Exploring the effect of an asset management system on the efficiency and reliability of transformers in a power utility

BY

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ABSTRACT

The research presents an analysis of Eskom's transmission transformer performance in support of the company's Asset Management System. Eskom Transmission is currently implementing an Asset Management approach to making investment decisions. Literature review revealed that the grid adopted PAS 55, currently considered the best practice in Asset Management in the industry, in 2010. The results from this analysis can be used to decide on appropriate asset strategies on whether to extend the life span of an asset or to replace it. This will ensure that most effective investment decisions are made in order to improve the reliability and lifespan of company's networks.

Eskom is experiencing the pressures of operating and maintaining older transmission substations with reductions in their work force and operating budgets.
The Grids have established a maintenance plan to perform scheduled maintenance to assess the condition of equipment which mainly follows the time based management in order to maintain reliable and cost-effective operation of plant. Time based maintenance and condition based maintenance are the main strategies used in Eskom Transmission. There is an increase in transformer maintenance defects due to network constraints, in sufficient maintenance teams, reduced skills, insufficient network contingencies etc. Substations need to be inspected on a regular basis by experienced substation personnel to effectively maintain continuous operation.

The data used in this study was collected by means of interviews and questionnaires of a sample group within the North Grid. More percentages of people in the Grid were not interviewed instead were issued with questionnaires. This was done in order to ensure that the sample group is a fair representation of the Grid. The results of this research confirm that there is in fact a real requirement to train the artisans and supervisors in terms of asset management principles to increase equipment reliability and performance.

Key words: reliability, maintenance, asset management system and availability.

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List of Abbreviations

AMS Asset Management System

APM Asset Management Performance

PAS Publicly Available Specification

Eskom Electricity Commission of South Africa

TWG Transformer Workgroup

YTD Year to Date

NCR Non Conformance Report

PDCA Plan Do Check Act

SAMP Strategic Asset Management Plan

ISO International Organization for Standardization

SME Small and Medium Enterprise

IPAM Poor Integrated Asset Management

HV High Voltage

OEM Original Equipment Manufacturer

DGA Dissolved Gas Oil Analyzer

CBM Condition Based Maintenance

IR Infrared Scanning

SFRA Sweep Frequency Response Analysis

KV Kilovolts

DP Depolarization Index

IEC International Electrotechnical Commission

IEEE Institute of Electrical and Electronic Engineers

TBM Time Based Management

CT Current Transformer

VT Voltage Transformer

CHAPTER: ONE

NATURE AND SCOPE OF THE STUDY

1.1 Background / overview of the study

Electricity is an essential resource for macro-economic survival in Southern Africa. Without a stable security of supply, no economic growth can take place and unreliable assets play an important role in terms of ensuring security and reliability of supply. The South African government identified electricity as a strategic part of its planning, growth and developmental objectives (Globaltech: 2010). Over the next few years the country anticipates to experience perpetual growth in electricity demand, driven by the growth in the industrial, mining and consumer sectors. As a result of higher than anticipated growth and limited investment in new generation infrastructure over the past 15 years, Eskom's generation reserve has fallen below the 10% margin. This reserve margin is below conventional industry benchmarks. Eskom plans to restore the generation reserve margin to around 15% in the medium to long-term (Globaltech: 2010). Based on the result of this low reserve margin, Eskom has reacted to the situation by putting in place a proactive Strategic Asset Management Plan (SAMP) that ensures that existing reserve margins are maintained for continued and reliable supply of electricity. In the event of any forced (unplanned) maintenance due to unhealthy assets, the country will be exposed to the risk of irregular blackouts. This will put pressure on other substations that are on load to postpone their planned maintenance schedules in order to cater for the shortfall.

An effective system for managing asset integrity and reliability is the most important barriers against failure in complex industrial facilities such as substation infrastructure. In the substations, assets are being pushed to their limits with increased loads on aging infrastructure and enhanced expectations of reliability. According to Haefeng & Asgarpoor (2012:69) substations are facing several challenges such as an increasing amount of aging equipment, mandatory compliance requirements, growing demand on systems and the need to cope with uncertainties.

The constraints faced by Eskom in so far as the tight margin of electricity is concerned are results of deteriorated assets and lack of investment on existing assets. Ageing substation infrastructure in the grids is an increasing concern for risk management. Due to this prevailing state of affairs, plant assets are forced to run for longer periods without planned maintenance being applied. Maintenance management and the reduction of costs are of the utmost importance for any business to sustain profitability and competitiveness.

The transformer must be operated and maintained in a manner that optimizes life cycle cost to ensure the correct balance between costs, performance and risk. There should be no excess inventory of unnecessary spares, but a strategy should be in place to ensure there are sufficient spares for critical and strategic plants, like transformers. Financial information management shall be developed and integrated across the life cycle stages of the transformer. Given the fact that the transformer is a critical asset to the organization it is vital to know and to attend to failure as soon as it occurs. This should be done in order to avoid high maintenance expenses later. Based on the related cost data, there will be a lot of uncertainties and the principle of fuzzy analytical hierarchy process method must be used to make a decision to either keep repairing the asset or replacing the transformer.

1.2 Literature review of the topic/research area

O'Hanlon (2014:20) defines an asset management system as the set of interrelated elements that support the asset management policy, the strategic asset management plans and asset management objectives. The asset management system is focused on ensuring that the resources necessary to meet the strategic assets management are specified and provided. The strategic asset management plan (SAMP) is documented information that specifies how the organizational objectives are linked to the asset management policy and how the organizational objectives support in achieving organizational objectives (O'Hanlon 2014:44). An asset management system is used by the organization to direct, coordinate and control asset management activities. It can provide improved risk control and gives assurance that the asset management objectives will be achieved on a consistent basis. The process of implementing an asset management system effectively brings new perspectives to the organization and new ideas on value creation from the use of assets. The management of assets is dependent on knowledge about the organization's assets in terms of both current equipment, business role of the assets and future prospects.

Plant assets are complex interconnected machines with many components operating in harmony when the system is balanced. When an interruption of the system occurs, the impact of the disturbance may cause the system to operate inappropriate to supply the grid. The electricity blackouts that swept the country around January 2008 (Eskom, 2010), and currently in 2015, left a negative dent on the image and reputation of the organisation – hence, the drive by one of its employees to conduct a study on maintenance strategy to shed light on how we can improve on the gaps that will be identified. Power system blackouts result in complete interruption of electricity supply to all consumers in the country. Blackouts may look like bad luck, but they are the result of the way the grid is managed (Novosel: 2008: 100). According to

(Eskom, 2007), in order to maintain a plant to maximum performance, one needs to spend money and ensure that key strategic spares are available in line with the lifespan of the equipment.

According to Muhr *et al.,* (*2006:537*) new developments in diagnostic tools and effective asset management systems are necessary for a reliable and economic evaluation of the condition of equipment in substations. Substation assets must be always fit for the purpose, safety and reliability, durable, value for the money and user comfort. Tanaka *et al., (*2010:6) mentioned that the criteria for assessing the health conditions of substation equipment or assets are as follows:

- The degree of degradation and obsolescence of equipment (phased out components, obsolete technologies and/ or retiring personnel);
- Environmental concerns such as transformer noise, and
- Once widely used but now unacceptable materials in the old equipment.

The definition of efficiency and effectiveness is based on an evaluation of organizations independently of its context. In order to evaluate efficiency and effectiveness of activity systems rather than organizations, this definition might be problematic. Efficiency means doing something at the lowest cost while effectiveness means doing the right things to create the most value for the company furthermore Jacobs & Chase (2011:15) stated that Efficiency is a cost-related advantage and effectiveness is an advantage of customer responsiveness within supply chain management research. This means that efficiency improvements are achieved through optimising the asset management system while effectiveness is achieved through customer orientation. The value concepts are related to efficiency and effectiveness. Value is defined as the attractiveness of a product relative to its price according to Jacobs and Chase (2011:15). If you can give a customer a better car at a lower price, the value goes way up.

The key components of an effective asset management strategy in the substation's asset reliability are the understanding of the complexities of the interconnected power grid, the need for proper planning, good maintenance and sound operating practises. The formulation of reliable power system strategies begins with accurate modelling and system analysis of strengths, weaknesses, limitations, expectations, and the interactions thereof. Haefeng & Asgarpoor (2012:1869) stated that maintenance restores or retains a plant asset to its designed functions where inspections and preventative maintenance are broadly adopted by the system. Both aging and maintenance will impact equipment performance. It is advisable to use the necessary mathematical models that will be able to address the mentioned problems into reliability assessment and systems especially for substations which have a bigger capacity.

Mathematical models also improve the equipment reliability of the entire power plant by the analysis of the conditions of the assets. The development of mathematical models representing the reliability characteristics of the electrical devices went hand-in-hand with the development of power system reliability evaluation techniques. The study involves analysis of the effects of failures of the major components in the substations. A great advantage of the mathematical approach is that the outcomes can be optimized.

Maintenance is part of asset management system. The objective of a maintenance policy is achieving failure free operation of the system and prolonging the remaining life of equipment. The remaining lifetime of the equipment depends on the frequency of making inspections and the quality of repairs. Maintenance activities mostly restore the condition of equipment to better than those it was found in or in its replacement with a new one. Eti e*t al.,* (2006:1163) argue that higher plant reliability leads to reductions in the frequency of equipment failure, wastage of energy, cost cutting and improve of revenue. To ensure that the system is reliable and efficient, the effective maintenance plan must be developed, implemented and measured. In most companies, the maintenance scheduled is missed and repairs and replacement only ensue after a breakdown. Society as whole is satisfied if the system does not fail. Eti e*t al.,* (2006:1164) continued saying that failure of the assets can affect the system output, safety compromised, environmental integrity, product quality, customer service, protection and operating cost in addition to incurring repair costs.

Scheduled or planned maintenance might be quite costly and not extend the lifetime of the assets as was expected therefore preferably maintenance should be carried out when needed.

Many infrastructure owner-operators are engaging consultants in order for them understanding where on the scale of asset management maturity they reside and what they need to do to get measurably closer to ISO 55000

1.3 Motivation of topic actuality

The impact of the current asset care will eventually lead to premature plant assets deterioration and the signs are already visible as shown by the incident management system. Most of the utility companies world-wide are far behind with maintenance, with the consequence of growing instability of their operations, which are becoming a serious threat to the economy of the affected countries. To keep the system stable the age and the condition of the plant assets need to be monitored and taken into account in planning, so that issues of reliability and risk, and disruptions to the power supply can be managed effectively. From an economical and environmental point of view, there is much to gain from healthy power system networks, because in principle the interruption of power supplies and load shedding are minimized. It is important that the control plant maintenance department establishes a maintenance strategy that will ensure that the transformers are operated and maintained optimally in order to increase appropriate levels of reliability and to optimize operational life of the transformer. Maintenance planning and scheduling is important in order to detect any abnormalities in the performance of the transformer before it can cause unnecessary damage.

1.4 Problem statement

The problem of equipment in Eskom substations is persisting due to the current capacity constraint. The problem however is that these plant assets are not being maintained. These plant assets are also never switched off often enough for vital maintenance due to power demand in the country. This is despite the fact that this equipment works harder than its designed capacity. Most of the assets are failing to realize their life span and end up collapsing before then due to poor maintenance. Although improving operation and maintenance processes could curtail some of the outages, the senior managers continue to plague asset managers on an ongoing basis. Generally, most of Eskom's substations are old and as such are impacted by frequent breakdowns. Outage slips and extensions take much longer than planned due to the state of many plants in the country. This was found to be the case when the selected plants (substations) where opened for inspection as part of the current study. This has a negative impact towards the revenue of the grid and the business as a whole. In order to sustain continued economic growth, companies and mines cannot afford to have disruptions of their production activities. Therefore, Eskom has to have a proper maintenance of its plant assets in order to provide investors with necessary confidence in the stability of energy supply.

1.5 Research objectives of the study

1.5.1 Primary objective

The primary objective of the research was to develop a procedure that quantitatively evaluates the health of power transformers in the selected substations of the grid. The study was also aimed at synthesizing the health conditions of individual substations into the indices of substation groups in an area or a region.

1.5.2 Secondary Objectives

The primary objective of this study was to prevent unexpected failure of the power transformers and other critical equipment within the power utility which may result in a loss of life and /or major financial adversity.

1.6 Hypotheses

- Effective plant asset management improves the performance of equipment thereby ensuring a revenue increase.
- Risk of unhealthy assets is minimised and the network system is sustainable.

1.7 Research design/method

1.7.1 Literature review:

The theoretical study was generally on the asset management system and specifically on the power transformer. The primary data used in this study was sourced from the transformer articles, set standards, internet, books, plant asset maintenance documentations, Eskom employees' records and intranet. All information gathered in this study was consolidated and evaluated in order for the researcher herein to reach better conclusions and make sensible recommendations in order to help improve operations of Eskom assets in the selected substations.

