the clock, its numbers were flashing and needed to be set.

He wondered why the clock failed during the night. His desktop computer, which is connected to an uninterruptible power supply (UPS) that can continuously supply reliable power in case of a power shortage, had managed to download a movie during the night. Considering this fact, Jabu concluded that no power cut had taken place that night, besides, the refrigerator and microwave oven were working well. Jabu had a great dilemma to answer! Otherwise he would get into trouble with his boss explaining the reason to be so late for work.

On his way to work he heard on the radio that there had been a major storm in the Southern part of Free State the previous night. He understood that the storm could be the main cause of his clock problems. Lightning during storms may cause faults in the power lines. These faults cause a sudden voltage reduction in most of the busbars of the electrical network, including the one that supplies electricity to Jabu's house, or the one that supplies your home.

This power quality event is called a voltage dip, and it lasts until the protection of the line trips, disconnecting the faulted line. When this line is the only electrical supply, the loads supplied by this line undergo a complete interruption of electricity, until the line is successfully reconnected. Jabu found out the origin of his time problem. But now he was concern about how to solve it, and he asked himself a question, "Is there any reliable power sources?"

There is no fully reliable power supply. The more reliable the supply, the more expensive it is. Therefore, we are talking about a cost/benefit compromise. The clock needs to improve its tolerance to voltage dips. Since the clock power demand is very low, a battery supply is enough to keep it working during these power quality events.

Despite the fact that these power quality events have been occurring in the power grid since it was built more than ninety years ago, the interest of consumers of electricity in this issue has risen during the last two decades. Power quality events began to be disruptive ever since the extended use of sensitive electronic loads such as personal computers, home electronic devices, adjustable speed drives, and industrial automation. Since then, the focus of research has been a characterization of power quality disturbances, analysis of the electromagnetic compatibility of equipment, and improvement of the equipment's tolerance.

In the afternoon after work, Jabu went back to his house, about 20 km from town. It was very cold and getting dark outside because of limited daylight, and warm days in June are rather few, especially in the Free State province. Therefore, people are dependent on electric lighting and heating most of the day.

He rested on the couch and started to play with his mobile phone. Ten minutes later, he started to feel very upset because the light was blinking. He thought to himself, somebody must be playing with the light switch! But as Jabu was alone in the house, there was nobody who could be playing with the light switch. The annoying problem was a power quality disturbance called flicker, which is noticed as variation in light intensity. It has been statistically proven that the level of annoyance follows a normal distribution reaching the maximum value when the variation happens 9 times per second. What really bothered Jabu was why was his incandescent lamp flickering.

Jabu was facing a power quality problem for the second time that day. Similar to the event in the morning, he wanted to know the cause of the flicker and how to mitigate the effects of the disturbance. He remembered that near his home there is a factory with several arc furnaces for steel production. These arc furnaces demand a huge amount of current that varies considerably during the melting process. The current variation produces a voltage variation that is proportional to the network impedance.

Network impedance reflects the "strength" of the network. In other words, networks with a very large power generation and power transmission capacity have low impedance. A strong network handles high demand variation very well with a minimum voltage variation. Although Jabu's house is not too far from town, electric energy to his house is supplied by long power lines from a remote substation. These long lines have a high impedance.

As a consequence of the network weakness and the high variation of the factory's power demand, Jabu was facing voltage fluctuations. These fluctuations provoked the light variations called flicker. This problem doesn't happen often in cities because the distribution networks are stronger and capable to handle high demand variations. Flicker analysis is not a simple issue and the first researches were conducted in the 1960s. As incandescent lamps have been used since the origin of electric systems, customers endured flicker disturbances for decades.

Power utility such as Eskom, concerned about this power quality disturbance, is working to satisfy customer demands. However, the solutions are not cheap and some of which are:

- Increase the power generation capacity;
- Build new transmission lines; or
- Relocate industrial customers.
- Jabu was concerned about his domestic problem and did not want to wait for years for a solution by the power utility. He thought that probably the voltage variation was not simultaneous in all the three phases of the distribution system. Considering that his house has a three-phase supply, he connected the lamps to different phases, after making some little changes in the electrical wiring of the house. As a result, the variation of luminescence of each lamp was compensated by the others. Jabu felt very proud of solving his flicker problem at no cost.

Two days after solving his flicker problem, Jabu was reading an email from a friend who owns a small factory. His friend was concerned with a problem he was facing in many production lines in his factory. He noticed that many motors used in the production line were suffering overheating, which reduces the lifetime of motors dramatically. The expected lifetime of the motors is 20 years. However, he reported that after 8 years he started to replace the motors because of the degradation caused by that overheating. He, therefore, wondered what was wrong with the motor specification.

Jabu answered his friend why his motors were failing so early. Due to the increase of voltage harmonics in the network, most of the motors are experiencing this fast ageing, and failing before completing half of their lifetime. He explained that these voltage harmonics are a common disturbance in industrial electric networks where there are many power electronic loads. These power electronic loads are the main source of harmonics in electric networks. He further explained that when making power factor correction in the factory, there is a possibility of creating a resonant circuit.

A resonant circuit occurs at the frequency when the impedance of the system (mostly the power transformers) and the impedance of the power factor correcting device (capacitors) are equal. This is called the resonant frequency and if there is an exciting frequency being produced by nonlinear loads at that frequency, they would be amplified and cause high distortion levels on the network. Furthermore, Jabu described this power quality disturbance and wrote back to his friend: "Harmonic distortion is characterized by the harmonic spectrum, where all frequencies are represented by the magnitude of the signal.

There are filters that mitigate the harmonic distortion. The filters are tuned to eliminate a specific harmonic. We need to evaluate the harmonic spectrum in your factory to design the suitable filters to reduce the harmonic distortion to extend the lifetime of your motors. This solution will be feasible if the cost of the filters is lower than the cost of motor replacement"

A few weeks later, Jabu received a phone call from his uncle who asked about the frequent power interruptions that were implemented by Eskom and are reported on mainstream media (televisions, radios and print publications). Jabu explained that these were due to insufficient generation capacity of electricity on the power grid which if not well managed, could result in a total blackout of the power system. This was to be managed by implementing compulsory load shedding to ensure that the power system has sufficient reserve capacity safely above the country's electricity demand. He explained that rotational load shedding is typically implemented whenever the system frequency falls below the 'safe' limit and is also used as a response strategy to cope with reduced output beyond reserve capacity from power stations taken offline unexpectedly such as emergency maintenances. Hmm..., I am not sure about that. Jabu's uncle remarks in reluctant agreement.

Realizing that his uncle is still not convinced of the actual causes of the power interruptions, Jabu explained: 'remember that Eskom supplies over 95% of the country's energy usage. During the 1980s, Eskom decommissioned three of its coal-fired power stations, as there was an excess of generation capacity at the time. With the demise of Apartheid in the 1990s, came huge investments and economic growth. This growth led to Eskom committing to the accelerated electrification of the previously marginalized households in rural communities, which resulted in a rapid growth in electricity demand. At the same time, the government tried to deregulate the electricity supply by inviting the private sector to build new power stations to meet the rapidly growing demand for electricity and Eskom was at the time prevented to build new power stations.

So, with no bidders coming forward to construct new power stations, there was effectively no investment into new generations in the early 1990s, which eventually resulted in the shortage of capacity that was experienced in the 2000s. In 1998, a detailed energy review was released by the Department of Minerals and Energy in which it was warned that unless timely steps were taken to ensure that demand does not exceed available supply capacity, generating capacity would reach its limit by the year 2007.

This was not surprising the first blackout was encountered since 2008 when Eskom declared a state of emergency and instructed its largest industrial customers to reduce consumption to minimal level. "Ahh, yes, I understand now."s Jabu's uncle remarked with eagerness.

Having impressed his uncle on explaining the causes of power interruptions problems in South Africa, Jabu was now excited to inform his uncle about some of the solutions available to address the power generation deficit to meet the country's demand. He explained that The South African Government had since allowed Eskom to build new coal fired power stations and encouraged a power generation mix of energy generation options for South Africa.

As a result, thereof, the South African government has approved the generation of electricity by Independent Power Producers (IPP's) in order to meet this demand. Renewable energy such as wind and photovoltaic solar was the popular source of energy and the IPP's have obtained licenses from the National Energy Regulator of South Africa to deliver energy to Eskom and municipalities.

His main concern was that since these renewable energy sources are distributed all over the electricity network and predominantly at medium voltage distribution networks with high impedance, their variability could affect or be affected by the existing power quality performance of the network. He then wondered how Eskom and the municipalities would be able to better manage the quality of electricity in the presence of these renewable energy sources.

This dissertation presents an investigation to evaluate the key factors that can influence a South African-based power utility's decision to utilize smart grid technologies for power quality management. Voltage dips, the power quality disturbance that caused malfunctioning of Jabu's alarm clock, every year cause losses of billions of rand's to manufacturing industries in South Africa and throughout the world. Power system harmonics, the power quality disturbance that caused overheating of motors at his friend's factory is becoming an important problem.

Other power quality problems such as voltage unbalance can also cause modern rotating machines to overheat and fail prematurely. For power utilities, the integration of intermittent renewable energy sources distributed throughout the network brings variability and uncertainty. At the same time, there will continue to be unexpected disturbances stemming from load variations, network faults and conventional generation outages. A technical solution to provide a reliable monitoring and *reporting method is needed to address this conjunction of difficulties in order to improve the future management of power quality in South Africa.*

1.2 Problem Statement

According to [1], it is said that the driving force (and indicator) for economic growth and development of a country is its energy consumption. Regarding this, it is found that the total energy consumed per capita is linearly dependent on technological progress and is a measure for the standard of living or quality of life achieved in all communities [2]. It has therefore been encouraged in modern society to consume available energy without constraint to achieve the highest quality of life.

Increase in global electricity usage, and the implications on the environment, is not sustainable without future consequences. Power utilities are facing a predicament in ensuring the quality of power supplied, whilst still meeting the increased supply demands.

The inescapable reality of the 18th century is that Nikola Tesla and Alexander Graham Bell are the key architects of today's electricity and communication systems respectively. If both were somehow placed on a time machine and transported to the 21st century, Bell would hardly recognize the components of today's communication systems. On the other hand, Nikola Tesla will still be able to recognize almost all the major components in today's electrical system. This means that the existing electrical power system needs some design improvements and important upgrades to cope with the 21st century needs.

Regardless of its lack of modernization, in terms of end-use, electricity remains the most efficient form of energy [3]. It provides a means of achieving most basics of human life. With the natural progression of technology and the desire to reproduce, society is forced to produce and consume more electricity to meet these needs. Since its discovery by Tesla, the world population has increased considerably; with an increase from 700 million in 1750 to 6.8 billion in 2009 and expected to reach 9.7 billion in 2050 [4]. This growing population along with the development of information technology, advanced manufacturing and other modern technologies has resulted in the increase of global electricity demand [3].

As part of the global growth, South Africa's main distributor of electricity, Eskom has in the past 20 years, committed to the electrification of households in rural communities, clinics and schools of previously disadvantaged communities; achieving an electrification milestone of 4.9 million connections [5]. This achievement, as well as the country's economic growth, has led to a considerable increase in South Africa's electricity demand, to a point that the power system was operated to a limited reserve margin.

In 2008 the consequence of operating the power system with a limited reserve margin was realized when Eskom was forced to introduce load shedding [6]. Due to the unprecedented occurrence of the load shedding events, renewable energy sources have seen an increase in development and application in South Africa, with an estimated target allocation of over 3.9 GW capacity on wind, solar and hydropower, and close to 1900 MW already contributing to the national electricity mix [7], [8].

This is in accordance with the capacity allocated to renewable energy generation [9] approved for the Independent Power Producers (IPP's). It has been designed to contribute toward sustainable socio-economic and environmental growth and to start and stimulate the renewable industry in South Africa. This is also in line with the government's commitment to contributing to a green economy [10].

On examining the outlook of renewables, the worldwide trend reflects the importance of developing countries in advancing renewable energy. Collectively, developing countries have more than half of global renewable power capacity, with China and India being the most rapidly expanding markets [11], [12]. Brazil produces most of the world's sugar-derived ethanol and has been adding new biomass and wind power plants [11]. In Africa, renewable markets are growing at rapid rates in countries such as Egypt, Tunisia, Kenya and Tanzania, with Kenya being the world leader in the number of solar power systems installed [12].

It is evident that an interest in renewable distributed energy sources has increased in recent years due to environmental concerns about global warming caused by the emission of greenhouse gases resulting from burning of fossil fuels [11], along with the need to diversify energy generation mix [13]. With a dilemma of sustainable development, providing basic needs, enabling energy mix, and maintaining the reliability of supply and voltage quality, there is a great need for improving the manner in which monitoring of the electricity network is achieved.

Monitoring relies strongly on the behaviour of consumers of electricity, and the strategies implemented by power utilities in managing power quality. Technologies such as smart grid can make possible the safe integration and control of intermittent sources of renewable energy (wind and photovoltaic solar energy), which could have a negative impact on power quality [14], [15]. Through these technologies, power utilities can better minimize the effect of power quality due to its enhanced monitoring ability of the network. As a result, smart grid technologies should be promoted and implemented for enhanced management of power quality for both the country and globally.

1.3 Rationale of the research

The existing electricity network infrastructure is over a century old and some of its important components have been operated beyond their useful life. Putting it differently, the ageing components of the electricity supply industry is of growing concern.

With the modern electricity comprising many nonlinear elements in conversion equipment, loads and power electronic converters also produces power quality problems in the form of harmonic distortion and as the ageing network infrastructure deteriorate further, it can result in catastrophic failure of critical equipment such as power transformers [16].

In South Africa, it has been identified that about 80% of the transmission lines and power transformers are over 25 years old and 40% of switchgear equipment such as circuit breakers are over 50 years old [17]. In addition, until recently, most of Eskom's performance measures were good: post-1990, power quality and security of supply were improving along with a rapid improvement in extending access to electricity.

However, in recent years, power quality has deteriorated as the ageing network is run to the maximum, and security of supply has been prejudiced by delays in implementing network investment programs [17].

With the advancement of solid-state devices and power electronic circuits, there has been an increase in the use of sensitive devices comprising of power electronics that are quite sensitive to power quality disturbances such as voltage dips, transients and harmonics [18]. In the absence of adequate backup supplies, even a slight disruption to the supply (i.e. a voltage dip) can shut down this sensitive equipment, resulting in economic losses to a wide range of industries, including financial, services, healthcare and process manufacturing

For a very long time and still ongoing, Eskom's slogan has been to keep the lights on, which is the ultimate mission of power utilities to pledge uninterrupted supply of electricity to end users. In doing so, long-distance transmission lines and distribution networks are employed for delivering power to end users. This process of transferring power from one voltage level to another has led to increased stresses to the entire network, resulting in a utility such as Eskom unable to keep its existing network operating at adequate levels of reliability and quality [17].

Existing constraints in reliability and efficiency of the present electricity network are the consequence of ageing infrastructure and a lack of inadequacy of innovation in the power utility industry. The range of problems confronted by the present electricity supply network is compounded by growing pressure from customers for higher reliability and power quality requirements needed in the digital era and has prompted the need to consider smart grid technology in improving the performance of the existing system.

In addition to aging infrastructure and nonlinear elements that give rise to power quality problems, the need to diversify energy mix in South Africa has attracted a number of private investments in renewable energy sources, They are known as the Renewable Energy Independent Power Producer Procurement Program (REIPPPP) and connect renewable energy sources onto the utilities existing network. Power range from 100 kW to a few MW [7], [8]. These renewable energy sources offer more possibilities to end-users, such as:

- Improving availability and reliability of electricity;
- Peak load shaving;

- Selling power back to utilities;
- Power quality (improvement of voltage regulation, by additional control in reactive power).

The increasing penetration rate of grid-connected renewable energy sources (RES) is likely to contribute technical concerns such as voltage waveform quality [14]. It has to be addressed solved in order to exploit the opportunities and benefits offered by RES. Power utilities, have the obligation as part of their license agreement issued by the National Energy Regulator to ensure that customer voltage qualities are kept within prescribed technical limits. The advancement of the modern electricity network where generation is mostly from environment-friendly sources with loads relying on power electronics and computerised control will require a proactive and "smart" approach to the management of PQ and network stability.

It has been shown that smart grid technologies can provide innovative methods of monitoring and control power system reliability [19], [20], [21]. These studies point out that the emergence of the smart grid is highly related to the need of integrating distributed renewable energy sources, improvement of energy efficiency, and meeting the demand for increased quality and reliable supply.

It is further pointed out that a smarter grid provides means to handle bi-directional power flow and can contain the problems associated with the intermittency of renewable energy sources [14]. Having information on power flow and demand can help to identify the cause of power system disturbances. By this better understanding of the root-cause, the goal is to reduce interruptions and waveform disturbances.

Amongst the solutions available is to design an intelligent system technical performance monitoring system reflecting the IEEE recommended practices on for example, power quality and voltage stability. This study qualitatively explores the opportunities of improving the standardised practises when measuring those parameters used for monitoring (such as PQ parameters) synchronously and to also include current.

The South African PQ standard is a Quality of Supply (QoS) standard based on benchmarking system technical performance on voltage only. As argued above, root-cause analysis of any event of concern fundamentally requires current to be included and why in this research, the latest version of the international PQ measuring standard is preferred. Edition 3 of the IEC 61000-4-30 includes the measurement of current and seems to allow the traditional boundaries between the different approaches to system technical performance, to become less prominent.

As an example in this postulation on a fresh look towards system operations (mostly distribution level in this research), using network coherent data measured according to the IEC 61000-4-30 Edition 3, by the inclusion of current parameters and improving time-stamping to be within the requirements of synchrophasors, a new type of Wide Area Measurement (WAM) is realised that is no longer aiming at small-signal dynamic stability in transmission networks.

It is already reported that a similar need exist in distribution networks where large integration of RES are done as the intermittent and unpredictable nature of generation power in this network, can cause dynamic instability between the distribution network and the transmission system, and between different RES within that distribution network.

It is also known in South Africa, that traction lines being energised from single-phase supplies are a major contributor to significant voltage instability. To the extent that RES and large mining operations in the Northern Cape had to interrupt production as resulting from phase voltages being too high and/or significantly unbalanced.

Also, it was found that the perceived reactive power support from RES as stipulated in their grid code agreements, could not be achieved under all network contingencies when voltage dips occur. Known as voltage dip ride-through capability, it was concluded that the technical design of these installations could not include accurate models of the grid-connected inverters and that they had to use simplified models that did not accurately predict the dynamic performance.

Having access to comprehensive system technical performance in these distribution networks will allow a smarter distribution grid that enable large-scale integration of environment friendly RES whilst serving end-users operating sophisticated loads with a sufficiently good voltage quality to remain making money and building the economy.

1.4 Research aims and objectives

The overall aim of this study is to evaluate key factors influencing a South African power utility's decision to utilize smart grid technologies on distribution network as to further enhance the management of system technical performance with specific reference to power quality. This involved the consideration of the following main question:

Does the use of smart grid technologies provide an opportunity to improve the system technical performance (such as power quality) in a South African-based power utility?

To answer this question effectively the research outcome that could justify evidence of being a "master of the science and knowledge" in this field of electrical engineering, some secondary research questions that provides context to the qualitative research reported in this dissertation:

- What is the scope of power quality management at South African power utilities?
    - How many of them do monitor PQ at all?
    - If they do monitor PQ, to what extent? In other words, where in the network is PQ measured? (Measurement strategy, do they monitor the inflow of energy and at what is considered as key customers?)
    - How many of them, and what is the extent, do use the results of PQ monitoring to manage their networks?
    - How many of them, and to what extent, do report to NERSA or own management on the annual system technical performance?
- How can smart grid technologies be utilised to improve network operations in a South African-based power utility?
- How does the experience and industry sensitivity to power quality influence the perceptions of industrial customers regarding the quality of electricity offered by power utilities?
- What are the key factors that influence a South African-based power utility's decision to utilise smart grid technology for power quality management?

Through the literature review and a conceptual framework, the research was accomplished using the following secondary research objectives:

- By developing a measurement instrument that measures the concepts of power quality management and what smart grid technology is about;
- By determining to what extent management of power quality is implemented by utilities in South Africa;
- By determining the extent to which South African power utilities can use smart grid technology to improve electrical network operations;
- By identifying themes, links and patterns in the description of research participants regarding their experience and industry sensitivity to power quality issues as well as their views on smart grid technology;
- By formulating factors influencing a South African-based power utility's decision to use smart grid technology for the management of power quality.

1.5 Conceptual framework

According to [22], [23], a conceptual framework is similar to a literature review as it lists the most important research work conducted on a specific subject. However, it goes beyond the elementary literature review and consequently, it underpins the framework for the research.

A conceptual framework, if well designed, can be seen as an instrument to support research [23], as it is structured in a way to best describe the research as it progresses [22]. This equips the researcher with the ability to develop an understanding of the situation under study.

Therefore, it is stated that the conceptual framework is seen as the central point of the study as it directs the research to the desired direction by [22], [23], [24]:

- Providing links from the literature to the research questions and research objectives;
- Enlightening the research design;
- Establishing points of reference for discussion of literature, methodology, as well as analysis of data; and
- Contributing to the reliability of the study.

1.6 The context of this study

In this study, the researcher conceptualized the research in terms of a framework that looks at the specific activities that involve managing power quality activities by utilities in the South African context. As a result, the researcher adopted the following models to use as a framework for this research:

- The model for Energy Management Systems – ISO 50001 [25];
- Framework for the management of power quality in South Africa, as defined in the National Electricity Regulator (NER) Power Quality Directive [26]; and
- The smart grid framework as described in [27].

1.7 Concept definition

In clarifying the concepts adopted in this study with definitions, the researcher wishes to emphasize that the principles for quality management are generic in nature, and therefore applicable for use in the context of electricity distribution. Accordingly, this study was conceptualized in terms of, and in consideration with the following delineations:

- **Quality management**: In this context, management is defined as a way or action to take charge or maintain control over [28], [29]. In this study, managing entails the skillful employment of scientific capabilities, skills and ingenuity to perform monitoring and measurement of power quality proactively and efficiently.
- **Energy Management System**: The model, developed by the International Organisation for Standardisation (ISO), provides a framework for implementing, maintaining and improving an Energy Management System, with the aim to achieve continuous improvement of energy performance.
    - A similar methodology to the Energy Management System can be applied to Power Quality, where the continuous improvement is key to increase reliability and performance [26], [30].
    - The authors in [30] further state that in managing power quality, it is absolutely mandatory to measure, analyse and improve power quality in a continuous process to achieve sustainable results. Therefore, fundamental to the model is the measurement, monitoring and management of power quality, for which smart grid technology is of specific interest, in accordance with the stated research objectives.
- **Smart grid conceptual architectural framework:** The National Institute of Standards and Technology (NIST) provides a framework for smart grid technologies, and it provides set of views and descriptions that are the basis for discussing the characteristics, uses, behaviour, interfaces, requirements and standards of the smart grid [27].
    - The framework for the smart grid is also described as a catalyst for creating a technical foundation for a smart power grid that links electricity with communication and computer control to achieve great gains in the enhancement of reliability, capacity and customer service [30], [31], [32]. It, therefore, provides methodologies and tools required for the implementation of advanced metering, distribution automation, demand response and wide-

area measurement capabilities [21]. The framework provides key components for future power delivery, as well as the integration issues for the smart grid, as discussed in [20], as part of interoperability of the components.

- **The NER PQ directive**: This framework forms the basis for the management of power quality in South Africa, in which utilities are required to implement a system to manage power quality on its network [26]. Different approaches to the framework were previously adopted in managing power quality, specifically, managing voltage dip performance for contractual obligation and continuous improvement [33].
    - Similar to the Energy Management framework, the approach adopted in [33] makes emphasis on the continued improvement of power quality, through the interaction between utilities and its customers. Equally, the framework became the basis for determining the role of a diverse set of technology in utility power quality management [34], in a manner that will improve both utility business efficiency and customer satisfaction. , for the context of this research, the NER directive framework provides a useful tool for which utility interaction with its customers is considered as one of the required components for the management of power quality.

These conceptual frameworks collectively underpin the joint framework for this research, with the model for Energy Management System (ISO 50001) used as the main contributor, adapted for the Management of power quality.

1.8 Research approach

In current research, a need to look beyond mainstream framework exists, utilizing diverse approaches in research design and methodology to enhance the understanding of the field under investigation [35]. It is mentioned in [36] that researchers often confuse the concepts of research design and research methodology and, consequently, these concepts necessitate clarification.

1.9 Research design

A number of authors have presented various meaning of research design and accordingly, these definitions are used in this research. According to [37], research design is best described as the overall plan according to which the participants of a proposed study are selected, along with the means to which data is to be collected. Babbie and Mouton in [36] describe research design as a plan or blueprint to conduct the research, likewise, in [38], research design is compared with an architectural blueprint.

Therefore, the manner in which the research design is organized will be to fulfil the role of achieving the purpose of the research; and this will be determined by the manner in which the research problem is formulated. In addition, it is stated that the research problem will also determine the methods and procedures, i.e., the types of measurements to be used, sampling, data collection and data analysis to be employed on the proposed research [39]. The research design of this study entails the overall strategy that the researcher undertakes to integrate the different elements of the study in a coherent and logical approach, in order to effectively address the research problem.

1.10 Research methodology

The overall research methodology concept was presented in [40], in the form of an “onion” in which the thoughts with regard to the research problem lie in the centre and several layers have to be “peeled away” before getting to this central position. On the other hand, it is stated in [36], [41] that the research methodology refers to the researcher’s general approach to carrying out the research project.

Research methodology is viewed as focusing on the research process and the kind of tools and procedures used in this research [42]. The research design and methodology are discussed in more detail in Chapter 4 and it provides the approach to which this research was conducted.

1.10.1.1 Empirical exploration

An empirical exploration was undertaken for the study, using qualitative and quantitative methods to obtain data that would support the reliability and validity of the research. The term empirical is described as knowledge derived by the process of practical and scientific experiences, experiments and enquiry [43].

It is stated in [44] that an empirical investigation entails having a planned process of collecting and analysing data in a systematic, purposeful and accountable manner. The goal of this empirical investigation was to obtain reliable and valid data, in accordance with the research problem and the associated research objectives. As the nature of the research problem and research objectives necessitated a purposeful research design to achieve the requirements of the stated research goals and consequently, the researcher decided on a mixed methods research design.

1.10.1.2 Mixed method research

Mixed methods research is considered as the type of research where qualitative and quantitative methods are combined in a single study [45] - [47]. When considering the research problem, accompanying research questions and the related objectives of this research, the researcher is convinced that the combination of qualitative and quantitative methods for this research offered the combined advantages of the respective qualities offered by both approaches [24]. Some of the advantages offered by the mixed methods approach are:

- To gain data from a wider range of perspective;
- To enhance the significance of interpretation;
- To clarify the underlying logic; and
- To explain unique circumstances, opinions and practices.

The combination of qualitative and quantitative approaches led to the adoption of a pragmatic position because it offers a workable solution to the many elements of the research problem [47], [48]. Specifically, the envisioned results had the potential to provide the researcher with a better understanding of the present and expected levels of power quality and perceptions on smart grid technology, described from both the power utility and industrial customer perspective.

1.10.1.3 Quantitative research

An empirical survey was chosen as a research method for the quantitative section of the mixed methods design. It is believed that a survey is most suitable in quantitative research for the purpose of collecting data by means of a questionnaire from respondents regarding their views, decisions along with past, current and future experiences [49], [50].

In terms of the quantitative research phase of this study, the survey presented an opportunity to obtain data about the current or extent of power quality management program employed by South African-based power utilities, as well as their stance regarding the use of smart grid technologies for their electrical network operations.

1.10.1.4 Study population and sample

The study population of the quantitative research comprised of a non-probability purposive selection of power utilities based on the researcher's personal experience and on commendations by experts in the field of power quality, for their involvement and interaction with the utilities, in accordance with the related selection criteria described in [41], [51]. Using this criterion, a number of utilities (municipalities and Eskom) were purposefully selected for use in this research, because the selected group of utilities was accepted as the study population.

1.10.1.5 Questionnaire as measurement instrument

A questionnaire was developed aligned with the dimensions and elements of power quality management and smart grid technology, yielding seven constructs in accordance with the research aims and objectives. The questionnaire comprised of forty-six test items that tapped the dimensions and elements of seven constructs.

A five-point Likert scale was used as the rating scale, to enable scores of either low or high value, to represent the extent of commitment, knowledge, decisions, opinions and experience of the respondents with regard to power quality management and smart grid technologies.

1.10.1.5.1 Validity of questionnaire

Validity, according to [52] refers to how well a technique, instrument or process measures a particular concept. It refers to the extent to which an empirical measure precisely reflects the concept or theory it is intended to measure, yielding scores that reflect the true variables being measured [53].

Validity of this research was improved by amongst others, using peer endorsement during the research design and methodology, in accordance with the stated research objectives. According to the authors in [53], [54], it is stated that validity is divided into three categories: 1) *construct validity*, 2) *predictive validity*, and 3) *content validity*. Content validity deals with the measure of how well the content of the instrument is well represented and suitable for the construct being measured.

In this research, content validity was supported by the questionnaire items constructed according to the theoretical underpinnings of power quality management and smart grid technologies. To ensure content validity, the questionnaire was subsequently pilot tested by subjecting it to a panel of experts in the field of power quality that validated the proposed questionnaire and made comments and recommendations regarding the representativeness and suitability of the questions.

This content validation exercise was concluded by computing a content validation index (CVI), reported to be the most widely used measure of content validity [55]. Content validation of the questionnaire is discussed in more detail in chapter 4 and provides the process undertaken to carry out the content validation.

1.10.1.5.2 Statistical analysis

Analysis of the quantitative survey data was done with the aid of the statistical consultancy services of the North-West University, Potchefstroom Campus. Collected data from the questionnaire was statistically converted using the SAS (Sas Institute Inc., 2011) computer program.

A single-stage statistical procedure was followed in which descriptive statistics were used to develop frequencies, means, ranking and standard deviations results in order to represent a specific statistical position of the recorded responses.

1.10.1.5.3 Generalisation

The purpose of this research was not to make use of a sample to generalize the findings to a particular population, but to determine the extent of the management of power quality program employed by a number of utilities in South Africa, as well as to measure their position regarding smart grid technologies, in order to arrive at a meaningful conclusions from the findings, and then to formulate key factors that could influence a South African-based power utility's decision to utilize smart grid technologies for power quality management. Therefore, no generalization was made to the population from which the sample was taken.

1.10.1.6 Qualitative research

Qualitative research entails an interpretive, naturalistic approach to its subject matter and investigates participants in their natural environment [56]. Qualitative research is further described in [37] as attempting to determine the dynamic and changeable nature of reality by collecting subjective data, presented verbally by people in the form of language instead of numbers, as would be the case with quantitative research. In this study, qualitative research methods were used in the form of semi-structured interviews, together with the structured questionnaire (quantitative research), as part of the mixed methods design.

1.10.1.6.1 Study population

Subject matter experts in the field under study were selected as participants based on their knowledge and direct involvement in electrical activities within their industry's as the study population for the qualitative phase of the proposed research. Specifically, the study population of the qualitative phase comprised of officials in positions dealing with power quality and electrical maintenance planning, at large key customers of Eskom distribution, in the Free State and North West provinces of South Africa. The study population and selection procedures, as described in Chapter Four, were applied when conducting interviews as part of the qualitative research.

1.10.1.6.2 Qualitative data analysis

The aim of the qualitative data analysis of this research was to examine the elements of the collected data set and to identify themes, links, and patterns in the description of the response from the participants, according to the stated research aims and objectives. In this study, the researcher used the delineation of the coding techniques for qualitative data analysis set out in [57], and performed the analysis of the data according to the thematic content analysis process, using the model for coding and data analysis during qualitative empirical research as proposed in [58]. Meanings, themes and patterns were examined and interpreted, so as to understand the social reality of the industry participants regarding power quality and smart grid technologies.

1.11 Dissertation layout

The contents of this dissertation is demarcated and presented by seven chapters as follows:

Chapter One: An orientation to the study

Chapter 1 explains to the general reader what power quality is about, the rationale for this research, the aim, followed by the objectives, the experimental design and methodology applied.

Chapter 2: Literature review

Chapter 2 presents part 1 of the literature review and delves into the theoretical background of power quality and smart grid technology. It briefly analyses for demonstration purposes the general phenomenon of electrical power quality reflecting the measuring principles of IEC 61000-4-30.

This chapter also provide an overview of what has been done by other researchers with regard to the subject of smart grid technology and further expound on the phasor measurement units as a component applicable for smart grid application.

Chapter 3: Conceptual framework

This chapter is part 2 of the literature review by focusing on the conceptual framework within which the overall design of the research is undertaken.

Chapter 4: Design and methodology

Chapter four contains detailed information on the quantitative and qualitative research design undertaken as part of a mixed methods research and data collection methodologies.

Chapter 5: Data analysis

Chapter 5 provide details of procedures in data analysis as undertaken during the research.

Chapter 6: Data analysis and interpretation

This chapter analyse and interpret quantitative and qualitative data.

Chapter 7: Conclusions and Recommendations

In Chapter 7 the research study is concluded by important findings along with the limitations identified to this research and finally proposes complimentary research topics.

2 Chapter 2: Literature Review

2.1 Introduction

Power utilities have an opportunity to improve the management of power quality making use of smart grid principles. Note that the focus is on distribution networks as end-users mostly connects to distribution voltages. Transmission networks are used to interconnect distribution networks and traditionally, as the feed-in of energy obtained from large thermal power stations.

In this research, the focus on distribution networks, as motivated in Chapter 1, stems from the future distribution network being characterised by the large-scale integration of RES and end-users that increasingly make use of equipment that can be more sensitive than before (power electronics and computerised control).

Power quality in the electricity network is presented from fundamental principles as well as the concept of the smart grid system. The goal is a better understanding on the opportunity for smart grid technologies as a control instrument.

2.1.1 What is power quality

Power quality is a set of parameters that are used to describe the quality of electrical energy in a practical power system. Deviations beyond a certain level need to be managed to ensure compatibility with customer equipment. For example, faults in a power system cause short-circuit currents to flow into the fault, realising voltage sag conditions in the interconnected electrical network. Voltage sags (or dips) is just one example of what is regarded as a PQ concern because normal operation of electrical equipment can be affected when the voltage applied to the terminals is reduced too much and for too long.

A number of concepts and parameters are generally used to represent the concept of “power quality” as shown in Figure 1. Three categories are defined as follows:

1. The steady-state quality of the voltage waveform is described by the magnitude, the distortion (due to harmonics), the symmetry between phases in terms of the 3 voltage phasors (magnitude and phase angle) and lastly, the “stability” of the voltage magnitude referred to as “flicker”.
2. Voltage dips, swells and transients are voltage waveform “disturbances”.
3. The continuity of electricity supply is categorised as “reliability” and is measured in terms of factors such as the frequency and duration of interruptions.

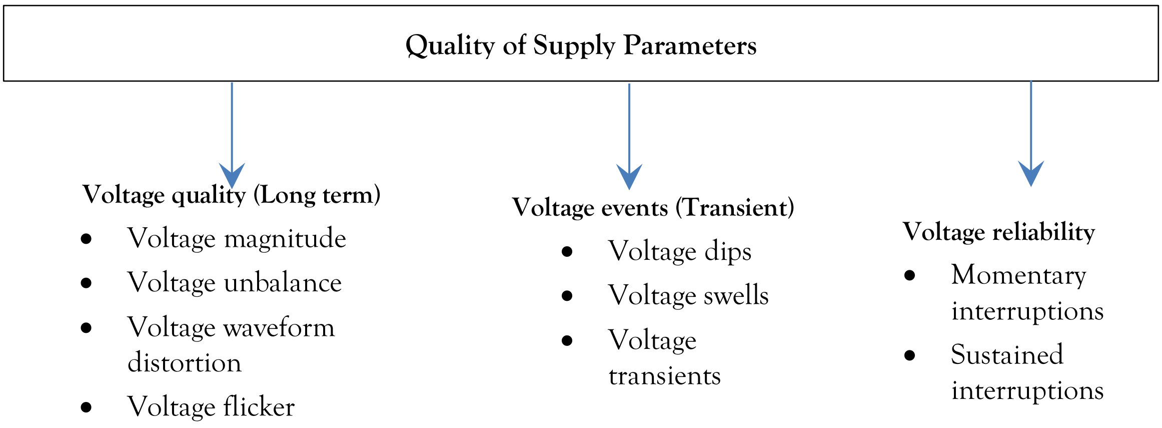

Figure 1: Quality of Supply parameters

There is a harmonised approach as to what constitute the concept of “power quality”. An international measuring standard, the IEC 61000-4-30 describe how PQ parameters should be recorded. The goal is that any instrument that complies to this measuring standard, will report the same result.

Every country will use a country-specific technical standard to analyse the recorded PQ for the purpose of assessing the compliance of a Point of Connection (PoC)[1] to the requirements of a technical standard applicable to that country. In South Africa, the NRS 048 series of documents are used as the technical standard, consisting of part 1 to part 9[2].

Of particular interest to this dissertation is NRS 048 part 2. At the time of writing, the 2007 version was in use and is reflected in this dissertation. Although an updated version exists, it has not yet been adopted by SA utilities as NERSA is not yet. A significant change in the 2015 version on the regulation of voltage has been the source of controversial discussion and concern amongst SA engineering communities and consequently, this dissertation is focusing on the 2007 version and accordingly, analysis of the PQ parameters is described in section 2.4 with reference to the application of this standard.

Before the different PQ parameters are discussed, the basic measuring principle of the IEC 61000-4-30 is briefly reviewed in the next section as these principles governs the application of the assessment principle in a technical standard on PQ such as NRS 048. But first, it is necessary to provide a description of power quality.

2.1.2 Power quality definition

The power quality fraternity has come a long way over the past few decades with identifying power quality problems and the first hurdle needed to overcome was defining exactly what power quality problems occur and how to define them. When an electrical network is referred to having power quality problems, it is implied that some deviations exists which results in equipment failure and decline in the performance of the network. A more general definition of power quality is:

> *It is the electrical supply problem manifesting in voltage, current, or frequency deviations that result in failure, disruption or mis operation of customer's equipment or processes [59].* Two definitions for power quality are given in [60], one according to the IEC which defines power quality as a "*set of parameters defining the properties of power quality delivered to the user in normal operating conditions in terms of continuity of supply and characteristics of voltage (symmetry, frequency, magnitude, waveform)*" and the other according to the IEEE which states "*the concept of powering and grounding electronic equipment in a manner that is suitable for the operation of that equipment and compatible with the premise wiring system and other connected equipment*".

According to [61], power quality is defined as "*any power problem manifested in voltage, current or frequency deviations that result in failure or incorrect operation of customer equipment*". It is evident from both the IEEE [60] and Dugan *et al. in* [61] definitions of power quality that the electricity that is delivered to the equipment must be such that it allows the equipment to work at its most optimal point. Detection of power quality deviations through measurements, monitoring and reactive management is considered an effective strategy. To detect power quality deviations, a monitoring system is required, which should be integrated into a management system. Such a power quality management system will, amongst other, address the following components:

- power quality measurement,
- power quality analysis and diagnosis,
- power quality mitigation by eliciting implementation of corrective measures.

2.2 Electromagnetic compatibility

In order to understand the concept of "PQ compatibility" it is first needed to analyse "electromagnetic compatibility" as the basis from which PQ compatibility is derived.

The reasonable and optimal functioning of electrical and electronic equipment with respect to electromagnetic disturbances is the aim of EMC. The IEC [62] defines electromagnetic compatibility as "*the ability of an equipment*

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[1] Traditionally known as a Point of Supply (PoS) or a Point of Delivery (PoD).

[2] Parts 1, 3 and 5 have been incorporated in the other parts and withdraw.

or system to function satisfactory in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment".

Electromagnetic disturbances may be radiated or conducted, and electrical/electronic equipment may potentially be sensitive to any or to both of these types of disturbances. The principle of conducted electromagnetic phenomena may exist on electrical network at both low and high frequencies resulting to voltage quality problems on the network [63].

The authors in [64] assert that voltage quality can be seen as an umbrella for deviations from ideal voltage conditions at a site in a network. This is equivalent to electromagnetic disturbances of the voltage at the site. According to [65], electromagnetic disturbances are defined as electromagnetic phenomena that may degrade the performance of equipment. Only in the case of no disturbances, is the voltage quality perfect. Therefore, adequate voltage quality contributes to the satisfactory function of electrical and electronic equipment in terms of EMC.

As the transformation from a centralized electrical grid system (centralized generation power stations) to a distributed electrical system (distributed renewable energy sources) is rapidly growing [66], technologies such as smart grid has drawn tremendous attention and introduce new technological concepts that require safe integration of renewables to the network and the interconnection between sensitive electrical and electronic components [19].

It is important to maintain electromagnetic compatibility between these components to assure uninterrupted and high-quality supply of electricity on the network. This means that sensors and higher speed communications networks will be needed as key components of the smart grid systems. It is described in [67], [68], that one of the "sensors" to be used in a smart grid is the "smart meter" that is electronic in nature and possesses a communications capability to provide information to the utility with respect to power usage, reliability, power quality etc.

From an EMC point of view, it is believed that the smart grid introduces some new elements that should be considered [69] and the design and placement of sensors with varying bandwidths may be affected by the electromagnetic environment in the electrical network. While South African-based utilities may be well aware (or likely to be aware) of the electromagnetic environment found in high and medium voltage substations, they may not be as much understanding of the appropriate EM environment in a wind power plant or PV power plant.

Power electronic based PV solar and wind energy equipment is known to emit disturbances causing power quality problems such as voltage fluctuations, waveform distortion, voltage flicker and voltage asymmetry [70], [71]. In addition, the presence of new devices that transmits electromagnetic disturbances being introduced creates the potential of interference. EMC specifications are also not routine in South Africa for home appliance manufacturers, who may not account for more complex EM environment present today from home appliances. The aim is to have an electromagnetic environment, where electrical equipment and systems function satisfactory without introducing intolerable electromagnetic disturbances to other equipment.

In order to preserve good quality of electricity on the network, regulatory standards are available that specifies the limits that must be imposed on loads and networks, with the objective being to provide an environment in which EMC is achieved [62]. To ensure compatibility of equipment connected on the network, it is necessary to control the maximum level of disturbance that may be present at any point in the network and establish a level of disturbance to which every item of equipment will be immune. In achieving EMC, it is stated in [63] that several parameters are to be specified and controlled. These are:

- Emission level;
- Immunity level;
- Compatibility level;
- Emission limit;
- Immunity limit;
- Planning level

In South Africa, the NRS048 standard is the application practice that provides guidelines for power utilities to use in the management of low frequency EMC parameters - this represents their internal objectives in designing the network in order to ensure system compatibility [72], [73]. Figure 2 shows the inter-relationship of these low frequency EMC parameters.

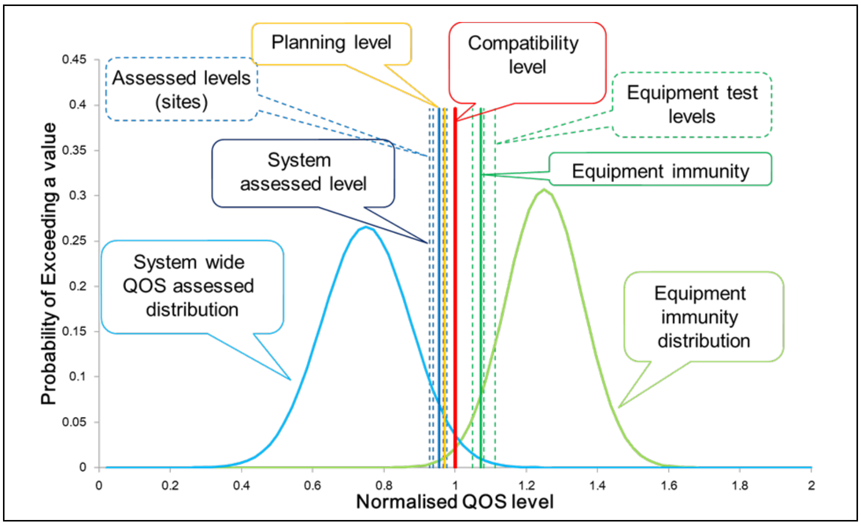

Figure 2: Compatibility concepts to achieve EMC [74]

The principle adopted in NRS048 is to set compatibility levels above the disturbance level that is greater than 95% of the measured values of the entire system over time. As a result, the ambient disturbance level will exceed compatibility level in only 5% of cases.

Figure 2 also shows that for each parameter, licensees need to set planning levels, below the compatibility level. These planning levels form internal power quality objectives, aimed at managing customer emission levels and system characteristics in order to achieve equipment compatibility levels. The concept of compatibility in PQ is further expounded in the next section, with emphasis on compatibility to NRS 048.

2.2.1 The NRS 048 concept of compatibility in PQ

The concept of compatibility in the context of PQ is to first qualify the specific PQ parameter, and secondly, for which a quantitative level can be set as requirement when the equipment is exposed to a supply variation up to this level, is required to function as normal.

This principle of compatibility can be best explained by the analysis of Figure 3.

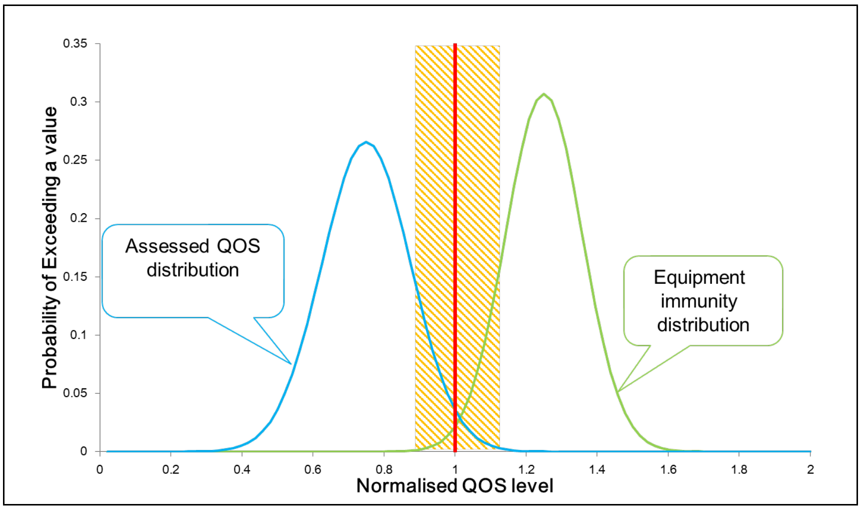

Figure 3: The concept of compatibility

A normal distribution (Figure 3) for the variation in supply conditions (blue curve) and for the variation in equipment immunity (green curve) depicts the changes of a PQ parameter over time and the difference between different equipment within the same batch and between different types. The concept of compatibility in PQ is based on this principle.

In order to better explain each probability distribution shown in Figure 3, equipment immunity (green curve) first and then the system assessed distribution (blue curve) is discussed below. Voltage magnitude is used as PQ parameter to support the explanation.

Consider the green curve in Figure 3: In a population of 100 pieces of the same type of electrical equipment, even if it is not from the same manufacturer, not all 100 pieces will have the same level of immunity against the magnitude of voltage. Some equipment will seize normal operation at a reduced voltage where other equipment could still be functioning normally. Some will fail at a level of increased voltage whilst others will still be functioning normally.

These two extremes are visualised in Figure 3 as the low probability on the left-hand side (lower values of voltage) and the low probability on the right-hand side when voltages are high. It means that some equipment has a lower immunity threshold and others a higher level of immunity. Most of the equipment will have the same level of immunity; that is around the peak of the green normal distribution curve.

Now consider the blue curve in Figure 3: When recording voltage magnitude over a period of time it can be expected that due to the changes in loading and supply conditions, voltage will change. Voltage can change at any time due to the change in loading or even due to how voltage is controlled at remote points in the network. Analysis of a voltage profile over time mostly result in a normal distribution as shown by the blue curve in Figure 3. Most of the time the voltage should be at a nominal value (being controlled by for example a tap changer), but sometimes it can be low and sometimes it can be high, albeit for a lesser period of time. This probability is displayed on the *y*-axis and the voltage magnitude on the *x*-axis.

Compatibility is portrayed as an area of overlap in Figure 3. If immunity is low and the PQ parameter (voltage magnitude) high enough that the 2 curves overlap, some consequence such as maloperation or even failure can realise.

Users have some control over the position of the green curve at the right-hand of the *x*-axis. Equipment specifications during tender processes can as example. acknowledge the network into which it will connect based on characteristic PQ performance of a specific PCC. Practically, it means special equipment to be used, either directly, or being compensated by regulating the voltage locally by means of specialised solutions (additional equipment such as an UPS). Doing this will move the green curve further to the right. Being further away from the left-hand curve resulting in less overlap. Additional costs will be incurred, and the level of expenditure will be the compromise of equipment availability against return on investment.

Utilities have similar control over the position of the blue curve on the *x*-axis. By spending money on lower fault levels and higher distribution/transmission voltages, voltage regulation can be improved (example of voltage magnitude used here). Even for a utility, some return on investment has to be considered and networks will sometimes be not optimally designed.

NRS 048 part 2-2007 is the document that defines the levels of compatibility for every PQ parameter [74]. If utilities manage their networks to contain the statistical variation of a PQ parameter to be less than a certain value (the right-hand values in the blue curve), than it is expected that the operational risk to users of electrical equipment will be minimised.

It implies that SA users have to acknowledge the compatibility levels in PQ set by the NRS 048 part 2-2007 for SA. Only a few users understand PQ beyond voltage magnitude. As example, users acquire sophisticated equipment from Europe that performs very well when energised from European networks, but when used in SA, the same performance is not achieved, even with PQ standards in each country similar. European utilities normally manage networks better due to reasons such as better budgeting and management practises. PQ is generally worse in Africa if compared.

2.2.2 The consequences of compatibility in PQ to users

Figure 2 and Figure 3 fully visualises the principles of PQ management to electrical utilities. By tracking the network technical performance, the position of the blue supply curve is made visible and based on this information, budgets for network management and upgrades can be planned.

In a practical network, the position and shape of the blue supply curve will be a compromise based on the considerations above. The real risk to users and utilities realise when no information exists on the position and shape of the blue supply curve and the green equipment immunity curve. Position of these curves is not time-independent and requires continuous updates of the system performance.

In South Africa, the quality of electricity is not regulated operationally. Regulatory requirements exist in theory, despite being mandatory both from a licensee perspective as set by the National Energy Regulator of SA (NERSA) and by the SA law. Practically, only a few municipalities do measure PQ parameters, and those that do measure, will rarely have sufficient visibility of system technical performance to derive the characteristic PQ performance of a network [75]. That is why this research aims to qualitatively measures the extent and how they operationally use measured data.

The consequence of not managing compatibility in PQ can be significant to both the utility and the user. When overlap of system disturbances and equipment immunity occurs, it realises for users as an operational or business risk. Production processes can be interrupted when equipment shuts down or fail. Not only the cost of equipment has to be considered, but also the loss in production, loss of sales and even the consequential reputational risk can (and has in SA) caused businesses to close doors [76].

This visualisation of compatibility in Figure 3 validates how important electricity of good quality is to an economy. It is an additional reason to the importance of the research undertaken and reported in this dissertation as this research reported on the extent by which users and local utilities regard PQ as important and do have measures in place to control it.

Since the inception of PQ measurement in SA, Eskom was and still is the leader of measuring PQ and using it to manage networks. As the only transmission supplier in SA and serving relatively good PQ to most municipalities, Eskom is probably the reason why electricity in SA has remained relatively good.

2.2.3 The limitations of compatibility in PQ

An electrical network cannot be operated to serve electrical energy 100% compliant to the minimum technical standard for 100% of the time. The principle of compatibility is therefore based on an approach that at any point (and between a number of points), it cannot be compliant to the compatibility criteria for a specific PQ parameter all of the time but should be for at least 95% of the time.

It means that a site can be non-compliant for 5% of the time. For one month, 5% translates to 1.5 days. If the 5% non-compliance concentrates during the 1.5 days, this site can be strictly regarded as compliant. From a user perspective, this remain a counter-productive situation. Fortunately, electrical networks do not behave in such manner and a statistical distribution of supply variations will normally cause the non-compliant states of a PoC to be distributed fairly uniformly over the time period.

It is the inherent complexity of the electric system that move electric energy from the point of generation to the point of consumption, combined with variations in weather, generation, demand and other factors that accounts for the many reasons why supply quality can be compromised. The authors in [64] consider PQ as only a compatibility problem, as PQ for them reflects how well the equipment connected to the network is compatible with the voltage events in the network. Compatibility problems consist of at least two solutions; clean up the power or make the equipment resilient. Typical solutions for a utility to clean up power quality are suggested in [77], [78].

2.3 Measuring principles of IEC 61000-4-30

The measurement of a voltage dip, swell and transient is done differently from how the measurement of steady-state parameters (magnitude, distortion and others). Traditionally, PQ measurement was based on measuring voltage parameters only. The reason was that since the utility delivers voltage to a customer and because the utility has to control that voltage to be within acceptable minimum levels of variation, the assessment of compliance to the technical requirements on PQ, has to be based on voltage.

The principle remains, namely that voltage in principle reflects the Quality of Supply (QoS). Non-linear loading and the interaction between these non-linear loads increased significantly over the past decade and the rate at which these devices are introduced, continue to increase. Power electronics are at the core of these devices enabling the versatility and energy-efficiency that make them an attractive solution. The principle of operation is however inherently non-linear.

This non-linearity realises in the waveform of the current withdrawn being not a replica of the voltage. Due to this current flowing through non-zero supply impedances, the resulting non-linear voltage drops manifest as "distortion" in the voltage at the terminals of the load. This distortion is normally studied by harmonic analysis and why the concept of Total Harmonic Distortion (THD) is used to qualify waveform distortion [61], [70], [78].

Analysis of harmonic currents helps to better understand voltage distortion and one reason why edition 3 of the PQ measuring standard, IEC61000-4-30, published in February 2015 included the measurement of PQ parameters for current [79].

The measurement of voltage for the purpose of detecting a voltage dip, swell or transient is presented in next in section 2.3.1 and thereafter, steady-state PQ parameters in section 2.3.2.

2.3.1 Measurement of voltage dips, swells and transients

The IEC 61000-4-30 standard requires that the voltage waveform be digitised with a minimum number of 128 samples per fundamental frequency cycle. The first goal is to track the rms voltage. It is needed for the instrument to know where the waveform zero crossings are as the fundamental frequency is not perfectly fixed at for example 50 Hz. A cycle can be less than, or even slightly more than 20 ms. Normally, it requires a dynamic sampling rate to adjust the number of samples in order for 128 samples (at least) to reflect only one fundamental frequency cycle.

Observe one cycle of a 50 Hz waveform shown in Figure 1. It is evident that less samples result in a less accurate "measurement" of the original waveform. The reason why 128 samples is needed comes from the Nyquist criterion (2^n) as the highest frequency component to be extracted by Fourier analysis will then be limited to the 64th harmonic component.

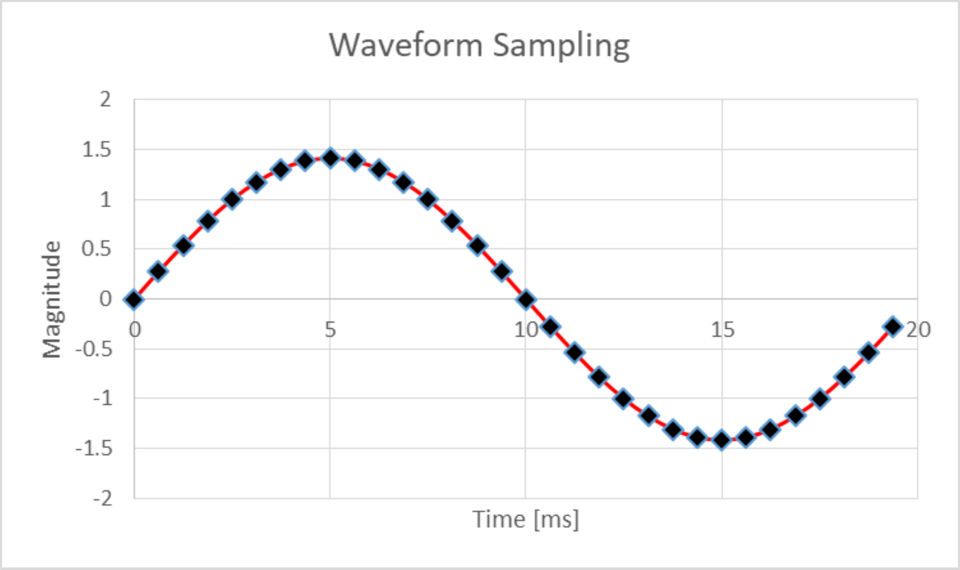

Figure 4: Sampling a 50 Hz waveform showing 32 points per cycle as illustration

Calculation of the rms voltage can occur after the first complete cycle consisting of N data points:

$$V_{rms} = \frac{\sqrt{\sum_1^N V_i^2}}{N}$$

Equation 1

Each data point (V_i) is squared and the squared sum divided by the number of samples N in Equation 1 to obtain V_{rms} the rms voltage. Knowledge of the harmonic content of the waveform is not needed.

It is possible (after the first full cycle at fundamental frequency) to update the rms voltage value in shorter intervals. A half-cycle as minimum is required by the IEC61000-4-30 when tracking voltage to detect a dip or swell condition. It means that a voltage dip (or swell) can only be detected 10 ms after it has started.

Two parameters, namely the depth and duration during the voltage sag condition has to be recorded according to the IEC61000-4-30 requirement, visualised in Figure 5.

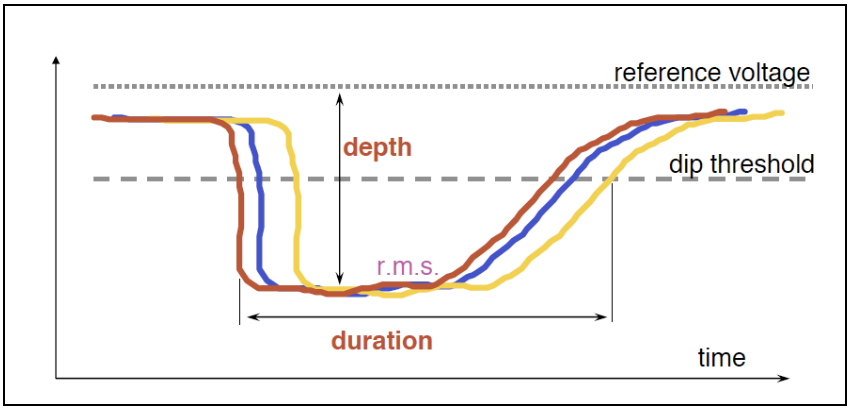

Figure 5: The IEC61000-4-30 measurement of a voltage dip [80]

The reference voltage is the setpoint where the network is operated. If a tap-changer exist, then a setting for example above 11 kV can be chosen for operational reasons. Under normal conditions, the tap-changer will keep the operating voltage near this point given the operating range of the tap-changer and the system voltage at the transformer is within specification. Otherwise, and also during the time period before the tap-changer operates (dead time) as well as in systems without active voltage control, the operating voltage at any moment can be less than this "expected" value of the 11 kV as example.

Observe that a fixed reference voltage is used in this explanation. It is possible to track voltage dips making use of a fixed threshold from the setpoint but in the explanation in this section, the principle of Figure 5 is applied as a customer will normally expect a fixed voltage at the point of supply.

Assume the operating voltage is at 10.6 kV. The IEC61000-4-30 specifies the onset of a dip condition is when the operating voltage sags below 10% of the reference value (11 kV in this case). Being at 10.6 kV, the dip condition will start when any one of the 3-phase voltages drops below 9.9 kV, meaning that a drop of only 700 V will trigger an instrument to start recording a voltage dip.

In Figure 5, the red phase triggered the instrument to record a dip. At that instant, the duration timer of the dip recorder is started and measured until the last phase voltage, yellow in this case, recovers above the 10% threshold. How these 2 dip parameters are used by the NRS 048 in dip classification, is discussed in section 2.5.

The same approach is used to detect a voltage swell condition. When voltage rise above 10% of the reference value, the instrument will be triggered to record a possible swell condition. If voltage remains above 10% for longer for a period of 3 s (in NRS 048 part 2-2007), then it is no longer a voltage swell but regarded as an overvoltage condition. This is discussed in more detail in section 2.6.1

2.3.2 Measurement of steady state PQ parameters

A fundamental measuring principle for steady-state parameters is defined in the IEC61000-4-30 by the 10/12-cycle block values. In a 50 Hz system, it is a 10-cycle block value (period of 20 ms) and in a 60 Hz system a 12-cycle block value (period is 16.666 ms) as the goal is to collect waveform data for 200 ms.

The Fourier analysis is then applied to the 200 ms block of voltage and current data points. Harmonic voltage and current phasors per harmonic order are then used to calculate active- and reactive power and sequence components for example. Many other parameters are derived and has the potential for a huge volume of data. A reduction of data is obtained by aggregation principles shown in Figure 6.

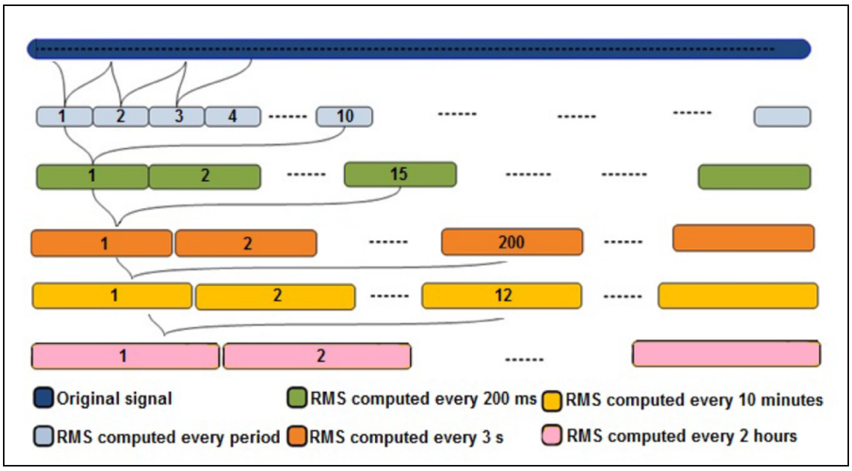

Figure 6: IEC 61000-4-30 aggregation principle [81]

Phasor information is lost when aggregating the 200 ms phasors to first 3 s (15 block values) and then to 10 min values as only rms values of the phasors are aggregated, not angles. A reduction factor of firstly 15 (from 200 ms to 3 s values) and then another reduction factor of 200 (from 3 s to 10 min values) result in an overall reduction factor of 3000.

Application of the NRS 048 part 2-2007 when assessing the compliance of a PoC to the minimum requirements, requires 10 min values. Any PQ instrument, when compliant to the IEC 61000-4-30 edition 3 requirements for Class A performance, will produce 10 min PQ data that will result in the exact same assessment of PQ at the same PoC.

2.4 The assessment of compliance to the compatibility and limit requirements of NRS 048

A set of PQ data has to be subjected to the assessment rules of NRS 048 part 2-2007. At least 7 consecutive days of 10 min values are needed, starting at midnight until midnight one week later. The idea is that a representative cycle in production (electricity at the power station and network operations) and consumption (at end-user) is needed.

This 7-day dataset could mask the PQ concern at a specific site as the data recorded could be during a time period when voltage quality was good due to special conditions during that time such as light loading, or some disturbing loads not active, good weather and others. The true character of the network is better revealed using more data over a longer period of time.

Only for voltage magnitude, an absolute limit value is stated whilst all other steady-state parameters for voltage quality (unbalance, distortion and flicker) is assessed based on a 95% percentile that has to be less than a value constituting compatibility between supply conditions and user equipment.

Networks being operated at or near the limit value for compatibility are strictly compliant, but from an operational point of view, not realising the goal of managing PQ. A borderline situation can be a risk to business (supply and use). For this reason, a planning level is applied with the idea that with a planning level value less than the limit value, the utility can intervene before a parameter increase beyond the compatibility requirement.

No limit value can be set to voltage dips and swells and the assessment of how well the network performed is done against a norm (benchmark). Characteristic values for dip performance are derived by the NRS 048 working group. The most recent version was published during 2015 with the idea that the NRS 048 part 2-2007 will soon be officially replaced by this 2015 update.

NERSA has proposed by means of the PQ directive that a utility will continuously record dips and swells and then over time; use this data to continuously improve network performance by benchmarking the existing performance of a network against the historical performance. It is normal to continuously attempt to improve business by knowing how well business is at any time but had limited success in the South Africa Electricity Supply Industry (ESI) and again, one of the reasons to the qualitative research undertaken in this dissertation.

Application of the assessment principles of NRS 048 part 2 in measuring dips and swells are presented next and then demonstrated by field data. Measures to mitigate concerns are lastly briefly presented.

2.5 Voltage dips and swells: classification and reporting

Voltage dips are by far the most well-known PQ parameter. For most users, PQ is only about voltage dips as the impact of voltage dips manifest in equipment that shuts down and production being lost [18]. Other PQ parameters requires dedicated instrumentation and software to be made visible and most users will not be aware of the extent of them.

Utilities have little control over voltage dips as a voltage dip id the result of a fault current reducing voltage by an increased voltage drop over some impedance. Fault currents are mostly due to unpredictable and uncontrollable causes. For example, birds are a major contributor to short-circuit conditions [82]. During take-off after been sitting on a transmission tower, a phenomenon called a “bird streamer” reduces the insulation strength between the line conductor and the earth potential.

The earth and line voltage are insulated by means of a string insulator (normally) and if the bird streamer across this insulation reduce the insulation strength to the extent that a flash-over occurs, the electrical arc constitute a fault current that is sustained as the surrounding air becomes ionised. This conduction path has to be interrupted to extinguish the arc by an overcurrent relay that trips an upstream breaker. If it recloses after a few seconds, normal line operations is restored, hence the concept of most faults being self-restoring.

The impedance between the PoC where the dip is recorded and where the fault current is flowing, determine the depth of the dip. At the fault current, the voltage should be near zero. A deep voltage dip means that the electrical distance, and mostly the physical distance, is low. As distance increase, the dip depth becomes shallower.

The duration of the dip is dictated by the trip time of the breaker clearing the fault. Depending on where in the power system (transmission or distribution level for example), typical trip times will be different and can be used to help identify the source of the voltage dip.

Not only birds, but also lightning, veld and cane fires, trees and even power system operators can be the root cause for a voltage dip [82]. An example of how different factors contributed to the dip performance of the Eskom network, is shown in Figure 7. The recommended set of root causes are defined by NRS 048-6 as the following:

- Equipment failure
- Planned work
- Operational causes
- Supply intake (non-licensed redistributors)
- Vegetation
- Fire
- Natural events
- Insulation pollution

- Wildlife
- Customer
- Theft and vandalism
- Third party
- Unknown
- Other

These categories may be further subdivided to assist in analysing the root causes, as well as managing the number of dips. For example, bird streamers can be reduced by installing bird guards that will deter birds from sitting close to the insulators and thereby reducing the number of dip events caused by bird streamers.

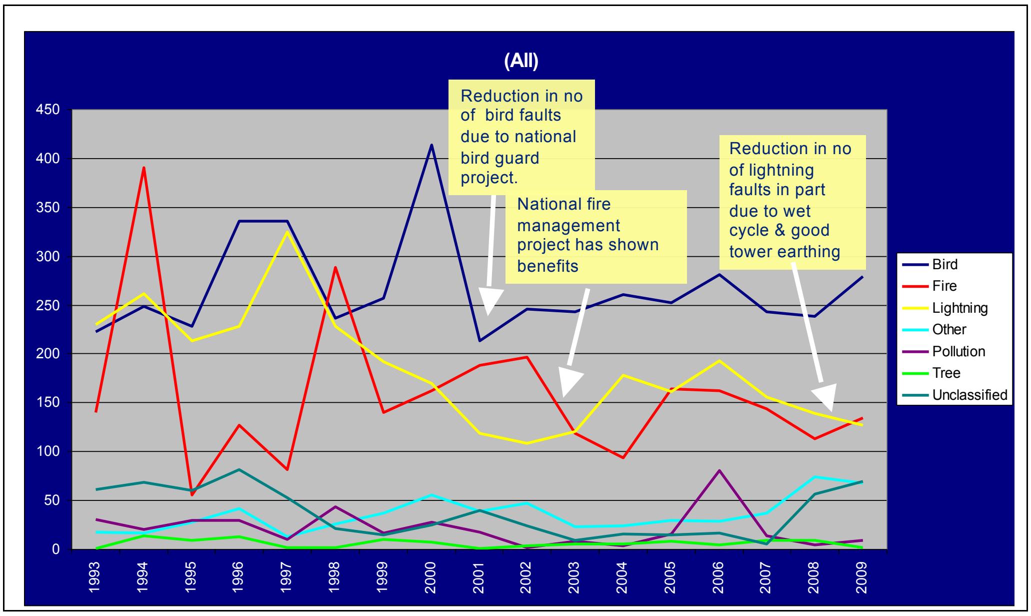

Figure 7: Eskom dip numbers and intervention results [80]

Each voltage dip will have a root cause. A number of voltage dips can also share the same root cause as the power system is interconnected and a fault current at one point in the network can be recorded as a voltage dip at a number of points. Each could have a somewhat different depth and duration due to different impedance values between the point of recording and where the fault occurs.

Not all voltage dips will be due to short-circuit conditions as resulting from a fault current flowing into the fault. Some voltage dips can be due to the energisation of an induction motor [83] as one example of how normal network operations can also cause dips.

During start-up of a rotating load, a current of up to ten times the full-load current can be withdrawn as the negative sequence impedance of the motor is much less than the positive sequence impedance. This negative sequence impedance is dictating current withdrawal during acceleration.

Energisation of a transformer or a capacitor bank installation can also cause a current inrush condition. This type of reasons will not cause widespread dips (only local) as the magnitude of their currents (on a per unit basis) are normally much less than the fault current flowing during a short-circuit condition.

Eskom has for many years researched the root cause of voltage dips by means of so-called “dip to trip matching” [33], [80]. A voltage dip due to a fault current has to correlate to a protection device that cleared that fault. The operation of a breaker is assumed to be recorded to retain the time and reason for operation. By matching the time of the dip and the trip time of the breaker, the reason for the fault can be linked to the voltage dip (or dips).

Retaining this root cause information over a period of time (preferably years), the trends can be analysed and the options to mitigate, evaluated and prioritised. The results of such process is summarised in Figure 7.

Intervention to reduce the number of dips due to birds has clearly contributed to the improvement of overall dip performance of the network. Similarly, for the management of fire and lightning, also referred to as "Operation Firebreak" [84], by pre-emptively implemented switching out transmission lines where farmers burn sugar cane in.

Different depths and durations can be expected for voltage dips recorded at different points in the network and even at the same point over a period of time. The approach to dip management in SA make use of a dip classification scheme which is presented next.

2.5.1 Voltage dip classification

A shallow and short dip can be regarded as "less serious" from a user perspective as the electrical equipment exposed to the dip, should "ride through" the dip. For this reason, dips are classified according to a category that group the "level of seriousness" into a specific category or "name". The NRS 048 part 2-2007 dip diagram is shown in Table 1.

Table 1: NRS 048 dip classification [74]

<table>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td rowspan="2">Range of dip depth
ΔU^b
(expressed as a percentage of declared voltage U_d)</td><td rowspan="2">Range of residual voltage
U_r
(expressed as a percentage of declared voltage U_d)</td><td colspan="3">Duration
T</td></tr>
<tr><td>$20 < t \leq 150$ ms</td><td>$150 < t \leq 600$ ms</td><td>$0{,}6 < t \leq 3$ s</td></tr>
<tr><td>$10 < \Delta U \leq 15$</td><td>$90 > U_r \geq 85$</td><td colspan="3">Y</td></tr>
<tr><td>$15 < \Delta U \leq 20$</td><td>$85 > U_r \geq 80$</td><td colspan="2"></td><td rowspan="2">Z1</td></tr>
<tr><td>$20 < \Delta U \leq 30$</td><td>$80 > U_r \geq 70$</td><td></td><td rowspan="3">S</td></tr>
<tr><td>$30 < \Delta U \leq 40$</td><td>$70 > U_r \geq 60$</td><td>X1[a]</td><td rowspan="3">Z2</td></tr>
<tr><td>$40 < \Delta U \leq 60$</td><td>$60 > U_r \geq 40$</td><td>X2</td></tr>
<tr><td>$60 < \Delta U \leq 100$</td><td>$40 > U_r \geq 0$</td><td colspan="2">T</td></tr>
<tr><td colspan="5">NOTE In the case of measurements on LV systems, it is acceptable to set the dip threshold at 0,85 pu.</td></tr>
<tr><td colspan="5">[a] A relatively large number of events fall into the X1 category. However, it is recognized that dips with complex characteristics (such as phase jump, UB, and multiple phases) might have a significant effect on customers' plant, even though these might be small in magnitude. Customers might not have the means to mitigate the effects of such dips on their plant.
[b] The preferred method of display is the dip depth (ΔU).</td></tr>
</table>

A range of depth values and duration is used to group dips into specific categories. For example, Z1 dips should be relatively close to the point where the dip is recorded as the duration of a Z1 dip is typically representative of a direct-online starting of an induction motor. A number of dips being closely grouped in the Z1 area, will probably be due to the same induction motor repeatedly started. Knowledge of the network where the recordings took place will then reveal the location of that motor and methods to contain the voltage sag condition can be devised, if needed. For example, it could be that a sensitive customer is connected to the same Point of Common Coupling (PCC) necessitating mitigation.

The duration of dips is linked to typical protection times in different types of networks. Transmission protection is typically set to operate very fast and why dips in the X1, X2 and T groups may indicate a fault in the transmission network. Alternatively, industrial level protection (e.g. protection of motors) may also indicate towards an X1-type dip having a cause in the local network. Dips in the range 150 ms to 600 ms are generally located in the distribution network, whilst the longer dips would indicate that backup protection operated to clear the fault condition.

Observe the grey area in Table 1. As the utility has limited control over the occurrence of voltage dips. Statistically, most of the voltage dips at any point in the network will concentrate in the Y category and if that number could be "ignored" by the system operators when analysing the root cause of the dips, a lot of effort is saved. In addition, technicians responsible for the local network cannot take responsibility for dips coming from a far-away network as Y dips can be far away due to being relatively shallow.

This Y dip category was not arbitrarily chosen. Internationally there is agreement that voltage dips that are located more or less in this area, must be tolerated by electrical equipment. When electrical equipment is exposed to these dips, the equipment should remain operating as designed.

The NRS 048 is the only known standard or specification that categorises dips using the underlying network and equipment sensitivity characteristics and internationally acclaimed for this reason.

Observe the voltage dips recorded at a Point of Connection (PoC) in a 66 kV distribution network over the period January to end of July 2017, shown in Figure 8 as NRS 048 scatterplot. Most of the dips, as expected, concentrate in the Y area. Similar distribution of dips in terms of depth and duration are found internationally.

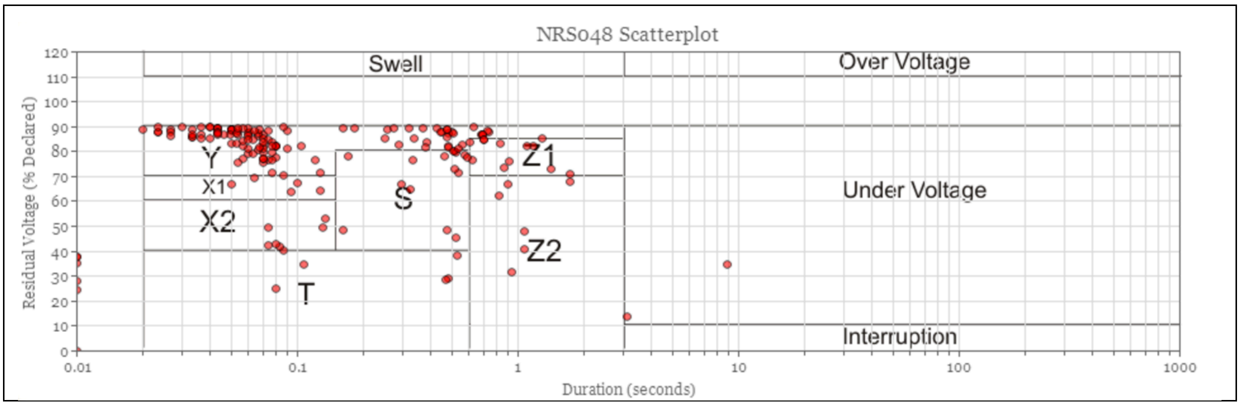

Figure 8: A NRS 048 scatterplot of voltage dips recorded in a 66 kV network

Different approaches to this concept of compatibility exist internationally [85]. Well-known examples are:

- The CBEMA "energy performance" curve for computer equipment,
- The SEMI F47-0706 compatibility curve for semiconductor processing equipment,
- And the Class definitions for immunity set by the IEC 61000-4-11 (equipment less than 16 A) and IEC 61000-4-34 (for equipment above 16 A).

