1. Introduction

South Africa experienced dramatic economic growth over the past decade. This has led to peak electricity demand problems. Load shifting can help to address this problem.

1.1. Background

1.1.1. Growing demand for electricity in the world

The world is experiencing an explosive growth in energy demand. Studies show that there is an 11 % increase in the annual electricity usage in most of the developing countries worldwide [1]. These studies included predictions of the energy consumption of the world up to the year 2020, as shown in Figure 1-1.

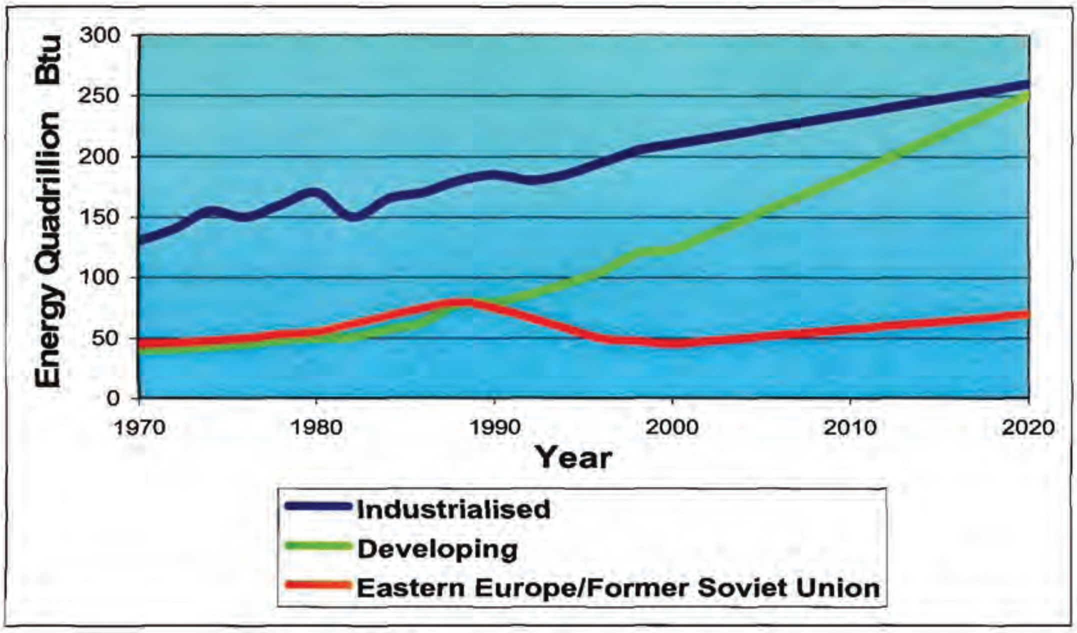

Figure 1-1 Global energy usage predictions [1]

A further study done by the US Department on Energy predicts that the world's primary energy consumption will increase by 59% over the period 1999 to 2020 [2]. These two independent predictions clearly show the expected increase in the future global energy consumption.

This growth has major implications. Most developing countries, which represent two billion people, or a third of the world's population, rely on coal as a major source of energy [3],[4]. The growth in predicted energy demand and the fact that predictions estimate low worldwide resources clearly indicates the possible energy crisis that is eminent in the near future.

South Africa, one of the least environmental friendly countries, emits around 7 t of CO_2 per person per annum into the air [5],[6]. This is due to our high energy usage per head and large industrial sectors. Another factor that contributes to this high figure is South Africa's reliance on coal as a main source of energy.

Looking at the electricity demand growth, the limited resources relied on to generate electricity and the environmental impact, it is clear that systems and philosophies have to be developed to better consume and manage our electricity consumption.

1.1.2. Problems with electricity demand in South Africa

South Africa uses 40% of all the electricity generated and consumed on the African continent [7]. This figure is high seeing that only 5.27% of Africa's population resides in South Africa [8],[9].