1.7.2 Empirical research:

Most companies world-wide including the Small and Medium –sized Enterprise (SME) are striving for competitive advantage and at minimizing operation costs in order to maximize their profits. In order for the power utility to be a successful company its entire supply and the maintenance processes need to be monitored regularly to ensure that the system is reliable and sustainable all the time. In this study an assessment was carried out on Eskom's substations through a survey and an interview process. An interview was arranged with senior managers who have good knowledge of the company's activities and its approach to quality and business excellence in order to compile the actual findings. Site visits were also conducted. The data collected from interviews was analyzed through applicable qualitative research methodologies.

1.8 Conclusion

Chapter one provided the background of the study. It described the problem statement. The next chapter provides the literature study to outline the asset management system in the power utility.

CHAPTER: TWO

LITERATURE REVIEW

2.1 Purpose and Chapter Outline

The purpose of this chapter is to provide a literature review on the effectiveness of the asset management system on power transformers at the power utility and to determine the common elements of this system. This is the best system to close the gaps within the current situations and to identify the better tools that can be used to increase the availability of the equipment. The concept of asset management system for transformer maintenance has been developed and applied for many decades world-wide. This study focuses more on power transformer with the aim of increasing the efficiency of asset management in Eskom substations.

Eskom and Transmission are facing a number of challenges. These challenges are helping ensure a security of supply while maintaining the sustainability of Eskom. Eskom has an ageing infrastructure which requires reinvestment in terms of maintenance and refurbishment. Further Transmission is faced with capacity constraints that require investment in new infrastructure.

As a result of this Transmission has adopted asset management as an approach to responding to these challenges. This will result in a defendable, systematic, systemic, sustainable and optimal way of decision making. Through asset management Transmission will be able to demonstrate the best value for money within the constrained funding environment.

Substation maintenance practices have been executed periodically in the past and presented for the purpose of achieving high reliability on the Transmission system particularly on critical equipment like power transformers. Given the fact that Eskom's network has aged over the years their maintenance costs have increased significantly in recent years. The skills shortage currently experienced by the power utility is exacerbating this situation particularly as they relate to Eskom's mandate of ensuring a sustainable supply of electricity.

2.2 Introduction to plant asset

A plant asset is a large complex facility that consists of various equipment types. It may also severely affect human lives over a wide area and cause huge amount of costs in cases of accidents arising from it. The effective asset management system reacts quickly to device malfunctions and failures of the equipment to keep the plant running at all times. The plant needs the best equipment reliability and safety since it may cause severe damage to the national grid. The reliability of the equipment is affected by the effectiveness of asset management processes which needs to be established and utilised efficiently.

2.3 Asset management system

Eskom Transmission has adopted the PAS 55 definition of Asset Management as systematic and coordinated activities and practices through which an organisation optimally manages its physical assets, and their associated performance, risks and expenditure over their lifecycle for the purpose of achieving its organisational strategic plan. Publicly Available Specification (PAS) 55 was first published by British Standards in 2004; it describes a systematic approach to the processes that link a company's objectives to the assets that are used to deliver. PAS 55 is not prescriptive in terms of approaches to asset management, but rather promotes requirements which allow companies to demonstrate effective asset management to stakeholders against an independent standard. PASS 55 has formally defined the purpose of asset management system as to develop an optimisation strategy of asset management regarding performance, risk and expense modelled over the life cycle.

BS – ISO 55001 stated that an integrated asset management system is vital for organizations that are heavily dependent upon physical assets in the creation or delivery of their services or products. Large numbers of assets, or diversity characteristics of assets and asset systems, particularly in an environment of conflicting stakeholder expectations, further increase the importance of having a systematic approach to managing the asset portfolio.

Figure 21 below shows different levels at which asset units can be identified and managed and ranging from discrete equipment items or components to complex functional systems, networks, sites or diverse portfolios. Many organizations identify assets as equipment units (sometimes referred to as "maintenance significant items" – the unit at which maintenance tasks or work orders are directed), whereas others use the term to describe functional systems or even integrated business units. It does not matter at what such level an asset unit is identified, provided that:

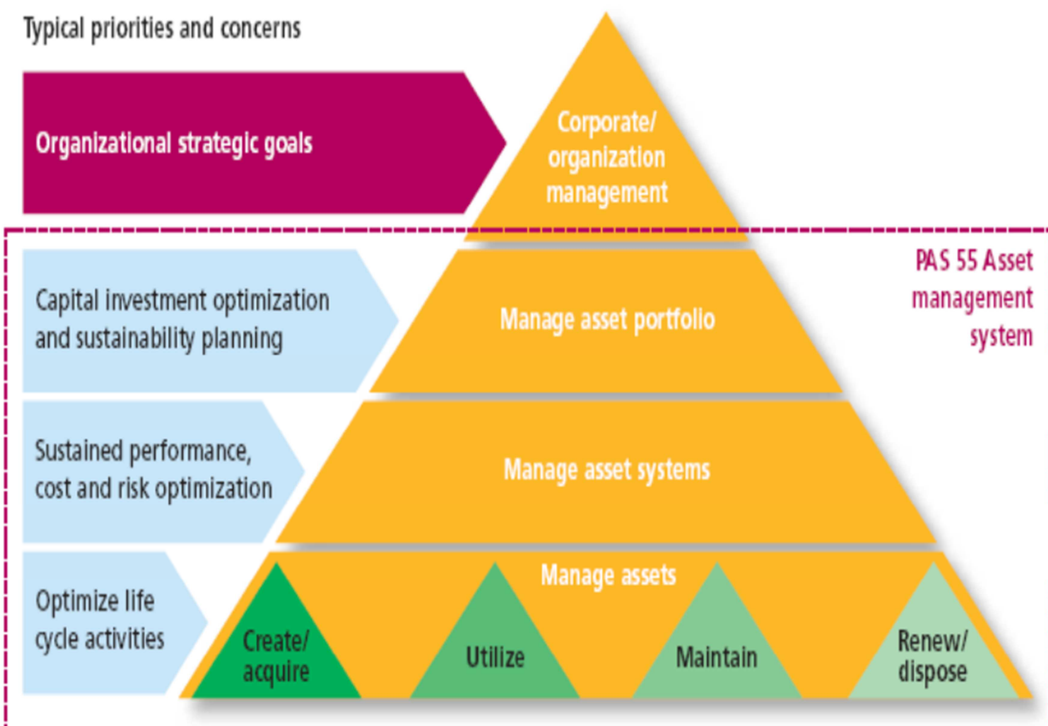
- the organization's goals and strategic priorities are directly reflected in the asset management plan(s);
- the asset life cycle costs, risks and performance are considered and optimized. (This will usually require definition of clear asset boundaries for measuring performance, life cycle expenditures and attributing associated risks.);
- the aggregations of assets (through integrated asset systems) and contributions of value (as part of the organization's portfolio) are managed in a coordinated and consistent manner;

➢ all parts of the organization understand and use the same terminology in relation to the assets, their components and their asset system groupings or aggregations.

This hierarchy brings challenges and opportunities at different levels. For example, discrete equipment items may have identifiable individual life cycles that can be optimized, whereas asset systems may have an indefinite horizon of required usage. Sustainability considerations should, therefore, be part of optimized decision making. A larger organization may also have a diverse portfolio of asset systems, each contributing to the overall goals of the organization, but presenting widely different investment opportunities, performance challenges and risks. An integrated asset management system is therefore essential to coordinate and optimize the diversity and complexity of assets in line with the organization's objectives and priorities.

The asset management focus will tend to differ at the various levels of asset integration in an organization. Furthermore Figure 2-1 shows examples of priorities that might be evident at the different levels of asset integration and management.

Figure 2-1: Levels of assets and their management



(Source: BS – ISO 55001: 2004)

Stakeholders (such as customers, the public, regulators and shareholders) are seeking assurance that the asset management system will deliver safety, continuity of service and financial performance. Organizations are ever more sensitive to the impact that adverse public opinion and negative publicity can have on their business when assets or asset systems fail. For most organizations, therefore, establishing, implementing and maintaining a formal asset management system is increasingly becoming a necessity rather than an option.

An asset management system is primarily designed to support the delivery of an organizational strategic plan, in turn aiming to meet the expectations of a variety of stakeholders. The organizational strategic plan is the starting point for development of the asset management policy, strategy, objectives and plans. These, in turn, direct the optimal combination of life cycle activities to be applied across the diverse portfolio of asset systems and assets (in accordance with their criticalities, condition and performance).

It is for good reason that industry world-wide is enthusiastically embracing the new ISO 5500 standard**.** A robust, integrated asset management system is the only way to ensure that:

- Service delivery and production managers have confidence in production capacity, product quality, cost of production and company image.
- Future refurbishment and replacement costs are predictable; the way in which assets contribute to company results can be maximised.
- Asset integrity and therefor value is preserved**.** Maximum return can be extracted from the initial capital outlay.

Good practice of asset management system is clearly visible in asset availability, asset reliability, and plant appearance and production consistency.

2.4 The principles of asset management

According to BS – ISO 55001 standard asset management is a holistic view and one that can unite different parts of an organization together in pursuit of shared strategic objectives. The key principles and attributes of successful asset management as shown in Figure 2-2 can be explained as follows:

Holistic: is the combined implications of managing all aspects which includes the combination of different asset types as the functional interdependencies and contributions of assets within asset systems, and the different asset life cycle phases and corresponding activities), rather than a compartmentalized approach.

Systematic: is a methodical approach, promoting consistent, repeatable and auditable decisions and actions.

Systemic: is considering the assets in their asset system context and optimizing the asset systems value (including sustainable performance, cost and risks) rather than optimizing individual assets in isolation.

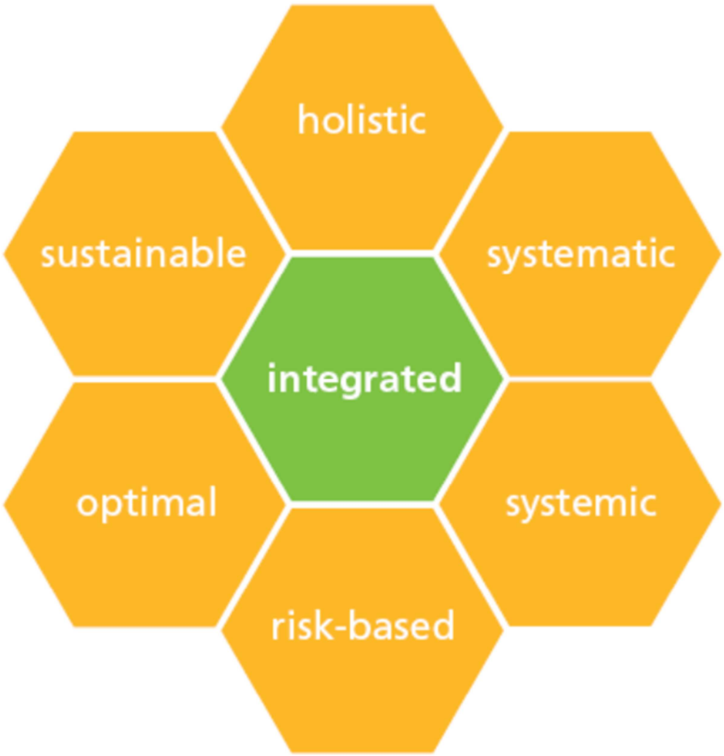
Risk-based: is focussing resources and expenditure, and setting priorities, appropriate to the identified risks and the associated cost/benefits.

Optimal: is establishing the best value compromise between competing factors, such as performance, cost and risk, associated with the assets over their life cycles.

Sustainable: is considering the long-term consequences of short-term activities to ensure that adequate provision is made for future requirements and obligations (such as economic or environmental sustainability, system performance, societal responsibility and other long-term objectives).

Integrated: is recognizing that interdependencies and combined effects are vital to success. This requires a combination of the above attributes, coordinated to deliver a joined-up approach and net value.