The similarity between the CBEMA and SEMI F47 curve can be seen in Figure 9. In both cases, the main idea is to help equipment manufacturers by specification of a tolerance level against variations in supply voltage. Note that the SEMI F47 curve requires semiconductor processing equipment to operate unaffected when voltage sags down to 50% of the nominal value for as long as 200 ms, a significant loss of energy to be sustained.

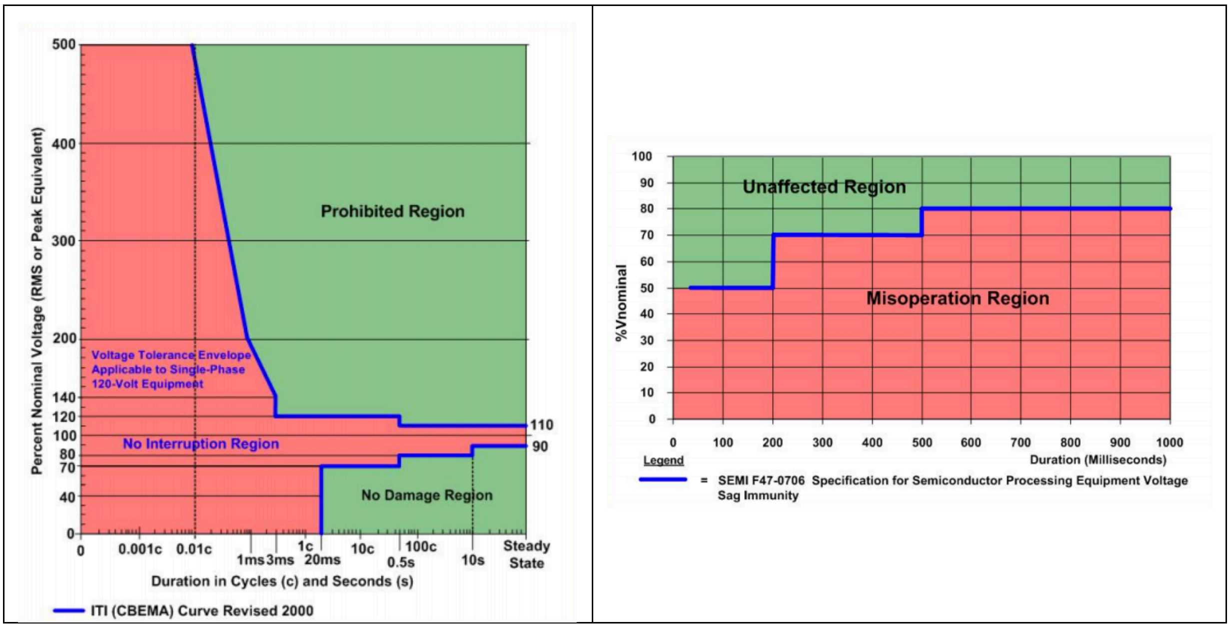

Figure 9: The CBEMA (left) and SEMI F47 equipment immunity curves [85]

The IEC61000-4-11 and IEC61000-4-34 uses a Class category to define the level of immunity for different levels of sensitivity to supply voltage variations:

- Class 1 is for the most sensitive equipment as can be expected in specialised laboratories using high-technology equipment. An UPS for example will be required to protect this equipment.
- Class 2 is for PCC's where general types of industrial customers and public networks connects.
- Class 3 is for PCC's where only industrial customers connect. Many solid-state converters, large machines being started, arc-furnaces and other disturbing loads are expected.
- Class X: This is where the user defines the level of compatibility.

The difference in the compatibility requirements of IEC61000-4-34 is presented in Figure 10.

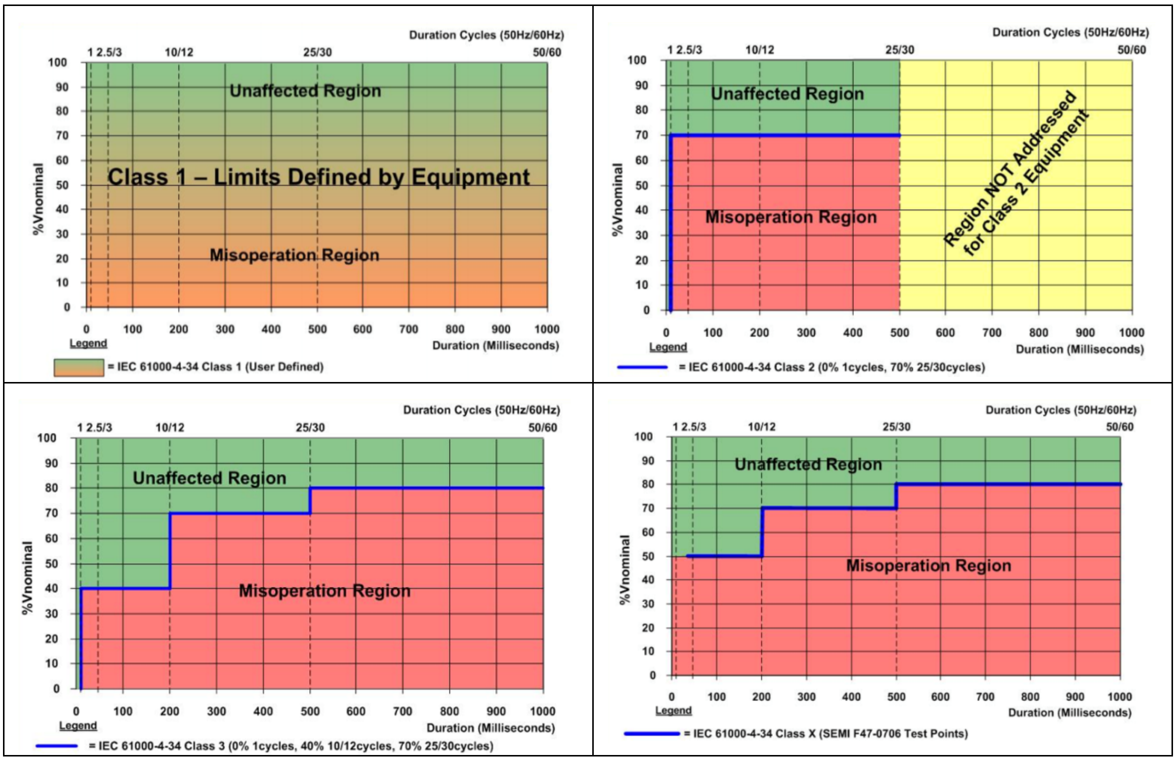

Figure 10: Different classes of IEC61000-4-34 immunity [86]

It is evident that voltage dips are considered from an immunity point of view. This is why mitigation of voltage dips is required to achieve equipment compatibility.

2.5.2 Mitigation of voltage dips

Much research has been performed in an effort to solve power quality problems [87], however, when a network or a customer is impacted by voltage dips, there are two main ways in which the voltage dip problem may be addressed. Either the power utility can invest in the network to improve the voltage dip performance (referred to as the "network solution") or the customer may use voltage dip mitigating techniques to protect the plant against resultant trips (referred to as the "customer solution").

Voltage dip mitigation has cost implications. A solution [88] must be assessed to determine the best techno-economic option as cost and performance is normally orthogonal. Bhattacharyya *et al.* in [88] adapted the concept in immunity of equipment, installations and processes based on a voltage dip survey conducted jointly by the CIGRE and CIRED WG C4.110 (*Voltage dip immunity of equipment in installations, scope and status of the work*) by providing a step-by-step guide on how to assess a voltage dip problem from a customer plant point of view. Of primary importance to the suggested guide is the network solutions and how the utilities network impact both the depth and the duration of the voltage dip.

Due to the lack of success in obligatory PQ regulation as required by NERSA in license agreements at utilities, uses have the options to install active voltage conditioning equipment. Various options exist in equipment that can boost the voltage during a voltage dip condition.

2.6 Steady state PQ parameters: voltage quality

Each PQ parameter (steady-state parameters in Figure 1) is managed from a compatibility approach and discussed per parameter below. It is done by using a real-world example and comprehensively analysed to demonstrate the application of NRS048. It is in support of the overall goal of this dissertation- namely to understand what the extent and success of PQ management is at utilities, how users perceive the QoS served to them and lastly how smart grid technology can help to improve or complement the existing state of affairs.

2.6.1 Voltage magnitude

When electricity is generated, it starts out as a smooth sinusoidal voltage waveform, $v(t)_{\text{Source}}$ in Figure 11. That is the traditional form of electrical energy as power stations uses electrical generators with the electromagnetic design aimed to produce a perfectly sinusoidal voltage waveform at the terminals.

If the electrical circuit from the terminals of this generator towards the load is closed, and if that load is a linear loading element such as a perfect resistor, then the current being withdrawn from that generator will be perfectly sinusoidal. Perfectly sinusoidal voltage drops will also result over the impedances between the generator and the load, resulting in a perfectly sinusoidal voltage at the load.

The consequence of concern for this scenario will be to maintain the magnitude of voltage within an acceptable range of variation. Ohm's law dictates that as current towards the load increase, the voltage at the terminals of the load will decrease and when current decrease, the voltage will increase.

Voltage magnitude regulation can be quantified by a technical standard. In South Africa, the NRS 048 series of documents are used to assess the regulation of voltage magnitude at a PoC. The PoC will normally be where the utility delivers the electrical energy to the user and where the minimum quality levels need to be maintained[3].

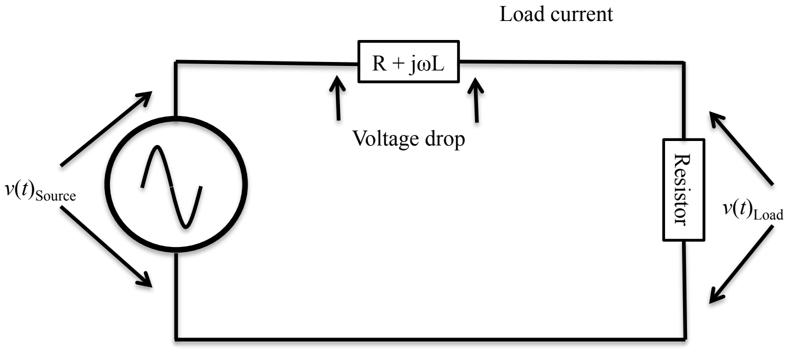

Figure 11: Principle of voltage regulation

2.6.1.1 The assessment of voltage magnitude

Voltage magnitude is assessed based on 10 min recorded values over a period of time as shown in Figure 12. It is clear that voltage has changed significantly during these 8 days and the goal of a voltage magnitude assessment is now to find out if this site was compliant to the requirements of the technical specification, NRS 048 part 2-2007. This assessment is discussed below to understand in detail how the voltage magnitude assessment is done.

In the case of NRS 048 part 2, and specifically the 2007 version, both compatibility and limit criteria are given. Changes to this approach exist in the 2015 version, but the 2007 version applies during the writing on this dissertation.

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[3] The regulation of PQ is discussed in section **Error! Reference source not found.**

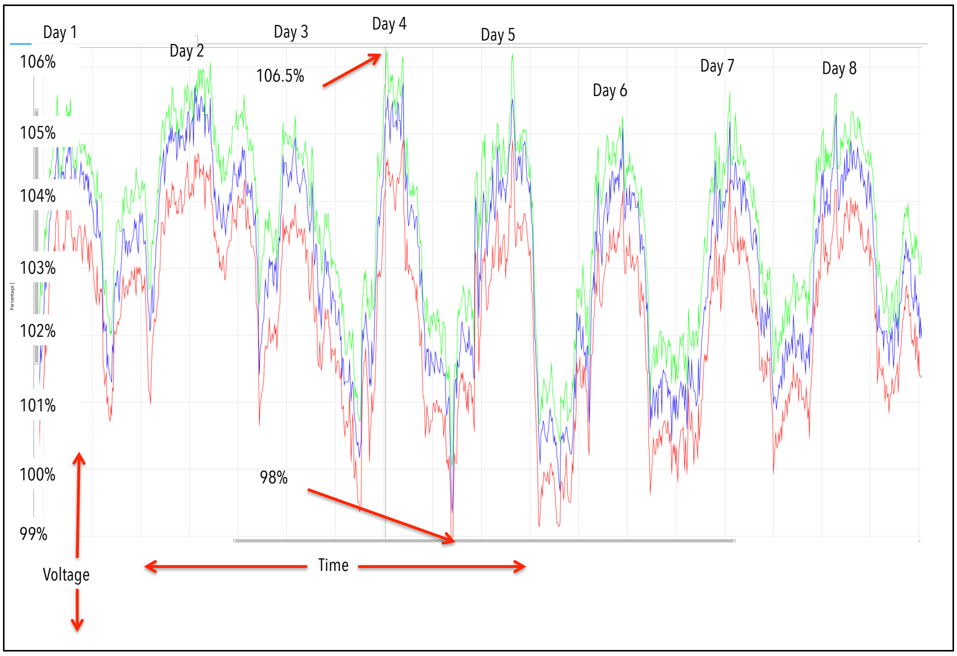

Figure 12: The variation of voltage over a period of time

Compatibility in voltage magnitude (networks above 500 V) requires that voltage be regulated between 105% and 95% of the reference or nominal value for 90% of the time. It is allowed to exceed the upper level for no more than 5% of the time and not drop below the lower level for more than 95% of the time. It means that a site may be outside the upper and lower levels for up to 10% of the time.

It is evident that if voltage rises too high, even for a short period of time, electrical equipment can be permanently damaged. For this reason, a limit value is also given as an absolute value to be never exceeded.

This limit value is different for different voltage levels, defined in NRS 048 part 2:2007. Maximum levels are defined based on equipment voltage specifications, derived from IEC 60071-1 [89] and adapted marginally for South African conditions in SANS 1019 [90], taking voltage insulation into account.

The statistical distribution of voltage variation during a month (for example), is dictated by a complimentary requirement to the compatibility requirement for 95% of the time. Voltage is not allowed to be beyond the 105% and 95% variation for more than 2 consecutive 10 min values. If the 3rd 10 min value is outside, then it means that this site was either above or below the compatibility levels for at least 30 min and is then regarded as non-compliant. This specification derived from the Electricity Regulation Act in force at the time of writing the specification.

It seems that voltage in Figure 12 has exceeded the 105% level, but it could be that it was within the allowed 5% of the time and why the total number of 10 min points that exceeded has to be tested against the 5% time criterion.

An analysis of the 10 min data points in Figure 12 is then conducted to test against the compatibility and limit criterion. Shown is a NRS 048 7-day sliding assessment to find per day, the maximum and minimum value for 95% of the time as well as the absolute highest value during that day. Day-by-day the values are then updated and graphed as shown in Figure 13.

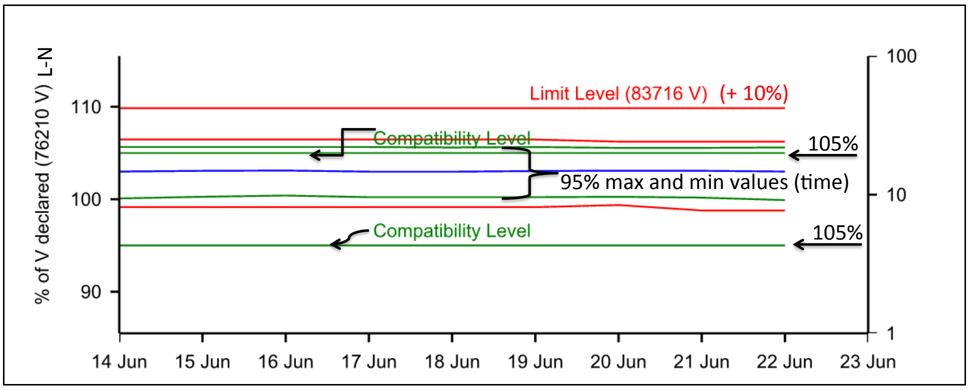

Figure 13: NRS048 voltage magnitude 7-day sliding assessment

Results of the assessment in Figure 13 is presented in Table 2.

Table 2: NRS 048 assessment to compatibility and limit criteria on voltage magnitude

Limit criterion	**Limit value**	**Absolute max value**	**Compliance to limit**
76 210 + 10% (V)	83 716 V	81 148 V	Comply
Compatibility criteria	**Compatibility value**	**Assessed value**	**Compliance to compatibility**
95% Highest weekly value (time)	76 210 + 5% (V)	105.7 %	Do not comply
95% Lowest weekly value (time)	76 210 - 5% (V)	99.9%	Comply

It seems that this site is non-compliant to the NRS048 part 2-2007 requirements on the regulation of voltage magnitude. These results in Table 2 has to be interpreted against the 7-day sliding assessment of Figure 13:

- The variation in voltage for 95% of the time is 5.8% around the average value of 100% of 132 kV (indicated as the L-N value of 76 210 V). This variation is well within the allowed 10% (+5% above and -5% below) for 95% of the time, but the setpoint of this site is not at 100% of 132 kV.
- Observe that the blue line is at 78 115 V as the tap changer at this site was set to 102.5% of the nominal voltage. It is controlled for an operational reason to be higher; this is the infeed to a long distribution feeder. In context therefore, the “do not comply” is strictly speaking not correct.
- This demonstrates how important it is to correctly apply the NRS048 part2-2007 requirements on compliance for voltage regulation. It would have been possible to adjust the recorded data by acknowledge the reference voltage on which the assessment is to be based as the value where the tap changer was set.
- The 5.8% variation for 95% of the time is an important benchmark of how well the fault level (or installed transformer size) is utilised, as the voltage variation is the result of current withdrawn through the supply impedance. In this case, the fault level is sufficient as it could sustained the variation in loading well.
- Observe that the average voltage (blue line) is perfectly flat. It is another demonstration of the usefulness of the NRS048 part 2-2007 assessment of voltage regulation: the tap changer at this 132 kV transformer is functional and controls the voltage perfectly at the setpoint.

2.6.1.2 Considerations on voltage magnitude

Since the supply voltage at a PoC change when loading change due to voltage drops over the supply impedances, voltage has to be continuously controlled by the system operator using devices such as automatic on-load tap changers [91] in order to achieve the delicate balance between supply and demand.

In doing so, the utility ensure that the supply voltage is maintained within a specified range of operations around the rated value. The international standard, IEC 038 distinguishes two different voltages in electrical networks and installations, namely:

- Supply voltage (which is the line-to-line or line-to-neutral voltage at the PCC), and
- Utility voltage (which is the line-to-line or line-to-neutral voltage at the terminal of the electrical device.

Accordingly, the European union make use of the PQ standard EN50160 as the main document in dealing with requirements concerning the utility's network [93], while in South Africa, the NRS 048 part 2-2007 is the standard document, with most of its values derived from the IEC 61000 series of documents [72], [73].

Both PQ documents characterize voltage parameters in distribution systems. In terms of compliance, the choice of regulation limits is one of balance between the cost of supply and use of electricity and as such, from a South African context, the NRS 048 part 2-2007 specifies the voltage regulation range of ±10% for voltage below 500 V and for voltages above and equal to 500 V, as ± 5%. In addition to using tap changers, reactive devices such as capacitor banks and reactors are also used to regulate voltage and to minimize technical losses [94].

2.6.2 Voltage unbalance

A number of different mathematical definitions of voltage unbalance exist [95], [96]. In the basic form, voltage unbalance refers to asymmetry in a polyphase system and includes both magnitude and phase displacement [74].

A supply network delivering perfectly symmetrical phase voltages can become asymmetrical due to unbalanced load currents being withdrawn or balanced load currents being drawn in a network where line impedances are not perfectly symmetrical.

Unbalanced voltage drops over the supply impedances due to load unbalance cause the loss of positive and negative sequence symmetry even with perfectly equal supply impedances per phase. There are a number of factors that influence the symmetry of a polyphase system [73]:

- Type of loads;
- Geometry of line towers;
- Unequal transformer tap settings;
- Open phase on the primary of a three-phase transformer in distribution system;
- Open delta connected transformer banks;
- Sustained single-phase faults;
- Unequal impedance in conductors of power supply; and
- Large reactive single-phase loads such as welders and arc furnaces.

Dugan *et al.* in [61] asserts that voltage unbalance of less than 2% on the power system is mostly caused by single-phase loads on the network, above 2% by arc furnaces and greater than 5% by blown fuses in a three-phase network, traction lines (two phase supplies) and single pole operations on three-phase three-pole circuit breakers.

To maintain balanced supply network [98] power utilities can influence voltage unbalance by the type of load that connected and at the design stage, the types of line towers and efforts to maintain a fair distribution of single-phase loads among phases.

2.6.2.1 The assessment of voltage unbalance

Voltage unbalance is assessed by expressing the ratio of the negative sequence voltage to the positive sequence voltage in the 50 Hz voltage phasors (frequency domain). First the frequency content of the time-domain waveform is determined by application of the Fourier transform. Then, by application of the Fortescue transform to the 50 Hz voltage phasors (frequency domain), the sequence domain components are found.

Voltage unbalance is then stated as the ratio in the rms values of the negative (V_2) to positive sequence voltage phasor (V_1) at 50 Hz (or 60 Hz) and expressed as percentage:

$$V_{UB} = \frac{100 * V_2}{V_1}$$

Equation 2

The above calculations are done for every 200 ms (10/12 cycles) block of data. Results for each block are aggregated to 10 min values for the purpose of applying a PQ standard.

Compliance to the compatibility requirement on voltage unbalance of NRS 048 part 2-2007 requires that 95% of the 10 min values during the period of investigation have to be less than 2% in LV, MV and HV networks and for EHV networks, less then 1.5%.

A trend based on 10 min values in phase voltages shown in Figure 12 indicates some degree of unbalance between phases. From those phase domain voltages, voltage unbalance 10 min values were found by application of Equation 2 resulting in the 10 min voltage unbalance values shown in Figure 14.

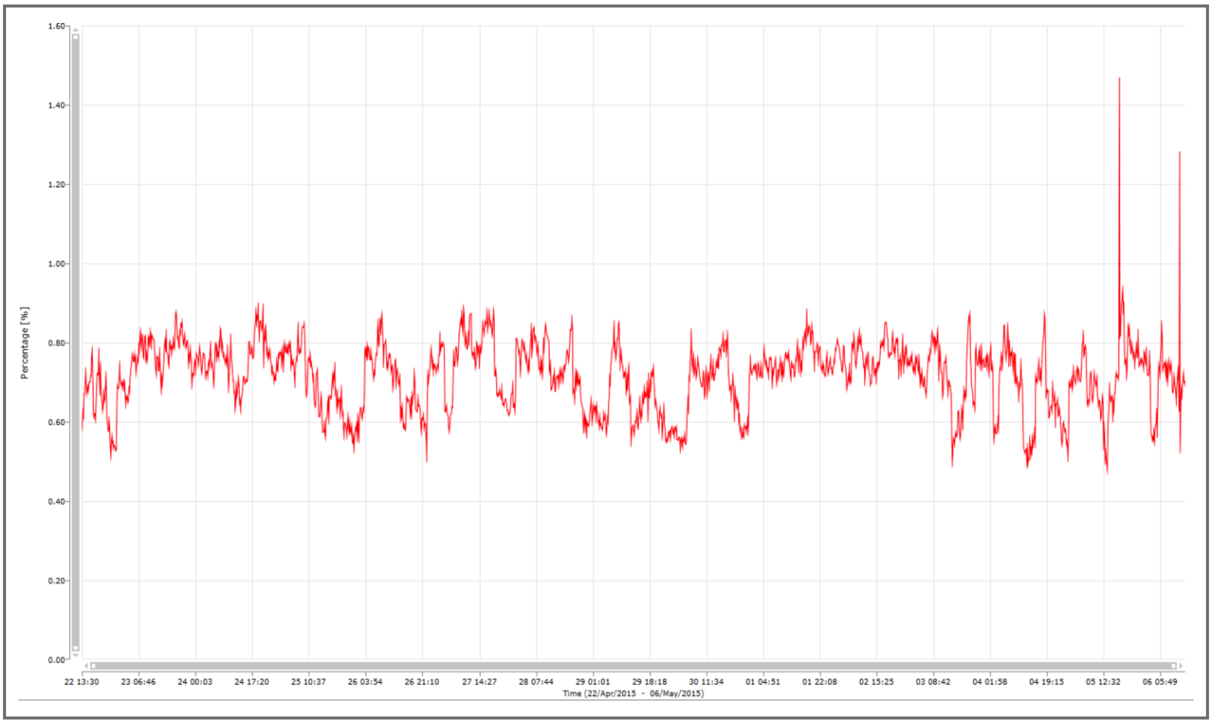

Figure 14: Trend of voltage unbalance, 10 min values

Using a 7-day sliding assessment in application of NRS048 part 2-2007, the results of the assessment to compliance to the compatibility requirements, is shown in Figure 15.

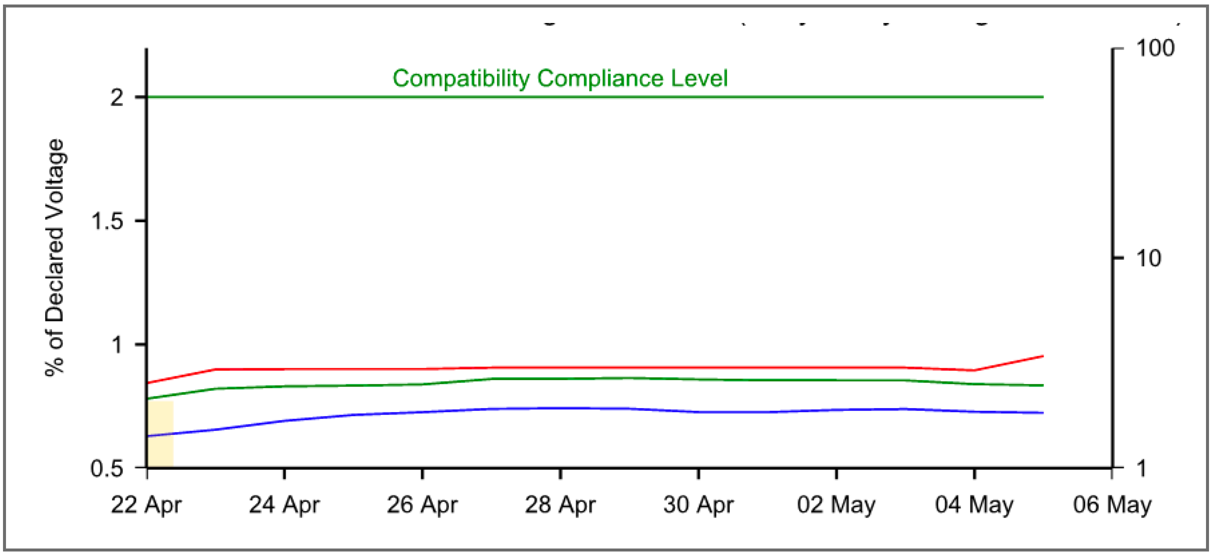

Figure 15: NRS 048 7-day sliding assessment of voltage unbalance

- On average, indicated by the blue line in Figure 15, voltage unbalance remained constant at around 0.7.
- The 95% value per day, indicated by the green line, resulted in the highest assessment value of 0.9.
- This site, based on the NRS048 part 2-2007 requirement for compatibility, is fully compliant.

No limit criteria are required for voltage unbalance.

2.6.2.2 The mitigation of voltage unbalance

Voltage unbalance mitigation mostly requires only the application of Ohm's law. If the single-phase loading of a 400 V transformer is not well balanced between phases, the unbalanced loading per phase conductor on the 230 V side of the transformer will result in unbalanced voltages on the 400 V side. Consideration of how single-phase loads are reticulated, is required.

Two-phase traction substations can be a cause of unbalanced loading of a 3-phase MV or HV line [100] and requires consideration, even with the line fully transposed. Transposition of line conductors aim to obtain as equivalent circuit to the supply source, a symmetrical impedance matrix. In Equation 3, it is required that $Z_{aa} = Z_{bb} = Z_{cc}$ and $Z_{ab} = Z_{ac} = Z_{ba} = Z_{bc} = Z_{ca} = Z_{cb}$ in order for a three-phase impedance to be symmetrical. Mutual impedances are considered in this example and represented by the off-diagonal elements.

$$\boldsymbol{Z}_{phase} = \begin{bmatrix} Z_{aa} & Z_{ab} & Z_{ac} \\ Z_{ba} & Z_{bb} & Z_{bc} \\ Z_{ca} & Z_{cb} & Z_{cc} \end{bmatrix}$$

Equation 3

It is also possible to continuously compensate for voltage unbalance by means of dedicated power electronic equipment. The basic principle is demonstrated by Figure 16.

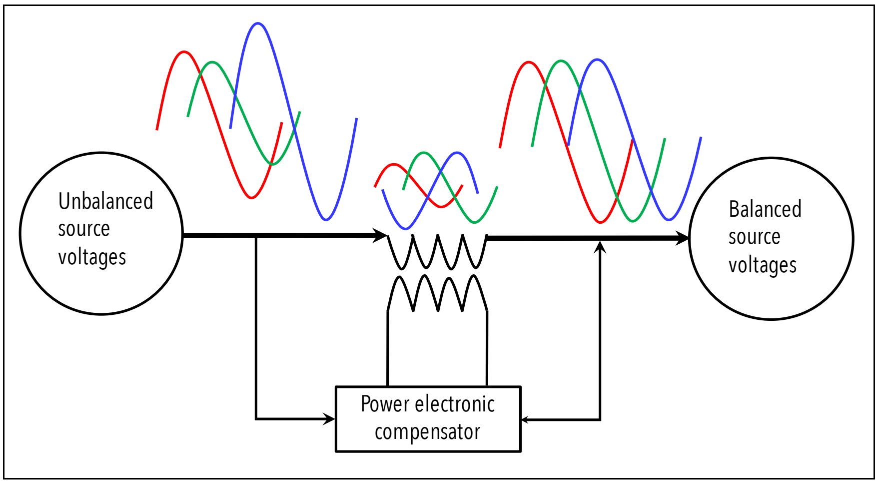

Figure 16: Compensating for voltage unbalance

The above configuration is mostly used only at power levels up to a few MW due to the constraints in the components being used. It is also possible to use the same configuration to simultaneously compensate for some of the voltage dips, harmonics and even to improve voltage regulation [101].

From a mathematical point of view, it requires compensation of the “unwanted” sequence domain voltages and currents and why it is possible to also compensate for voltage unbalance at much higher power levels by other configurations of static var compensators where the value of the parallel susceptance can be adjusted per phase.

Examples are the “Static Var Compensator”, normally referred to as SVC. Such a configuration is shown in Figure 17. In this case, the value of C is fixed whilst the value of inductive impedance can be linearly adjusted by means of the thyristor control, resulting in the variation in the parallel susceptance seen by the supply side. It means that the zero (where pertaining) and negative sequence 50 Hz currents are “trapped” by the SVC as resulting from the specific unbalanced condition.

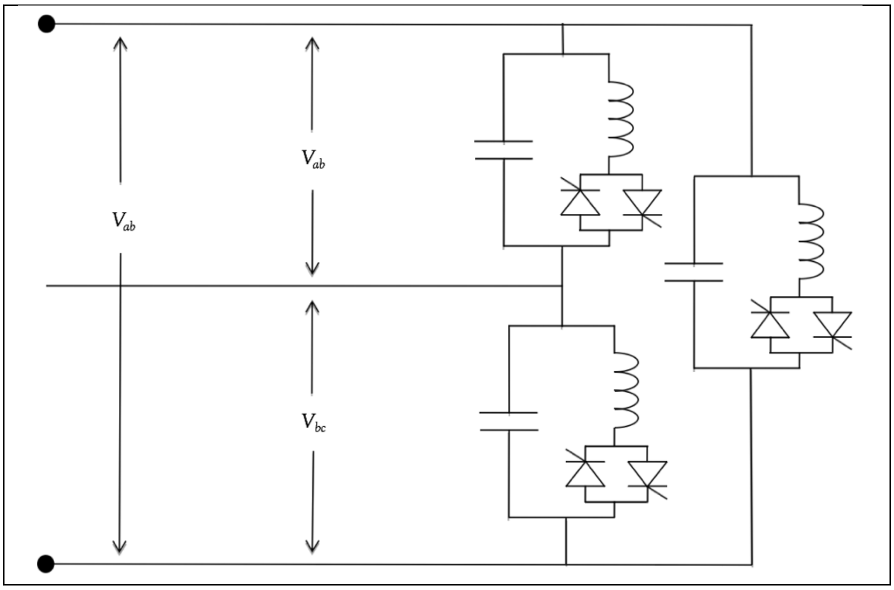

Figure 17: Static Var Compensator (SVC)

2.6.3 Voltage harmonics

Voltage harmonics are the result of current harmonics withdrawn through supply impedances resulting in harmonic voltage drops across. Current harmonics are the result of non-linear loads such as Variable Speed Drives (VSDs) and other power electronic equipment.

In a modern distribution system with RES that injects energy by means of solid-state interfaces (grid-connected inverters) and users that again connect solid-state devices to add sophistication in process control during energy conversion, current harmonics are part and parcel of the smarter distribution grid. In a distribution grid the line impedances are normally inductive, but cables and power factor correction equipment can cause a condition, known as resonance, which can amplify the voltage harmonics.

The circuit of Figure 18 indicates by means of the red arrow the path of interest in explaining resonance.

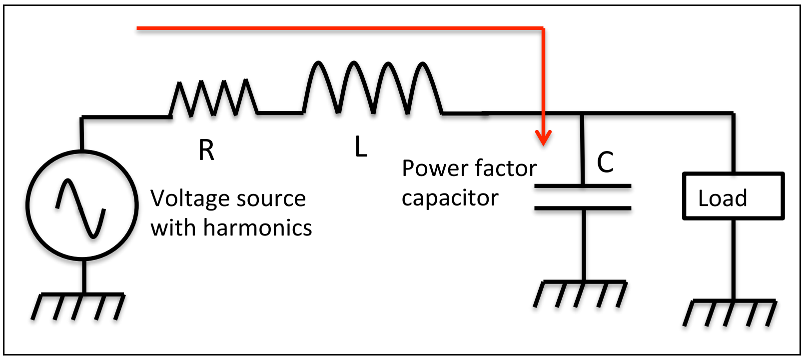

Figure 18: Resonant LC circuit

A resistive component R[4], inductor L and capacitor C in series resulting in a complex impedance Z will typically constitute a supply circuit to a load with an impedance $\boldsymbol{Z}(f_r)$ being a function of frequency (or harmonic h):

$$\boldsymbol{Z}(f_r) = R + j2\pi f_r L - j\frac{1}{2\pi f_r C}$$

Equation 4

A frequency f_r will exist where the inductive reactance X_L will be equal to the capacitive reactance X_C:

$$\boldsymbol{Z}(f_r) = R + jX_L - jX_C = 0$$

Equation 5

Impedance $\boldsymbol{Z}(f_r)$ is now at its lowest possible value, R. Assuming that the voltage source has a harmonic component at frequency f_r then that voltage harmonic will only "see" a low resistive path into the capacitor, resulting in a large current. This normally referred to as a resonant condition. Both series and parallel resonant paths can exist in a power system.

An increase in rms current result due to the contribution of the specific harmonic current and it can damage the capacitor by overheating or blowing a protection fuse rendering the reactive power injection at fundamental frequency useless.

Should a resonance condition occur, detuning the resonant frequency of the resonant circuit could mitigate the resonance. It normally requires an inductor to be added in series with the power factor correction capacitor as shown in Figure 19 to shift the resonant frequency to a frequency where no voltage harmonic occurs in the supply source.

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[4] R assumed to be frequency independent.

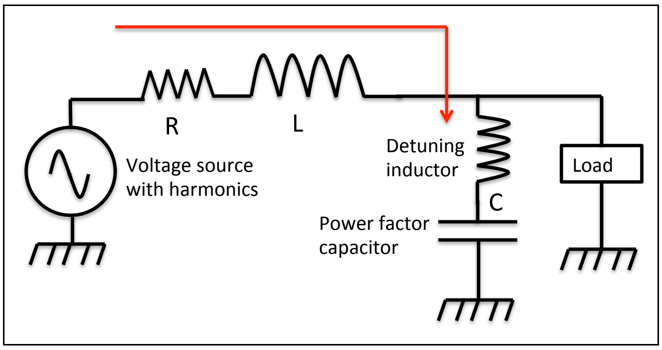

Figure 19: Detuning the resonant LC circuit

2.6.3.1 The assessment of voltage THD

Voltage waveform distortion due to the collective contribution of all voltage harmonics components is referred to as voltage Total Harmonic Distortion (THD). It is calculated based on IEC 61000-4-30 200 ms values as follows:

$$THD_V = \frac{\sqrt{\sum_{h\neq 1} V_h^2}}{V_1}$$

Equation 6

Voltage THD 200 ms values are then aggregated to 10 min values, expressed in % and then used in the assessment of compliance to the compatibility requirement on voltage waveform THD.

- If the voltage THD is 0%, it is because the summation of voltage harmonics in Equation 6 is zero, meaning that the voltage waveform is purely sinusoidal.
- Voltage THD has to be less than 8% for networks operated at voltages up to 33 kV during 95% of the time period under investigation (minimum time again being at least 7 consecutive days starting at midnight on Sunday until midnight the next Sunday).
- Voltage THD has to be less than 4% for networks operated at voltages above 33 kV during 95% of the time period under investigation.

Observe the trend of voltage THD shown in Figure 20.

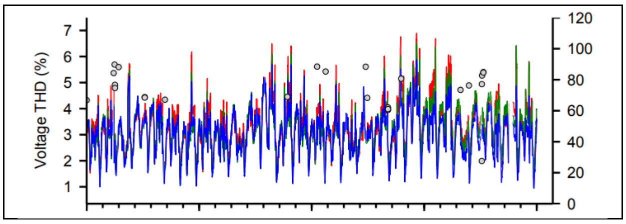

Figure 20: 10 min trend values of voltage THD at site of interest

Compatibility assesses how many 10 min values are above 8% as this site is operated at 11 kV. Less than 5% of the time, the voltage THD limit value may be exceeded. It is again done over the period of assessment based on a 7-day sliding approach shown in Figure 21.

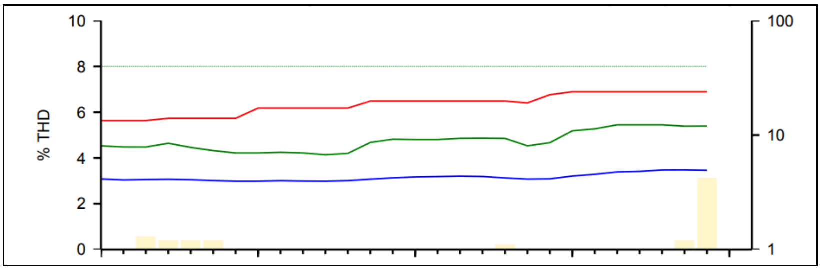

Figure 21: NRS 048 7-day sliding approach to assessment of voltage THD at 132 kV site of interest

The green line in Figure 21 is the 95% value and does not exceeds the 8% threshold. A highest value in those values that exceeded the 8% limit for more than 5% of the time, was recorded at 5.4%.

This site is nt compliant to the compatibility requirement of NRS 048 part 2-2007. Voltage THD at the infeed to the rest of the distribution network is high and the ability of downstream networks at lower voltages where most users connect, to contain the THD in voltage, is compromised by this relative, though compliant, voltage THD.

In addition to voltage THD, each individual voltage harmonic has to be less than a compatibility limit value even if the collective contribution of all voltage harmonics results in a voltage THD less than the limit value. Individual harmonics have to comply for 95% to the limit values stated in Table 3 for networks up to 33 kV.

Table 3: Compatibility levels for harmonic voltages for LV and MV networks (Expressed as a percentage of the reference voltage) [74]

1	2	3	4	5	6
Odd harmonics				**Even harmonics**	
Not multiples of 3		**Multiples of 3**[a]			
Harmonic order *h*	**Magnitude** %	**Harmonic order** *h*	**Magnitude** %	**Harmonic order** *H*	**Magnitude** %
5	6	3	5	2	2
7	5	9	1,5	4	1
11	3,5	15	0,5	6	0,5
13	3	21	0,3	8	0,5
$17 \leq h \leq 49$	$\{2{,}27 \times (17/h)\} - 0{,}27$	$21 \leq h \leq 45$	0,2	$10 \leq h \leq 50$	$\{0{,}25 \times (10/h)\} + 0{,}25$

[a] The levels given for odd harmonics that are multiples of 3 apply to zero sequence harmonics. Also on a three-phase network without a neutral conductor or without load connected between phase and earth, the actual values of the third and ninth harmonics might be much lower than the compatibility levels, depending on the voltage unbalance of the system.

For networks above 33 kV, the limit values are much less as shown in Table 4.

Table 4: Compatibility levels for harmonic voltages for HV and EHV networks (Expressed as a percentage of the reference voltage) [74]

Harmonic order *h*	**HV and EHV harmonic voltage** %
3	2,5
5	3,0
7	2,5
11	1,7

13	1,7
17	1,2
19	1,2
23	0,8
25	0,8
NOTE: The compatibility levels are those recommended by Cigré TB261, which contains recommendations derived from international data collected. Data for even harmonics and higher-order harmonics was not available, and has therefore not been included. Reference values for these harmonic orders may be based on the planning levels given in NRS 048-4.	

Voltage THD can now be analysed by individual harmonics shown in Figure 22.

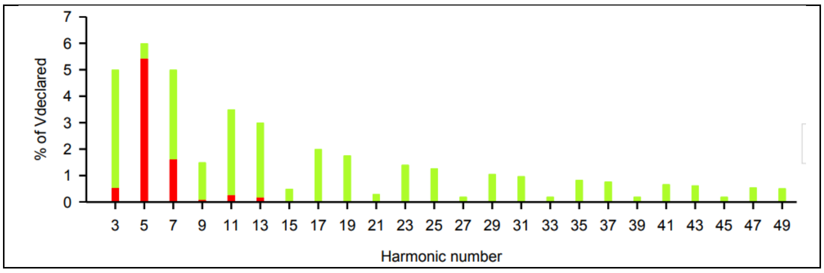

Figure 22: NRS 048 assessment of individual voltage harmonics at site of interest

The 5th voltage harmonic is the highest and the dominant contributor to voltage THD. It was assessed at 5.4% by (compatibility limit is 6%).

2.6.3.2 The mitigation of voltage harmonics

The relative high level in 5th harmonic shown in Figure 22 could be due to a local resonant condition at for example a capacitor bank and if so, then it could be mitigated by shifting the resonant frequency to where no voltage harmonic exist that can excite a resonant condition. Otherwise, the voltage harmonics can be filtered by a harmonic filter.

Many filter configurations exist [61]. A passive filter is normally the cheapest and may be designed to "trap" individual voltage harmonics by a low impedance path to the 5th voltage harmonic used in this example. It creates a short-circuit condition to the 5th harmonic voltage. Design of a harmonic filter requires a comprehensive study of the network harmonic impedance as the addition of impedance elements can change the resonant frequency of the circuit to amplify another harmonic, shifting the problem to a different harmonic.

Active harmonic filters are normally the most effective from a performance point-of-view and can track a shift in harmonic resonance. However, they may be very expensive and also requires detailed analysis of the system impedance and prevailing harmonic distortion conditions on the network.

Transmission and distribution system owners have the responsibility to manage the level of voltage harmonics as required by PQ regulatory requirements in a country but more importantly, the network owner simply has to contain the level of harmonics as all users are interconnected and some control is needed to how much harmonics may be injected into the electrical network.

The root cause of voltage harmonics remains in the withdrawal of current harmonics through non-zero supply impedances and international guidelines on how much current harmonics are allowed, exist. It is referred to as allocating harmonic emission to users with the ability to inject harmonic currents.

"Inject" is the result of the concept that if a single source of harmonics exist, then if fundamental frequency active power consumption is referenced as positive when being supplied by the voltage source and consumed by the load, then the harmonic active power at the PoC to that load, will result in a negative sign, indicating that it is consumed upstream in the supply system. That is why the withdrawal of current harmonics can be referred to as the "injection" of harmonic currents, or simply harmonic emission.

2.6.4 Voltage flicker

A voltage magnitude fluctuation can induce variation in the luminous flux of light sources, especially the incandescent lamp. When these variations occur in rapid succession having large magnitudes, they cause variations in luminous flux of light sources, termed voltage flicker.

Energy efficient lamps such as CFLs are reported to cause less lumens variation than a similar incandescent lamp connected to the same amount of voltage flicker. It seems that the change to LED lamps is causing flicker levels to be more important again as the variation in voltage amplitude reflects directly in the light production of the LED module.

Voltage flicker is in principle a modulation of the voltage amplitude and when that modulation occurs at a frequency of around 8.8 Hz, the human eye is susceptible to the adverse effect of voltage flicker. Normally the human will not recognise the variation in lux levels in a room, but as the eye attempts to compensate continuously, a general sense of irritation and headaches can develop, or worse, trigger an epileptic seizure.

The IEC standard, IEC61000-3-7 [108], defines voltage flicker as an impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuate with time. Implicated in the preceding IEC flicker definition, one may infer that flicker corresponds to the visual discomfort experienced by human beings, when exposed to variations in the luminous flux of light sources. These luminous flux variations called flicker are the result of voltage fluctuations shown in Figure 23.

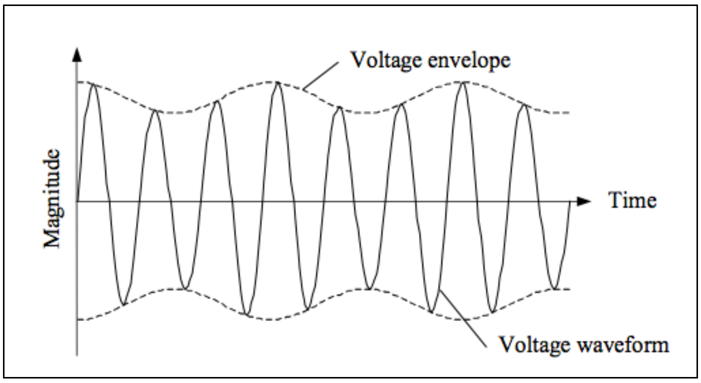

Figure 23: Modulation of voltage amplitude [80]

Flicker is measured by an emulation of how the human eye and brain will respond to variation in the lux levels in a room; the basic idea is shown in Figure 24.

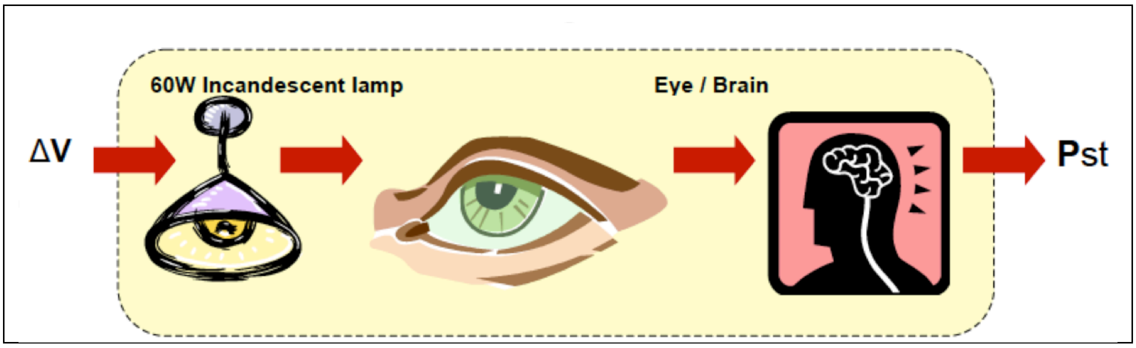

Figure 24 Flicker and the human [80]

2.6.4.1 The assessment of voltage flicker

Measuring flicker requires complex signal processing (shown in Figure 25) and why not all PQ instruments can record flicker. A 10 min P_{st} value is recorded, that is the short-term flicker severity index. It is then aggregated to a 2 h value representing the long-term flicker index, P_{lt}.

Based on the highest weekly 95% P_{lt} value, the compliance to the compatibility limit of 1.0 is found. Above the value of 1, approximately 50% of humans experience varying levels of discomfort.

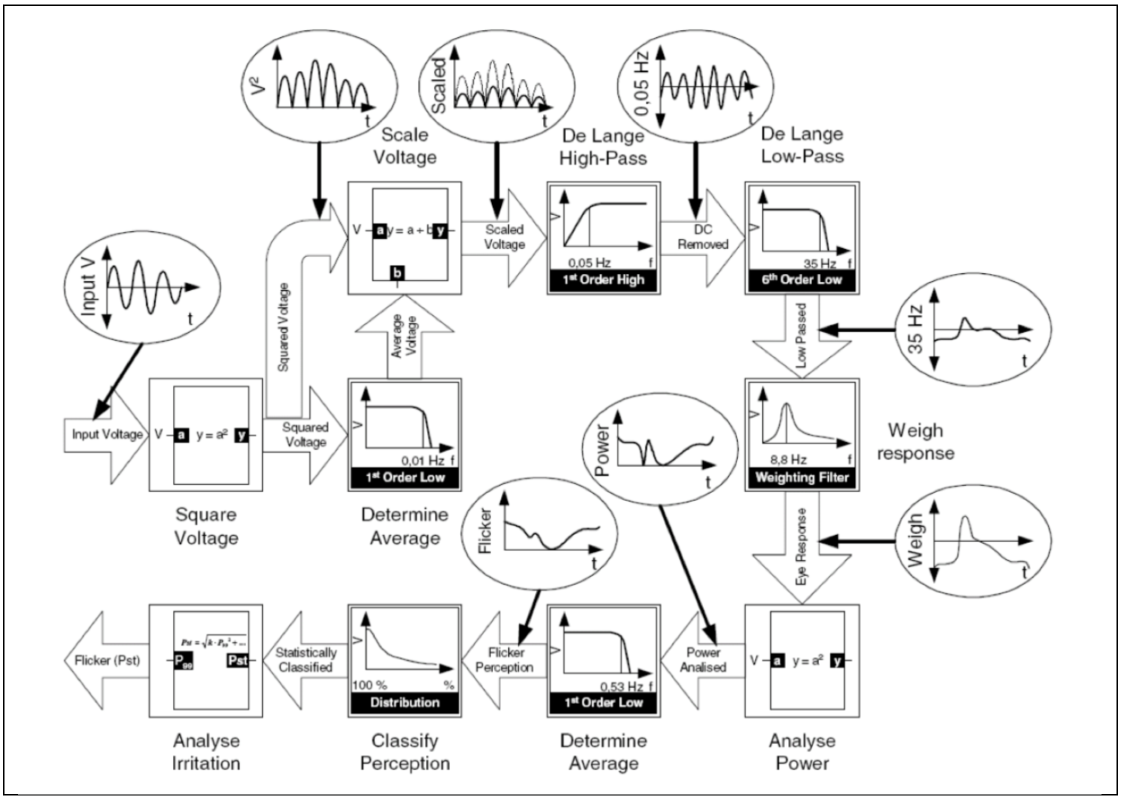

Figure 25 The UIE flicker meter [80]

Observe the trend of flicker recordings (P_{st} 10-min) shown in Figure 26:

- The compatibility requirement of the NRS 048 part 2-2007 requires that the long-term flicker has to be less than 1 for at least 95% of the time. Significant variation in the P_{st} values can be noted in Figure 26.
- Long-term flicker values (P_{lt}) as calculated in Equation 7 are used for the assessment of compatibility as the variation in flicker now resulting, excludes the impact of for example load fluctuations and interruptions not considered as root-cause to voltage flicker.

$$P_{lt} = 3\sqrt{\frac{\sum_{k=1}^{12} P_{st,k}^{3}}{12}}$$

Equation 7

Long term flicker P_{lt} is shown in Figure 27. The total number of values represent the total time on which the assessment is based as each value represents voltage flicker (voltage amplitude modulation) during the past 2 hours. By ignoring the worst (that is the highest) values during 5% of the time, the highest value remaining is the assessed value for flicker during 95% of the time.

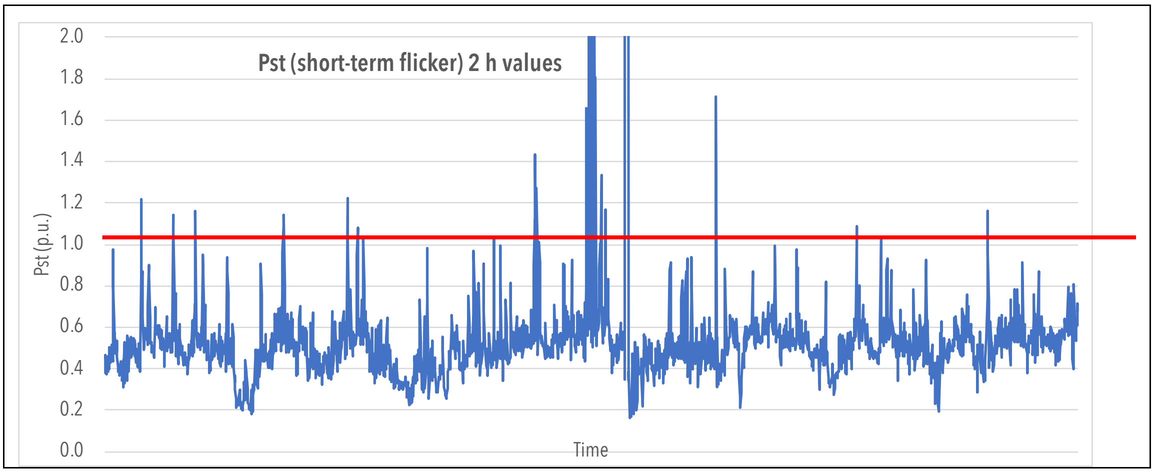

Figure 26 Voltage flicker 10-min P_{st} values

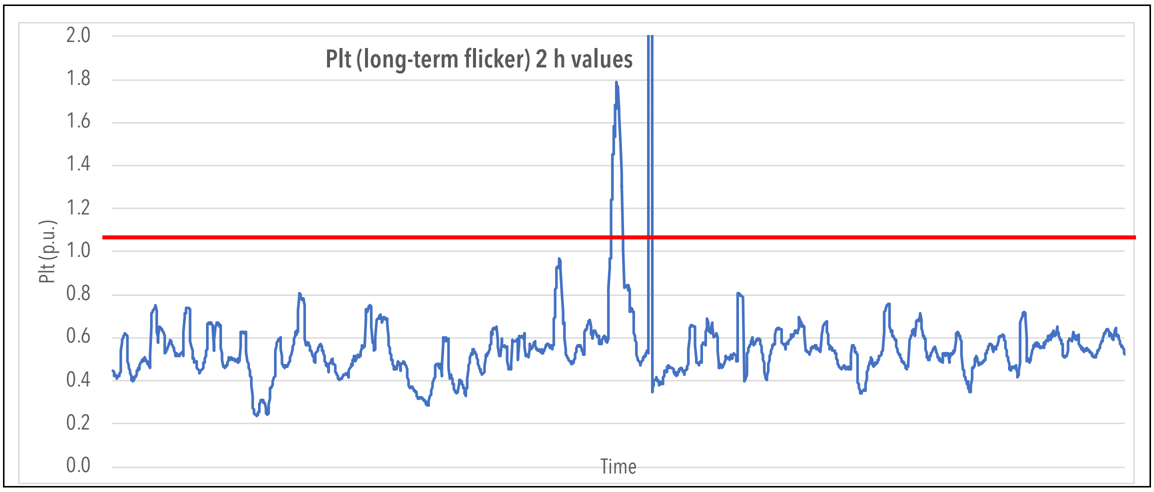

Figure 27 Voltage flicker 10-min P_{lt} values

The assessment is different if the source of the voltage flicker is on the high voltage network and as a result, a transfer factor is determined as shown in Figure 28. For this scenario, the transfer of flicker from the upstream HV busbar to other downstream busbars is dependent on a variety of network conditions, particularly the composition of loads [109]. Rotating machines and SVC's downstream the network may have an impact on the transfer factor and must be taken into consideration. The authors in [110] described this method and the evaluation criteria to be used to assess and predict voltage flicker from arc furnaces.

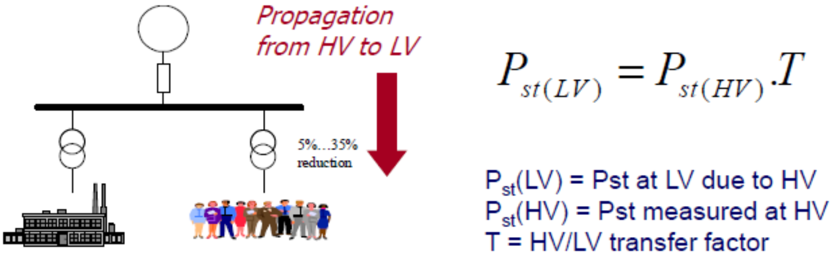

Figure 28: Voltage flicker propagation for flicker source at HV

Typical figures that may be used for the transfer factor *T* in Figure 28 have been identified and suggested by the joint CIGRE/CIRED WG C4.07: *Power quality indices and objectives* and given in Table 5.

Table 5: Typical figures used for transfer factor for voltage flicker propagation

VOLTAGE LEVEL	T_{pst} (AB)
EHV to HV	0.82
HV to MV	0.91
MV to LV	1.00

2.6.4.2 The mitigation of voltage flicker

Mitigation of voltage flicker can best be realised by understanding the root cause of flicker. Electric arc furnaces are known to be an important source of voltage flicker [99], [111]. In residential and small industries, frequent motor starts, and incompatible electronic switching devices are associated with flicker production, such as:

- Air or water compressor;
- Heat pumps and air conditioners;
- Welding machines;
- Power tools, and
- Dimmers, motion sensors, devices with timers and other equipment that uses solid-state switching for lighting control – commonly used with incompatible CFL or LED bulbs [101].

Wind turbines are an important source of flicker in distribution networks. Although environmentally clean energy, the connection of large-scale wind power plants to a distribution network can cause voltage flicker [112], [113]. The rapid variations of the wind turbine’s output power induce fluctuations in the network voltages, causing flicker.

Mitigation could be done at the source by controlling the fluctuation in current withdrawal. As it is Ohms law that dictate voltage flicker, it is in principle possible to increase the fault level (decrease the supply impedance) to a level where the voltage fluctuations are within the compatibility requirement.

That is mostly not practical due to engineering and cost constraints. Dedicated flicker mitigation equipment exists.

2.7 Impact of poor power quality

Power quality has an economic and a technical impact briefly discussed below.

2.7.1 Economic impact

Reliability is excluded as the consequence is obvious, this section is mostly dealing with voltage dips that pertain to this section.

Each voltage dip can present a local interruption to the user. When the voltage dip is severe enough, i.e. deep and/or long enough, there could be economic consequences:

- Production is lost;
- Raw material is lost resulting in raw material wastage;
- Reduced productivity levels, may include cleaning of machines;
- Lost opportunity for sales due to less production.

For some industries such as automobile manufacturers, voltage dips contribute to reputational risk in addition to the direct losses. Promises are made to potential customers on when to expect delivery of a vehicle and when it does not realise, that customer can consider a vehicle from the competition and the manufacturer who could not honour the promise to delivery, can over time gain the reputation of not being able to deliver as promised.

Limited information exists in Southern Africa to estimate economic losses in industry due to voltage dips (or poor PQ at large). In Europe and in the USA, the impact of poor PQ to users are much better observed and documented. Based on research done in the European Union, the financial impact of voltage dips to different sectors of industry as shown in Figure 29 is a reference for the Southern African economy.

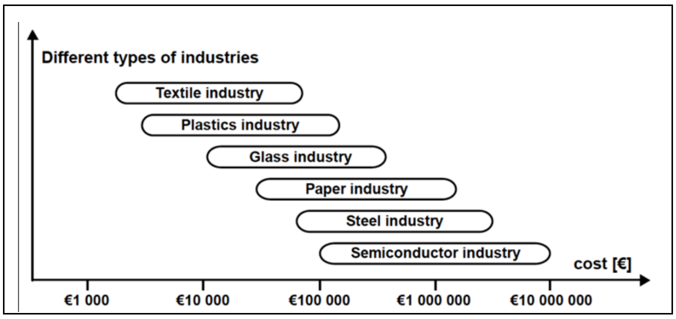

Figure 29: The impact of voltage dips to different industries [114]

The Leonardo Energy organisation did extensive research amongst the most important 25 EU countries to evaluate the cost of poor PQ due to all PQ parameters, not only voltage dips [115]. They reported in 2007 how the different PQ parameters contributed to costs in the left-hand side of Figure 30. How these costs are made up can be seen in the right-hand side of Figure 30.

These results can probably not be extrapolated directly to the South African context. Financial losses of 150 billion Euro represent 5% of the annual profit margin of the EU industries evaluated. Investment to prevent this loss is insignificant as only 300 million Euro was invested in PQ solutions. Overall, the EU study correlates to what was found by the Electrical Power Research Institute (EPRI) in the USA.

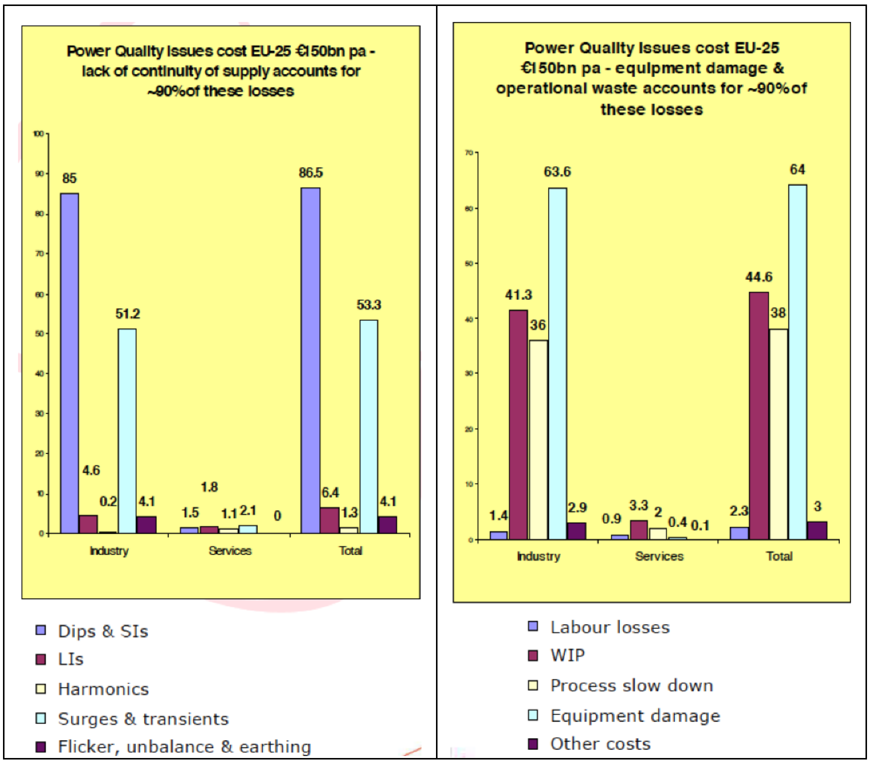

Figure 30: Graphs showing how different PQ parameters contribute to the cost of poor PQ[5] (left) and the different aspects contributing to that cost (right) [105]

2.7.2 Impact of poor PQ in South Africa

It was estimated in 1996 [77] that annual losses in South Africa by large industrial customers due to voltage dip events were in the order of R1.2 billion. Another study [116] revealed that major industrial customers in South Africa suffer annual losses of more than USD 200 million due to voltage dip problems in the 1990's. These losses are believed to include damage to equipment, improper operation of equipment, process disruption and

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[5] LI: Long interruptions, SI: Short interruptions, WIP: Work in Progress.

other anomalies [18]. The exact consequence is difficult to quantify and to generalise since different customers are differently affected.

Some of the indirect costs associated with voltage dips are:

- Plant downtime;
- Loss of production;
- Loss of revenue;
- Equipment replacement and decreased equipment life;
- Overtime labour cost during equipment repair;
- Product damage;
- Possible delayed shipment dates.

Root-cause analysis is needed in order to identify the best approach to mitigate the impact of voltage dips.

2.8 Power quality standardisation and regulation in SA

The purpose of this section is to place relevant standardization and regulatory bodies in the context of South Africa and then extend this to the PQ environment.

2.8.1 Standardisation

The South African Bureau of Standards (SABS) was established by section 2 of the Standards Act, 1945 (Act No. 24 of 45 1945) and confirmed by section 3 of the Standards Act, 2008 (Act No. 8 of 2008) [118]. As a subset of the SABS objectives, SABS has to maintain the South African notification system in terms of the Technical Barriers to Trade (TBTs) Agreement of the World Trade Organisation [119], [120]. Therefore, the underlying principle of standards is to ensure countries can trade without unnecessary barriers. This also applies to PQ as electricity is a universal commodity powering equipment obtained from all over the world.

An international approach to benchmark the technical performance of an electrical network from a PQ point of view is needed. The TBTs govern that user equipment manufactured in different countries should be compatible to the electricity available in any other country. From a PQ point of view, it is needed to understand how the electricity supplied by any electrical network will affect electrical equipment and why a PQ standard aims to set minimum levels to system technical performance. When the electricity is better than the minimum levels, then the user equipment should perform as designed.

2.8.2 Energy regulation in South Africa

The NER was created by the 1987 Electricity Act (Act 41 of 1987) with the following objective [121]:

> *"to exercise control over the electricity supply industry so as to ensure order in the generation and efficient supply of electricity, and to perform such other functions as may be assigned to it by or under this Act".*

Later known as NERSA, the quality of electricity was recognised as an important factor in protecting the economy. By means of the Power Quality Directive issued by NERSA, the principles to protect the suppliers and users of electricity in South Africa was defined, the regulatory framework for PQ in SA.

In a competitive ESI as found in Europe and the USA, market forces do create a self-regulating alternative to governmental regulation of PQ as users have a choice to suppliers. Poor performing electrical utilities will not remain in business. NERSA had a very important role to play in SA in protecting the ESI and the users served by this ESI.

Operationally it was envisaged that each licensee will monitor PQ and use the data to also manage PQ. Being part of the license agreement between NERSA and licensees, is was made compulsory since 2003 to monitor PQ.

Few licensees have done this and why the management of PQ in SA is mostly done by Eskom. Serving good quality electricity to licensees from the Eskom networks was the most important reason why many users connected to municipal networks, remained unaffected for many years.

This scenario is changing. Licensees have not maintained networks well and with the lack of budgets and operating skills, poor PQ at many users realised. Also, the Eskom distribution networks are changing, not only due to the lack of upgrades and maintenance, but due to the large-scale integration of RES. When battery storage connected to distribution networks becomes a reality, a smarter grid will be needed to contain the degradation of PQ.

This dissertation therefore investigates how the lack of success in the traditional approach to PQ regulation (i.e. in SA) can be mitigated by smart grid concepts and technology.

2.8.3 Development of PQ standards in South Africa

The IEC has defined a category of standards called Electromagnetic Compatibility (EMC) standards. These standards, technical reports and technical specifications are grouped under a number of documents in the IEC 61000 series. PQ is regarded as a subset of EMC. The IEC 61000 series consists of 6 parts: general, environment, limits, testing and measurement techniques, installation and mitigation guidelines, and generic standards.

In the USA, power quality standards were developed by the IEEE and formed a standards Coordinating Committee that has the responsibility of coordinating standards activities regarding power quality from all the different organizations doing development [124]. In general, national PQ standards will follow either the IEEE or the IEC series of PQ standards and will specify the detail of how in a specific region/country PQ has to be measured and reported upon.

NRS048 is used in South Africa and adopted in Southern and Eastern Africa. Since the first edition, dated 1996, it was similar to the European EN50160. Updates to this set of specifications have also included developments in other PQ standards. Reporting on voltage dips in SA is the major difference.

The 1996 edition of the NRS048 series limits in terms of voltage dip numbers which were soon realised to be unrealistic as utilities do not have control over most of these dips. Different versions followed based on finding the characteristic numbers in voltage dips for different networks. The latest edition is the 2015 version, not yet adopted by NERSA during the time of writing (2019) containing characteristic dip numbers based on national dip data collected up to year 2013.

It was needed to reflect what constitute a level of acceptable PQ, the NRS048 part 2 serves as basis to the technical requirements. A Power Quality Advisory Committee at NERSA comprised of electrical utilities, industry, consultants and the South African Bureau of Standards [73], developed the PQ directive which benchmark network performance by the NRS 048 part 2.

The idea was that by application of the PQ directive, that both suppliers and users understand what their obligations and rights are with respect to PQ and how the operational aspects of the ESI has to be conducted to safeguard the interest of all role players. The ISO 9000 principle of continuous improvement was embedded in this PQ directive.

Critical elements of the draft power quality directive have been included into the South African Grid Code: Governance Code for implementation [126].

2.8.4 Responsibilities for power quality

Management of PQ requires all stakeholders' collaboration. Although the compatibility levels of NRS 048-2 forms part of utilities license conditions, it is not possible for utilities to manage PQ on their own. The key responsibilities per stakeholder can be summarised as follows (focussing on voltage dip performance, but the principles are similar for other PQ parameters, e.g. harmonic distortion) [127]:

- Licensees:
  - Provision of information on expected dip and interruption performance at the contractual stage (i.e. design of the system and customer plant).
  - Implementation of management processes for dealing with complaints.
  - Ongoing interaction with customers (especially affected sensitive customers).
  - Power quality monitoring at many sites (see NRS 048-4 and NRS 048-6)
  - Provision of premium supply options (generally at additional cost).
- Customers:
  - Can request a specific managed interaction even if performance is good.
  - Focus on PQ considerations in the design and operation of the plant.
  - Required to take reasonable measures to optimise the immunity of plant.
  - Design stage: information available from licensee and NRS standards.
- Equipment suppliers:
  - The provision of dip performance characteristics of their equipment.
  - The provision of mitigation options.
- NERSA:
  - Mediate/arbitrate disputes (following the reporting process described in the governance code [126]).
  - Require annual reporting on performance from licensees.

The focus of this dissertation is on the customer experience, including municipalities. Their experience will be analysed in the context of their responsibilities.

2.8.5 Management of power quality

As mentioned in the previous section, management of PQ requires all stakeholders' collaboration. However, it remains the responsibility of the utility to advise the customer on their responsibilities, i.e. what can the customer expect and what they are allowed to contribute to the power quality levels.

2.8.5.1 What can a customer expect?

For the utility to advise the customer on what they can expect, the utility needs to monitor the power quality levels in the system. The NRS 048 part 4 [128] provides guidance on the number of PQ instruments that a utility must install and at what level these instruments should be installed.

It is advisable that the utility do long-term monitoring, so that the trends can be identified. In this way, a utility can also prioritise where refurbishments and upgrades are required, before any customers complain.

2.8.5.2 What are customers allowed in contributing to the degradation of PQ?

Customers may only contribute a portion to the reduced PQ level at any PoC. It is the responsibility of the utility to determine this portion, through a process called apportioning. Experience has shown that customers also need to be tutored on the reasons and implications of these portions, called emission limits.

The RPP grid code [129] requires that apportioning be done in line with international standards, i.e. IEC 61000-3-6/7/13. Allocation of harmonic emission limits are covered in IEC 61000-3-6.

Harmonic emission limits must be stipulated in a supply agreement. Apportioning can be seen as cutting a cake into pieces where the size of each piece is determined by an acceptable procedure such as in [130].

2.9 The need for a smart electricity grid

In the preceding and early paragraphs of this chapter, electrical power and especially voltage quality issues have been discussed from a variety of perspectives and through several case studies on which the typical problems regarding power quality occurring on electrical network have to be solved. These problems, in reality, are inherently as a result of the design decisions originally envisioned by Nikola Tesla in 1888 [131]. While valid for that era, Tesla's assumptions such as centralized generation, demand-driven control and unidirectional transmission are now considered obsolete.

Rapid industrialization, urbanization, continuous growth of infrastructure and the integration of renewable energy sources in the modern economy have led to a paradigm shift in the way electricity is generated, transmitted and consumed and consequently, it should come as no surprise that future electricity networks must meet several needs that Tesla never anticipated.

It is now possible to have sufficient levels of generation at distribution level to match demand and acquire that energy at a lower price than the price of what the utility can offer from large centralised generation sources. These sources of generation will mostly be renewable and because photo-voltaic and wind sources are variable and injected by means of a solid-state interface, special consideration is needed to control frequency and have sufficient energy available during all load conditions that can include grid-connected storage.

Micro-grids are a concept to describe to the local ownership and control of generation, storage and loading assets. Such a distribution system where the ability exists to generate and store sufficient energy to match loading, could also be operated in islanded mode if needed and synchronised to the traditional grid when needed and/or available.

Intelligent and autonomous control is needed as the centralised power system control centre under the continuous supervision of experienced network operators is no longer possible. This is where the smart grid needs to be realised for the electrical distribution system.

2.9.1 The smart grid definition

Although a common functional and technical definition of smart grid has yet to emerge [132], sufficient implicit commonalities in the description of smart grid exist; and the following definitions are considered from a variety of perspectives:

- The IEEE defines a smart grid as "an electrical network from the generation of electrical energy until the delivery to end-users, which make use of latest advances in wireless and other communication technologies and intelligent management system to ameliorate the robustness, reliability, energy efficiency and security of such network"
- In [133] it is defined as "an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those who do both – in order to efficiently deliver sustainable, economic and secure electricity supply".
- A third definition [134] describe the smart grid as a "modernized electrical grid that uses information and communication technology to gather and act on information, such as information about the behavior of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economic and sustainability of the production and distribution of electricity".

"Smart grid" is a broad concept that covers the entire electricity supply and is characterized by the use of technology to intelligently integrate the generation, storage, distribution and consumption of electricity. An organisation based definition for smart grid has been defined [135] by adopting the concept of "Smart Utility" and define it as "a utility that deploy and utilises a smart grid together with information and communication technologies and innovative software solutions and business processes in an integrated way, to transform the business model and add collaborative value across external stakeholders (city, country, region and society)". This definition allows power utilities to develop aspirations for future smart strategies.

2.9.2 Characteristics of a smart grid

While the smart grid is still evolving despite the lack of a universally agreed definition, there are a number of characteristics that remain common to many smart grid architectures, and some of which have been proposed [67], [68], [136], as typical key components and these include:

- **Intelligent appliances**: Intelligent appliances should be capable of deciding when to consume power based on pre-set customer preferences [21].
    - This can contain peak loads that impact electricity generation alleviating the need for new fossil power stations and cutting down on greenhouse emissions. Some case studies on smart grids have shown that consumers can save up to 25% on their energy usage by just providing them with information on consumption and the tools to manage consumption [137].
- **Smart meters**: Billing meters with two-way communication between consumers and power utilities to automate billing collection, to detect outages and to enable dispatching repair technicians to the correct location.
- **Smart substations**: Monitoring and control of critical and non-critical operational parameters and assets such as power factor performance, breakers, transformers and battery status. The IEC61850 protocol for example supports the automation and integration of different power system components to support the overall smart grid goals.
- **Smart distribution:** Provides capabilities for self-healing, self-balancing and self-optimizing, including automated monitoring and analysis tools capable of detecting or even predicting cable and equipment failures based on real-time system technical performance data [138].
- **Smart generation**: It is capable of "learning" the unique of power generation resources to optimize energy production, and to automatically maintain voltage, frequency and power factor standards based on measurements at multiple points in the network.
- **Universal access:** This necessitates for easy access to affordable, low-carbon electricity power generation (e.g., concentrating solar power systems, photovoltaic panels and wind turbine) and storage (e.g., in batteries, flywheels or super-capacitors) [139].

In addition to the smart grid components described above, the National Institute of Standards and Technology (NIST) in the USA coordinate the development of a framework that included protocols and model standards for information management to achieve interoperability of smart grid devices and systems [140].