South Africa's electricity demand growth follows the world trend. Predictions show that South Africa's electricity demand will grow by 85% over a period of 20 years from 2005 [11]. One of the factors that led to the overall growth of South Africa's electricity demand was the electrification of 3.5 million homes since 1993, which added 750 MW to South Africa's electricity consumption [8]. Electricity is the main source of power in the typical South African household and we use little alternative power sources, such as gas, compared to other countries [10].

In 2003, a joint venture between ESKOM and Shell International Renewable, failed in a project to distribute solar power units to housing in rural areas [12]. This project was terminated after it was deemed financially not viable.

South Africa is a developing country with major growth in the industrial and private sectors. A study done by Lavine, Gadgil, Meyers, Stafurik and Wilbanks [11] shows that developing countries, such as South Africa, has the biggest electricity usage growth compared to already developed countries such as the USA and European countries.

Predictions show that the electricity demand in South Africa will exceed the installed generating capacity as soon as 2007-2008 [13]-[15]. Predictions indicate a generation capacity of 65,000 MW will be needed in 2024 [16].

ESKOM is by far the largest electricity supplier in South Africa, generating 95% of the country's electricity [17]. Other suppliers are municipalities (1.5%) and private generators (2.7%) [17]. ESKOM is also the second cheapest and fifth largest international electricity supplier worldwide [18]. Figure 1-2 shows the typical ESKOM demand profile during the winter months [17].

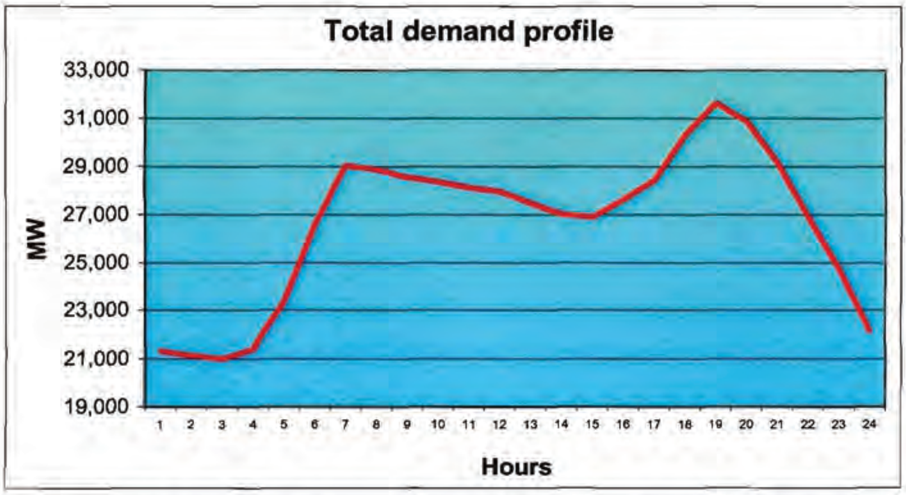

Figure 1-2 Total South African electricity demand – winter profile [17]

The energy usage peaks between 07H00 and 10H00, and then again between 18H00 and 20H00. This poses a problem to ESKOM.

Demand fluctuations require the operation of specific generation plants that can respond quickly. These peak load plants, such as gas turbine and hydro water plants, are much more expensive to operate than normal coal generation plants [20],[21]. Figure 1-3 shows the installed capacity of the peaking plant utilised by ESKOM.