Figure 2-2: Key principles and attributes of asset management



(Source: BS – ISO 55001:2004)

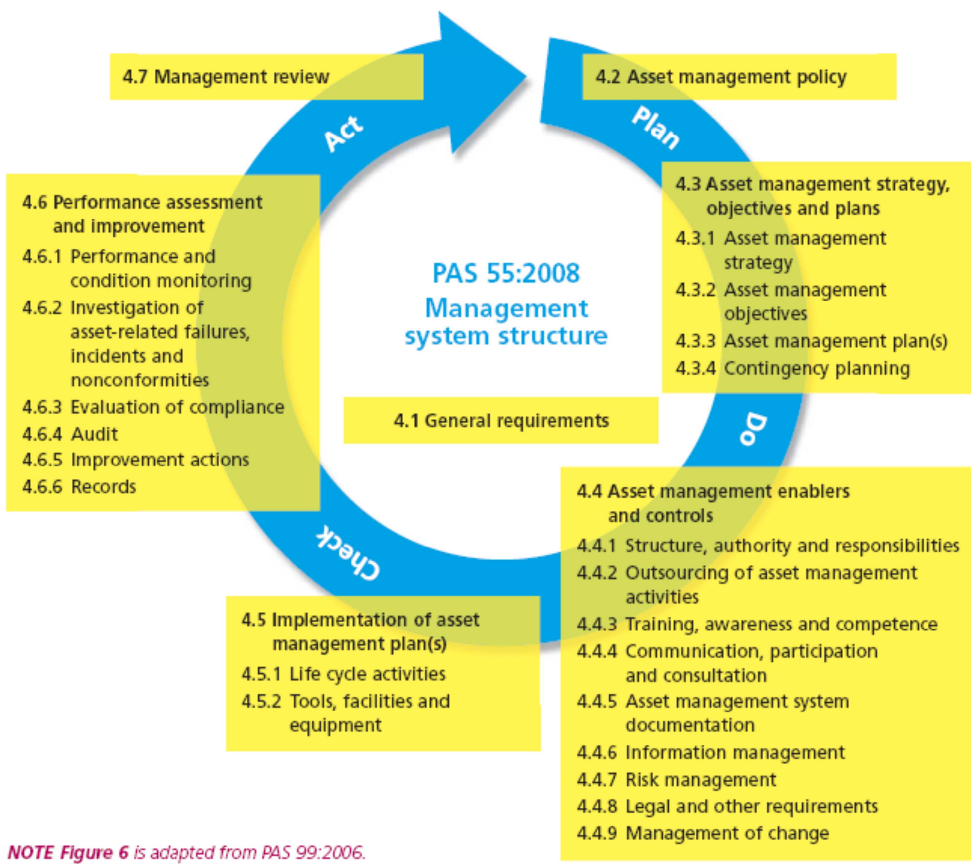
2.5 The Plan-Do-Check-Act methodology

BS – ISO 55001 stated that in order to enable organizations to align or integrate their asset management systems with other related management systems, such as for quality management (ISO 9001) and environmental management (ISO14001), the requirements of ISO standard are arranged within the Plan-Do-Check-Act (PDCA) as shown in Fig.2-3. Plan, Do, Check and Act is the foundation of continuous improvement and is also the foundation of an optimized asset management system.

Plan establish the asset management strategy, objectives and plans necessary to deliver results in accordance with the organization's asset management policy and the organizational strategic plan. Plan how to meet requirements before putting into action. Plans will be created and maintained, to deliver the required level of service of assets. Asset maintenance plans are to minimize life cycle costs consistent with achieving the outcomes specified.

- **Do** establish the enablers for implementing asset management (e.g. asset information management system(s)) and other necessary requirements (e.g. legal requirements) and implement the asset management plan(s). Implement processes in terms of added value.
- **Check** monitor and measure results against asset management policy, strategy objectives, legal and other requirements; record and report the results.
- **Act** takes actions to ensure that the asset management objectives are achieved and to continually improve the asset management system and asset management performance.

Figure 2-3: Structure of PDCA



(Sourced: BS – ISO 55001:2004)

2.6 Asset management performance

The principles of APM are aligned directly with the new ISO 55000 standards, which set a new benchmark for asset management best practise. The standard defines APM as about providing a framework for self-governance of the business of asset performance and reliability. ISO 55000 is an International Standards Organisation specification for an integrated, effective management system for assets. The scope of ISO 55000 encompasses the management system for assets, but only specifies neither the information management nor specifying how the maintenance is to be performed or how assets should be deposed or retired. Asset performance management is defined as optimising processes for the day-to-day operation of assets, to minimize costs and maximise production capacity, usually through minimising downtime and running to peak performance as much as possible DiMattheo (2013:16).

2.6.1 Poor Integrated Asset Management (IPAM) practices lead to:

- Loss of production time due to poor quality of maintenance and incorrect maintenance.
- Doubts regarding the accuracy and reliability of master data, including financial data.
- Unnecessary preventative maintenance work being scheduled.
- Spending money on expensive consultants on work that could be done in-house.
- A lack of confidence by management on where resources for assets should be spent and where it is needed most.

2.7 A strategic roadmap for asset performance management

DiMattheo (2013:10) defines seven levels of a reliability strategic road map for improving reliability and optimising maintenance.

2.7.1 Run to failure

It involves the software to detect failures remotely and instantly. It also assigns resources to prioritise the work. It is only used when the equipment is redundant, quickly replaced and the costs the same in failure as it does in controlled replacement DiMattheo (2013: 10).

2.7.2 Preventive – planned on Time

It is used when an asset has progressive wear based on time rather on usage, or when usage is constant DiMattheo (2013: 10).

2.7.3 Preventive – planned on usage

This maintenance is based on the equipment in use. Equipment in use is more reliable predictor of failure than the equipment which steady use. It is more applicable to the equipment which has variable usage that is not predictable DiMattheo (2013: 10).

2.7.4 Condition – based maintenance

It assesses the condition of assets before failure. It used when equipment has tell-tale signs and measures of extreme usage or parametric DiMattheo (2013: 11).

2.7.5 Predictive maintenance

This involves maintenance-based projections of wear characteristics. It is normally used when equipment has a progressive degradation and an eventual extreme limit DiMattheo (2013: 11).

2.7.6 Reliability- centered maintenance

It is for improving reliability of the equipment based on failure mode analysis. It is frequently used when planning the optimal maintenance regime for the most critical and expensive asset DiMattheo (2013: 11).

2.8 Overview of substations operations

In this section, the key literature in Eskom sub stations is power transformer. Trappey *at el.,* (2015:2) stated that power transformers are important and expensive plant assets for electrical network. The function of a transformer is to distribute and transmit electricity by stepping up and down the voltage for local consumptions. However, with the increase of the operation time or age of transformers, the probability of transformer operating defectively with a parts breakdown which may affect power supply stability increases. If the transformer can fail it cause unexpected power failure, therefore asset management system for power transformer is a critical issue for the operations management which need attention to be directed towards maintenance to avoid unexpected breakdowns. Figure 2-4 below shows the transmission network substation where the power transformers are connected to the grid.

Figure 2-4: HV Substation

(Source: Siemens AG: 2010)

2.8.1 Asset challenges in the substations

Asset management system is the best system to manage the asset integrity and reliability and furthermore is the most important barrier against failures of the equipment in the plant. In most substations assets are being pushed to their limits with increased loads on the aging infrastructure and enhance expectations of reliability. In order to succeed, the management need a better strategy for managing and maintain the new and old plant asset, the strategy that supports more economical to keep the plant available Biag (2014). Management need to look more of the following challenges:

- Unplanned outage: Aging equipment reliability leads to outages and unplanned downtime which eventually cause loss of revenue and unsatisfactory customer service.
- Risk Management: Regulatory compliance is a prerequisite for operations. Failure to comply carries financial penalties.
- Data Management: Most data are stored in archive but there is no way to turn that data into actionable intelligence when needed as most problematics are repeatable.
- Aging Workforce: Knowledge sharing. Knowledge is lost when workers retire or resign.

2.9 Power Transformer

Chakravorti *et al.,* (2013:1) describes power transformer as critical part of electricity network. This is due to the longer lead time and much greater cost per unit. The primary function of a power transformer is to transform system voltage from one nominal level to another. The transformer has to be capable of carrying the power flow under various operating conditions and contingencies. Transformers may be either autotransformers or multi-winding conventional transformers. A three-phase installation may consist of a three-phase unit or single-phase units. Three-phase units have lower construction and maintenance costs and can be built to the same efficiency ratings as single-phase units. Auto-transformers are considered primarily because of cost advantages where the voltage transformation ratio is favourable. Furthermore, auto-transformers are wye connected and for that they provide only an in-phase angular relationship between primary and secondary voltages. They are also smaller in physical size, lighter weight, lower regulation (voltage drop in transformer), smaller exciting currents and lower losses.

2.10 Transformer Life Cycle

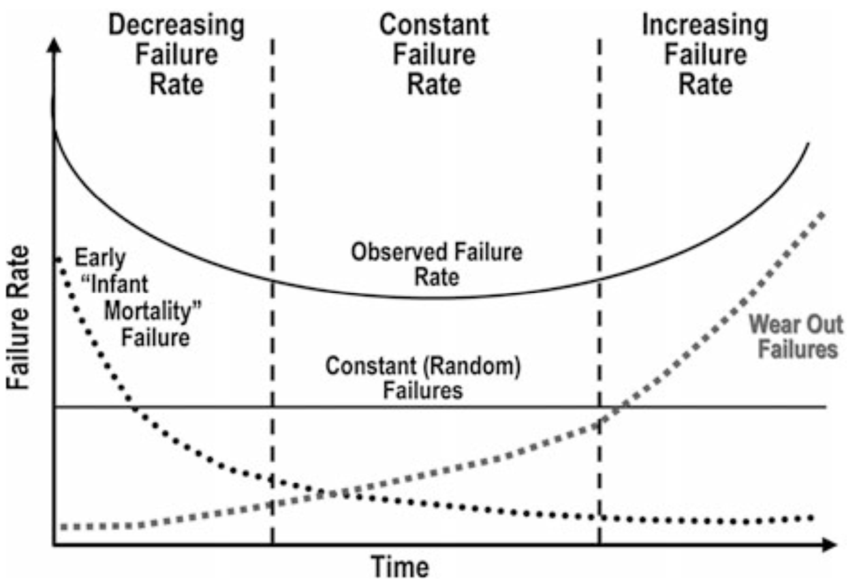
Chakravorti *et al.,* (2013:2) said that failure of transformer while in operation normally lead to significant revenue loss to the utility, potential environmental damage, explosion and fire hazards and expensive repairing or replacement costs. Furthermore they stated that the transformer failure rate has been found to follow the so-called Bathtub Curve as shown in Figure 2-5 below. The bathtub curve depicts the transformer life cycle which is characterized by three distinct phases as depicted in Figure 2-5.

- **Phase 1 – Infant – mortality period:** This is the phase has decreasing failure rate. It normally happened when a transformer has just been connected into a system and in operation. The performance can start to go down due to faults or defects caused by original equipment manufacturer (OEM) during manufacturing, delivery or incorrect installation. This usually manifests from day one up to the first year of service (infant mortality). Infant mortality failure includes failures before transformer is in steady state.

- **Phase 2 - Constant period:** This is the stage when most of the problems have been identified and rectified and it normally takes long. The unit will give a constant performance for a long period of time without problems. Most of manufacturing defects and incorrect installation are mostly cleared by now.

- **Phase 3 – Wear out phase:** This stage is normally related to the aging of the transformer. This stage has increasing failure rate. When a transformer start ageing, it will start giving problem and lot of repairs and maintenance will be required. This is the stage where a possibility of failure is high, unless proper mitigation factors are implemented. Interventions such as repairs and retrofitting can reduce the probability of transformer failure at this stage, provided it is done properly and if it is cost effective to do so. Some repairs are not cost effective and that is when a decision whether to repair or replace a transformer has to be made. Repair and retrofit must only be done if it will offer a solution that is both technically and economically efficient.

Figure 2-5: Transformer bathtub curve

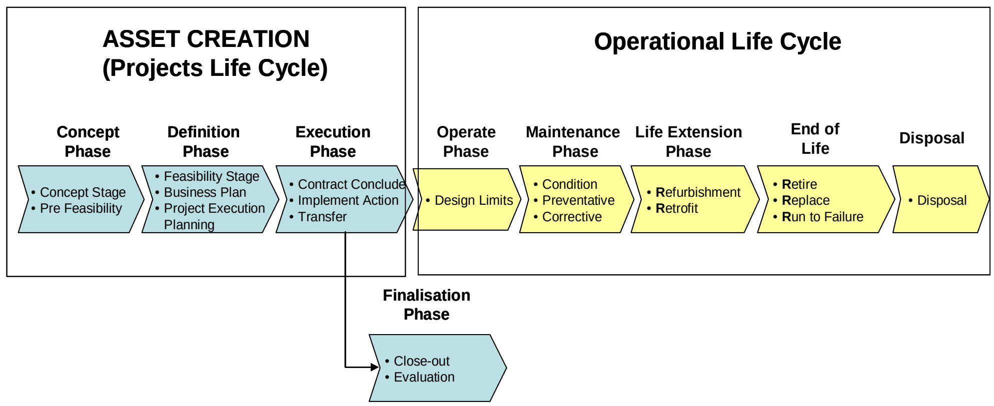


(Sourced from Recent Trends in the Conditions of Monitoring of Transformers: 2013)

2.11 Eskom transmission life cycle stages

Life cycle process flow diagram used in Eskom Transmission, namely asset creation stage (project life cycle) and operational life cycle stage is shown in Figure 2-6 below. These two life cycle stages consist of nine sub-stages, with asset creation consisting of four phases and operational phase consisting of five phases.

Figure 2-6: Equipment life cycle process flow diagram



(Source: Substation Asset Performance Management: 2014)

2.11.1 Asset Creation Phase (Project Life Cycle)

The asset creation process outlines the project life cycle process for the design, manufacture and construction of new equipment. The process includes identifying the need for the asset; establish appropriate technical specification, equipment evaluation and acceptance of the proposed solution.

2.11.2 Operational Life Cycle

The OEM operating and maintenance specification will be used as the baseline to determine and develop the generic operational lifecycle strategy for a specific make and type of the transformer. The operational life cycle document is reviewed on time based or when necessary i.e. Technical instruction from OEM or transformer specialist etc.