Interoperability in smart grid is further defined in [140] as "the capability of two or more networks, systems, devices, applications or components to exchange readily use information securely, effectively, and with little or inconvenience to the user". To achieve smart grid interoperability, Zhang et al. in [68] suggested considering the specific technologies for implementation in the following areas:

- **Integrated communications**: To include data acquisition, protection and control and to enable users to interact with intelligent electronic devices in an integrated network.
- **Sensing and measurement**: Technologies that support acquiring data to evaluate the health and integrity of the network and support automatic meter reading, elimination of billing estimates and prevent energy theft.
- **Advance components**: To determine the electrical behaviour of the network and can be applied in either standalone applications or connected together.
- **Advance control methods**: Include devices and algorithm that will analyse, diagnose and predict network condition and autonomously take appropriate action to eliminate, mitigate and prevent outages and power quality disturbances.
- **Improved Interfaces** and Decision Support: To convert complex power system data into information that can easily be understood by network operators.

The interoperability of these components on the power system is seen as a driving force for integrating new components and technology into the smart grid, enabling the required components to work together and to enable a resilient and reliable source of electricity. Interoperability of these components is aimed at ensuring the effective realization of the various objectives established for the evolution of the electricity system to smart grid. The authors in [135], [139] considers the development and deployment of the smart grid technologies toward the achievement of:

- To improve the reliability, availability, and security of the power supply for consumers,
- To maintain the quality of power supply to an increasing share of sensitive digital loads,
- To improve efficiency and economy in power generation, transmission, distribution, storage and utilization,
- To improve security and safety in network operation by observability and controllability of the power system,
- To enable and promote the integration and utilization of renewable and sustainable energies,
- To increase asset utilization and return on investment.

Although an electrical network can become smart over time, incremental changes and improvements in the system, requires commitment from all stakeholders and a viable business model. Table 6 summarises and compares the traditional electric grid to the evolutionary smart grid.

Table 6: From the traditional to the smart grid

Traditional grid	Envisioned smart grid
Centralized Generation	Distributed Generation
No Energy Storage	Energy Storage
One-way Communication	Two-way Communication
Electromechanical Devices	Digital Devices
Manual Restoration	Self-healing
Failures and Blackouts	Adaptive and Islanding
Reactive Approach	Proactive Approach
Total control by Utilities	Increased Customer Participation
Lack of real time monitoring	Extensive real time monitoring
Slow reaction time	Extremely fast reaction time

2.10 Global deployment of the smart grid

Worldwide trends show that smart grid deployment has been on the increase In the USA, funds were provided under the Smart Grid Investment Grant (SGIG) program, enabling 32 municipal utilities to deploy smart grid technologies and systems to improve the performance of their electric systems, providing benefits to customers and advance the United States' grid modernization [151].

A total of 99 projects received federal financial assistance for up to 50% of eligible project cost [151]. With the establishment of the American Recovery and Reinvestment Act of 2009, the U.S. Department of Energy (DOE) and the electricity industry were able to jointly invest over dollar 7.9 billion in smart grid investment grant projects. Amongst the smart grid modernisation initiative in the USA, FirstEnergy Services Corporation (FirstEnergy) receive dollar 57 million in funding to develop a smarter energy grid from the U.S. Department of Energy [152].

FirstEnergy Smart Grid Modernisation Initiative (SGMI) involved deployment of advanced metering infrastructure (AMI), distribution automation (DA), volt/VAR optimisation (VVO), time-based rate programs and direct load control (DLC) devices. The main objective of this initiative was to enable customers to have an informed participation in electricity consumption management, improve power quality and operational monitoring capabilities, optimise asset utilisation and operating efficiencies, evaluate wireless technologies, and to better predict and respond to abnormal system conditions.

In Europe, the European Unions (EU) mandate over smart grids and smart metering has been to drive activities in the sector in the major European Countries, with the aim being to replace at least 80% of electricity meters with smart meters by 2020 [153]. It is further believed that this metering and smart grid roll-out initiative was expected to reduce emissions in the EU by up to 9% and annual household energy consumption by similar amounts [153].

2.11 Synchronised monitoring in smart grid systems

An important goal of the smart grid is to increase operating efficiency and reducing operations and maintenance cost of the electricity network. Furthermore, observability can be enhanced if PQ data is monitored synchronously and applied intelligently. Such intelligence monitoring can be made possible by means of an Intelligent Measurement Device (IMD). Not only PQ, but other functionalities such as synchrophasors and billing can be implemented on the same device, collectively costing less than having different devices each with limited functionality.

2.11.1 The history of phasor measurement unit as example of an IMD

A Phasor Measurement Unit (PMU) is normally used to synchronously record fundamental frequency voltage and current phasors, normally referred to as synchrophasors. In principle, the phasor was first described by Charles Proteus Steinmetz in 1893 by presenting a paper on the simplified mathematical description of time-domain waveforms in AC circuits as "phasors" [154]. If this phasor is measured by synchronisation to an absolute time reference such as a Global Positioning System (GPS), then synchrophasors are possible; this is the focus of the PMU.

The PMU was developed in 1988 at Virginia Tech in the USA and soon gained popularity in wide area power system monitoring to protect and control large interconnected power systems [155], [156]. An international measurement standard was developed, the IEEE Std C37.118.1™ [157], [158], which defines the term and requirement for synchronised measurement of phasors and specifies the Total Vector Error (TVE) to be less than 1%.

PMU's were installed in first-world countries and Wide Area Monitoring Systems (WAMS) used to monitor inter-area and local area oscillation between electrical and mechanical systems. The main goal was to keep large interconnected power systems stable by having the oscillatory exchange of electro-mechanical energy within the stability bounds of that power system. Some control is possible to network configuration such as switching of lines and increasing levels of generation.

Due to advances in electronics and microprocessor speeds, the ability of measuring synchrophasors is no longer reserved for expensive PMUs. Many modern measurement platforms can also record synchrophasors and much better than the 1% TVE requirement. Application of synchrophasors in distribution systems where the phase angle between voltage phasors has to be observed within micro-degree resolution, is where the synchrophasor is now termed the "micro-synchrophasor" [158]. No operational application in distribution systems yet exist.

2.11.2 Opportunity for synchronous measurements in the smarter distribution grid

System technical performance in smarter distribution networks will be better understood making use of network coherent data as cause and effect can be related with improved certainty. The extent to which the data are recorded coherently, and what data, rely on the objective of the measurements.

It is relatively simple to attain time-stamping certainty better than what is required by synchrophasors (1 μs). This already allows the dynamic stability of generation sources to be tracked using the principles of small-signal stability analysis.

If this time-stamping certainty can be improved to be better than the fundamental frequency synchrophasors, the possibility of comparing harmonic phasors at different points in the network could lead to innovation in better emission assessment methods. Using a shared time-source such as GPS, any parameter, even when aggregated and measured anywhere, is directly comparable.

During voltage waveform events, by comparing waveform data before, during and after an event between different points allow for comprehensive root-cause analysis. This is possible when the events are accurately time-stamped and using the results of the root-cause analysis allows to devise a mitigation strategy.

The latter principle is probably the main advantage of having network coherent data available in the modernised distribution grid (the smart distribution grid): Distribution system operators can optimise the dispatch and control of resources to ensure that the network remains during all contingencies in a stable state of operation serving electricity at the most economical manner at levels of acceptable power quality to all users.

By doing this, the main objectives of a smart grid are realised in deploying electricity in a manner that grows and sustain economic activities. Fundamentally, the modern economy relies on electricity and the smarter distribution grid is the vehicle to be adapted for this purpose.

Modern PQ instruments can, with limited additional complexity, also record synchrophasors. This was demonstrated by means of a case study [79], on how sources of renewable energy generation interacted with the electrical network at distribution voltage levels. It is one of the goals of this research to consider this possibility to assess how synchronised PQ in a smart grid context can be used to improve system technical performance.

2.12 Conclusion

In this chapter, the concept of PQ was analysed within context of the South African power system. Measurement requirement of PQ parameters as described by the IEC61000-4-30 was presented.

Application of NRS048 part 2-2007 PQ standard in the assessment of the compliance of a point of supply to the compatibility requirements were analysed. Each PQ parameter was studied from a measurement, assessment and reporting point of view to understand how the NRS 048 part 2 have to be applied and interpreted.

The impact of PQ on users was evaluated and how smart grid concepts can be of benefit to the management of PQ in future distribution networks.

From a technical perspective, it is clear that there are significant advantages to using smarter PQ metering in an innovative smart grid context. This dissertation evaluates the potential advantages for a South African utility and user in terms of PQ.

Chapter 3 establish a conceptual framework for the research.

3 Chapter Three – Conceptual Framework

3.1 Introduction

The global growing drive to reduce carbon emission has compelled the need to diversify energy generation options in South Africa and as a result, solar and wind renewable energy sources are the popular choices. However, the challenges brought by the increasing opportunities of these renewable energy sources on electricity networks, combined with the increasing need to provide reliable power to customers has resulted in the smart grid technologies being seen as a highly contentious topic of discussion in the management of power quality.

This chapter provides a working definition of the key concepts and assessment approach, with specific reference to power quality management and smart grid technology. The chapter will shed light on the development of the conceptual framework and parameters undertaken to operationalize the concepts power quality management and smart grid technology in this research.

3.2 Power quality management concept

The evidence as given in the literature in Chapter 2, with regards to the challenges emanating from the performance of PQ parameters certainly require a proactive approach in the management of power quality by utilities. Management of power quality levels measured on the utility busbars can be supported by the pre-and post-assessment of connections of loads and renewable energy sources onto the utility network [165]; this was demonstrated in the analysis of voltage unbalance emission as an integral part in the management process of voltage unbalance.

Moreover, putting in place PQ systems such as that of Ekurhuleni [166] and Eskom [167] provides means of managing the data aspects of PQ. It is believed that the use of the internet and wireless networks can significantly enhance the performance of these systems [168], [169], [170]; making data much more accessible to individuals that deal with the PQ issues. Using integrated monitoring with PQ instruments spread all over the network with an online access to information such as in [166], [169] can enable voltage waveform incidence to be analyzed in the context of the root cause and source of the incident, enabling quick response to customer complaints or any network event that affects the power quality performance.

To improve system performance, Chan et al. in [170] made use of a PQ database to improve the voltage regulation performance by observing the recorded PQ performance trend and by correlating it to load fluctuations. This demonstrates the importance of data in PQ management, emphasized in [75], by using PQ data to introduce practical strategies to manage PQ incidence and voltage waveform quality parameters.

The importance of managing PQ on a daily basis can be done making use of a web-based PQ management system. Kushare et al. in [169] demonstrated how a web based real-time online power quality monitoring system is used to provide information supporting corrective actions on poor power quality problems. Three issues with respect to the importance of a PQ management system were identified:

- An evaluation of power quality performance levels in benchmarking against the minimum technical standard;
- Root-cause analysis and allocation of responsibilities to investigate and mitigate if possible; and
- Derive methods and procedures to improve PQ and to re-establish network performance objectives.

It is not needed nor economical to install PQ instruments at all busbars in a network. A number of studies have been conducted to determine the optimal placement of PQ instruments on the network [172], [173], [174], [175] balancing visibility on PQ performance against cost.

NRS048 part 4 served as a basis for establishing a power quality monitoring system, in which the placement (number and location) of instruments on the different voltage levels of the licensee's electricity network is suggested [73]. A PQ management need sufficient PQ instruments to provide intelligible information to adequately locate sources of disturbances on the network.

This research explores the opportunities for a South African based power utility to improve the PQ management making use of smart grid technology.

3.3 Quality management and smart grid

Implementation of smart grid technologies by power utilities should lead to increased network reliability, efficiency and improved power quality. It is succinctly stated in [176] that: ”the intelligence that makes the power grid “smart” comes from advanced electronic technologies that sense, monitor, measure, and provide communication and control; it serves as the foundation for range of equipment used in the grid infrastructure, including power quality monitors for improved management of power quality by utilities”.

This statement has not been tested locally. South Africa normally trailed the developed world in the adoption and deployment of technologies such as smart grid.

Eskom needs a business case or value proposition to fully explore key smart grid technologies that may improve power quality, network reliability and energy efficiency.

The first step of this research defines the concept of quality management mostly in the context of power quality and to use as well smart grid technologies. Various definitions to the terms exist in organizations, industries and literature and consequently, it was required to operationalise the terms in order to allow the concepts to be well-defined.

3.3.1 Parameters of power quality management

Methods for evaluating indices for power quality performance have been developed [177]. Developing similar indicators to measure overall effectiveness of a power quality management systems is challenging.

This is evident in that the concept of minimum service quality levels is seen as being controversial among electricity service provider [166]. A wide range of characteristics of power quality management exists as summarised in Table 7.

The economic law of diminishing returns applies to increasing the quality of electricity to customers. Implicated in the preceding statement, it is necessary to first describe the concept of quality management as it forms the basis upon which the concept of this research is derived.

3.3.1.1 Total quality management

Total quality management (TQM) is a standard philosophy of quality improvement and not regarded as a specific management strategy. TQM philosophy allows for the development of models of quality that serve the specific needs of the organization. It is defined [178] as an approach to the art of management describing the characteristics of an organization’s culture, values and attitude that determine how its products and service meet customer’s needs.

TQM is defined in [179] as: ‘The totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs’. In terms of electricity, the needs of consumers can be translated into features and characteristics, which includes aspects such as usability, safety, availability, reliability, maintainability and the protection of the environment. It follows that every action that impacts on these features and characteristics affect the quality of power supply to customers.

3.3.1.2 Quality management in the context of this research

Since the total quality management philosophy allows the development of models that serve the specific needs relating to improvement of quality, a model is proposed in [30] to implement, manage and continuously improve power quality in an electrical network. It applies recommendations of ISO 50001 on Energy Management.

It is chosen as a base model and adapted for use in a framework for power quality management. ISO 50001 model establishes a framework for implementing, maintaining and continuously improving energy management and performance.

The structure for an Energy management system is based on the methodology of "Do-Check-Act" illustrated in Figure 31.

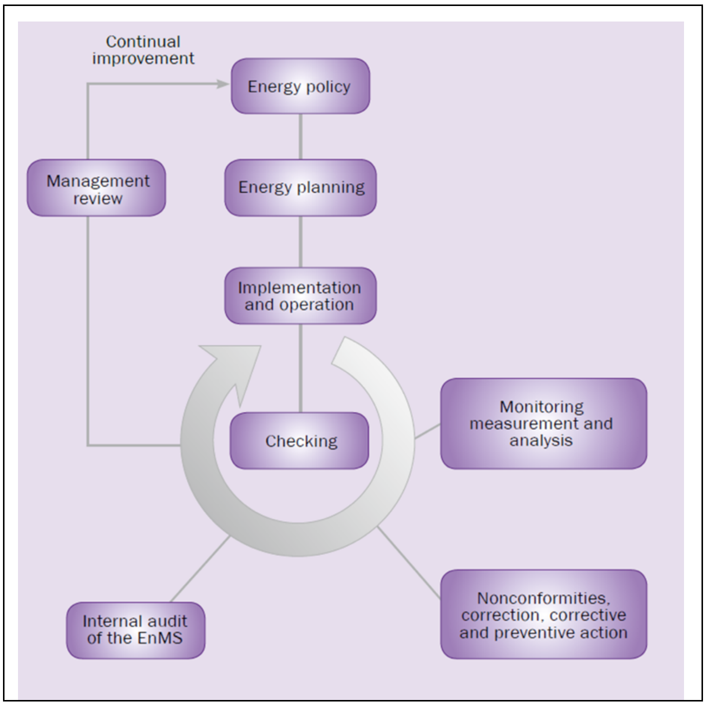

Figure 31: Energy management model, [25]

Applying a similar methodology to the ISO 50001, a Power Quality model is developed, where the continuous improvement is key to significantly increase reliability and performance. Ignatova *et al.* [30] identified similarities between energy management and power quality, concluding that to manage power quality, it is necessary to establish a power quality policy, a baseline, a plan and a management review process. It is mandatory to measure, analyse and improve power quality continuously.

Figure 32 illustrates a Power Quality Management model, adapted from ISO 50001. Fundamental to the model, amongst others, is the measurement and monitoring aspect of power quality, for which smart grid technology is investigated as part of this research.

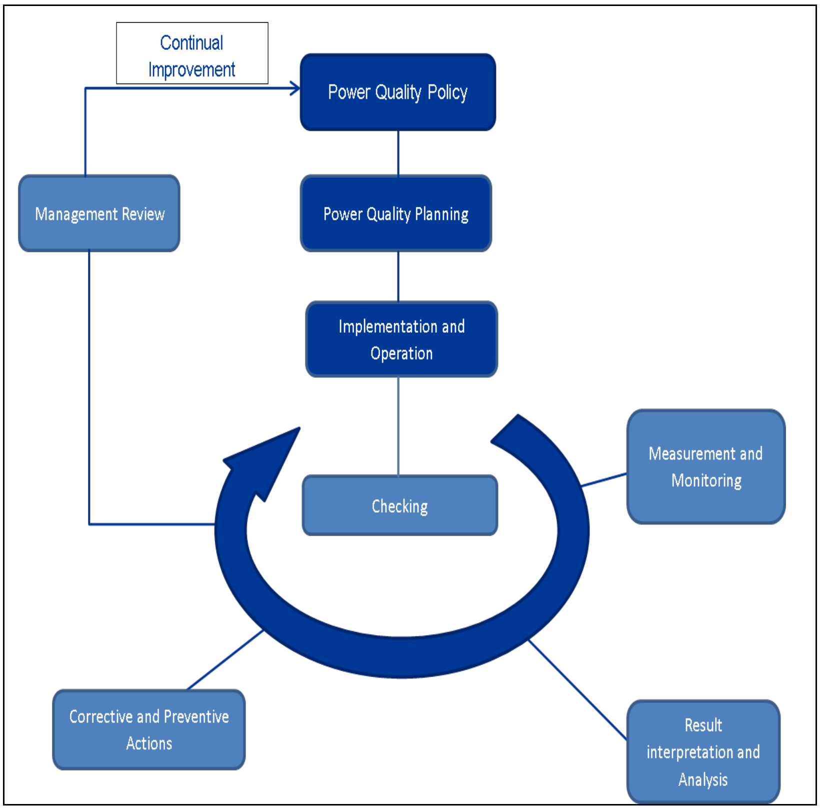

Figure 32: Power quality management model, adapted from ISO 50001

3.3.1.3 Extrapolation of parameters needed in a power quality management

Table 7 presents a summary of a wide range in characteristics of a Power Quality Management as extracted from literature and will be used in this research.

Table 7: Parameters of Power Quality Management

Parameter	Source reference
• Utility consciousness to PQ demonstrate commitment as the recognition of PQ issues experienced on its network enables the integration of those issues into the utility's strategic business plans.	[17]
• Management of PQ to be improved by enhancing performance of data management systems through use of internet and by online access to information, voltage waveform analysed to derive root-cause and event source • Utilities minimize potential quality of supply problems arising within network, type of network (e.g. overhead lines or underground cables) impact the quality of the supply.	[75], [166], [168], [169], [170]
• Good practices in power quality leadership • Mission statement and corporate value promotes power quality advocacy. • Framework for managing PQ initiatives within utility. • Network design strategies, including network equipment life cycle analysis. • Design, construction and maintenance control. Construction of electricity distribution network involves different phases and important to be done under controlled conditions. Phases that can lead to poor PQ should specify appropriate equipment; final equipment validated for compliance. • Power quality policy impact broader organization in the increase of revenue	[26], [30], [75], [180]

• Internal and external research and development initiatives • PQ performance review by continuous benchmarking.	
• Characteristic voltage dip performance across voltage categories and network types. • Continuous update of characteristic dip numbers and benchmarking of current performance against historic performance.	[125], [165]
• Pre-and post-assessment of grid compliance when new loads and renewable energy sources connects.	[166]
• Power quality management affects both utility and end-users as it involves service quality assessment and underlying management systems. • Technical network innovations i.e. FACTS devices to increase power transfer capability. • Job descriptions that stipulate responsibility to continuous monitoring and auditing of network disturbances to derive root-cause. • Accountability to PQ defined also at senior level. • Forums enabling articipation of customers and other stakeholders.	[30], [33], [180]
• PQ management includes relations between utility and customers. • Educate industrial customers on PQ. • Measure customer satisfaction. • Resolution of customer complaints and disputes.	[18], [26], [33], [82]

3.3.2 Features of a smart grid

Literature on smart grid technology, PMU's, PQ instrumentation and synchrophasors were reviewed in section. 2.8 and 2.9. Current and future developments of how these technologies can improve the monitoring of electrical network were identified.

In addition to smart grid definitions in section 2.8.1, Eskom [135] envisioned that "a smart utility is one that deploys and utilizes a smart grid, together with information and communication technologies, innovative software solutions and business processes in an integrated way, to transform the business model and add collaborative values across external stakeholders (city, country, region, society)". The Eskom smart vision states that the value proposition for smart grid sets the foundation for a utility to deliver benefits, including the following [18]:

- Business optimization through improved revenue and loss management.
- Improved customer experience on reliability and quality, lower cost, better information and service levels.
- Reduced environmental impact, an inclusive energy market, broader economic and societal benefits including industries stimulation by supplier development, localization and job creation.

It is emphasised that the successful realization of a smart grid requires amongst others, resolution of challenges emanating from policies, regulations, national standards and stakeholder engagement [135], [150]. Delineation of theories for smart grid and smart utility, led to the development of three dimensions of smart grid technology:

- Technical system operation,
- Cost-benefit and regulations,
- Social norms and behaviours.

From literature, PMUs are seen as an important technology of a smart utility that also monitor network stability. The benefit of having PMU data available [163] was demonstrated by the development of a variable impedance method scanning trajectory to identify constraints in the network.

Detection of voltage instability due to outages of transmission or generation equipment, the authors in [182] used synchrophasors to propose a sensitivity index in reactive power generation at loads. Monitoring voltage stability at grid-connected renewable energy source were demonstrated by using micro-synchrophasors obtained from an IMD that simultaneously implemented C 37.118-1 Synchrophasors measurement standard and the IEC 61000-4-30 edition PQ measuring standard [79].

Integrating renewable energy sources [14] requires bi-directional power flow and such distribution network requires advanced monitoring due to the intermittency of the renewable energy and because distribution networks were designed for voltage drops and it is at these points where RES connect. Smart grid SCADA systems can include [156] Distribution Network Operations (DMOs), PQ management, and small-signal stability features. The resolution of traditional SCADA data will have to be improved significantly. Modern communications and data management systems can readily accommodate the additional data volume needed for near real-time tracking of distribution system technical performance.

Important in the operation of a smart grid is the definition of demand response (DR) [142], [145]. It involves a set of utility actions at the utility, the end-user customer, or both in order to reduce the system demand.

Improved interaction and responsiveness of customers can realize a wide range of potential benefits on network operation such as improved reliability. Responsiveness of customers requires a set of values that will change behaviours in consumption. The specific social context has to be recognised.

The opinion that individual behaviour is rooted from saliency of specific contextual values finds support in the focus theory of normative conduct as developed in [184]. It addresses the influence of social context on personal conduct. Two kinds of norms exist: a descriptive norm that reflects what is perceived as normal in a given situation and an injunctive social norm that reflects the moral rules and procedures of that social group.

The effect of the social norm in guiding individual behaviour has recently been demonstrated in research on energy conservation where comparative electricity bills and injunctive social norm affect consumer behaviour [185]. From the above, parameters for the smart grid technology were derived as given in the next section.

3.3.2.1 Extrapolation of the parameters of smart grid

Table 8 summarises characteristics of smart grid technology by parameters for the concept smart grid technology.

Table 8: Parameters of smart grid technology

Parameter	Author
• Potential benefit of improving network reliability achieved by promoting interaction and responsiveness of customers on energy consumption through demand response initiatives.	[142], [145], [147]
• Social norms influencing consumer behaviour on energy consumption.	[183], [184], [185]
• Framework that includes protocols and model standards for information management to achieve system interoperability	[140]
• Network stability could be affected by RES, improve network monitoring by analysis of micro-synchrophasors. • Accurate time-stamping needed for waveform event analysis.	[79], [136], [156], [163], [182]
• Power quality parameters in system technical performance monitoring	[171], [186], [187]
• Realization of policies, regulations, national standards. • Value proposition for SA smart grid provides benefits to reduce environmental impact, enable more effective, responsive, and inclusive energy market, and broader economic and societal benefit, including industry stimulation, supplier development and localization and job creation.	[135], [140], [150]

3.4 Operationalisation of power quality management in a smart distribution grid

One of the most challenging parts of this research study was to develop a set of measures for the concepts power quality management and smart grid technologies. As a result, the method suggested in [52] was used to operationalise and define the concepts. It requires defining dimensions (characteristics) and elements (observable behaviours) from each concept as obtained from the literature study.

Dimensions were formulated as the construct of the concept and elements are then developed into the test items (questions) to measure the concept quantitatively. This process is shown in Figure 33.

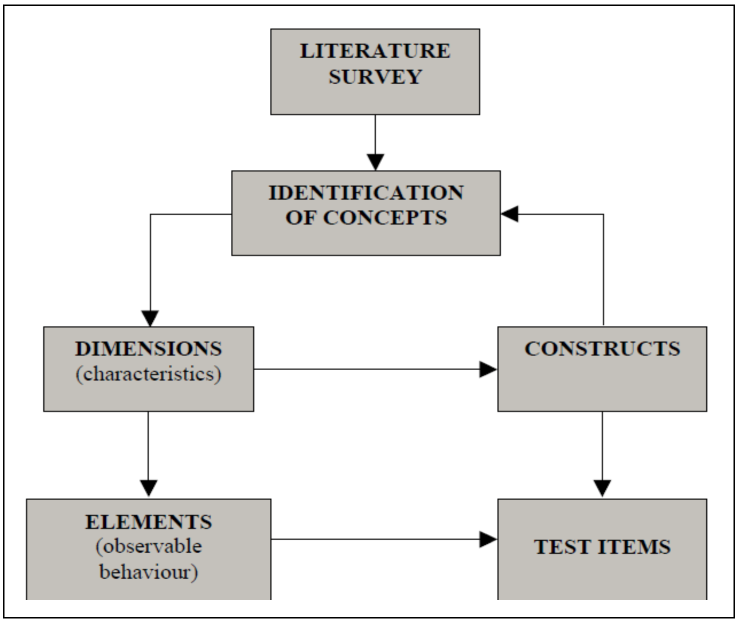

Figure 33: Identification of constructs and tests items

3.4.1 Power quality management components

During the initial stage of the development of the dimensions for the concept power quality management, the definitions provided in the literature study section 3.3.1, Table 8, were used. Four dimensions (constructs) of the concept power quality management (PQM) were developed:

- Top Management Commitment (TMC),
- Service Quality Assessment (SQA),
- Network Topology and Design (NTD) and
- Customer Interactions (CI).

Each dimension was then examined to identify corresponding observable behaviour (elements) within a power utility. The elements were used to develop test items (questions) for each construct. Dimensions and corresponding elements for the concept Power Quality Management are given in Table 9.

Number of test items derived per construct:

- Construct 1; Top Management Commitment: 12,
- Construct 2; Service Quality Assessment: 7,
- Construct 3; Network Topology and Design: 6,
- Construct 4; Customer Interaction: 5.

Table 9: Dimensions and elements for the concept power quality management

CONSTRUCT	ELEMENT
Construct 1: top management commitment	• Top Management drives and supports PQ initiatives within our Organization. • Policy to ensure PQ management programs. • Incorporates PQ initiatives into strategic business plans. • Budgets for PQ improvement projects • The utility adheres to PQ regulations. • Product quality is part of our corporate image. • Develops and implements objectives for continuous PQ improvement. • Communicates PQ performance to internal stakeholders. • Reports on PQ performance in annual reports. • Conducts internal PQ audits • Market research for consumer needs • Invests in PQ and research developments
Construct 2: service quality assessment	• Measures and monitor the quality and reliability of electricity • Use PQ data to identify network faults • Use PQ data to support network operations • Conduct PQ impact for new or alteration of customer load demand • Conducts PQ analysis on a network. • Identify root causes of PQ problems • Benchmark performance trend on the network
Construct 3: network topology and design	• Designs new networks to minimize or prevent PQ impact. • Applies preventative measures such as equipment life-cycle analysis. • Investigates and changes the current configuration of network to reduce or eliminate PQ problems • Maintain network to reduce faults • Implements technologies to reduce PQ distortions.
Construct 4: customer interactions	• Engages with customers to jointly resolve network related issues • Inform customers on PQ performance on network • Investigates supply problems experienced by customers • Emphasizing the PQ aspects of withdrawing energy from customers • Actively engages communities on the impact of damaging electricity infrastructures. • Appoints personnel specifically to liaise with customers

The resulting framework for the dimensions and elements for the concept power quality management is shown in Figure 34

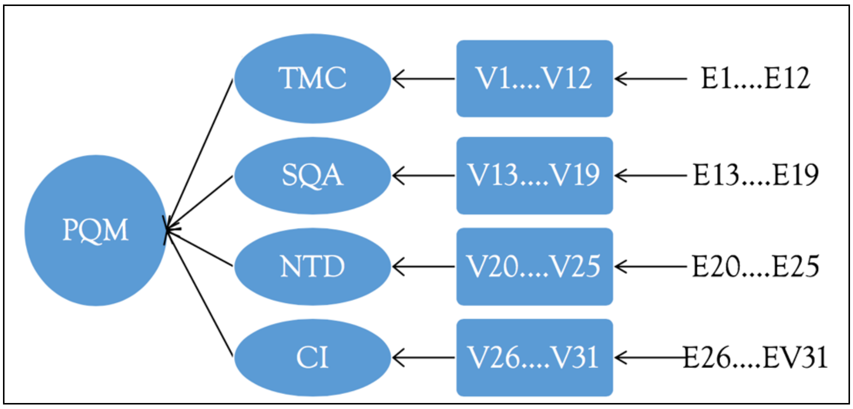

Figure 34: Framework for the dimensions of power quality management

3.4.2 Smart grid technology: components

The same approach was followed to develop the dimensions and elements of the concept smart grid technologies. Firstly, the smart grid was delineated into three dimensions:

- Construct 5: Technical System Operation (TSO),
- Construct 6 Cost-Benefit and Regulations (CBR), and
- Construct 7 Social Norms and Behaviors (SNB).

The elements for each dimension were identified from the literature, discussed in section. 3.3.2.1 and listed in, Table 3.

Six test items were developed for construct 5 (Technical System Operation), four test items for construct 6 (Cost-Benefit and Regulations) and four test items for construct 7 (Social Norms and Behaviours).

Dimensions and elements of the concept smart grid technologies are given in Table 10.

Table 10: Dimensions and elements of the concept smart grid technology

CONSTRUCT	ELEMENTS
CONSTRUCT 5: TECHNICAL SYSTEM OPERATIONS	• PQ measurement technology • Enables control of voltage quality in presence of renewable energy sources • Power system automation. • Creates platforms for the smart grid within the organization • Realizes energy loss reduction through network operational efficiencies. • Measures and monitors quality and stability of electricity • Provides infrastructure to accommodate smart grid
CONSTRUCT 6: COST-BENEFIT AND REGULATIONS	• Deliver service that exceeds expectations (enhanced product or service Value). • Policies and regulatory requirements for smart grids • Government incentives to encourage smart grid investments • Standards to achieve component interoperability
CONSTRUCT 7: SOCIAL NORMS AND BEHAVIORS	• Empowers consumers to change energy consumption behaviours • Enables cost savings to consumers using smart methods. • Facilitates reduction of environmental pollutions

	• Advancement of technological expertise to personnel

The framework for the concept smart grid technology is given in Figure 35.

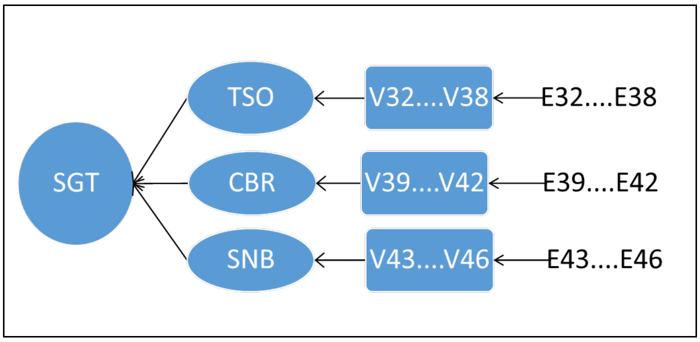

Figure 35: Framework for dimensions of smart grid technology

The final research instrument developed for this part of the study consisted of seven constructs measured by forty-six test items (questions) as derived in Table 9 and Table 10. Five test items were also included to obtain the demographic information about the participant.

This research instrument is shown in Appendix A.

3.5 Formulation of research questions and research objectives

The literature study presented in Chapter 2 and 3 indicated that smart grid technologies could provide intelligible information needed for the measurement and monitoring of power quality to improve the overall management of power quality by utilities. However, no empirical research exists to suggest that this is true for South African-based power utilities. This lack of information led to the following question:

Do smart grid technologies provide an opportunity to improve power quality management at a South African-based power utility?

Accordingly, the concepts Power Quality Management and Smart Grid Technology were delineated to obtain dimensions and elements for the concepts to allow quantitative measurement.

Literature presented in Chapter 2 (section 2.6.3), suggests PQ have a direct impact on the economy, specifically industrial customers. Muhamad *et al.* in [18] identified the need to educate industrial customers on PQ.

Developing understanding of PQ in industry stimulate mitigation measures at end-users that minimize operational risk. NERSA relates to this by a set of regulatory objectives for utilities [26]:

1. Reliable provision of service,
2. Quality of supply and service, in accordance with appropriate standards,
3. Customer satisfaction with the participants in the industry,
4. Resolution of complaints and disputes.

In view of the above objectives, the following secondary research questions were defined:

1. What is the scope of power quality management program employed by a South African-based power utility?
2. How can the smart grid technology be utilised to support network operations in a South African-based power utility?
3. How do the experiences and sensitivity to power quality influence the perceptions of industrial customers regarding the quality of electricity offered by power utilities?
4. What are the key factors that influence a South African-based utility's decision to utilize smart grid technologies for power quality management?

The above secondary research questions were used as basis to derive a number of secondary objectives:

1. To develop measures to measure the concepts Power Quality Management and Smart Grid Technologies.
2. To determine the scope of power quality management program in a South African-based power utility
3. To determine the extent to which South African-based power utilities can utilize smart grid technologies for their network operations.
4. To identify themes, links and patterns in the description of industry participants regarding their experience and industry sensitivity to power quality issues as well as their views on smart grid technologies.
5. To formulate factors influencing a South African-based power utility's decision to use smart grid technologies for power quality management.

The primary research objective of this dissertation is:

To determine whether using smart grid technologies provide an opportunity for improving the management of power quality in a South African utility

3.6 Conclusion

This chapter argued that the management of PQ has to be a fundamental objective of a power utility. Acquisition (buying from Eskom or own generation) of electricity at PQ levels well above the minimum technical standard is needed to deliver that electricity at an acceptable level of PQ to end-users as it can be expected that during the transportation of this electricity (distribution lines, transformers), PQ will become less compared to the level of PQ where it was acquired.

Electricity of a good PQ is needed to keep business processes at the power utility sustainable because the most income to the utility is obtained from industrial and commercial customers and when they cannot operate their business processes in a reliable and predictable manner, their financial success is compromised. Losing their income not only reflects a direct financial loss due to the loss of sales, it also manifests in the loss of return-on-investment in electricity infrastructure needed to supply a customer.

Objectives of the research required a theoretical framework and that needed delineation of concepts in PQ management and smart grid technology. From the literature analysis, parameters were developed and operationalized quantitative measurement.

Research questions were formulated that will allow qualitative measurement of the constructs and associated elements derived.

4 Chapter 4 –Research methodology

4.1 Introduction

From the motivation of the research problem in Chapter 1 a research methodology is derived to qualitatively identify and assess opportunities in smart grid technologies to improve the management of power quality in the South African context.

Research philosophies that underpins execution of the research is critically evaluated in this chapter. Qualitatively research requires the consideration of these philosophies as the measurement instruments are not exact, allowing for skewing of research results if application is not well understood.

4.2 Research philosophies

As the quest for knowledge is rapidly gaining momentum amongst researchers of diverse cultures in South Africa, one of the most prevalent challenges encountered is the difficulty in relating to and understanding the role of theory in research. Consequently, the concept of theory necessitates some clarification. As such, opinions have been suggested [188] that the main role of theory is to guide the researcher. Interpreting the views by the authors in [49], a theory could best be described as an attempt to develop a general explanation of some phenomenon.

A theory defines non-observable constructs that are inferred from observable facts and events and are believed to have an effect on the phenomenon under study. It further implies that a theory describes the relationship among key variables for explaining current state or predicting future occurrences.

These views [49] have provided impetus to the research and endorsed the view and rationale for a discussion of the research design and methodology. Apart from a proper understanding of the concept of theory, the research also required an understanding and knowledge of the related research philosophies that underpin the different principles of research.

The research philosophy that underpins this study is reflected by means of different research paradigms namely, positivism, interpretivism and pragmatism. In understanding these different paradigms, it is necessary to first obtain the holistic meaning of the term paradigm.

It has been pointed out in [189] that four different meanings exist:

- a worldview;
- an epistemological stance;
- shared beliefs among a community of researchers;
- model examples of research.

A paradigm is defined in [45] as "a worldview, together with the various philosophical assumptions associated with that point of view." Likewise, the term "mental model" is used in [190] in much the same way as a worldview, for the purpose of this study, the research requires a paradigm most relevant to the research design.

In order to ensure a comprehensive approach to the research question, research methods and data were explored from different viewpoints. Positivism [191] recognizes working with an observable social reality and that the end product of such research can be law-like generalisations similar to those produced by the physical and natural scientists".

Interpretivism approach argues that there is far too much, ever changing complexity to be defined by "laws" [40]. Saunders et al. in [40] state that "the practical reality is that research rarely falls precisely into one philosophical domain" as well as that the combination of both is common in research. "Deductive reasoning is the development of a theory and hypothesis (or hypotheses) and design of a research strategies to test the hypotheses" [40], [192], [193], [194]. This mainly associates with positivism.

Positivists [193] believe that the world operate on a cause and effect to get to the objective truth. This philosophical viewpoint is based on scientific method of finding out the truth about the world and whose believes further extends to that a researcher is an external observer of the world that he/she is studying. It is believed that for the positivist, emphasis is made on methodology to facilitate replication and quantifiable observations for statistical analysis [195]. This implies that the research is independent of and neither affects nor is affected by the subject of the research and consequently, the generation of data should be independent of human opinions and judgment.

Inductive reasoning is when data is collected first and then theories developed as a result of the data analysis [40] associated mostly with interpretivism.

Interpretivism, also called the phenomenological approach, focusses on exploring the complexity of social phenomena with a view to gaining understanding. The purpose of research in interpretivism is to understand and interpreting everyday events, experiences and social structures as well as the values people attach to these phenomena [196]. Interpretivists attempt to understand subjective realities and to offer explanations which are meaningful for the participants in the research.

From the above deliberation, the approach to social phenomena for the study should reflect the construction of common knowledge; it implies the following assumptions:

- The social world is observed by seeing what meanings people give to it and interpreting these meanings from their viewpoints;
- Social phenomena can only be understood by looking at the reality.

Gathering and measuring facts would consequently not disclose the essence of social phenomena; rather the research has to explore for example why different large industrial customers of South African-based power utilities have different experiences with regards to power quality and to understand how these differences result in the different perceptions and meaning to their respective power utilities.

In this way, the researcher would be able to make sense of how different industrial customers of power utilities interpret their power quality experiences. The researcher was required to probe into the process of subjective interpretation, acknowledging the motivations, interests, intensions, beliefs, values and reasons and the self-understanding of the participants [188], [195], and [197].

From these theoretical concepts, the conclusion could be drawn that quantitative methods of generating data are more suitable for the positivist's paradigm, while qualitative methods are more suitable for the interpretive paradigm. Differences in these philosophical paradigms raise a salient question of whether this research should be addressed by a single research approach or by more than one research approach.

It should be noted that the research problem, accompanying research questions and related research objectives thereof in this research are of multifaceted nature and this played a key role in determining the type of research strategy used. Another school of thought indicates that when both qualitative and quantitative research methods are combined, then their separate efficiencies are improved [198].

This brings to attention the theory of pragmatism. Pragmatism is regarded as the deconstructive paradigm that advocates the use of mixed methods in research, "sidesteps the contentious issues of truth and reality" [199], [200] and focuses instead on 'what works' as the truth regarding the research questions under investigation [45], [201]. Research pragmatism philosophy is characterized by the shared principles of positivism and interpretivism [188]. It means that in pragmatism, the focus of research is on the research question and different methods can be employed to answer this question.

4.3 Research methodology

Methodology [191] is described as an overall approach to a problem which could be put into practice in a research process from the theoretical underpinning to collection and analysis of data. Also, methodology has been identified [194], [195], [202] as the "overall approach to the entire process of the research study".

Variation in methodology is according to the problems to be investigated. Saunders *et al.* in [40] use an "onion" in which the thoughts with regard to the research problem lie in the centre and several layers have to be "peeled away" before getting to this central position.

These layers are important aspects in determining the research methodology for a particular research study. Research philosophy, approach, strategy, time horizon and techniques were the layers as shown in Figure 36 [40].

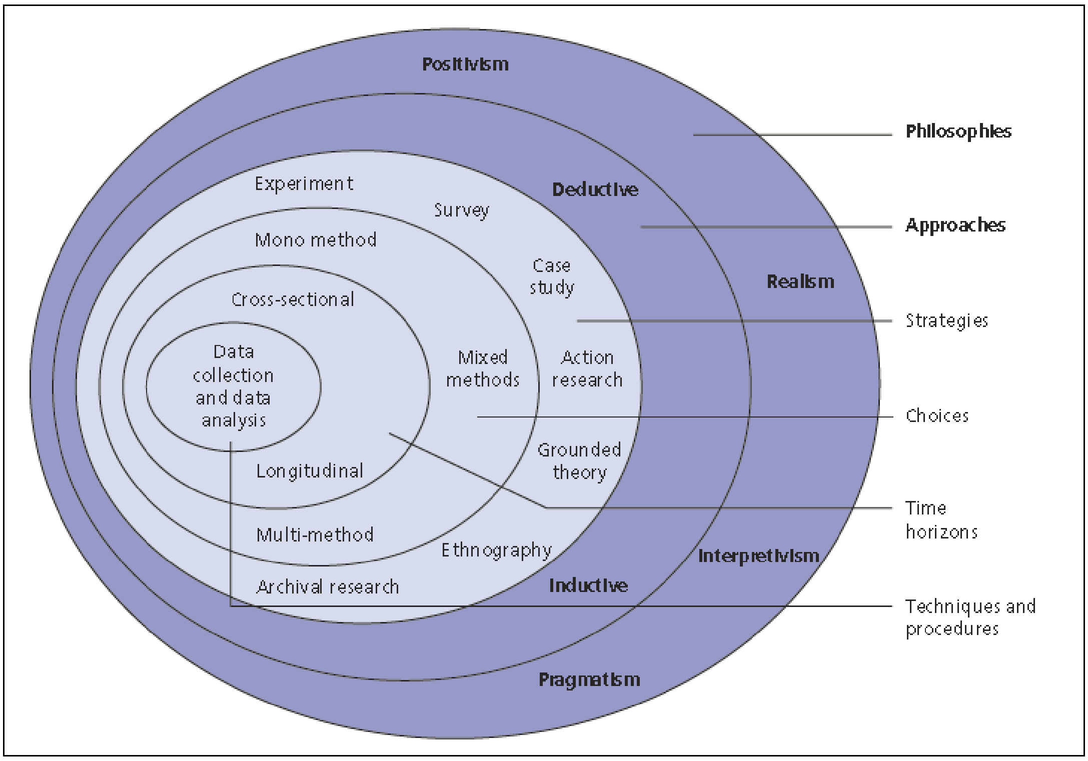

Figure 36: The research onion as research methodology [40]

Research methodology needs a process, tools and procedures [42]. From the literature study, empirical research has to be conducted and why a research strategy was derived.

4.3.1 Literature review and research strategy

Chapter 2 and 3 presented a literature review. It made use of scientific journal papers, reports by professional institutions and Government Gazetted documents. It was mainly obtained from the internet search engines and the Eskom electronic internet database (Hyperwave). The goal was to derive information on the current state of power quality on a global context and smart grid technologies can be used to improve current practises.

4.3.2 Empirical research and research strategy

An empirical study was undertaken using qualitative and quantitative methods to obtain field data Empirical is defined [43] as knowledge derived by the process of practical scientific experiences, experiments and enquiries.

Purpose of this empirical investigation was to obtain reliable valid field data needed for the research objectives. The research problem entailed evaluating key factors influencing a South African-based power utility's decision to utilize smart grid technologies for power quality management.

Research questions enquired about opportunities for power utilities to use smart grid in South Africa, the current scope of power quality program within South African power utilities, the perception of industrial customers about the level of power quality on the power utility's network and views of industrial customers on smart grid technologies to support monitoring and management of power quality.

The following research objectives were defined:

- To develop measures for the concepts power quality management and smart grid technology;
- To determine the scope of power quality management program in a South African-based power utility;

- To determine the extent to which South African-based power utilities can utilise smart grid technology for their network operations;
- To identify themes, links and patterns in the description of industry participants regarding their experiences and industry sensitivity to power quality issues, as well as on their views about smart grid technology; and
- To formulate factors influencing a South African-based power utility's decision to use smart grid technology for power quality management.

From the scope and complexity of the research problem, a mixed methods approach is used and presented next.

4.3.3 Quantitative and qualitative research

The convictions of researchers are that different approaches to research encompass both theory and method. Two approaches are widely recognized namely, qualitative and quantitative research [40], [50], [194], and [198].

In quantitative research, researchers are concerned with an objective reality that is "out there to be discovered" [40], [50], whereas qualitative research associates with the understanding of a social situation from the perspective of the participants and that researchers interact with that being researched [24], [40], [203].

Quantitative and qualitative researchers differ in the view of the world as they seek to attain knowledge using different approaches to research [46]. It is argued in [203] that quantitative and qualitative approaches should be viewed as a balancing method that, when used jointly, provides options to study complex problems facing social scientists.

According to [40], some researchers perceives qualitative studies to be best suited for investigating themes and relationships at the case level, whereas quantitative studies are best applied in validating those themes and relationships using samples and populations. Considering this, it follows that qualitative research can be used as a discovery mechanism, while quantitative research is employed as the affirming mechanism.

From a quantitative aspect, the goal of research is "collecting 'facts", which when accumulated will provide verification and elaboration [204]. On the other hand, the goal of qualitative research is to "better understand human behaviour and experiences, grasp the processes by which people construct meaning and to describe what those meanings are" [204].

Table 11 list the differing assumptions underlying quantitative and qualitative research. The rationale for including this information is to reveal the greater depth of acquiring the advantages derived from adding the analytic induction of qualitative approach to the systematic and objective process of a quantitative approach.

Table 11: The differing assumptions underlying quantitative and qualitative research [205]

Quantitative research	Qualitative research
Assume an objective social reality	Assume that social reality is constructed by the participants in it.
Assume that social reality is constant across time and settings	Assume that social reality is continuously constructed in a local situation.
View causal relationship among social phenomena from mechanist perspective	Assign human intensions a major role in explaining causal relationships among social phenomena.
Take an objective, detach stance towards research participants and their settings	Become personally involved with research participants, to the point of sharing perspectives and assuming a caring attitude.
Study populations or sample that represent population	Study cases.
Study behaviour and observable beliefs	Study meanings that individuals create and other internal phenomena.
Study human behaviour in natural or contrived setting	Study human actions in natural settings.
Analyse social reality into variable	Make holistic observation of the total context within which social reality is constructed.
Use preconceived concepts and theory to determine what data will be gathered. Generate numerical data to present the social environment	Discover concepts and theories after data have been gathered; generate verbal and pictorial data to represent the social environment.
Use statistical methods to analyse data	Use analytic induction to analyse data.
Use statistical inference procedure to generalize findings from sample to define population. Generalize findings from sample to a defined population	Generalize case findings by researching for other similar cases.
Prepare impersonal, objective reports of research findings	Prepare reports that reflect constructions of the data and awareness so that reader will form their own construction from what is reported.

From Table 11, quantitative and qualitative designs differ in the sense that in a quantitative approach, the researcher test a theory by first specifying a hypothesis and then collect data to either support or refute the hypothesis. Data is collected by means of an instrument that measures attitude and analysed using statistical procedures and hypotheses testing.

Qualitative approach seeks to create meaning from the opinions of participants [203]. In view of the above, it may be necessary in a study to first gather qualitative opinions of participants in order to determine what information is needed for in-depth analysis and thereafter carry out a quantitative study from the known information gathered by qualitative research.

In this study, the research objectives necessitated the concurrent use of both research methods.

4.3.4 Mixed methods research

The research problem and objectives presented in this study favoured different research techniques. The main function [42] of designing a research strategy is to enable the researcher to anticipate what the appropriate decisions are likely to be, as to maximize the validity of the eventual results.

In terms of collecting the relevant data, the study focuses on:

- Scope of power quality management program at South African-based power utilities,
- Perceptions that industrial customers have on the power quality received from power utility, and
- Stance of power utilities and industrial customers regarding the use of smart grid technologies to support the management of power quality.

The design for this research is a multi-approach that implies choosing from different alternatives to ensure that the research purpose and perspective are clarified and achieved. Types of measurement, sampling of data, collection of data and data analysis are determined by the methods and procedures used.

Using both a qualitative and quantitative approach is regarded as pragmatic research paradigm [24], [203], [206]. It is a philosophical partner of the mixed methods research.

Mixed methods are considered a workable solution to multifaceted research problems and a practical “middle ground” orientation in relation to positivism and interpretivism [47].

4.3.4.1 Rationale for mixed methods research

The line of thinking brought by the basic elements of mixed methods research in accommodating the collection of both quantitative and qualitative data has led to adopting the mixed method as preferred research strategy in this study. It is stated that the goal of mixed methods research [47], [206] is not to replace qualitative or the quantitative approaches in conducting research but to utilize the strengths of each leading to a better understanding of the research problem compared to using a single approach.

Two major advantages of mixed methods in the same study [40] are that firstly different methods can be used for different purposes in a study. Secondly, it enables triangulation.

Choosing a mixed method design:

- Ensure the research question is answered from different perspectives,
- Variation in data collection supports data validation,
- Contains “gaps” in data collected,
- Enhance significance of data interpretation,
- Allow for unexpected developments,
- Improve convergence and collaboration of findings,
- Explain personal circumstances, approaches, opinions and practices of different respondents
- A combination of methods enhances triangulation of data,
- A combination facilitates both internal and external perspectives,
- A combination allows emphasis at different stages of the research process.

4.3.5 Research strategy

A research strategy is defined in [40], [41] as the “general plan of how the researcher will go about answering the research questions”. Research strategy has been identified in [208] as a “general orientation to the conduct of research” and provides [191] the overall direction of the research.

Appropriate research strategy [40], [44] has to be selected from research questions and objectives, the extent of existing knowledge on the subject area researched, time and resources available and philosophical underpinnings of the researcher.

4.3.6 Research design

A research design entails the overall strategy that the researcher undertakes to integrate the different elements of a study in a coherent and logical approach, ensuring that the research problem is effectively addressed. It constitutes the blueprint for collection, measurement and analysis of data.

Serving as a functional plan in which certain research methods and procedures are linked together to obtain reliable and data that is valid for empirical analysis [39]. The research design provides the researcher with a research framework as it guides the methods, decisions and sets the basis for data interpretation.

Research design [37] is best described as the overall plan according to which the participants of a proposed study are selected and what data will be collected. Babbie and Mouton [36] describe research design as a plan oar blueprint to research and compared [38] with an architectural blueprint.

Research design is also the plan of action that links philosophical assumptions to specific methods [46]. This means that selecting a research design involves identifying research questions, information needed to appropriately answer specific research questions and the most effective strategies required to obtain the answers.

This study uses research design as a guideline to choose methods for data collection, sampling and analysis [39] making use of mixed methods involving both qualitative and quantitative approaches. An empirical design was undertaken involving a survey, interviews and phenomenology.

A phenomenological study [41] attempts to understand people's perceptions, perspectives and views of a particular situation. Observing multiple perspectives on the same situation enables the research to generalize on from an insider's perspective.

4.4 Quantitative research design

Quantitative research methods emphasize objective measurements. Statistical, mathematical or numerical analysis of data is collected by polls, questionnaires, or by manipulating pre-existing statistical data [204]. It requires numerical data and where possible, generalizing it across groups of people or to explain a particular phenomenon [36], [209].

An objective approach is needed when evaluating data to exclude bias from the researcher's perspective. Data collection methods are structured. A questionnaire is typically used to collect data statistical analysis [40].

4.4.1 Statistical survey as research method

Survey methods are used extensively for data collection in social sciences [42]. It is defined as a brief interview or discussion with individuals regarding a particular topic.

Surveys require researchers to elicit information from respondents in providing the researcher insight into the meaning and importance of the response. Data can be collected using interviews and questionnaires. For the purpose of this phase of the study, a questionnaire was chosen.

4.4.2 Research model and hypotheses

4.4.2.1 Research model

The power quality management model proposed in [30] was used as a starting point for the development of a theoretical model for this research (Par. 3.3.1.2; Figure 32). It shows links between corporate strategies, power quality management, monitoring and measurement for continuous improvement.

"To manage power quality, it is necessary to establish a PQ policy, baseline, plan and management review, and it is absolutely mandatory to measure, analyse and improve power quality in a continuous process" [30]. It is proposed [26], [30 that monitoring, and measurement is an important component of power quality management determined by the commitment to monitoring.

Power quality performance affects the overall perceptions toward electricity. Power quality management performance was measured in [180] using the utility's ability to proactively resolve power quality problems and the choice of indicator was influenced by the "manner in which the utility's PQ performance is continually assessed, valued and reflected by commercial and residential customers".

The model in [30] was found to be lacking by the delineation of the concept power quality management and smart grid technologies relate. Chapter 2 and 3 indicates that concept power quality management involves more than only commitment to monitoring.

A dimension of customer interaction is needed. Secondly, the author in used only. The traditional approach to PQ measurement [30] can be significantly improved using modern intelligent devices incorporated as a smart grid system. This research proposes dimensions of smart grid technologies to facilitate the management of power quality. The full hypothesized structural model for power quality management is given in Figure 37.

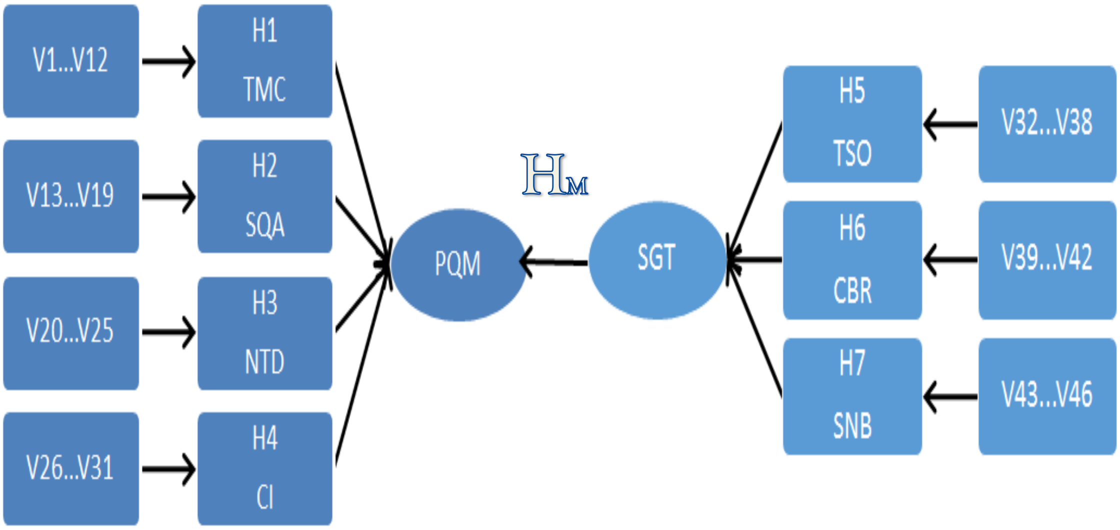

Figure 37: Complete model for the link between Power Quality Management and Smart Grid Technology

The above-model proposes that Power Quality Management is defined by 4 constructs:

1. Top management commitment,
2. Service quality assessment,
3. Network topology and design and
4. Customer Interactions.

Smart grid technology to be used monitor and measure power quality are:

1. Technical system and operation,
2. Cost-benefit and regulations and
3. Social Norms and Behaviours.

Lastly, the model proposes that Smart grid technology can enhance the management of PQ.

4.4.2.2 Construct definition and hypotheses development

A research hypothesis is defined in [210] as "a specific, clear, and testable proposition or predictive statement about the possible outcome of a scientific research study based on a particular property of a population, such as presumed differences between groups on a particular variable or relationship between variables." It is regarded as a supposition or proposed explanation made on the basis of limited evidence as a starting point for further investigation.

McMillen in [211] refers to a hypothesis as an informed guess or prediction that indicates what the researcher thinks the results will be before the study is carried out. In the contrary, [194] states that hypotheses could also be the suggested end-product resulting from an exploratory research in the outlining of a research problem.

In this study, the aim of the hypotheses is to state a priory expectation about the results of the quantitative phase of this research. Using the dimensions for the concepts of PQ management and smart grid technology, a number of hypotheses are required:

- Hypothesis 1: Top management commitment as influence to PQ management

The term Corporate Quality Management as defined in ISO [212] [25], providing public and private sector strategies to manage quality, increase energy efficiency and improve performance. The NERA PQ Directive [26] requires continual improvement as an aspect of the ISO management system. Utilities have to identify appropriate technical standards and codes of practices on PQ for the management of PQ issues.

From these definitions, *Construct 1: Top Management Commitment* measures the extent to which top managements or managements of utilities recognizes the importance of PQ issues within their utility and if integration into the utility's strategic and operational plans took place.

- Hypothesis 2: Service quality assessment as an influence to PQ management

The PQ Directive [26] make use of the NRS 048 part 2-2007 as minimum technical standard to PQ technical performance [33].

Assessment of PQ needs instrumentation to collect field data. Different classes of data are defined by the NRS 048 making use of an international PQ measuring standard, the IEC 61000-4-30, edition 3. When the compliance to the minimum technical requirements of PQ has to be assessed (NRS 048 part 2-2007 or 2015), then a Class A IEC 61000-4-30 edition 3 instrument is needed. When such certification of the instrument does not exist, PQ data can still be used for PQ management, but is now regarded as statistical data only.

- Hypothesis 3: Network topology and design as an influence to PQ management

This construct measures the extent to which a utility designs, operate and incorporates technologies to mitigate the impact of PQ problems to customers. Included are the possible application of network life-cycle analysis and technical innovations.

Network life-cycle analysis examines trends of PQ parameters and potential impacts on the electrical network throughout its life cycle, from construction to operation. Technical innovations to be considered are for example voltage regulators and harmonic filters.

- Hypothesis 4: Customer interaction in PQ management

PQ Management aims to improvement interaction between utilities and customers. It requires transparent communication on root causes and impacts on customers (including financial) resulting from power quality events.

Utility-customer partnership improve the confidence that the customer has in the utility's technical staff dealing with their power quality concerns [82]. Partnership implies trust and needed by the utility to disclose the reliability and quality of power.

- Hypothesis 5: Technical system operation using smart grid technology

A framework for smart grid technologies is proposed [27], [28] that comprise network operations, business network, and consumer network.

Electrical utilities handle electricity generation, transmission, distribution and consumption to maintain the stability and efficiency of the entire system [145], [149]. They need communication networks, sensing and measurement and methods to control and support decisions.

The deployment of these technologies and application provides potential for driving innovative methods of producing, consuming and controlling electricity, yielding benefits to utilities, consumers and the society.

- Hypothesis 6: Cost-benefit and regulations related to smart grid technology

This measure the potential benefit perceived by a utility from investment in smart grid initiatives [150]. The deliberations are on the premise that finding ways of incentivising utilities to pursue innovative solutions can be considered beneficial from the view point of society. The researcher proposes the following hypothesis:

- Hypothesis 7: Social norms and behaviors relates to smart grid technology

It is acknowledged [183] that multiple motives and different value orientations may coexist in the same individual and differently prioritized according to the specific social context. The argument that individual behaviour stems from saliency of specific contextual values finds support in the focus theory of normative conduct [184] addressing the influence of social context on personal conduct.

Two norms exist: a descriptive norm on the perception we have of what is normal in a given situation and an injunctive social norm that explicitly reflects the moral rules and guidelines of the social group. Injunctive norm tends to motivate and constraint our actions through the promise of social rewards or sanction [213].

The effect of social norm in guiding individual behaviour has been demonstrated in research on energy conservation [185] where by the use of comparative electricity bills that employs injunctive social norm (conveying that energy conservation is pro social) affects consumer behaviour. It demonstrated that non-price-intervention can substantially and cost-effectively change consumer behaviour.

Social norms and behaviours can be affected by implementing smart metering initiatives such as in demand response [145].

The final hypothesis can now be derived:

H_M: Smart Grid Technologies can have a positive effect on PQ Management, monitoring and measuring using smart grid technologies.

4.4.3 Research questionnaire

4.4.3.1 Constraint during questionnaire design

This phase of the research employed self-administered questionnaires that were delivered and returned electronically via email and the internet. A questionnaire is believed to provide an efficient way of collecting responses from a large sample prior to quantitative analysis because each respondent is requested to respond to the same set of questions.

It is for that reason that this technique was used in this phase of the study due to the need to solicit responses from the same questions. It collects quantitative data to make analytical inferences from the sampled target population. The internet was the most convenient resource to distribute and collect survey forms.

4.4.3.2 Attributes of the research questionnaire

The main attributes of a research questionnaire are provided by Saunders *et al.* [40].

- Respondents were selected as senior engineers at the participating power utility and assumed to be computer literate with access to the internet.
- Confidence level that the correct person has responded to the questionnaire is high with the use of email.
- Online questionnaires support a sample size that is geographically distributed (as is the case in this study).
- Probability of contamination or distortion of answers given by respondents is low.
- This method suits closed-ended type questions that are not too complex.

4.4.3.3 Design of the research questionnaire

The dimensions and elements of power quality management and smart grid technologies were tapped to develop the test items of this phase of the research instrument. A questionnaire allows standardization and comparison of survey data [40].

Six demographic questions about respondents were used and forty-six test items tapped the dimensions and elements of the 7 constructs. It is attached as Appendix B.

A five-point Likert scale was used as rating scale. It is an itemized rating scale that provided categories of responses from which the respondents select the one most relevant for answering the question under consideration. The scale was assigned polar points with levels defined in Table 12.

Table 12: Rating scale used for the survey questionnaire

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1	2	3	4	5

"Neutral" implies that the respondent does not know an answer to the question. It is stated [52] that "research indicates that a five-point scale is just as good as any scale and an increase from five to seven or nine points on a rating scale does not necessarily improve the reliability of the ratings".

Since an interval scale permits coding, it has the advantage of allowing the researcher to perform arithmetic evaluations on the data collected from respondents [204]. The survey forms were designed as 13 web pages using the online survey development cloud-based computer software (*i.e.*, Survey Monkey):

- An introduction page summarizing the purpose of the research and research objectives.
- A page with detailed instructions on the completion of the questionnaire and description of each construct.
- A page with a statement of declaration.
- Pages with research questionnaires.

In order to ensure logical order of flow, the questionnaire was split into three sections as follows:

- Section A: measure the utility power quality program.
- Section B: Measure the utility's perception on smart grid technologies.
- Section C: Demographic information – to obtain demographical information from the respondents in order to describe the target population.

All the web pages of the questionnaire are listed as Appendix B. Statement of declaration ensured the participant confidentiality of his or her responses. The response data was sent automatically to the data server.

4.4.3.4 Limitations of online questionnaire

A possible problem anticipated with the use of online administration of questionnaire was a very low response rate (10% or less). The following reasons were contributing:

- Non-response bias was expected as the respondents had to take additional steps to locate and complete the questionnaire [40]. Non-response bias makes it difficult to obtain a representative sample and consequently, this affect, if any, the generalizability of the research.
- Sample selection bias because predominantly, larger municipalities and the main power utility (Eskom – Distribution group) were purposefully selected to participate in the study. Lack of human resources and finances in terms of PQ were the leading causes [214] when no response was received from majority participants of the chosen sample.
- Unwillingness to participate also threatened the response rate from the identified participants. Out of the identified sample participants, only 11 responses were received. Non-response to email survey [215] is likely to be due to adopted attitude towards survey topic or the use of email for the survey itself.

Since purposive sampling was used, this threatened the representativeness of the sample as it was selected out of expert judgment. A representative sample becomes valid over the domain it represents, providing external validity and becomes valid for the sample when measured correctly and consequently, providing internal validity.

4.4.3.5 Validity of research questionnaire

In the development of a questionnaire instrument for data collection, the phenomena of interest have to be translated into a concept that can be measured. Without a proper method for data collection [53], [216] the validity of conclusions derived from the questionnaire becomes questionable.

Care and monitoring of the design of each question or item of the questionnaire must be taken regarding clarity, consistency, relevance and impartiality. Response rate, reliability and validity can be maximized by [40]:

- Careful design of individual questions;
- Clear and pleasing layout of the questionnaire;
- Lucid explanation of the purpose of the questionnaire;
- Pilot testing;
- Carefully planned and executed administration.

Validity [52] refers to the extent to which an empirical measure precisely reflects the concept or theory it is intended to measure, yielding scores that reflect the true variables being measured and divided into three categories [53], [54]: (1) *construct validity*, (2) *predictive validity* and (3) *content validity*. These aspects are delineated as follows:

Construct validity measures how well the results obtained from the test measures the fitting theory. *Construct validity* consists *convergent validity* and *discriminant validity*.

Convergent validity occurs when the same concept is measured by two different instruments and high correlation is obtained from the groups of indicators [54], [217], whereas *discriminant validity* occurs when two different variables are measured, and the groups of indicators are uncorrelated [217]

Predictive validity is the ability of a measure to predict a future criterion [52], [218].

Content validity "deals with the measure of delineating the dimensions and elements of a concept" [52]. The minimum index for content validity is termed *face validity*.

In this research, actions to promote the validity of the research instrument are discussed in the sections below.

4.4.3.5.1 Phase validity

Firstly, the wording of the questions was tested using the checklist of sixteen questions given by Saunders *et al.* in [40].

As an example, question 4 of the checklist reads as follows: "are the words used in your question familiar, and will all respondents understand them in the same way?"

Using the above checklist, test item 35 of the research questionnaire contained wording such as "mixed technologies" and subsequently, the wording was clarified by providing examples of what was meant by "mixed technologies", as it denoted Flexible Alternating Current Transmission System (FACTS) devices (such as a Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM)) and renewable energy sources such as wind and solar. This was done to ensure that all survey respondents interpret the question correctly.

4.4.3.5.2 Content validity

The provisional research instrument (questionnaire) was pilot tested by subjecting it to a panel of experts in the field of PQ that validated the proposed tests items and made comments and recommendations regarding the representativeness and suitability of the questions.

This serves as content validation of the questionnaire, in that the expert had to validate whether the questionnaire covered the content being researched [40], [43]. According to [219], "the development of a content valid instrument is typically achieved by a rational analysis of the instrument (questionnaire) by experts familiar with the stated constructs or the research subject."

4.4.3.5.3 Selection of expert panel

Saunders *et al.* in [40] recommend that the number of people chosen for the expert panel should be sufficient to include any possible major variations in the population that may have an influence on the responses. The target population for this phase of the study was South African-based power utilities.

Since the content validity was to rely upon judgment of an expert panel, the expert panel ought to possess extensive knowledge and demonstrate a good grasp of the subject being explored. The adequacy of the final content of the test instrument was based on the collective opinions of the experts based on their professional assurance [219].

For the purpose of representativeness of the expert panel, academic, business and power utilities were included. Fourteen experts were selected:

- Academic: 3
- Business: 3
- Power utilities: 3

Power utilities included chief engineers from the power utility (Eskom – Transmission and Distribution) who had extensive years specializing in the field of power quality;

Academics included individuals who have specialized in PQity research from three different South African academic institutions;

Business included top or senior management representative of companies who were doing consulting work on power quality research and development.

Initially the panel members were contacted via telephone and asked whether they would participate in the research exercise as expert panel members. After their permission had been granted, a letter explaining the research objectives were sent to the members via email (communication via email was a specific request of all panel members).

The correspondence email to the expert panel members is given in appendix C. Included in the correspondence were the summary of the research, a short description of each measured construct, a detailed instruction on completing the questionnaire and the specific requirements of the expert members regarding the assessment of the questionnaire. After one week of sending the questionnaire a reminder email was sent to all the participants and within one week, a total of eight responses were received from the original fourteen requests. All the responses were received via email-as this was a specific request by the researcher. A response rate of 57% was accepted by the researcher. Finally, a thank-you message was sent to each respondent via email.

4.4.3.5.4 Content validity method

The requirement of this exercise was for the expert members to indicate whether each questionnaire item on a scale is congruent with (or relevant to) the constructs being measured. It entailed computing the percentage of items (questions) deemed to be relevant for each expert, and then taking an average of the percentages across experts [55].

This approach is referred to as the Content Validation Index (CVI), reported to be the most widely used measure of content validity [55]. Two types of CVIs [220] are used by researchers to compute the content validation index. The first type involves the validity of individual items (I-CVI) and the second the content validity of the overall scale (S-CVI).

Two methods of computing the S-CVI index are given [55] the S-CVI/UA and S-CVI/AVE. For the purpose of this study, S-CVI was restricted to the definition of S-CVI/AVE [55] as “the average proportion of items on an instrument that achieved a rating of 3 or 4 by the content experts”.

The panel of experts was requested to rate each scale item in terms of its relevance to the underlying constructs. A minimum of 3 experts [220] may be used with more than 10 experts are unnecessary.

Eight experts were used to evaluate content validity. A 3-point or 5-point rating scales should be avoided [220] as a 4-point scale avoids an indecisive midpoint.

Table 13 below presents the rating scale used.

Table 13: Rating scale used during piloting of the questionnaire

Not relevant	Somewhat relevant	Quite relevant	Highly relevant
1	2	3	4

4.4.3.5.5 Content validity index benchmark

For the rating to be considered a reasonable representation of the universe of possible ratings, it is recommended in [220] that the I-CVI should be 1.00 when there are five or fewer experts, and no lower than 0.78 when there are six or more experts. Consequently, an I-CVI benchmark value of 0.78 was used to evaluate the expert judgment of the questionnaire items; information obtained from the I-CVI was used to guide in revising, deleting or substituting items of the questionnaire, however, items with an I-CVI of 0.78 and above were considered for automatic inclusion in the final questionnaire. In terms of the S-CVI, a minimum benchmark value of 0.8 has been recommended [221]. Therefore, the researcher adopted these benchmark values in carrying out the content validation of the questionnaire in this study.

4.4.3.5.6 Content validity analysis

From a set of 47 questionnaire items, content validity process yielded 46 items from 7 constructs, consisting of Top Management Commitment (12 items), Service Quality Assessment (7 items), Network Topology and Design (6 items), Customer Interactions (6 items), Technical System Operation (7 items), Cost Benefit and Regulation (4 items) and Social Norms and Behaviour (4 items).

A Microsoft Excel program was used for the calculation of the I-CVI as well as the S-CVI/AVE. The I-CVI value was calculated for each group of items in order to illustrate the content validity at both item and at scale level. In the different subsection the range of I-CVI was higher than the recommended, which is 0.70 and above. The I-CVI values for the different subsections of the questionnaire are given in Table 14.

Table 14: Content validation analysis for the constructs of the questionnaire

Construct	Experts	Items	I-CVI range	S-CVI/AVE
Top Management Commitment	8	1 – 13	0.35 – 1.00	0.92
Service Quality Assessment	8	14 – 20	0.88 – 1.00	0.93
Network Topology and Design	8	21 – 26	0.63 – 1.00	0.79
Customer Interaction	8	27 – 32	0.88 – 1.00	0.95
Technical System Operations	8	33 – 39	0.63 – 1.00	0.88
Cost-Benefit and Regulation	8	40 – 43	0.63 – 1.00	0.81
Social Norms and Behaviours	8	44 – 47	0.88 – 1.00	0.94

From Table 14 above, it is quite clear that the I-CVI for 98% of the items (46 items) varied from 0.63 to 1.00 and the S-CVI varied from 0.70 to 0.92. Following the analysis in Table 8, amendments were made to the initial version of the questionnaire. Although the original version of the questionnaire had 47 items, the revised version was reduced to 46 items, with item 11 (under Top Management Commitment) removed (with an I-CVI of 0.35). according to the authors in [55], items with an I-CVI of 0.65 and above has a greater chance of being interpreted the same way as items meeting the criteria set out in [220], even without being rephrased. However, for purposes of this study, the researcher used comments made by the experts to rephrase the items with an I-CVI rating of between 0.63 and 0.75 and subsequently included these items in the final questionnaire. Due to lack of time and the difficulties in reaching out to experts, the revised version of the questionnaire with the amendments made was not sent back to the panel of experts for evaluation. The details of the amended items are as follows:

(1) Item 11 of the questionnaire was judged by several panel members to be of no relevance from a power quality regulatory perspective and suggested that the item be removed. From the ratings, calculation of the content validity index for the item (I-CVI) yielded a score of 0.35. The item read as: "Our organization conduct market research to determine consumer needs for power quality acceptable electricity". The members argued that power utilities were required to comply with regulatory compliance as well as contractual obligations and not just consumer needs for acceptable electricity as this may vary. As a result, the item was removed from the final questionnaire.

(2) Some of the panel members suggested rephrasing in wording for some of the items, in order to ensure clarity to the question; most of the items had an I-CVI score of between 0.63 and 0.75. After rephrasing or rewording, the items were then included in the final design of the questionnaire. The following are the items that were rephrased:

- Item 5 of the questionnaire read as follows: our organization has a policy of regulatory PQ compliance. the item was subsequently rephrased to: our organization has a PQ policy to ensure our network comply to regulatory standards
- Item 6 of the questionnaire read as follows: adherence to PQ regulations is part of our corporate image. One panel member suggested the question be rephrased and it was consequently changed to: ensuring product reliability and quality is part of our corporate image.
- Item 22 of the questionnaire read as follows: our network consists of predominantly underground cables. Three panel members remarked that they did not understand the purpose of the question. The question had an I-CVI of 0.63. The question was later rephrased using suggested comments, and was changed to: We prioritize installation of underground cables when designing our MV distribution network
- Item 41 of the questionnaire read as follows: regulatory standards are required to provide incentives to utilities in terms of rate recovery for smart grid investments. Some panel members found it difficult to interpret the question and suggested rephrasing hence, it was later rephrased to: Incentive-based approach through regulatory standards can influence our utility to undertake smart grid investment initiatives.

No further comments were made on the research questionnaire and after implementing the stated changes; the research instrument was endorsed by the research supervisor and co-supervisor and thereafter finalized and administered for the collection of data from participants

4.4.4 Population and sample selection

4.4.4.1 Study population

The electricity supply industry in South Africa is largely dominated by Eskom, which generates, transmit and distribute over 95% of the country's electricity [222]. In turn, Eskom sell electricity to a number of customers, including to municipalities, which distribute power to end users. It follows therefore that collectively, Eskom and the municipalities take responsibility for the distribution of electricity to end-users and consequently, power utilities are the study population of interest in this phase of the study.

The population of power utilities licensed to distribute electricity in South Africa consisted of a total of 188 utilities [214]. The power utilities comprised of the following: 174 municipal distributors, 13 private distributors and Eskom. The Eastern Cape (28, or 16%) and Kwazulu-Natal (26, or 15%) had the highest and second highest number of licensed utilities; while Gauteng (9, or 5%) had the smallest number of licensed utilities in the categories of municipal distributors in South Africa. The provincial municipal distributors are also classified as either a metropolitan municipality or the local municipality. Figure 38 shows a map of South Africa with the metropolitan boundaries as part of the study population. The reference to study population in this phase of data collection refers to members of a group of people defined as respondents to whom the research measurements refer by reported results, findings and conclusions [209].