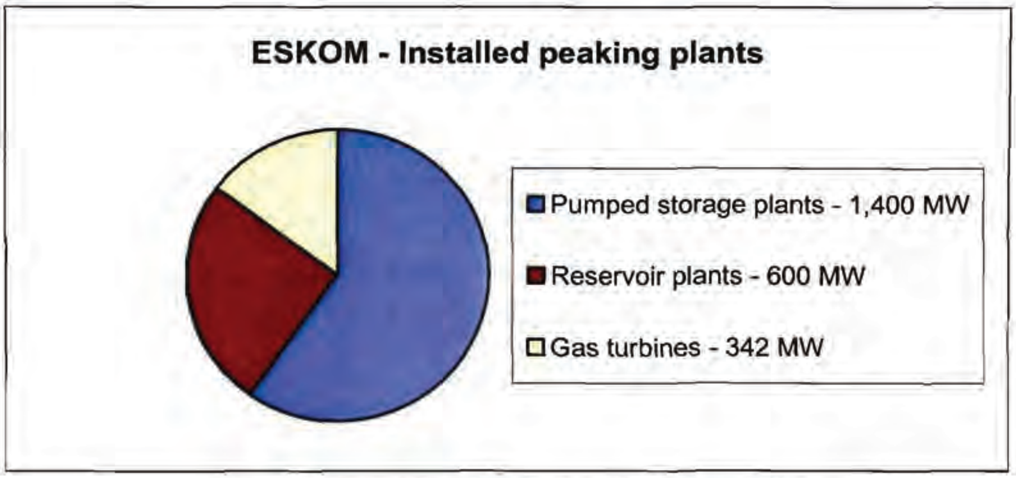

Figure 1-3 ESKOM - Installed peaking plants [21]

As a safety factor power generation plants usually aim to have 15% more generation capacity than the maximum demand [22]. This is usually referred to as the generation safety margin. Currently ESKOM is running at a safety margin of between 5% and 7% [17],[23]. ESKOM's current licensed capacity is around 39.8 GW, but their net maximum operational capacity is only around 35 GW [24],[25].

By levelling out this demand peak, ESKOM would be able to increase their demand safety margin, postpone the need for additional power plants, and lower the maintenance cost of electricity peak load plants. According to the latest ESKOM planning, the building of a peak load power station will be in the cost region of R 16 billion [26],[27].

The problem is proliferated by the growth in peak demand. The growth of the peak demand is estimated to continue at a rate of a 1,000 MW per year [19]. ESKOM's plan to introduce the PBMR (Pebble Bed Modular Reactor) nuclear power generation units into the supply grid, was drastically postponed due to the lack of investors [28].

The Reconstruction and Development Program of the South African government states that "Energy efficiency and conservation must be a cornerstone of energy policies" [29]. The Department of Minerals and Energy also states the importance of programs that manage the energy consumption of South Africa [30]. These statements add to ESKOM's incentive to pursue the management of the peak demand.

1.1.3. Energy intensity of the mining sector

South Africa is a world leader in the mining industry. During 1995 South Africa produced 23% of worldwide gold production [31]. Mining is one of South Africa's main export earners and the mining sector creates work for around 417,000 people per year [32]. There was 3% annual growth in South Africa's industrial sector during the last few years and the growth is predicted to persist [33].

The mining industry is one of the biggest electricity users in South Africa. It is estimated that mining consumes 18% of South Africa's generated electricity [34]-[37]. This compared to the consumption of other sectors is illustrated in Figure 1-4 [36]. Deep level mines consumed 83% of electricity consumed by the mining industry, which is 15% of the electricity generated in South Africa [38].