2.12 Reliability of the plant

Haifeng (2012:1868) stated that the plants are facing several challenges such as an increasing amount of aging equipment, mandatory compliance requirements, growing demand on systems and the need to cope with uncertainties. Extreme reliability is demanded of plant equipment, and even though the failure risk of plant equipment particularly power transformers is small when failures occur, they inevitably lead to high repair costs, long downtime and possible safety risks. The costs of transformers are too expensive to replace regularly and must be properly maintained to maximise their life expectancy.

Equation 1: Reliability

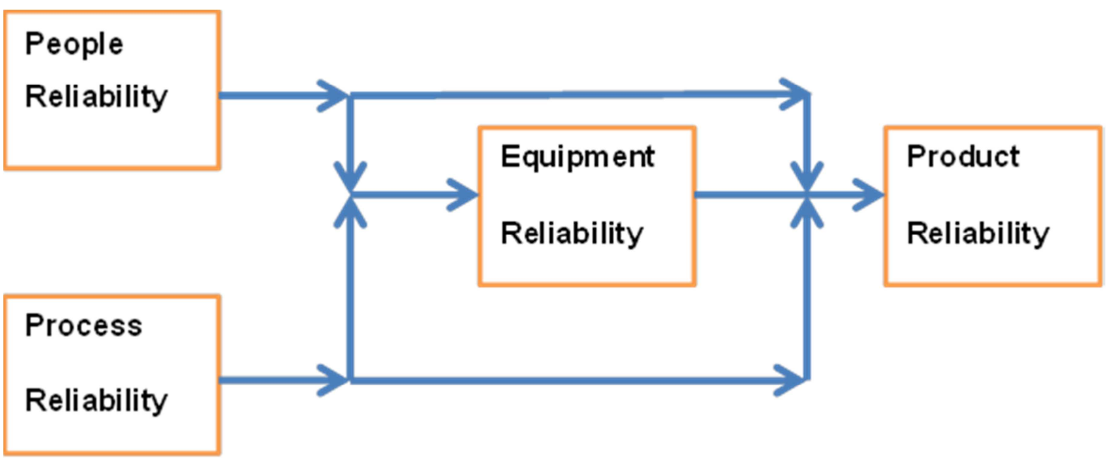
$$\text{Reliability 'by the book'} = R(t) = \frac{1}{e^{\frac{t}{MTBF}}}$$

Meaning definition:

Overall equipment Effectiveness = availability x performance rate x quality rate

Reliability is defined as the process used to determine what must be done to ensure that any transformer or its component continues to do whatever it was designed to do under the existing circumstances during its life span. Figure 2-7 below depicts the link between the stakeholders in terms of reliability. Equation 1 is the formula used to calculate the reliability of the equipment.

Figure 2-7: Asset Management Models



People reliability

The following aspects contribute to people reliability which enhance the equipment and product reliability:

- Good leadership;
- Training and development;
- Communication, and
- Performance management.

Process reliability

It is consist of the following process:

- Business processes;
- Work Management process, and

- Production process.

Equipment reliability

- Tools;
- Assessment, and
- Reliability teams.

Product reliability

Process control

2.13 Maintenance management

According to Maintenance Execution Strategy for Transformer of Eskom maintenance is defined as a combination of all technical, administration and managerial actions during the lifecycle of an item intended to retain it in, or restore it is experiencing the pressures of operating and maintaining older transmission substations with reductions in their work force and operating budgets. The Grids have established a maintenance plan to perform scheduled maintenance to assess the condition of equipment which mainly follows the time based regime in order to maintain reliable and cost-effective operation of plant. A good maintenance program is required in order to:

- satisfy both external and divisional customers;
- effectively utilising resources, and
- provide the best possible reliability and availability.

Substations need to be inspected on a regular basis by experienced substation personnel to effectively maintain continuous operation. The inspection of key substation components/equipment includes:

- Batteries;
- Transformers and Reactors;
- Infrared Scanning;
- Isolators and Circuit Breakers;
- Current and Voltage Transformers;
- Protective Relays;
- Shunt capacitor Banks;
- Dissolved Gas Oil Sampling and Analysis (DGA), and
- Substation and Facility Equipment.

In order to achieve these goals the following must be addressed:

- Acknowledge that maintenance patterns must be altered based on the condition of the equipment rather than using a time-based approach, and
- The aging of equipment further adds to the problem, were older equipment requires increased maintenance plan. This can be done by an accurate assessment of the condition of equipment and the use of condition assessment methods as to assess the maintenance intervals of the plant.

Eskom Transmission maintenance is guided by maintenance policy to ensure that a uniform approach is taken by all parties involved in making decisions about plant maintenance, and the requirements set out in the policy document are compulsory. Eskom Transmission maintenance policy stipulates that maintenance in Transmission will be planned, executed and controlled in accordance with Transmission's commitment to the requirements of ISO9001 (2008), ISO14001 and the OHS Act, with the aim to:

- Optimise maintenance cost;
- Ensure high levels of plant availability;
- Extend plant life;
- Ensure quality of supply delivery to customers;
- Ensure the safety of people;
- Preserve the environment, and
- Contribute to the long term viability and development of Transmission.

2.14 Maintenance management strategy

Chakravorti *et al.,* (2013:6) emphasized that prevention of failure and keeping the transformers in good operational conditions is an essential matter power utilities.
There are two main strategies used by Eskom Transmission in the substations to conduct maintenance. These strategies are tabled and discussed below as follows:

2.14.1 Time based maintenance:

Eskom Transmission has been using this strategy most of the time. In this case maintenance is carried out at predetermined intervals using a schedule consistent with company's strategic planning or according to specified criteria irrespective of the necessary of the maintenance and is intended to reduce the probability of failure. Chakravorti *et al.,* (2013:6) emphasised that time based maintenance is a safe method and it is recommended for transformers and conventional on load tap changers, however it is cost intensive. Trappey *at el.,* (2015:2) highlighted that the time base strategy could fail when faults are not detected during the time interval between planned maintenance times, therefore, efficient and effective fault detection techniques and accurate predictions are important for equipment managers to manage transformer conditions to avoid unplanned outages.

2.14.2 Condition based maintenance

Chakravorti *et al.,* (2013:6) further said condition based maintenance is cutting cost and is carried out without interrupting the steady supply of the electrical power. If the actual condition of the transformer is really detected or known, then the costs can be minimized in CBM by carrying out maintenance only when the condition of the transformer requires it. Condition based maintenance is an advanced and up-to date maintenance strategy and is an alternative to time based maintenance. It is a maintenance program that recommends maintenance decisions based on the information collected through condition monitoring and data is used to predict failures. The data can be used to determine the condition of the transformer and to evaluate when corrective action must be taken. It consists of three main steps: data acquisition, data processing and maintenance decision-making. Diagnostics and prognostics are two important aspects of a CBM program. It is based on performance and/or parameter monitoring and the subsequent actions. It allows extending maintenance intervals to the limit and thus exploits equipment reserves.

Due to bad Eskom financial status, where Eskom is trying to raise funds for its build programmes, Eskom has recently put more focus on condition based maintenance strategy for maintaining their equipment, including transformers, especially tap changers as they are the most expensive equipment to maintain. An assessment is firstly done to determine the condition of a transformer and a decision taken to either maintain or defer the maintenance, otherwise it should only be maintained if the tap changer operation counter exceeds the OEM recommended number of operations. Transmission staff in the operating grids is responsible for maintenance planning, scheduling, execution and control according to a prescribed and standardised process, and conformance to this process is audited from time to time. The maintenance planning, scheduling and control is done on the Transmission National computerised maintenance and outage management systems.

Transmission Technology department ensures that the maintenance standards and procedures exist and are kept up to date. Business Integration & Performance Management department in transmission make analyses performance and perform random audits to make sure that the organisation is adhering to Eskom business management system and all work done according to standards and procedures.

A.J.C. Trappey *at el.,* (2015:2) said that condition based maintenance provides a proactive maintenance strategy with benefits such as:

- Determining an accurate time to repair or perform the maintenance activities according to current and future conditions of an asset;
- Using additional information to reduce maintenance costs through preventing over maintenance, and
- Allowing the equipment managers more time to develop appropriate maintenance plans.
- Reducing the parts used for replacement.

Condition-based maintenance enhances the performance, reliability and the lifespan of transformers.

2.15 Eskom Transmission maintenance and life enhancement strategies

Eskom uses the following techniques, amongst others, for life management of transformers in transmission division:

2.15.1 Enhancement strategies

- **N-1 contingency**

To increase redundancy of transformers, where-by even if one transformer is lost, the remaining unit should be able to carry full load without any problems, and this ensures that no customer is interrupted if one unit is lost.

- **Replacements of aging transformers**

Aging units are identified and analysis done to determine the condition of the transformer. The main tool used is the CCRA (critical condition risk assessment), which will give us a score and the score determines whether a replacement is necessary or not. Oil analysis and electrical tests are part of the CCRA.

- **Specifying and use low maintenance technologies:**

- Vacuum tap changers – only maintained after 300 000 operations;
- Welded main covers – no gasket leaks;
- Resin impregnated (RIP) bushings – no oil inside the bushing, hence no bushing oil leaks;
- Online dryers – preserve paper insulation by removing moisture from the insulation paper, and
- Conservator air bags – eliminate oil oxidation.

- **On-line oil filtering**

This is the filter system which removes moisture from the transformer (on-line) while the transformer is in service. It is intended for long-term use, where it reduces moisture in a transformer to acceptable limits over a long period of time. A bigger plant is also available and it is only used for transformers which are very wet to remove excessive moisture from units.

2.16 Condition Monitoring

Transformer condition monitoring is measuring and recording evidence of deterioration or degradation in the condition of the transformer. It is linked to predictive maintenance and includes any inspection that uses any technology to predict when failures are likely to occur. Prevention of failure and keeping the transformers in good operational condition is an important issue for power utilities.

It is well known that regular oil analysis is useful in monitoring the condition of the power transformer. The analysis of insulating oils provides information about the oil, but also enables the detection of other possible problems, including contact arcing, aging insulating paper and other latent faults and is an indispensable part of a cost-efficient electrical maintenance program. Transformer maintenance has evolved over the past 20 years from a necessary item of expenditure to a strategic tool in the management of electrical transmission and distribution networks. Extreme reliability is demanded of electric power distribution, and even though the failure risk of a transformer and other oil-filled electrical equipment is small, when failures occur, they inevitably lead to high repair costs, long downtime and possible safety risks.

Moreover, transformers are too expensive to replace regularly and must be properly maintained to maximize their life expectancy. By accurately monitoring the condition of the oil, suddenly occurring faults can be discovered in time and outages can potentially be avoided. Furthermore, an efficient approach to maintenance can be adopted and the optimum intervals determined for replacement. The following condition monitoring methods are used in Eskom Transmission for power transformers:

2.16.1 On-line gas analyser

Online gas analysers are installed on transformers for early detection of deteriorating condition of a transformer. The system is connected to the transformer and continuously sample and analyses the oil for gases and send a notification if a limit has been exceeded. This gas analyser detects gasses, such as, methane, ethane, ethylene, acetylene, carbon monoxide and carbon dioxide. The information is also downloaded at a central point and analysis and trending are done, and this helps in identifying developing faults before a catastrophic failure occurs. These analysers improve the turnaround time for making transformer-related decisions. Figure 2-8 below shows the two types of gas analysers which are used in transmission:

Figure 2-8: Two makes of gas analysers used in Eskom Transmission

(Source: Eskom transformer and reactor maintenance report: 2012)

2.16.2 Infrared Scanning (IR scanning)

This is done to identify hot spots or hot connections in a transformer that may lead to further problems. Infrared will indicate external joint issues, bushing tap problems, oil levels in bushings and radiators, blockages in radiators, fan function - it can also indicate tank heating from stray flux, or frame tank circulating current. The infrared scanning (IR) is done every six months in transmission station as part of conditioning monitoring.

2.16.3 Laboratory oil analysis

Insulating oil is the life blood of the transformer and as such serves four main functions for a transformer. These functions are listed below as follows:

- Acts as dielectric and insulating material;
- Acts as a cooling medium;
- Protects solid insulation by acting as a barrier between the paper and the damaging effects of oxygen and moisture, and
- It is used as a diagnostic tool to determine the condition of the transformer.

Tap changer diverters are only tested for water and electrical strength. Water and kV (electrical strength) analysis are done to determine moisture content and electrical strength of the transformer respectively. Moisture content of a transformer plays a major role determining transformer life span. It decreases the electrical strength of the unit, and every time the moisture content doubles, the expected life of a transformer is cut into half.