Figure 38: Map of South Africa with metropolitan boundaries [223]

4.4.4.2 Sampling and selection

Sampling refers to taking a portion or a smaller number of units of a population as a representative or having particular features of the total population [224], [225]. It is noted however; that the above meaning does not clearly state that the sample taken is actually representative but rather that the sample taken is perceived to be representative of the population. The concept of representativeness and its association to generalization has been emphasized [226]. Generalization is obtained in a study when it is assumed that a portion of a sample is observed in a group of subjects other than the population.

The term sample implies the simultaneous existence of a population or universe of which the sample is a smaller section, or a set of individuals or groups selected from a population [224]. According to Bernard in [44], a sample is an element of the population considered for actual inclusion in the study. It constitutes the small portion of the entire set of objects, events or persons, which together comprise the subject of a study. The purpose of selecting a sample is to ensure that the characteristics of the subjects in the study appear in the same proportion as they exist in the total population [44], [204], [224]. Therefore, a sample assists in explaining some features of the population under study.

It is further stated in [52], that "probability sampling design is used when the representativeness of the sample is of importance for purposes of wider generalizability." However, in this research, the purpose of the study was not to make use of a sample to generalize the findings to the particular population, but to make inference on the sample itself, evaluate the scope of power quality program employed by utilities in South Africa as well as the utilities position with regards to smart grid technologies. Consequently, a non-probability sampling procedure was selected for the identification of power utilities, because the researcher had no guarantee that these utilities were either representative of the population of power utilities in South Africa, or that they had an equal opportunity of being selected for this particular study.

Specifically, a sample was selected from different provinces; because the identified power utilities were accepted as the target population to determine the general scope employed relating to the aspect of managing power quality. According to [227], purposive sampling is considered the most important type of non-probability sampling. In this type of sampling, researchers rely on their experiences, skill and/or previous research findings to purposefully obtain units of analysis such that the obtained sample may be considered as being representative of the population of interest.

Adequacy of this kind of sampling for quantitative study depends upon the judgment of the researcher and is occasionally referred to as judgment sampling [44]. In purposive sampling, the researcher must first think critically about the parameters and thereafter choose the sample case accordingly.

It is stated in [51] that a justifiable criterion for selecting purposive sampling can primarily be when there is a limited number of people that have expertise in the area being researched, or when the interest of the research is on a specific field or a small group. Criteria for selecting participants are of critical importance, understood as being symbiotic.

In this study, two power quality specialists from Eskom and two Business Development Executives from CT Lab (PTY) were involved in the selection of municipalities because of their knowledge and experience regarding their interaction with these municipalities in terms of power quality.

Based on their knowledge and experience, these individuals identified a sampling frame of municipalities in the nine provinces, and as such, twenty six (26) local municipal utilities and metropolitan utilities were purposefully selected, according to criteria related to the diverse context of municipalities in South Africa, and based on findings in the 2013 NERSA audit report conducted on selected municipalities [214].

As the main supplier of electricity, Eskom was also purposefully selected to participate in the study. Table 15 show the number of utilities per province and Eskom (nationally) identified to participate and the number of responses received.

Table 15: Selected sample of South African utilities with responses

Province	Utilities Identified	Responses
Eastern Cape	3	0
Free State	4	2
Gauteng	4	2
Kwazulu-Natal	4	1
Limpopo	3	0
Mpumalanga	3	2
North West	2	1
Northern Cape	2	1
Western Cape	1	1
Eskom (National)	1	1
Total	27	11

Although Eskom distribution comprised of nine areas of operations from which participants could have been selected, the researcher instead chose one participant from the national committee responsible for the steering of activities relating to the subject of power quality, to participate, representing Eskom distribution as a single entity. This was because the objective of the study questionnaire was to determine the extent of power quality management programs and these are considered executive policies for the utility. In terms of the municipalities, the following criteria were identified by the specialists:

- Municipalities that had installed or in the process of installing power quality instruments for the management of power quality,
- Proven leading role and involvement of municipalities managers in dealing with power quality issues, especially engagement with Eskom,
- Best practices in terms of complying to power quality reporting to NERSA.

The list of municipalities along with Eskom was accepted as the sampling frame for the selection of power utilities that met the required minimum criteria for the management aspects of power quality. A senior engineer or manager from each utility was purposefully selected. These respondents were purposefully selected because of their positions in policy-making and direct involvement with power quality issues in their utilities.

To establish contacts to some of the municipalities, the researcher obtained a directory of licensed distributors from NERSA, which was found to have the comprehensive listing of South African-based utilities. The directory provided contact names, telephone numbers and direct email addresses of the listed distributors. Along with the recommendations by the specialists, the researcher made use of the NERSA directory and obtained contact telephone numbers and email addresses and proceeded with the study.

4.4.5 Collection of quantitative data

The time horizon of this phase of the study was cross-directional and the data was gathered once over a period of three months. An email containing a brief description of the research and objectives was sent to the participants. A direct link to the internet web address was also contained within the email. The participants were requested to return the completed questionnaire within two weeks.

The design of the research questionnaire was such that the completed questionnaire responses was directly sent and stored on the Survey Monkey data server. The first email sent to the utility participants is given in Appendix D. According to the author in [40], it is stated that non-responses in survey questionnaire may be due to four problems as:

- Refusal to respond;
- Ineligibility to respond;
- Inability to locate respondent;
- Respondent located but unable to make contact.

For the purpose of this study, the respondents and non-respondents are discussed below.

4.4.5.1 Survey response difficulties

After two weeks of sending the initial invite, only 2 completed questionnaires and 8 non-responses were received. After three weeks, a further 3 completed questionnaires and 3 non-responses were received. After one month, a reminder was sent to the participants requesting them to return the completed questionnaire if they have not already done so (see Appendix E).

This was followed by another reminder after five days. The first reminder resulted in 2 additional responses and 4 non-responses.

The second reminder produced 2 responses and 3 non-responses. At the end of the second month, a total of 9 completed questionnaires were received as well as a total of 18 non-responses. After reviewing the responses received, the researcher was not satisfied with the non-responses from the metropolitan municipalities (in Gauteng and in Eastern Cape).

A further request was sent via email to request for their participation and were given two weeks to send their completed questionnaires. This request produced 2 additional responses and 2 non-responses. At the end of three months, a total of 11 completed questionnaires were received along with a total of 16 non-responses. The reasons given by non-respondents are shown in Figure 39.

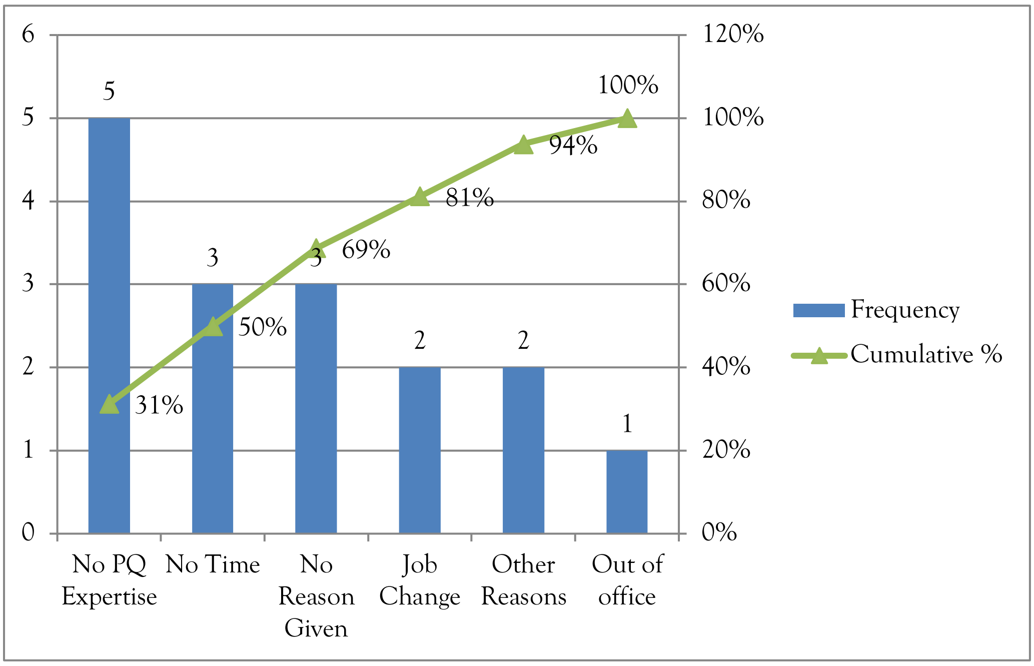

Figure 39: Non-respondents' analysis of utilities

Analysis of the Pareto diagram in Figure 39 indicates that a number of non-responses were due to the following reasons:

(a) Five respondents indicated that they were willing to complete the questionnaire but did not have the required expertise within their utility to respond to the subject of power quality.

(b) Three respondents stated that they did not have time to complete the questionnaire.

(c) Three respondents gave no reason for their non-response, only indicating that they were not willing to participate in the research study.

(d) Two respondents stated that they have changed positions in the company and unable to respond to the PQ questionnaire.

Other reasons for non-responses included lack of authority to complete the questionnaire or the utility's policy denied disclosure of the information required by the questionnaire. Finally, one respondent was out of office and did not return in time to complete the questionnaire.

In addition to the quantitative component of the empirical research, qualitative research methods in the form of semi-structured interviews were also used in combination with a closed-ended structured questionnaire as part of the mixed methods research design. The qualitative research design is discussed in the next section.

4.5 Qualitative research design

Divergent conceptions of the requirements of rigorous enquiry are found amongst qualitative researchers. Consequently, qualitative method of enquiry are characterized with rich quotations, descriptions and narrations as researchers attempts to capture conversations, experiences, perspectives and meanings from participants. Putting it simply, this method entails researching with words instead of numbers [194], [228]. Qualitative research enables gathering of more comprehensive understanding of activities relating to human behaviour and the attributes that rule such behaviour.

This approach is intuitive in nature as it expands the scope of research to finding out the why and how of things that happen in addition to what, where and when things happen. According to [229], qualitative method requires less pre-specification as the design evolves and the research proceeds. This attribute of qualitative research qualifies the variable sampling for the type of this study to be much smaller to work with than the larger and more complex samples normally used in quantitative research. As such, it is concerned with non-statistical methods and small samples that are often purposefully selected [44], [50], [211], [230], and [231].

Some of the key characteristics of the qualitative research, as described in [41], [44], [203], which influenced the choice of this method to addressing the secondary questions of this research in terms of power quality from the perspectives of industrial customers are:

- It promotes a more diverse reaction from participants
- Qualitative study is usually conducted in natural settings. Natural settings (such as offices, boardrooms) are preferred locations for qualitative studies.
- The extensive use of descriptive data. Qualitative researchers are likely to describe a phenomenon with words instead of numbers
- The search for meaning is often evident. The search for meaning focusses in qualitative research on how people attempt to make sense of their lives.
- It is often based on inductive logic, going from the specific to the general.

4.5.1 Study population

A study population is generally a collection of individuals or objects that is the main focus of a scientific query from which a sample is actually selected. For the purpose of this study, the researcher chose large power users of electricity – industrial customers, from the power utility, Eskom, purposefully selected within the Free State and North West Provinces – based on their sensitive nature of load in terms of exposure to power quality as the target population for the qualitative phase of this research. The study population comprised of individuals in the positions of electrical engineering, dealing with power quality related issues within their firms (industrial customers).

4.5.2 Sampling

Sampling is referred to as the process of selecting units (such as people, organizations) from a chosen population, such that by studying the sample, results can be fairly generalized with the intention of representing the particular population [44], [224]. In applied social research, special circumstances may exist where it is not feasible, practical or theoretical sensible to do random sampling, non-probability sampling procedure is alternatives to be considered [232].

For this reason, the researcher used purposive sampling to select a segment of Eskom's industrial key customers, from the Free State and North West provinces. Participation from industrial customers supplied by Ekurhuleni metropolitan utility was also requested.

The participants in this phase of research were purposefully selected based on their load demand classification (i.e., Large Power Users (LPU)) and sensitive nature of their production in terms of power quality on the electrical network. The number of participants was regarded as being sufficient, based on the saturation principle of diminishing returns – the notion that each additional unit of information would supply less new information than the preceding one, until new information diminishes to nothing [233], [234], and [235].

Since no two-research works are alike, and saturation for one is not nearly enough for another, achieving saturation in this study was made through the use of probing questions to the participants. However, factors for considerations are outlined in [234] that could affect the potential sample size in a qualitative study, yielding to qualitative data saturation. These are:

- The heterogeneity of the population;
- The number of selection criteria;
- The extent to which 'nesting' of criteria is needed;
- Groups of special interest that require intensive study;
- Multiple samples within one study;

- Types of data collection methods used; and
- The budget and resources available

It is also stated in [236] that a large sample size does not always guarantee data saturation, nor does a small size – rather what constitute the sample size. Applying the reasoning of Burmeister and Aitken in [236], the saturation principle holds true by view that participants were chosen and grouped into pairs according to their industry sector, with the aim of achieving data triangulation. The concept of triangulation was suggested in [56] for correlating people, time, and space; hence the selection of a minimum of two large industrial customers from a sector of similar industrial classification and this was sufficient for this study.

4.5.3 Reliability and validity

Insofar as the definitions of reliability and validity, in quantitative research, two elements are revealed: firstly, with regards to reliability, whether the results are replicable. Secondly, with regards to validity, whether the means of measurement are accurate and whether they are actually measuring what they are intended to measure. The concepts of reliability and validity are viewed differently by qualitative researchers who strongly consider these concepts defined in quantitative terms as inadequate [237], [238].

These terms as defined in quantitative terms may not apply to the qualitative research paradigm. It is believed that term such as precision [239], credibility and transferability [240], [241] are suggested alternative ways to demonstrate reliability and validity outside the linguistic confines of a quantitative paradigm. In qualitative paradigms, reliability and validity are conceptualized as trustworthiness and rigor [53], [216], [241].

The existing growing trend of emphasizing the use of rigor to demonstrate reliability and validity in qualitative research was followed in this section of the research [242]. Rigor refers to the demonstration of integrity and competence in qualitative research by adherence to detail and accuracy to ensure authenticity and trustworthiness of the research process. The rigor of the qualitative section relates to the overall planning and implementation to ensure the authenticity and trustworthiness procedures, according to the following criteria [47]:

- Credibility: According to [216], engaging multiple methods such as observations, interviews and recordings will lead to more valid, reliable and diverse construction of realities. In this research, engagement with the data (recordings, notes and transcripts) was thoroughly done to demonstrate clear links between the data and the interpretations.
- Dependability: according to [216], [240], [241], dependability is similar to the notion of reliability in quantitative research. The purpose of this test was to provide indications of stability and consistency in the process of enquiry. This was done to ensure that the research process was logical, traceable and clearly documented by providing a detailed account of the research process.
- Authenticity: the development of the question items was based on the theoretical basis as described in the literature study. Furthermore, the interview schedule was first carried out during the pilot test, to ensure that data to be collected is reasonable, valid and unbiased.
- Confirmation: an audit was implemented by going through the research process, to ensure that the data and interpretations of the responses were sound and confirmed responses. During interpretation, the intention was not to generalize findings to a population, but rather to identify accepted principles relating to the research topic. According to Seidman in [216], by interviewing a number of participants, researchers can connect their experiences and check the comments of one participant against those of others; the goal is to understand how the participants understand and make meaning of their experience. If the interview structure works to allow participants to make sense to themselves as well as to the interviewer, then it has gone a long way toward validity. , the trustworthiness of this research phase was ensured by implementing the following criteria: credibility, dependability, authenticity and confirming. The description in the qualitative research process of: what was done; how it was done; and why it was done- as well as adherence to the identified criteria for qualitative research, ensured the authenticity and trustworthiness of this research phase.

4.5.4 Collection of qualitative data

Data collection in research is commonly achieved through the use of measuring instruments. The term measuring instrument refers to various methods through which a researcher obtains data for the research undertaking [44], [243]. Measuring instruments include questionnaire, interviews (standardized open-ended, semi-structured and structured), observations, focus group discussion and experiment [188], [216], [243], [244].

In this phase of this research, interviews were used to collect data from participants. Hence, an engineering representative of industrial key customers from each of the two provinces (Free State and North-West), were requested to participate in an interview to contribute to the achievement of the identified research objectives. An example of the correspondence email with the industry participants is given in Appendix F.

4.5.4.1 Interviewing as an instrument

Interview is a measuring instrument otherwise known as oral questionnaire. It involves a process in which a researcher solicits information from respondents through verbal interaction. In an interview, the quantity and quality of information exchanged would depend on how intelligent and creative the interviewer is at understanding and managing the conversation [216], [225].

According to [245], interviewers are usually deeply and inescapably mixed up in creating meaning that seemingly reside with the views of the participants. Furthermore, the authors in [44], [235], [246] state that the goal of any qualitative research interview is to see the research subject from the perspective of the interviewees and to understand reasons for having such specific perspective. In achieving this goal, the following general characteristics of a qualitative research interview are presented [246]:

- Low degree of structure imposed by the interviewer;
- A preponderance of open questions;
- A focus on specific situations and action sequences in the world of the interviewees
- The interview should not be seeking responses to specific questions, but rather initiating the respondent to unfold data. Therefore, the role of an interviewer is exhaustive as they have to ask questions, record answers and also attempts to maintain the interview motivating and meaningful to the interviewees [44], [216]. Circumstances leading to the implementation of a qualitative research interview have been defined by the author in [246] and are listed as:
- Where a study focuses on the meaning of a specific phenomenon to the participants;
- Where historical accounts are required on how a particular phenomenon is developing;
- Where exploratory study is required before or in combination with carrying out a quantitative study;
- Where a quantitative study has been carried out, and qualitative data are required to validate particular measures or to further clarify meaning of the findings.
- Depending on the nature of the resulting event as determined by the researcher initiating the interview for a particular study, three types of interviews used in educational research are specified: standardized open-ended, semi-structured and structured [44], [216], and [247]. For the purposes of this study, semi-structured interviews were conducted in accordance with a schedule for semi-structured interview proposed in [247]. The schedule specifies predetermined questions and sequences for the interviewer (See Appendix H).

4.5.4.1.1 Semi-structured interviews

A semi-structured interview is considered as an interviewing procedure with an interview guide [44], [216], and [228]. Semi-structured interviewing follows all the principles of unstructured interviewing, with the exception that the participants are not expected to move to far beyond the scope defined by the interview guide. In this research, interviewing guide as a data-gathering method was used to:

- Clarify vague statements;
- Permit exploration of the topic of smart grid technology;

- Produce a deeply experiential account of the extent of the effect of power quality to large industrial customers.

Interviews are flexible data collection instruments as the researcher can obtain data from a variety of perspective [44], [216]. , interviews can produce informative responses unobtainable in any other method, which can support or be supported by other data from questionnaires and standardized test responses. In this research, the interviews afforded the researcher the opportunity to obtain perceptions of industrial customers regarding the issues of power quality, the different impact thereof to their operations, as well as their views on smart grid technologies.

4.5.4.1.2 The interview procedure

In order to ensure accurate capturing of interview responses, a digital voice recorder was used to record the responses of the participants. This was also done to ensure that the data collected is credible and usable, ensure reliability [216]. According to the authors in [245], a model for assessing nonverbal communication exists; which are to be considered by researchers when collecting qualitative data during interviews, which might influence the reliability of data from the participants. The model consists of six fundamental emotions that are associated with innate facial expressions, and which can influence the response by the participants.

These six emotions are happiness, sadness, anger, fear, disgust, and surprise. In order to control the emotion exhibited by the interviewee in responding to each interview question, the researcher insured that the interviews took place at the premises of each of the industrial customers – eliminating the fear of being on unfamiliar location.

Prior to the commencement of the interview, the researcher orally allowed the participant to make a final decision about whether to participate, and after being provided with all the information needed to make an informed decision whether to participate, a consent form was signed by both the researcher and the participant, and a copy of the signed consent form was later sent to the participant via email for possible future enquiry. The informed consent form used during the interviews is given as Appendix G.

4.5.4.1.3 The interview schedules

The aim of the interview schedule was to ensure that the questions asked are likely to yield as much as possible, information about the study phenomenon and consequently, for the purpose of this study, the structured part of the interview was developed according to the research objectives. The interview questions were designed to include the following topics:

- Understanding of customer awareness regarding power quality regulatory policies;
- Good practice of technical assessment of network in terms of power quality issues;
- Perspectives on the current status and expectations of power quality performance;
- Views on the cooperation between the customer and power utilities in dealing with power quality issues;
- Importance/necessity of power quality monitoring and measurement, and the future prospects of using the technology of smart grid to manage performance.

In order to allow more clarifying, probing and detailed response to questions, a semi-structured interview was selected for its suitability. The interview schedule and procedure is given in Appendix H.

4.5.4.1.4 Interview location and duration

In this research, interview location is described as the location where through interview, the exchange of information between the researcher and the research participant takes place. As such, it is said to represents a scale of socio-spatial relations, manifesting the intersection of broader power dynamics at multiple scales, such as the environment-with the social relations constructed in the interview setting itself [248], [249]. These authors suggest that the environment of the interview reflect the relationships of the researcher with the interview participant, the participant with the site, and the site within the sociocultural context that affects both researcher and participant.

Primarily, the author's text frames the question of interview location in terms of convenience for participants and researchers, suggesting that the location should be quiet and easy to find. For the purpose of this study, the interviews were conducted at the premises of the customers for their convenience and consequently, to ensure reliable response by managing participants emotional expression [245]. The interview was seen as a relaxed conversation with a peer rather than an interview, with a structured approach for asking the questions, to ensure time efficiency. Table 16 shows the participants interviewed, the location and duration for conducting the interviews.

To accomplish the purpose of the interviews, the researcher used a 90-minute duration suggested in [216]. The author further indicates that anything shorter than 90 minutes in an interview seems too short; given that the purpose of an interview approach is to have the participants reconstruct their experiences, put it in the context of their lives, and reflect on its meaning. In this study, the interviews were conducted to obtain the views of industrial customers in terms of their experiences and impact of power quality to their industry, as well as their views on the use of smart grid technology.

Table 16: Industry participants in the semi-structured Interviews including locations and duration

Industry sector	Location	Interview duration
Participant 1: Chemical	Participant's offices in Sasolburg, Free State	95 Minutes
Participant 2: Chemical	Participant's offices in Sasolburg, Free State	93 Minutes
Participant 3: Cement manufacturer	Participant's offices in Mafikeng, North West	88 Minutes
Participant 4: Gold Mining	Participant's offices in Welkom, Free State	110 Minutes
Participant 5: Gold Mining	Participant's offices in Welkom, Free State	100 Minutes
Participant 6: Water pumping and purification	Participant's offices in Bloemfontein, Free State	85 Minutes
Participant 7: Water pumping and purification	Participant's offices in Welkom, Free State	115 Minutes

4.6 Ethical consideration

The term ethics is a philosophical term derived from the Ancient Greek word ethikos, which is derived from the word ethos, meaning custom or personality and it involves a social code that convey moral integrity and consistent principles that govern a person's behaviour or the conducting of an activity [250], [251]. In relation to the ethics of science, it is viewed that the ethics of science is more concerned of what is wrong and what is right when conducting research [42]. It is further specified that regardless of the research design, sampling technique and choice of data collection methods, all research are subjected to ethical considerations [40], [252], and [253]. In this research, the following steps were taken by the researcher to ensure ethical considerations of the research:

- A detailed request was submitted to the Eskom's Further Study Committee and consent, permission and approval was granted by the Customer Services Department to collect research data from Eskom's LPU customers (Appendix I) ;
- Consent, permission and approval for the research was obtained from Ekurhuleni metropolitan utility for the collection of research data from their industrial customers (Appendix J);
- Informed consent was obtained from each participant that was interviewed;
- Participants were not subjected to any possible stress, humiliation or loss of self-esteem;
- The researcher ensured that participants would remain anonymous; the right to privacy and confidentiality of information obtained was guaranteed through a written statement in the introduction page of the online questionnaire.

Ethical considerations in research have mainly to do with permission to conduct the research, the participation of respondents and the process employed to analyse data [216]. , Care was taken to avoid any prejudice to participants in terms of sensitivity of the research topic concerning respondents with regards to the competencies required by industrial customers to deal with power quality issues.

4.7 Conclusion

In this chapter the research design and methodology were discussed. A mixed methods research design was identified to ensure accomplishment of the set objectives of this study namely: (1) to develop measures for the concepts power quality management and smart grid technology, (2) to determine the scope of power quality management program in a South African-based power utility, (3) to determine the extent to which South African-based power utilities can use smart grid technology for their network operations, (4) to identify themes, links and patterns in the description of industrial key customers regarding their experience and industry sensitivity to PQ issues, as well as their views on the use of smart grid technologies on distribution networks, and (5) to formulate key factors that can influence a South African-based power utility's decision to use smart grid technology for the management of power quality. In conclusion, it may be stated that the research design and related methodologies were developed with the aim of obtaining reliable and valid data. In Chapter Five, the theory and approach to the analysis of both the quantitative and qualitative data is presented.

5 Chapter 5 – Data analysis Approach

5.1 Introduction

In Chapter Four, the process, rationale and the purpose of the mixed method research design was described and explained in detail. The mixed method design was carried out in this research study, to obtain an experiential overview of the extent and description of power quality, as portrayed by groups of identified utilities and large consumers of electricity in South Africa. Also described in chapter Four, a combination of quantitative and qualitative research methodologies was employed for the purpose of all-inclusive responses and to provide for unexpected developments and personal circumstances. As a result, these procedures led to the decision of collecting both quantitative and qualitative data. In this chapter, the approach of analysing the collected quantitative and qualitative data is presented.

5.2 What is data analysis

The quality of developing evidence-based conclusions and recommendations in research fundamentally relies on the researcher's abilities to collect and analyse qualitative and quantitative data. To achieve this, it is useful to reflect on the related theory that underpins the common methods and techniques of data analysis. But first, it is important to build on the definition of data analysis.

Data analysis is described in [254] as "the process of bringing order, structure and meaning to the mass of collected data". It is further described as untidy, ambiguous and time-consuming but also as a creative and fascinating process. Generally speaking, data analysis does not proceed in linear fashion but rather it is the activity of making sense of interpreting and hypothesizing data that signifies a search for all-encompassing statement among categories of data [255].

Inferring from these statements, it can be said that data analysis requires some form of logic reasoning applied to research. In this regard, Best and Khan in [49] clearly indicate that the analysis and interpretation of data represents the application of deductive and inductive logic to the research. On the other hand, it is stated in [46] that the analysis of data through interpretive approach, which involves deduction from the data obtained, relies primarily on what it feels like to be a participant in the action under study, which is part of the qualitative research.

It is believed in [256] that a subtle difference exists between the quantitative and qualitative methods of analysing data; whereas quantitative data analysis often focus on measuring the parts in an issue, in qualitative data analysis, it is preferred to create a picture which covers the whole image in it. , as for the process of qualitative data analysis, the researcher inevitably dives deep into the subject or phenomenon under study; and often relies on their experience of the particular settings to be able to read the information provided by the participants involved in the study.

It should be emphasized that this research report employed a mixed method of data collection, namely a combination of quantitative and qualitative methods, which entails focusing on the adoption of a pragmatic position and also used a phenomenological approach in conducting the qualitative part of this research. It is concisely stated in [257] that the word data points relate to information that is collected in a systematic manner and organized and recorded to enable the reader to correctly interpret the information.

As such, data are not randomly collected, but in response to pre-defined questions that the researcher wishes to address. Implicated in the preceding views of Thompson in [257] are the two methods used to analyse data, namely qualitative and quantitative. It is stated that in a qualitative study, an inseparable relationship between data collection and data analysis exists in order to build a coherent interpretation of data [204], [205]. , numerous forms of data or information are collected for further analysis using a variety of approach or from different participants. This data is interpreted to establish an enriched and significantly meaningful viewpoint [204]. An important view when analysing qualitative data is reiterated in [257] that qualitative data must be systematic, sequential, verifiable and continuous.

It follows that qualitative data involves a process where a researcher takes descriptive information and offer an explanation or interpretation. It therefore requires time, it is jeopardized by delay, is a process of comparison, it is improved by feedback; it seeks to clarify and entertains alternative meanings.

In data analysis, the purpose of conducting a quantitative study is to generate findings, whereas qualitative methods use words (interview transcripts, documents, blogs, pictures, videos, etc.) to generate a framework for communicating the idea of what the data reveals.

Regardless of the method used (qualitative or quantitative), the purpose of conducting a study is to produce findings and to do so, data should be analysed and transformed into findings. In this study, data will be analysed using both the qualitative and quantitative methods. For that reason, the researcher considered the underlying differences and similarities between qualitative and quantitative methods of data analysis as outlined in [40], [205]. According to these authors, qualitative and quantitative analyses of data are similar in four ways; and both methods involve:

- Inference – the use of reasoning to reach a conclusion based on evidence;
- A public method or process- revealing their study design in some way;
- Comparison as a central process – identification of patterns or aspects that are similar or different; and
- Striving to avoid errors, false conclusions and misleading inferences.

It should be outlined that the fundamental differences between qualitative and quantitative data analysis, according to the authors in [194], [205] includes:

- Qualitative data analysis is less standardized with the wide variety approaches to qualitative research matched by the many approaches to data analysis, while quantitative researchers choose from a specialized, standard set of data analysis techniques;
- The results of qualitative data analysis often guide subsequent data collection, and analysis is a less-distinct final stage of the research process than quantitative analysis, where data analysis does not begin until all data have been collected and condensed into numbers;
- Qualitative researchers create new concepts and theories by blending together empirical and abstract concepts, while quantitative researchers manipulate numbers in order to test hypotheses with variable constructs; and
- Qualitative data analysis is in the form of words, which are relatively imprecise, diffused and context based, whereas quantitative researchers use the language of statistical relationships in analysis.

The views of Gall et al. in [205] were further supported by [41], [258], that in qualitative research, the researcher does not intend to "test" hypotheses but has a deep tendency to create an appropriate theory by using the inductive method to "describe, analyse and interpret the constructive aspects of the social world, whereas in quantitative research, the researcher seeks to prove and confirm hypotheses through a deductive method combined with a number of theories. Robson in [229] further points out that in qualitative analysis, the fundamental requirement is a clear thinking approach expected from the analyst. , for qualitative methods, two ways of analysing qualitative data are identified [259] namely; one approach is to examine the findings with a pre-defined framework, which reflects the research aims, objectives and interests.

This approach is closely aligned with policies and programmatic research which has pre-determined interests. It allows researchers to focus on particular responses and abandon the rest-framework analysis [260]. The second approach make use of an exploratory perspective, encouraging researchers to consider and code all collected data, allowing for new impressions to shape the interpretation in different and unexpected directions – thematic network analysis [259]. More often, qualitative analysis can include a mix of both approaches (as in the case of this study). However, whichever approach adopted, researchers are expected to be familiar with the collected data, for better interpretation.

In closing, when analysing qualitative data, the researcher should be mindful of the sequential list of what is described as "a fairly classic set of analytic moves" [261]:

- Giving codes to the initial set of materials obtained from observation, interviews and documenting analysis;
- Adding comments and reflections, i.e., memos;
- Going through the materials, trying to identify similar phrases, patterns, themes, relationships, sequences and differences between sub-group;
- Taking identified patterns and themes out of the field to help focus the next wave of data collection;
- Gradually elaborating a small set of generalisations that cover the consistency in the data; and
- Linking the generalisations to a formalized body of knowledge in the form of constructs.

Reasoning and discussion of data analysis and interpretation, the views, ideas and suggestions of various perspectives offered by the different researchers and authors have been identified as important aspects for use in this study. Next, the researcher will explore the approach carried out for the analysis and interpretation of the quantitative and qualitative data collected in this dissertation.

5.3 Quantitative data analysis

The collection of quantitative data was not the ultimate goal of this research, but to help the researcher understand the characteristics of the sampled participants in the quantitative phase of the research. Therefore, the purpose of collecting the quantitative data was to analyse and summarize the data to answer the research questions in this study. In research, statistics helps to turn quantitative data into useful information to help with decision-making [256]; it can be used to summarize data, describe patterns, relationships and connections among phenomena so as to explain, predict and control their occurrence.

Statistics provides a range of procedures for gathering, organizing, analysing and presenting quantitative data. According to the authors in [218], statistics can be descriptive or inferential. Descriptive statistics helps to summarize data whereas inferential statistics is useful to identify statistically significant differences between groups of data (such as intervention and control groups) in a randomized study [257]. Since the study did not make use of a random sample to make generalization on a particular population, the focus was on descriptive statistics; using numerical and categorical variables.

5.3.1 Preparation of quantitative data

The SAS (SAS Institute Inc., 2011) computer program was used to convert the raw data received from the participants. The data was entered into a data table with two dimensions: the number of cases (respondents) entered in the column entry and the number of variables entered into rows. The variables were coded V1 to V46, corresponding to the questionnaire test items 1 to 46.

The responses for the variables contained words (i.e., strongly disagree, disagree, neutral, agree, strongly agree) which were coded into numbers as follows: strongly disagree = 1, disagree = 2, neutral = 3, agree = 4, and strongly agree = 5. The web response method was designed to allow only completed questionnaires to be returned to the researcher.

The accuracy of data entry was ensured by spot-checking every record [52] and empty responses from questionnaire items were excluded, and all valid data was ready for analysis. The author in [52] further state that "in data analysis, there are three objectives to be achieved: getting a feel for the data, testing the goodness of the data, and testing the hypotheses developed for the research."

In this study, the analysis of the quantitative data was not intended to test for the developed hypotheses, but to get an idea from the participants with regards to their scope of power quality and their views on the use of smart grid technology and consequently, the first two objectives as described in [52] were sufficient for this research.

5.4 Descriptive statistics

A single-stage statistical procedure was followed; in which descriptive statistics was used to "describe (and compare) the variables numerically" [40]. Frequency tables, means, ranking and standard deviation in the data was developed in order to represent the statistical position of the participants over the range of the measured items.

5.4.1 Reliability analysis approach

Norm and Hatcher in [218] state that it is very important to assess scale reliability early in the data analysis since there is no point in performing additional analysis if the scales used in the study were not reliable. It is further stated in [262] that whenever researchers want to measure something, some element of error will be present; and this is referred to as measurement error.

Reliability refers to the extent to which test scores are free of measurement error. The reliability of a measure indicates the stability and consistency with which the instrument measures the concept and helps to assess the "goodness of the data" [52]. A reliability coefficient indicates the variance in an observed variable accounted for by true scores given by participants in a study – it therefore excludes the measurement errors associated with the score [218].

An instrument is said to be reliable when it provides consistent scores with repeated administration and with administration by alternate means [218]. Several procedures exist for establishing the reliability of an instrument, such as the test-retest and alternate-form methods and the split-half technique [218], [263]. For the purpose of this study, a pilot study was conducted by subjecting the questionnaire to a panel of experts; and the Cronbach alpha coefficient (a) was used to measure the reliability of the questionnaire.

In addition to the reliability results carried out in the pilot study, responses obtained from the study participants were also used to evaluate the reliability of the questionnaire. The reliability results for the actual study are discussed in Chapter 6 (Par. 6.2.1).

The Cronbach's alpha reliability coefficient is used for multipoint scaled items (as in the case of this research) and measure the consistency with which the respondent's answer all the items in a measure – it is also known as the internal consistency reliability of a scale [218]. Norm and Hatcher in [218] further describe internal consistency as "the extent to which the individual items that constitute a test correlate with one another or with the test total".

If the items are strongly correlated with one another, their internal consistency is high, and the alpha coefficient will be close to one. On the other hand, if the items are poorly designed and do not correlate strongly, the alpha coefficient will be close to zero. Equation 7 is the formula for Cronbach's alpha coefficient used in this study.

$$\propto = \left(\frac{\boldsymbol{N}}{\boldsymbol{N}-\mathbf{1}}\right) * \left(\frac{\boldsymbol{S}^{2} - \sum \boldsymbol{S}_{i}^{2}}{\boldsymbol{S}^{2}}\right)$$

Equation 8

Where

$\propto$ = Cronbach's coefficient alpha

N = number of items making up the instrument

S = sum of the scale score

S^2 = variance of the summated scale score

Guidelines for the interpretation of Cronbach's alpha coefficient have been widely suggested and generally accepted by researchers [52], [218], [263], and, reliability assessment for the quantitative part of the study was done using the following benchmarking:

- Where Cronbach's alpha is > 0.8, the internal consistency reliability is good (the items in the scale are highly correlated with one another and there are sufficient number of items);
- Where Cronbach's alpha is >0.6 and < 0.8, the internal consistency reliability is acceptable; and

- Where Cronbach's alpha is < 0.6, the internal consistency reliability is poor (the items in the scales indicate a low correlation with one another and/or there are insufficient number of items)

For this study a manual method was used to calculate the Cronbach alpha coefficient (a) to assess the internal consistency of the various question items of the questionnaire. A Microsoft excel spreadsheet was used; the Cronbach alpha coefficient was calculated for each group of items given by the constructs, in order to demonstrate the internal consistency of each construct. It also serves another purpose in indicating, to some extent, the level of measuring the construct validity of the questionnaire.

5.5 Qualitative data analysis

Unlike in most quantitative methodologies, qualitative analysis does not follow a formula-like procedure that can be systematically and analytically applied. When embarking on a qualitative analysis process, researchers are to work on a slightly more instinctive and not always in a more tangible way. This implies that for qualitative analysis, rigour is achieved in a different way to a quantitative study. A number of meanings for qualitative analysis have been presented by various authors and as such, qualitative analysis is defined in [194], [264] as the process of making sense of the views and opinions of research participants regarding situations, corresponding patterns, themes, categories and consistent similarities.

It is pointed out in [265] that qualitative data analysis is regarded as a process of transforming qualitative data that is collected by means of analytic procedures, into a clear, understandable, insightful, trustworthy and even original analysis. Qualitative data analysis is also theorized in [228] as an analysis that transforms data into findings; thereby reducing the volume of raw information, sifting significance from trivialities, identifying significant patterns and constructing a framework for communicating the essence of what is revealed by the data.

It is succinctly stated in [44] that analysis "is the search for patterns in data and for ideas that help why those patterns are there in the first place". Likewise, data analysis is further summarized in [197], [216] as a continuous, developing and repeating processes during which transcribed interview data are investigated for meaning and clarity.

For the purpose of this study, the researcher adapted the definition of qualitative data analysis from Taylor and Gibbs in [265] and describes the analysis of qualitative data for this study as the range of processes and procedure undertaken to move from the qualitative data collected by means of semi-structured interviews, obtained from large industrial key customers of Eskom, into some form of explanation, understanding or interpretation of their experiences and situations regarding power quality, in accordance with the stated objectives of this research.

5.6 Data analysis approach

In qualitative methods, an understanding exists that there is no one right way to analyse qualitative data, hence several approaches are available. Two distinct approaches to qualitative analysis as given in [44], are described in this dissertation, and they form basis for the analysis of the qualitative data carried out in this research. The approaches are described below.

i) Grounded theory

Grounded theory is concerned with the outlining of inductive methods of analysing qualitative research, allowing social theory to be generated systematically from data. Putting it differently, theories are 'grounded' in rigorous empirical research, rather than produced in the abstract [238].

Grounded theory is also therefore an exploratory method and as such, it makes use of an exploratory perspective, encouraging researchers to consider and code all collected data, allowing for new impression to shape the interpretation in different and unexpected directions – thematic content analysis [259].

ii) Framework analysis

In contrast to grounded theory, framework analysis is explicitly developed in the context of applied policy research, and as such, it is aimed to examine the findings with a pre-determined framework, which reflects the research aims and interests, and to meet specific required information and provide outcomes or recommendations, often within a short timescale [260]. Framework analysis shares many of the common features of qualitative analysis, similar to the grounded theory, as it is also termed thematic analysis [58]. The defining feature of framework analysis is the matrix output: rows (cases), columns (codes) and 'cells' of summarized data, providing a structure into which the researcher can systematically reduce the data for further analysis [261].

Both approach of analysing qualitative data is seen to be appropriate for use in this study, as the collected data was in the form of words and narratives, consisting of transcripts of individual interviews with participants from industrial customers. Since this research involved an explorative study to identify themes and common patterns in the description of perspectives of the research participants, a combination of both the grounded theory and framework approaches were used. This combined approach enabled themes to be developed both inductively from the accounts of the participants and deductively from predefined concepts from the literature. This approach to analysis entailed the following steps as described in [44], [259]:

- Getting familiar with the data (reading and re-reading);
- Coding (labelling) the whole text;
- Searching for themes with broader patterns of meaning;
- Reviewing themes to make sure they fit the data;
- Defining and naming themes; and
- The write-up (creating a coherent narrative that includes quotes from the interviewees).

In conferring to the above steps, the authors in [58] further established a systematic and flexible framework approach for the management and analysis of qualitative data. The authors presented a step-by-step guide to illustrate the main stages of the analysis process. The framework method enables summarised data, providing a structure into which researchers could systematically reduce the data, in order to analyse it by case or by code. The procedure for the framework analysis comprises of seven stages of analysis [58]:

- Stage 1: Transcription;
- Stage 2: Familiarisation with the interview;
- Stage 3: Coding;
- Stage 4: Developing a working analytical framework;
- Stage 5: Applying the analytical framework;
- Stage 6: Charting data into the framework matrix; and
- Stage 7: Interpreting the data.

5.6.1 Preparation of qualitative data

Since the purpose of analysing data is to obtain usable and useful information, generate findings that can ultimately be transformed into new knowledge, this necessitated time and effort of preparing the collected data for analysis. During the process of engaging with qualitative data, not only does the researcher wishes to identify and emphasize recurring themes, but also different steps, procedures and processes that are available to the researcher.

Accordingly, the initial step in analysing qualitative data involves organizing the data [44], [49], [259]. However, it should be emphasized that the method of organizing the data may vary depending on the research strategy and data collection techniques implemented. In the same context, it is stated in [266], that the first step in organizing qualitative data begins with proofreading the material and underlining key phrases, whereas for voice-recorded interviews, the process begins with the act of transcribing the recordings [216].

Once the data have been organized, the researcher can proceed to the subsequent stage of describing the data in the analysis. The third and final stage of the analysis process is described in [228], namely interpretation and it involves the explanation of the findings, answering why questions, assigning significance to particular results and putting patterns into an analytic framework. However, before getting to the final stage of the analysis, the researcher was required to first prepare the data prior to the analysis and accordingly, the following process was taken:

- Managing raw data. Since most data was collected using a voice recorder during the interviews, the initial step was to transform the audio data into transcripts of meaningful units of analysis, so as to make it accessible for further processing. Transformation of the data was done using a Digital Talking Book Player (Victor Reader, version 3.0.3), with audio playback abilities;
- Data reduction. Since not all data would be useful, it was important to get a holistic sense of the data by reading several times (immersion), classify and categorise repeatedly, thereby allowing for deeper immersion and familiarity; idea of what the participants are saying and the feel of the results;
- Data verification. In order to ensure the quality of the qualitative data, the researcher asked the participants to verify the validity of the content of their specific data. Also referred to as member checking, this was also to ascertain that what is conveyed by the participant is accurately portrayed [241], [267]. This gave confidence to the researcher that the transcribed data was credible and a true reflection of the views of the participant.
- Coding. After the data was verified, the researcher began with the initial coding process by including all raw data that was identified as usable.

5.6.2 Data coding principles

In the description of the qualitative analysis process up to now, the term “coding” has been dominant. When analysing qualitative data, a meaningful interpretation of the data will have to be obtained. According to Saldaña in [57], a code is described as “most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data”.

Typical data to analyse using coding includes interview transcripts, participant’s observation field notes, journal’s, documents, literature, etc. since this phase of the study employed a semi-structured interview to collect qualitative data, it follows therefore that the collected data is befitting to be coded for analysis and consequently, the range of coding methods described by Saldaña in [57] was used to perform the data coding for the analysis in this study.

For qualitative analysis, the purpose of using codes is to provide essence-capturing and essential elements of the research narrative that, when clustered together according to similarity – patterns, they actively facilitate the development of categories and, analysis of their connections.

During analysis, themes are induced from the characteristics of the phenomena being studied and various approaches and techniques are available. In this study, the following typical aspects of a qualitative analytical technique suggested by [44], [194] were followed, which consists of the following:

- Coding or classifying field notes, observations or interview transcripts by either inferring from the words being examined, or from the repeated use of words or phrases, thereby checking for any development of pattern;
- Examining these classifications to identify associations between them, as well as to begin the process of understanding the developed associations, yielding credibility beyond the case under study;
- Making explicit of these patterns, commonalities and differences, i.e., making sense of the data, and taking these by now developed constructs into the field to test or refine;
- Elaborating a set of generalizations, which suggest that a certain relationship hold firm in the setting being examined and to affirm that these cover all the known eventualities in the data set; and
- Formalizing these theoretical constructs and making inferences from them to other cases in place and time.

During the identification of the developing patterns, it is stated in [229] that a researcher should not just think of patterns as stable regularities, but rather as varying forms of data developments, characterized by:

- Similarities (things happen the same way);
- Difference (they happen in predictably different ways);

- Frequency (they happen often or seldom);
- Sequence (they happen in a certain order);
- Correspondence (they happen in relation to other activities or events); and
- Causation (one appears to cause another).

In so far as the discussion of the qualitative data analysis presented, there are noticeable variations in the number and description of the steps for the same process by various authors. In conferring to these various approaches of analysing data, along with the delineation of the coding techniques set out in [57], this study further deliberated on the views of [268], who posits that the process of data analysis consists of six key elements, namely:

- *Defining and identifying data.* Before analyzing the data, it is important to obtain a clear understanding of the meaning of the data and more importantly, the data required in accordance with the research question and objectives.
- *Collecting and storing data.* During data collection, most researchers begin to form opinions and judgment, which yield to developing theories in the mind of the researcher and as such, not only is the emphasis placed on the method of data collection, but also to store data to make them accessible for analysis. In this case, the interviews were recorded by means of a digital recorder, transcribed and stored in a computer for further analysis.
- *Data reduction and sampling.* During the data collection process, reaching a point of data saturation implied that all data were reduced, filtered and sampled through the process of analysis. Consequently, for the data analysis, it was critical for the researcher to determine what data was already known to be important or relevant, in accordance with the intended purpose of the research. In other words, the researcher needed to establish and distinguish between data that was not relevant and data that captured the essence and evidence that the researcher wished to focus on for a detailed analysis. Hence, it was important to establish prevalence's and similarities during the interviews.
- *Structuring and coding data.* Structuring and coding of data underpins the key research outcomes and can be used to shape the data to test, refine or confirm established theories, apply theories to new circumstances or use it to generate new theory or model. During coding, the amount of data has to be divided into segments and these segments assigned codes which relate to analytic themes being developed [259]. The developed themes are expected to be applied consistently over the period of analysis and over the range of data. Coding is the initial step carried out toward an even more rigorous and evocative analysis and interpretation for a report, as described by Saldaña in [57]. It is inferred that structuring and coding signifies an analytical process of elaboration of data for instance, obtained from semi-structured interviews in related themes, to establish an understandable framework and associations derived from the language of the contributing participant, and in the case of this study, from large industrial key customers of power utilities. A process of coding was followed as part of the data analysis of the qualitative phase of this study, using the principles and guidelines of coding techniques described in [57].
- *Theory building and testing.* As research is aimed at generating new knowledge, it is helpful to take into consideration the available strategies for generating meaning from qualitative data as described in [261]. In relation to theory building and testing as part of the process of data analysis for the current study, the framework created far made an insight to the research question under investigation. Therefore, in building and testing of theory, it was important to observe the reaction of respondents on the question asked and also to ensure that a point of data saturation is attained. During analysis, the researchers' ability to show how the developed themes and concept systematically interrelate should lead toward the development of theory [238].
- *Reporting of research.* The reporting of research in the form of a report, constructing an argument based on the findings obtained from the process of data analysis. In the end, the conclusions drawn from the information should contribute to the body of knowledge and represent new meaning and understanding of the research question. This should therefore be useful in making a conclusion on the experiences of the participants in this phase of this study.

The preceding paragraphs set out to provide the theoretical framework and context for the qualitative data analysis of this particular study. As described, qualitative data are in the form of text, and the process of analysis entails the examining of all components of the data sets in order to clarify concepts and constructs, as well as the deconstruction of textual data into manageable categories, patterns, themes and relationships in accordance with the research aims and objectives.

As much as various steps, procedures and processes are described by a number of authors, this study focused on the data analytic technique given in [57] by incorporating the analytic possibilities of the grounded theory approach into the framework procedure for analysis as described in [58], along with recommendations in [197]. This led to the identification of thematic relationships from various categories, which was informed by inquisitive questions that included amongst others, the following [197]:

- What was the relationship (s) in meaning between all the categories?
- What can be deduced from the categories as a whole?
- What meaning was missing?
- What was fore grounded in the analysis?
- What has moved in the background, in other words, what is no longer important or necessary?
- What alternative explanations were possible?
- How were the research aims addressed by the various categories?

5.7 Conclusion

In this chapter, the approach to analyse the data collected from both the quantitative and qualitative phases of this research were presented. This was to ensure that the appropriate approach to analysing the collected data is applied, in accordance with the stated research objectives. In Chapter Six, the collected data will be presented, analysed, described and interpreted in a systematic manner to enlighten for the unfolding of the empirical segment of this research, enabling the researcher to identify factors that influences a South African-based power utility's decision to utilize smart grid technologies for power quality management.

6 Chapter 6 – Results: Data presentation and analysis

6.1 Introduction

Chapter Five described the quantitative and qualitative data analysis process. In this chapter, the analysis process is implemented, as the next step in the research process. The information in this chapter is meant to present data in an understandable and interpretable form, to identify developing trends and patterns to reach the research objectives.

This would enable the researcher to identify key factors that influence a South African based power utility's decision to utilize smart grid technologies for power quality management. The first section will focus on the quantitative analysis performed, followed by the qualitative analysis in the second part of the chapter. While not directly coupled, the combination of the quantitative and qualitative results enabled the researcher to obtain a comprehensive view of the application domain.

6.2 Analysis of quantitative data

For the analysis, each part of the questionnaire will be considered and discussed, using descriptive statistical techniques, as a sub-unit of the entire questionnaire, the first sub-unit of the questionnaire being the profile information of the respondents. But before presenting the descriptive analysis of the questionnaire, the researcher provides credibility to the measurement instrument, by evaluating its reliability.

6.2.1 Reliability of the questionnaire as measurement instrument

The measurement instrument for the quantitative part of the study was adopted after a thorough review of literature on power quality and smart grid technologies followed by examination by expert panel as piloting; nevertheless, the researcher tried to reaffirm the reliability to a degree of satisfaction with the help of internal consistency reliability. The questionnaire was aimed at obtaining information about the scope of the power quality management program implemented by the responding utility, in addition to information about the respondent's perceptions regarding the use of smart grid technologies.

The components of the questionnaire concerning the scope of power quality management program consisted of the following constructs: Top Management Commitment (questions designated as variables V1 – V12); Service Quality Assessment (questions V13 – V19); Network Topology and Design (questions V20 – V25) and Customer Interactions (questions V26 – V31).

The questionnaire component regarding the perceptions on smart grid technologies consisted of the following constructs: Technical System Operation (questions V32 – V38); Cost-Benefit and Regulations (questions V39 – V42) and Social Norms and Behaviour (questions V43 – V46). The reliability results of the questionnaire is presented in Table 17 below.

Table 17: Reliability results – utilities response

CONSTRUCT DESIGN	CRONBACH ALPHA (a)	INTER-ITEM CORRELATION
Construct 1: Top Management Commitment	0.925	0.451
Construct 2: Service Quality Assessment	0.868	0.318
Construct 3: Network Topology and Design	0.870	0.419
Construct 4: Customer Interaction	0.925	0.772
Construct 5: Technical System Operation	0.775	0.498
Construct 6: Cost Benefit and Regulations	0.866	0.351
Construct 7: Social Norms and Behaviours	0.736	0.683

From the calculated Cronbach alpha and inter-item correlation for the actual study of this research (results in Table 17), all seven values of Cronbach's alpha indicated that the reliability of the questionnaire can be regarded as acceptable, with alpha (a) ranging between 0.736 – 0.925, since a range of between 0.6 and 0.90 is regarded as acceptable, according to the authors in [52], [269]. Most items in each construct appeared to be worthy of retention, since the alpha value decreases if any of the items are removed.

An exception to this was item V28 (in construct 4) which, when removed, would increase the alpha value to a = 0.928. This suggested that this item did not appear to be a reliable item for this construct. This is further substantiated through inter-item correlation that items for construct 4 (Customer Interaction) along with items for construct 7 (Social Norms and Behaviours) of the questionnaire did not relate coherently with one another as they did not propagate within the range 0.15 – 0.50 as prescribed by the authors in [270]. However, it is observed that five of the inter-item correlations were within the range 0.15 – 0.50, indicating that all items in the specific constructs related coherently with one another. The fact that for two of the respondent's inter-item correlation did not fall within the range 0.15 – 0.50, could be attributed to the following:

- In the case of construct 4: Customer interactions, it could be that the researcher included items that did not belong on the scale. This was observed that if item V28 was removed, the Cronbach alpha value increased, which meant the removal of this item would make the questionnaire more reliable.
- In the case of construct 7: Social norms and behaviours, it could be that the researcher addressed more than one aspect concerning smart grid technologies and the social interventions that did not relate to one another, and consequently not leading to coherent correlation by way of inter-item correlation [270].

The next section discusses the results of the indicators to determine the scope required for the management of power quality, along with the recorded results from the respondents required to evaluate the respondent's perception regarding the use of smart grid technologies. The analysis begins with the profile information of the respondents, as the first sub-unit of the analysis.

6.2.2 Profiling of study participants in the survey questionnaire

The profile information collected comprised of biographical information of the respondents and it included an indication of the category in which the utility falls, the designation of the respondent within their utility, the category in which the utility falls in terms of their customer load, whether or not their utility implemented a PQM program, the number of years their utility has implemented a PQM program and whether or not they have dedicated PQ personnel to deal with specific PQ issues.

6.2.2.1 Biographical information

The respondents were required to answer questions regarding the name of their utility and their designation, which would enable the researcher to ascertain that the response was relevant to this study. The questions together with the responses are described below:

- **Composition of respondents (question 1)**

In Figure 40 below, the utility composition for this study is shown. A total of 11 responses from the power utility sector completed the questionnaire. From the response received, 55% of the respondents were from the metropolitan utilities and from Eskom – Distribution Group, while 45% were from local municipal utilities. This demonstrates that the results obtained from the respondents reflect the population that was intended for this study (Par. 4.4.5).

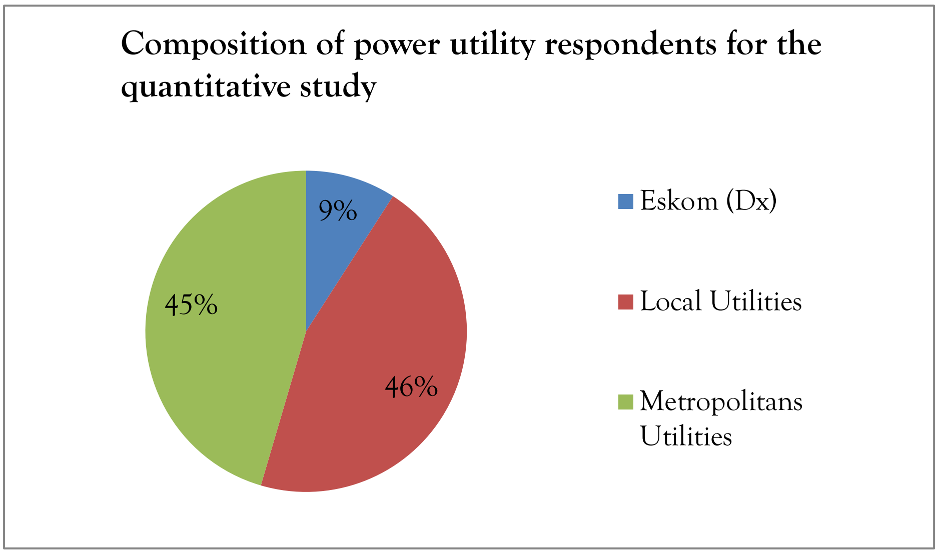

Figure 40: Composition of power utilities respondents for the quantitative study

- **Designation of respondents (question 2)**

The designations of the respondents are indicated in Figure 41. The chart indicates that the majority of respondents were from management and chief engineer designations. Two respondents did not specify their designation and, are designated as "other". This confirms that the respondents should have been reasonably informed about their utility's position in terms of PQM and their response should, therefore, be useful.

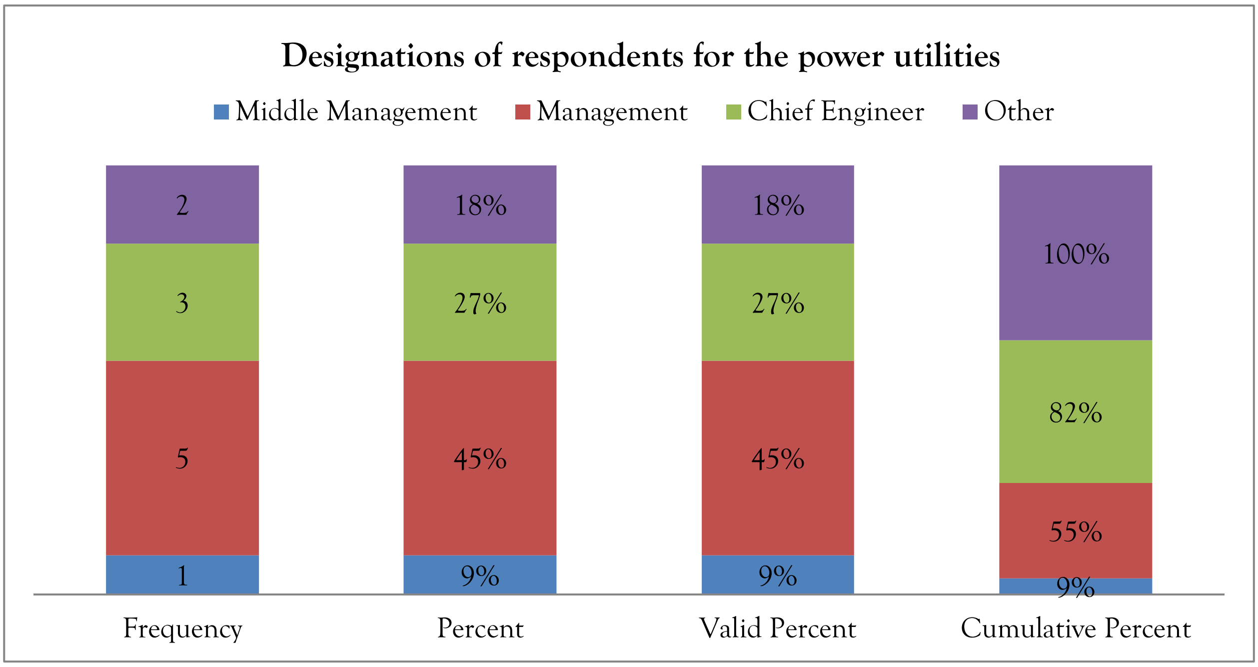

Figure 41: Designations of respondents for the power utilities

- **Respondents' spread of customer load (question 3)**

This question was open-ended, and it aimed to establish the classification of customers supplied by each of the respondents. From the response, the results were summarized and interpreted such that on average, the majority of the respondent' supply capacity comprised of the following customer load categories: 50% Large Power Users, followed by 35% residential and 15% comprising of commercial loads (shopping centres, etc.). Three of the respondents did not provide any numeric information and the response could not be used as part of the customer load statistics given for this question. The aforementioned responses are as follows: one respondent indicated 2MVA, another respondent by stating “mainly commercial and residential”, and lastly, one respondent indicated “mixed”. Since this data could not be represented numerically, it is to be reasoned that this response is not suitable for meeting the biographical data requirement for profiling the respondents in this study, as the results cannot be appropriately applied to make a meaningful interpretation on the categories of customers supplied by the respondent.

- **Availability of a PQM program (question 4)**

The aim of this question was to determine if the respondents had a power quality program implemented within their utility. The extent of power quality management employed is evaluated in accordance with the program that exists in a specific utility. The results are shown in Figure 42.

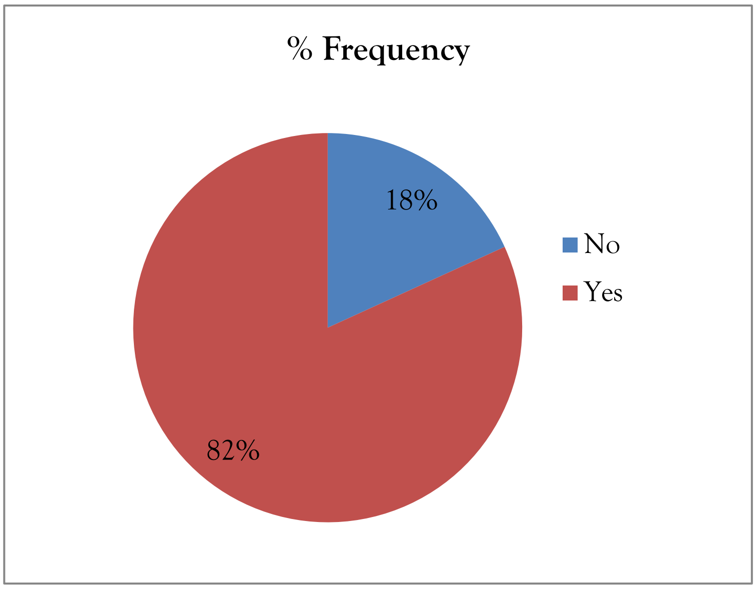

Figure 42: Power utilities respondents with a PQM program

From the chart presented above, it is observed that 2 (18%) of the respondents indicated that they did not have a program in place for the management of power quality within their utility, while 9(82%) of the respondents indicated that they had a power quality program in place.

- **Number of years with a PQM program (question 5)**

This question is an extension of the PQM program for the previous question and it aimed to determine the number of years the respondents implemented a PQM program. According to [71] the number of years that a utility has implemented PQM measures, may function as a “yardstick” to measure utility’s commitment to power quality. From the respondents who gave a positive (yes) answer to the preceding question, 44% of the respondents reported more than 10 years implementation of a power quality management program, which indicates a significant commitment. Of these 44 % of utilities, the longest reported period was 20 years, while amongst the respondents who had a PQM program, the shortest period reported was less than 5 years. The response is shown in Table 18 below.

Table 18: Years with a PQM program

NO. OF YEARS WITH PQM PROGRAM	FREQUENCY	% FREQUENCY
Below 5 years	2	22%
5 – 10 years	1	11%
Greater 10 years	4	44%
Missing	2	22%
Total	9	100%

From Table 18 above, it is encouraging to note that there are respondents who recently initiated programs for managing power quality. This implies that some utilities and possibly smaller utilities are recognizing the importance of power quality. Responses from utilities who have implemented PQs measures were of particular importance in this study.

- **Availability of personnel dealing with PQ issues (question 6)**

This question was aimed at establishing whether the responding utilities had dedicated PQM personnel to deal with power quality issues. It was noted that 64% of the respondents indicated that they had dedicated personnel to oversee the program of power quality within their utility. The remaining 36% of the respondents reported that they did not have personnel dealing with PQ issues.

The results are shown in Figure 43 . This response corroborates findings by Van Wyk in [75] in that the larger utility, Eskom has a PQ representative (expert) to oversee the management of PQ in each of their regions (Operating units). He further went on to state that metropolitan utilities typically appointed one or two PQ experts to manage PQ within their utility, while smaller utilities (municipalities) mostly did not have dedicated PQ personnel for managing PQ functions.

In summary, the profiling of the study participants indicates that majority of the respondents were large utilities (metropolitans and Eskom). This implies that 55% of the recorded responses were mainly from the perspective of large utilities with resources and expertise to advance the management of power quality [75]. This particular aspect will be looked at more closely in the remainder of this analysis, by assessing the indicators that determine the extent of power quality management.

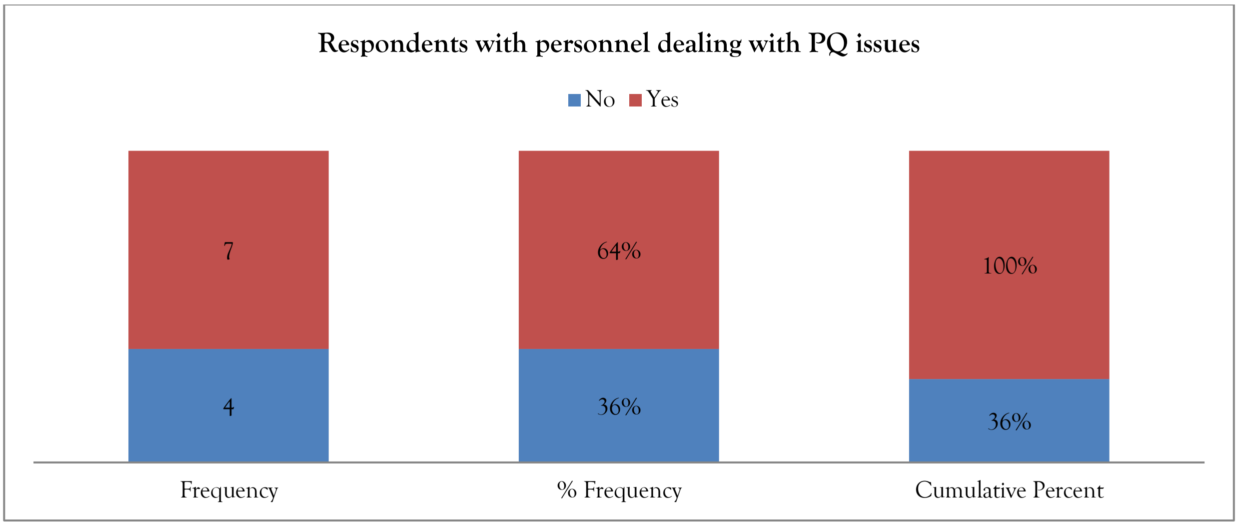

Figure 43: Respondents with personnel dealing with PQ issues

6.2.3 Section A and B: Indicators for PQM program and smart grid

Based on the Information collected in section A and Section B of the questionnaire, an assessment was done on the extent to which respondents manage power quality on their electrical network, along with the respondent's perceptions (views) in relation to the use of smart grid technologies on electrical network. The aforementioned assessment is analysed using descriptive statistics, by looking at the indicators to determine the scope required for the management of power quality and the perception of the use of smart grid technologies. The analysis begins with the Presentation and description of the different question items, after which the constructs were ranked to understand their significance in the research.

A five-point Likert scale was used in this research to determine the extent of knowledge and understanding of respondents in relation to power quality management and smart grid technologies, in accordance with the objectives of this research. For better interpretation, the five-point Likert scale of the questionnaire was reduced and merged into two categories to facilitate and support an analysis of more specific interpretations with reference to either low or high value.

A mean score of more than 3.0 was interpreted as of high positive value (agree and strongly agree), whereas a mean score of 3.0 and below was interpreted as a low or negative value (disagree and strongly disagree). The abovementioned high and low values of reference were selected as pointers within the five-point Likert scale to serve as specific indicators of either low (negative) or high (positive) values for each question item.

This procedure was applied throughout the interpretation of the questionnaire, with the neutral response designated as "Do not know" during the description of the response using frequency tables. The results for construct 1: Top management commitment are presented in Table 19 below. From the table, it is noticeable that the different questions of the construct produced high mean value scores with the mean value ranging between 3.36 for question V12 and 4.36 for question V5, which indicates a high positive mean.

Examining the overall mean for the construct top management commitment given by the means in Table 19, the response indicates a high mean score of 3.83. These responses reflect the importance of leadership among all role-players in utilities that addresses the challenge to drive the utility's corporate image and maintain relationships with different stakeholders, which ultimately impacts and has an influence on the management of power quality.

It can also be said that the identified importance of commitment by utilities' management is well supported in literature, for instance by the authors in [30], who believes that a utility's leadership should be well-informed of new developments to ensure high operational efficiency and capabilities and provide a unity of purpose, while also establishing direction of the utility in relation to regulatory compliance.

Top management commitment has also been regarded by the authors in [66], [180] as a significant benefit in programs for the management of power quality by distribution utilities. The author in [180] further states that if patience and discipline is demonstrated by top management of utilities, high level of PQ and high level of end user' satisfaction can be achieved through the effective implementation of PQM programs.

Table 19: Responses analysis – Construct 1: Top management commitment

VARIABLE	N	MIN	MAX	MEAN	STD DEV
V1	11	1	5	3.73	1.35
V2	11	2	5	3.91	1.00
V3	11	1	5	3.55	1.23
V4	11	2	5	3.73	1.05
V5	11	3	5	4.36	0.64
V6	11	2	5	4.09	1.08
V7	11	2	5	3.82	1.03
V8	11	1	5	3.82	1.40
V9	11	2	5	3.91	1.08
V10	11	2	5	3.45	1.08
V11	11	2	5	4.27	0.96
V12	11	2	5	3.36	0.98

In Table 20 the responses contributing to construct 2: Service quality assessment, is summarized. The results show that the responses scored high mean values for the different questions of the construct, with the mean value ranging between 3.09 for question V19 and 4.27 for question V15. In general, the construct yielded a mean score value of 3.73, which is regarded as a high positive mean.

Table 20: Responses analysis – Construct 2: Service quality assessment

VARIABLE	N	MIN	MAX	MEAN	STD DEV
V13	11	2	5	4.09	1.08
V14	11	2	5	4.00	1.04
V15	11	2	5	4.27	0.86
V16	11	2	5	3.45	1.16
V17	11	2	5	3.73	1.21
V18	11	2	5	3.36	1.30
V19	11	1	5	3.09	1.38

Table 21 summarizes the responses contributing towards construct 3: Network topology and design. The results show that high mean values were calculated for all of the questions within the construct, with the mean value ranging between 3.18 for question V22 and 4.36 for question V24. The overall mean for the construct is 3.95(a high positive mean).

Table 21: Responses analysis – Construct 3: Network topology and design

VARIABLE	N	MIN	MAX	MEAN	STD DEV
V20	11	3	5	4.00	0.60
V21	11	2	5	4.27	0.96
V22	11	2	4	3.18	0.83
V23	11	2	5	3.91	0.79
V24	11	2	5	4.36	0.88
V25	11	2	5	4.00	0.85

The results of the final construct (Construct 4: Customer interactions) of the questionnaire component on the scope of PQM program is summarised in Table 22. The results indicate high mean values for the majority of questions of the construct, with a mean value ranging between 3.27 for question V26 and 4.45 for question V27. An exception to this is the response to question V31, yielding a low mean score value of only 2.91, which indicates a low negative mean for this item. However, the responses yielded a mean score value of 3.64 for the construct Customer interactions, which is still regarded as a high positive mean.

Table 22: Responses analysis – Construct 4: Customer interactions

VARIABLE	N	MIN	MAX	MEAN	STD DEV
V26	11	2	5	3.27	1.21
V27	11	2	5	4.45	0.99
V28	11	2	5	4.09	1.08
V29	11	2	5	3.64	1.07
V30	11	1	5	3.64	1.37
V31	11	1	5	2.73	1.21

The respondent's perceptions concerning smart grid technologies were measured using three constructs. The first construct (Construct 5: Technical system operations) is summarized in Table 23. The results indicate that the utilities' responses scored high mean values for the majority of the questions of the construct, with mean values ranging between 3.45 for question V38 and 4.64 for question V33.

It is however noted that question V37 of the construct yielded a mean score value of 1.91, which is a low negative mean score from the respondents and also pointed out to a lack of realisation to utilise PQ performance data to predict maintenance requirements on the network. The construct Technical system operations have however yielded an overall mean score of 3.82, which indicates a high mean score.

Table 23: Responses analysis – Construct 5: Technical system operations

VARIABLE	N	MIN	MAX	MEAN	STD DEV
V32	11	2	5	4.09	1.08
V33	11	4	5	4.64	0.48
V34	11	2	5	4.36	0.98
V35	11	2	5	3.82	1.11
V36	11	2	5	4.45	0.89
V37	11	1	3	1.91	0.67
V38	11	2	5	3.45	0.89

Table 24 gives the response for construct 6: Cost-benefit and regulations. The results show that the utilities' responses scored high mean values for the different questions of the construct, with mean values ranging between 3.45 for question V41 and 3.82 for question V42. The mean score for the construct has also a high positive mean score of 3.68.

Table 24: Responses analysis – Construct 6: Cost-benefit and regulations

VARIABLE	N	MIN	MAX	MEAN	STD DEV
V39	11	1	5	3.73	1.21
V40	11	2	5	3.73	1.05
V41	11	2	4	3.45	0.89
V42	11	2	5	3.82	0.72

Finally, Table 25 provides the results for Construct 7: Social norms and behaviour. The results show that the utilities' responses scored high mean values for the different questions of the construct, with mean values ranging between 3.82 for question V46 and 4.46 for question V43. The responses have also yielded a high score mean value for the construct, with a mean score of 4.02, which is the highest among all the constructs of the questionnaire.

Table 25: Responses analysis – Construct 7: Social norms and behaviour

VARIABLE	N	MIN	MAX	MEAN	STD DEV
V43	11	2	5	4.36	0.88
V44	11	2	5	3.91	1.00
V45	11	2	5	4.00	0.95
V46	11	2	5	3.82	0.83

6.2.3.1 Indicators as elements for interpretation

A selection of specific items (questions) of the constructs of the questionnaire was considered as important elements of references or indicators for further interpretation. These elements form part of the important attributes required to address the objectives in this research, in accordance with the referenced literature regarding the management of power quality and smart grid technologies. The results of these elements are presented by means of frequency tables and diagrams and are discussed below:

- **Power quality management systems**

It was found that having a power quality policy within a utility is an important aspect in the management of power quality [30]. It was, therefore, necessary in this study to establish whether the respondents had a power quality policy within their organisation for managing power quality programs.

In Figure 44 the responses can be seen; it indicates that 91% of the respondents mentioned that their utility had a policy for managing power quality. However, only 82% of the same respondents indicated that their utility had implemented (or were in a process of implementing) a power quality management system, in accordance with the NER PQ directive, to comply with the requirements of NRS 048 standard.

In cross-referencing the responses with results for Construct 1 (Par. 6.2.3; Table 19), it is noticeable that the responses to these questions yielded mean scores of 4.36 for question V5 and 4.27 for question V11, which then indicates high positive mean scores. Given the responses received on the intended study sample, this data supports findings from studies done by Newbery and Eberhard in [17] that less than 15% of licensed distributors of electricity in South Africa had a program for managing power quality for their networks.

The respondent profiles indicated that there are respondents who only recently started to manage power quality. Although encouraging, this data indicates that not much progress has been made to date by South African utilities with regards to power quality.

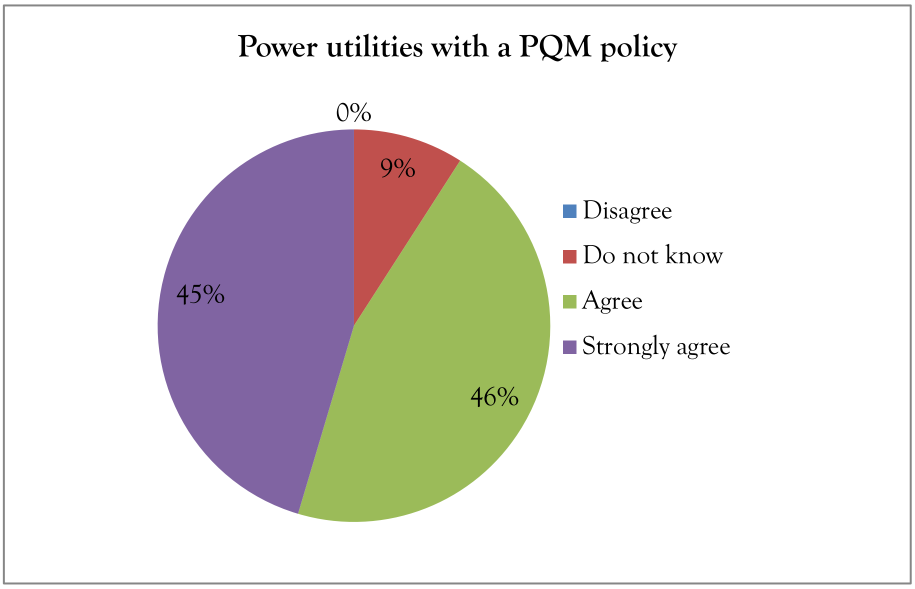

Figure 44: Power utilities with a PQM policy

- **Analysis of PQ trends and impact assessment**

In Table 26 the summarized responses to questions V16, V17 and V22 can be seen. The reviewed literature revealed that the electricity network is subjected to a number of different power quality disturbances, affecting either the magnitude, the waveform or the phase balance of the supplied voltage, and all of these disturbances can have a negative impact on the electrical system performance (par. 2.5 and par. 2.6).