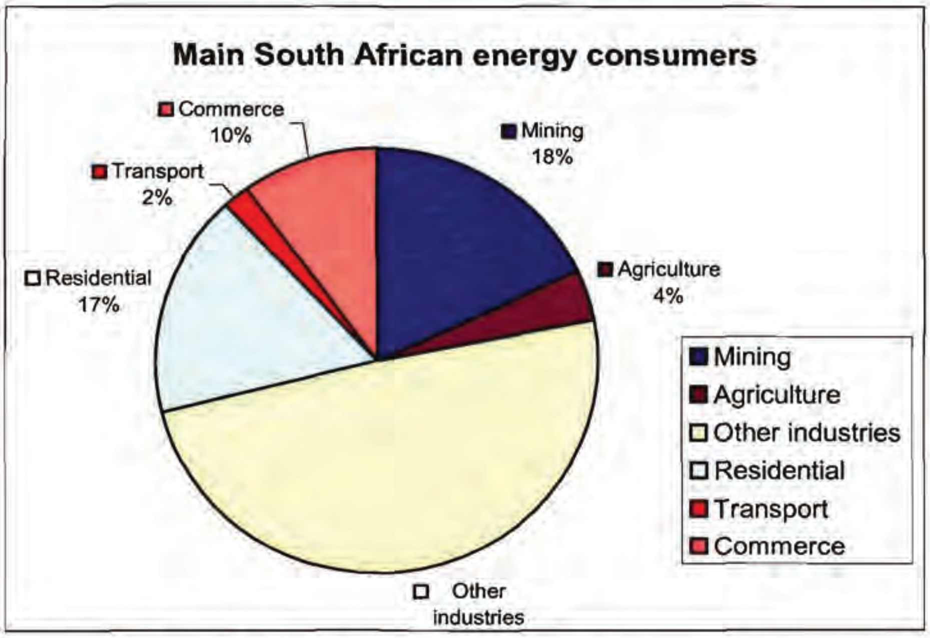

Figure 1-4 Main South African energy consumers [36]

South Africa's gold production peaked in 1970 with some 1266 tons being produced. After this peak production period, production reduced to only 517 tons produced in

1994 and only 420 tons in 1995 [39]. South African's gold production was 394 tons in the year 2001 [40]. This decline in production did not lead to a reduced electricity demand. As the mines become deeper, the electricity demand rises due to the increased power consumed to cool the deeper mine environment, and the increased depths from which ore is hoisted.

It is however predicted that the gold recovered in South Africa up to date, only accounts for 40% of the resources still available. There are still massive gold resources to be recovered in the Witwatersrand basin [39]. The attempt to recover this gold will lead to even deeper mines, which will increase the electricity demand of the mining industry even more.

The mining sector consumed 18 % of electricity generated during 1996 in South Africa. This motivated South African electricity suppliers to invest in studies that would reduce the demand of the large energy user such as gold mines [22],[26],[43]. The Association of Energy Engineers predicted that 70% of big and industrial electricity users could benefit from load management programs [41].

Lane [47] estimates that a 27% peak load reduction can be achieved on a typical South African deep mine. This peak load reduction can be achieved with optimised schedules for electrical systems [47]. Taking these saving predictions into account, one can calculate the potential savings that could be made if such an optimised scheduling system were to be implemented.

Up to 30 % of the cost of a typical` deep gold mine's electrical bill is due to energy used in peak electrical billing hours. This figure is high because a unit of electricity in peak demand periods can cost up to eight times the average unit price [52]. This implies that an 8 % reduction can be achieved on the total electricity bill on a mine when this optimised schedule for the electrical systems, as suggested by Lane [47], is implemented.

South Africa's gold and platinum mines consumed 26.0 GWh of electricity during the year 2000 [43],[44]. The average unit cost in this year was 10 c/kWh. This means that the total electricity cost paid by gold and platinum mines was R 2.6 billion. Deep level mines represent 65 % of all these gold and platinum mines. Therefore the total savings that could have been realised in the year 2000 with optimised scheduling on deep mines in South Africa for electrical systems is estimated to be in the order of R 135 million.

It is shown that there is a 3% annual growth in the South African economical activities [53]. Due to the growth of the industrial and mining sector's demand for power, and the anticipated rise in electricity cost, it can be assumed that this estimated potential saving will increase in future.

1.1.4. Time-based pricing systems

Seeing the current demand profile situation, it is clear that ESKOM must level out the electricity demand profile. One way of doing this is to motivate electricity users to use less electricity during peak demand hours and to schedule electricity-hungry processes to off-peak hours. This process of shifting demand is termed 'load shift' or 'load shifting'.

Another possibility to address the problem is by applying EE (Energy Efficiency). EE is focussed on the efficiency of the system, reducing the amount of electricity used wherever possible. ESKOM is currently busy with many such programs. The research presented in this thesis is focused on load shifting. No automated system that focuses on load shifting in the South African mining water pumping environment has been found, which emphasise the need for this study.

ESKOM has set specific load shift goals and targets for 2025 (or over the next 25 years). The goal is set at a deferral of 3.67 GW over this period. For the industrial and commercial sectors, it is envisaged to defer some 535 MW by 2020 by means of load management and load shifting [45]. The National Energy Regulator set a target for ESKOM to lower the demand peak by 153 MW per year [46].