2.16.4 Age assessment:

This is assessing the condition of transformers per age. The two main methods used carry these kinds of assessment are listed and discussed below as follows:

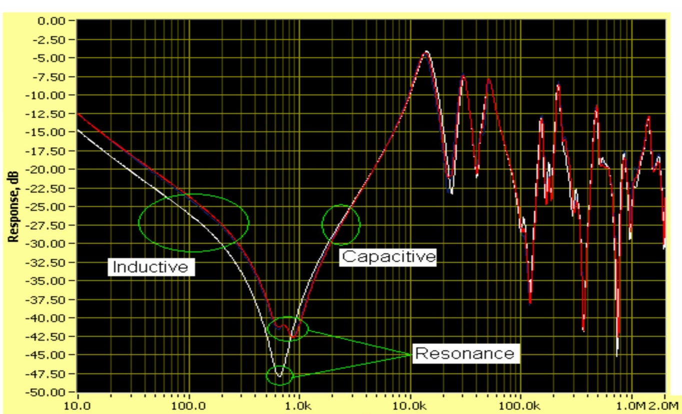
2.16.4.1 Electrical tests:

This involves switching out a unit and performs electrical tests which include:

- **Sweep frequency response Analysis (SFRA)**

The test measures the loss of mechanical integrity in the form of winding deformation and core displacement in power transformers which can be attributed to the large electromechanical forces due to fault currents, winding shrinkage causing the release of the clamping pressure and during transformer transportation and relocation. This test passes a range of frequencies between 10 Hz to 2MHz through the transformer and then calculates the transfer function. From the trace responses indicated in Figure 2-9 below it is clear that mechanical conditions can be assessed:

Figure 2-9: Frequency Response of Transformer



(Eskom transformer and reactor maintenance report: 2012)

2.16.4.2 Bushing Tan δ and Capacitance test

This is done on bushings equipped with a test tap. The test measures the condition of the main bushing insulation to the test tap and also the condition of the test tap insulation to ground and core Insulation between tapped layer and bushing ground sleeve.

2.16.4.3 Ratio tests

This test is performed at 10kV with capacitor and is very effective in detection of turn-to-turn or partial turn-to-turn failure when compared to lower voltage such as 380 V ration measurement. Ratio test has been used very successfully over a number of years for the following purposes:

- Confirm ratios are within 0.5% of nameplate data;
- Detect short circuited turn-to-turn;
- Detect open circuit windings; and
- Confirm tap lead connections.

2.16.4.4 Exciting Currents

The single-phase exciting-current test is useful in locating problems such as defects in the magnetic core structure, failures in the turn-to-turn insulation, or problems in the tap-changing device.

2.16.5 Manual oil analysis:

Oil sample is manually taken from the transformer to the laboratory and the following analyses are then done: acidity in oil, furans, depolarisation index (DP), Interfacial tension, sludge, moisture in oil, tan delta, saturation, water and kV. An analysis is then performed by an engineer to determine the condition of the transformer, and a bad result can lead to raising a project to replace the unit before it fails in service. The method used are types of DGA (Dissolved Gas Analyser) techniques such as IEC, Roger's Ratio's, IEEE, etc. that have been used with great success. These methods suffer from drawbacks like their inability to determine a normal operating transformer and returning of codes with no diagnosis. However, DGA does give warning of a developing fault that can prompt further investigation.

2.17 Condition monitoring of transformers

The cost of replacing and refurbishing the transformers varies from a few hundred thousand to several millions of rands. In a large power utility the number of transformers particularly in transmission network excluding those in the distribution network could be anything between five hundred thousand and seventy depends on the size of the transformer and the work to be done. Failure of a transformer while in service usually leads to significant revenue loss to the utility, potential environmental damage, loss of power, explosion and fire hazards and expensive repairing or replacement costs.

2.18 Transformer Workgroup (TWG)

The transformer workgroup comprises of approximately thirty members from different provinces in transmission grids ranging. These members range from national and local grid specialists to other key role players who can add value in achieving the goals of the TWG. The transformer workgroup’s main mandate is to provide strategic direction in terms of the functionalities of the transformers in the power utility. The TWG meets quarterly every year for two to three days. The main functions and roles of TWG with respect to transformers and reactors are listed below as follows, among others:

- The compilation and execution of maintenance philosophies, Life Cycle Management Plans and documentation such as modification instructions and technical instructions;
- The review of transformer and reactor performance statistics and to improve functional plans;
- Transformer training and skills capacity building;
- Review condition monitoring and new technologies;
- Review of research and development initiatives;
- Prioritizing of short, medium and long term transformer and reactor national projects;
- Information sharing on failures to identify common issues to improve performance;
- Specification for spares and strategic spares for relevant contracts, and
- Review of quality issues.

2.18.1 Transformer failure

During the first TWG meeting which was held during the second quarter of the year, in Cape Town information on failure to identify common issues to improve performance were shared. Chakravorti *et al.,* (2013:1) define a failure of a transformer as either any forced outage of a transformer due to its failure in service, explosion, malfunction or trouble which requires extensive factory or field repair. Transportation damage which grows gradually during service as well as the minor troubles which may require an equipment outage are not considered to be severe failures. Transformer failures can be broadly classified as electrical, thermal and mechanical malfunctions which occur mostly during assembly and/or transportation. These failures are also classified as being either internal or external. Failure can come about as a result of, among others, insulation degradation, PD, increased moisture content, overheating and winding resonance. These causes fall under the internal category, whereas the faults due to lightning strikes, switching over-voltages, system faults and system overload, among others fall under the external category.

2.18.2 Incident Review for 2015/16 YTD

There are four transformer failures reported in 2015/16 YTD shared in the TWG. One failure was classified as severe and it took place in Grootvlei HV yard which falls under in North East grid. Another failure which was also regarded as severe happened in Kronos substation which falls under Northern Cape grid. The transformer and Reactor failures which took in the period under review are shown in Tables 2-1, 2.2 and 2.3 below.

Table 2-1: Transformer and Reactor Failures

Classification/Period	***2011/12***	***2012/13***	***2013/14***	***2014/15***	***2015/16***
Failure - Power Transformer	*4*	*3*	*2*	*3*	*4*
Failure - Reactor	*1*	*0*	*0*	*0*	*1*
Total	***5***	***3***	***2***	***3***	***5***

Table 2-2: Transformer and Reactor YTD

Classification/Period	***2011/12***	***2012/13***	***2013/14***	***2014/15***	***2015/16***
Severe Failure - Power Transformer	*1*	*1*	*1*	*0*	*1*
Severe Failure - Reactor	*1*	*0*	*0*	*0*	*1*
Total	***2***	***1***	***1***	***0***	***2***

Table 2-3: Grid Performance YTD

Grid/Period	**2011/12**	**2012/13**	**2013/14**	**2014/15**	**2015/16**
Apollo CS	**2**	**0**	**1**	**2**	**1**
Failure - Power Transformer	*2*	*0*	*1*	*2*	*1*
Central	**3**	**3**	**4**	**5**	**0**
Failure - Power Transformer	*3*	*3*	*4*	*5*	*0*
East	**4**	**0**	**3**	**4**	**0**
Failure - Power Transformer	*4*	*0*	*3*	*4*	*0*
Free State	**1**	**2**	**0**	**0**	**0**
Failure - Power Transformer	*0*	*2*	*0*	*0*	*0*
Failure - Reactor	*1*	*0*	*0*	*0*	*0*
North	**1**	**3**	**0**	**3**	**1**
Failure - Power Transformer	*1*	*2*	*0*	*3*	*1*
Failure - Reactor	*0*	*1*	*0*	*0*	*0*
North East	**2**	**2**	**4**	**3**	**1**
Failure - Power Transformer	*1*	*2*	*4*	*3*	*1*
Failure - Reactor	*1*	*0*	*0*	*0*	*0*
North West	**1**	**5**	**2**	**2**	**0**
Failure - Power Transformer	*1*	*5*	*2*	*2*	*0*
Northern Cape	**3**	**0**	**3**	**5**	**1**
Failure - Power Transformer	*2*	*0*	*3*	*2*	*0*
Failure - Reactor	*1*	*0*	*0*	*3*	*1*
South	**1**	**2**	**0**	**0**	**0**

Failure - Power Transformer	*1*	*2*	*0*	*0*	*0*
Failure - Reactor	*0*	*0*	*0*	*0*	*0*
West	**0**	**0**	**2**	**1**	**1**
Failure - Power Transformer	*0*	*0*	*2*	*0*	*1*
Failure - Reactor	*0*	*0*	*0*	*1*	*0*
Grand Total	**18**	**17**	**19**	**25**	**5**

2.18.3 Transformer & Reactor Trips

As shown in Table 2-4 below there are six trips recorded YTD. The information reflected in in this Table is sorted according to the grid an event date.

Table 2.4: Transformer and Reactor Trips

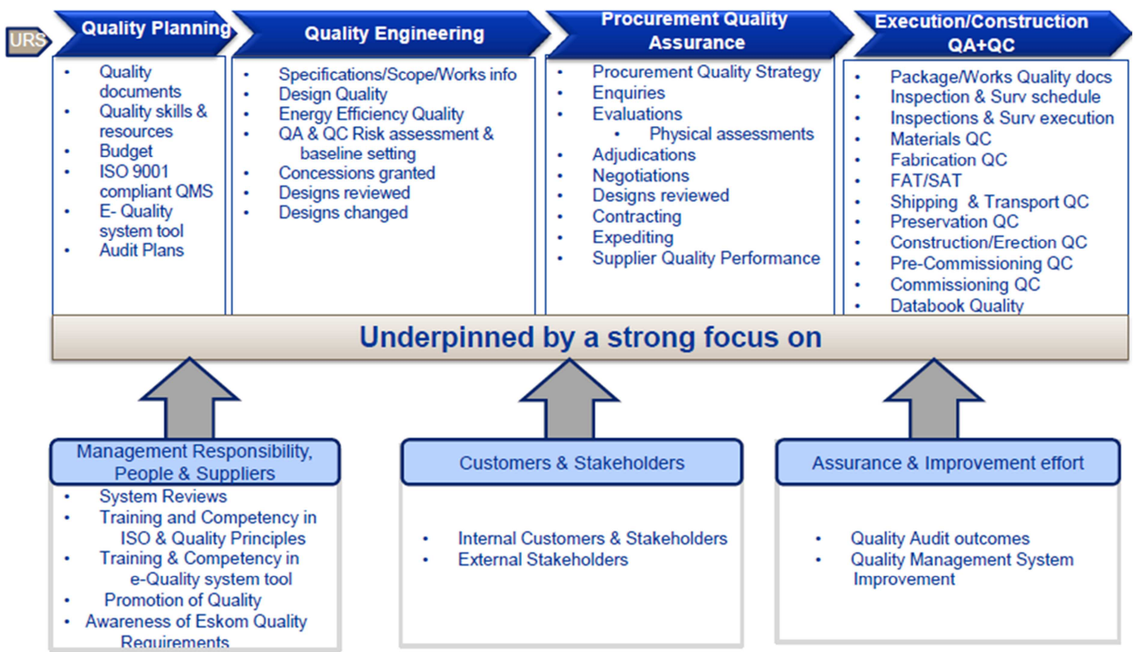
Date	Incident ID	Grid	Incident Description	Incident Comment
16-Apr-15	63886	Central	Eiger, Transformer No3 275kV Tripped	At Eiger substation in the Central Grid at 06:08 on 16 April 2015 Transformer No3 275/88/22kV tripped. On investigation the clip-on terminal in the 275kV junction box was found corroded and this was replaced. The restricted E/F relay was also replaced. There was no interruption of supply to Transmission customers.
22-Apr-15	63935	North East	Arnot, Transformer No1 400/275/11kV Tripped	At Arnot substation in the North Eastern Grid at 01:24 on 22 April 2015 Transformer No1 400/275/11kV tripped due to the Auxiliary transformer trip. On investigation it was found that there was a cable fault at Generation. There was no interruption of supply to Transmission customers.

05-May-15	63953	North	Matimba, Witkop No2 400kV Line Reactor Tripped	At Matimba substation in the Northern Grid at 15:52 on 5 May 2015 the Witkop Line Reactor No2 400kV tripped. There was no interruption of supply to Transmission customers. On investigation, nothing was found to account for the trip (Note: The incident was wrongly captured on morning report as No1 Rx).
18-May-15	64036	North East	Hendrina, Station Transformer No2/3 132/6.6kV Tripped	At Hendrina substation in the North Eastern Grid at 02:40 on 18 May 2015 Station Transformer No2 and No3 132/6.6kV tripped. On investigation it was found that transformer No3 tripped in sympathy with transformer No2 NEC fault. Transformer No2 NEC failed internally. There was no interruption of supply to Transmission customers.
30-May-15	64042	East	Danskraal, Coupling Transformer 1 275/132/22kV Tripped	At Danskraal substation in the Eastern Grid at 17:28 on 30 May 2015 Coupling Transformer No1 275/132/22kV tripped due to a failed red phase surge arrester. On investigation it was found that the surge arrester failed due to a combination of duty cycle and possible puncturing of an end fitting leading to moisture ingress. There was no interruption of supply to Transmission customers.
03-Jun-15	64068	Northern Cape	Gromis, Transformer No2 220/66/22kV Tripped	At Gromis substation in the Northern Cape Grid at 08:30 on 3 June 2015 Transformer No2 220/66/22kV tripped due to a storm in the area. The transformer was tested and then returned to service. There was no interruption of supply to Transmission customers.