To manage power quality, the most frequent and disturbances with the highest possible impact should be thoroughly analysed with greater priority. Impact analysis is regarded as a proactive measure in the management of power quality [165]. In this study, 64% of the respondents indicated that they conducted power quality impact analysis before connecting customers to their network and 36% of the respondents stated that they did not perform impact analysis (response to question V16).

The statement relating to performing internal investigation to determine root causes of PQ problems, yielded the following responses: 64% of the respondents agreed that they performed investigations internally to determine root causes of PQ problems, 9% of the respondents neither agreed nor disagreed, which implied that they did not know the answer while 27% of the respondents disagreed with this statement (response to question V17).

Given that impact analysis prior to connecting customers is regarded as a proactive measure in the management of power quality, it was interesting to note that some respondents in this study either disagreed or did not know the answers to the two questions. An inference to this data finds support from remarks by Van Wyk in [75] that the importance of PQ management is not recognised by most municipal utility managers in South Africa.

Another observation to the responses was to question V22, where only 45% of the respondents indicated that they conducted network life-cycle analysis to predict a decline in PQ performance. Jayatunga et al. in [165] considered the life-cycle analysis of a network to be a proactive program that monitors activities to identify conditions that could affect power quality and actions that will help utilities to avoid problems.

It is, therefore, crucial that life-cycle network analysis should be accepted as an integral part of utilities' network diagnostic processes so as to adopt a more proactive approach to managing power quality.

Table 26: Utility's response to analysis of PQ (questions V16, V17 and V22)

RESPONSE	V16 (% FREQUENCY)	V17 (% FREQUENCY)	V22 (% FREQUENCY)
Disagree	36%	27%	27%
Do not know	0%	9%	27%
Agree	64%	64%	45%

- **Network design and performance benchmarking**

The authors in [17] mentioned that regulations require that electrical network specifications, design, installation and commissioning should meet all applicable codes and standards and utilities should consider availability, operability, maintainability and power quality. It is stated that the type of network architecture, configuration and equipment used for each load can give rise to power quality performance on the utility's network.

In Figure 45 it can be seen that 91% of respondents in this study believe that they design their network with a view to optimize power quality (response to V20). Moreover, 82% of the respondents agreed that installation of MV cables forms part of their utility's priority when designing their distribution network (response to V21).

Given the response to these two questions, this data could be supported by the fact that majority of the respondents in this study are utility re-distributors (Par. 6.2.2, Figure 40), mostly located in a smaller geographical area and whose network infrastructures are for the most part, likely to consist of underground cables in cities

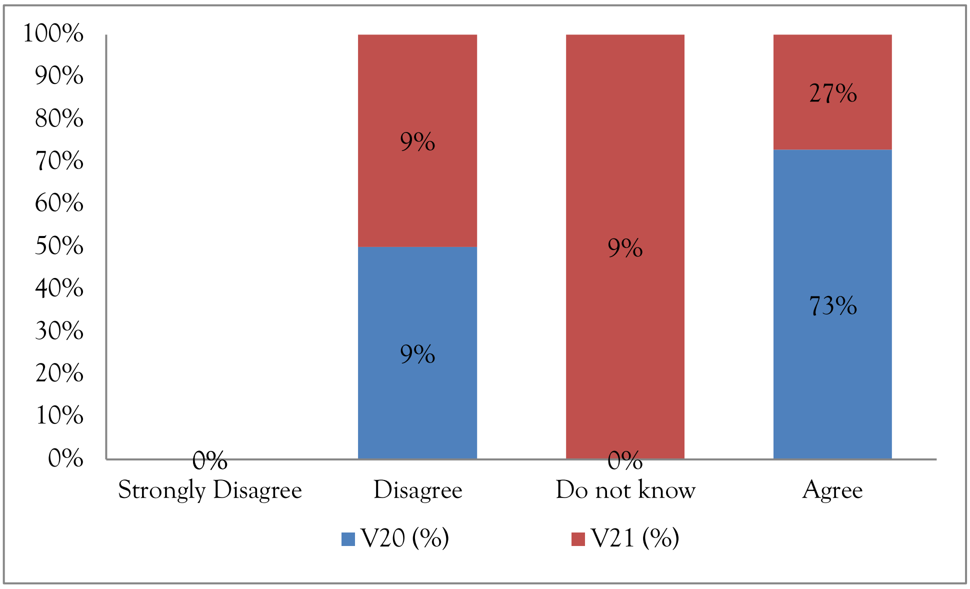

Figure 45: Power utilities response to network design for PQ consideration (response to V20 and V21)

In relation to benchmarking of PQ performance, an interesting observation worth noting is that 55% of the respondents indicated that they frequently performed analysis to benchmark performances of PQ parameters, especially voltage dips, to derive characteristic number of voltage dip performance on their network, while 45% of the respondents disagreed with the statement (response to question V18).

In addition, 45% of the respondents further indicated that they did not benchmark PQ performance of their network with other similar utility networks, 18% of the respondents indicated that they did not know while 36% of the respondents agreed with the statement (response to question V19). The results are summarized in Table 27.

Table 27: Benchmarking of PQ performance by power utilities (response to questions V18 and V19)

RESPONSE	V18 (% FREQUENCY)	V19 (% FREQUENCY)
Disagree	45%	45%
Do not know	0%	18%
Agree	55%	36%

This data (responses to question V19) supports the statement by the author in [75] that benchmarking of performance trends of different utilities should be regarded as the core services to be expected from NERSA, in the acknowledgement of their responsibility to the national economy. It suggests, therefore, that the majority of utilities in this study perceive benchmarking of PQ performance amongst each other's to be insignificant and time-consuming.

Delport in [166] stated that analysis of recorded PQ data is feasible for larger utilities such as Eskom and Ekurhuleni, with sufficient resources to benchmark network performance, such as establishing developing trends of characteristic levels in steady state parameter.

Data in Table 27 also support further remarks by the same author in [166] that indicative numbers in voltage dips could be estimated as function of network type (cable or overhead) and voltage level, with the intention to benchmark a PQ measurement site against what network of the same type experiences (comparison of responses to questions V18 and V21)

- **Network maintenance approach based on PQ**

Implementing maintenance policies on network equipment with an approach to corrective, preventive and predictive measures has been regarded as being helpful to operators and maintenance personnel in making the right decisions and taking the appropriate actions such as safeguarding premature failure of power transformers [138]. The authors further went on to indicate that maintenance of the electrical network based on power quality performance can also be useful for event tracking, fault analysis and root cause analysis.

Regarding network maintenance in general, 91% of the study respondents indicated that they had a network maintenance plan for their electrical network to ensure good power quality. However, 91% of the same respondents disagreed with the statement that they made use of PQ data to predict for maintenance of their networks (response to question V37).

As observed and described earlier in the results (Par. 6.2.3, Table 23), this question also yielded a low mean score of 1.91, suggesting a lack of realisation to a PQ-based maintenance approach by the respondents. This might be due to the fact that respondents might be of the opinion that PQ performance data could only be used for a specific purpose, and they (the respondents) had not considered using PQ data to plan for maintenance.

They also might not need to change existing maintenance philosophies, as the frequency of maintenance might increase, resulting in high maintenance cost, given the rate of decline in PQ performance as described in the literature (Par. 2.5 and Par. 2.6).

The responses are shown in Figure 46. This data supports findings by Stewart and Flynn in [138] who remarked that internationally, power quality trends has not been extensively used by utilities to inform their decisions on their network operations and maintenance. It is believed that power quality data trends can forecast and notify utility personnel when discrete network and equipment parameters may be exceeded, allowing for the execution of proactive maintenance, instead of facing unscheduled breakdowns.

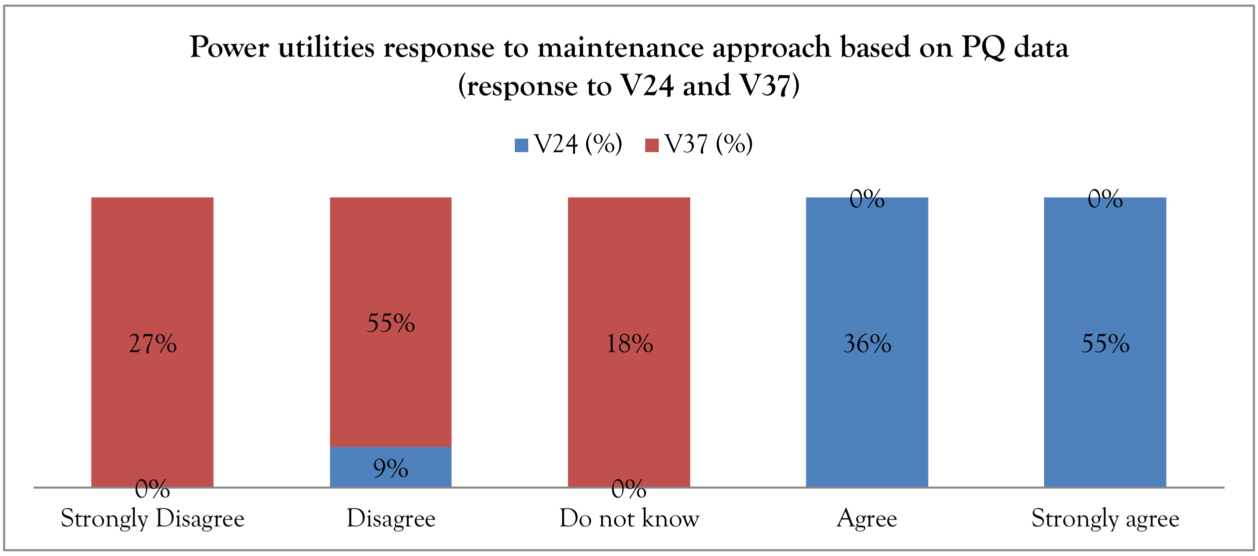

Figure 46: Power utilities response to maintenance approach based on PQ data (response to V24 and V37)

- **Aspects of Communicating and reporting of PQ performance**

In terms of communicating power quality data, 55% of the respondents indicated that they communicate their PQ data with their customers (response to question V26). However, only 36% of the same respondents agreed that communication of PQ performance data promoted strong relations with key customers, while 64% of the respondents disagreed with this statement (response to question V31). The responses are summarized in Figure 47.

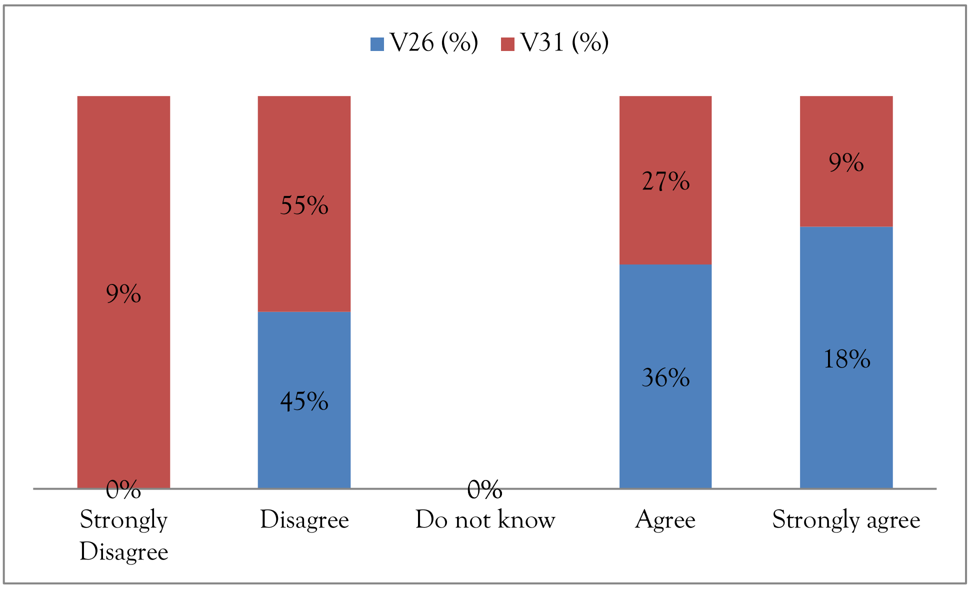

Figure 47: Power utilities response regarding communicating PQ data (response to V26 and V31)

With regards to respondents who developed relations with key customers, the response in Figure 47 (response to V31) is consistent with remarks by the authors in [33], that interacting with customers provide opportunities for utilities to make use of measured PQ data to evaluate the impact of PQ disturbances such as voltage dips on a customer's plant.

Through this interaction, utilities are able to exchange network events with their customers, in order to promptly resolve PQ problems on the network. This response is further consistent with findings in [82] that customer interactions through power quality forums between utilities and customers assist in maintaining the open lines of communication, thereby facilitating a free exchange of risk management information, with the aim to ensure economic benefits to both parties.

Regarding communication of PQ data to internal stakeholders and reporting the PQ performance annually to NERSA, it is interesting to note that 73% of the respondents indicated that they communicated their PQ performance to their internal stakeholder (response to question V8), but that only 55% of the same respondents indicated that they reported/submitted their PQ performance annually to NERSA (response to question V9). Regarding this, Van Wyk in [75] remarked that submission of PQ statistics by utilities is the general requirement by the regulator which is required for benchmarking the PQ performance received from licenced utilities, and to define characteristic values of PQ parameters.

Given the responses received (55%), this data (response to question V9[however, does not support the findings in [73] who concluded through research that only one utility reports their PQ performance on an annual basis, and all other utilities only provide the PQ performance upon request by NERSA. The responses to these two statements (questions V8 and V9) are summarised in Table 28.

Table 28: Internal communication and annual submission of PQ performance to NERSA (response to questions V8 and V9)

RESPONSE	V8 (% FREQUENCY)	V9 (% FREQUENCY)
Disagree	27%	36%
Do not know	0%	9%
Agree	73%	55%

- **PQ monitoring and measurement**

In the business world, a popular adage exists that “you cannot manage what you don’t measure”. This principle is acknowledged by the author in [30] as a useful measure to the management of power quality, as also Applicable to the world of energy management systems. The commitment to PQ measurement and perceived usefulness of modern technology instruments was tested in different constructs and questionnaire items, to establish how the respondents perceive the value offered by these instruments, in the management of power quality.

It was noted that 82% of the respondents indicated that they conducted measurement of power quality on their electrical network, while 18% of the respondents disagreed with the statement, which implied that they did not measure power quality on their network (response to question V13).

The same response was given regarding the use of modern technology to improve the monitoring of PQ performance: 82% of the respondents agreed with the statement (response to question V32). In Figure 48 the response to these two statements are summarised. This data allows for an interesting observation, given that some of the responses to these statements (response to questions V13 and V32) were from smaller local utilities. It is also observed that on the profiling of the respondents (par. 6.2.2.1,

Biographical information – Figure 43), 64% of the respondents were found to have personnel dealing with PQ issues within their utilities. The fact that more respondents agreed with the statements in this subsection (response to question V13 and V32), could be attributed to the fact that some smaller local utilities have or are starting to have an outsourced business model of PQ monitoring [75], in order to gain access to similar resources and expertise in PQ management as found in the larger utilities.

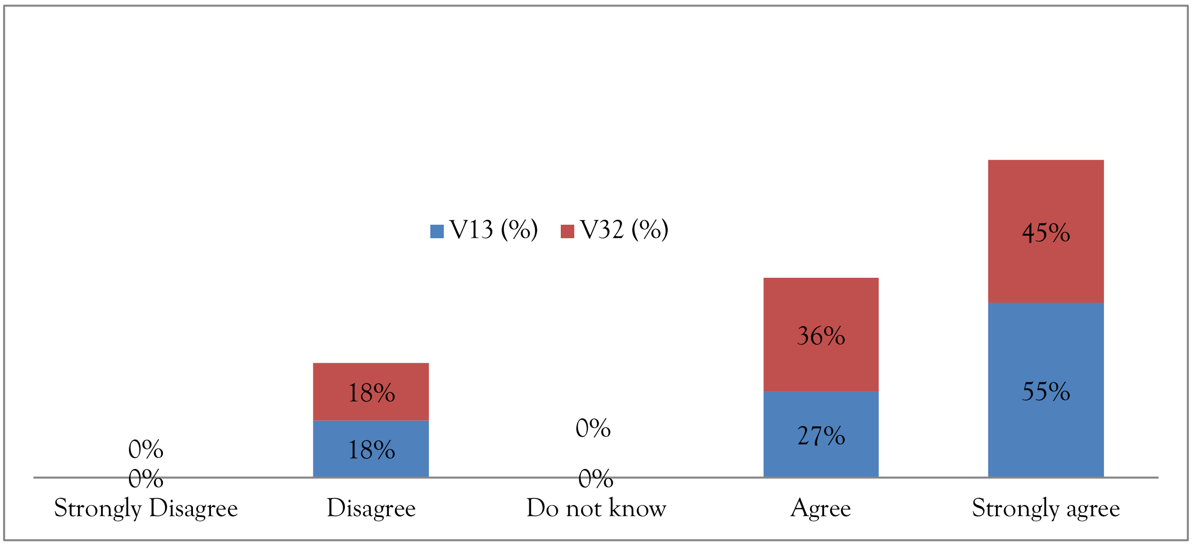

Figure 48: Utilities response regarding PQ monitoring and measurement (response to V13 and V32)

- **Monitoring and measurement based on a smart grid concept**

The concept of the smart grid is viewed in the literature as mainly an idealized model from which various components are to be taken and added to the real system as particular local problems arise [271]. It is also believed, amongst other benefits, that better PQ, especially in voltage control and voltage dip impact are the intentions of the smart grid [71], [272].

One of the main objectives of this study is to determine the extent to which utilities perceive the benefit of using smart grid technology for their network operations. , 82% of respondents in this study agreed that implementing smart grid technologies can enable their utilities to increase power distribution efficiencies and reduce operating costs (response to question V34).

With regards to the threats posed by the integration of renewable energy sources distributed throughout the electrical network, 64% of the respondents indicated that the deployment of smart grids can enable their utility to improve voltage stability and system reliability (response to question V35). And the statement regarding implementation of automated methods of detecting PQ problems for possible enhancement of PQ management yielded the following responses: 91% of the respondents agreed with the statement, and only 9% of the respondents disagreed (response to question V36). The responses to these questions are given in Table 29.

Table 29: Power utility's response on smart grid approach to PQ monitoring (response to questions V34, V35 and V36)

RESPONSE	V34 (% FREQUENCY)	V35 (% FREQUENCY)	V36 (% FREQUENCY)
Disagree	9%	18%	9%
Do not know	9%	18%	0%
Agree	82%	64%	91%

The data in Table 29 demonstrates acceptance by the respondents regarding the potential benefits of smart grid technologies on their operations. It also supports the literature in [21], [68], [71], [150], [271], [272], and [275] that the extensive monitoring of a smart grid can allow utility companies to proactively investigate network voltage deficiencies, in conjunction with predetermined duration thresholds by determining if potential voltage problems exist and if necessary, implement corrective actions.

The authors in [71] describe proactive approach as achieved by eliminating the customer during the investigation, as the means of identifying system deficiencies (voltage, current and frequency) fluctuations found through a smart grid monitoring system which will enable the utility to utilize only the known standards and regulatory tariffs as a guide for determining these system deficiencies.

- **Value proposition and incentives for Smart grid**

The authors in [137], [150], [273] states that understanding and communicating the value proposition of a smart grid deployment to each stakeholder in the Electricity Supply Industry (ESI) is seen to be unnerving; as the financial environment for risk and reward or the return on investment can challenge business plans for smart grid investments. Developing a suitable incentive structure that aligns economic and regulatory policies with energy efficiencies and environmental objectives need to be tailored to each utility according to its resources and expertise [274], [275].

Accordingly, 73% of the respondents in this study indicated that they understood the value proposition of a smart grid deployment (response to question V39). And 64% of the respondents agreed that regulatory standards are required to provide incentives aimed at rate recoveries for investing in smart grids (response to question V40). The responses to these 2 questions are summarized in Table 30.

Table 30: Power utilities response on value for smart grid and incentives (response to questions V39 and V40)

RESPONSE	V39 (% FREQUENCY)	V40 (% FREQUENCY)
Disagree	18%	18%
Do not know	9%	18%
Agree	73%	64%

- Enabling efficient energy transfer and the environment

Lastly, regarding efficient transfer of energy for emission reduction, 82% of respondents indicated that the smart grid can qualify their expectations of efficient energy transfer as well as cost and energy saving for their customers (response to question V44). In terms of the smart grid and the environment, 73% of the respondents indicated that they considered smart grid as a tool to facilitate the reduction of the country's environmental impact, 9% of the respondents disagreed with the statement, while 18% indicated that they did not know (response to question V45).

Regarding the potential challenges likely to emanate from the integration of renewable energy sources, 64% of the respondents agreed that smart grid can enable their utilities to improve voltage stability and system reliability, 18% of the respondents disagreed with the statement and 18% said they did not know (response to question V35). The responses are summarized in Table 31.

Table 31: Power utilities response on enabling efficient energy transfer and the environment (response to questions V43, V44 and V45)

RESPONSE	V43 (% FREQUENCY)	V44 (% FREQUENCY)	V45 (% FREQUENCY)
Disagree	9%	18%	9%
Do not know	0%	0%	18%
Agree	91%	82%	73%

The data in Table 31, in relation to the statement on the environment (response to V45) is consistent with the findings from the literature in [9], [135], [150], [273]. It describes the leading purpose of the smart grid vision as an integrated approach to mitigate global warming, considered to have the capabilities of serving as a basic tool to reach the objectives for climate change.

In this regard, energy management systems accompanied by renewable energy sources (such as solar and wind) as alternatives are the potential options to safeguard the environment through reduction of carbon emissions. While renewable energy sources are considered as alternatives, it is asserted in [276] that the integration of renewable energy sources at distribution level can presents challenges for the controllability of these resources and for the operation of the electricity system.

The authors state that this is due to the fact that wind turbines spin more on some days than others, on the other hand, photovoltaic solar panels production drops when the sky is overcast. The data in Table 31 is therefore consistent with the literature which indicates that smart grid technologies, capable of gathering real-time feedback on the electricity supply and demand, help reduce peak load and enable the integration of wind and solar energy sources.

6.2.4 Conclusion: Descriptive statistics

The quantitative data collected by the questionnaire was presented and analysed in the previous sections according to the aims and objectives of this research. The constructs of the questionnaire are considered to be appropriate in conveying the intended meaning required to measure (observe) the scope of power quality management program in a South African utility. All the constructs recorded high means (values greater than 3.0), and, therefore, it can be deduced that a utility should have the following in place (rated from highest to lowest priority:

- Network topology and design (mean 3.95);
- Top management commitment (mean 3.80);
- Service quality assessment (mean 3.73); and
- Customer interactions (mean 3.64).

In terms of the measure for smart grid technologies, the formulated constructs are also regarded as suitable measures to determine the extent to which a South African utility perceives the use of smart grid technologies for their network operations. Ranked in the order of highest to lowest mean, the results for the constructs are as follows:

- Social norms and behaviours (mean 4.02);
- Technical system operations (mean 3.82); and
- Cost-benefit and regulations (mean 3.68).

Based on the results presented, the respondents were in agreement with the constructs required to manage power quality in a utility. Similarly, the respondents were unanimous regarding their perceptions of the use of smart grid technologies. It can, therefore, be concluded that all the different constructs of the questionnaire yielded high mean scores from the utilities that took part in this study. A specific selection of the responses from each of the constructs was considered as important elements of references or markers for further interpretation (par. 6.2.3.1).

Based on these preceding discussions and data presented, it can be confirmed that the views and beliefs expressed by the respondents are certainly regarded as amongst the significant findings to be considered in the formulation of factors that can influence a South African based power utility to utilize smart grid technologies for power quality management. The following section describes the second stage of the empirical investigation, namely that of the qualitative data analysis obtained from the semi-structured interviews.

6.3 Analysis of qualitative data

In so far as the qualitative section of this research report, semi-structured interviews were conducted. The interviews took place over a period of eighteen months, from September 2015 to March 2017. Large industrial key customers of South African power utilities were requested to take part in an interview regarding their sensitivity and experiences of their industries concerning power quality, as well as to provide viewpoints on the use of smart grid technologies for the monitoring of power quality.

By using the semi-structured interview method, a wide range of qualitative data from large industrial key customers of power utilities was collected, which also ensured that their perspectives could be described as accurately as possible. To ensure that the participant was adequately informed regarding power quality within their industry, all seven of the participants were directly involved with the day-to-day running of electrical activities within their industry. In addition, all the participants had more than 5 years of related work experience in dealing with electrical power quality.

Each of the interviews lasted a minimum of 85 minutes. Prior to the analysis, the recorded data was transcribed and sent to each respondent for verification. This also serves to ensure the trustworthiness and credibility of the collected data. The feedback obtained from the respondents was used to update the transcripts, which was then prepared for analysis.

6.3.1 Overview of qualitative analysis

Regarding the analysis of qualitative data, the authors in [277] state that there is little standardisation with no systematic rules where a specific type of qualitative data relates to a particular type of analysis. It is further pronounced in [224] that no single qualitative data analysis approach is universally accepted, and variations always exist in the number of steps for the same process of analysing data by different researchers.

From the preceding views, it can be deduced that each particular qualitative data analysis will be a uniquely designed activity. The qualitative data analysis of this research (responses from the semi-structured interviews) was done according to a qualitative content analysis that included the data analytic techniques given in [57] with the framework procedure for analysis as described in [58] along with recommendations in [197], in order to discover themes in line with the research topic.

This analytic approach involved reading and rereading the interview transcripts to uncover any salient codes and categories, subsequently collapsing them into themes. By using the framework method of analysis, the following content and thematic analysis were followed:

- The transcribed text was thoroughly read in detail, to obtain a comprehensive idea and be familiar with the content and context before the coding process was initiated to identify units of meaning or labels.
- The transcribed data was then arranged in meaningful groups according to related codes. As progress was made with the analysis, additional sub-themes and sub-groups were included to identify meaning connections, relationships and developing trends. The coding process for the transcripts was done using the coding techniques described in [57] and specifically, three coding techniques were used, namely: Open coding, Axial coding and Selective coding.
    - Open coding entailed the identification and labelling of segments of meaning from the transcripts in relation to the research topic. During open coding, the emphasis was placed on wording, phrasing, context, consistency, frequency and specificity of comments. The authors in [278] believe that during coding, a phrase or sentence is much preferred than a word for a label as it captures complete ideas. Accordingly, the segments of meaning from the transcripts were labelled in a descriptive manner.
    - Axial coding was done by reviewing and examining the initial codes that were identified during the open coding process. Categories and patterns were identified during this step and organised in terms of causality, context and coherence.
    - Selective coding as the final coding procedure entailed selective scanning of all codes that were identified for comparison and association to the research question.
- After coding the first three transcripts, a set of codes that emerged during the open coding procedure were adopted to be applied as working codes to all subsequent transcripts. This formed a working analytical framework which was subjected to several iterations until all transcripts were coded and no additional codes emerged.
- The developed working analytical framework was then applied by indexing subsequent transcripts using categories and codes. This entailed the selective coding procedure, through refinement and scanning of all codes that were subsequently used in the final analytical framework
- Using Microsoft Excel, a spreadsheet was used to chart the data into a matrix. This enabled the researcher to summarise the data by categories from each transcript and ensured that the data was ready for interpretation.

From the preceding discussion, it follows that the analytic process was followed by inquisitive questions to identify thematic relationships from the various categories, in line with both the inductive and deductive reasoning process and consequently, the following questions as suggested by the authors in [194] were considered in directing the identification of thematic relations:

- What was the relationship in meaning between all the categories?
- What can be deduced from the categories as a whole?

- What meaning was missing?
- What has moved to the background, in other words, what is no longer important or necessary?
- What alternative explanations were possible?
- How were the research objectives addressed by the various categories?

Although the content analysis procedure involves a systematic and transparent procedure for processing data, it can be regarded as being adaptable or be flexible to the specific needs and requirements of the researcher. In general, content analysis comprised of the following steps, beginning with preparing the data and proceeding through writing up the findings.

In summary, the aforementioned content analysis procedure was adapted according to the needs of the researcher, in order to identify themes that were further used as a basis for reasoning, deliberation and the formulation of syntheses and conclusions to contribute, in combination with the data from the quantitative analysis, to the evaluation of factors influencing a South African based power utility to utilise smart grid technologies for power quality management.

Before getting into the detailed exploration of the framework approach to the content analysis of the interview data undertaken for this report, it was necessary to first provide a brief overview of the context of the source of data, which was essentially to obtain background information about the respondent which also served as a way in which the researcher gained trust and established rapport with the participants [44]. Moreover, this was also used as a point of contact to carry out the interview and to provide information on the consent to participate in the research.

6.3.2 Context of the study participants in the semi-structured interviews

A summary of the data gathered during each interview will be provided in this section for each of the participant. This information was useful in obtaining the technical environment on which the participants manage their operations. It should nevertheless be noted that the information provided for the description of the participant at each industry may not necessarily be representative of the views of the entire industry on all aspects of the responses, hence the study may not be a complete representation of reality, but rather an exploration and description of perspectives of the participants in this research. All the participants who took part in this study were Eskom's key customers, and each of their backgrounds is provided below.

- The context of the participant 1 in the study

The participant 1 categorized their industry sector as being part of the chemical sector. They stated that their operations comprised of about 24 points of deliveries from which they are connected to the utility's network, primarily via 88kV overhead lines from the utility's main transmission station (MTS), namely 275/88kV transmission substation. At the time of conducting the interview, their total load consumption within the utility's transmission supply area for all their PoD's was mentioned to be around 200MW.

The typical loads that were used for their operations were described as consisting of 80% rotating machines (motors) and power electronic devices which included: variable speed drives (VSD's), uninterruptible power supplies (UPS's), rectifiers and process reactors. In terms of staff members required to administer and engage with the utility regarding power quality issues, they have a technical support group that has engineers whose role includes amongst others, power quality.

The participant whose response description was recorded in this study is amongst the engineers within the technical support group, who frequently collaborated with the utility to solve power quality problems. The participant had 7 years of related experience in the field of electrical engineering.

- The context of the participant 2 in the study

According to the participant of this particular industry, their industry classification is also categorized as being the chemical sector. They are also supplied from the utility's 275/88kV main transmission substation, with only one PoD directly connected to an 11kV line from an 88/11kV substation. At the time of conducting the interview, their total agreed maximum demand with the utility was 14.5MVA, which was expected to increase to 20MVA in the next twelve months.

They mentioned that about 90% of their loads comprised of motors. The sizes of their motors range between 0.17kW and 450kW. They did not have a dedicated team or section to deal with power quality issues, hence they were not extensively skilled in power quality. The participant who took part in the descriptions recorded for this industry as the participant was a Manager for technical operations, with just over 15 years of related work experience in electrical engineering.

- The context of the participant 3 in this study

According to the participant in this industry, they classify their industry as being a manufacturing sector, focusing mainly on the production of cement and related products used in the building industries, namely roof tiles. From an electrical supply point of view, they mentioned that their main supply is the utility's 275/132/88kV main transmission substation, via an 88kV ring network.

They have two Pods from which they take supply from the utility. At the time of conducting the interview, the participant mentioned that their annual power consumption was around 34MW. Their loads comprised of motors, Kilns, Mills and large process fans.

They described their largest motor to be rated at 4.5MW, with direct online starting procedure. In terms of PQ personnel, they mentioned that they had a team of engineers responsible for power quality and power consumption management within their plant. The designation of the participant who contributed in the descriptions recorded for this industry as the participant was mentioned to be that of the Electrical manager. He mentioned having over 15 years of related experience in electrical engineering.

- The context of the participant 4 in this study

The participant 4 classified their industry category as being the mining sector, focusing on the mining and production of gold. They mentioned having operations from various PoD's, supplied from various distribution substations, on a number of ring networks. The main transmission substation that supplies these networks was described as one of the utility's 400/132kV transmission substation.

At the time of conducting the interview, the participant mentioned that their agreed maximum demand was 120MVA, allocated to four PoD's with an average annual consumption of 74.5MW. In terms of consumption, the participant described their highest equipment being predominantly motors, which drives a variety of loads, including winders, mills and compressors.

Motor sizes were described to range between 1.8MW and 3MW, according to design specifications. However, the participant mentioned that majority of the large motors were derated; with the 1.8MW motor operated at 1.3MW, while the 3MW motor was operated at 2.2MW.

In summary, the participant mentioned that majority of loads for their operations consisted of motors ranging from synchronous motors, DC drives and thyristor drives. As for the personnel to deal with PQ issues, the participant mentioned that there is a certain level of skills within their group to look at PQ related issues but further mentioned that PQ investigations they cannot resolve through internal investigations, they would then outsource to consultants for a detailed investigation. T

he designation of the participant who contributed in the description recorded for this industry as the participant was mentioned to be that of a Chief electrician, with over 25 years of related experience in electrical engineering.

- The context of the participant 5 in this study

Similar to the context described in the participant 4, the participant 5 classified their industry category to be the Mining sector, focusing on the mining and production of gold. The participant mentioned having a total of 36 PoD's in the Free State area, supplied from various 132kV and 44kV distribution networks from the utility. The main transmission substations for these distribution networks are three of the utility's transmission substations. At the time of conducting the interview, the participant mentioned that their power consumption was around 300MW, with the majority of their loads consisting of motors.

Their typical production motor sizes range from 7.5kW up to 2.5MW, which are started directly online. In essence, about 90% of the participant's load is consumed by motors. In terms of staff for dealing with PQ, the participant mentioned that they have a Chief electrician overseeing all PQ related activities, and if they cannot resolve the problem within their facility, they would appoint consultants for detailed investigation. The designation of the participant who contributed in the description for this industry as the participant was mentioned to be that of an Electrical manager, with over 20 years of electrical engineering experience.

- The context of the participant 6 in this study

The participant 6 described their industry category as the Water pumping and purification sector. They mentioned having various PoD's from which they took supply from the utility, predominantly in the Eastern part of the Free State province. Supply to these PoDs is received from the utility's 132/88kV distribution substation, via an 88kV radial line.

At the time of conducting the interview, the total agreed demand for three of the PoD's mentioned by the participant was 16.5MVA. This being a water pumping industry, the participant mentioned that majority of their loads were motors with PLC's for control. The designation of the participant who contributed in the description for this industry as the participant was mentioned to be that of a senior electrician, with over 25 years of electrical engineering experience.

- The context of the participant 7 in this study

Similar to the participant 6, the participant 7 in this study described their industry category as the Water pumping and purification sector. They mentioned having various PoDs from which they took supply from the utility, predominantly in the Welkom area. Supply to these PoDs is received from various 132kV and 44kV networks from the utility's distribution substations. At the time of conducting the interview, the agreed maximum demand for three of the PoDs mentioned by the participant was 17MVA.

Their load comprised mainly of motors, which they mentioned to be around 90% of their total energy consumption. Their motor load composition ranges between 55kW to 2MW. Soft starters with VSDs are installed for starting and control of the larger motors. The designation of the participant who contributed in the description for this industry as the participant was mentioned to be that of Regional Manager, with over 25 years of electrical engineering experience.

6.3.3 The framework analysis process

Analysis of the interview data was done according to the framework analysis process as described in Chapter 5 (Par. 5.4.1). A combined approach to analysis was taken, enabling themes to be developed both inductively from the accounts (experiences and views) of the participants and deductively from existing literature, in line with the aims and objectives of the study. Initially, all notes and transcripts were read to gain an overview of the context of the gathered data, which represented the content analysis of the data [228], [279].

Content analysis was performed throughout the inductive analysis of the transcribed data, followed by a three-step coding process that comprised of open coding, axial coding and selective coding procedures. The aforementioned procedures led to the identification of codes of interests used in the interpretation step of the analysis. The process used for the identification of codes is described in the next sections.

6.3.3.1 Data coding and analytical framework

In the initial step of the coding process, an open coding procedure was undertaken, which led to the initial identification and development of a working analytical framework through the description of names for specific units of meaning in relation to the research objectives. This enabled the use of an inductive approach to identify themes in the data and then returning to the literature using theories deductively to further explain certain aspects of the emerging themes, which were systematically tagged with descriptive codes. These descriptive codes were used to represent and identify the words that the participants used to describe their views and experiences [261], consistent with the questions that were asked during the interview.

All these codes were considered preliminary qualitative indicators and were further evaluated manually during the axial and selective coding steps, through a process of refining, applying and refining the analytical framework for consistency and relevance to compile a final list of codes. During the axial and selective coding process, the codes were studied to determine whether some of the codes were related and could be merged. Before the codes were merged, the text associated with the codes was further examined to ensure that the merged codes had similarities on the meaning of the text. The passage of text from the transcripts was then revisited to decide on the suitable code.

For instance, on one passage of text from one transcript, the code 'Synchronised measurement of PQ' was identified, whereas, on the same passage of text, the codes 'holistic view of PQ' and 'online view of every point on the network' were also identified as codes. Despite the difference in semantics, it was identified that all labels were conferring to the same aspect and meaning of observing power quality on the network.

The transcript was then revisited, and it was concluded that the term synchronised measurement of PQ better captured the idea and this code was applied. Some of the codes that were reduced to one code using the above-mentioned procedure are as follows:

- The code incident reporting procedure was applied as the chosen code alongside the code contacting a representative at the utility, as they both captured the process through which PQ enquiries are made.
- The code event communication was applied as the selected code alongside the codes of event notification and negotiated event.
- The code starting methods were applied as the selected code alongside the code sequential start-up.

All the codes that were identified during the initial stage of the coding process formed part of the initial analytical framework and subsequently, more transcripts were coded using the initial framework, taking care to note any new codes or expressions which did not fit the existing set. Throughout the analysis, the initial framework was frequently revised to incorporate new and refined codes.

At this point, some recurrent codes that were conceptually related were grouped together. For example, four codes (PQ expectations, sensitive to PQ disturbances, voltage quality problem occurrences and power interruptions occurrences) each related to the underlying activities of power system reliability and quality, were then grouped together to make an overarching category which was named "Perceived PQ experiences". Similarly, some codes that were regarded as elements suitable for describing key concepts were subjected to further refinement processes and then used as overarching categories for grouping conceptually related codes.

The following are two such examples; the first being the code taking precautions, which was subsequently rephrased and used to form the category of PQ risk mitigation measures, and the second is the code negative outcome, which was renamed and assigned the category of PQ risk to operations.

Process of refining and applying the analytical framework was repeated until no new codes were generated, after which the selective coding procedure was used to produce the final analytical framework. The final framework consisted of forty codes of interests, clustered into eight main components (categories), which were subsequently used as part of the interpretation of the data analysis done for the qualitative part of this study. Table 32 through to Table 34 presents the final framework of categories with constituent codes and their description used in this research report.

Table 32: Final analytical framework – categories 1 to 2 with constituent codes

Code	Description
Regulatory Awareness	
Awareness to PQ standards	This entailed the respondent’s awareness to PQ related standards which included NRS 048, international measurement standard set to the recording of PQ and PQ instrument complying to IEC 61000-4-30 Class A requirement.
The mandate of utilities on PQ	This relates to the customer’s understanding of the mandate of power utilities regarding PQ and the manner in which PQ is managed
Familiar with PQ clauses	This relates to how well the customer is familiar with PQ clauses that is included or likely to be included in supply contracts with the utility
PQ Management mechanism	
Utility / Customer partnership	Views on the importance of partnerships between utility and customers in dealing with PQ issues
Technical meetings	How well technical meetings between utilities and customers is perceived as mechanism to discuss PQ issues
Incident reporting procedure	Barriers, gaps, advantages and drawbacks on the methods of reporting PQ/ network incidences
Event communication	PQ communication, punctuality, feedback and accuracy of response to PQ issues
Priority to large customers	Provision of service to customers according to their categories (Commercial, industries, residential, etc.)
PQ expertise	Availability of expertise to diagnose and confirm PQ problems for ease of engaging with utilities
Accessibility of PQ data to customers	Means of accessing network PQ data by customers for self-assessment of equipment compatibility

Table 33: Final analytical framework – categories 3 to 6 with constituent codes

Code	Description
Perceived PQ experiences	
PQ expectations	Expectations of customer in relations to PQ supplied at PoC for all parameters
Sensitive to PQ problems	Likelihood of customer facility to be affected by PQ event. This entail also the negative impact associated with the PQ problem.
Voltage quality problem occurrences	Specific voltage quality parameters that are experienced at PoCs
Power interruption occurrences	Severity of interruption impact to be experienced or likely to be experienced by customer (i.e. Frequency, time and duration)
PQ Risk to Operations	
Loss of production	Impact/outcome in terms of production losses to be incurred as a result of a PQ problem
Overtime costs	Likelihood of incurring cost from overtime paid to workers as a result of a PQ problem.
Safety risk to employees	Risk of employees getting injured resulting from a PQ problem/event.
Damage to equipment	Likelihood of customer equipment being damaged/malfunction as a result of PQ
Mine flooding with water	Impact of PQ to customer facility resulting in water flooding due to lack of supply caused by PQ problem
Water hammering to infrastructure	Infrastructure damage that is likely to occur resulting from a PQ event.
Impact on water quality	Sudden loss of supply that is uncontrolled leading to pollution of water
Risk of explosion	Possible explosion that may occur due to lack of supply caused by a PQ problem
PQ Risk Mitigation Measures	
Equipment compatibility	Extent to which customer equipment are compatible with PQ supplied at PoCs
Equipment rating	Voltage, Current, Frequency, and fault level (kA) rating of equipment at customer facilities
PQ-centred procurement	Purchase, re-configuration of equipment to minimise impact to the network
Harmonic filtering	Efforts to reduce voltage distortions produced/likely to be produced at customer facilities
Voltage ride through capabilities	Measures undertaken to reduce impact of voltage dips from and to the network
Protection scheme	Entails protection measures undertaken to protect equipment from adverse PQ events (e.g. over/undervoltages, over/under frequency, unbalance protection, phase rotation, etc.)

Starting methods	Methods of motor starting employed and sequential switching of loads to reduce starting burden on the network
Preventive maintenance	Maintenance undertaken to reduce probability of equipment failure and decline in PQ
PQ - based premium	
PQ-based premium	Likelihood of customer paying more on premiums/rates that are based on PQ performance

Table 34: Final analytical framework – categories 7 to 8 with constituent codes

Code	Description
PQ Measurement Philosophies	
Importance of PQ measurement	How well customers perceive the importance of PQ measurement within their facility
Awareness to smart grid	How well customers understand and believe in the concept of smart grid
PQ on SCADA	Perceptions on the value of SCADA system in the monitoring of PQ by utilities
Synchronised measurement of PQ	Perceptions on the use of synchronised method of monitoring and measurement of PQ on a WAN
Facilitating PQ mitigation	Perceived views to describe how smart grid can also be utilised to facilitate mitigation of PQ
Load switching capabilities	Capabilities of smart grids described as enabling of load switching to support demand response
Early detection of anomalies	Described as the benefit of the smart grid to enable early detection of anomalies on networks
Real-time system	Smart grid described as a system to provide real-time observation of network parameters.
Smart Grid Obstacles	
Smart grid obstacles	Potential perceived threats and hindrances toward the deployment of smart grid

After all the descriptive codes (sub-themes) from the notes and transcripts were assigned to their associated categories (main themes) and applied to the final analytical frameworks as in Table 32, Table 33, and Table 34, data matrices were subsequently used as a method of displaying and organising the emerged themes or codes, in order to make an initial observation on the accounts given by all the participants.

6.3.3.2 Charting data into the framework matrices

The purpose of the semi-structured interview was to identify themes, links and patterns during the interpretation process that would describe the account and experiences of the participants, in relation to power quality and smart grid technologies. In the preceding paragraph, the process of identifying themes or codes was performed by applying the final analytical framework. In this section, each theme from the final analytical framework is populated into a data matrix.

The matrix comprised of one row per the participant and one column per sub-theme or code, and each corresponding data entry contained a paraphrased version of the description given by each of the participants regarding the specific theme. Table 37 through to Table 52 present the summaries of the data matrices for each theme.

These tables also serve to provide an initial observation as well as a comparison on the accounts between each of the participants and each theme. This provided ease of reference to what was said by which of the participant on the specific theme. In order to increase the legibility of the data matrices, some of the presented tables were split into more than one table, with alphabetic numberings A, B, C, etc., specified at the end of the Caption text. All these associated tables can be found in Appendix A.

6.3.4 Analytical memos: discussion of qualitative data

In the preceding sections, themes were generated from the data set by reviewing the matrices and making connections within and between the participants and categories. This process was influenced both by the original research objectives and by new concepts generated inductively from the data.

In this section, the researcher attempted to go beyond the connections made within and between the participants and categories, by presenting descriptions and accounts given by the individual participants, towards developing themes which offered possible explanations for what could be deduced from the data.

Through the use of analytical memos, all categories and their associated codes identified from the data and regarded as the most important aspects were discussed. The memos are structured with sub-headings, which included a description of the category, specific codes relating to the category and a summary of the raw data. Bold and italic fonts were used to look for patterns within the data and to include illustrative quotations with references to the original transcripts in order to further justify conclusions [279]. The descriptions of the memos for each category are discussed in the next paragraphs.

6.3.4.1 Analytic memo 1: Regulatory awareness

Regulatory awareness is amongst the categories that emerged during the analysis of the qualitative data. This category was used to group codes identified to describe the account and experiences given by the respondents, in relation to the regulations required for the management of power quality. Three specific codes relating to this category were identified, namely: Awareness to PQ standards; Mandate of utilities on PQ; and Familiar with PQ clauses. The description on the first code is discussed below.

Awareness to PQ standards

The first code assigned to the category of regulatory awareness is concerning awareness of PQ standards. As the literature overview consistently revealed a growing consciousness by the end- users of electricity on power quality and an increased demand for high-quality power, awareness to PQ standards by customers is significant in understanding the problems associated with power quality variations [280]. Understanding by a customer means being able to relate the causes of power quality variations to the impact on equipment and processes within their facility. The author in [280] further suggests that awareness to PQ standards by customers enable them to have an understanding of the utility power system, their own electric system and the equipment characteristics.

The authors in [281], [282] also identified lack of end-user's awareness regarding power quality and the associated standards as a barrier to power quality programs by utilities, which serve as mechanisms to facilitate power quality improvements. In the context of the current research report, awareness to PQ standards represented the respondent's understanding of local and international standards regarding the management of PQ, which included awareness to the NRS 048 and the IEC 6000-4-30 standards. Six of the seven respondents indicated that they were aware of the applicable standard used to measure PQ in South Africa, an example of such responses include:

"Yes, I am aware. It is part of the NRS 048 series of documents" (Participant 1);

"Yes, I am aware of the standard. I don't know the name, but I do have it" (Participant 2);

"Yes, I know about NRS 048. Not in that much detail but I know about the standard" (Participant 5);

"I know of the standard, but I am not familiar with it" (Participant 7).

These preceding responses, although some degree of awareness by some of the respondents were mentioned regarding the PQ standard, it is evident from the responses that none of the respondents gave an explicit account regarding their full awareness of the specific standard. This may imply that the respondents do not fully utilise the PQ standard as part of their day-to-day in dealing with power quality issues. That being said, these responses, to a large degree, are consistent with findings from the authors in [282] who identified lack of awareness to PQ and associated standards by customers as one of the barriers to power quality programs. This may further point toward the inadequacy of the customer to have the full understanding of the PQ issues impacting their facility.

Likewise, regarding awareness to the international measurement standard set to the recording of PQ, only one respondent indicated being aware of the standard but mentioned that he did not have full detail requirement of the standard. One respondent also mentioned relying on the PQ manufacturer specifications as assurance of their measured PQ and said:

"No, I just know of the local one we spoke about earlier and I haven't paid much attention to the international one. As for our instruments, we make use of brand names of instruments such as Schneider and ION so in that sense, we rely on the manufacturer specification to make sure they've got the right standard" (Participant 5).

Alongside the code awareness to PQ standards, the code mandate of utilities on PQ was identified and is discussed below.

The Mandate of utilities on PQ

The second code assigned to the category of regulatory awareness is in relation to the mandate of power utilities regarding power quality. In terms of the mandate to utilities, the NERSA Power Quality Directive compels utilities to plan their network and manage the levels of pollutions generated by each individual customer in order to meet compatibility levels defined for the parameters of PQ [26].

Alluded to in the literature overview, these form basis on which PQ objectives are established for managing customer emission and system characteristic in order to achieve equipment compatibility levels (Par. 2.3; Figure 3). in relation to the current study, it is important for customers to understand the manner in which utilities apply the regulatory requirement to manage PQ for all its customers and it is also important for customers to engage with the utility and perform functions that require knowledge, skills and attributes in order to contribute to the effective management of power quality by utilities [82], [280]. Responses related to the mandate of utilities on PQ referred to the important requirement of utilities to comply with the regulatory requirements. Some of these responses are:

"I know that there is an act that then references the power quality requirements within the NRS, and I think it is essentially how utilities are mandated to comply with the requirements" (Participant 1);

"I have read through the various NERSA documents, but I wouldn't say I am an expert on how NERSA governs utilities on power quality, but I do believe there are a set of rules that the utilities need to comply with" (Participant 2);

"Yes, we do understand these regulatory requirements. Utilities are using it to set minimum power quality requirement to manage power quality for its customers" (Participant 3);

"I would say I know of the process, but I don't really know the process itself. So, I know that NERSA sets the rules and utilities have to abide by those rules. But what those rules are and exactly how the process of how it is derived and communicated, that I am not sure" (Participant 7).

These responses, to some degree correlated with the argument from the literature study that the mandate of utilities should have a particular focus and emphasis on managing customer activities that serve as a measure of control of power quality emissions (Par. 2.3), which, consistent with the literature overview, can be regarded as an important task of managing power quality. In concluding the category of regulatory awareness, the code relating to familiarity with PQ clauses is discussed next.

Familiarity with PQ clauses

The third and final code that was assigned to the category of regulatory awareness relates to familiar with PQ clauses. As was revealed in the literature study, power quality is an important aspect of managing risk in the electrical supply industry. Just as outlined in the preceding code, from a South African context, NERSA had set requirements via the Power Quality Directive and the NRS 048 documents for implementation by all the stakeholders to regulate and manage power quality. The aim of the PQ directive was to ensure that licensed utilities put in place a power quality management system that will ensure that PQ parameters at the points of common coupling among stakeholders are measured, recorded and analysed for future network improvement as well as the resolution of potential complaints with customers.

NRS 048 part 4 is the version of the NRS 048 series of documents, which serve as a guideline for licensees aimed to aid in the implementation of the regulatory framework that is outlined in the Power Quality Directive, and as also outlined by the authors in [82], it provides a basic overview of drawing up power quality contracts between the customer and the licensee. Of significant to this study are the PQ clauses that would form part of the contract between the customer and the licensee and the following responses regarding familiar with PQ clauses were mentioned by the respondents:

"I know that we do have PQ clauses, I just cannot personally tell about it. I have seen the clauses but not as part of the supply agreement but as part of the connection agreement for our generators. I do know that there is an annexure with the PQ requirements that have a large basis on the NRS 048" (Participant 1);

"Yes, we are familiar with the clauses. It is part of the energy supply agreement between us and Eskom" (Participant 3);

"Yes, we are aware of these clauses. From our contract with Eskom, the clauses are stipulated with regard to power quality" (Participant 6).

Two other respondents also indicated that they were familiar with the clauses and mentioned the significance of having the clauses and said:

"Yes, I am familiar with the clauses. I think I might have read them some 8 years ago. To my understanding, the clauses are simple to make us aware of our rights in dealing with PQ issues. I remember we once had a small incident in the previous years which we reported and sorted it out with the utility. so in my view, the clauses are good as they are there to protect both parties in dealing with PQ issues and in the event of a dispute, so the PQ clauses give some point of reference" (Participant 4);

"I am familiar and have seen the clauses, but I haven't taken them into much detail. We have recently revised most of our supply agreements and I have noted our voltage regulation limits to be ±7.5%."; "with regards to the clauses, it is important to have them as it is the qualifying measures for the quality of the product or service that the utility is endeavouring to supply so definitely a critical part of the supply agreement" (Participant 5).

Another similar response to the previous response also mentioned the same importance:

"I know that the clauses are in the contract. I think having the clauses complete the contract. Obviously, if there is some kind of a dispute regarding power quality, you need something to fall back on. Even if the clause is not in the contract word-for-word, even if it is referred to in a standard, there should be some reference so as to ensure a common understanding"; "With the current working relationship between Eskom and ourselves, if there is a problem, we try to resolve it without the legal route. But once you go beyond that point, then you need to have some baseline legal document in the form of these power quality clauses" (Participant 7).

The preceding responses, particularly with an emphasis on responses given by the last two respondents, to some degree demonstrate an understanding of the importance of the application mechanism that is available in dealing with PQ issues. Therefore, consistent with the framework that is outlined in the NER Power Quality Directive [26], awareness to the PQ clauses by the respondents demonstrated an informed awareness of their rights and obligations with regard to the power quality supplied by their utilities, which then further puts pressure on utilities to ensure that the needs and expectations of customers in terms of power quality and reliability of supply are reasonably fulfilled. Apart from the codes assigned to the category of regulatory awareness, codes for the category of PQ management mechanism also came to the fore.

6.3.4.2 Analytic memo 2: PQ management mechanism

Codes were assigned to the category of PQ management mechanism and for the purpose of this study, PQ management mechanism relates to the respondent's realisation to the effectiveness of measures undertaken by the utility to involve its customers in the management of power quality. The specific codes assigned to the category of PQ management mechanism are Utility/customer partnership; Technical meetings; Incident reporting procedure; Event communication; Priority to large customers; PQ expertise; and accessibility of PQ data to customers. The descriptions given by the respondents in relation to the codes are discussed below.

Utility/customer partnership and technical meetings

The first code assigned to the category of PQ management mechanism relates to utility/customer partnership. According to [283], it is said that "customers are the heartbeat of all businesses and developing a healthy relationship with customers is crucial to the success of a business". It is further said that maintaining a strong customer relationship is key in helping businesses to sustain its performance and competitiveness [194], [284]. In relation to power quality, the literature review revealed that developing a partnership approach to power quality issues, customer operations can be maintained to run smoothly. Customers do not always have the expertise or time to focus on identifying, characterising and solving power quality problems and this is believed to be an area wherein a partnership arrangement with customers, utilities can provide valuable services for customers, including power quality [33], [82], [280]. Accordingly, responses related to utility/customer partnership covered respondents' viewpoint and perceptions about the importance of collaboration in managing power quality.

To a certain extent, responses relating to this code indicated consistency with the literature that promoted and highlighted the significance of utility partnering with customers to resolve PQ issues. The following responses and examples from respondents serve to corroborate the preceding view:

"I agree. That is the main control mechanism that we have for dealing with PQ issues" (Participant 1);

"Yes, I totally agree. We normally interface with Eskom when we have power quality issues. There should be an agreement" (Participant 3);

"I agree. You can't have just the utility managing power quality or just the customer try to manage it, it would have to be a partnership" (Participant 5);

"Yes, I agree with that. You need to have a good relationship with the power utility. It is obvious that should be the starting point in dealing with future PQ problems"; "that is also related to having a good relationship with the utility such that when something goes wrong or there are supply problems, then you know who to contact in order to rectify the problem (Participant 6).

Along with the preceding responses from the above code, the respondents considered technical meeting which was assigned as a second code of the category PQ management mechanism, as an important aspect of dealing with PQ issues. As one respondent explicitly stated:

"But if we experience a lot of power dips for instance towards the end of last year, we would contact our representative at Eskom to arrange a meeting so as to discuss these issues"; also, when we have our quarterly technical meetings to discuss all issues, feedback is given on quality of supply issues" (Participant 3).

Likewise, another respondent gave a number of similar responses regarding having meetings and said:

"Most of the information with regards to something that will change such as the demand or in terms of generation coming on line we do inform the utility in order to sign agreements but in terms of plants that will be commissioned or shut down, that is handled during our Bi-monthly meetings"; "The timing of an interruption do matters so we need to be involved and it be communicated to us which is typically at our Bi-monthly meetings"; "Feedback is always communicated for all that is monitored in terms of the Bi-monthly technical meetings that we have with the utility,. .."; "Currently, there is limited monitoring in this network but there are several monitoring points in the distributor's network around Makalu and we have several monitoring points as a customer where we compare our data during the Bi-monthly meetings " (Participant 1).

The following responses were further mentioned by the respondents concerning the importance of technical meetings:

"We are aware of the PQ. This form part of our discussion during our quarterly meetings with Eskom, where the performance is shared with us" (The participant 4);

"For our larger mining operations, there are power quality meters and that is where we get information from the utility during our regular meetings"; "Like in our regular technical meetings, we pick up events that the utility don't pick up or don't know how to classify, or at times the utility pick up events that we don't." (Participant 5);

"We are normally informed of the PQ through presentations done during our technical meetings" (Participant 6).

It seems from these responses that technical meetings along with a good relationship with the utility were regarded as the noteworthy aspects concerning the management of PQ. These responses were also consistent with responses from the quantitative section (Par. 6.2.3.1, Figure 47), supported by the literature findings in [33] that interactions between utilities and customers provided opportunities for utilities to make use of PQ data to evaluate the impact of PQ to customers.

The aspect of engaging with customers is also consistent with the viewpoint in [82], in stating that engaging with customers through problem solving meetings and customer forums could be regarded as a rich arsenal that can be used for addressing and identifying problems, in order to avoid possible PQ disputes which could easily be avoided if there is a better understanding of the problems, causes, and solutions by all parties involved.

Collaborating this view with the responses from the respondents, it is clear that utility/customer partnership and technical meetings are considered as mechanisms to collectively bring solutions to PQ problems. Responsibility lies with power utilities to have a thorough understanding of the processes of customers they serve as well as a thorough knowledge of the power quality they supply, which is significant to the objectives of this study.

To resolve any gaps between the quality of power supplied and the required documenting process by customer processes responses that represented the respondent's account and experience about incident reporting procedure are presented below.

Incident reporting procedure

The third code assigned to the category of PQ management mechanism is relating to incident reporting procedure. Incident reporting procedure is seen as the initial process by which customers communicate or lodge complaints relating to power quality concerns to the utility, for the purpose of obtaining causes of such incidences on the electrical network. A quick glance at the responses from this code, to a certain degree, indicated a close association with responses from the preceding codes as it also relates to establishing contact with the utility regarding PQ events. Responses given by the respondents were:

"We have actually complaint twice in the past year that I know off. We've had a bad year. The complaint was lodged through our representative at Eskom"; *"Feedback is always communicated for all that is monitored in terms of the bi-monthly meetings that we have with the utility, as well as any queries that we lodge through our representative at the utility"* (Participant 1);

"Not really. It's only when we experience power outages that we call the Call Centre to lodge a complaint but if we experience a lot of power dips for instance towards the end of last year, we would contact our representative at Eskom to arrange a meeting…" (Participant 3);

"Yes, we do regularly. We do call our representative at the utility and enquire about what happened" (Participant 5).

One respondent reported using more than one process of reporting incidences:

"Yes, we do lodge complaint. We do it via the Contact Centre or via our representative at Eskom" (Participant 6).

The same respondent held the view that with the relationship that they have established with the local technical people from the utility, they would sometimes find it convenient to contact them directly to ask if they were aware of the supply problem on the network:

"At times, with the understanding that we have with the local Eskom field guys, I would contact them to ask if they are aware of the problem we are having with the supply before I can actually call the Contact Centre to report the fault" (Participant 6) and further stated that: *"It is more convenient to call the local guys first because they mostly know what is happening with the network. We would call and ask whether they know what the problem is, and whether they are working to resolve it at that time, or should we report it via the call centre"* (Participant 6).

The importance of the preceding responses is that an assigned role of handling PQ queries from specific customers can be a best practice to be implemented by power utilities in resolving PQ issues and is viewed as imperative for the management of PQ.

This particular view is also consistent with responses from one of the questions in the quantitative section of this report (Par. 6.2.3, Table 22) where about 64% (response to question V29, Mean value: 3.64) of the respondents indicated that they had a customer relations personnel to communicate PQ issues with their customers, as this is also regarded as the norm for Eskom, that service to key customers are offered according to the load demand classification and other network supply requirement [82], [285]. In light of this, it was acknowledged that the nature of customers that contributed to the responses herein are different from other consumers of electricity and therefore it can be assumed that incident reporting procedures that work in one customer classification such as residential customers will not necessarily be effective in another type of customers, for instance, large customers who in total contribute more than 80% of the revenue.

Put simply, what works in residential customers may not be effective or appropriate for large customers. Moreover, the consequence of poor power quality to large customers is more detrimental to the economy than it can be for residential consumers. That said though, this is consistent with the objectives of the qualitative section of this report, to identify themes, links and patterns in the description of research participants regarding their experience and industry sensitivity to power quality problems, to contribute towards the evaluation of factors influencing a South African based power utility to utilise smart grid technology for the management of power quality. The next code assigned to the category of PQ management mechanism is discussed below.

Event communication

The next code associated with the category of PQ management mechanism is related to communication. Concerning communication, the author in [286] holds the belief that communication is often overlooked, but the ability to communicate is necessary to convey the thoughts and visions of an organization, whose fundamental goal is to deliver a message to potential consumers designed to convince them to perform a specific action. For the current study, communication can be regarded as significant for customers and utilities, so as to effectively manage all issues influencing power quality performance. More specifically, communication helps utilities to involve their customers in matters pertaining to power quality.

Communication serves as a foundation for managing and all essential information is communicated to customers who in turn exchange information so as to resolve the issues. More importantly, utilities as owners of the electricity networks must communicate effectively with their customers so as to achieve the utility's goals and objectives of managing PQ issues as suggested in the NER PQ directive [26]. , one can say that effective communication is an element of the successful resolution of the problems that may arise from PQ. In other words, as the authors in [82] explicitly state: "however if there is little or no communication between the parties, frustration usually results, leading to a variety of behaviours including angry phone calls, threatening letters, or lodging a dispute with the regulator for mediation or arbitration. Often this unpleasantness could have been avoided if there was a better understanding of the problems, causes, and solutions by all parties involved."

Regarding the importance of event communication, the following quotes from the respondents confirm the previously stated views between a utility and communication of PQ issues:

"I think that communication is handled very well. Feedback is always communicated for all that is monitored in terms of the Bi-monthly meetings that we have with the utility, as well as with any queries that we lodge through our representative at the utility."; "The timing of an interruption does matter so we need to be involved and it is communicated to us which is typically at our Bi-monthly meetings." (Participant 1);

"However, for planned outages, it is not a problem to us as it is timeously communicated to us and we can also align each other's maintenances"; "For planned outages or emergency repairs communicated to us timeously, we can scale down our load but keep the continuous process running, i.e., the Kilns"; "In general, communication from the utility is good. We only had an encounter early last year where we were told that maintenance work will be done on the lines, but we did not get feedback. Its only after we arranged another meeting that feedback was given regarding the maintenance of the lines" (Participant 3);

"If it is an unplanned event or a breakdown maintenance that has to be carried out at short notice, and Eskom need to urgently do some repairs, this can be negotiated between us and Eskom."; "At this stage, all communications between us and Eskom has been good" (Participant 4).

Also implicated in the above requirements of communication is the ability of the parties concern to handle conflicts, to establish good relations, as also alluded to by the respondents in the first code of this category as well as other related responses from the interviews: *"With the current working relationship between Eskom and ourselves, if there is a problem, we try to resolve it without the legal route."* (Participant 7).

The preceding responses are consistent with the viewpoints in [82] that communication of power quality issues with the view to understanding and enabling the resolution of many of these issues experienced by both or several parties is clearly the desired relationship between customers and utilities. The overall aspect of communication between the utility and the customer was also considered to be relevant by respondents in the quantitative segment of this research report, as the construct for customer interactions were considered relevant with a mean value of 3.64 (Par. 6.2.3, Table 22). The next code assigned to the category of PQ management mechanism is discussed below.

Priority to large customers

As expressed by the respondents in the code of incident reporting procedure, these responses led to the development of the fifth code, namely priority to large customers that was also assigned to the category of PQ management mechanism. Although only one respondent alluded to the fact that utilities should give high priority to large customers in dealing with supply issues, this particular response gave a valuable insight into the manner in which large customers expected to be given service by the utilities, as the respondent said:

"As I already explained, it takes about 4 hours for the utility to react. Previously, it was quick when we didn't have to go the call centre route to obtain a reference number. Our understanding is that the call centre gets all the complaints, including domestic users do not know that we are a large consumer and need high priority hence they just put your name on the list" (Participant 3).

The respondent further mentioned escalating some of the issues with the utility: *"We recently had a meeting with Eskom, including Eskom head office to discuss these issues and they also agreed that large customers should follow a different route from that of domestic users"* (Participant 3).

The preceding response to some degree indicated consistency with responses that emphasised the importance of having a close relationship with the utility as was also reported in the previous codes. In this code, however, the respondent alluded to the need for utilities to give high priority to large customers in dealing with supply issues so as to restore power or resolve power quality issues as quickly as possible.

The respondent's view seems to be consistent with the literature study in that quick restoration of supply to businesses and industries should be aimed at safeguarding human lives and to minimize potential economic losses (Par. 2.6), which is also in coherence with remarks in [82] that for many industries, electricity is fundamental for both international competitiveness and business survival. That being said, utilities are expected to come up with strategies and investments decisions on their electrical infrastructure that will ensure a reliable supply of on-demand electricity and improved power quality performance that is not disruptive to customer operations. The code PQ expertise is discussed next.

PQ expertise

PQ expertise is the sixth code assigned to the category of PQ management mechanism. Although the literature review revealed that monitoring of power quality is a regulatory service provided by licensed utilities to their customers, it is also important for industrial and commercial customers to possess some level of expertise required to diagnose and confirm PQ problems within their operations. Moreover, many studies have revealed that most of the problems happen within the customer's facilities [18], [280], and this means that the ability of a customer to effectively diagnose and confirm PQ problems would provide a range of benefits both for the customer and the utility.

To the customers, the benefit would be far less economic impact than the potential damages that may derive. In the current study, responses related to PQ expertise were significant for the understanding of the PQ skill available in the day-to-day running of operations at the customer's facilities and the ability to diagnose and confirm PQ problems in order to effectively collaborate with the utility on PQ related issues. These responses linked up with the viewpoint from responses from an earlier code relating to utility/customer partnership that solving PQ problems can best be achieved through a partnership between the utility and customers, which, consistent with the literature overview, can also be regarded as amongst the fundamental component of PQ management.

In a nutshell, responses related to PQ expertise, also served as a fundamental component for managing power quality as pointed out by one respondent:

"Yes, we do have skills. We have a technical support group that has engineers in it. It is not dedicated PQ engineers as we don't do specialisation. It would be general engineers who look at power quality, protection and projects so we do not have

sections of people dedicated to one aspect but as part of the duties of this technical support engineering group are monitoring and following up with the utility on power quality issues." (Participant 1).

Another respondent also gave a similar response and said: *"Yes. We do have a team (champion and engineers) responsible for power quality and power consumption within the plant."* (Participant 3).

Of significant to observe from the preceding responses is the fact that the respondents mentioned having a team that comprised of engineers to deal with power quality issues. These responses, in particular, were also consistent with responses from the same respondents in another category for the code relating to the importance of PQ measurement (Par. 6.3.3.7) where they also revealed that they had PQ instrument installed to measure PQ within their network.

This is also in support of the efforts to improve power quality, which is an exception to the remarks by the authors in [83] that a large number of electricity users do not invest in the field of power quality and ignore the efficiency that can be derived from correcting the problems with poor power quality. In contrast to the preceding responses, one of the respondents mentioned that they did not have PQ skills to diagnose PQ but revealed that they outsourced the PQ functions and explicitly stated:

"Not within the firm. We have appointed the services of external Consultants to manage our power quality. I am personally not an expert in power quality"; "We are currently in the process of installing PQ meters within the plant for a full spectrum measurement of power quality parameters, which we outsourced to a reputable consulting company." (Participant 2).

The following three responses implied having limited PQ expertise and that they often outsourced for detailed analysis: *"Yes we do. There is a certain level within the...... Group, but what we cannot manage within, then we outsourced to Consultants"* (Participant 4);

"Yes, I would say so. We have a chief electrician and have loggers/meters on the incomes and if we need to investigate further, then we get a third party but we can identify and liaise with the utility and also with our own people to try and get to the root cause" (Participant 5);

"Yes, I think we have. Although I don't think we invested specifically in the required equipment to do that. But I will refer for example, to one of our pump station in the North West area, we would find that the pumps regularly trips because of a problem from the utility side, so when we do instantaneous measurement, we would find that the voltage would be up to 450V and our equipment would just trip" (Participant 7).

These responses signified a limitation and a possible threat to the respondent about the inadequacy of in-house PQ skills to fully diagnose and analyse PQ problems, which is consistent with the aims of this particular study, to evaluate factors that would influence power utilities in South Africa to explore the use of smart grid technologies for the management of PQ. The final code assigned to the category of PQ management mechanism is discussed below.

Accessibility of PQ data to customers

As briefly outlined above, accessibility of PQ data to customers is the seventh and final code assigned to the category of PQ management mechanism. This refers to making power quality information accessible to electricity users whenever it is required. As outlined in the literature overview, industrial and commercial customers are increasingly affected by poor power quality problems and access to power quality data on the utility's network can help customers to take some preventive actions. Majority of respondents in this study provided views about the manner in which they obtain access or are informed of the PQ data supplied at their points of connection.

They mentioned relying mostly on meetings with the utility to be informed of such PQ information. Some of the responses given by the respondents are:

"Yes, we are informed of the PQ data. We have a quarterly meeting with Eskom and their QoS person do attend to give us a report for the past three months on power quality issues," (Participant 3);

"Yes, we are aware of the PQ. This form part of our discussion during our quarterly meetings with Eskom, where the PQ performance is shared with us" (Participant 4);

"Yes, we are normally informed through presentation done during our meetings and there is now an open-door policy where we get communicated about voltage dips and power quality in general" (Participant 6).

The following response from one of the respondents was interesting and is of particular importance in relation to the current study when the respondent finally concluded the response by including the statement *"I would like to see the PQ information for the rest of everyone who is supplied from the same network."*

Initially, though, the respondent gave a similar response to that given by the other respondents and stated, *"Yes. That is mainly at our Bi-monthly meetings or on request or following incidence with the local Eskom guys. We also have own measurements at all our points of supply"* (Participant 1).

The respondent further mentioned that they were satisfied with the data and also considered PQ historical data in the purchasing of equipment and said: *"We are also satisfied with the manner in which we receive PQ information from the utility"; "That takes into account what historically we have measured on the network with regards to various parameters. So, it is important that we should also consider PQ historical data in the purchasing and the setting up of all the equipment that we have"* (Participant 1).

The concluding remark made by this particular respondent was about making use of PQ data to get a more understanding of PQ on the network and therefore said:

"If somehow, we had access to see our data, the distributor's data and other customer's data in the same network, we would get a more understanding of what is happening with the PQ without having to compare. I would like to see the PQ information for the rest of everyone who is supplied from the same network"; "I don't know how practical it would be for users to have that but I can really see the use for it and I think it will be more of a use for the distributor" (Participant 1).

This response, in particular, can find support in the views by the authors in [75], [169], who advocated the use of web-based PQ monitoring systems, which can provide access to such PQ information to customers. The significance of the response from this respondent was the proposition that having more access to PQ information would be of more use to the utility, as well as to enable customers' ease of access to PQ information at their PoDs.

In support of such propositions, it is believed that such PQ information can further be facilitated by the use of power system instrumentations offered by PQ recorders that are designed according to the latest edition (edition 3) of the IEC 61000-4-30 Class A requirements [79]. In relation to the current study, this proposition lies once more therein that a need is expressed for utilities to have an intelligent approach of collecting PQ data that can easily be accessible to customers.

Consistent with responses that were also reported in this research report in another category (Par. 6.3.3.7), coherently with conclusions by [79], along with findings from [75], [169] that a web-based real-time power quality monitoring will be useful to provide accessible data to industrial customers and utilities, the need expressed by the respondents is in line with the purpose of the current research report to evaluate key technologies that can be used by utilities to manage power quality.

6.3.4.3 Analytic memo 3: Perceived PQ experiences

The category 'Perceived PQ experiences' was identified as an account used to describe the environment and challenges relating to specific PQ event experiences. The specific codes that are related to this category are PQ expectations; sensitive to power quality disturbances; voltage quality problems occurrences; and power interruption occurrences. The description given by the respondents on the assigned codes is given below:

PQ expectations

The first code assigned to the category of perceived PQ experiences is regarding expectations. The expectations of the participants in this research, in relation to the levels of power quality that is supplied to their points of connections is that it should comply with standards and that specific PQ parameters should remain within set limits:

"We expect all parameters of power quality to be within limits. So, we expect the THD to be less than 8%, the individual voltage harmonics to be within the limits set by the NRS 048, voltage regulations to be within ±10% and frequency to be within ±2.5%." (Participant 1);

"As I mentioned earlier, one would expect the quality to be almost 99.9% at the right voltage, at the right waveform, and you want it to be as constant as possible, and that's going to make our lives simple" (Participant 2).

The participants expressed some concerns on their business sustainability and expected that PQ performance levels should enable them to leverage and optimise their infrastructure and maintain good operating environment and said: *"We expect the power quality to be within limits and enable us to be sustainable in our productions for 24/7"* (Participant 6).

The above quotes clearly indicate that the issue of power quality has greater expectations for the interests of users of electricity. This has also been pronounced in [77], who stated that the challenge for the present decade is no longer the reduction of interruption duration, but also to better meet each customer's expectations and to provide the most proper level of quality they need.

This particular theme of desirable quality of power by the participants is a case in point for further analysis to investigate specifically, the fundamental nature of perceived attributes of power quality, which are described and discussed in the following codes.

Sensitive to PQ disturbances

The second code associated with the category of perceived PQ experiences is related to the sensitive nature of industries to power quality. Concerning sensitive to power quality, the author in [287] holds the belief that the increasing use of electronics for industrial application has led to equipment and process operations in the industries to be sensitive to power quality. For the current study the participants considered their industries to be sensitive to power quality and this is also a risk to their operations.

Power quality anomalies such as interruptions and frequency deviations and voltage quality problems manifesting as voltage dips, voltage regulations, voltage unbalance and voltage harmonics have a greater impact on their industries. Power quality has a negative impact on the effective functioning of industries. In other words, as the authors in [288] explicitly state that "sensitive industries suffer economically from power quality as critical process loads are being adversely affected by electromagnetic phenomena". Hence, regarding being sensitive to power quality, specifically voltage dips and system frequency, the following quotes from two respondents confirm the previously stated views:

"We have a specific concern with regards to voltage dips. If we had harmonic problems (luckily, we don't) from the supply or other customers, that would be an issue. We also keep a very close eye in terms of system frequency because we have our own generation units which are very sensitive to variations to grid frequency" (Participant 1);

"During rainy season with thunderstorms in the vicinity of the network, we experience power dips and cannot buy equipment that is too sensitive to dips. For instance, on one of our Kiln lines some of our equipment installed is DC VSD for our DC motor and every time we experience a voltage dip on the network, they trip, and this interrupts the process" (Participant 3).

In addition, the recorded response was also in line with the literature overview that power quality has an impact to users as a consequence of not managing compatibility in PQ (Par. 2.3.2; par. 2.6). This is regarded as a potential operational or business risk to industries, due to overlapping of system disturbances and their levels of equipment immunity, for which certain users may not have sufficient control measures. This view has also manifested in related response from the interviews:

"But there are some old installations that might not have protection against single phasing although I know it supposed to have it. So, we have old equipment that might not be protected against all types of power quality disturbances" (Participant 5).

Voltage quality problem occurrences as the next code are discussed next.

Voltage quality problem occurrences

The perceived occurrences of voltage quality problems relate to the frequent occurrences of power quality activities, which are likely to have a significant impact on the ability of industries and commercial customers to operate normally (Par. 2.3.2). An overview of the responses about the typical voltage quality issues led to a classification of responses on the following PQ parameters:

i) Voltage Dips

All the respondents in this study revealed that they frequently experienced voltage dip events, and this was regarded as a potential risk to their operations. Some of the responses made regarding the occurrence of voltage dips, included, amongst others, the following quote:

"Yes, we do experience dips. We have a lot of seasonal power dips during rainy season with thunderstorms in the vicinity of the network, we experience power dips and ...." (Participant 3).