ESKOM grouped their load shift efforts into commercial, residential and industrial projects. Residential load shift projects include home-electricity-usages-awareness programs, the implementation of more efficient heating and cooking systems etc. Commercial load shift projects include research in more effective building air conditioning systems, efficient lighting etc.

To enforce this load shift principle in the industrial sector, ESKOM introduced RTP (Real Time Pricing) in January 1999 [48]. RTP, an hourly electrical price profile, is applied to certain large electricity users. The principle works as follows: The RTP for a certain hour would be low if ESKOM predicted the cost of generation to be low. On the other hand, the RTP would be high for an hour that ESKOM predicted the cost of generation to be high.

The aim of RTP is to prompt the industrial user to use less electricity during expensive high peak hours and more electricity during inexpensive off-peak periods. In other words, RTP motivates the industrial user to shift load.

There are four ESKOM pricing structures that apply the RTP principle to the industrial sector. They are NightSave, Megaflex, MiniFlex and Wholesale Electricity Pricing (WEP) [49]. The case studies to test the system that is presented in this thesis were done on South African mines where the Megaflex pricing structure is applied. Therefore the following section is devoted to explain this pricing structure.

1.1.5. Megaflex pricing system

Megaflex pricing, a RTP pricing system focussed on industrial electricity users, was phased in between 2002 and 2004 [50][51]. The complete working and conditions as per supplier of ESKOM's Megaflex billing system can be seen as reference [52]. Following is a short summary of how the Megaflex billing system works.

Defined time periods:	Weekdays	Saturday	Sunday
Peak	07H00 - 10H00 18H00 - 20H00	N/A	N/A
Standard	06H00 - 07H00 10H00 - 18h00 20H00 - 22H00	07H00 - 12H00 18H00 - 20H00	N/A
Off-peak	22H00 - 06H00	12H00 - 18H00 20H00 - 07H00	Whole day

Table 1-1 Megaflex - Demand periods [52]

The Megaflex system divides a week into three periods. These are Peak, Standard and Off-Peak times. Electricity is then priced according to these periods, where in peak time electricity is most expensive and in off-peak periods the cheapest. These peak periods correspond to the peaks in the total ESKOM demand as shown in Figure 1-2.

Megaflex also differentiates between demand seasons. They are High-demand season, which is June to August and Low-demand season, which is September to May.

1 April 2005 - 31 March 2006		
High-demand season (June - August)		Low-demand season (September - May)
57.50 c/kWh	Peak	17.61 c/kWh
16.59 c/kWh	Standard	11.66 c/kWh
9.84 c/kWh	Off-peak	8.80 c/kWh

1 April 2006 - 31 March 2007		
High-demand season (June - August)		Low-demand season (September - May)
59.53 c/kWh	Peak	16.89 c/kWh
15.74 c/kWh	Standard	10.49 c/kWh
8.56 c/kWh	Off-peak	7.43 c/kWh

Table 1-2 Megaflex - Tariffs according to season and demand periods [52]

Thus, every hour of every day is billed according to a certain tariff, depending on the time of day and the season of the year.

1.1.6. The ESKOM DSM program

The introduction of variable electricity pricing systems like Megaflex in itself did not shift load. Load is only shifted when the industries react to variable electricity pricing systems by using more electricity in cheaper periods and less electricity in expensive periods.

To boost reaction to variable electricity pricing systems, ESKOM incorporated the DSM (Demand Side Management) principle [54] that sponsors:

1. Projects that successfully respond to variable electricity pricing.
2. Companies that initiate successful response to variable electricity pricing.

DSM, a principle incorporated by ESKOM, focuses on load shift projects. DSM is bent on the planning and implementation of projects that influence the way electricity is being used [55]. The term DSM is used to describe the planning (Scheduling) and implementation of activities to influence the time, pattern and amount of electricity usage in such a way that it produces a change in the load profile of the industry.