2.19 Quality assurance

The South African Grid Code, System Operations and Transmission Grids requires assurance and documentation to the effect that a plant connected to the Transmission system meets the required technical specifications, has been correctly installed and can be energise and put on load safely. The functional reliability of transformer installation depends on the suitability and the quality of the transformer, components and the processes employed. Eskom Transmission requires that all work to be done should be in accordance with ISO 9001 Quality standard, and the following quality value chain has been formulated and implemented. Eskom is using quality value chain as shown in Figure 2-10 to manage and maintain quality management system within the organisation.

Figure 2-10: Quality Value Chain



(Source: Eskom Quality Management system QM 58:2010)

The following documents have been developed to be used as preferred tools to manage and control the quality requirements:

2.19.1 Inspection and test plan

Inspection and test plan is a document which defines the sequence of quality control related activities to be performed during maintenance, manufacturing, erection and re-commissioning, it also indicates all necessary hold and witness points, specific parameters to be met, supervisors name and employer and the signatures of designated quality control personnel. The inspection and test plan is normally developed before any work can start and must be reviewed and approved by the client to ensure that all activities are sequential and are in line with the given scope of work. This is an agreement between the person who will be doing the job, normally a contractor and the client. The document contains the scope of work, witness point and hold points which the contractor cannot proceed with the next activity before an agreement is reached. This ensures that the critical activities are not skipped and had been witnessed to make sure the activity has been done properly.

2.19.2 Checking of equipment after maintenance

Senior advisors/engineers are responsible for quality assurance during maintenance of a transformer. They make sure that the work being done is according to scope of work and according to standards and procedures. Electrical tests are also performed in the present of these personnel who will verify and accept the test results of the transformer. At the completion of maintenance, a work report is issued.

2.19.3 Quality checks of newly installed transformer

A newly transformer is installed by project execution department, This transformer then gets handed over to operating units after the installation has been completed. The operating units get involved from the concept phase till the end so that things are done according to correct standards and procedures.

2.19.4 Non-conformance of product (NCR)

Non-conforming product or service should be identified and controlled as quickly as possible, to prevent its unintended further processing or use. Further to the mere correction and control of non-conformities, the root causes thereof must be eliminated to prevent recurrence. This procedure shall apply throughout Eskom Holdings Limited Divisions, and all those suppliers who are involved in Eskom’s procurement and supply chain management process.

2.19.5 Risk management plan

There are identified risks as shown in Table 2-5 below that could impact on its ability to achieve the uninterrupted service to the customers. The risks are recorded in a risk register which designed to set out the primary risks and actions to be taken to mitigate such risks. The risk register should have reviewing interval to ensure that the information is up to date and if new or developing risks are identified and prioritised. The Table below identifies the description of the risk, source of the risk and the response to risks.

Table 2-5: Risk Management Plan

Risk category	**description of the risk**	**source of the risk**	**response to risks**
Service delivery	Ageing asset	Overloading of the assets. Planned and unplanned outages. Ineffectiveness of the maintenance plan. Lack of technical skills.	Developing better asset management system. Retaining experienced stuff.
Compliance	Failure to meet regulatory requirements by the contractor	Lack of compliance. No consequential action taken against non-compliance particularly the contractors.	Enforce disciplinary process to non-compliance. Provide awareness session on the internal control
Human resource	Shortage of technical skills.	Ageing workforce and resignations. Personnel development and promotion opportunities are limited.	Develop succession plan. Review the retention strategy. Offer retired stuff short term contract
Project and contract management	Defects and delay of the projects	Emerging contractors are offered bigger scope.	Applying/implement project risk assessment process.

2.20 Chapter Summary

In this chapter the asset management system and maintenance were researched. By implementing asset management system effectively and efficiently, the plant integrity, safety and reliability of the equipment will be increased.

The accurate and complete asset register together with defect and failures histories associated to each asset is important for being able to perform detailed performance analysis. The analysis of Eskom Transmission's transformer and reactor performance has revealed that it these assets have improved significantly over the five year period reviewed. This would indicate that the effort and dedication by the TWG members and other relevant stakeholders has yielded positive results. This work included the implementation of the replacement project for poor performing transformers and reactors and addressing those with recurring defects by the issuing of modification instructions. The analysis has also helped to highlight specific transformers and reactors that have a high risk of failure in the future as well as those that are presently performing poor. The analysis technique indicate opportunities that if addressed should lead to further performance improvement in future. Transmission will continue to strive to reduce faults, to be cost efficient and to be a top quartile performance in the world. With the implementation of asset management system, the performance is foreseen to improve even further.

Prevention of failure and the keeping of transformers in good operational condition is an important issues for power utilities therefore a good maintenance strategy must be employed. Traditionally time-based maintenance (TBM) was carried out in which transformers were maintained at regular time intervals irrespective of the necessity of the maintenance. Today, however, power utilities are performing condition-based maintenance (CBM) as opposed to TBM. Most power utilities are cutting costs by carrying out CBM, without interrupting the healthy plant, because the maintenance is required when the condition transformer needs maintenance. Therefore reliable diagnostic tools are required to monitor and assess the internal condition of transformers.

CHAPTER: THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter covers the tools and methods employed in this study in order to meet the requirements needed in order to make a better analysis, arrive at clear conclusions and make sensible recommendations. The chapter discusses the research approach, the sample, the data types, data collection and analysis, reliability, validity and generalisability. It also pays particular attention to ethics and the protection of participants.

Welman *et al.,* (2005:2) define research methodology as a process used in collecting and analyzing information in a research project. Research methodology may include publication research, interviews, surveys and other research techniques and could also include both present and historical information. It considers and explains the logic behind research methods and techniques.

3.2 Research design, methods and procedure

In this study the quantitative approach was selected to be used to gather information from selected transmission substations. Questionnaires were selected and designed as the most applicable method in obtaining data for this study. The data collected through this method was used to support the research study. Standardized questionnaires are generally designed to provide sufficient information to be analyzed and do also assist in reducing errors that could be attributed to the interviewer. This is the reason why questionnaires were selected in this study. Interviews were also another method employed in gathering data for this study. James & Sabine (1995:3) observe that surveys done through interviews are expensive but do give the interviewer an opportunity to give more explanations to the respondents in order to enhance their participation through guiding the questioning, answering the respondent's questions and through clarifying the meaning of given responses. There are two types of interviewing, namely, in-person and telephone interviews. Both methods are important in gathering information. The two interviewing methods were used in this study. Permission was sought from management to conduct the study in the company and was granted. The confidentiality of the respondents was respected and upheld throughout the collection and analysis of the data collected for purposes of this study. The questionnaire used in this study did not require any form of identification such as names or personnel/employee numbers from the respondents. This research study was conducted at the North grid's substations. The general findings of this study are therefore based on these substations. The approach that was used in this study is as defined below:

- Interviews were held with relevant Grid staff members who are responsible for substations or yard maintenance: This was done to determine the extent to which asset management system complies with the Transmission standards and procedure requirements;
- A review of completed work orders was carried out: This was done in order to assess content accuracy and completeness;
- Interviews with relevant grid staff responsible for maintenance and inspections at the selected substations: This was done in order to determine the compliance levels at these substation regarding maintenance and inspections, and
- A questionnaire was distributed to selected staff members dealing with asset management at the selected substations: This was done in order to examine if the asset management system is developed and implemented effectively at these substations.

3.3 Questionnaires

Cummings & Worley (2009:124) stated that one of the most efficient ways to collect data is through questionnaires. Hasas and Mohammed (2010:22) emphasized that a questionnaire should consist of some characteristics; like- questions should be meaningful to the different respondents, it should be simple, clear and understandable. The questionnaire designed and distributed for purposes of this study included aspects relating to three items, namely, asset management, transformer and maintenance. Table 3-1 below shows the advantages and disadvantages of using questionnaires.

Table 3-1: Advantages and disadvantages of questionnaires

Advantages	**Disadvantages**
1. Responses can be quantified and summarized.	1. Little opportunity for empathy with subjects
2.Large samples and large quantities of data	2. Predetermined questions - no change to change
3. Relatively inexpensive	3. Over interpretation of data possible
	4. Response biases possible

3.4 Interviews

A second important measurement technique is the individual or group interview. Cummings & Worley (2009:126) asserts that interviews are probably the mostly widely used technique for collecting data. In this study, the same questions used in the questionnaires were also used in the interviews. Interviews also do have their own advantages and disadvantages. These are depicted in Table 3.2 below.

Table 3-2: Advantages and disadvantages of interviews

Advantages	**Disadvantages**
1. Adaptive – allows customization	1. Relatively expensive
2.Source of rich data	2. Bias with interviewer responses
3. Empathetic	3.Coding and interpreter can be difficult
4. Process with rapport with subjects	4. Self-report bias possible

In this study the interviewees were taken through the questionnaire (Appendix A) and asked to give their opinion on each theme and question. Their responses were then taken into account during the quantitative analysis of data received.

3.5 Determination of data sources

The type of data used in this study is qualitative in nature. This is presented in a form of text or images. According to Welman *et al., (*2005:8) the purpose of using a quantitative method in research is to evaluate objective data consisting of numbers while qualitative research deals with subjective data that is produced by the minds of respondents or interviewees. Data used are considered confidential and are as follows:

- Documentation;
- Incident reports, and
- Policies.

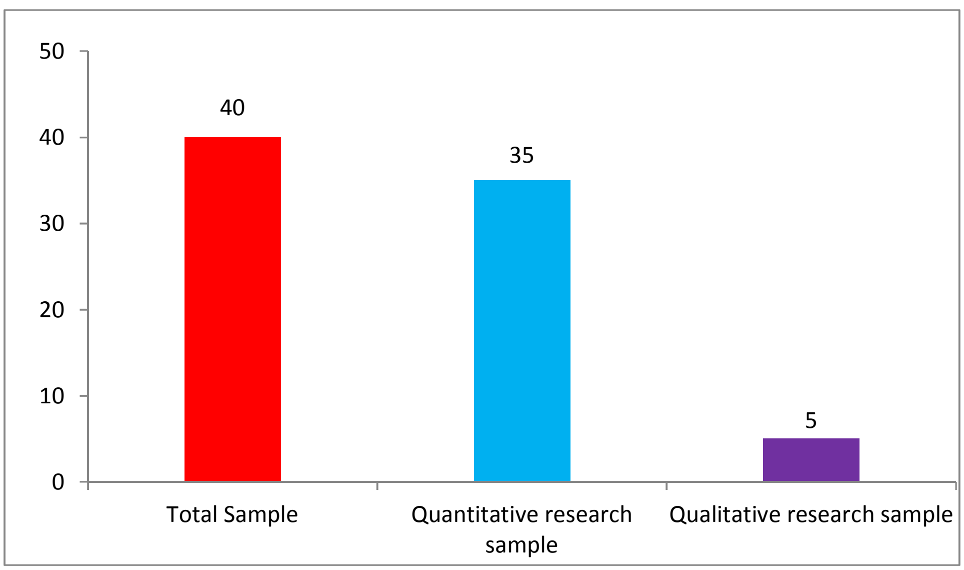
3.6 Sample size

A sample is a portion or subset of the population that represents the entire group which the researcher is interested in interviewing and is drawn when it is impractical to survey everyone in the population (James & Sabine, 1995:14). The sample size is an important feature of any empirical study in which the goal is to make conclusions about a population. Behr (1988:13) stated that a decision on the optimum size of the sample has to be taken with due regard to the kind of statistics to be used in the analysis of the data. The population size determines the sample size .The larger the sample size, the more sure positive responses or true reflection from the population. The sample population used in this study is depicted in both Table 3.3 and Figure 3.1 below.

Table 3-3: Total Sample Population

Total Sample	40
Quantitative research sample	35
Qualitative research sample	5

Figure 3.1: Sample Population



3.7 Sample selection

The only way to avoid bias during sample selection, random sampling is the better option to employ. According to Behr (1988:14) random sampling gives every member an equal chance of being chosen in a research study. Bias exists due to an error in the sample selection process wherein a subset of the data is systematically excluded due to particular aspects which were not considered during the process. The samples of 4 substations in the North Grid were randomly selected from 11 substations. The characteristics of the 40 sample used in this study cuts across gender, race, age, qualifications and positions.

3.8 Sampling procedure

In this study, the sample area is the North Grid substations where the questionnaires were administered to make sample size more appropriate in understanding the impact of the assert management system. A sampling procedure defines the rules that specify how the system calculates the sample size and it contains information about the valuation of inspection characteristics during the results according the attributive, variable, manual inspections. Buckingham & Sauders (2004:98) advised that a small fraction of the whole target population provides remarkably accurate parameters of the whole population provided the fraction is selected carefully and methodically. There are two types of sampling procedure which, namely, probability and non-probability procedures. Non-probability sampling procedures are less complicated and more economical and can also provide valuable information but their result cannot be generalized to a large population nor can their statistics be used to indicate the reliability of the results to be calculated. A probability procedure on the other hand provides the researcher with the ability to gather information from a relatively small numbers of a large population and to accurately generalize the results to the entire population (Welman *et al.,* 2005: 68).