The account from the preceding respondent was supported by another closely related response from another respondent who remarked: *"Yes, our biggest concern is dips, so if we have a voltage dip event that stays on the network for 800ms, we will lose the plant or portion of it . ..."* (Participant 1).

Occurences of voltage dip events as alluded to by all the respondents, these particular responses were consistent with the literature review and alongside the remarks made by the authors in [18], [77], [82], [84] that voltage dip events are by far considered the most frequent power quality event responsible for causing all manufacturing downtimes in industries.

From a South African point of view, the rate of voltage dip occurrence has also been attributed by the fact that the electrical infrastructure predominantly consisted of overhead lines that are exposed to various disturbances [17]. This viewpoint is also consistent with findings in [84], that many of the voltage dip events in South Africa typically occurred during lightning seasons. They further observed that as far as large industrial customers is concern, voltage dips of less than 30% to 40% in magnitude, and a duration shorter than 150ms, have a high probability of occurring on HV networks; however many customers are not affected by these events.

This last statement by the authors in [84] forms the basis on which customers could implement voltage dip ride through capabilities for their sensitive processes. Incoherence with this statement thereof, some respondents indicated the importance of implementing voltage ride through capabilities as measures to safeguard their operations:

"Yes, we have, as far as we can. If we are at the limit where equipment damage is possible, there is not much that we can do. However, for those events that we should be able to survive, it's not much safeguarding equipment, but safeguarding production so we have implemented voltage ride through capabilities on most of our motors and VSD's" (Participant 1);

"Yes, as I said, the whole process may stop depending on the depth and duration of the dip. Some of the smaller dips we have a ride through capabilities" (Participant 3).

ii) Voltage unbalance and voltage harmonics

In terms of voltage unbalance and voltage harmonics occurrences, all the respondents mentioned that they did not experienced any problems with these parameters, no further account was provided.

Voltage magnitude (voltage regulation)

Regarding voltage magnitude, three out of the seven respondents mentioned that they frequently experienced problems with the regulation of the voltage magnitudes at their PoC's. Concerning this, the literature review (Par. 2.5.2.1) put emphasis on the importance of maintaining variation of the voltage magnitude within prescribed limits, as this may cause damage to electrical equipment. So, the responses echoed by the participants regarding occurrences of voltage magnitude regulation problems provide an important indication that power quality is an important aspect of the electrical network that should be proactively managed, in order to maintain appropriate quality of voltage supply to customers. The code power interruption occurrences are discussed next.

Power interruption occurrences

Occurrences of Power interruption is the fourth and last code assigned to the category of perceived PQ experiences. Regarding power interruptions, a closer look at the literature study revealed a close association with the description of the term reliability.

Reliability is a concept that addresses the longer-term adequacy of the electrical system to supply power to its customers as well as with the shorter-term security of supply [289]. As a result, adequacy is specifically associated with the planning of the network, while the security of supply is linked with the operation of the network. These two aspects of reliability are further defined, respectively by the same authors in [289] as "*the ability of the system to supply the aggregate electric power and energy requirements within current ratings and voltage limits, taking into account planned and unplanned component outages*" and "*the ability of the system to respond to disturbances arising within that system*".

As in [290], it is explicitly stated that not all interruptions have the same level of impact, so the degree of severity is of significance to the particular customer facility that is impacted. , in the case of the current study, three of the seven respondents indicated that they frequently experienced power interruption events, which had a negative impact on their operations.

However, amongst the four respondents who indicated no occurrence of power interruptions, one respondent reported since they had several points where they took supply from the utility, occurrence of power interruptions was not a problem for their larger intake points, but they frequently experienced interruptions on their smaller points connected on rural networks and said **"No. For the large pumps, we don't experience power interruptions, but we do experience interruptions on pumps located on rural lines" (Participant 7)**.

From this particular response, it can be inferred that customer operations that are connected on rural lines are at increased risk of experiencing PQ problems, and this may require good electric detective intelligence to determine root causes of such PQ problems. In so far as the occurrences of power interruptions, over and above the preceding responses herein, responses about the occurrence of power interruptions were also classified according to the following severity levels: frequency of interruption occurrence, duration of interruption and time of interruption. These aspects are discussed below.

Frequency of interruption occurrences

A consensus response was given where all the respondents mentioning that in terms of power interruptions, the frequency of occurrences was of specific concern. Examples of some of the responses that were mentioned by the respondents are:

"Yes, the frequency of power interruptions is of concern. Although the probability is low, the consequences thereof is high. Because once we go down, it will take us days to normalise the plant" (Participant 1);

"Yes, it is a concern. For the past few months, we had a couple of outages which is of concern. There were issues with a transformer at the Eskom substation and three repair works were done in three successive weeks for the same problem, each costing us about 24 hours of production" (Participant 3);

"Yes, as previously explained, we cannot afford to have power interruptions due to the safety concerns to the people working underground in the shafts, resulting from explosions of the methane gas" (Participant 4);

"Yes, at one of our pump stations at. ... ... The last two interruptions occurred without prior notice. The supply went off and we were not informed. But it might have been due to communication problem from our side I am not sure, maybe Eskom informed our head office who then forgot to relay the message to us, but it was an interruption without notice." (Participant 6).

Duration of the interruption

Duration of power interruptions is amongst the concerns voiced by the respondents, as having a detrimental effect on their operations. Some of the responses, as articulated by two of the respondents are:

"At times we would have to plan around production schedule where we plan outages or high-risk activities. , together with the utility would plan specific activities to take place at a low-risk period for the factory but there is never a no risk"; "so we can

never plan to run, for instance, without both incoming lines at our specific points of supply. We can't run for a month in a high-risk condition such as N-1, but we can try and plan the condition to coincide with a time of reduced load in the factory and reduced production so that if we lose the remaining supply, the impact will be less" (Participant 1);

"Yes, the longer the interruption, the higher is the risk. Should the supply be interrupted, it could take up to 12 hours to fully bring the shaft to normal, and just on the safety aspect. This is because we have to travel a few kilometres underground, to ensure that the ventilation system is working properly before we could safely send people underground to begin production" (Participant 4)

Time at which the interruption occurs

The third and last aspect of concern mentioned by the respondents regarding power interruptions is the time at which an interruption occurs. Although some respondents acknowledged the fact that not all interruptions can be planned, it is important for the utility to have measures in place to minimise the occurrence of unplanned interruptions and that those interruptions that can be planned, be communicated in time with customers.

Examples of the responses mentioned are:

"The timing of an interruption does matters so we need to be involved and it is communicated to us which is typically at our Bi-monthly meeting" (Participant 1);

" It is always of concern since our production line is a continuous process. For planned outage or emergency repairs communicated to us timeously, we can scale down our load but keep the continuous process running" (Participant 3);

"In terms of planned interruptions, we normally plan it along with when Eskom do their maintenances so to be on the safe side. We also time our maintenance typically on Sundays, when there is no production or when the production is very low. In that case, the risk is much lower for us as there are very few people underground. If it is an unplanned event or breakdown maintenance that has to be carried out at short notice, and Eskom need to urgently do some repairs, this can be negotiated between us and Eskom. So, we would obviously come to the party and understand that urgent repairs have to be done so as to prevent further breakdowns" (Participant 4).

Similarly, the other two respondents from a similar sector gave similar views and one such response is:

"This is somehow a difficult one because the timing is always wrong. Reason being the utility's high season is our low season and vice versa. When the utility utilises its low demand season for the interruptions to do maintenance or whatsoever, that for us is always our high demand season. So that timing is never right. But we do understand that the utility has to maintain the network and we try to accommodate as far as possible" (Participant 6).

Although the preceding responses made more emphasis on timing of interruptions mainly for planned events, it is evident from the responses thereof that regardless of the basis of the interruption, it would seem important that random occurrences of interruptions be closely managed in order to minimise faults on the network and to ensure that customers are able to withstand interruptions with the least possible disruptions.

6.3.4.4 Analytic memo 4: PQ risk to operations

As outlined in the literature, power quality is known as a major contributor to operational risk at both the distributors and users of electricity. To the user, PQ has greater consequences, including huge financial impact, particularly to industries (Par. 2.6). In this study PQ risk to operations refers to the potential risk that emanates from PQ problems, and that result to a significant impact on the respondent's operations. The specific codes assigned to the category of PQ risk to operations are Loss of production; overtime costs; safety risk to employees; mine flooding with water; damage to equipment; risk of explosion; impact to water quality; and water hammering to infrastructure. The descriptions given by the respondents relating to the first code are given below.

Loss of production

The first code assigned to the category of PQ risk to operations relate to the loss of production. According to the literature review, loss of production is concerned with the penal outcome as a result of non-delivery or products, which cannot be manufactured because of an equipment breakdown due to poor power quality (Par. 2.6).

In this study, loss of production by the respondents play an important role in the realisation of its overall impact, and as has been stressed throughout this research report. Power utilities are required to effectively manage power quality in order to proactively minimise the technical impact, so as to contain the operational risk to customers.

Industrial customers are expected to manage their production on a variety of electrical network settings with a range of PQ anomalies which can cause breakdowns and are often required to deliver their products or services regardless of the power that is delivered by the utilities. The author in [18] reviewed the literature on the impact of power quality to industries and revealed that many industries suffer financially due to the loss of production caused by poor power quality.

Results from the qualitative analysis of this study confirmed the findings by this author and other views expressed in the literature. All the responses indicated to a resulting loss of production due to power quality:

"If we experience a voltage dip that is outside the limit resulting in us losing a point of supply, we could incur losses of around R 50 Million just on one point, for an outage on all the points, the value will even be 10 times more. The concern will be production loss as a result of equipment damage and not much about the equipment itself" (Participant 1);

"There are various plants in our site, doing various activities. Should the granulation plant trips, we lose about R 2 Million per hour. Subsequently, if we trip Nitric Acid 2, and unable to restart within 12 hours, during that time, we will incur production losses" (Participant 2).

Another response, although not to a specific PQ parameter, expressed concerns due to power interruptions,

"If we have a voltage dip, we can most probably recover, and we may not have a loss. If we have an interruption for more than an hour, we would start losing a day's production of gold. I cannot quantify the monitory value, but we will definitely suffer financial losses due to the loss of gold that we could have produced" (Participant 4).

Another respondent mentioned: *"We will definitely incur a financial loss due to loss of income as we wouldn't be selling water at that time"* (Participant 6).

Although the respondents in this study came from different sectors, what seemed to be evident is that the respondents were consistent with each other in that they would all experience loss of production should a PQ event interrupt their supply.

These responses linked up with the argument from the literature study that power quality disturbances have a direct impact on loss of production to a wide range of industries (Par. 2.6), as indicated in [114], [115]. Utilities have the obligation to maintain voltage quality within minimum standards at all points where customers connect and for that reason, emphasis and steps that serve as a measure of control to improve the performance of power quality, which, consistent with the literature overview, can be regarded as the main and focal point of power utilities, which is also consistent with the aims and objectives of this particular study.

Overtime costs

Apart from costs incurred due to loss of production, overtime costs resulting from PQ events came to the revelation. As the second code assigned to the category of PQ risk to operations, overtime costs were identified by the respondents as one of the operational risks posed by power quality. From the literature review, it has been shown that the impact of voltage waveform events, through a voltage dip performance at a point of connection can cause computerised process controls to be regularly interrupted (Par. 2.3.2; Par. 2.4.1). It is also revealed from the literature study that not only production is interrupted, but man-hours are lost in industries and the consequential damage to the economy becomes evident.

In the case of the current study, two of the respondents mentioned overtime costs as one of the additional costs likely to be incurred due to equipment failure from PQ events: *"Depending on the power quality event, we may also incur costs due to the risk of equipment failure. There will also be overtime cost but the monitory value that makes the most impact is primarily the production of gold" (Participant 5).*

The other response that gave amongst others, a similar response said: *"Should a PQ event interrupts our production, we will definitely incur financial loss. The losses may be categorised to include: cost on equipment replacement, overtime cost on labour,"* (Participant 6).

These responses, although only from two respondents, are important to the category of PQ risk to operations and, important to this study as it point towards the fact that economic losses due to PQ events are huge across all industrial sectors. The code safety risk to employees is discussed next.

Safety risk to employees

Although not reviewed as part of the literature, safety risk to employees is one of the third code that emerged in the category of PQ risk to operations. It was described by the respondents that PQ events are likely to pose threats to human lives, given the nature of their operations.

Three of the respondents indicated the importance of minimising the impact of PQ events, due to the potential risk to their employees that may emanate from unexpected plant shutdowns. As one respondent explicitly mentioned, *"There will also be safety risk to workers due to the explosive nature of our plant";" this is a risk for us as we lost production and risk to the workers who had to clean the blocked lines as it is explosive due to the accumulation of gasses"* (Participant 2).

The other two responses came from respondents of the same industrial sector, as the first one alluded: *"As previously explained, we cannot afford to have unexpected power interruptions due to the safety concern to the people working underground in the shafts,"* (Participant 5). The same respondent further went on to state: *"The first would be a safety risk of people working underground and the second would be the financial aspect. So, the moment there is an unplanned outage, even if it is minutes, you could have a risk of people getting trapped in the shaft, people underground without proper ventilation…"* (Participant 5).

The other responded indicated the same impact and described:

"So, if it happens more frequently, it will be disastrous for the mining industry. This is because the process takes a while to be restarted, so production is lost and there is also a risk to workers going underground, and a sudden loss of supply would result in possible injuries and loss of lives" (The participant 4).

These responses demonstrate the stringent safety requirements that characterised these specific industries and are consistent with the statement made by Anglo American in [291] that explicitly stated that "Every employee at Anglo American has the right to go home safely at the end of every day. It is our role to make that right a reality."

This statement, in support of the responses made by the respondents in this study, to a large degree implies that the safety of employees are the main priorities in these industries and that every effort is made to achieve the objectives of zero harm by managing amongst others, their activities in a manner that eliminates incidences and minimises risk of injuries and loss of life. The preceding viewpoints that were expressed by the respondents, together with supporting citation from the publication in [291], has some relevance to the current study, in that it highlights the importance of ensuring that acceptable levels of power quality are delivered at points of customer connections.

Damage to equipment

Risk of equipment failure or equipment breakdown due to power quality events that are out of limits is the fourth code assigned to the category of PQ risk to operations. Needless to say, that power quality is usually characterised in terms of the effect on the supply voltage, its manifestations are evident through transformer issues, such as noise, additional heat or premature failure and unexpected equipment shutdown.

Literature revealed that customer establishments, particularly industrial customers find reasons to pay more attention to power quality, as they can no longer endure non-delivery of products, which cannot be manufactured because of machine breakdown due to poor power quality [292], [293]. Consistent with the literature review, respondents in this study indicated that they would incur equipment breakdown due to events of PQ, and as one particular respondent alluded:

"Some of the other risks, depending on the frequencies and depth of the voltage sag/dip are incidences of damage to equipment such as the VSDs. So, if such a breakdown were to occur, it may take longer as we will have to repair the breakdown then restart the process"; "If a PQ event were to occur, we would incur a loss of production and possible equipment breakdown" (Participant 3).

The respondent further mentioned the impact to other adjacent equipment on their production processes due to the breakdown of equipment and said: *"If the Kiln has to be off for two to three hours due to equipment breakdown resulting from PQ event, then the Kiln will have to be re-heated and ramped up to full production"* (Participant 3).

Critical to the response given by this respondent is the fact that their operations comprised of processes that required continuous operation and any anomalies to the supply would have a negative impact to the process, *"This is so because the process that we run is a continuous process. If we have a power outage or power dip, it affects the process, which means then a long time to restart which may result in loss of production"* (Participant 3).

Another response in particular, although not having much concern about equipment damage, mentioned this in terms of the impact it would have on their production and said: *"The concern will be production loss as a result of equipment damage and not much about the equipment itself"* (Participant 1).

Regardless of the emphasis on loss of production by the respondent, it is important to note that equipment failure or breakdown is mentioned as the resulting cause of the losses to be incurred and the response is consistent with the response from other respondents who consistently mentioned damage to sensitive equipment due to a variety of power quality problems, which is also consistent with the literature review regarding the impact of poor power quality to customers (Par. 2.6). In line with the code of damage to equipment, two associated codes that were assigned to the category of PQ risk to operations came to the fore and are discussed next.

Mine flooding with water and water hammering to infrastructure

The fifth and sixth codes assigned to the category of PQ risk to operations relates to mine flooding with water and water hammering to infrastructures. These codes were to a large degree, associated with the code of risk of damage to equipment. Each code was said to be unique to a particular respondent or pair of respondents with a similar context of operation in terms of industrial classification.

The common attributes of the codes are that each code was mentioned by the respondents to be the contributing cause of damage to equipment, which could occur as a consequent of a PQ event. , the possibility of a Mine flooding with water was mentioned by two of the seven respondents who described the impact as:

"So, in terms of equipment, one safety aspect which I have not yet mentioned is that we could suffer equipment damage due to flooding from underground water" (Participant 4).

The other response that was made in relation to this code had a similar account: *"For more than a day that we don't have power, we start getting part of the mine flooded with water and we start losing underground equipment for pumping. Although we do have emergency equipment to evacuate people, it would be disastrous for a mine or a shaft not to have power for an extended period as we start losing some of the infrastructures and we would spend millions repairing what would be damaged by the flooding"* (Participant 5).

Likewise, two of the respondents were explicit in describing a similar consequence of damage to equipment, which served to describe the account given on the code of water hammering to infrastructure:

"The problem with a PQ event causing a sudden interruption of supply is that if we don't stop the pumps prior to the interruption, it will cause water hammering to our infrastructures which may cause pipes to burst to result in extra repair cost as well as interruption of water supply to our customers" (Participant 6).

The other respondent gave a similar response and said: *"So our main problem is the sudden trip of the supply. The problem is that the water will flow backwards due to loss of pressure in the forward direction. This could cause, for instance, water hammering to our infrastructure, resulting in damage to equipment in the sense that if the reflex valve is not operating correctly, you could have the pumps and motors running in reverse direction, so a mechanical failure may occur"* (Participant 7).

It is evident from the views and account given by the respondents that regardless of the type of industry that the respondent belongs and the manner in which there are different factors contributing to the resulting damage to equipment following a PQ event, of significant importance is the fact that each of the different factors eventually does cause equipment damage. , in line with the objectives of this research study, having a healthy electrical network, with the adequate policy of PQ monitoring and PQ management, particularly at the distribution level, is essential to minimise the occurrence of PQ problems. The next codes assigned to the category of PQ risk to operations are discussed below.

Impact to water quality and risk of explosion

The impact to water quality and risk of explosion are some of the codes identified during the analysis and assigned as the final codes on the category of PQ risk to operations. Regarding the code impact to water quality, one respondent made a remark on the negative impact that power quality events that can result in unexpected interruption of their water purifying process could have on the quality of their product, in other words, the quality of drinking water in the water supply system, and said:

"Yes, it is a risk. If we have a power problem or outage on the purification plants, resulting in everything coming to a standstill, then the purification process could be affected by that" (Participant 7).

The respondent further described the process: *"So we have dosing facilities that use the purifying chemicals, and we have a process that runs continuously and smoothly. So once interrupted, the levels of water in the settling ponds and the number of chemicals that were dosed is impacted which can affect the water quality"; "This because we have a stream of raw water flowing in a canal, and you will have a dosing pump, which doses a certain amount of chemicals. So, if you trip the supply, the dosing chemicals will trip immediately due to the stopping of the pump. But the canal will have a hydraulic flow, so you will have a volume of water that goes through that was not dosed"* (Participant 7). The preceding remarks by the respondent highlighted the importance of safeguarding water resources as well as to ensure that the quality of drinking water is safe for consumption.

An example hereof is: *"if it so happens that there is water in the system that was not dosed with chemicals and end up in the reservoir and the quality is not good, then we will have to dose in the reservoirs with HTH which then becomes extra efforts and costs"* (Participant 7).

This particular emphasis on ensuring good quality of drinking water that is safe for consumption, also find support in the statement from the Blue Drop report in [294], which state that "Access to sufficient water is a right as enshrined in the Constitution. However, it cannot be said that this right is realised if the quality of that water poses a health risk for human consumption."

From the remarks and response from the respondents, it is common knowledge that all water sources need to be protected and preserved. It follows that drinking water also needs to be properly sanitised, as it is being polluted by contaminants. This is also consistent with the objectives of this particular study to ensure a good supply of electricity by utilities, through technology interventions in the management of PQ to customers, which would then enable the customers to focus mainly on their operations and have less to worry about the problems of power quality.

Concerning the final code assigned to the category of PQ risk to operations, namely risk of explosions, two respondents provided valuable information regarding the possible impact of PQ events in their industries. One respondent mentioned long shutdowns to their plant due to unexpected interruptions which further posed the risk of explosion.

They mentioned having chemicals that if not safely controlled in the production lines due to unexpected shutdowns, explosions may occur in the plant and said:

"We had an over frequency event trip at the plant about two weeks ago which occurred at night between 11:00 PM and 12:00 AM and we didn't have all the resources in the plant and subsequent to that, the plant was off for over a week due to blocked Ammonium nitrate lines. This is a risk for us as we lost production and a safety risk to the workers who had to clean the blocked lines as it is explosive due to the accumulation of gasses" (Participant 2). This particular response finds support in [295] that ammonium nitrate possesses a potential lethal downside in that if it comes into contact with an open flame or other igniting sources, it explodes violently.

The explosive force occurs when solid ammonium nitrate decomposes very rapidly into gasses. Confinement or gas phase reactions appeared to be the important parameters for the initiation of the explosion of the ammonium nitrate at elevated temperatures, which is consistent with the account and concerns given by the respondent in this study. Another respondent raised a similar concern on the specific risk to workers and warned about the consequences of lack of ventilation due to power interruptions:

"In terms of the ventilation equipment, these are associated with the lives of about 8,500 people that are underground at any given time. So we have methane gas that must be ventilated at all times and any problems with the power quality resulting in loss of supply could elevate the methane resulting in explosions and this may have a direct impact on the lives of our people underground" (Participant 4).

The significance of the preceding responses, also consistent with the responses from the preceding code, lies therein that good quality of electricity should be supplied to customers and it is imperative for consideration in this research report as one of the influences to utilities in utilising advanced methods of PQ monitoring, to support the management and enhance the performance required to maintain compliance.

6.3.4.5 Analytic memo 5: PQ risk mitigation measures

PQ risk mitigation measures relates to the extent to which the participants make emphasis in mitigating the effects of power quality, for power quality disturbances produced within their plant or from the utility's network. The specific codes assigned to this category are equipment compatibility; equipment rating; PQ-centred procurement approach; protection schemes; harmonic filtering; voltage ride through capabilities; starting methods and preventive maintenance. The descriptions given by the participants in relation to these codes are summarised below:

Equipment compatibility and equipment rating

The first code assigned to the category of PQ risk mitigation measures relates to equipment compatibility. From the responses mentioned regarding equipment compatibility, six of the respondents revealed that the equipment used for their operations were compatible with the PQ that was supplied at their PoC's. Amongst the responses given are:

"Yes, our equipment is compatible with the set limits but once or twice we do drift out and that is discussed in the bi-monthly meetings" (Participant 1);

"Yes, I believe that our equipment is compatible within the percent voltages at the 50Hz frequency" (The participant 2);

"Yes, our equipment is fairly compatible" (Participant 7).

In contrast with the above responses, one respondent indicated having old equipment that might not be compatible:

"Not for all equipment. I don't think we've got the specifications and details of power quality on most of the equipment. Most of them are legacy equipment, so I don't know if their spec would even be available. So, we don't know if they are compatible. So currently, we only look at the voltages and kA ratings" (Participant 5).

Although one respondent indicated that some equipment might not be fully compatible with the PQ, no failure or malfunctioning of equipment were reported by the same respondent, so in general, these responses were consistent with viewpoint from literature that indicated the need to understand the concept and requirement of equipment compatibility regarding the management of power quality in South Africa (Par. 2.3.1). In coherence with the literature overview, a response from one respondent indicated that failure to some equipment is an issue regarding compatibility to certain PQ disturbances.

"Yes, currently all our equipment is compatible. We do from time-to-time have issues of harmonics causing damage to our small VSD's. For larger VSD's, we do our own harmonic filtering so in summary, our equipment is compatible" (Participant 3). Concerning the response stated above, it would seem that the particular respondent implied that certain equipment is able to withstand PQ disturbances and others are not.

This particular response is also consistent with the literature study that in a typical population of 100 pieces of the same type of electrical equipment, even if it is not from the same manufacturer, not all the pieces of equipment will have the same level of immunity against the PQ disturbance (Par. 2.3.1). With a particular focus and emphasis on the unique South African context, utilities can manage their network to contain statistical variations of PQ parameters in order to achieve compatibility level, and this would enable reduction of operational risk to users of electrical equipment.

In terms of the second code for the category PQ risk mitigation measures, namely equipment rating, all the seven respondents indicated that their equipment was properly rated to operate according to the design network set by the utility. Amongst the responses that were recorded included:

"Yes, for sure they are properly rated. These refer mainly to the fault level rating of our equipment. We haven't had a situation where the fault current rating of our equipment is below the fault level rating of the grid" (Participant 4);

"Yes, I believe so. I can't think of a situation where we have incorrectly rated equipment. My biggest concern with equipment rating would probably be fault current rating but even in that regard, I think that most of our equipment, especially switchgear breakers are at least rated correctly within specifications" (Participant 5).

The responses above correlate with the literature overview and were noted as a compulsory minimum requirement as the aspect of fault level has a clear meaning and is relevant to the management of power quality. The next code assigned to the category of PQ risk mitigation is discussed below.

PQ-centred procurement approach

PQ-centred procurement approach entails a skilful and well-defined technical approach undertaken by large industrial users of electricity in the process of acquiring and installation of equipment, in order to realise the objectives of minimising the effect of PQ on the electrical network. In relation to the current study, industrial customers play an important role in enabling utilities to realise their efforts in reducing the effects of PQ on the network and, as has been emphasised in [18], [26], [33], large industrial customers are required to manage PQ disturbances within their facilities, by ensuring that functioning of installed equipment does not negatively influence the performance of power quality on the entire network.

It is imperative that any procured equipment and installation by industrial customers should have the least disturbing effect on the network. Results from the qualitative analysis revealed that the majority of responses related to the procurement and installation of equipment acceded albeit with reservations, to the importance of interacting with the utility when making decisions to purchase equipment.

"Yes. For the most part, it would be part of the specifications that go out for the purchasing of the equipment but most of the equipment we get can be configured to perform well within the PQ we have so it is more of the engineering conditioning we do and the configuration we do after the equipment is purchased" (Participant 1);

"Yes, for sure, we do consider PQ on our procurement. It is part of our design. As much as our existing equipment is compatible, if we want to buy more equipment for expansion, we get to the design of the equipment that we need, which must fit to our load requirement and fault level and then double check with our equipment supplier for what is specified, and we make sure that we are in line and that we can cater to our switchgear and to ensure that the equipment can work on the fault level as prescribed by the utility" (Participant 4).

These responses were to a certain extent in accordance with the requirement expressed by the respondents in the quantitative section of this study (Par. 6.2.3.1, Figure 47), regarding the interaction with customers by the utility when dealing with PQ issues.

Other responses from the participants indicated that they would inform the utility when making larger installations that may impact PQ:

"If we do fairly larger installations, we will do all our designs and double check with the utility for things like fault level for protection settings. This is because if I increase my installation, I will definitely increase my loading requirement which will also impact Power quality" (Participant 4);

"In 2009 we commissioned a new Kiln line with two mills and before construction, we engaged with the utility to inform them that our NMD will increase and we also indicated the type of supply we would require" (Participant 3).

The preceding response to some degree indicated consistency with responses that emphasised the importance of equipment compatibility as was also reported in the previous codes as efforts to limit the effect of PQ on the network.

Harmonic filtering and voltage ride through capabilities

Harmonic filtering and voltage ride through capabilities were amongst the codes that were assigned to the category of PQ risk mitigation measures. Harmonic filtering entailed efforts undertaken by the participant in limiting the harmonic content on the electricity network. As stated in the literature review, these efforts include the application of tuned filters to "trap" harmonics generated within the customer facility, which provides a low-impedance path for the harmonic currents from the harmonic sources (Par. 2.5.3).

In this study, responses that mentioned the application of filters to limit the effect of harmonics included:

"We also have power factor correction capacitors that are also tuned as filtering units with regards to filtering out harmonics in our system but that is where we have rectifier transformers, mostly for our own internal generated harmonics and not necessarily network harmonics" (Participant 1).

The same respondent also held the opinion that harmonic filtering can possibly be one of the mitigation measures undertaken through the implementation of smart grid technologies: *"I suppose though that you can also build something that automatically switches filter banks if you measure harmonics at a specific level"* (Participant 1).

One respondent also acknowledged that since harmonics could either be generated from the network side or within their facility, it was necessary to limit the impact on the network and said:

"As indicated earlier, on the VSD's, we have capacitor banks that are tuned to do harmonic filtering. Some of the harmonics can either be generated from our side or from the network for that we have harmonic filtering to minimise the impact on the network" (Participant 3). Another respondent who also mentioned having harmonic filters indicated: *"On our larger motors, we also have harmonic filters for the thyristors drives"* (Participant 4).

These particular responses were supported in the literature that advocated the need to address harmonics (Par. 2.5.3), as one of the strides for industrial power users to meet IEEE standard. The reviewed literature indicated that the IEEE 519 is a standard developed to guide utilities and their customers in order to limit harmonic content so as to provide better power quality for all users. These responses, even though not from all respondents, indicated the need to understand the complexity of the dynamic nature and challenges of mitigating harmonics as part of the management of power quality.

The views and opinions expressed by the respondents were also consistent with the views by the authors in [61], [104], who advocated the need to implement harmonic mitigation to limit the effect of poor quality and also indicated that various types of harmonic filters were available and depending on the application and economic viability, power utilities and industrial users can mitigate harmonics on the network.

The next code assigned to the category of PQ mitigation measures relates to voltage dip ride-through capabilities. Incoherence with the literature overview (Par. 2.5), responses from the respondents indicated that voltage dips were the most problematic power quality issues impacting their industries, as also proven to be the most aspects of power quality by the authors in [77], [84], [280], and [295]. In order to reduce the consequences of voltage dips, two strategies are considered possible in the literature study; the first can be accomplished by increasing the voltage dip immunity of sensitive equipment and the other, according to [297], is the improvement of the utility's network offered by network-connected distributed generation, which proves to be a balancing solution.

Consequently, three responses from the respondents indicated the implementation of the approach of increasing the voltage dip immunity of their sensitive equipment:

"For those voltage dip events that we should be able to survive, it's not much safeguarding equipment but, safeguarding production so we have implemented voltage dip ride through capabilities on most of our motors and VSD's" (Participant 1);

"as I said, the whole process may stop depending on the depth and duration of the dip. Some of the smaller dips we have a voltage ride through capabilities but mostly, the one Kiln line with sensitive equipment will trip every time we experience a large voltage dip" (Participant 3).

The last and final response regarding the mitigation of voltage dips indicated the use of UPS installations: *"As a control measure, we have started the process of installing UPS systems into our PLC which will ensure we have a ride through capabilities for voltage dips produced from the utility's network"* (Participant 6).

These responses, though consistent with the literature review on the need for users to implement strategies to increase the voltage dip immunity of their sensitive equipment, of particular interest for further explanation is the response from (The participant 6), who indicated specifically, the use of UPS systems for the voltage dip ride through capabilities on their PLCs control units. This response is consistent with remarks in [280] that PLCs are some of the components most vulnerable to voltage dips on the electricity network. An interesting observation from the response is the use of UPS systems for the mitigation measures.

According to the same authors in [280], UPS systems may not be regarded as adequate means to protect PLCs against voltage dips. The authors argue that either Constant Voltage Transformers (CVTs) or Dynamic Sag/dips Correctors (DySCs) are the optimum solutions to protect PLCs and the associated components against voltage dips.

The author further makes contrasting arguments that given the associated cost of implementation, these solutions might not be cost effective for the majority of users of electricity. Tied to the preceding views, in relation to the current study, these should be amongst some of the factors to be considered in influencing utilities to utilise smart grid technologies to enhance the management of power quality.

Protection schemes and starting methods

The next code assigned to the category of PQ risk mitigation measures is protection schemes. It relates to the technical activities undertaken to protect individuals and electrical equipment. In the case of equipment, the intention is to minimise the damage and expense caused by faults and adverse power quality abnormalities. In power system protection, relays are used to detect and act on abnormalities and as such, the IEEE defines protective relays as "relays whose function is to detect defective lines, equipment or other power system conditions of abnormal or dangerous nature and to initiate appropriate control circuit action" [298].

A different interpretation of the above definition would mean that relays detect and locate faults by measuring electrical quantities in the power system which are different during normal and intolerable conditions. In this study, responses from the participants indicated implementation of a range of protection measures to safeguard operations: *"On our supply breakers on the incomes, we have protection settings for protecting our network and within the plant itself, we have protection settings on specific equipment"* (Participant 3).

From the literature, it has been revealed that electrical loads are usually sensitive to voltage variations which can cause severe load damages whenever high voltage fluctuations arise. It follows that specific loads can be protected using specific relays. Incoherence with the literature, responses that mentioned having specific relays for protection included the following:

"Yes, we have, as far as we could. We have protection in terms of over/under voltage, over/under frequency and motor protection units" (Participant 6);

"Yes, we have protection settings for that. I am not sure of the specifics, but I would say we have protection against over/under voltage, which we would definitely trip. Even over/under frequency, we would trip"; *"we also have protection relays against phase failure as well as phase rotation relays"* (Participant 7).

Given that all respondents indicated having predominantly motor loads, it was interesting to note that only one respondent highlighted the importance of voltage unbalance protection and said: *"We have prioritised motor protection for most of our large motors, protecting against voltage unbalance and over/under voltage"* (Participant 5).

The same respondent highlighted the lack of adequate protection for some equipment and stressed: *"but there are some old installations that might not have protection against single phasing although I know it supposed to have. So, we have old equipment that might not be protected against all types of power quality disturbances"* (Participant 5).

All of the above-stated responses pointed toward the importance of protecting equipment for a variety of power quality disturbances occurring on the network. Needless to say, that these responses relating to voltage unbalance protection, even though from only one respondent, were consistent with the viewpoint from literature (Par. 2.5.2) that indicated the importance of protecting rotating loads against voltage unbalance.

The significance of the responses relating to protection schemes in the context of this research was to determine the ability of industrial key customers to safeguard their sensitive equipment against different levels of adverse power quality events. In so far as voltage dips, protection schemes can be designed to minimise both the depth and the duration of a voltage dip, which require proper discrimination and coordination of the protection settings as an important aspect of managing the voltage dip performance, in line with the objectives of this study. The next code assigned to the category of PQ risk mitigation measures relates to starting methods. In the research, the participants mentioned that the implementation of starting methods may be regarded as interventions to reduce the effects of voltage dip events produced within their plant.

One of the participants mentioned that installation of soft starters was some of the measures undertaken to limit the production of voltage dips: *"We do have some measures in place to contain dips that can be produced within our plant. We have installed soft starters for our large motors to limit the starting current which can cause dips on the network. We also have VSD's as well to control the speed of the motors"* (Participant 2).

Some of the participants described having starting procedures as methods of starting their loads one at a time so as not to cause dips: *"Yes we do have measures in place. The way we start up the plant is done sequentially we do not put a huge load at once that may cause dips"* (Participant 3);

"To a certain extent, we do have measures in place. The procedure and the PLC's are such that we do not start all the pumps at once, which may have an influence on the supply" (Participant 7).

What is evident from the above responses is the fact that these responses from respondents on starting methods coincided with the views in [69] that among the PQ problems, voltage dips constitute the most frequent and prime factor that affect the performances of induction motors. Equally, these responses are further consistent with the viewpoint in [83] that voltage dips due to switching (on or off) of large induction motors, especially across-the-line, will affect plant operations causing adjacent motors on the network to trip, either by under voltage or overcurrent relays. Methods of minimising inrush current during starting of motors are emphasised in reducing voltage dip intensity. Stated differently, starting methods play a critical role in alleviating the production of voltage dips by large industrial customers.

Preventive maintenance

The final code assigned to the category of PQ risk mitigation measures relates to preventive maintenance. Preventive maintenance refers to the ability to handle physical assets in an optimal way in order to fulfil production goals whilst considering the risk of failure [299], [300]. The definition of preventative maintenance is in accordance with the definition of asset management given in [301], who further states that a good preventative maintenance supports asset management. From a reliability and power quality viewpoint, the reason for preventative maintenance is evident, that is to increase the reliability of equipment and to improve power quality by reducing the probability of failure.

More specifically, in relation to this study, preventative maintenance refers to the ability to lessen the effect of voltage dip by ensuring that relevant equipment on the network is proactively maintained. Responses that regarded preventative maintenance as means to manage PQ, specifically voltage dip events included:

"For the most part, in terms of being proactive, it would be through equipment monitoring and doing equipment maintenance on time according to the schedule…" (Participant 1).

Two of the respondents mentioned maintenance of overhead lines to prevent faults: "*So in terms of our 6.6kV overhead lines, we also have regular maintenances and bush clearing so as to reduce the number of faults that could be caused by trees"* (Participant 4);

"We also look after our overhead lines although this is not done formally so we don't have many internal procedures to do these regular maintenances but the guys do pay attention from time to time and if there are risks, they would get a contractor to say please clear the lines" (Participant 5).

These views show commitment by the respondents in support of the efforts to manage faults that give rise to PQ events on the network. The responses were further consistent with the viewpoint from the literature that indicated the importance of undertaking preventative maintenance of electric power networks in order to reduce the likelihood of failure or significant degradation, which often causes a decrease in PQ performance.

6.3.4.6 Analytic memo 6: PQ-based premium

PQ based premium is the only code that was assigned to this category; hence the same name is used synonymously for the code and the category. PQ based premium entail having a contract between the utility and the customer, where the customer can specify the minimum level of power quality needed within the contract [302]. For a higher subscription, a form of guarantee is given by the utility of a minimum level and if this level is not achieved, financial compensation is paid by the utility to the customer concerned. As Hulshorst et al. in [302] further pronounced that price and quality are complementary to each other, the authors further state that together, these define the value that customers derive from consuming electricity.

For the customer to avoid high costs of equipment failure, an electricity supply of satisfactory quality has to be obtained and that their electrical equipment should be capable of functioning as required when slight disturbances occur. Therefore, consistent with the preceding viewpoints, four respondents in this study held the view that if utilities were to guarantee acceptable quality levels at their connection points, they would pay for such PQ based premium, as one respondent explains

"Yes, we would pay. I think we are actually doing that already. In terms of outages specifically, we are on premium connection because we cannot afford outages, therefore we do the doubling up and we pay for the extra supply so that we minimize the probability of unplanned shutdown and also allow the utility to do the unplanned outages without us being interrupted. So, I think we are already making that decision." (Participant 1).

The same respondent further stated that they were in discussion with the utility to relocate some of their operations from problematic PQ areas: *"We are also making some investments decisions where we are engaging with the utility to move some of our points of supply away from problematic areas where there is a lot of incident's and failure, so the answer is yes, we would pay."* (Participant 1).

Other respondents also held an equally similar view and said: *"Yes, we would. It is an engagement process between us and the utility. If it is of benefit and is really a payback for us, then yes. If Eskom meets the minimum requirements then there is no need but if spending money is to improve our PQ on the plant, then we would pay."* (Participant 2);

"Yes, we would pay more. But I am not sure if the utility can guarantee that. Looking at all the production losses we incur, it would be a good financial payback if we were to be guaranteed reasonable PQ" (Participant 3).

One final respondent remarked that his view is that any large consumer of electricity is likely to do their utmost best to have the best quality of supply available: *"In my opinion, any large consumer of electricity, depending on their operations, they will do everything in their best to have the best quality of supply available to protect their assets or machinery against damage which may affect their production. So, I think that we are paying more already to ensure that the power quality enables us to run our production. But then again, if there is a cost benefit, in other words, if improving power quality will result in us improving our profit, then there is no doubt that we can pay. So, the answer is yes, provided that the cost to improve the quality does not take us out of business, and that this will result in us having fewer disruptions"* (Participant 4).

The responses seem to be in coherence with the remarks in [302] that premium power option is amongst the guaranteed power quality contracts offered by Eskom to its large customers. Premium power quality-based contract provides the customer with a better power quality than can be offered from the existing network, where Eskom make additional investments on the network or on the customer side, which then guarantees the customer an improved power quality at a cost. Preceding viewpoints from the respondents, along with the remarks given by Hulshorst et al. in [302], are in line with the objectives of this study, to determine the extent to which South African utilities can benefit from using smart grid technologies for their network operations.

6.3.4.7 Analytic memo 7: PQ measurement philosophy

The category of PQ measurement philosophy was used to group all codes identified in relation to the monitoring and control of power quality issues. As outlined in the literature review, the monitoring and controlling of power quality issues are becoming more important in order to maintain power system stability, the need for appropriate techniques to monitor the various power quality issues was regarded as an important aspect of managing power quality. the following eight codes were assigned to the category of PQ measurement philosophy: Importance of PQ measurement; Awareness to smart grid technologies; PQ on SCADA; synchronised measurement of PQ;

Facilitating PQ mitigation; load switching capabilities; Early detection of anomalies; and real-time systems. The descriptions of the account given by the respondents regarding the codes are given below:

Importance of PQ measurements

Power quality measurement is the first code that was assigned to the category of PQ measurement philosophy. Regarding measurement of PQ, the majority of responses in this research report were recorded that viewed the importance of PQ measurement as being representative of the fundamental aspect of power quality management, as it enables them to identify power quality problems, avert downtimes and increase profitability: *"Yes we do PQ measurement. As also mentioned earlier, we have a section that does the PQ monitoring (hardware and meters) as part of our PQ management system."*; *"It is important to do PQ measurement because there is a direct consequence should we go out of limits"* (Participant 1).

The above quotes clearly indicate that PQ measurement is extremely important in the management of power quality and is in accordance with the main requirement of managing PQ as discussed in the literature study (Par. 2.5.7; par. 3.3). Consistent with the responses given by the participants, the importance of PQ measurement at customer facilities was emphasised by the authors in [18] and described the objectives of PQ monitoring and measurement being to enable diagnosis of incompatibilities between the utility's network and the customer load. This has also been alluded to by the authors in [292] that in order to manage costs resulting from incompatibility of PQ, industrial customers have started to pay attention to the measured level of power quality supplied by utilities, which is regarded as a fundamental factor in these sectors.

Since the interview schedule allowed for more probing questions that yielded other perspectives, some respondents indicated using consultants for their PQ measurements:

"Yes, we do measurements, but only basic PQ measurement. We are currently in the process of installing PQ meters within the plant for a full spectrum measurement of power quality parameters, which we outsourced to a reputable consulting company" (Participant 2);

"Yes, PQ measurement is important, we have a third-party company that does our monitoring of power quality. We started with the monitoring of the PoD's about six years ago, and we are now spreading into our internal network" (Participant 4).

From the responses, it is evident that measurement of power quality by the respondents is certainly regarded as an important activity, in an acknowledgement that consistent with the literature review, the issues of power quality has the potential to greatly affect the system performance, leading to system loss, safety and economic consequences.

That being said, this may further necessitate for an accurate and reliable monitoring and control of the power system, which is in line with the goal of this research report, namely to evaluate key factors that influence a South African – based power utility to utilise smart grid technologies for power quality monitoring and to improve the management thereof. The second code assigned to the category of PQ measurement philosophy is discussed next.

Awareness to smart grid technology

The second code associated with the PQ measurement philosophies is related to awareness to smart grid technologies. Concerning smart grid technologies, the authors in (271) hold the view that the technology of smart grid is mainly an idealised model from which various components are to be taken and added to the real system as particular local system arise. Putting emphasis on the customer, the authors further described the aim of the smart grid to introduce more options to customers, including time-of-use tariffs. For the current study, smart grid technologies can be regarded as significant for the management of power quality by utilities so as to enable advanced controllability of the network that will analyse, diagnose and predict network condition and autonomously take appropriate actions (Par. 2.8).

More specifically, smart grid technologies help utilities to eliminate, mitigate and prevent outages and power quality disturbances., one can say that smart grid technology is an enabler of PQ mitigation and for that matter, PQ management by utilities. Hence, regarding the awareness and the usefulness of the smart grid, the following quotes from two respondents confirm the previously stated views regarding smart grid technologies:

"Yes, I am aware of the smart grid. My high-level understanding of it is that you will have automation in your grid. Just like we have for our distribution network, you would have PQ meters that you would also access from a system that might be a SCADA but doesn't necessarily have to be a SCADA, it can just be a separate power quality monitoring system where you would have an online view of every point on the network" (Participant 1);

"Yes, I am aware of the smart grid. It is a technology that I think we should be looking at, which we can be able to control equipment much easier. So, the older technologies, in terms of power generation, especially coal-fired stations, you can't just switch off and switch on whenever you like. So, at night when the demand is low and you don't need the excess power, you can't just switch off the turbine for few hours at night and switch back on in the morning when you need it. So, some other technologies such as renewables may be better suited for that and the smart grid could be able to enable that" (Participant 7).

These quotes from the respondents certainly do indicate some opportunities that could emanate from the technologies given by the smart grid. Specifically, the views and emphasis on the ability of the smart grid to control power generation and demand as expressed by one of the respondent, also coincided with the viewpoint in [187] who stated that the smart grid is a technology that can control, or influence both production and consumption to be integrated into the power system. more specifically, in coherence with the quotation from (The participant 7), the authors in [187] described the benefit of smart grid technologies for use in the automatic curtailments of production of power, where for renewable sources such as solar and wind, the primary energy is usually transformed into electricity whenever it is available but if generation exceeds consumption, these renewable sources may be turned off or curtailed.

From a South African perspective, the responses are to a certain extent, in coherence with the literature that the smart grid vision forms part of a greater framework that is being developed by the South Africa smart grid initiative [303] to guide the effective transition to a modernised national electricity infrastructure. With this, therefore, exists an opportunity to incorporate intelligence and automation into the network that can optimally support the integration of clean energy sources, so as to meet the electricity requirements of all users.

PQ on SCADA and synchronised measurement of PQ

The third and fourth codes assigned to the category of PQ measurement philosophy relate, respectively to the monitoring of power quality on the SCADA system and synchronised measurement of PQ. Since power utilities use the SCADA system to detect current flow and line voltage, to monitor the operation of circuit breakers, and to take sections of the network online or offline, some benefit of the SCADA system was considered by the authors in [287], [304], [305] on the design operation of smart grid technologies.

SCADA is considered to enable operators to easily control switching elements of the network and monitor electrical parameter changes in real time. In addition to monitoring changes in power flow, voltage variations and total harmonic distortions were considered some of the feasible electrical parameters to help facilitate identification of power quality problems by informing the operators of various abnormalities.

These views also manifested in related response from the interviews: *"Yes, I think PQ should be included to SCADA. If SCADA could contribute to maintaining the performance of power quality, then it should. It should be an integral part of their business"* (Participant 4).

This response was supported by a similar response from another respondent who said: *"Yes, it should be included. But I wonder if it is not done already. As far as I am concern, it would be good to monitor these critical parameters on SCADA. Since you already have communication with substations through the SCADA, you might as well include the PQ parameters. It could help to identify problems much quicker"* (Participant 7).

Besides the views of the preceding respondents, another respondent described the lack of PQ monitoring on SCADA as being a reactive approach of managing PQ and echoed: *"I am actually shocked, I thought it was. Yes, it must definitely be included. I believe it should be helpful to have PQ on SCADA otherwise, it becomes difficult to manage PQ. It is always being reactive to try and get the information from various points, whereas if it is life and real, I think the system operators can assist"* (Participant 5).

The above-stated response expressed disappointment with the fact that currently, monitoring of power quality was not done on a SCADA system by the utility. The respondents held a strong view that having power quality monitored on the SCADA system could help to solve PQ problems on the network.

Regarding the code synchronised monitoring of PQ, in coherence with the literature overview (Par. 2.9), all the respondents responded positively and expressed a view that synchronised measurement of PQ in a Wide Area Network (WAN) would be beneficial to the management of power quality:

"I agree, I think this is what I have just explained earlier. It would be helpful to have a real-time synchronised system. This may ensure coordinated measurement of PQ and proactively pinpoint the location of faults" (Participant 5);

"I agree that synchronised monitoring of PQ in a wide area network can support a better understanding of PQ. I believe that from a utility perspective if you have such measurement procedures in place, the efficiency of the service that they deliver to us as a customer should increase "(Participant 6).

These responses seem to suggest that synchronised monitoring in a wide area monitoring of PQ is a system that can be effectively used to address the essential requirements necessary for the management of power quality by utilities. More specifically, having a synchronised system can deliver network information necessary to support quantifiable justification for PQ system improvements by both the utility and its customers. As also mentioned in other responses from the interviews as being the mandate of utilities to comply with PQ standards (Par. 6.3.3.1), a synchronised WAM of PQ can be useful to provide detailed and accurate information necessary to verify compliance with standards such as NRS 048, in the context of South Africa.

One respondent further mentioned that synchronised monitoring could enable the utility to have full awareness of network power quality as a necessary step toward implementing PQ improvements. They perceived this as an opportunity to address the issue of limited information to customers:

"Yes, I agree that synchronised monitoring of PQ can support the better understanding of PQ. It would be nice if we have that. Also, from the user perspective, I suppose there is very limited information that is possible to get but, from the distributor side, if you get a holistic view of the monitored PQ, it would be helpful." (Participant 1).

From the above quote, one may infer that providing more information for the network is essential for improving PQ, as a consequence, the implementation of a wide area monitoring system able to acquire information on various points on the network and to distribute synchronised data on the utility's network is required.

Facilitating PQ mitigation and load switching capabilities

Facilitation of PQ mitigation and load switching capabilities are amongst the codes that relate to the category of PQ measurement philosophies. Facilitation of PQ mitigation was described by two respondents; first by one respondent who envisioned the benefit of a smart grid technology that could provide automation on the network and through the use of intelligent devices, enable load switching capabilities so as to mitigate PQ:

"I don't see the smart grid as an interventionist idea but having intelligent devices that can-do monitoring and reporting. I suppose though that you can also build something that automatically switches filter banks if you measure harmonics at a specific level. So, in terms of that scenario, to some extent yes, and to some we do on a limited scale however, I can see the benefit in terms of not waiting for an operator to react to a specific event." (Participant 1); the second related response was given in support of implementing synchronised monitoring of PQ which was regarded as a means to facilitate solving of PQ problems:

"I would support synchronised monitoring. It would be to the advantage of the utility and to us. If the measuring instrument is there, it would be nice to know exactly where the problem is coming from. The point is if something happens on the network and you don't have information, then you cannot solve or mitigate the problem" (Participant 7).

These responses are consistent with the viewpoints in [21], [186], [187] that facilitation of PQ mitigation is amongst the important advanced distribution automation (ADA) operating systems that is worth mentioning in the smart grid technologies, for which PQ mitigation such as volt and var control and network reconfiguration or self-healing can be achieved.

Moreover, through monitoring, the detection of power quality disturbances such as long-duration undervoltage and overvoltage, voltage and current unbalance is made possible which then enable automatic switching of the capacitor bank to mitigate the PQ problems. The final codes assigned to the category of PQ measurement philosophy are discussed below.

Early detection of anomalies and real-time systems

The final codes assigned to the category of PQ measurement philosophies relate to early detection of anomalies and real-time systems. Early detection of anomalies refers to the identification of sources of power quality disturbances that is likely to cause equipment downtime and/or damage, resulting in a loss of productivity. Responses that made mention of early detection of PQ problems regarded it as being proactive in dealing with PQ issues. One respondent mentioned using online monitoring for problem identification:

"In terms of being proactive, for the most part, it is through maintenance and online monitoring so that we detect problems early and if we haven't and there is a fault, we clear it as quickly as possible" (Participant 1).

The other two responses were described in the context of the SCADA system:

"Since the utility already has communication with substations through the SCADA, you might as well include the PQ parameters. So, I don't see it as much of a problem. It could help to identify problems much quicker" (Participant 7).

The preceding respondent was supported by another similar response from another respondent who said that: *"So the worse thing is that if you have equipment at the mine that trips, and you don't know why and you start looking for the reasons, you could take longer to identify the fault, meanwhile if you could perhaps have the SCADA detecting the fault as it happens, then it becomes much easier to locate the problem"* (Participant 4).

In terms of the code real-time system, one respondent mentioned it as a potential benefit to the utility: *"So if power quality is truly important, then I can see the benefit of having a real-time system that reports on PQ. It will give a whole new perspective if people can visualise immediately where faults and PQ problems are occurring on the network, and help in locating the position where the faults or PQ problems are occurring, and also reducing the time needed to react to rectify the problems"* (Participant 5).

Although one other respondent gave a response regarding real-time system, this particular response was made as a contrasting view regarding monitoring of PQ on SCADA**:** *"We are already having a problem managing the real-time events that are seen by the operator, i.e., breaker status, alarms, events, etc. and if we add PQ information that the operators themselves cannot do much about, it would be a problem. In real-time, the network operator is mostly concerned with getting information on what is going on, what can be done about it right now and sometimes call other people to act immediately." (Participant 1).*

The views expressed by this respondent suggest that the SCADA system should not be used to monitor PQ, however, what is evident from this particular response is consistent with other responses whose views about the real-time system is that it would be beneficial to the monitoring of network activities.

Reflecting on the responses given in relation to both codes, these particular responses were supported in the literature that advocated the need to have systems implemented by utilities to guide the actions of network operators and all other stakeholders involved and responsible for power quality, in an attempt to improve the efficiency of resolving power quality problems.

The significance of the responses related to the codes assigned to the category of PQ measurement philosophies, to contribute toward the evaluation of factors influencing power utilities to utilise smart grid technologies for power quality management in the context of South Africa, was to determine from the account and views given by the respondents, the relationship between smart grid technologies and the monitoring of power quality.

The views expressed by the respondents is consistent with the literature overview that a PQ assessment of critical points on the electrical network is required, so as to collect usable and coherent information about the network [79], and to understand the performance of the network. With this information available, utilities can develop management strategies and intervention system in order to maintain voltage quality within targets. Apart from the codes assigned to the category of PQ measurement philosophies, one code related to the smart grid obstacles also came to the fore and is discussed in the next and last analytical memo.

6.3.4.8 Analytic memo 8: Obstacles for smart grids

Although the importance, value and potential benefit of the smart grid are acknowledged, it has to be stated that responses related to the obstacles for implementing the technologies of smart grid should be seen as a drawback for future development trends worth noting. As outlined in the literature overview (Par. 1.2; Par. 1.3), the basic structure of the current electric power grid has remained unchanged for many years and the process of planning and implementation of the smart grid presents a defining opportunity to consider some of the inherent emanating challenges. Responses related to smart grid obstacles covered respondent's viewpoint and perceptions about the implementation by utilities in South Africa.

To a large extent, responses related to this code showed consistency with the literature that specifically highlighted ageing of the electrical network. The response below from one respondent serve to support the preceding view: *"I think we can hugely improve it. If we have a smart grid and have the capabilities of switching different loads, it will definitely improve. However, at the moment, ageing of parts of the network seems to be a challenge"* (Participant 3). The respondent further provided a specific example and said: *"I am not sure whether it will be possible for the existing network to cater for smart grid technology, e.g., breakers and switching on the utility's network"* (Participant 3).

The views by these respondents seem to be in coherence with the findings in [306] that revealed findings from a study undertaken by EDI Holdings, who determined the status of the assets in the electricity distribution industry in South Africa. Consistent with the views raised by the respondents herein, the author revealed that there was significant underinvestment in infrastructure maintenance, refurbishment and strengthening across most of the electricity distribution utilities in South Africa. Ageing of the electrical network is seen as the result of underinvestment of these infrastructure developments, which the respondents perceived as an obstacle in the implementation of the smart grid.

The following response from one of the respondents was interesting and is of particular importance in relation to the current study, when the respondent referred to "allow the utility to impact on your area of control" and stated, *"The biggest obstacle will be to get people to buy into this idea of giving some of the control away, where you allow the utility to impact on your area of control. So, I think if you can convince the leadership of utilities to go that route, then the engineering solution would be simple"* (Participant 5).

Another similar view was expressed by another respondent who said: *"The obstacles would be the cost of implementation and the ability to implement – we are a vast country, we got too many structures in place in the form of Eskom and municipalities, a big network with different entities looking at certain sections and to obtain a common system or common measurement will be a challenge"* (Participant 2).

These responses also correlated with the viewpoint in [307], a publication on the barriers to the smart grid to implementation. An implication of the response from these respondents was the fact that they indicated to the fact that stakeholder alignment and the motivation for change amongst the role players should play an important role in the successful realisation of the smart grid by utilities, as also alluded to in [150]. So, the expressed views are in line with the purpose of the current research report to evaluate factors influencing a South African based power utility to utilise smart grid technologies for PQ management.

Responses are also of particular significance to the current study, and the perceptions that a number of obstacles to hinder the implementation of the smart grid may be explained from a South African context, but care must be taken not to adopt and overemphasise on the obstacles that are seen as stumbling blocks to the opportunities of modernising the electrical grid.

Obstacles may be seen as a threat to the deployment of the smart grid technology however, this might not be unique to South Africa and lessons learnt from deployed smart grid projects [150] would be a point in case for future reference.

In a review of the overall responses alluded to by the respondents in this section of the research report, the significance thereof laid therein in the identification of specific themes on the one hand, and on the other hand in that they provided valuable distinguishing aspects of their operating environment as points of reference to the specific requirements regarding power quality which would be helpful in the evaluation of factors influencing a South African based power utility to utilise smart grid technologies for PQ management.

6.3.5 General remarks

In closing, over and above the preceding responses representing the respondents' viewpoints and perceptions about the experiences and industry sensitivity to power quality and views and perceptions on smart grid technologies, one general response was recorded that allowed for attaining additional data and bring forth new insight on the research.

It was unexpected, and yet encouraging when one respondent expressed his wishes, appreciation and support at the end of the interview, and remarked: *"My only wish is that this should not only be an academic exercise, it should go on further to enable Eskom to improve on the performance of our power quality. So, we as customers, and when I say we, I mean all customers and not just us, can then focus on our production and not worry much about the quality as this technology you are researching can solve the problems for us"; "So I think I will stop here. But I think it is a very good and interesting research. You've got an amazing topic; I'm really looking forward to the resulting product"* (Participant 7). The significance of this particular remark was that it serves to corroborate the rationale of this research that was postulated at the beginning of this research report.

6.3.6 Synthesis: Analysis of qualitative data

In this section (Par. 6.3), the presentation and discussion of the interview data about the viewpoints and perceptions of respondents related to the qualitative section of this research was provided. Eight pertinent themes were identified, namely regulatory awareness, PQ management mechanism, perceived PQ experiences, PQ risk to operations, PQ risk mitigation measures, PQ-based premium, PQ measurement philosophies and smart grid obstacles. When managing power quality, adequate level of compliance will have to be achieved at customer PoCs to ensure equipment compatibility.

Viewpoints and perceptions of respondents, together with supporting quotes associated with power quality experience were presented. In addition, responses with Substantiated evidence supported by quotations from the interview transcripts and the literature review concerning smart grid linked with PQ monitoring, including specific monitoring and PQ management areas was seen as well.

Monitoring and PQ management areas discussed included amongst others, PQ on SCADA, synchronized measurement of PQ, early detection of anomalies and real-time system. These areas were described by the respondents' viewpoints and perceptions about the monitoring of power quality.

Respondents mainly based their views regarding the expected benefits of real-time monitoring of PQ as an understanding of the function of the smart grid technology, which could be useful for the better overall management of PQ.

Viewpoints and perceptions of respondents concerning the theme PQ measurement philosophies in the qualitative data analysis confirmed the views of the literature and indicated that smart grid technologies can provide efficient means of network monitoring, including monitoring of power quality at distribution level.

In summary, it can therefore be said that the expectations expressed by the respondents regarding power quality is indicative of the experiences and industry sensitivity to power quality, which necessitate for an intelligent approach of monitoring and as such, the viewpoints and perceptions are that power utilities have to incorporate these monitoring techniques as part of their PQ management strategies. At this point in the analysis, the culmination of this section led to the accomplishment of objective four of the research.

In the next section, the data from the quantitative and qualitative sections was used in conjunction with the literature findings, to provide information required to formulate factors to influence a power utility's decision to use smart grid technologies for their network operations, to further support the management of power quality that were in relation to the research aims.

6.4 Formulation of factors towards the use of smart grid technologies

In this section, the SWOT concept for strategic positioning [308] was used to identify factors that can influence a South African utility's decision to adopt the implementation of smart grid technology for the management of power quality on distribution networks. The SWOT (Strength Weaknesses Opportunities Threats) analysis is a decision-making support tool to analytically and methodically analyse the internal and external elements in prospective of positive and negative attributes [309].

This is illustrated in Figure 49. By identifying the strengths, weaknesses, opportunities, and threats in relation to the literature and linking findings from the quantitative and qualitative data, this section used the SWOT analysis to serve as a fundamental methodology to aid the researcher to identify, in the context of this study, the internal and external factors in prospective of positive and negative attributes which are significant to influence a power utility's decision to explore the use of smart grid technologies.

In advancing the analysis thereof, SWOT factors were formulated on the basis of the extent of power quality management program by the power utility respondents, responses from industry participants from the qualitative study, along with analysis of existing electrical network in the context of South Africa. This was followed by the formulation of SWOT factors for the identified opportunities therein to improve the management of power quality in a South African-based power utility. While based on empirical data and literature findings, the conclusion drawn from the SWOT analysis are an expert decree of the researcher's interpretation.

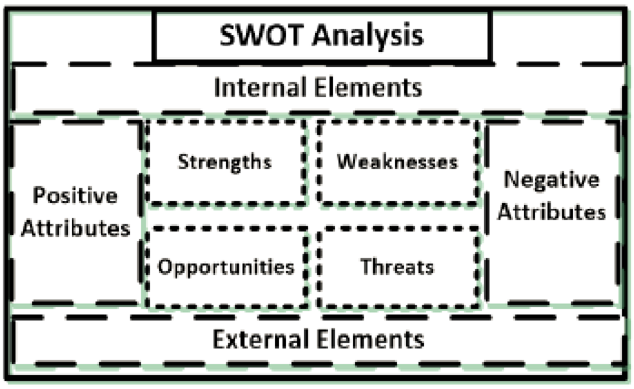

Figure 49: SWOT analysis concept – Internal and External elements [309]

6.4.1 SWOT factors on the existing PQM program by utilities

On the path toward achieving the requirements of the objective of this study, a thorough understanding of the different constraints and inter-connections among technical factors from the analysis of the participating utilities' responses was necessary. As a result, thereof, a set of four-dimensional factors were identified by using SWOT analysis as discussed below

6.4.1.1 Utility's status assessment on PQM program – Strengths Factors

According to the author in [310], strengths in SWOT analysis are internal factors that identify existing expertise and capabilities in an organisation. The power utilities are the organisations of interests in this study as was outlined in Chapter four (Par. 4.4.5.1) and therefore have capabilities entrenched within. In order to identify the power utilities' strengths, the researcher looked at the majority of the respondents who responded either positively-indicating a strength, or negatively-indicating a weakness in the information from responses in the quantitative section of this study (Par. 6.2), along with information derived from the literature study (Ch. 2; Ch. 3).

It was important to identify the power utilities' strengths in order to use them in the South African context, to inform the decision to influence the use of smart grid for the management of power quality. In order for strength to be sustained as strength, a number of significant factors are suggested by the researcher. The strength factors identified from the SWOT analysis, in relation to the existing PQM program and the literature findings are discussed below.

1. *Availability of PQ policies*: The power utilities respondents' information in Figure 44 indicated the availability of a PQM policy as explicitly shown by them, seen as a strength. In order to ensure that power quality management programs are implemented by a power utility, a PQM policy is required that adopts set of standards that clearly contemplates serious efforts to maintain good performance of power quality, which includes requirements for power quality monitoring and measurements.
2. *Existing hierarchy of electrical infrastructure, with network design for PQ considerations*: The utilities' respondents' information in Figure 45 indicated strengths on the utilities' network design for PQ consideration. In order to maintain good performance of power quality, emphasis should be placed in the design of the electrical network.

As the proliferation of electronic equipment and other sensitive devices throughout manufacturing and office environment increases, the need to design the electrical network with an eye toward power quality issues is required. Generally, by undertaking well-designed electrical networks, and in consideration for the environment and disturbing loads to be expected on the network, the researcher is of the opinion that power utilities can reasonably provide assurance of an adequate electrical network that could be expected to serve the needs of customers.

In [17], a number of specific aspects are identified that could be considered by power utilities in the design of electrical networks. Aspects such as availability, operability, maintainability, and power quality could be reinforced by the effective and good design of the electrical network.

- *Increasing focus on renewable sources of energy mix*: The utilities' respondents' information in Table 29 revealed a strength for acknowledging the mix of power generation through the integration of renewable energy sources distributed throughout their electrical network. The pursuit for more renewable sources of energy (wind and solar) by the power utilities would mean lowering harmful carbon emissions and significantly reduce South Africa's environmental impact. This is consistent with the statement in [9] that renewable energy sources is strategically viewed as a way through which South Africa, in partnership with power utilities and other stakeholders can respond to the challenge of climate change, improve energy security by diversifying sources of energy supply, and boost green growth through localization and empowerment.
- *Analysis of PQ performance trends*: The assessment of PQ performance trends by the utilities' respondents in Table 26 indicated strength. In order to maintain good performance of power quality, advances in monitoring equipment that can assess and characterise disturbances and power quality variations is required. Majority of the utilities in this study, especially the larger utilities showed strength in the ability to make use of PQ monitoring tools that can present information as individual events, such as disturbance waveforms and trends. By comparing network events with recorded typical power quality variation characteristics and correlating them with network events such as the energisation of an induction motor, some power utilities in this study are able to determine the causes of PQ variations on the network. This finding is consistent with the literature findings in [33], [82], where an analysis called "dip-to-trip matching" is performed by Eskom, in which a voltage dip due to a fault current is correlated with a protection device that cleared the fault, thereby linking the reason for the fault to the voltage dip (Par. 2.5.1). This enables the utility to later analyse the trends, after which the options to mitigate can be evaluated and prioritised.

6.4.1.2 Utility's status assessment on PQM program – Weaknesses factors

The weaknesses factors identified are discussed below.

1. *Lack of efficiencies in energy transfers*: Energy efficiency is one of the focal issues that will define the electricity supply industry in South Africa, and the capacity required to deliver for the future generations. This study revealed through the literature overview that a loss and disturbance free electricity can only occur in an ideal world (Par. 2.3.3). However, until such time that this theoretical ideal situation is achieved, it is necessary to make end-user's electricity consumption as efficient as possible, and to ensure compatibility of equipment in the case of disturbances. This is amongst the weakness factors identified on distribution networks in the context of South Africa, which requires

solutions to make utilities aware of where the power losses and disturbances are taking place at any point on the network.

2. *Aging distribution network that battles to support rapid growing and changing network requirements*: The South African electricity infrastructure has aged and are battling to support rapid growing and changing network requirements - utilities has been under immense pressure to invest in the renewal and expansion of these aged network. These are the perceived challenges affecting the adequacy of acceptable quality of electricity and economic activities for industries. During the qualitative phase of the study, the element of aging network was described by the respondent in the Cement industry as one of the possible limitations in the deployment of the smart grid (Par. 6.3.3.2).
3. *Insufficient electricity generation capacity*: Due to strong economic growth, South Africa has in the late 2007, seen its electricity reserved margin between supply and demand drop to levels which made the power system vulnerable, leading to events of load schedule that took place in 2008 [6]. The introduction of the demand-side management programs is some of the interventions put in place for achieving savings in electricity consumptions. The need to address this weakness seemed to have also appealed to a number of private investments to increase generation capacity from renewable energy sources by the IPPs into the utility's grid [7], [8].
4. *Inability to meet changing and more demanding customer expectations on PQ*: With the modern electricity comprising many nonlinear elements in conversion equipment, loads and power electronic converters which produces PQ problems, utility's distribution network are unable to keep up with the PQ requirements of most industry customers. Industry participants in this study articulated high expectations from power utilities about what was required of the level of PQ performance at their PoC's (Par. 6.3.3.2; and

5. Table 41), and the inability to meet these expected qualities of electricity is one of the identified utility's weaknesses factor in terms of the management of PQ.

6.4.1.3 Utility's status assessment on PQM program – Opportunities factors

The following opportunities factors were identified in relation to the utility's status assessment on PQ, as well as identified from the literature study:

1. *Upgrading of existing electrical infrastructures*: The electrical infrastructure as one of the key-enabling component of PQ performance measure and is responsible to make sure adequate PQ performance is reasonably achieved at various points on distribution network and to be managed more effectively to better serve customer requirements on PQ. This identified opportunity emanates from the backdrop of the literature findings in [17], in which they point out to a NERSA audit finding conducted on eleven major electricity distributors in South Africa. The report revealed a need to refurbish and upgrade the country's electricity distribution infrastructure, in order to, amongst others, curb the spate of faults and outages on distribution networks.
2. *Technology advancement and Innovation*: smart ICT revolution and technology advancement has set the platform for opportunities to improve PQ monitoring on electricity networks, due to the fact that data collection, access and exchange issues are now easier with the introduction of IoT (internet of things), which enables identifying, locating, positing and managing network by transmitting and exchanging information between things by defined protocols using sensors and GPS [309]. In the current study, the preceding viewpoints seems to correspond with the power utility's respondents information in Table 29, who indicated a smart grid technology as an opportunity that could be exploited to leverage a positive change to neutralize the current threats posed by the existing concerns relating to power quality. In coherence with the response from the quantitative study, responses from the semi-structured interviews revealed that the industry participants also collaborated the responses from the quantitative study, where the use of smart grid was perceived as an opportunity toward an innovative solution for addressing PQ challenges.
3. *Automated substation and network infrastructure*: With the introduction of the smart grids, it is expected that the current electrical network should undergo a fundamental change. Participants in the qualitative phase of this study perceived the smart grid as an automation of the grid, with intelligent devices that can perform monitoring and reporting of PQ performance. They regarded the smart grid as a system where utilities could have an online view of the PQ for the network being monitored (Par. 6.3.2.2; Table 50). This was also revealed by participants in the quantitative study, who concurred with the use of automated methods of detecting PQ problems for the possible enhancement of PQ performance (Par. 6.2.3; Figure 48, Table 29). The findings in this study seems to be consistent with remarks by the national Institute of Standards and Technology (NIST) in [140] in stating that smart grid provide an opportunity to move from a centrally produced network to distributive controlled network, meeting stochastic demands, and to enable automatic control by ensuring that system behaviour is monitored in real-time by maintaining network stability. This therefore suggest a solution that can intelligently monitor and manage the grid infrastructure.
4. *Use of smart metering instrumentation for synchronised monitoring of PQ through SCADA system*: as alluded to in the preceding positive factor, the installation of smart metering technologies is amongst the solutions that can be deployed to intelligently monitor and manage electricity network infrastructure. Future trends and developments in operations centres also make the SCADA systems an increasingly ubiquitous choice to visualise, detect and mitigate possible anomalies across the entire network [287]. Participants in the semi-structured interviews described the use of the SCADA system as an opportunity for power utilities to use in the identification of PQ problems on the network. They further alluded to the capability of SCADA system in providing synchronised visualisation of PQ parameters in a real-time monitoring system. Smart metering instrumentations, therefore, if equipped with suitable ICT (Information and Communication Technology) and OT (Operational technology), their capabilities can be integrated into the SCADA so as to enable solutions that help power utilities gain more value from the measured data.

5. *Enabling consumer awareness on energy-efficiency and demand management*: Amongst the goals to be fulfilled by the smart grid are, in accordance with the literature review, to improve operational efficiency, enhance demand response and to change customer behaviour in relation to energy use (Par. 2.8.3.2). It presents as a critical infrastructure of society that can be utilised by end-users of electricity to interact with the utility's electricity demand for efficient grid utilisation. This was highly regarded by the utility participants in the quantitative study as a prospect to qualify their expectations of efficient energy transfer as well as cost and energy saving for their customers (Par. 6.2.3; Table 31).

6.4.1.4 Utility's status assessment on PQM program – Threats factors

Threats factors identified are discussed below:

1. *Infrastructure maturity and technology immaturity:* The literature study revealed that most of existing electricity networks in developing countries, particularly in South Africa are still based on 20th century technology [311] and are incapable of meeting the growing demands due to constraint supply networks, high technical losses and high cost of power outages [17]. Under these circumstances, maintaining network reliability and adequate power quality becomes a challenging task that cannot be compromised. A network with intolerable high level of power quality disturbances leans forwards the electrical network under severe stress and if not resolved, it may result to a threat to the entire network leading to unrecoverable financial loss to both the utility and customers.
2. *Frequent network faults leading to voltage dip incidences and line trips*: as the environment has a significant impact on the frequency of faults that give rise to voltage dips, majority of distribution networks in South Africa appear vulnerable to a number of faults, resulting to voltage dip events. The literature study revealed that birds, lightning, veld and cane fires, and trees are the typical causes of these frequent faults on South African network, which always remains a threat to power utilities in the management of power quality (Par. 2.5.1). The participants in the semi-structured interview revealed that voltage dip events were the biggest threats that emanate from frequent faults on the utility's network (6.3.3.2; Table 40).
3. PQ risk to industry operations: the risk of poor power quality to industries has a greater impact far more than just production losses and equipment failure and breakdowns. Identified as a threat, industries respondents revealed a PQ risk to their operations (Par. 6.3.2.2; Table 42 – Table 44), which would inform the severity of threat to the power utility and on what basis their services can be judged. A typical example is the impact to the Chemicals and mining industries, which subject to the severity and impact of the PQ event thereof, explosions may occur, resulting in loss of human life (Par. 6.3.2.2; Table 44).
4. Lack of distribution network automation and control: one of the identified threats relating to the existing distribution network is the prolonged reaction and restoration time, which is observed when a fault has occurred. This scenario was described by two of the industry participants in this study (Cement manufacturing and Water pumping and purification) as a risk to their operations, who in most instances, when a disturbance cause a fault on the network, the utility's network operators are unable to identify the exact location of the faulted section of the line. So, due to lack of automation, the dispatched restoration team will have to perform trial and error operations on the network in an effort to find the exact location of the fault, which take long to restore supply. Technologies such as distance to fault locator may potentially be utilised in reducing the impact of faults by speeding up the restoration process.
5. *Environmental footprint: Environmental footprint is amongst the threat factors confronted by utilities in South Africa*. As the generation of power is dominated by coal-fired power stations, it is required to transition to a diverse mix of energy as the threats of climate change are evident. In the realization of the threats, participants in the quantitative study acknowledged the current impact to the environment, and realises for an opportunity in smart grid as a tool to facilitate the reduction of the environmental impact (Par. 6.2.3.1; Table 31). As a result thereof, this research identified strategies to improve on the internal weaknesses by taking advantage of external opportunities, in order to avoid or reduce the effects of these external threats.

In sum, a number of opportunities were identified by the research participants in this study, which are perceived as beneficial to power utilities in neutralising the existing threats. In cross-referencing the identified opportunities with the literature, the findings seems to be consistent with the roadmap to transform from traditional electrical utility network to an intelligent grid [27], [135], [303] which is also consistent with the definition for smart grid described in this dissertation (Par. 2.8.1). As a result, thereof, smart grid technologies are assumed to be the opportunities required to enhance the management of power quality by utilities. A summary of the four-dimensional factors identified in relation to the existing status of power quality management program by the utilities, supported by the literature review, is shown in Table 35, thereafter, the factors relating to the smart grid as an opportunity to use in the management of power quality are discussed.