DSM type programs date back to 1980 [56]. The first DSM program was launched in the USA in 1980 [56]. These programs were also later implemented in the United Kingdom, Europe and Australia [56].

The launch of DSM projects has, apart from the lowering of peak demand, additional advantages [57],[56].

The introduction of DSM led to a reduction in:

1. Fuel consumption of power plants.
2. Distribution losses.
3. Emission of CO_2, SO_2, and NO_2 due to electricity generation.

ESKOM adapted the DSM principle in 1992 and the first South African DSM program was launched in 1994 [58]. The National Energy Regulator mandated ESKOM to administer all South African DSM projects in 2003 [59].

A company that focuses on finding and promoting ways for large energy users to respond to variable electricity pricing is called an ESCO (Energy Service Company). One definition of an ESCO is a company that develops, installs, and finances projects at client sites and is designed to improve the energy efficiency and maintenance costs for client's facilities over a seven to ten year time period [60].

The technical and performance risks of these projects are placed on the ESCO [61]. No risk is placed on the client, thus motivating the client to participate in the venture [62].

The ESCO industry is three decades old [63]. Its beginnings can be traced to the oil crisis in the late 1970s, which made business out of reducing the growing energy bills of larger companies. Currently the ESCO industry in North America facilitates $2 billion annual investment in energy efficiency [63].

Since ESKOM launched the DSM initiative about 180 ESCOs has been registered in SA [64]. As ESCO help to realise ESKOM's vision to shift load, they qualify for part of the funding provided by DSM. To govern the relationship between ESCO and ESKOM, the following conditions were laid down for ESCOs to comply with before they qualify for DSM funding:

1. The ESCO is responsible for identifying, implementing, and maintaining projects.
2. ESKOM will fund the capital to cover any equipment cost and implementation.
3. The client and the ESCO will share in the savings made as a result of the load shifting. This will motivate the projects to yield sustainable results.

4. An independent party will verify the total load shifted, and electricity cost savings realised.

1.2. A unique DSM solution

1.2.1. Introduction

Section 1.1.3 explained the size of the mining industry in South Africa and the amount of electricity it consumes. To address energy consumption in South African mines, a breakdown of and an in-depth look at the electricity consumption of a typical deep level mine are needed.

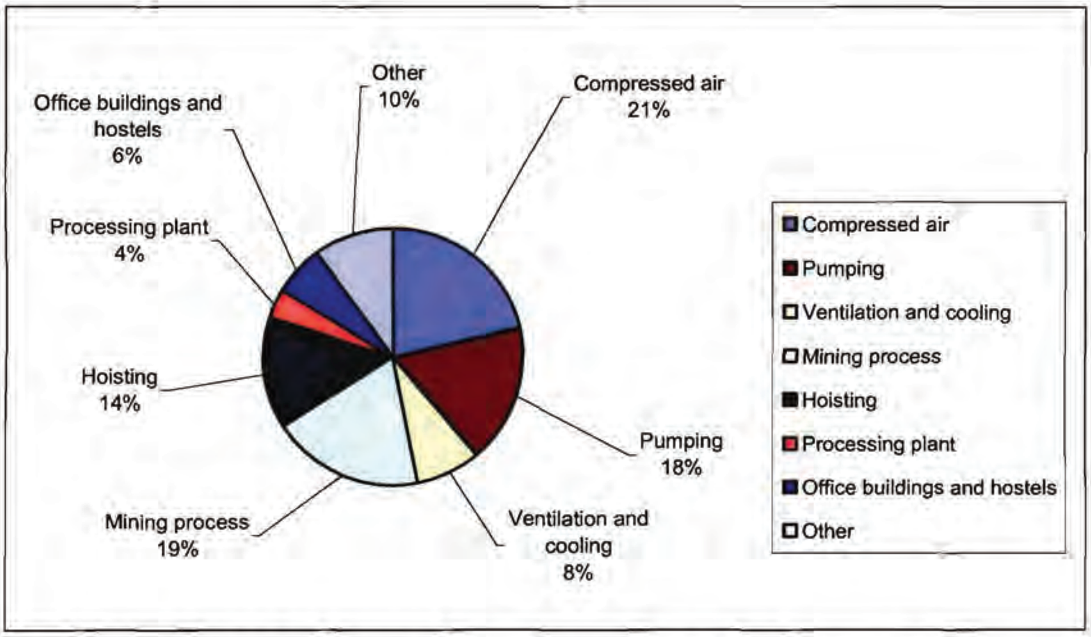

Figure 1-5 Breakdown of energy consumption in mining sector [67]