3.9 Data collection technique

This research study is based on the combination of qualitative and quantitative research methodologies. These techniques were used in collecting and analyzing the data used in this study. The qualitative method was used by the researcher herein in formulating and conducting interviews with the selected respondents while the quantitative method was used in the formulation and analysis of the questionnaire. There are other various data collection techniques that can be used to collect data such. These are listed below as follows:

- Transformer workgroup methodology;
- Checklists;
- Documentation, and
- Maintenance records.

To ensure a high response rate of completing the questionnaires, senior manager of the Grid will request all the relevant people to give the researcher a support needed.

To increase respondent participation, the researcher will predominantly issue the questionnaire directly to the senior manager or supervisor to distribute to the relevant people who know the substations.

3.10 Data analysis of questionnaire

Buckingham & Sauders (2004:43) stated that the questionnaires are easy to construct and cheaper to use. Buckingham & Sauders (2004:43) further assert that a questionnaire is a prepared set of written questions which are formulated for purposes of statistical comparison of the information gathered.

3.11 Summary

The interviews and questionnaires are planned to be carried out with the people who are mostly involved in the selected substations. Management was not targeted as they are not hands on. Their involvement in this study is mainly to help to get more access and information through their permission. In setting up the interviews in this study, some challenges were encountered. The researcher herein was however able to put measures in place to deal with these challenges and ensured the maximum turn out recorded in this study. The responses of the respondents were relevant to the purpose and research questions. Reliability was maintained by sending back the survey findings to some of the respondents for checking the misrepresentation.

CHAPTER: FOUR

DATA ANALYSIS AND INTERPRETATION

4.1 Purpose and the chapter outline

The purpose of the chapter is to validate those substations that were able to carry out their regular maintenance as per asset management systems and procedures and within the stipulated requirements. The information gathered from these substations was accurately documented accurately through the use of both the interviews and questionnaires. The current study focused on the methodologies employed by the selected substations in keeping their expensive assets in a perfect working under the current network and skills shortage constraints. There are four sections in the asset management model used by the selected substations. These are asset management system, transformer comprehension, maintenance and training.

In this chapter a correlation between these sections is calculated with the aim of identifying the gaps which need the attention of the management of the selected substations in order for them to act accordingly. The deficiencies and the challenges within the substations were also investigated with a view of improving the overall performance of the assets in the substations. The implementation of the asset management system posed challenges with regard to employee involvement and communication, and the empirical study measure this to achieve the study objectives.

4.2 Study design

The research methods employed in collecting data for this study were interviews and questionnaires. Questionnaire was used in order to gather the information from the employees who are involved in the maintenance of assets in the selected substations. The questions used in the questionnaire were the same ones used in the interviews with employees. This was to ensure that the data collected was consistent. In the questionnaire and interview, the respondents were asked on their views on the implementation of the asset management system and about their perceptions about a possible full implementation of the system.

4.3 Sample selection

The choice of population is owing to the limited resources available in the researcher's travel budget and time available for the study. The researcher would have loved to widen the sample population to include all the substations in the Northern grid.The samples of 4 substations in the Northern Grid were randomly selected from 11 substations. From these 4 substations 15 maintenance personnel and 25 artisans were also randomly selected to participate in the completion of the questionnaire by the senior advisor. These artisans were selected from a total of 60 employees who are working in the selected substations. A total of five from the selected 25 did not return their questionnaires.

4.4 Interviews

The questions in questionnaire were divided into sections. In the beginning, the questionnaire contained the demographic information of the respondents. The people who were interviewed are the following:

- 1 Artisan;
- 1 Supervisor;
- 1 Senior Advisor, and
- 1 Manager.

4.5 Interviews questions

The questions used in the interviews were structured with an aim of determining the gaps and the effectiveness of the system and also to prioritize the require focus area. The initial interviews were conducted with the mangers. The second round of the interviews was conducted with the people who were closely involved in the plant.

4.6 Raw data collected

A few of summary results are presented here.

4.6.1 Respondent 1- Artisan

Artisan cannot differentiate between asset management system and the maintenance procedures. Asset management system is not completely defined in their grid. In his opinion asset management system is the way they maintain their assets in the plant to make sure that all the equipment's are available and reliable all the time.

More training is required to improve their level of insight in terms of asset management system. Financial constraints that they are facing in their department, even though is the problem of the whole organization, incapacitate them to attend trainings and also to have more resources. He continued by saying that to improve reliability of the plant, significant maintenance planning is required and followed all the times.

4.6.2 Respondent 2 – Supervisor

She is aware of the asset management system however more training is required to enhance thoughtful of the system so that she can make sure that the system is fully implemented and maintained. She wrote motivation letter to her manager to advise and show him the shortage of the stuff. She believes that to improve the reliability of the transformers and other equipments in the plant, more maintenance artisans must be employed because currently they are doing more with less and sometimes other tasks are done in rush which might lead them to mistakes which might affect healthy plant.

4.6.3 Respondent 3 – Senior Advisor

He had good understanding of the asset management system. He had seen it as best tool or system which they are using to ensure that the network is not interrupted by unplanned or forced maintenance. He said that in their grid they believe that the reliability of the equipment can also be improved if roles and responsibilities of all employees involved in the substation are clearly defined and outlined. Quality personnel must ensure that corrective and preventative actions are closed in case of non-compliance or defective equipment's.

It is great desire to sufficient spares because most of their stations had old transformers and equipment which they have reached lifespan period. Some of the equipment's are not reliable due to aging which needs to be replaced with new and more reliable technology.

4.6.4 Respondent 4 – Manager

This respondent had a fully understanding of asset management and keeps on encouraging his subordinates to implement the system fully without compromising. He said that asset management is not all about repairing equipment that failed, it minimize cost, increase productivity, good allocation of labor to labors and saving valuable time. Moreover asset management is about identifying, mitigating and eliminating risk. He mentioned that the overall efficiency of the equipment is monitor 24/7 at the control room. He stated that the refresher train is required to artisans and supervisors particularly on how to manage or control documents.

In his opinion, the plant reliability can be improved by undertaking planned replaced of equipment per financial year and allocate enough budget to execute the project. Good relationship with the suppliers that providing spares is vital so that the suppliers can familiarize themselves with what their clients' needs or if there is any changes or improvement in terms of technology on the exits designs and how can the system be improved meet the current technology. The below table 4-1 indicates the answers obtained from the interviews and are marked with X to indicate the deep knowledge of the activities.

Table 4-1: Interview Summary

	Asset management system A	Transformer comprehension B	Maintenance plan C	Training plan D
Manager	X		X	
Senior Advisor	X	X	X	X
Supervisor		X	X	X
Artisan		X	X	X

4.7 Questionnaire population

The questionnaires were sent to Northern grid to validate if the questions asked are relevant with what they are doing and distribute to the relevant employees. The summary of the responses is populated on table 4-1. The activities per responses are populated referred to the below indicators.

A – Asset management system

B – Transformer comprehension

C – Maintenance plan

D – Training plan

Questions related to A – Asset management system are as follows

➢ Do you know what existing assets you have and where they are?
➢ Do you know the quality of the assets?
➢ Do you know functions of the assets and their value adding?

➢ Do you know the condition of all transformers in the substation?
➢ Do you know what you expect from your assets in the short, medium and long-term?
➢ Can your assets deliver your asset management objectives cost effectively?
➢ Are you getting the most value from your assets?
➢ Are you continually improving your asset management system performance, and realizing the benefits of the improvements?
➢ Do you know what and where improvements will be most effective?
➢ Do you have the necessary asset management policy, strategy and plan to ensure that you manage your assets in a sustainable way?

Questions related to B – Transformer comprehension

➢ Are routine in service inspections and condition monitoring of transformer up to date?
➢ Do you know the condition of all transformers in the substation?
➢ Is there any daily or weekly/monthly checklist of the transformer?
➢ Is the substation inspection procedures and standards adhered to all the time?
➢ Is asset management system required to improve the performance of the transformers?
➢ Are the transformers failing timeously?
➢ Are the root causes identified and prevented?
➢ Are transformers repaired or replaced in required time?

Questions related to C – maintenance plan

➢ Are planned maintenance programme followed all the time?
➢ Are maintenance work executed unplanned and interfering with the healthy equipment?
➢ Is condition-based maintenance effective in the substation?
➢ Do you think preventive maintenance is the best maintenance method to use?
➢ Are employees involved in making decision on the maintenance procedure?
➢ Is the maintenance master data regularly reviewed?
➢ Is there a long term strategic equipment replacement plan?

Questions related to D – Training plan

➢ Are the artisans and supervisors trained on the asset management system?
➢ Are there any barriers in terms of training?
➢ Is there any a structural training programme in place for engineering personnel?
➢ Is there a career path designed per individual to promote personal growth?
➢ Are the employees keen to be trained to enhance their knowledge capabilities?
➢ Are the new employees trained and make them aware of the procedures and the standards of the substations?
➢ Is management communicating with the employee during the implementing of any changes?
➢ Is there a succession planning strategy in place?

Table 4-2: Sampling Characteristics

Demographics	Subgroups	Percentage
Gender	Male	82
	Female	18
Age	18 - 30	9
	25 - 40	57
	41 - 50	26
	51 - 65	9
Race	White	17
	Black	71
	Coloured	6
	Indian	6
Qualification	Grade 12	9
	Certificate	31
	Diploma	37
	Degree	17
	Post graduate	6
Positions	Artisan	30
	Supervisor	27
	Senior Advisor	18
	Manager	18
	Other	6

Table 4-2 indicates the percentages responses from demographics and subgroups. The majority of sample in terms of gender is males (82%), aged is between 25 and 40 years, race are black (71%), qualification mostly holds diploma (37%) and lastly positions as artisan by 30%.

4.8 Questionnaire

Section A: Assets management system

Section A: Assets management system	Yes	No	N/A
1. Do you know what existing assets you have and where they are?	32	2	0
2. Do you know the quality of the assets?	25	10	0
3. Do you know functions of the assets and their value adding?	28	7	0
4. Do you know the condition of all transformers in the substation?	22	12	0
5. Do you know what you expect from your assets in the short, medium and long-term?	29	5	0
6. Can your assets deliver your asset management objectives cost effectively?	27	7	0
7. Are you getting the most value from your assets?	26	7	0
8. Are you continually improving your asset management system performance, and realizing the benefits of the improvements?	27	5	0
9. Do you know what and where improvements will be most effective?	22	13	0
10. Do you have the necessary asset management policy, strategy and plan to ensure that you manage your assets in a sustainable way?	24	9	0

Section B: Transformer comprehension

Section B: Transformer comprehension	Yes	No	N/A
1. Are routine in service inspections and condition monitoring of transformer up to date?	29	4	0
2. Do you know the condition of all transformers in the substation?	26	4	0
3. Is there any daily or weekly/monthly checklist of the transformer?	34	0	0
4. Is the substation inspection procedures and standards adhered to all the time?	25	9	0
5. Is asset management system required to improve the performance of the transformers?	21	14	0

6. Are the transformers failing timeously?	8	26	0
7. Are the root causes identified and prevented?	20	7	0
8. Are transformers repaired or replaced in required time?	20	12	0

Section C: Maintenance plan	Yes	No	N/A
1. Are planned maintenance programme followed all the time?	27	7	0
2. Are maintenance work executed unplanned and interfering with the healthy equipment?	12	21	0
3. Is condition-based maintenance effective in the substation?	23	11	0
4. Do you think preventive maintenance is the best maintenance method to use?	25	9	0
5. Are employees involved in making decision on the maintenance procedure?	19	15	0
6. Is the maintenance master data regularly reviewed?	21	9	0
7. Is there a long term strategic equipment replacement plan?	24	7	0

Section D: Personal training and development plan	Yes	No	N/A
1. Are the artisans and supervisors trained on the asset management system?	22	13	0
2. Are there any barriers in terms of training?	24	10	0
3. Is there any a structural training programme in place for engineering personnel?	18	15	0
4. Is there a career path designed per individual to promote personal growth?	16	17	0
5. Are the employees keen to be trained to enhance their knowledge capabilities?	27	7	0
6. Are the new employees trained and make them aware of the procedures and the standards of the substations?	26	9	0
7. Is management communicating with the employee during the implementing of any changes?	25	8	0
8. Is there a succession planning strategy in place?	19	13	

The total number of participants to the questionnaires is 35 out of 65 and four of them are interviewed and in total is 39. The questionnaires were distributed and 35 of them were returned for analysis.

Table 4-3: Summary of Responses to Questionnaires

Tools	Total number of responses	Actual non-compliance	Percentage Non-compliance
A – Asset management system	339	122	36%
B – Transformer comprehension	263	80	30%
C – Maintenance plan	230	79	34%
D – Training plan	269	92	34%

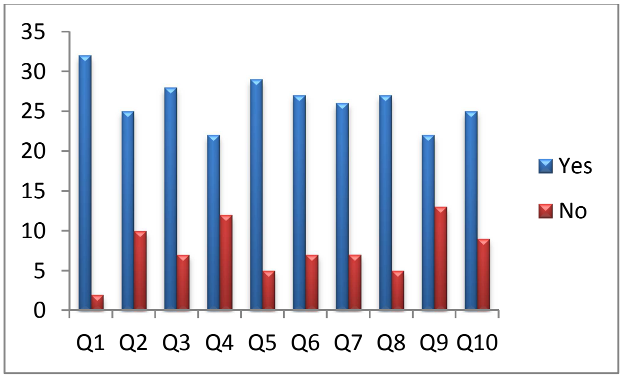
4.9 Data analysis of questionnaire

The results of questionnaires are analyzed in four sections namely asset management system, transformer comprehension, maintenance plan and training plan.