Table 35: Identified SWOT factors and their notational representation – PQM programs

Identified SWOT Factors	Notational representation
Availability of PQ policies	PQM, S1
Network design for PQ considerations	PQM, S2
Increasing focus on renewable sources of energy mix	PQM, S3
Analysis of PQM trends	PQM, S4
Lack of efficiencies in energy transfer and higher technical losses	PQM, W1
Aging distribution infrastructure	PQM, W2
Insufficient electricity generation capacity	PQM, W3
Inability to meet changing and more demanding customer expectation's on PQ	PQM, W4
Use of smart grid technology	PQM,O
Infrastructure and technology immaturity	PQM, T1
Frequent network faults leading to voltage dips and line trips	PQM, T2
PQ risk to industry operations	PQM, T3
Lack of distribution automation and control	PQM, T4
Environmental footprint	PQM,T5

6.4.2 SWOT factors on the influencing decision to use smart grid

The preceding section described the SWOT analysis in relation to the existing PQM programs by utilities in this study, along with information derived from the literature study regarding the status of electricity in the context of South Africa. As a result thereof, factors to influence the decision to use smart grid technologies by a South African utility need to be identified on the basis of SWOT opportunities identified in the preceding section (Par. 6.4.1; Table 35).

On the path toward the deployment of smart grid technology, an important aspect is the understanding and realisation of the smart grid benefits by utilities. Based on SWOT analysis, the coordination of positively attributed elements (strengths) with positively attributed external elements (opportunities) were used to generate strengths-opportunities strategies, to potentially utilise the internal strengths to take advantage of external opportunities.

In the context of this study, internal elements are regarded as elements that are of applicability to the electricity supply industry in South Africa, whereas external elements are elements that are new and technological and social sustainability prospective, also in the context of South Africa. These elements are analysed in this section.

As stated in the literature, the intelligence brought by smart grids have already been tested and implemented in several countries in order to optimise operation and management of the electrical network [150], [156]. This may provide an edge to the aims and objectives of this study to leverage on the successes gained by the forerunners and to draw meaningful conclusions for this research toward the implementation of the smart grid.

One of the key benefits of the smart grid is the automation and control through SCADA implementation, which plays a vital role in providing quality and reliability of supply to consumers. Consistent with the views of the author in [275], the authors in [71], alludes to the intentions of the smart grid as to provide better PQ, especially in voltage control and voltage dip impact.

So, in accordance with the literature, where the benefits of smart grids are clearly distinguished, the identified factors to influence a South African-based utility's decision to utilise smart grid could also for instant make provision for improving the monitoring of power quality. The deployment of smart grid technology by power utilities in South Africa can be based upon planning and regulatory frameworks and policies and reforms. For the utilisation of smart grid, interoperability of systems for synchronisation between generation, transmission and distribution with market, operations and service provider is essential.

The utilisation of smart grid will ultimately require a lot of standards, specifications and regulatory framework. This particular aspect also emerged during the quantitative phase of the empirical study and it was revealed that majority of the utility's respondents perceived the availability of technical standards to achieve interoperability of various equipment as a driving force toward the deployment of smart grid.

Accordingly, the IEEE has already taken the initiative to identify these requirements and map the rules and guidelines on how the smart grid should operate with interoperability between different technologies [68], [140]. In the context of South Africa, research institutions and particularly the Research Testing and Innovation Centre (RTIC) at Eskom can initially be experimented as an autonomous substation that can serve the purpose of a micro grid for future large scale deployment, where all the protocols and standards can be implemented for testing purpose by utilities.

Although a number of positive factors emerged from the empirical study toward the utilisation of smart grid technologies in the South African context, its practical deployment also emerged as an important factor due to a number of constraints and challenges such as that described by the authors in [312], namely technical, financial, geographical and political aspects. These constraints and challenges were perceived by the industrial key customer respondents' information in the qualitative phase of this study as the possible obstacles for the deployment of smart grid in South Africa (Par. 6.3.3.2;Table 52).

Some of the obstacles mentioned included aging of the electrical network, quantification of the economic benefits, cost of deployment and lack of trust by users or other entities to cooperate. In view of the above-mentioned obstacles, Utilities in South Africa need to prioritise the implementation of an aspect of the smart grid to suit specific leverage areas of constraint or need.

The approach adopted should also be perceived in the broader context of the structure of the electricity supply industry in South Africa, which comprises mainly Eskom, large metropolitan utilities and smaller municipal utilities. Table 36 give a summary of the resultant factors identified using SWOT analysis, in relation to the positive influence to serve as decisions to encourage the deployment of a smart grid by power utilities in the context of South Africa.

Table 36: Identified SWOT factors and their notational representation – Smart grid implementations

Identified SWOT Factors	Notational representation
Use of proven models implemented by other countries and organisations globally	SG,S1
Access to clean and sustainable renewable energy sources (solar and wind)	SG,S2
Reducing the environmental footprint	SG,S3
High initial infrastructure and deployment cost	SG,W1
Standards and interoperability issues	SG,W2
Collaboration with research institutions to develop SG pilot systems	SG,O1
Government support to develop small-scale microgrids	SG,O2
Efficient, automatic modernized electricity network	SG,O3
Safe integration of renewable energy technologies and maintain voltage stability	SG,O4
Advanced methods of distribution automation to improve PQ monitoring and reliability	SG,O5
Dynamic real-time decision and management of network parameters and disturbance identification on SCADA	SG,O6

6.5 Conclusions: Data analysis

To be able to evaluate factors that can influence a South African power utility's decision to use the technology of smart grid on distribution network for the effective management of power quality, a survey questionnaire was compiled based on the literature study and theoretical framework. In addition, a semi-structured interview was conducted. In this chapter, the quantitative and qualitative data from the empirical investigation in accordance with the mixed methods research were presented, analysed and interpreted.

Although not directly coupled, the data from the quantitative and qualitative methods were used to obtain comprehensive data in accordance with the research aims and objectives, and the literature study, with specific reference to the theoretical framework. Together, the data was used as a platform (basis) for the formulation of factors that can influence a power utility's decision to utilise smart grid for the management of power quality on distribution network. in summary, the data from the quantitative section provided insights on the respondents' information regarding their scope of power quality management programs as well as their views on smart grid technologies, while the data from the qualitative section provided information about the respondents' understanding of their experiences and industry sensitivity to power quality as well as their views on the use of smart grid technologies.

Both the quantitative and qualitative data were in relation to the research aims and objectives. From the quantitative data, it was found that power utilities should be able to use the developed constructs to adequately measure the scope of their power quality management programs as well as the extent that smart grid can be used for power quality management for distribution networks. No significant differences were found between the different industries regarding the impact of power quality to their operations, and in coherence with findings from the quantitative section, it was found that smart grid can enhance the management of power quality.

Subsequently, these results indicated that the SWOT analysis technique can be applied for the identification of SWOT factors, while the process of connecting the quantitative and qualitative data, in alignment with the literature study contributed to the formulation of key factors to influence a power utility's decision to use smart grid for the management of power quality. In the next and last Chapter, the summary, findings and conclusions are presented, whilst the chapter is concluded with suggestions and recommendations for exploring the innovative possibilities to improve the future management of power quality on distribution networks.

7 Chapter 7 – Summary, Findings, Conclusions and Recommendations

7.1 Introduction

Chapter Six presented the results of the empirical study, analysed and interpreted, culminating in the formulation of key factors influencing a South African-based power utility to utilize smart grid technologies for power quality management. In this final chapter, the research is concluded with a summary of the previous chapters, with the aim of providing an overview of the study. Findings of the study are provided, and final conclusions are drawn. The chapter also states the limitations and the significance of the study and concludes with recommendations for both South African-based power utilities and for further research

7.2 Overview of dissertation

In this dissertation, the influence of smart grid technology on electrical networks was examined, and its practical application explored for use by a power utility to facilitate the monitoring and management of power quality. This led to the formulation of factors that could influence a South African-based power utility to utilise the smart grid technologies for power quality management on distribution networks. A mixed methods approach was followed, consisting of both quantitative and qualitative data analysis of empirically collected data.

In the quantitative phase of the study, a single-stage statistical procedure was implemented for the analysis of survey questionnaire data, while a thematic content analysis of semi-structured interview field notes was implemented as part of the qualitative phase of the study. While not directly coupled, the combination of the quantitative and qualitative analyses of power utilities and industrial key customers' responses provided valuable information on the formulation of key factors influencing a South African-based power utility's decision to utilise smart grid technology, which could further be used to enhance the management of power quality.

In Chapter One, an orientation and background to the research problem was provided, starting with an unconventional poetic approach at the beginning of the chapter. After this, the research questions were formulated to outline the focus of this research. The conceptual framework that underpinned the progression of this research was also emphasised by expounding on the key concepts adopted in this study, which subsequently informed the design that was implemented to obtain answers to the research questions.

In Chapter Two, a study of the relevant literature on power quality and smart grid technologies were presented. Power quality was delineated from an electromagnetic compatibility perspective, the measuring principles of IEC 61000-4-30 and the assessment of compliance to the compatibility of NRS048. Practical case studies were used to demonstrate the NRS048 compatibility requirements.

From this relevant literature, the impact of poor power quality was presented, followed by standards and regulatory requirement relating to power quality, with specific emphasis on responsibilities by all the relevant stakeholders. the relevant literature on smart grid technologies were represented by looking at the characteristics and operations, along with the emphasis on the synchronised measurement capabilities offered by the phasor measurement units (PMUs). Related work was discussed, and the gaps and opportunities in the literature, which this study aimed to address were identified.

In Chapter Three, technical literature was used to develop the conceptual framework for the research questionnaire used in the quantitative study. For this purpose, parameters of power quality management and smart grid technologies were identified, after which a set of measures for the concepts power quality management and smart grid technologies were developed. Each of the concepts led to the establishment of a framework to measure the respective concepts, after which a model was proposed for the link between Power Quality Management and Smart Grid Technologies.

In Chapter Four, the researcher presented the detailed design of the study, which comprised detailed information concerning the quantitative and qualitative research design, target populations for the study, data collection methodologies and measures taken to ensure trustworthiness of both the data and the findings. Before the detailed design, the researcher gave a description of the research paradigms, in which it was revealed that a pragmatic approach would be followed as it was best suited for this research.

During the quantitative part of the research design, the elements and indicators to determine the scope required for the management of power quality and the perception of the use of the smart grid technologies were identified by means of a structured questionnaire as part of the empirical research design. The questionnaire was constructed in alignment with the literature review (Ch. 2; Ch. 3), the theoretical frameworks for the concept power quality management (Ch. 3, Par. 3.4, Figure 34) and the concept smart grid technologies (Ch. 3, Par. 3.4, Figure 35), and the research objectives (Ch. 1, Par. 1.4). The design of the quantitative study was performed in accordance with the proposed relationship between power quality management and smart grid technologies, for which a detailed model was proposed (Par. 4.4.2, Figure 37).

As part of the empirical exploration that would support the reliability and validity of the research, semi-structured interviews were conducted as part of the qualitative phase of the mixed method research, in order to collect field notes on the views and opinions of key customers, relating to power quality experiences, as well as to obtain in-depth information on the topic of smart grid technologies, in accordance with the research objectives (Ch. 1, Par. 1.4). Finally, the researcher paid attention to ethical considerations.

In Chapter Five (Par. 5.2; Par. 5.3), the researcher described the methods that was followed to analyse the data that was collected in the research. In the strategies of enquiry (Ch. 5), the researcher revealed that the quantitative part focused on descriptive analysis, for which a single-stage statistical analysis was undertaken, while a phenomenological approach, specifically, a qualitative thematic content analysis – framework approach was followed in the qualitative part (Par. 5.4), taking a combined approach to analysis, enabling themes to be developed both inductively from the accounts (experiences and views of the participants and deductively from the literature (Ch. 2; Ch. 3).

In Chapter Six, the analysis of the data from both the survey and the semi-structured interviews were presented. During the analysis of the quantitative data, the section started with the presentation and description of the reliability results, after which the profile information of the participating utilities was presented by means of biographical information.

A single-stage statistical procedure was then implemented, in which descriptive statistics was used to analyse and interpret the quantitative data. In Section 6.2.3 the data analysis initially focused on the mean differences amongst the constructs that were obtained from the utilities responses for Section B, followed by analysis of a selection of indicators for further interpretation on the scope required to manage power quality as well as the utility's perceptions on smart grid technologies.

The analysis of the qualitative data started with a short description of the interviewing process and the documentation of the interview data, followed by the presentation of the context of the participating industrial customers, after which a detailed qualitative data analysis process was implemented to identify themes and categorise codes that emerged from the field notes.

Matrices (included as Appendix A) were used to compare the responses by the various participants in order to identify trends. Analytical memos were then created to interpret and cross-reference the results with the literature. In Section 6.4, the final research objective was achieved. The empirical and literature findings were used in a SWOT analysis process to formulate factors that could serve as influence on a South African power utility to use smart grid technologies on distribution networks.

The analysis culminated in the identification of factors influencing a South African-based power utility's decision to utilise smart grid technology, which can further be used to enhance the management of power quality.

7.3 Research findings

In this section, the research findings are presented. The findings in relation to the literature study are discussed first, followed by the findings in relation to the aims and objectives of this research.

7.3.1 Findings from the literature

After the review of the literature in Chapter Two and Chapter Three, the significant findings presented in this section came to the fore. These findings are necessary for power utilities and regulatory bodies who establishes and implement policies for the management of power quality. The findings informed amongst others, the compilation and design of the research questionnaire and were based on the literature study in Chapter Two and Chapter Three: power quality and power quality management for distribution networks. The findings were also necessary to correlate findings obtained in the empirical section of this research.

7.3.1.1 Findings from the literature overview relating to PQ

The literature review regarding power quality management was delineated on two aspects, namely power quality (PQ) and total quality management (TQM), with the latter forming the basis upon which the management of power quality was progressed throughout this research. Regarding power quality, findings from the literature revealed various descriptions for Power Quality and two definitions were given by the authors in [60].

One according to the IEC which defines power quality as a "set of parameters defining the properties of power quality delivered to the user in normal operating conditions in terms of continuity of supply and characteristics of voltage (symmetry, frequency, magnitude, waveform) and the other according to the IEEE which states " the concept of powering and grounding electronic equipment in a manner that is suitable for the operation of that equipment and compatible with the premise wiring system and other connected equipment" (Par. 2.2.1).

From a quality management perspective, the author in [178] referred to total quality management as: 'The totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs'. Aligning the preceding definition with electricity delivery, it was found that the needs of consumers can be translated into features and characteristics, which included aspects such as usability, safety, availability, reliability, maintainability and the protection of the environment. In this dissertation, the researcher looked at the parameters that defines the quality of electricity for distribution networks, to determine the level required to achieve electromagnetic compatibility of equipment and incorporates into a quality management model for effective management.

The literature indicated that to ensure compatibility of equipment connected on the network, power utility should control the maximum level of disturbance that may be present at any point on the network and establish a level of disturbance to which every equipment will be immune [63]; (Par. 2.3). Power utilities need to manage their networks to contain the statistical variation of a PQ parameter to be less than a certain value (Par. 2.3; Figure 3), so as to minimize operational risk to users. This provides the principles of PQ management to power utilities however, the literature finding revealed risks to users and power utilities when no information existed on the position of the compatibility curves (Par. 2.3; Figure 3).

Monitoring and measurement of PQ was required to ensure continuous updating of system performance. Continuous monitoring will ensure enhancement of PQ management. The consequence of not managing compatibility in PQ was considered to be significant to both the power utility and the user and for the user, when overlap of system disturbances and equipment immunity occurs, an operational or business risk is realized. The authors in [76] indicate that the loss in production, loss of sales and even the consequential reputational risk due to a voltage dip event that result to an interruption of supply can cause businesses to close doors (Par. 2.3.2). This realizes for production processes to be interrupted when equipment shuts down or fail due to poor PQ.

The literature finding on voltage harmonics indicated that the assessment of harmonic emissions on distribution networks can now be improved due to the inclusion of the measurement of PQ parameters for currents on the edition 3 of the IEC61000-4-30 [79], which can help to qualify waveform distortions [61], [70], [78]. Qualifying waveform distortion simply implies having sufficient measurement samples to ensure more accurate measurement of the original waveform (Par. 2.4.1). the authors in [81] clearly state that the measurement of voltage dips and voltage swells is, as per the IEC61000-4-30, digitized with a minimum number of 128 samples per fundamental frequency cycle in order to track the rms voltage, while steady-state parameters is defined as the 10/12-cycle block values.

When assessing the compliance of a PoC for minimum requirements applying the NRS 048 part 2-2007, the assessment have to be in line with site conformance, which implies that some measurement standards have to be specified. The literature finding further revealed that any PQ instrument used, when compliant to the measurement standard IEC61000-4-30 edition 3 requirements for Class A performance, will produce data that will result in the exact same assessment of the same PoC for the same period of measurement. The author in [117] indicate that with the knowledge to identify and mitigate power quality events on the network, user process reliability can be significantly improved (Par. 2.5.2). It is preferable that large power utilities perform measurement of PQ and perform analysis to identify problematic areas, as they have the necessary expertise and resources [75]; (Par. 3.3.2). The assessment and management of power quality have to be actively driven by power utilities and be able to meet customer expectations.

In the context of this research, a customer refers to industrial key customers and the assessment of PQ must not only meet the expectations of the customers in terms of performance of their PoCs, but must also ensure that voltage dips problems do not result in damage to equipment, improper operation of equipment, process disruption and other anomalies [18].

The literature clearly states that although the compatibility levels of NRS 048-2 form part of utilities license conditions, the management of power quality requires collaboration from all stakeholders, including customers (Par. 2.7.4). Customers must define the minimum requirement of its facility regarding power quality and therefore, be described as the immunity level, where immunity is related to equipment compatibility and where customers ultimately determine the level of satisfaction with the power quality and other services. This includes evaluating the extent to which the power utility says it will do to deliver safe, secure and reliable quality of electricity.

For power utilities, PQ management practices need to focus on continuous improvement as a form of quality assurance, in order to measure the overall delivery of electricity [30]. Stark in [178] emphasizes that continuous improvement of all operations and activities is fundamental to TQM (Par. 3.3.1.1). A quality management philosophy for emphasizing on continuous improvement of quality may put the high regard for customers and their needs, which is associated with the perspective of TQM, where the continuous improvement is key to significantly increase the quality of service (Par. 3.3.1.2).

This finding is supported by the authors in [30] who asserted that to manage power quality, it is necessary to establish a power quality policy, baseline, plan and management review, and it is absolutely mandatory to measure, analyse and improve power quality in a continuous process.

Based on the literature review, the findings on the management of power quality by a utility would result from developing appropriate constructs required for assessing the relevant aspects of power quality management. In quantitative research development, a construct is considered an idea or theory containing various conceptual elements, typically considered to be subjective and not based on empirical evidence.

Findings from reviewing the literature revealed that power quality management by a utility can be assessed using Four constructs, namely Top Management Commitment, Service Quality Assessment, Network Topology and Design, and Customer Interactions (Par. 3.4.1 and Figure 34). After providing theoretical definitions for each of the construct for conceptual clarity, the researcher then hypothesized from the literature findings that each of the constructs has an influence in the management of power quality by utilities. Having discussed the literature findings on power quality and the management thereof from a quality management perspective, the researcher now discusses the findings that emerged from the literature review with regard to smart grid technologies.

7.3.1.2 Findings from the literature overview relating to smart grid

In so far as the smart grid technology, from a meaning perspective, findings from the literature revealed a lack of a developed common functional definition [132]; (Par. 2.8.1) however, what seemed evident is that it is an evolving concept that covers the entire electricity supply and is characterized by the use of technology to intelligently integrate the generation, storage, distribution and consumption of electricity.

Focusing on the meaning, the literature finding further outlined a smart utility definition [135], and defined it as a utility that deploy and utilizes a smart grid together with information and communication technologies and innovative software solutions and business processes in an integrated way, to transform the business model and add collaborative value across external stakeholders (city, country, region and society) (Par. 2.8.1).

While it is accepted that no common functional and technical definition is yet to emerge, the smart utility definition is a finding worth noting, as it incorporates within, the elements required for the deployment of the smart grid in a power utility. According to [66], [68], [136] it is pointed out that for the smart grid, a number of key elements remain common for many smart grid architectures for deployment by utilities.

The literature finding is that intelligent devices, smart substations, smart distribution, smart generation and universal access are some of the common elements of the smart grid [71], [187]. Moreover, it is clearly stated in [140] that to achieve interoperability of smart grid devices and systems, a framework that included protocols and model standards for information management was needed.

Another finding from the literature was that if interoperability of smart grid components is achieved, different networks, systems, devices, applications or components would be possible and be able to exchange readily use information with less inconvenience to the user. This is explicitly referred to by the authors in [68] who indicates the specific technologies for implementation in some areas of smart grid, namely integrated communications, sensing and measurement, advanced components, advanced control methods, improved interfaces and decision support, improved reliability, availability and supply security, maintaining the quality of supply to sensitive digital loads, improve efficiency and economy in power generation, transmission and distribution, and improve security and safety in network operation.

The literature revealed that these areas, if implemented, will increase operating efficiency, reducing operations and maintenance cost of the electricity network. Another literature finding was that observability of the network can be enhanced if PQ data is to be monitored synchronously (Par. 2.9). If phasors and waveforms are accurately time-stamped to the GPS clock, dynamic phenomena and the inception of waveform events can be better understood [155], [156]; (Par. 2.9.1).

This synchronization requirement brought into focus, the aspect of phasor measurement unit or Synchrophasor. PQ instruments should have abilities to provide measurements made possible by Synchrophasor, which is why the literature finding further revealed that many modern PQ measurement platforms can also record synchrophasors much better than the 1% TVE required [79], [158]; (Par. 2.9.1).

Literature highlighted positive findings pertaining to the practical applications of synchrophasors on electrical networks. This aspect find support in [155], [156], [159], and [160] in which it was reported that Synchrophasor data can be used for dynamic state estimation, real-time congestion management, adaptive protection, corrective or preventive stability control. A lack of real-time information such as reactive power monitoring and voltage stability protection system for a wide area power system visualization was also found to pose a risk for power system operators to maintain their situation awareness [161], [162]; (Par. 2.9.2).

Literature on Synchrophasor further revealed that Synchrophasor data can be used to develop a variable impedance scanning trajectory sensitivity method for identifying problematic parameters of an electrical network [163]. Another literature finding on Synchrophasor was the use of Synchrophasor data by the authors in [164], in which the parameter variation caused by a sagged conductor was addressed based on measurement done using a Synchrophasor device. So, improved monitoring and corrective action capabilities can allow network operators to utilise the power system more efficiently.

In short, assessing and mitigating problems associated with voltage security remain a critical concern for power system utilities. It is well understood that voltage quality and therefore its security, is driven by a balance of reactive power in a network. It is of particular interest to discover what areas in a distribution network may encounter reactive power deficiencies or even other network disturbances. From the literature study, the literature findings revealed compelling evidence to suggest that the technology of smart grid, if equipped with the relevant smart meter instrumentation and communication infrastructure and implementing full network automation, can provide intelligible information to facilitate the monitoring and measurement of various parameters on the network, which can also be done effectively through the SCADA system [287], [304], [305].

As much as the literature revealed substantial benefits of the smart grid technology, the use of phasor measurement units (or Synchrophasor) devices on smart grid systems was found to provide the resulting possibility of real-time measurements to enable different power system applications to improve amongst others, the system stability, state estimation, load estimation, electrical network protection, wide-area security assessment, power quality and reliability of the electrical network.

With these possibilities, it seems therefore that the smart grid technology can be of major benefit for application on distribution networks, with the findings revealing available lessons from deployed smart grid projects [150]. From the reviewed literature, the findings on the use of smart grid by a utility led to the development of appropriate constructs required for assessing the relevant aspects of the smart grid implementation by a utility.

Literature revealed that the views on smart grid by a utility can be assessed using three constructs, namely Technical system operation, Cost-benefit and regulation, and Social norms and behaviours (Par. 3.4.2; Table 10, Figure 35). Following the development of the constructs, it was hypothesised from the literature findings that each of the constructs were relevant to the views on quantifying the perceptions regarding smart grid technologies.

7.3.2 Findings as related to the aims and objectives of the study

In this section, the most important findings in terms of each of the research objectives will be discussed.

7.3.2.1 Objective 1: To develop measures for the concepts power quality management and smart grid

This objective was mainly achieved through the literature review. It was necessary to achieve this first, since it determined the implementation of the subsequent objectives, determined the focus of the study and provided the framework for the compilation of the questionnaire in the quantitative phase of the study.

Through analysing the literature relating to power quality management and smart grid technology and the power quality management model was used as a framework that served to implement, manage and continuously improve power quality for an electrical network. Fundamental to the model, amongst others, was the measurement and monitoring aspect of power quality, for which smart grid technology was investigated as part of this research.

The development of the measures for the concepts power quality management and smart grid technology entailed a process of developing a questionnaire and this comprised of (1) identifying parameters and elements for the two concepts; as well as (2) adhering to the criteria for reliability and validity.

In the development stage of the parameters to quantify power quality management and smart grid technology, a summary of a wide range of characteristics for each concept was extracted from the literature along with the corresponding supporting references, after which the definitions of the characteristics (dimensions) and elements (observable behaviours) were operationalised using the method suggested by Sekaran in [52] to form the constructs and test items that measured the concepts quantitatively.

The definitions provided by the literature review yielded four dimensions that can be used to measure power quality management, namely:

1. Top Management Commitment (TMC);
2. Service Quality Assessment (SQA);
3. Network Topology and Design (NTD); and
4. Customer Interactions (CI).

Smart grid technology could be measured using three dimensions as

5. Technical System Operation (TSO);
6. Cost-Benefit and Regulations (CBR); and
7. Social Norms and Behaviours (SNB).

The development of the measures yielded four hypotheses for Power Quality Management (Par. 4.4.2, Figure 37):

Hypotheses H1 = Construct 1, H2 = Construct 2, H3 = Construct 3 and H4 = Construct 4; and then hypothesised that each construct can appropriately measure the scope of power quality management program in a South African power utility.

Whilst the measure for Smart Grid Technologies led to three hypotheses as (Par. 4.4.2, Figure 37):

Hypotheses H5 = Construct 5, H6 = Construct 6 and H7 = Construct 7; and each hypothesised to be the suitable measure for smart grid as a useful technology to facilitate network operations by a South African utility

From the above-mentioned concepts, the researcher then hypothesised that there is a link between Smart Grid Technologies and Power Quality. Through smart grid technologies, a South African-based power utility can have an opportunity to enhance the management of power quality on its distribution network.

Hypothesis HM: ***Smart Grid Technologies has a positive effect on Power Quality Management in a South African-based power utility.***

This led to the development of a research instrument that comprised of seven constructs measured by forty-six test items (questions). The questionnaire items were each anchored with a Likert scale, from which respondents selected one of five alternatives, indicating how much they agreed with the contents. Reliability criteria referred to the assessment of the instrument, which was achieved by test of internal consistency for each construct using Cronbach's alpha coefficient, while criteria for validity referred to the search for validation evidence, by way of face and content validity.

7.3.2.2 Objective 2: To determine the scope of power quality management program employed by a utility in South Africa

This objective was achieved by analysing the data obtained from the power utility responses to the questionnaire items in Section A and Section B that focused on the scope of power quality management program. A comparison of the constructs means obtained for the Sections indicate that the utilities responded more favourably to the constructs required for a power quality management program in a utility. The data might imply that the utilities are more contented with the aspects of the proposed program to manage power quality, and believes that for better power quality performance, a utility should have the following in place.

- *Network Topology and Design (mean 3.95).* Utilities possibly consider the distribution network as the origins of many PQ problems , in terms of network adequacy, it is deduced that a proper distribution network with adequate planning and maintenance is essential to minimize the occurrence of PQ problems (Par. 6.2.3; Table 21).
- *Top Management Commitment (mean 3.80).* Utilities possibly believe that commitment and discipline by top management of distribution utilities is required to put long-term strategies and planning for power quality, as well as to admit their level of knowledge in the past about power quality issues, and what the existing problems are they still encountering. This data further indicate that the utilities believe that commitment by top management is crucial in the implementation of power quality management programs, which can help distribution networks to achieve the objectives of presenting good power quality performance (Par. 6.2.3; Table 19).
- *Service Quality Assessment (mean 3.73).* The positive response given by the utilities on service quality suggests that since power quality issues are causing significant disturbances to distribution networks and to end users, service quality assessment construct was considered significant for a power quality management program, in identifying the more common PQ disturbances that occur on distribution networks. These findings indicates that the elements of service quality assessment are necessary for a power quality management program, to enable PQ diagnosis systems to be implemented on distribution networks for improved network performance (Par. 6.2.3; Table 20).
- *Customer Interactions (mean 3.64).* Although ranked lowest amongst the four constructs, the respondents held a view that efforts of interacting with customers is an aspect of consideration in the management of power quality. customer interaction efforts were confirmed by the responses given by the respondents on five of the six questions under customer interactions which dealt with the

proposition that customer interactions have an influence on the effective management of power quality. Something worth noting is that on one of the questions of the service interaction construct, majority of the respondents responded negatively, indicating that that they did not developed strong relations with customers in terms of PQ data communications. However, the main finding of this construct indicates that the majority of the utilities responses confirmed a strong focus on relations through meetings and complaint management, thereby advancing customer interactions as a measure for the management of power quality (Par. 6.2.3; Table 22), as it was also established in the literature that interacting with customers is important in providing power quality improvement solutions, by enabling the establishment of compatibility between the utility's electrical supply and the customer facility, in order to characterize the expected quality.

A brief reflection on the data used to assess the constructs highlights the fact that the utilities considered the four constructs to be appropriate for implementation in the management of power quality. This means that hypotheses H1, H2, H3 and H4 are accepted, i.e., that construct 1 to four can appropriately influence the scope of power quality management program to be employed by a South African power utility.

To expand on this objective, Chapter 6 further identified aspects to determine the extent of power quality management by the utilities. Six leading indicators relevant to managing power quality were highlighted with supporting evidence from the literature (Par. 6.2.3.1). The significance of selecting these leading indicators was necessary in the essence that power utilities needs to accomplish some degree of licensing requirements towards the management of power quality.

Such activities would ensure that utilities provide appropriate power quality performance information for its electrical networks, since the availability of this performance information would enable possible enhancement of deteriorating performance trends, as well as to match the quality expectations of customers. The effectiveness of the utility's power quality management program is evaluated by the extent to which the utility approach power quality issues described by the leading indicators as discussed (Par. 6.2.3.1). Findings for the leading indicators were derived from the questionnaire items of the constructs (Par. 6.2.3; Table 19 to Table 25) and are listed below:

- *Indicator 1: Power quality management systems (Par. 6.2.3.1; Figure 44).* Data in question V5, revealed that 91% of the utilities responded that their utility had a policy for managing power quality for their electrical network.
- *Indicator 2: PQ monitoring and measurements (Par. 6.2.3.1; Figure 48).* In response to question V13, 82% of the utilities indicated that they conducted measurement of power quality on their electrical network. This response also implied that some smaller local utilities have started to put emphasis on the measurement of power quality for their electrical network. A sound example may be for the utilities to have an outsourced business model of PQ monitoring and measurement, especially if they have limited skills internally to do PQ monitoring.
- *Indicator 3: Analysis of PQ trends and impact assessment (Par. 6.2.3.1; Table 26).* According to the data in Table 26, there were 64% of the utilities who agreed with question V17 that they performed investigations internally to determine root causes of PQ problems and equally, there were 64% of the respondents who agreed with question V16 that they performed impact analysis before connecting customers. When responding to question V22, only 45% of the utilities indicated that they conducted network life-cycle analysis to predict a decline in PQ performance. A total of 55% did not agree with this statement, while 36% of the respondents did not agree with both the questions in V16 and V17. This negative response implies that the participants possibly did not recognized the importance of managing power quality activities. The utilities might not have previously dealt with a customer complaint regarding power quality, who threatened to lodge claims for damages caused by PQ problems.
- Indicator 4: Network design and performance benchmarking (Par. 6.2.3.1; Figure 45, Table 27). The majority of the respondents in question V20 (91%) indicated that they usually design their network with a view to optimize PQ. In addition, when responding to question V21, 82% of the respondents agreed that installation of MV cables formed part of their utility's priority when designing their

distribution networks. These findings imply that there might be some advantage towards the design nature of the distribution networks. According to the data presented in Table 27, findings relating to benchmarking of performances were revealed. In response to question V18, the respondents were marginally divided 50/50 on the issue of performing analysis for benchmarking performance of PQ parameters such as voltage dips, in order to derive their characteristic numbers on the network. 55% agreed and 45% disagreed with this statement. This response implies that some utilities frequently performed analysis of voltage dip performance of their network to derive dip characteristic performance for benchmarking purposes, while other utilities did not perform these analyses. Besides benchmarking of PQ parameters for deriving characteristic number of dip performance, the utilities responded to question V19, on whether they benchmarked PQ performance of their network with other similar utility networks. 45% agreed while 36% disagreed. This response might imply that the utilities believes that benchmarking of PQ performance of their networks with networks of other similar utilities does not necessarily translate to improved performance on their network because the networks used for benchmarking might not be subjected to the same level of disturbances.

- *Indicator 5: Network maintenance approach based on PQ (Par. 6.2.3.1; Figure 46).* According to the chart in Figure 46, there were 82% of utilities in question V37 who disagreed that they made use of PQ data to predict for the maintenance of their networks. This response implies that the respondents did not recognize the use of PQ data as a trigger for maintenance. The respondents might be of the opinion that PQ performance data might not be useful to inform them of the need for maintenance on the network. Hence, Figure 46 further revealed in question V24 that 91% of the respondents indicated that they had a maintenance plan for their electrical network to ensure good PQ performance.
- Indicator 6: Aspects of communicating and reporting of PQ performance (Par. 6.2.3.1; Figure 47, Table 28). In Figure 47 (question V26), the majority of the utilities indicated that they communicated their PQ data with their customers. In comparison with the response in question V31, 64% of the respondents disagreed with the statement that communication of PQ performance data promoted strong relations with key customers. This might imply that the utilities were not convinced that communicating PQ data to customers does improve relations of dealing with PQ issues, so they are not confident that improving relations with customers can be facilitated through regular communication of PQ data. Referring to Table 28, the responses indicated lack of adherence to PQ regulations by some participating utilities. The issue of reporting PQ data annually to the electricity regulator should be adhered to by all licensed utilities. Moreover, submission of PQ data by licensed utilities is useful for benchmarking their performance and to define characteristic values in PQ parameters throughout South Africa. In summary, the responses revealed by this quantitative data about the scope of PQ program undertaken by the utilities form a valuable contribution to this study.

7.3.2.3 Objective 3: To determine the extent to which utilities in SA perceives the use of smart grid on distribution network

This objective was achieved by analysing the data obtained from the power utilities responses to the questionnaire items in Section A and Section B that focused on the perceptions regarding the use of smart grid technology to support their electrical network operations.

Three constructs were developed to measure the perceptions of the respondents regarding smart grid technology. The analysis of the constructs' means obtained from the data indicate a favourable response, which implies that the constructs were an appropriate measure for smart grid technology. On evaluating the means for the constructs, the study found that the utilities perceptions on the use of smart grid technology were ranked according to the following means:

- *Social norms and behaviour (mean 4.02).* The utilities possibly believe that unlocking the potentials of smart grid technology can be realized through behavioural science in engaging consumers to reduce energy consumption for efficient network utilization. This data further indicate that the utilities are of the opinion that in each of the areas of opportunities offered by smart grid (to reduce energy consumption through efficiency, to shift use to off-peak times of day, and to expand distributed generation options) social norms and behaviour forms an integral part, as some of the smart grid components such as advanced metering infrastructure technology (AMI) requires consumer adoption and proper use for effective implementation (Par. 6.2.3; Table 25). These findings are consistent with the views in [135], [303], where it was found that smart grid must not only include technology, environmental impact, regulatory framework and information and communication technology, but also societal requirements and governmental edicts. This study found that power utilities considered smart grid as a mechanism for job creation and advancement of a technically skilled workforce, which serves to support the economic growth and development of the country.

- *Technical system operations (mean 3.82).* utilities possibly considers the threats posed by the intermittent and non-monotonic nature of renewable energy sources and believe that the distribution network possibly requires an integration of advanced monitoring and control technologies, as well as integration with automation processes in order to control the divergent energy flows and at the same time, enhancing the efficiency in production and consumption of power and improves voltage stability and system reliability (Par. 6.2.3;Table 23).
- *Cost-benefit and regulations (mean 3.68).* in conceding to the fact that smart grids are a key component of the global strategy toward a future low-carbon energy sources, utilities possibly believes that significant investments is required, as well as a provision of equitable allocation of short term cost and long term benefits amongst different stakeholders in order to minimise possible uncertainties and guaranteed incentives for investments on smart grids. Furthermore, the utilities possibly believes that policies and regulatory frameworks are needed to support the modernisation of their electricity networks in order to achieve interoperability of smart grid components (Par. 6.2.3; Table 24).

From the preceding findings, analysis of the data used to assess the constructs revealed that the utilities considered the three constructs to be an appropriate measure suitable for measuring aspects of a smart grid. it follows that hypotheses H5, H6 and H7 are also accepted, i.e., that constructs 5 to 7 are related to smart grid, as a useful technology to facilitate network operations.

Chapter 6 further discussed aspects to determine the extent to which the respondents perceived the use of smart grid to support their network operations. The researcher identified three leading indicators from the responses made by the participants on the questionnaire items of the constructs (Par. 6.2.3; Table 23 to Table 25). The findings on the leading indicators for the respondents' perceptions on smart grid are given below:

- *Indicator 1:* Monitoring and measurement based on a smart grid concept (Par. 6.2.3.1; Table 29). Data represented in Table 29, response to question V34 revealed that 82% of the respondents agreed that deploying smart grid technology can enable their utilities to increase power distribution efficiencies and reduce operating costs. In response to question V35, 64% of the respondents believed that with the integration of renewable energy sources on the electrical network, smart grids can enable their utilities to improve voltage stability and system reliability. In addition, responses for question V36 revealed that majority of the respondents (91%) indicated that their utility can enhance the management of PQ if they were to implement automated methods of detecting PQ problems. These responses might imply that the utilities have a greater awareness of the potential benefits offered by the smart grid technology, which bring into the fore, the issue of a need for a smart electricity grid (Par. 2.8).
- *Indicator 2:* Value proposition and incentives for smart grid (Par. 6.2.3.1; Table 30). Data in question V39, revealed that 73% of utilities responded that they understood the value proposition of a smart grid deployment. In response to question V40, 64% of the utility respondents indicated that regulatory standards were required to provide incentives aimed at rate recoveries for investing in smart grids. This response imply that the respondents envisage that there might be significant cost to utilities when deploying new smart grid technologies, and regulatory recovery of these costs might be an issue for the majority of utilities in South Africa, creating disincentive to technology deployment. This particular aspect also found support in [150] where it was reported that Government funding has been the major enabler for successful smart grid deployment which helps since high capital cost is required. Furthermore, this might also imply that the utilities believe that it might be difficult for them to

demonstrate positive net benefits, which might cause consumer protection agencies to oppose the deployment.

- *Indicator 3*: Efficient energy transfer and the environment (Par. 6.2.3.1; Table 31). According to the data presented in Table 31, the majority of the responses in question V43 (91%) of the respondents agreed with the statement that empowering consumers, communities and society in changing energy consumption behaviour is fundamental to the utilities energy market. In responding to question V44, 82% of the respondents indicated that the smart grid can qualify their expectations of efficient energy transfer as well as cost and energy savings for their customers. These responses might imply that the utilities are mindful of two aspects; (1) that they might need to engage consumers to change their behaviour in terms of the efficient use of energy and (2) that the consumer acceptance of smart grids and smart metering technology deployment might hinge on the consumer's desire to change energy consumptions. In responding to question V45, 73% of the respondents considered smart grid as a tool to facilitate the reduction of the country's environmental impact. This finding might imply that the utilities considers smart grid and smart meter technology to be at the forefront of the efforts to help protect the environment by allowing consumers to better control their energy consumptions and enabling the safe integration of clean renewable distributed generation sources. This might be due to the fact that, as an example, an increase in network efficiency generates energy savings equivalent to eliminating emissions likely to emanate from millions of vehicles in the country.

Following the findings in relation to the quantitative study, the findings in relation to the qualitative study are now presented.

7.3.2.4 Objective 4: Themes, Links and patterns in the description of industrial customers regarding their experiences and industry sensitivity to PQ issues and their views on smart grids

This objective was achieved by analysing the qualitative data obtained from the industrial customers' responses to the field notes from the semi-structured interview gathered to obtain the perspectives of industries regarding their experiences and industry sensitivity to power quality, as well as their views on the use of smart grid technologies on electrical networks in South Africa.

During the analysis, data reduction by means of an exploratory content and thematic analysis was done and themes were generated and labelled (Par. 6.3.3.1; Table 32 to Table 34). Data matrices were then used for displaying and organizing the themes in order to make a comparison of the accounts between the participants (Appendix A). The findings revealed that the description by the industry participants that were identified in the study, can be grouped into one of eight main themes:

1. Regulatory awareness;
2. PQ management mechanism;
3. Perceived PQ experiences;
4. PQ risk to operations;
5. PQ risk mitigation measures;
6. PQ-based premium;
7. PQ measurement philosophy; and
8. Smart grid obstacle.

Apart from small differences in views, impact and significance, the themes developed for the account on power quality experiences for the different industry participants (Cement, chemicals, mining, and water pumping and purification) were contextually related. Another related finding was that industries from different industry sectors exhibited some similar and other completely different experiences regarding power quality problems and the associated PQ risk to operations.

The one noticeable trend identified in this study was that all the industry participants revealed a similar account in that their industrial operations were sensitive to a variety of power quality problems, with voltage dip events being the most commonly experienced. Consistent with the views of the authors in [18], [77], [116] it was also quite evident from the data that regardless of the type of the industry, the economic threats to the industries due to poor power quality is a reality, and that a need and demand for a clean and reliable supply of electricity exist to ensure that economical and technical losses caused by PQ related problems are significantly reduced.

Findings in relation to the theme of PQ management mechanism revealed that most industry participants considered technical meetings to have a positive effect on the management of power quality. the most frequent description that emerged from the analyses were expressed mainly by one participant in the chemical industry, followed by the participants in the Cement manufacturing and the gold mining industry, as well as one participant in the water pumping and purification industry.

The study found that frequent scheduling of technical meetings with the utility had a positive effect in the partnership between the utility and the industries in sharing prevalence of network events and identifies solutions required to improve PQ performance. This data seemed to support the findings by the authors in [33], [82] that there is considerable evidence that relationship between utilities and customers can have a positive effect on identifying solutions to PQ problems.

Another particular aspect that came to the fore during the semi-structured interviews was the fact that apart from production losses and equipment damage, occurrence of a PQ event would have a detrimental effect on the safety of personnel. Here, the greatest hazards were found to arise from explosions leading to continuous fire risk, mainly for the chemicals and the mining industries.

Regarding safety of personnel, another finding from the mining industry participant was that prolonged lack of supply leading to adequate ventilation at underground levels were hazardous to personnel which might lead to suffocation and even explosion from accumulation of hazardous methane gasses. From the water pumping and purification industries, it was found that contamination of drinking water may occur due to PQ events that lead to an interruption of supply (Par. 6.3.3.2; Table 44).

Increasing use of high technology for production equipment, some industry participants revealed that some of their equipment operated at different voltage values and if any interruption in the equipment's control unit occurs due to voltage drop, voltage dip or voltage fluctuations outside the tolerance level, it could take several hours for the equipment to return to acceptable performance values, which meant a direct manufacturing loss.

It appears that power quality monitoring with proactive capabilities of detecting PQ problems are necessary in order to characterise all electromagnetic phenomena at a particular point on the network, so as to reduce the level of disturbances with the aim to minimize production losses, damage to equipment and avoid loss of human life.

A need for a smart grid technology for real-time monitoring of power quality was also identified as one of the main findings in the semi-structured interviews. The need for real-time monitoring was regarded by the industry participants as a proactive way of dealing with issues of power quality on the electrical network and to meet the expectations of all customers in terms of PQ performance. This also brought into the fore, another revelation by the industry participants that monitoring of power quality parameters should also be done on the SCADA system and form part of the standard practice of network parameter visualisation by utilities. This finding seems to be consistent with remarks in [287] in stating that the SCADA system will become a universal choice to visualize, detect and mitigate possible anomalies on the electrical network, which was further highlighted by the authors in [304], [305].

It might then seem less significant for power utilities to have more sophisticated and proactive means of managing certain aspects of the network such as power quality more intensively, as the increase in intermittent and unpredictable renewable energy sources together with the increasing use of modern electronic devices will put highest requirements on power balance control, from primary control through operational planning. Power utilities, however, will need to come up with technology solutions that achieve certain characteristics required for the planning, designing, operation and maintenance of the desired smart grid.

It was also evident that power quality should not be viewed as a separate aspect of the right of electricity offered by the utilities, but as a standard condition of delivering power. This requirement in particular, was consistent with findings in [313] who stated that in some countries in South America, legislation forces the power utilities to deliver a good power quality level, or otherwise to pay a penalty if the quality is outside the set limits. A similarity from the data sets (quantitative and qualitative) was observe with reference to the need and importance of real-time monitoring as an opportunity for the utilities in South Africa to enhance the management of power quality.

It was also found that not only can real-time monitoring provide opportunities for power utilities to identify PQ problems, but also enable large customers to have access to meaningful PQ information readily available, which then enable them a more informed decisions regarding power quality. So, the findings from the qualitative data from the interviews were consistent with the findings from the quantitative section and also correlate with the findings by the authors in [21], [71], and [187] who stated that enabling real-time monitoring for advanced distribution automation is an important benefit offered by the smart grid technology.

In summary, the semi-structured interviews, in conjunction with findings from the quantitative section, mainly emphasised on the need that exists for the effective management of power quality, and to inform the possibilities that smart grid technologies can be of benefit to power utilities. This forms the basis on which factors that can influence the use of these technologies by South African utilities are evaluated.

7.3.2.5 Objective 5: To formulate factors to influence a South African utility's decision to utilise smart grid for PQ management

This objective was achieved by combining findings from the literature and the findings from the empirical study, which together was used to formulate factors that can influence a South African based power utility's decision to use smart grid technologies for the management of power quality.

In Chapter 6, the extent of power quality management program employed by a sample of power utilities was emphasized along with their perceptions on the use of smart grid technologies on distribution networks to support their electrical operations. Underpinned by the total quality management philosophy, a power quality management framework relevant to managing power quality was used as suggested by the author in [30] and indicators for both power quality management and smart grid technologies were identified for further interpretation in the quantitative section of the empirical study.

The significance of using the total quality management philosophy was necessary in the sense that it could be adapted to serve the purpose of this study and hence, smart grid technology was used to serve the aspect required for the measurement and monitoring of power quality. Over and above the indicators identified in the quantitative section, description given by industry participants in the semi-structured interviews of the qualitative phase of the empirical study were interpreted to produce findings in line with the aims and objectives of this research. Until far, the findings for the objectives in this study has led to the formulation of factors influencing the decision to use smart grid technologies by utilities in South Africa.

In achieving this, a multi-criteria factor was identified on the basis of four-dimensional strategic elements, namely Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis concept suggested in [308], [309]. SWOT factors were formulated on the basis of two strategic positions, namely SWOT factors on the extent of PQM program employed by utilities in combination with analysis of existing network from the literature, and SWOT factors derived from the ensuing smart grid as opportunities.

These factors served the purpose of evaluating the SWOT (Strength Weaknesses Opportunities Threats) regarding smart grid technologies toward the monitoring and management of power quality, in order to enhance the performance thereof.

7.3.2.6 Findings on the SWOT factors relating to the scope of PQ management program by power utilities

In so far as the major findings from the empirical investigation, the following **Strengths** factors on the extent of PQM program employed by the power utilities as well as on the existing electrical network were noted:

1. Availability of policies to ensure PQ management;

2. Existing hierarchy of electrical infrastructure, with network designed for PQ considerations;
3. Increasing focus on renewable energy mix; and
4. Ability to analyse PQ performance trends, especially by the larger utilities.

The following **Weaknesses** in the extent of power quality management programs and analysis of existing electricity infrastructure were derived from the data:

1. Lack of efficiencies in energy transfers and higher technical losses;
2. Aging distribution network infrastructure that battles to support rapid growing and changing network requirements;
3. Insufficient electricity generation capacity; and
4. Inability to meet changing and more demanding customer expectations on PQ.

Opportunities and **Threats** were also derived from the data and the following threats are discussed first:

- Infrastructure and technology immaturity;
- Frequent network faults leading to voltage dip incidences and line trips;
- PQ risk to industry operations;
- Lack of distribution network automation and control; and
- Environmental footprints

From the empirical research, the analysis of the data revealed a number of findings as opportunities that were indicated by the research participants for exploration to benefit power utilities in neutralising the possible Threat factors that emanate from the inadequacy of the power quality management programs employed by the utilities, and to address the aging existing electricity infrastructure.

It was found that a number of opportunities, namely, upgrading of existing electrical infrastructure, technology advancement and innovation, automated substation infrastructure, installation of smart metering instrumentation and monitoring through SCADA systems, and enabling consumer awareness about energy-efficiency and demand management were amongst the opportunities that can be explored by a South African power utility.

When cross-referenced with the literature findings, the preceding opportunities were found to be consistent with the roadmap to transform from traditional electrical utility network to intelligent grid, made possible by the smart grid [27], [140], [135], [150], [303] . In pursuit of these opportunities, findings relating to the decision to influence the implementation of the smart grid in perspective were formulated. The findings are discussed next.

7.3.2.7 Findings on the SWOT factors relating to the opportunities of implementing smart grid

As alluded to in the preceding paragraph, the empirical study identified opportunities for utilities to transform from traditional electrical utility network to intelligent grid. Consequently, findings on the SWOT factors leading to the decision to make use of smart grid technologies in this study were derived from the data analysis in Chapter 6 (Par. 6.2; Par. 6.3) and the following **Strengths** factors were subsequently formulated (Par. 6.4.2; Table 36):

- 1: Use of proven models implemented by other countries and organisations globally;
- 2: Access to clean and sustainable renewable energy sources (solar and wind); and
- 3: Reducing the environmental footprint.

From the research findings, the following factors were formulated as potential **Weaknesses** toward the deployment of smart grid by the power utilities:

- 1: High initial infrastructure and deployment cost; and
- 2: Interoperability issues between different technologies relating to proprietary issues from instrument suppliers

In spite of the resulting weaknesses expressed in the study, findings from the SWOT analysis led to the formulation of the following significant factors on the basis of **opportunities** derived in relation to the utilization of the smart grid technologies (Par. 6.4.2; Table 36):

- 1: Power utilities can have a collaboration with research institutions and non-governmental institutions to develop smart grid pilot systems;
- 2: power utilities can be in a better position to have support from government to develop microgrids at smaller scale that would benefit all segments of the distribution network;
- 3: Efficient, automatic modernised electricity network;
- 4: Power utilities can be enabled to safely integrate the technologies of renewable energy generations (solar and wind farms) into the distribution network, and maintain an efficient voltage control capability;
- 5: Using advanced methods of distribution automation can enable the utilities to improve the monitoring of power quality and reliability of supply by proactively rerouting supply networks during times of power outages or severe voltage fluctuations; and
- 6: Opportunities to have a dynamic real-time decision and management of network parameters and identification of disturbances can be achieved through the SCADA systems.

Without a shadow of doubt, it can be said that it is possible for a South African-based power utility to make use of smart grid technologies which ultimately serves as meaningful contribution to a power quality monitoring and measurement system that could be integrated to improve the management of power quality in distribution networks. In the preceding sections, the most important findings of this study in relation to the research aims and objectives were presented. The next section provides the answers to the main research question.

7.4 Answer to the main research question

The research question investigated in this study was as follows:

> *Does the use of smart grid technologies provide an opportunity to improve the management of power quality in a South African-based power utility?*

The empirical investigation revealed through the quantitative study that there are opportunities for using smart grid technologies, :

> H_M: *The use of smart grid technologies provides an opportunity for a South African-based power utility o improve the management of power quality.*

In support of the quantitative study, this research revealed through the explorative qualitative study that the use of smart grid technologies provide power utilities with an advantage to make use of the SCADA system to proactively monitor and detect causes of power quality problems on the network, ensure compliance with electricity regulations in terms of power quality, promote customer relationships and gain end-user trust by making power quality performance data readily accessible when needed.

As such, the qualitative study also provides plausible supposition that smart grid technologies do provide an opportunity for a utility to enhance the management of power quality in South Africa. From the proposition made in the quantitative study, hypothesis H_M is therefore accepted, and the primary research question is answered.

7.5 Limitations of the study

This study was limited in to the following ways:

1. During the pilot study, the participants of the expert panel were chosen for their knowledge of the field of power quality and excluded less informed yet affected individuals. This may have created bias in the design of the research questionnaire. However, reliability assessment of the constructs yielded plausible scores indicating that respondents understood the questions and therefore bias was not present.

2. The low response rate of 5.8% represented 11 utilities respondents and the authors in [218] recommends a sample size of at least five times the number of test items in the research questionnaire for factor analysis, hence, the study was limited to a single-stage statistical procedure, in which descriptive statistics was used for the analysis.
3. Because the researcher did not have extensive experience in primary data collection using survey, the nature of implementation of data collection might have resulted to a low response rate and consequently, this meant that the researcher had a limited amount of quantitative data to work with. Had the researcher expanded the sampling frame within the target population to contribute to the research, a more comprehensive and holistic view of the scope of power quality management program and the perception on smart grid technology could have been obtained leading to adequate samples to perform structural equation modelling and the testing of hypotheses using statistical analysis.
4. The authors in [218] further possets that data-driven modification to correlation models resulting from low response rate may result in a model that does not generalise to a population or to other samples. , the research instrument used should be considered tentative until it is successfully subjected to adequate samples so that generalisation of the results can be easily justified. With only 11 utilities from a total of 188 licensed utilities spread over the country, a great deal of uniformity could be expected. It could be argued that these 11 utilities, which includes Eskom that spans all over the nine provinces would make more meaningful differences, however this assumption cannot be argued statistically. However, the findings obtained from the data may be useful for similar context and participants with similar biographical characteristics.
5. Since the study entailed collecting qualitative data as part of the mixed method approach, only large industry participants supplied by Eskom were interviewed, which limited the researcher to compare experiences and accounts by industry participants supplied by other utilities such as Ekurhuleni metropolitan. This may have revealed different themes than would have featured if other industry participants were considered. However, the data saturation that occurred strengthened the researcher's confidence in the findings.
6. It should also be borne in mind that some of the interviews were conducted three years ago (from September of 2015), which meant that a great deal may have changed since the data was collected. For instance, these interviews were conducted during the period of the frequent load shedding events which may have influenced the perceptions in the response by the industry participants.
7. Since analysis of the qualitative data required a labour-intensive analysis process such as categorization and coding, this posed a limitation to the researcher as it required extensive experience to obtain data from the industry respondents.
8. Lastly, another limitation to the researcher in relation to the analysis of the qualitative data was that since the researcher is a person with visual impairment (blindness), it was not possible to utilise computer-aided text software such as the ATLAS.ti for the analysis to compare codes and build and refine categories, to define conceptual similarities and to discover patterns from the data, mainly due to accessibility issues between the ATLAS.ti software and the JAWS computer software used by the researcher to interact with the computer. However, reading and rereading of the transcribed interview data enabled the researcher to summarise the themes manually by using Microsoft excel spreadsheets in order to reach the findings. To strengthen the researcher's confidence in the findings, the researcher drew strength in the statement by the author in [314] who states that "Computer software can provide assistance to analyse data, but it cannot do the analysis for the researcher." another personal limitation to the researcher which posed limitations to the quality of the research dissertation is that the researcher utilised the support of other individuals who assisted in the plotting of charts and schematics.

7.6 Significance of the study

This study is significant due to the following reasons:

- The management of power quality in South Africa need to be approached differently by power utilities as the manner in which electricity is generated, transmitted, distributed and consumed has changed;
- Implementing smart grid technologies on distribution network in the context of South Africa is a developing concept worth exploring;
- The study was also empirically investigated as a field of study for the first time towards the enhancement of power quality management by a South African-based power utility;
- Exploring the opportunities of using network coherent data from power quality instrument designed according to edition three of IEC 61000-4-30 Class A requirement is significant in the monitoring and measurement of power quality, which can be incorporated as a smart grid component on South African distribution networks; and
- The knowledge gained from prior scholarly research on smart grid and implementation by other countries is significant for South African power utilities. The next section covers the resulting conclusions drawn from this study.

7.7 Conclusions

7.7.1 Objective 1: Development of an instrument to measure the concepts PQ management and smart grid

The following conclusions were drawn in relation to research objective 1 – to develop an instrument to measure the concepts power quality management and smart grid technology.

It is possible to describe and delineate theories relating to power quality and monitoring and measurement technologies, thereafter, operationalise them to develop an instrument to quantitatively measure the concepts power quality management and smart grid technology by means of a literature review.

The concept power quality management, or the scope of power quality management program in a power utility can adequately be assessed using the following elements:

1. Top management commitment;
2. Service quality assessment;
3. Network topology and design; and
4. Customer interaction.

The concept smart grid technology can be measured using the following elements:

1. Technical system operations;
2. Cost-benefit and regulations; and
3. Social norms and behaviours.

The measurement instrument can be regarded as a reliable instrument for use by a power utility to determine its scope of power quality management program as well as to measure the extent to which smart grid technology can be used for their network operations. It is concluded that through inter-item correlation, items on the questionnaire reliably measure the construct they were intended to measure.

Based on the preceding, it can be inferred that a power utility should dispose of many different activities in the effective management of power quality.

7.7.2 Objective 2: Scope of PQM program employed by a South African utility

The following conclusions were drawn in relation to research objective 2 – to determine the scope of power quality management program employed by a South African-based power utility:

- It is possible to empirically determine the scope of power quality management program employed by a South African based power utility at the hand of a structured questionnaire that was constructed in alignment with the literature overview, a theoretical framework for quality management and the research objectives as referred to previously (Par. 7.5.1) and these play an important role in assessing the scope employed by a South African utility in the management of power quality.

- Although some form of power quality management programs exists for the power utilities, not much progress has been made to date by South African utilities with regard to power quality management. Power quality management mostly exist at large power utilities, with sufficient resources and expertise on power quality, however, there are local utilities (small municipalities) who are starting to have power quality management programs.
- Not all the utilities who have a power quality management program conducted power quality impact analysis before connecting customers to their network. It is to be reasoned that the utilities did not proactively manage customer installations that are likely to cause PQ disturbances on their networks.
- There are utilities who still do not perform investigations to determine root causes of PQ problems on their electrical networks.
- Majority of the utilities did not do network life-cycle analysis to predict a decline in PQ performance. This tended to create the impression that the network life-cycle analyses in general, are merely regarded as insignificant which do not necessarily be seen as helpful to identify conditions that could affect power quality performance.
- While the utilities' electrical networks are designed with a view to optimise power quality, not all the utilities performed analysis to benchmark performance of PQ parameters, especially voltage dips, to derive characteristic number of voltage dip performance on their network.
- Majority of the utilities consider benchmarking of PQ performance amongst each other's to be insignificant and time-consuming.
- Although electrical network maintenance policies existed to ensure good power quality, the utilities do not make use of PQ data to predict for maintenance of their networks. It seems that PQ performance data is not regarded as intelligible enough to inform the need for maintenance on the electrical network.
- Power utilities do not adequately form relations with their key customers by communicating PQ performance data. A lack of adequate PQ information by key customers make it difficult for a partnership between utilities and customers to speedily resolve PQ problems.
- Not all the utilities reported their PQ performance annually to NERSA. The absence of PQ performance data for a variety of networks that must be reported to NERSA can result in a lack of accurate PQ statistics needed to understand the PQ performance view from a South African context.

It can be concluded that the current scope employed by the utilities in the management of power quality need a different approach, which advocates for proactive methods of monitoring and measurement of power quality.

7.7.3 Objective 3: Extent to which power utilities perceives the use of smart grid on distribution network

The following conclusions were drawn in relation to research objective 3 – to determine the extent to which South African based power utilities perceives the use of smart grid technologies for their network operations:

- It is possible to empirically determine the extent to which South African power utilities perceives the manner in which smart grid technology can be used for their network operations at the hand of a structured questionnaire that was constructed in alignment with the literature overview, a conceptual framework for smart grid technology and the research objective as referred to previously (Par. 7.5.1).
- Power utilities have a desire to make use of modern technology to improve the monitoring of PQ performance on their networks
- There is a greater awareness of the concept of smart grid technology by power utilities in South Africa. There is also coherence amongst the utilities in terms of understanding the value proposition of the smart grid deployment.

- Power utilities have a high expectation on the smart grid technology in providing efficient energy transfer capabilities, cost savings for their customers as well as to serve as a blueprint and starting point for the reduction of future environmental impact.
- The deployment of smart grid technology can enable a South African based power utility to improve voltage stability and system reliability emanating from the variable nature of distributed renewable energy sources.

It is possible to use the benefits offered by a smart grid technology to enable automated methods of detecting PQ problems which further enhances the management of PQ in a South African power utility

From the data that were collected, it seemed that the extent to which power utilities perceived the use of smart grid technology for their network operations bears relation to the efficient running of the electrical network for better power quality and consequently, these perceived attributes were used to formulate factors as being the focal point of this research, namely to evaluate the key factors influencing a South African power utility's decision to utilise smart grid technology for power quality management.

Based on the preceding, it can be inferred that the extent to which power utilities can utilise smart grid technology for their network operations can be beneficial to enhance the monitoring and measurement of power quality on distribution networks.

7.7.4 Objective 4: Themes, links and patterns on the descriptions by industrial customers on their experiences and industry sensitivity to PQ issues and their views on smart grid

The following conclusions were drawn in relation to research objective 4 – to provide the description by key industrial customers regarding their experience and industry sensitivity to PQ issues, as well as their views on the use of smart grid technology:

The description and account given by the industry participants that were identified in the qualitative phase of this study, can be grouped into one of eight themes:

1. Regulatory awareness;
2. PQ management mechanism;
3. Perceived PQ experiences;
4. PQ risk to operations;
5. PQ risk mitigation measures;
6. PQ-based premium;
7. PQ measurement philosophies; and
8. Smart grid obstacles.

Except for small differences, the experiences and account on each theme by the industry participants in the different industrial sectors are the same. Where small differences occur, they are related to the PQ requirements, impact to the industry and the type and size of the industry in terms of energy demand.

Although some industry participants revealed awareness of the NRS 048 standard for the management of PQ in South Africa, industry participants do not have an awareness of the international measurement standards relating to the measurement of PQ as well as the understanding of a PQ instrument complying with IEC61000-4-30 Class A requirement. When purchasing PQ instruments, they merely rely on the instrument manufacturer specification for the instrument conformance to PQ measurement standards.

Industry participants' operations are sensitive to the majority of PQ parameters, with voltage dip incidences being the most frequently experienced events by all the industry sectors. Industry participants that are supplied via rural MV reticulation networks are also experiencing high prevalence of supply interruptions.

The negative impact of poor PQ to industry participants can result in loss of production, overtime costs, and safety risk to employees, water flooding in the shafts, damage to equipment, risk of explosion, impact to water quality and water hammering to infrastructure. All the industry participants will unequivocally suffer loss of income from loss of production should a PQ problem cause a prolonged shutdown of their operations.

Occurrence of a PQ event that result in interruption of supply to the chemical and mining industry participants can result in explosions which also poses a safety risk to workers.

The water pumping and purification industry is sensitive to PQ, in the sense that any uncontrolled shutdown of the pumping system due to a sudden loss of supply can result to contamination of drinking water.

In mitigating the effects of PQ, not all industry participants have voltage ride through capabilities to protect their sensitive equipment against less severe dips. Although their equipment was compatible with the PQ at PoCs, some industry participants have limited protection schemes for protecting their facilities against other adverse PQ. It seems important for the industrial customers to understand the concept and requirement of equipment compatibility in the management of power quality.

With a desire for good PQ, majority of the industry participants have a willingness to pay for an electricity supply with impeccable PQ performance that is not disruptive to their operations.

From the perspective of measurement philosophy, conclusions can be drawn that clearly indicate that measurement of PQ are considered highly important by the industry participants. All of the industries make provision for PQ measurement on the utility's incomer as well as within their own network.

The smart grid technology is viewed by the industry participants as an automation of the grid, with intelligent devices that can perform monitoring and reporting of PQ. It can serve as a system where the utility can have an online view of the monitored PQ. In relation to power generation, the smart grid is better suited for control of renewable sources

The smart grid provides opportunity for PQ reporting in a real-time system, enabling the power utility to immediately visualise where faults and PQ problems are occurring on the network.

Synchronized measurement of PQ can be made possible through smart grid which provides benefits to utilities to better understand and locate sources of PQ problems. Coordinated measurement of PQ is made possible in order to assist to pinpoint fault locations and help diagnose problems on the network.

Visualizing of PQ parameters on SCADA should be the integral part of the utility's business. There seems to be value in the ability of the SCADA system to help to detect and possibly classify parameters such as a voltage dip event as it occurs on the network

From the preceding, the main conclusions drawn from the empirical research are that power quality is becoming more important to industrial customers as energy efficiency equipment are incorporated into the utility's network and as renewable energy sources is connected in distribution networks. Moreover, during the normal operation of the network, the interaction of these equipment and the renewable energy sources with the existing electricity network give rise to faults and many other PQ related problems. As a result, thereof, industry participants (Cement manufacturers, Chemicals, Gold mining and Water pumping and purification) exhibit similar needs with regard to power quality but unequivocally suffer from disturbances such as voltage dips. It should be the intentions of any utility and the industrial customer to adopt measurement standards for power quality in order to proactively identify these disturbances, and to limit them to those which will not cause damage to either utility or customer equipment. From a utility perspective, this form the basis for evaluating factors to influence a power utility's decision to utilise smart grid technologies for the management of power quality.

7.7.5 Objective 5: Factors influencing a utility's decision in South Africa to use smart grids for PQ management

The culmination of this study led to the formulation of important factors influencing a South African-based power utility's decision to use smart grid technology for power quality management in accordance with research objective 5 of this study, which enabled the researcher to make the following conclusions:

The SWOT analysis technique can offer possibilities of highlighting the challenges of existing scope of power quality management program employed by a South African power utility and the prospect opportunities of implementing smart grid technologies to enhance the PQ management programs in perspective.

The existing scope of power quality management program in a South African power utility possesses the following Strengths which informed the decision towards a shift in the potential use of monitoring technologies:

1. Availability of policies for the management of PQ;
2. Existing hierarchy of electrical infrastructure, with network designed for PQ considerations;
3. Increasing focus on renewable energy mix on electrical networks; and
4. Existing efforts of analysing PQ trends, especially by large power utilities (Eskom and Metropolitans utilities)

It is indeed possible to neutralize the current threats posed by the existing concerns relating to power quality as revealed by industry participants in the empirical study of this research (Par. 7.5.4).

From the prospect opportunities of implementing smart grid by the utilities, conclusions were drawn as the influencing Strength Opportunities factors, and the following are Strength factors:

1. South African power utilities can make use of proven models implemented by other countries and other organisations globally;
2. A potential of accessing clean and sustainable renewable energy sources exist for a South African power utility; and
3. South African power utilities have accessible means of reducing the environmental footprint.

The following are the conclusions drawn in relation to the Opportunities factors:

1. It is possible for a power utility to have a collaboration with research institutions and non-governmental institutions to develop smart grid pilot systems;
2. Development of microgrid system at smaller scale is possible and can be backed by government;
3. Power utilities can be enabled to possess an efficient, automatic modernized electricity network;
4. The efficient integration of distributed renewable energy sources is an aspect of persuasion to a South African utility;
5. Improving power quality and reliability through advanced distribution automation is possible; and
6. It is possible to achieve a dynamic real-time decision and management of network parameters and identification of PQ disturbances through the smart grid concept on a SCADA system.

In general, through the use of intelligent data concentrators connected to PQ instrumentations designed according to edition 3 of IEC 61000-4-30 Class A requirements, it is possible for a South African power utility to be in a better position in terms of improved monitoring and management of PQ on the network. Smart metering and advanced grid wide area real-time monitoring information can make the network more reliable with less adverse PQ disturbances, due to the potential ability to quickly respond real time to sudden shifts in power consumptions or problems with the distribution lines, thereby increasing its resiliency.

Factors influencing a power utility's decision to use smart grid for their power quality management program indicate that strategic efforts are required from power utilities to not only upgrade the existing network infrastructure to improve the management of PQ, but explore opportunities toward self-healing and resilient distribution networks by integrating renewable energy sources into the network through Information and Communication Technologies, and smart sensing and instrumentation.

This formed the basis for the factors influencing the use of smart grid technologies for the management of power quality by a South African power utility, based on the conclusion drawn from the utilities responses and accounts from the industry participants. It can be said that the research findings and the conclusions drawn empirically demonstrate that the use of smart grid technologies cited in various literatures can be regarded as precursors for a shift in the manner in which power quality can be monitored and measured on distribution networks, which underpins the management of power quality in power utilities.

7.8 Recommendations

Since the introduction of pollution tax reforms by the then Finance Minister Trevor Manuel in the 2004 South African budget, South African businesses and organisations were later encouraged to undertake the use of clean technologies and failing which, a fine could be imposed to companies that pollute the environment [315].

More than a decade later, compliance to environmental legislation on air quality by companies has not improved significantly, and the major contributors (Eskom and Sasol) to air pollutions continues to be exempted and are granted postponement by the South African government from the air quality act [316]. This have seemingly also been vocalized by David Le Page of Fossil Free South Africa during the NERSA hearing in October 2017, that South Africa has the 13th largest emissions in the world, and Eskom is the largest contributor in the country [317].

In his view, Eskom has the greatest responsibility to decarbonise the environment by generating, transmitting and distributing electricity in an environmentally-conscious manner. This is amongst the reasons why the South African Smart Grid Initiative (SASGI) policy workgroup created a national framework through the smart grid vision [303], in order to steer a national approach to smart grid implementation in South Africa.

The intention of developing the implementation of smart grid solutions were amongst others, to facilitate the integration of renewable energy, supporting national energy objectives and a transition towards a low-carbon economy. In addition, the smart grid aspiration would be positioned to enable the electricity network to bring other benefits to customers through improved quality of supply and better energy consumption management. It stands to reason that all power utilities should implement power quality management programs by incorporating modern technologies to effectively deal with the challenges, needs and expectations of customers regarding PQ issues.

7.8.1 Recommendations in relation to the research findings

All power utilities in South Africa should have strategies for implementing power quality management programs with the intention to resolve PQ challenges and to meet and exceed the expectations of electricity users which are based on noticeable quality objectives (Top management commitment, Service quality assessment, Network topology and design and Customer interactions) and to further undertake innovative solutions with sophisticated measurement methods not only for adequate power quality, but also for detecting the potential causes of the power quality anomalies.

Although South African power utilities are taking steps towards the management of power quality-as indicated by the number of utilities who recently started to implement power quality management programs, the use of preventative measures such as impact analysis before connecting customers on the network, however, is very limited in South African power utilities. If analysis such as impact analysis are performed prior to connecting customers, this would minimize PQ disturbances such as voltage harmonics before it occurs.

This research indicates that fewer power utilities are taking part in the annual reporting of PQ performance statistics to NERSA. At the core of reasons for this are the lack of PQ expertise within the majority of utilities to perform investigations to determine root causes of PQ problems and lack of commitment by management at smaller municipalities to undertake PQ management programs. In accordance with the purpose of the study it can be recommended that the National Energy Regulator of South Africa investigate and enforces compliance of measurement of PQ, investigate nonconformities to PQ standards and to report the annual statistics thereof.

The need for addressing the challenges of responding to the changing energy system and expectations of customers on adequate power quality are indicative of the prevailing effect poor PQ has on customer equipment and on the utility's network. The need for the afore-mentioned was identified as a motivation for the current study and was further substantiated by the views from the industry participants in the semi-structured interviews.

A need exists to integrate the monitoring of PQ into the SCADA system to proactively detect problems as they occur on the network. In other words, it is recommended that power utilities make use of the SCADA system not only to monitor the steady-state performance of electrical networks to track the voltage, current and power flow, but also to monitor and visualize a wide range of PQ parameters. An approach such as the preceding may lead to proactive management of power quality at customer's PoC's, whilst encouraging solutions on the upstream of the distribution networks.

If technologies such as the smart grid are strengthened by investments in research and development, power utilities can gain technical capabilities in proactive monitoring of power quality. Utilities can also operate their networks more efficiently, by enabling an adequate balance between supply and demand. In the smart grid vision strategy report published in 2013 by the Department of Energy aimed at facilitating the development of establishing an adequate electricity supply system for South Africa, the following reasons for a shift toward a smart grid were suggested [303]:

1. Improvement and upgrade of the "business as usual" grid; and
2. The outcome of substantial benefits that come with establishing a smart grid.

Once again, the report states that while South Africa is confronted with the challenges of responding to the changing energy system requirements, it has also mostly trailed the world in the adoption of advanced monitoring technologies offered by the smart grid. South Africa is however in a favourable position where this coincides with the need for infrastructure investments to advance the smart grid technology development and lessons learnt by the precursors in implementation. Power utilities could also work closer with policy makers and government to encourage utility-specific smart grid implementation.

In a concerted effort to be amongst the utilities implementing smart grid technologies in the context of South Africa, this research indicates that through Technical system architecture, cost-benefit and regulations and social norms and behaviours, the extent to which a utility perceives the use of smart grid on its electrical network can be empirically assessed.

This then clearly shows a strong desire by power utilities on advancing the management of power quality. the utilities could promote the use of intelligent PQ monitoring technologies by implementing pre-emptive strategies of real-time online fault and PQ problem detection so as to minimize corrective-based interventions

This research indicates that implementing PQ measurement strategies that incorporates the technology of smart grid by a South African utility is virtually up to the utility itself, shown through the following influences (Par. 6.4.2, Table 36):

1. Power utilities can have a collaboration with research institutions and non-governmental institutions to develop smart grid pilot systems;
2. Concerted effort by utilities to develop microgrid system that would benefit all segments of the distribution network should be backed by government;
3. Utilities should be able to possess an efficient, automatic modernized electricity network;
4. Utilities should have an opportunity to safely integrate the technologies of renewable energy generation (solar and wind) into the distribution network, and maintain efficient voltage control capabilities;
5. The use of advanced distribution automation should enable utilities to improve the monitoring of power quality and reliability of supply by proactively rerouting supply networks during times of power outages or severe voltage fluctuations; and
6. Achieving a dynamic real-time decision and management of network parameters and identification of system disturbances should be enhanced through a smart grid on a SCADA system.

Apart from just transitioning from smart grid from the current electricity network, the use of distribution automation employing advanced PQ instruments designed according to edition three of the IEC 61000-4-30 Class A requirements for the surveillance and recording of PQ should also provide large industrial customers with PQ information that will benchmark the overall system performance, assist in preventative maintenance, assess network performance and sensitivity to process equipment.

In addition to loss of income and equipment damage due to a PQ event, this research indicates that Risk of explosions leading to a possible loss of human lives may occur at industrial operations like the chemical and the gold mining, and it is recommended that power utilities consider the implications of having PQ disturbances that can result in a loss of life to industries.

Furthermore, the research indicates that communicating power quality performance data strengthens partnerships with key customers in partnering to resolve PQ issues. This is also not uncommon to Eskom, as demonstrated by the approach taken to giving its key customers individual attention and customised solutions in order to meet their unique requirements [82]. It would therefore benefit the power utilities to have its real-time PQ performance data accessible to its industrial customers, which would further heighten the already existing partnership.

Finally, this research also indicated a need for synchronized measurement of power quality data in a wide area network. This would allow comparison of PQ data measured at different locations as though the measurements were all made by a single instrument. This can be made possible by synchronization of the PMUs using a common time distribution such as the GPS.

It is recommended for power utilities in South Africa to consider the use of PQ instruments with precise time protocols that can allow synchronized data measurement such as phase angle variations across a wide area, which would be useful for comparison of PQ disturbances on smart grid implementation for distribution networks.

7.8.2 Recommendations for future research

The empirical research of this study show that smart grid technologies can provide opportunities for a South African power utility to enhance the management of power quality at distribution level. Since this is the first known study in South Africa to delineate the concepts power quality management and smart grid technology and measure them quantitatively, it would benefit the research area if further empirical research were conducted on larger sample size and to further measure the causal nature of these concepts in order to either confirm or refute these findings.

It is also recommended that analysis of large industrial customers supplied by other South African utilities and by Eskom in all the provinces be performed to evaluate their experiences and industry sensitivity to PQ issues and whether the use of smart grid technologies could indeed be a solution to the management of power quality. For this purpose, the findings of the qualitative study can also be developed to a survey questionnaire to statistically test the model and to determine causal relationships.