Figure 1-5 shows a breakdown of the energy consumed by the mining sector. Compressed air consumes a huge quantity of energy, as pneumatics is widely used in the mining environment due to its safety and versatility. Adapting the compressed air system for load shifting and/or EE is difficult, because the compressed air is closely linked to the mine's production.

Hoisting also takes up a sizeable amount of electricity. The amount of electricity used for hoisting is directly linked to the depth of the mine. Investigations regarding hoisting projects are already under way on South African mines [65].

Pumping also consumes a huge amount of energy. There still is unlocked potential in the control of the water pumping system as suggested by Lane [47]. These projects are feasible as the pumps are controlled manually to maintain dam levels. This research is therefore focused on further optimising the control already present.

1.2.2. Pumping of water in deep mines

Up to 40% of the electricity consumed on a typical South African gold mine is used for cooling and water pumping [66],[67].

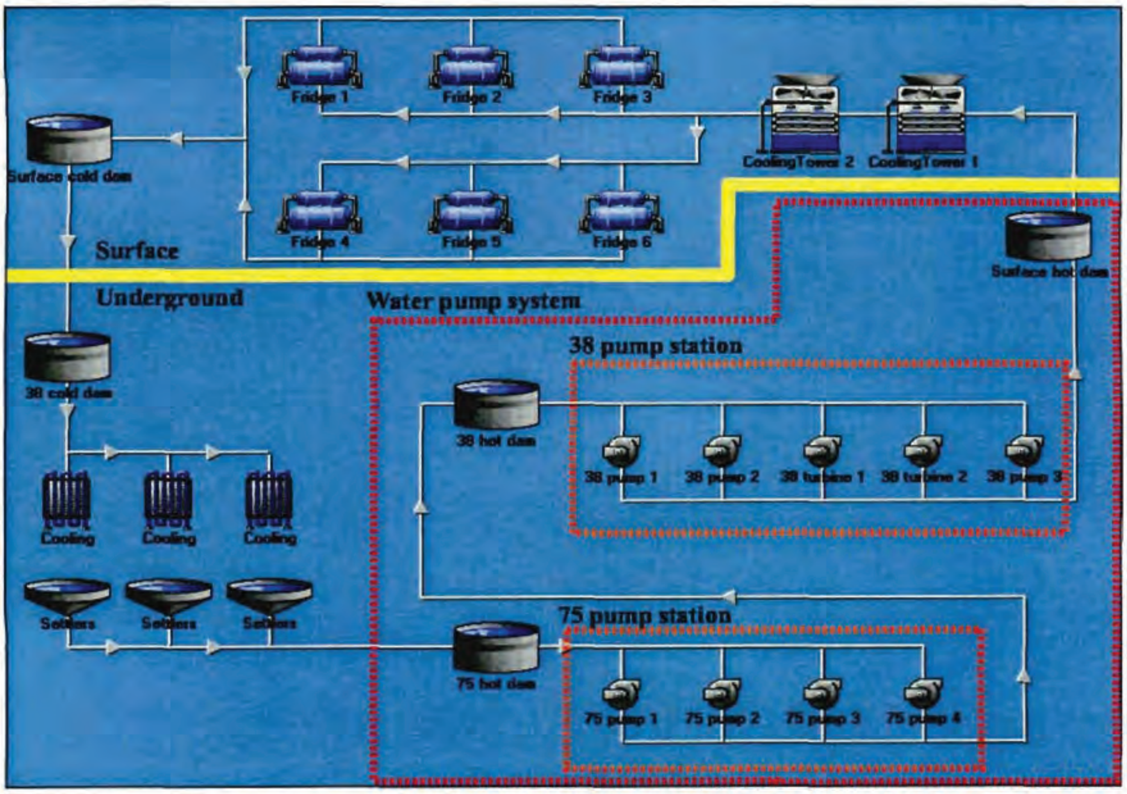

Figure 1-6 Water cycle of typical gold mine

Figure 1-6 shows a layout of a typical water pumping cycle of a South African gold mine. Beginning with the refrigeration plants (marked "Fridge 1" to "Fridge 6"), water is cooled down to an average of 3°C. The cooled water then flows down the mine to a series of bulk air coolers (marked "Cooling") that is used to cool the air in the mine- working environment [68].

Underground, the mine working water combined with fissure water flows into settlers. The settlers remove a certain degree of mud and sediment from the water, from where the clean water is fed into underground dams. The water is then pumped to the surface by pump stations, each consisting of between 3 and 8 pumps running in parallel. These pumps can range from between 1 MW to 4 MW.