4.9.1 Asset management system

Fig 4-1 shows that in question 1, 32 employees out of 34 have knowledge about their assets and whereabouts. The knowledge of assets helps to understand the status of assets in the plant. The interviews and questionnaires indicated that most of people who are involved in the substations are familiar with the transformer except those new employees who are still undergoing the training. Some of the transformers their status are not easily visible, need to be diagnosed. In question 9, some artisans don’t know if the system is effective or not.

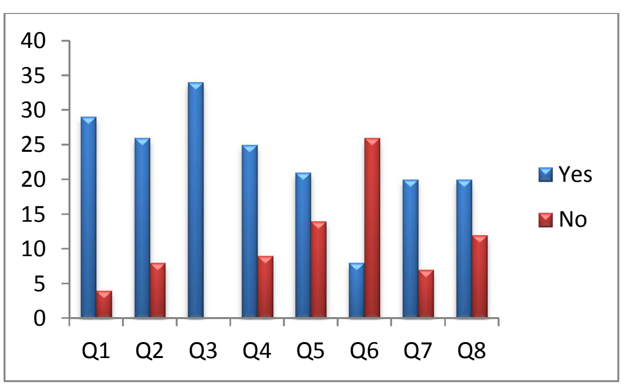
Figure 4-1: Asset Management System responses



4.9.2 Transformer comprehension

Fig 4-2 can be interpreted that most employees involved in the substations have sufficient knowledge of the existing transformer. Routine inspection and condition monitoring is conducted using existing daily or weekly/monthly checklist of the transformers. Documents to monitor the conditions of the transformer are in place and implemented accordingly. The outcome of this graph corresponds with the results obtained of the interviews whereby the documents are developed to ensure that the transformers are maintained to avoid unnecessary outage. Procedures and maintenance policy are in place. From Q6, the graph indicated that the transformers are not failing timeously due to proper maintenance strategy employed in the substations and moreover the implementation of the strategy has been strongly observed by the management.

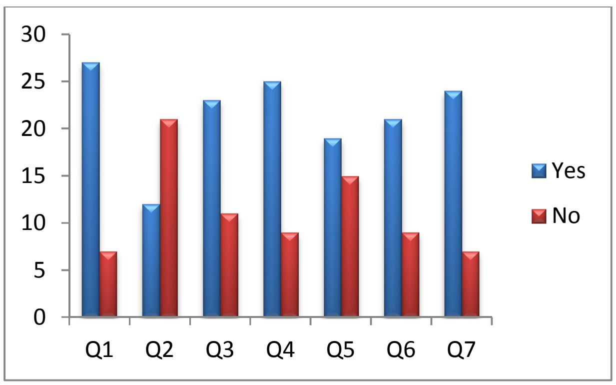
Figure 4-2: Transformer Comprehension responses



4.9.3 Maintenance plan

The responses from Q1 on Fig 4-3 indicated that there are planned maintenance programme which are followed all the time. North grid was selected as the best grid in transmission division. It is able to maintain its competitiveness as leading and reliable grid within transmission by following the maintenance programme without avoiding anyone. Most of maintenance work executed planned without interfering with the healthy equipment's. From the interview of artisan indicated that sometimes is difficult to carry out maintenance on other transformers due to unavailability of previous maintenance records.

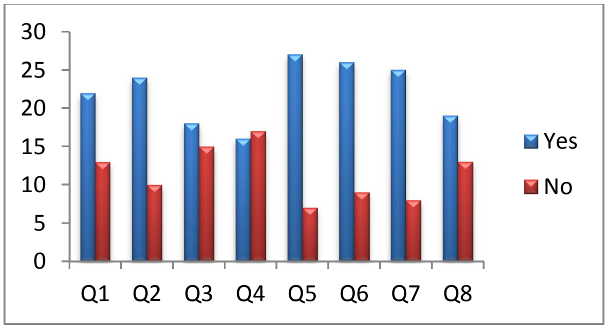
Figure 4-3: Maintenance Plan Responses



4.9.4 Training plan

Both artisans and supervisors from the Fig 4-4 indicated that they are willing to be trained particularly on asset management system. The interviews and questionnaire responses indicate the need for training awareness. Although the graph indicates that there are barriers in terms of training, the management encourages the individuals to a structural training programme and make sure that the individuals adhere to their plans.

Figure 4-4: Training Plan Responses



4.10 Summary

The data collected from interviews and questionnaires. The data collected from 35 responses from the questionnaires.

From the interview indicated that Senior Advisor is acquainted with all commodities than other people. The artisan and the supervisor from the questionnaires and interview indicated that the need of training in terms of asset management is required so that the substation can be more reliable in terms of healthy transformers.

CHAPTER: FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The effective maintenance and asset management system within the substations of the power utility plays an essential role in ensuring the company's crucial equipment is kept functional and reliable at all times. The aim of this research was to develop a procedure that quantitatively evaluates the health of power transformers in the selected substation of the grids in order to prevent unexpected failure of the power transformers and other critical equipment which may result in a loss of life and /or major financial adversity.

Performance and reliability of transformers in the power utility is impacted by a number of factors. These are, among others: increased maintenance defects, unfirmed stations, and inadequate protection coordination between transmission and distribution substations. The increase in load demand from the existing transformer fleet and a reduction in capital expenditure to maintain and/or replace transformer projects or fund expansions have also contributed to accelerated aging. This is mainly due to the fact that the current transformers are forced to operate at higher levels than expected. There is an increase in transformer maintenance defects due to network constraints, in sufficient maintenance teams, reduced skills transfer and insufficient network contingencies to allow for planned outages to clear the defects identified.

Effective asset management system incorporating maintenance procedures/policies is vital in the power utility in order to have uninterrupted power supply to the grid. Maintenance efficiency improves plant availability and reliability, business effectiveness, safety, environmental integrity, energy efficiency, customer service and minimizes costs.

5.2 Achievement of study objectives

This research achieved the objective of the study by identifying the need of improving the asset management system and training the employees involved in the substations particularly artisans and supervisors. From the incident report from TWG it was indicated that most power transformers in the grids are monitored and maintained using maintenance strategy/policy.

5.3 Recommendations

The interviews and questionnaire responses indicate that training in terms of asset management system is required. A sufficient budgetary allocation should be made available for the proposed training given the complexity nature of the current asset management equipment. The proposed training could help improve the mastery of the equipment among the employees who are assigned to handle its maintenance and repairs.

Based on the given responses, the maintenance policy and asset management system were developed by company management and as such are well known among all the managers. The personnel that deals with the maintenance and repairs at the selected substations was found not to have the same level of knowledge and understanding as that of their managers in this regard. In order to improve this situation, it is recommended that the personnel involved with both maintenance and repairs at the selected substations such as artisans and supervisors be involve in the reformulation and/or improvement of the existing maintenance policy and asset management system. . The role of management in this regard will be to provide the resources to ensure that decisions arrived at as part of the process proposed herein are viable and sustainable. A successful maintenance programme and/or policies can only be developed and implemented effectively by the people who are involved in the maintenance of the equipment in the substations.

The power utility must develop a tool for substation asset management that measures and visualizes the health conditions of substation equipment particularly transformers. The monitoring systems that are currently in place at the selected substations show indications of a potential trip or alarm given the poor state of health of the equipment at these substations.

The analysis of the power utility's transmission transformer and reactor performance revealed some signs of improvements over the recent five year period. TWG should therefore be kept in order for the system to continue sharing failures report from respective grids. The analysis has also helped to highlight specific transformers and reactors that have a high risk of failure in the future as well as those that are presently performing poorly. The analysis technique indicates opportunities which should lead to further performance improvement in future. With the implementation of asset management system, the performance is foreseen to improve even further.

Putting more emphasis on new technology in other substations could be more vital in this regard and can ultimately ensure that the grid will be more sustainable in terms of power delivery going forward. Using a conditions-based maintenance strategy might be risky in terms of trips and malfunctions therefore preventative maintenance is recommended to achieve long-term performance of the transformers or other equipment.

The replacement of the old and unreliable transformers which have reached their lifespan will also enhance the reliability of the substations. Apart from the aging transformer concerns, transmission grid must endeavour to upgrade and expand to meeting the growing demand of electricity in the country.

Management should provide the artisan and supervisors with appropriate equipment's to measure, monitor and assess the conditions of the transformer in the substations.

In conclusion, all though Eskom is experiencing financial constraints, it is vital to develop, implement and maintain the asset management system throughout the entire company considering the cost implications, performance impacts and the associated risks. The individuals dealing with the asset management system need to know and master the system in order for the company to achieve the desired objectives of the grid. There is no solution to prevent interruptions in the network but there are some measures that can be implemented in order to minimise the impact of unreliability of the equipment.

5.4 Recommendations for further research

This study, however, only assessed some of the substations in one grid. A more widespread research covering all substations on the national grids is still needed in order to clarify the implementation of asset management system as well as the conditions of power transformers.

Based on the findings and results of the current research study on four activities in the selected substations which were analyzed from different employees in the different substation, the researcher would like to recommend for further research to the protection schemes of the transformer in order to ensure optimal schemes. This research only focused on one commodity in the selected substations which is power transformer and as such did not include other commodities like switch gears, CT & VT which may also interrupt the healthy network if they are malfunctioning. Due to small sample taken, the results cannot be considered to be representative of all grids and their substations as such cannot be generalized. The generalization of the results of this study would present a misrepresentation of all the company's grids. Further research using advanced statistical procedures in order to provide a more comprehensive report on the state of transmission substations in the country is recommended.

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ANNEXURES

Demographic Information

Gender	Male	
	Female	

Age	18 - 30	25 - 40	41 -50	51 - 65	
Race	White	Black	Coloured	Indian	other

Your Highest Qualifications	Less than Grade 12	Grade 12	Certificate	Diploma	Degree	Post graduate

Position	Artisan	Supervisor	Senior Advisor	Manager	Other (Specify)

Section A: Assets management system

1. Do you know what existing assets you have and where they are?	Yes	No	N/A
2. Do you know the quality of the assets?	Yes	No	N/A
3. Do you know functions of the assets and their value adding?	Yes	No	N/A
4. Do you know the condition of all transformers in the substation?	Yes	No	N/A
5. Do you know what you expect from your assets in the short, medium and long-term?	Yes	No	N/A
6. Can your assets deliver your asset management objectives cost effectively?	Yes	No	N/A
7. Are you getting the most value from your assets?	Yes	No	N/A
8. Are you continually improving your asset management system performance, and realizing the benefits of the improvements?	Yes	No	N/A
9. Do you know what and where improvements will be most effective?	Yes	No	N/A
10. Do you have the necessary asset management policy, strategy and	Yes	No	N/A

plan to ensure that you manage your assets in a sustainable way?			

Section B: Transformer comprehension

1. Are routine in service inspections and condition monitoring of transformer up to date?	Yes	No	N/A
2. Do you know the condition of all transformers in the substation?	Yes	No	N/A
3. Is there any daily or weekly/monthly checklist of the transformer?	Yes	No	N/A
4. Is the substation inspection procedures and standards adhered to all the time?	Yes	No	N/A
5. Is asset management system required to improve the performance of the transformers?	Yes	No	N/A
6. Are the transformers failing timeously?	Yes	No	N/A
7. Are the root causes identified and prevented?	Yes	No	N/A
8. Are transformers repaired or replaced in required time?	Yes	No	N/A

Section C: Maintenance plan

1. Are planned maintenance programme followed all the time?	Yes	No	N/A
2. Are maintenance work executed unplanned and interfering with the healthy equipment?	Yes	No	N/A
3. Is condition-based maintenance effective in the substation?	Yes	No	N/A
4. Do you think preventive maintenance is the best maintenance method to use?	Yes	No	N/A
5. Are employees involved in making decision on the maintenance procedure?	Yes	No	N/A
6. Is the maintenance master data regularly reviewed?	Yes	No	N/A
7. Is there a long term strategic equipment replacement plan?	Yes	No	N/A
	Yes	No	N/A

Section D: Personal training and development plan

1. Are the artisans and supervisors trained on the asset management system?	Yes	No	N/A
2. Are there any barriers in terms of training?	Yes	No	N/A
3. Is there any a structural training programme in place for engineering personnel?	Yes	No	N/A
4. Is there a career path designed per individual to promote personal growth?	Yes	No	N/A
5. Are the employees keen to be trained to enhance their knowledge	Yes	No	N/A

capabilities?			
6. Are the new employees trained and make them aware of the procedures and the standards of the substations?	Yes	No	N/A
7. Is management communicating with the employee during the implementing of any changes?	Yes	No	N/A
8. Is there a succession planning strategy in place?	Yes	No	N/A