In addition, the study could also be repeated after five years to determine if South African-based power utilities are moving towards the modern intelligent methods of PQ monitoring and measurement within the context of the smart grid technologies.

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Appendix A: Data charts used for qualitative analysis

Table 37: Data Matrix, theme – regulatory awareness

Participant:	Awareness to PQ standards	The mandate of utilities on PQ	Familiar with PQ clauses
Participant 1	The participant mentioned being aware of the NRS 048 standard and described it as being part of the NRS series of documents. However, in terms of the international standards, the participant mentioned that they did not know the standard for the measurement of PQ and also did not know of a PQ instrument complying with IEC 61000-40-30 Class A requirement.	The participant mentioned the mandate of utilities as a compliance requirement to an act that references the PQ requirement within the NRS standard.	The participant mentioned being familiar with the existence of PQ clauses, but specifically as part of the annexure on the generator connection agreement.
Participant 2	The participant mentioned being aware of the NRS 048 and also had a copy of the standard but said that he did not really know its specific name. They did not know the measurement requirement of IEC 61000-4-30 Class A standard.	The participant mentioned that utilities are mandated to comply with the set of rules that are entrenched in the regulation of electricity	They were not familiar with the PQ clauses but indicated that PQ clauses are important for supply agreements between customers and the utility
Participant 3	The participant mentioned that they were aware of the NRS 048 standard, but did not really know its name. They also mentioned being aware of the international standard for the recording of PQ. Although they did not exactly know the IEC requirement, they mentioned that their PQ instrument did comply with the standard.	The participant mentioned that the utility's mandate is to comply with the NERSA rules, and further stated that utilities have to use the rules to set minimum PQ requirements to manage PQ for its customers.	The participant mentioned that they were familiar with the PQ clauses in supply agreements. The described the clauses as being part of the energy supply agreement with the utility.
Participant 4	They mentioned that they were not fully aware of the NRS 048 standard locally at their firm, but their senior within the organizational hierarchy would be familiar with the standard. They were also not familiar with the international standard for the recording of PQ. Although they personally did not know the IEC requirement, they believed that the consulting company that they make use of for their PQ monitoring new the PQ instrument requirement	Not mentioned by the participant	The participant mentioned that they were familiar with the PQ clauses in supply agreements. They describe the clauses as something that enables them to be aware of their rights in dealing with PQ issues.
Participant 5	The participant mentioned that they were aware of the NRS 048 standard, but not the specifics. They did not know of the international standard for the recording of PQ. They also did not know the PQ instrument compliant requirement to the IEC 61000-4-30 Class A.	Not mentioned by the participant	The participant mentioned that they were familiar with the PQ clauses in supply agreements. They mentioned knowing the clauses but maintained that they have not paid many details to the clauses. They, however, described the PQ clauses as important and consider them as qualifying measures for the service by the utility, they are a critical part of the supply agreement with the utility
Participant 6	The participant mentioned that they were aware of the NRS 048 standard. Regarding the recording of PQ, they mentioned that they did not know the details, but they usually refer to the user manual that comes with the meters. As for the requirement of a PQ instrument complying with the IEC standard, the participant said that they did not know.	Not mentioned by the participant	The participant mentioned being aware of PQ clauses in supply agreement. They mentioned that the clauses are stipulated in relation to PQ, as part of their supply agreement with the utility. The clauses are considered to be important and being aware of the clauses enables the participant to know their obligations regarding PQ
Participant 7	The participant mentioned that they knew of the NRS 048 standard, but were not familiar with the details. As for the international standard, and the	The participant mentioned that utilities have a mandate to abide by the rules set in the	The participant mentioned being aware of the PQ clauses contained in the supply agreement with the utility. They further

	compliance requirement of a PQ instrument to IEC, the participant mentioned that they did not know	regulations, but they did not exactly know the process of how the utility should follow to manage PQ.	mentioned that having the clauses is important as it enforces the agreement in the event of a dispute between them and the utility

Table 38: Data Matrix, theme – PQ management mechanism (Part A)

Participant:	Utility / customer partnership	Technical meetings	Incident reporting procedure
Participant 1	Utility/customer partnership was mentioned as an important aspect in the management of PQ issues. They believe that it provides the main mechanism through which the utility can be engaged on PQ related issues.	Technical meetings are regarded as important means on which both parties are able to discuss issues impacting PQ performance. They mentioned having bi-monthly meetings where they engage with the utility on technical issues. They are able to follow up on progress made to resolve PQ issues and discuss factory plants to be commissioned and planned shutdowns.	Incident reporting procedure was mentioned as the method by which PQ related issues are lodged with the utility. Lodging queries/complaints impacting their operations is done by contacting their representative (Customer executive) at the utility. This includes billing, maintenances, and PQ.
Participant 2	Utility/customer partnership was mentioned as an important aspect in the management of PQ issues. They described this as a two-way communication, in that frequent consultations is made with the utility on PQ related matters and in turn, utility responds to these matters.	Not mentioned by the participant	The participant liaises with their representative (Customer executive) at the utility to lodge all queries impacting their operations, including, billing, maintenances and PQ.
Participant 3	The participant mentioned that interfacing with the utility enables the exchange of information when they have PQ issues that needed to be resolved. , they regard utility/customer partnership as an important aspect of managing PQ issues.	They regarded technical meetings as important means on which both parties are able to discuss issues impacting PQ performance. They hold quarterly meetings with the utility where the QoS specialist from the utility would present the PQ performance of the network. They also request Ad-hoc meetings with the utility to urgently address issues of voltage dip occurrences.	Lodging queries/complaint mainly relating to voltage dip incidences is normally done through contacting their representative (Customer executive) at the utility. There are instances where they are required to submit queries via the utility's call centre number.
Participant	Utility/customer partnership was mentioned as an important aspect of managing PQ issues. They regard it as a starting point on which to establish a relationship that would be beneficial to both parties on PQ related issues.	Technical meetings are regarded as important means on which both parties are able to discuss issues impacting PQ performance. They have quarterly meetings with the utility where the PQ performance is shared and all other technical matters are discussed.	Not mentioned by the participant
Participant 5	They consider utility/customer partnership as an important aspect of managing PQ issues. They mentioned that it is not only the utility's role to manage PQ issues, but customers as well have a role to play, so the value of a partnership is important.	Technical meetings are regarded as important means on which both parties are able to discuss issues impacting PQ performance. They hold regular meetings with the utility, where they discuss mainly voltage dip events that might have incorrectly been classified by the utility. These regular meetings are also means by which the utility give a high-level plan of projects to be undertaken on the network, and likewise, they would give their plans of operational expansion to the utility.	Lodging queries/complaint impacting their operations are normally done by contacting their representative (customer executive) at the utility.
Participant 6	Utility/customer partnership was mentioned as an important aspect of managing PQ issues. It is regarded as the starting point on which to establish a relationship that would be beneficial to both parties on future PQ related issues.	They mentioned technical meetings as important means on which both parties are able to discuss issues impacting PQ. They mentioned that during meetings, the utility is able to make presentations on PQ performance of the network.	Lodging queries/complaint impacting their operations are normally done by contacting their representative (customer executive) at the utility or by calling the call centre or contacting the utility's field staff dealing with technical issues in the vicinity of their operations.
Participant 7	The participant mentioned that a good relationship between the utility and its customers is important, as it enables sharing of information needed to resolve PQ issues. They also mentioned that this partnership is important to them, as they are	Not mentioned by the participant	Not mentioned by the participant

	basically in the same business of providing essential services.		

Table 39: Data Matrix, theme – PQ management mechanism (Part B)

Participant:	Event communication	Priority to large customers	PQ expertise	Customer access to PQ data
Participant 1	Through event communication, they would plan with the utility to have specific activities such as planned maintenance to take place at a low risk for their factory. The timing of a planned interruption is of great importance so they need to be involved and communicated in time.	Not mentioned by the participant	Identification of PQ problems can be attributed to the availability of PQ expertise within their firm who are able to investigate and diagnose PQ related issues and this makes better interaction with the utility on PQ issues.	The participant mentioned access to PQ data to be important for customers. They mentioned that access to such PQ information is made available to them mainly during their regular meetings with the utility. PQ information is also made available on request or as a follow-up on specific incidences with the utility's local technical personnel
Participant 2	Event communication was regarded as extremely important as it enables them to better plan their operations. There are instances where they experienced under voltage problems and the utility would sufficiently communicate to give feedback on the cause.	Not mentioned by the participant	The participant mentioned that they did not have PQ expertise within their firm to investigate and diagnose PQ related issues. Identification of PQ problems within the firm is therefore done through the use of consultants, who they appoint to manage PQ measurements and investigations.	The participant mentioned access to PQ data to be important for customers. They also mentioned that they were not fully informed of the PQ performance information at their PoD, although they have a fir sense of what they themselves are monitoring, such as frequency and voltage magnitude. They mentioned that they do not get a formal PQ performance report from the utility.
Participant 3	For planned maintenance or emergency work, the utility would communicate to them in time and they get to align each other's maintenances. So if informed, they are able to scale down their load but keep the continuous process running. So they regard event communication as important.	Priority to large customers was mentioned in that large customers should be given high priority by the utility in dealing with supply-related issues. They mentioned that the current process of reporting faults result in longer duration of addressing supply issues such as power interruptions. They believe that large customers should have a different process of lodging fault related queries, separate from other categories of customers.	The participant mentioned that PQ expertise is available within their firm to investigate and diagnose PQ related problems. There is a team comprising of engineers who are responsible for PQ and power consumption related issues within the firm.	The participant mentioned access to PQ data to be important for customers. Access to PQ data is made available to them during the regular meetings with the utility, where the QoS person would give a performance report on the PQ parameters that are measured on the network.
Participant 4	They regarded event communication as extremely important. For planned maintenance, the utility would inform them in time and they would then coordinate each other's maintenances, typically on Sundays at low or no production, the risk would be very low. For unplanned event or breakdown repairs, this gets to be negotiated	Not mentioned by the participant	The participant mentioned that there is a certain level of PQ expertise available in the entire organisation and within their plant to deal with certain PQ issues. What cannot be managed within the organisation and in the plant is then outsourced to external consultants who will	The participant mentioned access to PQ data to be important for customers. This information is made available to them during meetings with the utility, where mainly, technical issues are discussed.

	with the utility so communication is important.		investigate in detail and make recommendations.	
Participant 5	Event communication is regarded as extremely important. For planned maintenance, the utility would notify them in time and they would plan and accommodate them to execute, typically on Sundays at reduced production. For unplanned interruptions, there is not much they can do so the impact will have to be minimised.	Not mentioned by the participant	The participants mentioned that they have chief electricians within the firm who have the expertise to investigate and diagnose PQ problems on their network. External consultants are also appointed to investigate further for any inconclusive results.	The participant mentioned access to PQ data to be important for customers. This information is made available to them during meetings with the utility, albeit on PoD's for their larger mining operations. This forms part of the sample points where the utility share PQ information to them during their regular meetings.
Participant 6	Event communication was regarded as extremely important. An event that is timeously communicated to them such as planned maintenance or repairs enables them to prepare and they then ensure that adequate reservoir capacity is maintained to supply water during the interruption.	Not mentioned by the participant	The participant mentioned that they had PQ expertise available within the firm to investigate and diagnose PQ related problems.	Access to PQ data is made available to them through presentations done during regular meetings with the utility. They mentioned that an open door policy exists where PQ information gets communicated to them by the utility.
Participant 7	Event communication was regarded as extremely important. Recently, the utility would contact them to indicate that they were aware of the supply problem and that are working on it. Notification of events by the utility is extremely important, especially for the remote pumping stations on rural lines, so as to avoid unnecessary dispatching of their technical personnel to the stations. This also enables them an opportunity to communicate to their customers regarding a possible shortage of water.	Not mentioned by the participant	The participant mentioned that PQ expertise is available within the firm with first line knowledge to detect PQ problems and to further engage with the utility. However, they mentioned that they don't have PQ instruments to perform detailed analysis of PQ problems.	Access to PQ information was mentioned to be important for customers. They did not have a formal way of accessing this information for the utility. In instances where the supply would trip, at one of their bigger pump stations, they would pick it up on their SCADA system but would not know the exact cause.

Table 40: Data Matrix, theme – Perceived PQ experiences (Part A)

Participant:	PQ expectations	Sensitive to PQ problems
Participant 1	The participant mentioned that their expectations of PQ were that all parameters should conform to limits. In terms of voltage dip occurrences, they would expect that they are cleared quickly	The participant mentioned that their plant was sensitive to a variety of PQ related disturbances, and this posed a risk to their operations. These included: power interruptions, voltage dips, voltage magnitude (regulation), and voltage unbalance and voltage harmonics.
Participant 2	PQ parameters conforming to limits were the major expectations expressed by the participant, in that power should be within specifications, reliable and available.	The participant mentioned that their plant was sensitive to a variety of PQ related disturbances, and this posed a risk to their operations. These included: power interruptions, voltage dips, voltage magnitude (regulation), and voltage unbalance and voltage harmonics.
Participant 3	PQ parameters conforming to limits were the expectations expressed by the participant. They experienced a high number of voltage dip events hence they would expect the utility to improve on the performance of voltage dip events.	The participant mentioned that their plant was sensitive to a variety of PQ related disturbances, and this posed a risk to their operations. These included: power interruptions, voltage dips, voltage magnitude (regulation), and voltage unbalance and voltage harmonics.
Participant 4	PQ conforming to limits were the high expectations expressed by the participant. Given the risky environment of their operations due to possible gas explosions, power should be at its best so as to safeguard lives of underground workers.	The participant mentioned that their plant was sensitive to a variety of PQ related disturbances, and this posed a risk to their operations. These included: power interruptions, voltage dips, voltage magnitude (regulation), and voltage unbalance and voltage harmonics.
Participant 5	The participant mentioned that their expectations of power quality are that it should be perfect all the times.	The participant mentioned that their plant was sensitive to a variety of PQ related disturbances, and this posed a risk to their operations. These included: power interruptions, voltage dips, voltage magnitude (regulation), and voltage unbalance and voltage harmonics.
Participant 6	PQ parameters conforming to limits were the expectations expressed by the participant, so as to enable them to have a sustainable production and delivery of water	The participant mentioned that their plant was sensitive to a variety of PQ related disturbances, and this posed a risk to their operations. These included: power interruptions, voltage dips, voltage magnitude (regulation), and voltage unbalance and voltage harmonics.
Participant 7	PQ parameters conforming to limits were the high expectations expressed by the participant, especially for the power to be always available with fewer disturbances.	The participant mentioned that their plant was sensitive to a variety of PQ related disturbances, and this posed a risk to their operations. These included: power interruptions, voltage dips, voltage magnitude (regulation), and voltage unbalance and voltage harmonics.

Table 41: Data Matrix, theme – Perceived PQ experiences (Part B)

Participant:	Voltage quality problem occurrences	Power interruption occurrences
Participant 1	Voltage quality problem occurrences were mentioned by the participant to be frequently occurring at their PoD's, and this has a significant impact on their operations. They mentioned that voltage dip events were the PQ problems they frequently experience.	Power interruption event occurrences were deliberated on three aspects, namely frequency of occurrence, duration of the interruption occurrence and time of the interruption occurrence. The participant mentioned that they did not frequently experience power interruptions, but mentioned that in the event of an occurrence, the duration and timing of interruptions would be of great concern to their industry. They mentioned the consequences as being unable to normalise their plant within time.
Participant 2	Voltage quality problems in the form of voltage dip events were mentioned to be frequently occurring and experienced by the participant, and this has a significant impact on their operations.	Power interruption event occurrences were deliberated on three aspects, namely frequency of occurrence, duration of the interruption occurrence and time of the interruption occurrence. The participant mentioned that they frequently experienced power interruptions, and further mentioned that in the event of these interruption occurrences, the duration and timing thereof were of great concern to their industry. They mentioned that the consequences thereof were that they would have to stop their chemical plant which is also unsafe for personnel
Participant 3	Voltage quality problems in the form of voltage dip events were mentioned to be frequently occurring and experienced by the participant, and has a significant impact on their operations. The experienced voltage dip events were said to mostly occur during the rainy season	Power interruption event occurrences were deliberated on three aspects, namely frequency of occurrence, duration of the interruption occurrence and time of the interruption occurrence. The participant mentioned that they frequently experienced power interruptions, and further mentioned that all the three aspects of interruptions (frequency, duration and timing) were of great concern for their industry. They mentioned that the impact thereof is that since their operation is a continuous process, any interruption to the Kiln would require them to pre-heat for hours before starting the production process which then increases their operational expenditure.
Participant 4	Voltage quality problems in the form of voltage dip events were mentioned to be frequently occurring and experienced by the participant, and has a significant impact on their operations. The experienced voltage dip events were said to mostly occur during the rainy season	Power interruption event occurrences were deliberated on three aspects, namely frequency of occurrence, duration of the interruption occurrence and time of the interruption occurrence. The participant mentioned that they did not experience power interruptions but mentioned that all the three aspects of interruptions (frequency, duration and timing) were of great concern for their industry. They mentioned that any kind of interruption thereof would pose a safety risk to underground workers due to possible explosions and flooding that may damage equipment.
Participant 5	Voltage quality problems in the form of voltage dip events and voltage regulations were mentioned to be frequently occurring and experienced by the participant and has a significant impact on their operations.	Power interruption event occurrences were deliberated on three aspects, namely frequency of occurrence, duration of the interruption occurrence and time of the interruption occurrence. The participant mentioned that they did not experience power interruptions but mentioned that all the three aspects of interruptions (frequency, duration and timing) were of great concern for their industry. They mentioned that an interruption would result in the interruption of their processes and this will take a while to restart operations, leading to production loss, the risk to underground workers, explosions and possible damage to equipment due to flooding.
Participant 6	Voltage quality problems in the form of voltage dip events and voltage regulations were mentioned to be frequently occurring and experienced by the participant, and has a significant impact on their operations.	Power interruption event occurrences were deliberated on three aspects, namely frequency of occurrence, duration of the interruption occurrence and time of the interruption occurrence. The participant mentioned that they frequently experienced power interruptions, and further mentioned that all the three aspects of interruptions (frequency, duration and timing) were of great concern for their industry. They mentioned that sudden interruption of supply would result in damage to their infrastructure such as the bursting of pipes, due to water hammering. Also, longer duration of interruptions may lead to the depletion of water in reservoirs and an inability to supply water.
Participant 7	Voltage quality problems in the form of voltage dip events and voltage regulations were mentioned to be frequently occurring and experienced by the participant, and has a significant impact on their operations. They mentioned that the voltage dip	Power interruption event occurrences were deliberated on three aspects, namely frequency of occurrence, duration of the interruption occurrence and time of the interruption occurrence. The participant mentioned that they frequently experienced power interruptions, mainly on their smaller points supplied from rural lines. They further mentioned that all the three aspects of

	incidences are more problematic at PoD's on rural lines	interruptions (frequency, duration and timing) were of great concern for their industry. A sudden interruption of supply would result in damage to their infrastructure such as the bursting of pipes, due to water hammering. Also, longer duration of interruptions may lead to the depletion of water in reservoirs and an inability to supply water.

Table 42: Data Matrix, theme – PQ risks to operations (Part A)

Participant:	Loss of production	Overtime costs	Safety risk to employees
Participant 1	Loss of production was mentioned as one of the consequences that could result from a PQ event. The participant mentioned that Loss of supply due to a voltage dip that is outside limits could result in losses amounting to over 50 million on a single point. For all the points, the loss could be 10 times more. Measures to mitigate PQ are taken in an effort to safeguard production	Not mentioned by the participant	Not mentioned by the participant
Participant 2	The participant mentioned the loss of production as one of the consequences that could result from PQ events. They have various plants doing different activities and these can be impacted by PQ, and each can suffer production losses if a PQ event were to interrupt supply for an extended period.	Not mentioned by the participant	Safety risk to employees was mentioned as an aspect for concern if a PQ event were to occur and interrupt the supply of electricity to their plant. Being a chemical plant, the explosive nature of chemicals poses a risk to the factory workers.
Participant 3	The participant mentioned the loss of production as one of the consequences likely to occur from a PQ event. Should a PQ event occur and disrupt the Kiln, the process has to be stopped and this could delay product delivery and loss of income due to penalties.	Not mentioned by the participant	Not mentioned by the participant
Participant 4	The participant mentioned loss of production to be one of the consequences likely to occur as a result of a PQ event. Financially, the entire shift's production could be lost, resulting in millions of Rand worth of gold production that could have been produced.	Not mentioned by the participant	Safety risk to employees was mentioned as the main aspect of concern if a PQ event was to occur and interrupt the supply of power to underground equipment. Lack of ventilation to mine shaft could result in an explosion which could pose a safety hazard to underground workers
Participant 5	The participant mentioned loss of production to be one of the consequences likely to occur as a result of PQ problems, particularly supply interruptions. Supply loss for more than an hour would result in financial loss due to lost opportunity of gold production.	Overtime cost was mentioned as one of the consequences likely to be incurred due to a PQ event. Depending on the type and extent of the problem, additional work hours as overtime may be put in to restore the mine to normal operation.	Safety risk to employees was mentioned as a main aspect of concern if a PQ event was to occur and interrupt the supply of power. A sudden occurrence of a PQ event impacting equipment may result in possible injuries and possible loss of lives to workers going underground.
Participant 6	The participant mentioned the loss of production as the biggest impact to their business that could occur as a result of PQ problems. Interruption of production of water due to a PQ event, the financial loss may incur as they would not be selling water at that time.	Overtime cost was mentioned to be one of the possible costs to be incurred as a result of PQ events impacting their operations. Associated with being an essential service provider, additional time to repair or replace equipment is key to the restoration of water supply.	Not mentioned by the participant
Participant 7	Loss of production was mentioned to be a resulting risk to their business likely to occur from PQ problems. Depending on the time taken to restore supply in the event of a supply interruption due to a fault, reservoirs may run empty resulting in loss of income as they would not be selling water.	Not mentioned by the participant	Not mentioned by the participant

Table 43: Data Matrix, theme – PQ risks to operations (Part B)

Participant:	Damage to equipment	Mine flooding with water	Water hammering to infrastructures
Participant 1	Risk of equipment failure and damage due to voltage dip event is regarded as the biggest threat to their operations, and their main concern of failure is that it would result in loss of production	Not mentioned by the participant	Not mentioned by the participant
Participant 2	Not mentioned by the participant	Not mentioned by the participant	Not mentioned by the participant
Participant 3	Risk of failure and damage to equipment such as VSD's was mentioned to be of concern due to voltage dip events. They regard the VSD's as one of the most sensitive equipment of their system and a frequent exposure to voltage dips would result in them getting damaged.	Not mentioned by the participant	Not mentioned by the participant
Participant 4	Risk of failure and damage to equipment was mentioned as one of the likely consequences of PQ problems. They mentioned that any prolonged inability of the mine to pump the accumulation of underground water would result in some equipment to be immersed in water and damage may occur	Mine flooding with water was mentioned as one of the possible consequences likely to occur as a result of a PQ event. Unplanned interruption or sudden loss of supply may lead to accumulation of underground water which would then result in damage to underground equipment.	Not mentioned by the participant
Participant 5	Risk of failure and damage to equipment was mentioned to be one of the likely consequences of PQ problems. They mentioned that any prolonged inability of the mine to pump the accumulation of underground water would result in some equipment to be immersed in water and damage may occur	Mine flooding with water was mentioned to be one of the possible consequences likely to occur if a PQ event were to interrupt supply. They describe this as being disastrous for the mining industry. A lack of supply resulting from a PQ problem could impact the mine's ability to pump out the excessive accumulation of underground water which may later cause damage to some underground equipment	Not mentioned by the participant
Participant 6	Risk of damage to equipment was mentioned to be one of the likely consequences resulting from PQ problems. A burst of pipes due to sudden tripping an uncontrolled shutdown of pumps may occur putting the production and supply of water at risk.	Not mentioned by the participant	Water hammering was mentioned by the participant as the damaging process to their infrastructure which may occur as a result of a sudden loss of supply due to a PQ problem. If pumps were to suddenly trip, hammering may occur and cause damage to infrastructure in the form of pipe bursts
Participant 7	Risk of damage to equipment was mentioned to be one of the likely consequences resulting from PQ problems. The burst of pipes due to sudden tripping an uncontrolled shutdown of pumps may occur putting the production and supply of water at risk.	Not mentioned by the participant	Water hammering was mentioned by the participant as the damaging process to their infrastructure which may occur as a result of a PQ event. A sudden tripping of water pumping equipment during normal operation may cause water to flow backwards, resulting in damage to infrastructure.

Table 44: Data Matrix, theme – PQ risks to operations (Part C)

Participant:	Impact on water quality	Risk of explosion
Participant 1	Not mentioned by the participant	Not mentioned by the participant
Participant 2	Not mentioned by the participant	The participant mentioned the risk of explosion to be one of the likely consequences of PQ problems. Any unexpected supply trips resulting in equipment damages may result in the ammonium-nitrate lines to be blocked, and this is potentially explosive due to gas formation.
Participant 3	Not mentioned by the participant	Not mentioned by the participant
Participant 4	Not mentioned by the participant	The participant mentioned the risk of explosion to be one of the likely consequences due to PQ problems. A continuous supply of power is important to ensure sufficient ventilation is available, in order to reduce the levels of methane gas, which is elevated, the explosion may occur
Participant 5	Not mentioned by the participant	Not mentioned by the participant
Participant 6	Not mentioned by the participant	Not mentioned by the participant
Participant 7	A participant mentioned the impact to water quality to be amongst their business risk associated with sudden loss of supply due to possible PQ problems. Any unforeseen interruption of supply to the purification plant may result in the quality of drinking water to be affected.	Not mentioned by the participant

Table 45: Data Matrix, theme – PQ mitigation measures (Part A)

Participant:	Equipment compatibility	Equipment rating	PQ-centred procurement approach
Participant 1	The participant mentioned that all their production equipment were compatible with the levels of PQ supplied at their PoD's, but believe that at times, some equipment do drift out of limits	The participant mentioned that all their equipment were properly rated to operate on the supply provided by the utility.	A PQ-centred procurement approach is undertaken by ensuring that most of the procured equipment is configured to perform well within the PQ environment, so they believe in the engineering conditioning and configuration of the procured equipment.
Participant 2	The participant mentioned that all their equipment were compatible with the level of PQ supplied at PoD's	The participant mentioned that all their equipment were properly rated to operate on the supply provided by the utility, with specific emphasis made on system frequency and fault level rating.	The participant mentioned that they have not recently procured any equipment, but they held a view that any installations of new equipment should be undertaken to mitigate the effect of PQ
Participant 3	The participant mentioned that most of their equipment was compatible with the levels of PQ supplied at their PoD's, but from time to time, their small VSD's do get damaged due to harmonics.	The participant mentioned that all their equipment were properly rated to operate on the supply provided by the utility.	Procurement of equipment is done in consultation with the utility, so as to inform them of the possible increase in demand, which could have an impact on PQ.
Participant 4	The participant mentioned that all their equipment were compatible with the levels of PQ supplied at their PoD's	The participant mentioned that all their equipment were properly rated to operate on the supply provided by the utility, with specific emphasis on fault level rating.	The participant mentioned that for procurement of larger equipment, all designs are done and this also necessitates that they inform the utility to verify information relating to fault levels and any impact to PQ.
Participant 5	The participant mentioned that most of their equipment was compatible with the PQ levels, but mentioned that they had old equipment with no specifications and no indication of PQ requirements which might not be compatible.	The participant mentioned that all their equipment were properly rated to operate on the supply provided by the utility, with specific emphasis on fault level rating for switchgear.	The participant mentioned that they did not make procurement of equipment on the basis of PQ. They believe that all their equipment is likely to have an impact on PQ
Participant 6	The participant mentioned that all their equipment were compatible with the levels of PQ supplied at their PoD's.	The participant mentioned that all their equipment were properly rated to operate on the supply provided by the utility. They make emphasis on achieving the design fault level ratings.	The participant mentioned that PQ-centred procurement approach is normally undertaken on production equipment, which is typically large motor pumps.
Participant 7	The participant mentioned that all their equipment were compatible with the levels of PQ supplied at their PoD's.	The participant mentioned that all their equipment were properly rated to operate on the supply provided by the utility.	A PQ-centred procurement approach is undertaken if a specific pump station is to be augmented and the supply is upgraded to accommodate an increase in the load requirement. This may then require an investigation to determine the anticipated load increase and motor sizes.

Table 46: Data Matrix, theme – PQ mitigation measures (Part B)

Participant:	Harmonic filtering	Protection schemes	Voltage ride through capabilities
Participant 1	Harmonic filtering units were mentioned as part of power factor correction installation where they have capacitor banks that are tuned to limit internally generated harmonics but not necessarily network harmonics. The participant also expressed views in that harmonic filtering devices can also be embedded into systems to automatically mitigate for harmonics.	Protection schemes were mentioned as measures implemented to mitigate the effect of PQ, such as the implementation of protection settings and grading to ensure quick fault clearing and minimize the impact on the network.	Voltage ride through capabilities was mentioned as measures implemented within their firm, specifically on motors and VSD's, to safeguard production.
Participant 2	Not mentioned by the participant	Protection schemes were mentioned as measures implemented to mitigate the impact of PQ, including over/under voltage protection as standard protection.	Not mentioned by the participant
Participant 3	Harmonic filtering was mentioned as part of power factor correction capacitor bank installations on the VSD's to minimize the impact on the network.	The participant mentioned that protection schemes are implemented as protection measures for the network and within their plant, protection for specific equipment is done such as over/under voltage protection to VSD's and unbalance protection for motors.	Voltage ride through capabilities was mentioned to be measures taken to ensure process continuity to their sensitive Kiln line, but only for smaller dips. For the mills, the participant mentioned that they can ride through, even on large dips.
Participant 4	Harmonic filtering was mentioned as part of the thyristor drive installations, in order to minimize the impact of harmonics generated within.	The participant mentioned that protection schemes are implemented as measures to mitigate the effect of PQ on all substations. For larger motor installations, protection includes: over/under voltage protection. Regular protection testing is also implemented to ensure effective operation and to minimize impact to the network	Not mentioned by the participant
Participant 5	Not mentioned by the participant	The participant mentioned that protection schemes are implemented as measures to protect motors and to mitigate PQ, with protection units consisting of: over/under voltage protection, voltage unbalance protection and general motor protection.	Not mentioned by the participant
Participant 6	Not mentioned by the participant	The participant mentioned that protection schemes are implemented as measures undertaken to mitigate PQ, which includes: over/under voltage protection, over/under frequency protection and motor protection units.	Voltage ride through capabilities was mentioned as control measures undertaken by way of installing UPS systems on their PLC's to limit the effect of manageable voltage dip events which may have an impact on water pumping operations
Participant 7	Not mentioned by the participant	The participant mentioned that protection schemes are implemented as measures to mitigate for PQ, which includes: over/under voltage protection, over/under frequency protection, phase failure protection and protection against phase rotation errors.	Not mentioned by the participant

Table 47: Data Matrix, theme – PQ mitigation measures (Part C)

Participant:	Starting methods	Preventive maintenance
Participant 1	Not mentioned by the participant	Preventive maintenance was mentioned as proactive measures undertaken to mitigate the impact on PQ. Equipment monitoring is performed to support maintenance requirement of equipment so as to prevent failure which might have an impact on PQ.
Participant 2	Starting methods were mentioned as one of the measures undertaken to reduce the impact on PQ. Soft starters are installed on large motors in order to limit the starting current which has the potential to cause voltage dips on the network.	The participant mentioned that they have implemented preventive maintenance programs as measures to reduce the impact on PQ by ensuring that proactive maintenance of transformers and other equipment is done in time so as to reduce faults.
Participant 3	Starting methods were mentioned as one of the measures undertaken to reduce the impact on PQ. They described the manner in which they start-up their plant as being sequential, so as not to put a huge load that may cause voltage dips on the network	The participant mentioned that preventive maintenance is put in place as measures to reduce the impact on PQ performance. This is in the form of time-based maintenance at fixed intervals which is done on VSD's and transformers.
Participant 4	Not mentioned by the participant	The participant mentioned that preventive maintenance has been put in place as measures to reduce the impact on PQ performance. They have fixed schedule time – based maintenance. Substation equipment is maintained annually. They also have condition-based maintenance implemented as preventive measures on motors. Bush clearing is also done on overhead lines to prevent trees and vegetation to grow under the lines
Participant 5	Not mentioned by the participant	Preventive maintenance is implemented as proactive measures undertaken to reduce the impact on PQ performance. They mostly do maintenance on a time-based interval. Condition-based maintenance is also done on mechanical equipment to reduce the probability of faults.
Participant 6	Starting methods were mentioned as one of the measures undertaken to reduce the impact on PQ. They mentioned having PLC systems for their pumps, so as to allow sequential starting of the pumps and to limit the starting current withdrawn from the network	Preventive maintenance is implemented as proactive measures undertaken to reduce the impact on PQ performance. Their maintenance is time-based with a fixed interval.
Participant 7	Starting methods were mentioned as one of the measures undertaken to reduce the impact on PQ. They mentioned having soft starters comprising of VSD's. PLC systems are also used as procedures for starting up one pump at a time so as not to cause stress on the network.	Preventive maintenance is implemented as proactive measures undertaken to reduce the impact on PQ performance. Their maintenance is mainly fixed interval time -based mechanical maintenance, to check bearings on motors.

Table 48: Data Matrix, theme – PQ based premium

Participant:	**PQ – based premium**
Participant 1	PQ-based premium is an investment that they are already making as an industry so as to avoid interruption of power supply to their operations. Paying for an extra supply or feeder enable them to minimize the probability of unplanned shutdowns. The participant mentioned that they would pay for a premium that can be based on high levels of PQ.
Participant 2	The participant mentioned a PQ-based premium as a cost they would pay if it would be of benefit to them in terms of improving PQ for their firm.
Participant 3	The participant would pay a PQ-based premium if the utility were to guarantee good PQ. They mentioned that it would be a financial payback for them to compensate for the production losses likely to incur due to PQ events.
Participant 4	The PQ-based premium was mentioned as a premium that the participant would pay if there was going to be a cost-benefit, i.e., if improving PQ is to result in them making more profit from their operations.
Participant 5	They mentioned that they couldn't afford to pay a PQ-based premium at this stage
Participant 6	Not mentioned by Participant
Participant 7	The participant mentioned that they wouldn’t want to pay additional premium to cater for PQ. They mentioned that they haven’t been inconvenienced to the extent that they could then imagine paying extra for PQ. It is only when they are expanding their operations that they would pay.

Table 49: Data Matrix, theme – PQ measurement philosophies (part A)

Participant:	Importance of PQ measurement	Awareness to smart grid	PQ on SCADA
Participant 1	PQ measurement is regarded as extremely important for their firm. There is a specific concern regarding voltage dips as there are direct consequences for being out of limit. PQ measurement also enables them to keep track of system frequency to ensure that their internal generation units are not impacted. So they have a section that does the monitoring as part of their PQ management system.	The participant expressed their awareness of the smart grid technologies. They described it as an automation of the grid with intelligent devices that can perform monitoring and reporting of PQ. It was viewed as a system where the utility can have an online view of the monitored PQ.	The participant held a view that PQ on SCADA could overwhelm the network operators with too much information that they cannot handle. They mentioned that breaker status, alarms, etc. are already problematic to manage and to include also PQ would be more problematic. They are of the opinion that PQ should be managed on a background system to the SCADA.
Participant 2	The participant regard PQ measurement as extremely important for their firm, like PQ, affect the effectiveness of their operations. They wouldn't want to unnecessarily trip from a PQ event they could've avoided if the measurement was done to detect the problem ahead of time, as this would be risky to their plant due to chemical explosions. The participant recently outsourced the function of PQ measurement and monitoring to consultants.	The participant expressed their awareness of the smart grid technologies. No further account was given.	Monitoring of PQ on SCADA was mentioned as it can be helpful to the utility to better understand and visualize the level of QoS on the network.
Participant 3	The participant regarded PQ measurement as extremely important for their firm as their plant consists of a continuous process that can easily be affected by PQ events, and if stopped, it could take longer to restart. They have PQ instruments installed on the incomers as well as within their network	The participant mentioned that they were aware of the smart grid technologies, but mainly on the application for town automation. They mentioned that having a smart grid system with the capabilities to switch different loads, PQ performance can definitely be improved.	Monitoring of PQ on SCADA was mentioned as it is believed that it can be helpful to utilities by enabling network controllers to identify QoS problems on the network
Participant 4	PQ measurement is considered important for their business. They have PQ instruments installed at their Pods and a consulting company is appointed for the monitoring of their PQ.	Not mentioned by the participant	Monitoring of PQ on SCADA was mentioned as helpful as it can contribute to maintaining PQ performance. They hold a view that visualizing PQ on SCADA should be an integral part of the utility's business. They see value in the ability of the SCADA system to be used for detecting and possibly to classify a voltage dip event as it occurs.
Participant 5	PQ measurement is considered important for their business, as PQ events can have an impact on their production, the lifespan of equipment and the cost to the company. They have a consulting company doing their metering, including PQ measurement. PQ data is also stored in the server for future retrieval.	The participant expressed awareness of the smart grid technologies and stated that they have been to an exhibition workshop hosted by Schneider on smart grid for municipality application. They've also read some articles about the smart grid on the What Now magazine.	Monitoring of PQ on SCADA was mentioned as helpful as it would make it easy to manage PQ. The participant described as being reactive to try and obtain information from various points, whereas if on SCADA, operators can easily locate problem areas on the network.
Participant 6	PQ measurement is considered important for their business, as they are an essential service provider. The participant emphasizes that they cannot afford to have their services interrupted or their equipment damaged due to a PQ event, as this could put the production and supply of water to their customers at risk. They do PQ measurement at points where they have large operating pumps.	The participant indicated their awareness of the smart grid technologies but did not have more details of it.	Monitoring of PQ on SCADA was mentioned as helpful as it would provide an efficient way of solving problems occurring on the network

Participant 7	PQ measurement was mentioned to be important for their business. They are currently limited in their measurement capabilities, as they only measure basic parameters such as over / under voltage, which also serves as a protection unit for their equipment. The participant indicated that they did not have fully installed PQ measurement instrumentation, hence they make use of a portable instrument to measure voltages, but voltage unbalance is embedded within the motor protection relays.	A participant mentioned their awareness of smart grid technologies and described it as a technology that can be used to control equipment much easier. In terms of power generation, the participant described the smart grid to be better suited for control of renewable energy sources. Also described to be useful for demand-side management in terms of capacity availability.	Monitoring of PQ on SCADA was mentioned to be critical for the utility, as they believe it would then help to identify PQ problems much quicker

Table 50: Data Matrix, theme – PQ measurement philosophies (part B)

Participant:	Synchronised measurement of PQ	Facilitating PQ mitigation	Load switching capabilities
Participant 1	Synchronized measurement of PQ data was mentioned to potentially be helpful and provide benefits to utilities in enabling a better understanding of PQ. Their view is that if sufficient network information is provided, it can enable utilities to have a holistic view of the monitored PQ.	Facilitation of PQ mitigation mentioned by the participant entailed: automation of the network, online PQ meter access capabilities, detection, intelligent devices and automatic switching.	Embedding load switching capabilities to automatically switch devices such as filtering units upon detection of harmonics on the network was mentioned by the participant, as a potential benefit expected from smart grid technologies, thereby facilitating mitigation by eliminating human interventions.
Participant 2	Synchronized measurement of PQ was mentioned by the participant to be a potential means through which a better understanding of PQ can be achieved by utilities.	Not mentioned by the participant	Not mentioned by the participant
Participant 3	Synchronized measurement of PQ was mentioned to provide a better understanding of PQ. A participant mentioned that since they are connected on a bigger (lengthy) network where they often impacted by faults occurring very far, having a wide area monitoring can enable the utility to better understand the causes of the QoS problems	Not mentioned by the participant	Load switching capabilities were mentioned as an advantage that can be realised as part of the utilisation of the smart grid technologies to enable switching of different loads to improve PQ
Participant 4	Synchronized measurement of PQ was mentioned to provide a better understanding of PQ. They believe that the utility can enhance PQ performance by accurately locating the origins of faults.	Not mentioned by the participant	Not mentioned by the participant
Participant 5	A participant mentioned that synchronised measurement of PQ can provide a better understanding of PQ performance. They described synchronized measurement as being able to provide a coordinated measurement that would assist to pinpoint locations of faults and help diagnose PQ problems on the network	Not mentioned by the participant	Not mentioned by the participant
Participant 6	A synchronised measurement was mentioned to provide a better understanding of PQ performance by the utility. The participant believes that this would also increase the efficiency of service delivered to customers, as the utility would have a perfect way of data gathering resulting in better methods of detecting PQ problems.	Not mentioned by the participant	Not mentioned by the participant
Participant 7	Synchronised measurement was mentioned to provide a holistic view of the monitored PQ, and it is said to provide an advantage to them as customers and to the utility, as it would enable the utility to locate origins of PQ problems and provide solutions quicker.	Facilitating PQ mitigation was mentioned to be made possible by having network information. The participant believes that since the basis of synchronised measurement is to provide more network information that is reliable, this information also facilitates to solve PQ problems	Not mentioned by the participant

Table 51: Data Matrix, theme – PQ measurement philosophies (part C)

Participant:	Early detection of anomalies	Real-time system
Participant 1	Early detection of anomalies was mentioned as proactive means that could be undertaken through online monitoring, in order to minimize the impact or possible impact of PQ on the utility's network.	A participant mentioned that in real-time systems, network operators are mostly concerned about the present state along with what can be done at that moment and to act immediately. PQ mitigation as an immediate action is considered through having a real-time system of monitoring.
Participant 2	Not mentioned by the research the participant	Not mentioned by the participant
Participant 3	Not mentioned by the participant	Not mentioned by the participant
Participant 4	Early detection of anomalies was mentioned as part of describing one of the benefits that the SCADA system could provide to utilities in detecting incidence's as they happen. The participant believes that this could also enable utilities to quickly provide reasons for events such as breaker trips caused by PQ events.	Not mentioned by the participant
Participant 5	Not mentioned by the participant	The real-time system was mentioned as a system that reports on PQ, so as to give a whole new perspective for the utility to immediately visualize where faults and PQ problems are occurring on the network.
Participant 6	Not mentioned by the participant	Not mentioned by Participant
Participant 7	Early detection of anomalies was mentioned to emphasise one of the benefits to be realized from the use of the SCADA system. In describing the effectiveness of the SCADA, the participant held the view that early detection of PQ problems can be made possible thereof by the system	Not mentioned by the participant

Table 52: Data Matrix, theme – Smart grid obstacles

Participant:	Smart grid obstacles
Participant 1	Obstacles were mentioned by the participant in relation to the implementation of smart grid technologies, which include: possible theft of critical components and to quantify the possible economic benefits
Participant 2	Obstacles were mentioned by the participant in relation to the implementation of smart grid technologies, which include: the cost of implementation and the ability to implement due to the complexity of our network infrastructure comprising of many entities such as Eskom and the municipalities
Participant 3	The participant mentioned ageing of parts of the electrical network as a potential obstacle to the implementation of the smart grid system. They mentioned being doubtful that the existing network could cater for the deployment of the smart grid.
Participant 4	Not mentioned by the participant
Participant 5	The participant believes that getting everyone on board to buy into the idea of the smart grid will be a possible obstacle. They mentioned that lack of trust by users or other entities to allow the utility to impact their area of control will be problematic.
Participant 6	Not mentioned by the participant
Participant 7	Not mentioned by the participant

Appendix B: Quantitative study – Survey questions

CONSTRUCT 1: TOP MANAGEMENT COMMITMENT				
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

- Top management drives and support power quality initiatives within our organization
- Our power quality management program is effectively managed to provide power quality levels that is reasonable to our customers
- Top management incorporates power quality initiatives into strategic business plans
- Top management budgets for the implementation of power quality improvement projects
- Our organization has a PQ policy to ensure our network complies to regulatory standards
- Ensuring product quality and reliability is part of our corporate image
- Top management develop and implement objectives for continuous PQ improvements
- PQ performance of our network is communicated monthly to our internal stakeholders
- Top management reports our PQ performance annually to NERSA
- Our organization frequently performs internal PQ audits to assess for NRS 048 compliance
- We have implemented (or we are in the process of implementing) a formal PQ monitoring system in our firm (for example in accordance with the NER directive)
- Our organization invests in PQ research and development projects to improve the performance of our networks

CONSTRUCT 2: SERVICE QUALITY ASSESSMENT				
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

- We measure and monitor the quantity of PQ emission/disturbances generated on our networks
- We often use PQ data to identify/analyze faults within our networks
- Our utility use PQ data to support the operational processes of our network
- We conduct PQ impact analysis before connecting customers to our network
- We conduct internal investigations to understand root causes of PQ problems on our network
- We do PQ benchmarking to identify trends and to derive characteristic numbers of voltage dips performance
- We benchmark the PQ performance of our networks with similar networks of other utilities

CONSTRUCT 3: NETWORK TOPOLOGY AND DESIGN				
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

- Our utility designs its networks with a view to optimize PQ
- We prioritise installation of underground cables when designing our MV distribution networks
- We conduct network life-cycle analysis to predict decline in PQ performance
- We modify our network to mitigate PQ problems
- Our utility has a network maintenance plan to ensure good PQ
- We implement technical innovations on our networks to improve PQ performance

CONSTRUCT 4: CUSTOMER INTERACTIONS				
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

We have regular sessions with our customers to presents the PQ performance of our networks

- We investigate customer complaints or claims caused by PQ problems
- We track investigated PQ complains from our customers to ensure recommended corrective actions are implemented
- Our PQ performance data is accessible to our customers
- We do have customer relations personnel to communicate PQ issues to our customers
- We have developed strong relationships with key customers by communicating PQ performance data

CONSTRUCT 5: TECHNICAL SYSTEM OPERATION				
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

- Our utility uses modern PQ devices to improve the monitoring of PQ performance
- Our utility is familiar with the concept of smart grid technology
- Implementing smart grid technology can enable our utility to increase power distribution efficiency and reduce operating costs
- With the integration of renewable energy sources distributed throughout the network, smart grids can enable our utility to improve voltage stability and system reliability
- Implementing automated methods of detecting PQ problems can enhance the management of PQ in our utility
- We have enhanced our maintenance philosophy by using PQ data to predict for maintenance on our network
- Our existing electrical infrastructure can accommodate the deployment of mixed technologies

CONSTRUCT 6: COST BENEFIT AND REGULATIONS				
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

- The leadership of our utility understand the value proposition of the smart grid deployment
- Regulatory standards are required to provide incentives to utilities in terms of rate recovery for smart grid investments
- Our utility has a greater awareness of the various policies and regulatory initiatives introduced to promote the development of smart grids
- Availability of technical standards for smart grid components to achieve interoperability of equipment can facilitate the deployment of smart grid in our utility

CONSTRUCT 7: SOCIAL NORMS AND BEHAVIOURS				
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

- Empowering consumers, communities and societies in changing energy consumption behaviours is fundamental to the utility’s energy market
- Our expectations of efficient energy transfer as well as cost savings for our customers can be achieved through the use of smart grid technologies
- Our utility consider smart grid as a tool to facilitate the reduction of environmental impact
- Our utility understands the beneficial aspect of smart grid investment as a mechanism for job creation and advancement of a technically skilled workforce

Appendix C: Online Administration of Survey to Power Utility Respondents

Survey: Measuring the extent of power quality measures employed by electric utilities

By volunteering for this research study, you are expected to complete the following survey in electronic format, expressing your opinion as accurately and honestly as possible and to answer to the best of your knowledge on behalf of your organization.

The identity of all research participants will be treated with strict confidentiality and solely for the purpose of this research study and will not be shared with any other parties.

You may choose to withdraw your consent from this research at any time.

By clicking on Start you consent to take part in the study

Start

Survey: Measuring the extent of power quality measures employed by electric utilities

Survey Background

Thank you for taking the time to participate in this survey. This is a self-administered survey that form part of a research project at the Potchefstroom Campus of the North West University. The focus area for the research is the management of power quality by exploring the opportunities of utilizing Smart Grid Technologies.

The dimensions and elements of Power Quality Management and Smart Grid Technology were tapped to develop the test items contained in this research questionnaire. The questionnaire consists of closed-ended questions relating to the implementation of Power Quality program at the participating utility as well as the utility's perspective on Smart Grid Technology. Seven demographic questions that include the utility's network supply and demand basis are also included at the end of the questionnaire. The information collected in this survey will help us determine what level of power quality program exists to manage the quality of electricity in South Africa, and to assess whether technologies such as Smart Grid can be employed to support the management thereof. The use of coherent data from modern PQ instruments that conforms to the measurement requirement of IEC 61000-4-30 Class A instrument will be considered as the key component of the Smart Grid.

This survey should not take more than 25 minutes to complete, and all information obtained will be kept strictly confidential and shall be used solely for research purpose. We will greatly appreciate your time and effort in completing this research questionnaire.

Where the terms "Organization" and "Utility" appears on the questionnaire, they shall be regarded as having essentially the same meaning, unless the context indicate otherwise.

This questionnaire is in three parts;

Part A measures the utility's power Quality Program;

Part B measures the utility's perception on Smart Grid Technology; and

Part C collects the biographical data, mainly about the utility's network.

A five-point Likert scale is used as the rating scale for part A and part B of the questionnaire. The Likert scale is "an itemized scale which offers a category of responses out of which you should pick the one that is most relevant for answering the question under consideration". The scale is anchored with polar points 1 = strongly disagree and 5 = strongly agree.

Survey: Measuring the extent of power quality measures employed by electric utilities

General Information

*1. Please provide the following information in order to identify the utility you represent.

The name of the utility:

Your name and surname:

Your email address:

Your contact number:

Your designation:

Survey: Measuring the extent of power quality measures employed by electric utilities

Part A: Power Quality Management Program of utility

Part A comprises four (4) sets of questions relating to:

1. Top Management Commitment;
2. Service Quality Assessment;
3. Network Topology and Design Innovations; and
4. Customer Interactions.

Top Management commitment

In terms of measuring Top Management Commitment, please select the most appropriate value between 1 and 5, where 1 = strongly disagree and 5 = strongly agree.

- Top Management drives and support power quality initiatives within our organization;
- Our power quality management program is effectively managed to provide power quality levels that is reasonable to our customers.
- Top management incorporates power quality initiatives into strategic business plans;
- Top management budgets for the implementation of power quality improvement projects;
- Our organization has a policy to ensure our network complies to regulatory standards.
- Ensuring product quality and reliability is part of our corporate image;
- Top management develop and implement objectives for continuous power quality improvements;
- Power quality performance of our network is communicated monthly to our internal stakeholders.
- Top management reports our power quality performance annually to NERSA;
- Our organization frequently performs internal power quality audits to assess for NRS048 compliance;
- We have implemented (or we are in the process of implementing) a formal power quality monitoring system in our utility;
- Our organization invests in power quality research and development projects to improve the performance of our network;

Service Quality Assessment

In terms of service quality assessment, please select the most appropriate value between 1 and 5, where 1 = strongly disagree and 5 = strongly agree.

Strongly disagree Disagree Neutral Agree Strongly agree

- We measure and monitor the quantity of power quality emissions/disturbances generated on our network;
- We often use PQ data to identify/analyze faults within our network;
- Our utility use PQ data to support the operational processes of our network;
- We conduct PQ impact analysis before connecting customers to our network;
- We conduct internal investigations to understand root causes of PQ problems on our network;
- We do PQ benchmarking to identify trends and to derive characteristic numbers of voltage dips performance;
- We benchmark the PQ performance of our network with similar networks of other utilities.

Network Topology and Design Innovations

In terms of Network Topology and Design Innovations, please select the most appropriate value between 1 and 5, where 1 = strongly disagree and 5 = strongly agree.

- Our utility designs its networks with a view to optimize PQ;
- We prioritize installation of underground cables when designing our MV distribution network;
- We conduct network lifecycle analysis to predict decline in PQ performance;
- We modify our network to mitigate PQ problems;
- Our utility has a network plan to ensure good PQ;
- We implement technical innovations on our networks to improve PQ performance.

Customer Interactions

In terms of customer interactions, please select the most appropriate value between 1 and 5, where 1 = strongly disagree and 5 = strongly agree.

- We have regular sessions with our customers to presents the PQ performance of our network;
- We investigate customer complaints or claims caused by PQ problems;
- We track investigated PQ complaints from our customers to ensure recommended corrective actions are implemented;
- Our PQ performance data is accessible to our customers;
- We do have customer relations personnel to communicate PQ issues to our customers;
- We have developed strong relationships with key customers by communicating PQ performance data;

Part B: Utility's perception on Smart Grid Technology

In this section, the definition for Smart Grid is adopted from the IEEE as: "an electrical network from the generation of electrical energy until the delivery to end-users, which make use of latest advances in wireless and other communication technology and intelligent information management systems to ameliorate the robustness, reliability, energy efficiency and security of such network".

Included in this definition are the applications of (A) Modern PQ instruments for PQ monitoring and (B) Mixed technology within the utility's network. modern PQ instruments denote instruments that conform to the measurement requirement of IEC 61000430 Class A instruments. Mixed technology comprises FACTS devices such as Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), and other technologies etc. and renewable energy sources such as wind and solar).

This section comprises three (3) sets of questions related to:

1. Technical System Operation and Architecture;
2. Cost Benefit and Regulations; and
3. Social Norms and Behaviors.

Technical System Operation and Architecture

In terms of technical system operation and architecture, please select the most appropriate value between 1 and 5, where 1 = strongly disagree and = strongly agree.

- Our utility uses modern PQ devices to improve the monitoring of PQ performance;
- Our utility is familiar with the concept of Smart Grid Technology;
- Implementing Smart Grid Technology can enable our utility to increase power distribution efficiency and reduce operating costs;
- With the integration of renewable energy sources distributed throughout the network, Smart Grids can enable our utility to improve voltage stability and system reliability;

- Implementing automated methods of detecting PQ problems can enhance the management of PQ in our utility;
- We have enhanced our maintenance philosophy by using PQ data to predict for maintenance on our network
- Our existing electrical infrastructure can accommodate the deployment of Mixed Technologies.

Cost Benefit and Regulations

In terms of cost benefit and regulations for Smart Grids, please select the most appropriate value between 1 and 5, where 1 = strongly disagree and 5 = strongly agree.

- The leadership of our utility understand the value proposition of the smart grid deployment
- Regulatory standards are required to provide incentives to utilities in terms of rate recovery for smart grid investments
- Our utility has a greater awareness of the various policies and regulatory initiatives introduced to promote the development of Smart Grids;
- Availability of technical standards for Smart Grid components to achieve interoperability of equipment can facilitate the deployment of Smart Grid in our utility.

Social Norms and Behaviors

In terms of social norms and behaviors, please select the most appropriate value between 1 and 5, where 1 = strongly disagree and 5 = strongly agree.

- Empowering consumers, communities and society in changing energy consumption behavior is fundamental to the utilities energy market;
- Our expectations of efficient energy transfer as well as cost savings for our customers can be achieved through the use of Smart Grid Technologies;
- Our utility considers Smart Grid as a tool to facilitate the reduction of environmental impact;
- Our utility understands the beneficial aspect of Smart Grid investment as a mechanism for job creation and advancement of a technically skilled workforce.

Part C: Demographic Information

In terms of biographic information, please answer the following questions, and where applicable, please select the most appropriate answer

1. What is the size of your network in terms of supply capacity (i.e. MVA or MW)? Size in this case refers to the maximum (sum total) agreed power of your network from each generator or intake point.

2. What is the spread of your load (customer) base (i.e. large power users, small power users and residential) in terms of consumption?

3. Do you have a power quality management program (PQM) in place?

Yes No

4. If Yes, how long have you had this PQM program:?

5. How many PQ instruments do you have installed on your network and on which voltage categories are they installed (i.e. EHV, HV, MV or LV):?

6. Do you have a dedicated PQ personnel dealing with PQ issues?

Yes No

We appreciate your cooperation and the time you took to provide the requested information.

Thank You, End

Appendix D: Invite Letter to Expert Panel

Research Title: Evaluation of key factors influencing a South African-based electrical utility to utilize smart grid technologies for power quality management

Dear Member

Invitation to participate as a research expert panel member

My name is Jabulani Mbhombhi and I am currently undertaking postgraduate studies at the Potchefstroom Campus of the North West University. As part of the requirements for a Master's degree in electrical and electronics engineering, I am conducting a research study specializing in the field of power quality. In valuing your expertise, I would like to invite you to participate in this research as an expert panel member. You are selected as part of a panel consisting of thirteen individuals that were carefully selected to serve as experts for the research.

As an expert panel member, you are requested to make comments and recommendations on the representativeness and suitability of the survey questions of the research questionnaire. This will serve as the content validation of the research instrument for the study and will enable the increased probability that the questions of the survey are interpreted equally by all the intended participants.

Your contribution together with those of the other members will assist in the progression of this research and the future planning for smart grid technologies can be achieved by understanding its distinguishable aspects thereof in the advancement of the rapidly changing environment in the electricity industry.

Specific details of the research instrument (questionnaires) are enclosed as annexures (A1 and A2) for your attention. An introduction page as well as the purpose and objectives of the study are also included. For further information regarding this research, please contact my supervisor, Prof. Johan Rens, professor at the School for Electrical and Electronic Engineering at the Potchefstroom Campus of the North West University. Prof. Rens' mailing address, telephone number and email address are:

A.P.J Rens, Professor

School of Electrical, electronic & Computer Engineering

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Looking forward to your participation and help in charting an appropriate instrument for my research activity

Sincerely;

S.J. Mbhombhi, Researcher

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Appendix E: First Correspondence Email with Respondents (Power Utilities)

14 May 2015

ATTENTION: MR. P.J. MOLOTO

CITY OF EKURHULENI METROPOLITAN MUNICIPALITY

Dear Mr. Moloto

POSTGRADUATE RESEARCH REQUEST

My name is Jabulani Mbhombhi and I am employed by Eskom – Distribution Group. I am situated in Bloemfontein and employed as a Quality of Supply Engineer for the Free State Operating unit, with over five years of experience performing investigations involving power quality on Eskom's network. Registered as a professional Engineer with ECSA since June 2011, I have been a member of various QoS Committees in Eskom, ensuring that Eskom's obligations to NERSA PQ requirements are adhered to.

In advancing my knowledge of managing power quality, I am currently conducting research to determine the relationship between Power quality Management, Smart Grid Technology and Customer Satisfaction in South African-based utilities. This survey is part of a research project which is in fulfillment of a Master of Engineering degree at the Potchefstroom Campus of the School of Electrical, Electronic & Computer Engineering at the North West University. You have been selected as a participant in this work.

The information you provide on this survey will help us better understand what level of Power Quality Program exists to manage the quality of electricity in South Africa, and to determine the role Smart Grid Technology can play to support the management thereof.

I would greatly appreciate your time and effort in completing this research survey! It should take you approximately 25 minutes to complete the questionnaire.

Please note that your participation is voluntary, and you are free to decline to participate in this survey. Also note that your participation will remain anonymous and there are no foreseeable risks associated with the completion of this survey.

To complete the survey please click on the following link to access the research web page:

https://www.surveymonkey.com/s/PQMUtilities

Your response will be kept strictly confidential and will be used solely for research purpose. Only members of the research team will have access to the information you give.

I would greatly appreciate it if you could return the completed questionnaire by no later than 29 May 2015; just click on the submit button at the end of the questionnaire to return it to me. If you have any questions or enquiries regarding the research project, please contact me or my supervisors, Prof. Johan Rens and Mrs. Leenta Grobler. Our contact details are provided below.

Thank-you for your time and assistance in furthering this research endeavor

Best Regards

Jabulani Mbhombhi

Jabulani Mbhombhi	Prof. Johan Rens	Mrs. Leenta Grobler
(082) 566 xxxx	(083) 235 xxxx	(082) 878 xxxx
(051) 404 2187	(018) 299 1978	(018) 299 4058
mbhombsj@eskom.co.za	Johan.rens@nwu.ac.za	

Appendix F: First Reminder Email with Respondents (Power Utilities)

12 June 2015

Dear Participant,

POSTGRADUATE RESEARCH REQUEST

I have not received sufficient responses to finalise my research, so it would be of great help to me if you would take the time to complete the research questionnaire. It should take you approximately 25 minutes to complete. The following link provides direct access to the research web page and access to the research questionnaire:

https://www.surveymonkey.com/s/PQMUtilities

Your response will be kept strictly confidential and will be used solely for research purpose. Only members of the research team will have access to the information you give.

I would greatly appreciate it if you could return the completed questionnaire by no later than 17 June 2015; just click on the submit button at the end of the questionnaire to return it to me. If you have any questions or enquiries regarding the research project, please contact me or my supervisors, Prof. Johan Rens and Mrs. Leenta Grobler. Our contact details are provided below.

Thank-you for your time and assistance in furthering this research endeavor

Best Regards

Jabulani Mbhombhi

Jabulani Mbhombhi	Prof. Johan Rens	Mrs. Leenta Grobler
(082) 566 xxxx	(083) 235 xxxx	(082) 878 xxxx
(051) 404 2187	(018) 299 1978	(018) 299 4058
mbhombsj@eskom.co.za	Johan.rens@nwu.ac.za	

Appendix G: Correspondents' email with Respondents (Industrial Key Customers)

24 February 2016

Attention: Mr. X

Industry name – xxxx

Dear Mr. x

This is Jabulani from Eskom, situated in Bloemfontein. I would like to thank you for taking my call and for the time to talk to me. As per our telephonic conversation, I am doing research on power quality as part of a Masters study. The research is conducted at the North West University.

As part of this research, a selected number of Eskom's key customers have been identified to participate in this research by commenting (survey) on the sensitivity or experience of their industry regarding power quality. Your industry has been identified as a suitable key customer to participate in the survey.

Attached to this mail is a document that will provide you with background information about the research. Included in the document is a consent form for confidentiality assurance to be signed by both parties during the survey. I will later consult with you so as to agree on a suitable date where I can come to your offices to have a one-on-one interview with you while I am documenting your response and experience on power quality issues, as well as your views on the smart grid technology.

This research has also been endorsed by Eskom and I have also copied hereto Mrs. Dikeledi Mokoena (Customer Executive at Eskom) on this mail

Once again, thank you for supporting this research and looking forward to meeting with you

Best Regards

Jabulani Mbhombhi (Pr Eng.)

Quality of Supply

Plant Management

Distribution – Free State Operating Unit

Bloemfontein

Tel:+27 51 404 2187

Mobile:+27 82 566 xxxx

Fax:+27 86 537 7892

E-mail: mbhombsj@eskom.co.za

Appendix H: Informed Consent Form Used During Semi-Structured Interviews

Faculty of Engineering

NORTH-WEST UNIVERSITY ®
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOM CAMPUS

Informed consent form for participants to comment on the sensitivity of their enterprise/industry to Power Quality

This informed consent form is for persons of interest who would be able to comment on the sensitivity of their enterprise/industry to Power Quality and who we are inviting to participate in the research titled "*An evaluation of the key factors that influence a South African based electrical utility to utilize smart grid technologies for power quality management*". The principle investigator for this study is Mr. Jabulani Mbhombhi, a candidate in pursuant of an M. Eng. (Electrical and Electronics) degree, specializing in power quality.

This Informed Consent Form has two parts:

- Information Sheet (to share information about the study with you)
- Certificate of Consent (for signatures if you choose to participate)

You will be given a copy of the full Informed Consent Form

Part I: Information Sheet

Introduction

I am Jabulani Mbhombhi, currently working for ESKOM, and pursuing Master's Degree in Engineering in the field of Power Quality. The information provided in this document serves to invite you to be part of this research. Before you decide, you can talk to anyone you feel comfortable with about the research.

Purpose of the research

With the ever increasing number of customers connecting large sensitive devices that comprises power electronics that are quite sensitive to power quality disturbances on the supply network, and the integration of renewable energy sources distributed throughout the network in South Africa, monitoring of power quality will become more and more important to power utilities. Without a well-established power quality management program with advanced monitoring, fault detection and identification, the integration of these renewable energy sources could affect voltage stability, voltage unbalance and waveform distortion. PQ events such as voltage dips may also result in large financial consequences to customers (mainly industries with process plants), resulting in reduced customer satisfaction. In extreme cases, poor quality of the electrical supply may also result in financial losses to the power utilities.

Power quality can be improved through system-side solutions, customer service entrance solutions, power conditioning for selected equipment within a customer facility, or improved specifications and equipment design. However, providing solutions to power quality problems on the electrical network require a strategy for monitoring and analysis of the network. The research question that will be answered in this study is: *Does the use of smart grid technologies provide an opportunity to improve the management of power quality in a South African-based electrical utility?*

The study will explore the opportunities of using network coherent data from power quality instruments designed according to the latest draft of IEC 61000-4-30 Class A requirements, to be incorporated as a smart grid component.

This part of the study is not quantitative (as most of you would be used to) based on statistics and questionnaires, due to the relatively small number of applicable customers who could be approached in the country. A small number of respondents would have led to insignificant conclusions from a statistical point of view. According to Seidman in (Seidman,2005), qualitative research methods are concerned with the meanings and interpretation of phenomena and processes in their contexts. A qualitative research approach is, therefore, followed in this study, as this is the most suitable to analyse unstructured data in order to provide a detailed description. For the study, a Multiple Case Study method is followed in order to develop an in-depth description of the key factors that influence a South African based power utility to employ smart grid for the management of power quality.

Type of Research Intervention

This research will involve your participation in an interview that will take about one and a half hour.

Participant Selection

Interviews are being conducted as part of research work conducted at the North West University – Potchefstroom Campus. The survey aim is to determine the extent of power quality on distribution networks of a South African-based power utility, evaluated from the customer perspective. The information collected will then be used to evaluate whether technology such as smart grid can be employed to support the management of power quality. As the main distributor of electricity in South Africa, Eskom will use this research as input to its technology advancement criteria for power delivery at Distribution level. The survey interview comprises of five domains of enquiry to assess the customer's stance on power quality.

The interviews will be conducted with one representative each; from a minimum of 15 industrial/commercial key customers of ESKOM and / or local utility, who, from the nature of their business, are sensitive to power quality problems.

Voluntary Participation

Your participation in this research is entirely voluntary and all information provided will be treated as confidential. It is your choice whether to participate or not. The choice that you make will have no bearing on your service whatsoever with the power utility or on any service-related evaluations or reports. You may change your mind later and stop participating even if you agreed earlier.

Procedures

We are asking you to help us learn more about your enterprise's/industry's sensitivity to power quality problems. We are inviting you to take part in this research project. If you accept, you will be asked to participate in an interview with the researcher.

During the interview, the researcher or another interviewer will sit down with you in a comfortable place of your choice. If you do not wish to answer any of the questions during the interview, you may say so and the interviewer will move on to the next question. No one else but the interviewers will be present unless you would like someone else to be there. The information will be recorded in the form of audio recordings and written field notes and is confidential, and no one else except the research team will have access to the information documented during your interview.

Duration

The research takes place over 1.5 years in total. During that time, we may visit you once more for interviewing and may follow up via email if more information is needed.

Risks

There is a risk that you may share some personal or confidential information by chance, or that you may feel uncomfortable talking about some of the topics. However, we do not wish for this to happen. You may state that a certain part of what you are disclosing is off the record, and the research team will then not document this but do so only for information that will be beneficial to this research.

Benefits

This research will provide input to a South African-based power utility's technology advancement criterion for power delivery at Distribution level and to ensure that management of power quality is achieved in accordance with advanced measurement requirement with accurate time stamping to facilitate easy identification of power quality problems.

Confidentiality

We will not be sharing information about you to anyone outside of the research team or the power utility. The information that we collect from this research project will be kept private. Any information about you and your enterprise/industry will have a number on it instead of your name. Only the researchers will know what your number is and we will lock that information up with a lock and key. It will not be shared with or given to anyone. Eskom may however use this information to evaluate potential valuable technologies to improve the management of power quality to its customers. Any disclosure of confidential information shall be limited within Eskom to its management, officers, partners and / or employees having a need to know and shall not disclose confidential information to any third party (whether an individual or other customer) without the prior written consent of disclosure.

Sharing the Results

Nothing that you tell us will be shared with anybody outside the research team, and nothing will be attributed to you by name. The knowledge that we get from this research will be shared with you and your power utility before it is made widely available to the public. Each participant will receive a summary of the results. Following this, we will publish the results so that other interested people may learn from the research.

Right to Refuse or Withdraw

You do not have to take part in this research if you do not wish to do so and choosing to participate will not affect your service with the power utility or service-related evaluations in any way. You may stop participating in the interview at any time that you wish without your service being affected. I will give you an opportunity at the end of the study to review your remarks, and you can ask to modify or remove portions of those, if you do not agree with my notes or if I did not understand you correctly.

Who to Contact

If you have any questions, you can ask them now or later. If you wish to ask questions later, you may contact me at any of the following places:

Cellphone: 082 566 xxxx

Email: MbhombSJ@eskom.co.za

Part II: Certificate of Consent

The Certificate of Consent can be found on the next page of this document.

Faculty of Engineering

NORTH-WEST UNIVERSITY ®
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOM CAMPUS

Certificate of Consent

I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions I have been asked have been answered to my satisfaction. I consent voluntarily to be a participant in this study

Print Name of Participant: ______________________________________

Signature of Participant: ______________________________________

Date: ______________________________
Day/month/year

Statement by the researcher/person taking consent

I have provided the information sheet to the potential participant, and to the best of my ability made sure that the participant understands that the following will be done:

1. One semi-structured open-ended interview will be conducted with the interviewee, during which he/she will be informed of what the interview is about, the aim of the study and how the interview fits into the study.
2. During the interviews, responses made will be recorded in the form of audio recordings along with summarising interview notes, as field notes. The field notes will be used to identify recurring themes. Based on these themes information will be grouped into categories, and the relationships between these categories utilised to describe the situation in each case study.
3. If further information is needed, the principle researcher will contact the interviewees via email.

I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

Print Name of Researcher/person taking the consent: ____

Signature of Researcher /person taking the consent: ______________________________________

Date: ______________________________
Day/month/year

Appendix I: Interview Procedure

Interview procedure: Masters' student Mr. S. J. Mbhombhi

When arriving at the interview location, the researcher provided the participant with context to the visit and the study. the interview should and was seen as a relaxed conversation with a peer rather than an interview, with a somewhat structured approach, for time efficiency and to cover material more completely. Questions asked during the interview covered the following five domains of enquiries:

1. Customer's general awareness of PQ
2. Customer internal technical assessment to support PQ management
3. Customer's viewpoint on the utilities PQ (Product reliability and quality)
4. Customer's assessment of how the utility deals with their PQ related complaints
5. Customer commitment to PQ monitoring and use of advance monitoring technologies (Smart Grid).

Appendix J: Approval by Eskom to Conduct Research with LPU Customers

From: Zuhdi Hamza
Sent: 31 October 2014 02:15 PM
To: Jabulani Mbhombhi
Cc: Lana Potgieter
Subject: FW: Approval for key customer survey: Masters studies

Good day Jabulani,

You have been granted approval to proceed with your research. However there are conditions attached as outlined below.

Regards

Zuhdi Hamza | Senior Manager | Customer Service Operations | Eastern Cape

Eskom Holdings | Sunnilaws Office Park | Cnr Quenera Dr and Bonza Bay Rd | East London | South Africa

Direct +27 43 703 2297 | Mobile +27 83 232 xxxx | Fax 086 539 2508

Hamzaz@eskom.co.za

Assistant: Khalida Booi Direct +27 43 703 2455 or Internal 8710 – 2455

Booikh@eskom.co.za

From: Marion Hughes
Sent: 31 October 2014 1:38 PM
To: Zuhdi Hamza; Algie Kiewitz
Cc: Len Turner
Subject: RE: Approval for key customer survey: Masters studies

Good day Zuhdi,

I had a discussion with Algie regarding this.

In essence we support this research with the following proviso:

- 1. We limit the research to a sample of the Key Customer/LPU database;
- 2. That Jabulani liaises with the Eskom department that will benefit most from this research and get almost sign-off of the questionnaire;
- 3. That Len Turner assists with a confidential and ethical sign-off. (I had a discussion with Len Turner)

We wish Jabulani success in his studies and can confirm that we both support further studies.

Kind regards

Marion Hughes | General Manager | Customer Services Operations

Eskom Holdings | 1 Maxwell Drive, Johannesburg | Gauteng | South Africa
Direct +27 11 800 6022 | Mobile +27 79 490 xxxx | Fax 086 538 1821

hughesm@eskom.co.za

Assistant Elvin Behn Direct +27 21 859 4364 or Internal 8926 – 2022

BehnEE@eskom.co.za

From: Zuhdi Hamza
Sent: Thursday, October 30, 2014 6:43 PM

To: Algie Kiewitz; Marion Hughes
Subject: FW: Approval for key customer survey: Masters studies

Good day Algie, Marion

Reminder to please confirm your approval on the request below.

Regards

Zuhdi Hamza | Senior Manager | Customer Service Operations | Eastern Cape

Eskom Holdings | Sunnilaws Office Park | Cnr Quenera Dr and Bonza Bay Rd | East London | South Africa

Direct +27 43 703 2297 | Mobile +27 83 232 xxxx | Fax 086 539 2508

Hamzaz@eskom.co.za

Assistant: Khalida Booi Direct +27 43 703 2455 or Internal 8710 – 2455

Booikh@eskom.co.za

From: Zuhdi Hamza
Sent: 23 October 2014 1:47 PM
To: Algie Kiewitz; Marion Hughes
Subject: FW: Approval for key customer survey: Masters studies

Good day Algie and Marion,

The details in the mail below bears reference. This is a request from Jabulani Mbhombhi, an Eskom employee and Masters student, who will be conducting research on power quality and smart grid. He intends targeting Eskom Key and Large customers (a random sample) across the country. Attached is the draft of the questionnaire that he will be using for your information. (His definition of Key is large power users)

The purpose of my mail is to solicit your approval that he may contact our customers to conduct this research. This research will be beneficial to him in his studies as well as to Eskom. He will make contact with the customers via the customer executives whom will be contacted prior to engaging the customer so that customers do not confuse this with our customer satisfaction surveys. I personally support that we allow him to conduct this research.

Should we require him to add any specific questions to his questionnaire related to the research topic, he is willing to do so.

Your support for this initiative will be appreciated.

Regards

Zuhdi Hamza | Senior Manager | Customer Service Operations | Eastern Cape

Eskom Holdings | Sunnilaws Office Park | Cnr Quenera Dr and Bonza Bay Rd | East London | South Africa

Direct +27 43 703 2297 | Mobile +27 83 232 xxxx | Fax 086 539 2508

Hamzaz@eskom.co.za

Assistant: Khalida Booi Direct +27 43 703 2455 or Internal 8710 – 2455

Booikh@eskom.co.za

Appendix K: Consent by Ekurhuleni to collect Research Data from Industrial Customers

Ekurhuleni
METROPOLITAN MUNICIPALITY

OFFICE OF THE HEAD OF DEPARTMENT: ENERGY

<Street Address>

Cnr s

Boksburg
1460

Enquiries: **Fred Fryer**
Tel: **011 999 5755**
e-mail: **freddie.fryer@ekurhuleni.gov.za**

<Postal Address>

www.ekurhuleni.com

26 February 2016

Mr. Jabulani Mbhombhi (Pr Eng)
Manager: Business Improvement and Support
Business Improvement and Performance Management
Distribution – Free State Operating Unit
Bloemfontein
Tel:+2751 404 2187
Cell:+27 82566 xxxx
Fax:+27 86 5377892
E-mail: mbhombsj@eskom.co.za

RESEARCH PROJECT ON POWER QUALITY TO INDUSTRIAL CUSTOMERS

It is noted that you are conducting research in power quality, as part of your master's studies with North West University – Potchefstroom Campus. Professor Johan Rens is the supervisor for the research work. As part of the research, industrial customers will be approached to comment on their sensitivity to power quality or Quality of Supply. The City of Ekurhuleni was identified as having a considerable number of suitable industrial customers, who could add value to the study survey.

Our City appreciates the knowledge that will be gained by this important study and you are hereby permitted to involve a selection of industrial customers, electrically connected to the Ekurhuleni grid. It is understood that the study will assist South African-based power utilities to better understand the extent of power quality from a customer perspective. This will enable us to come up with proactive means of identifying QoS problems affecting customer operations.

The survey will be in the form of one-on-one interviews to be conducted at a location convenient for the industrial customer.

Best of luck with your studies.

Yours sincerely

MARK WILSON (Pr Eng)

HEAD OF DEPARTMENT: ENERGY