Each pump station has a maximum head capacity. The energy usage per volume of water pumped, increases as the delivery head is increased. Therefore the deeper the mine, the more electricity is needed to pump the used water to surface.

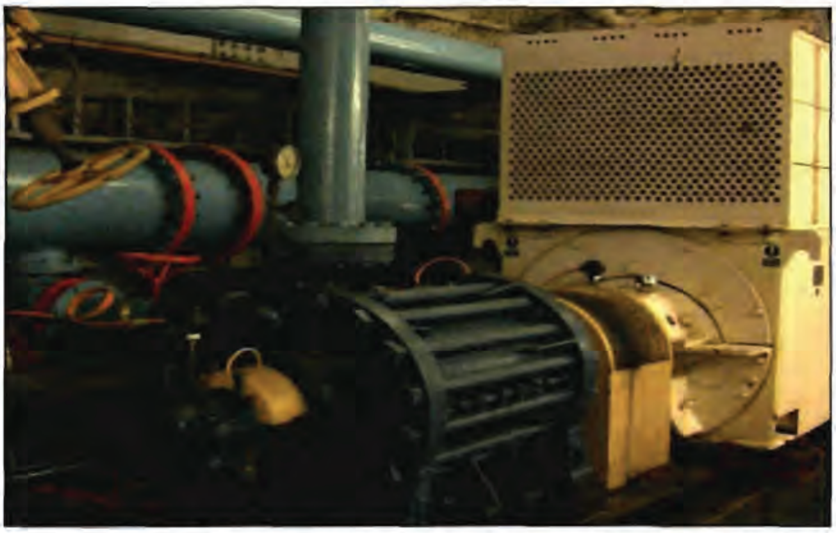

Figure 1-7 Typical electrical pump used in deep level mines

1.2.3. Advantages of automated electrical load shifting

When shifting load, electricity is used during periods when electricity is cheaper. Therefore, applying this on the water pumping system of a mine will lower the running cost of the system. This will not lower the daily delivery of the pumping system, as the same running time can be maintained.

Load shifting, as discussed in sections 1.1.4, 1.1.5 and 1.1.6, is part of ESKOM's goal, as it will lower the overall peak demand. Although shifting load on one of these projects will not achieve ESKOM's goal, every project and/or system where load shifting is applied, adds to the total load shifted within the ESKOM supply grid.

Summarised, shifting load on the water pumping system of a deep level mine has the following advantages:

1. Decreasing the running cost of the pumping system.
2. Contributing to ESKOM's goal of lowering the total peak demand.

Some mines have attempted optimised manual control. These attempts were mostly met by poor results with the exception of Joel Mine and Deelkraal (recently shut down). These mines achieved good result due to the simplicity of their pump systems and large buffer capacity of their underground dams. Manual control lacks the sustainability to realise reliable results. An automated system will overcome these hurdles by specialisation and cutting out human dependency.

Benefits gained from systems that will automatically shift load are:

1. Such a system will be beneficial to ESKOM because it will help even out the total electricity demand profile. The implications of this were discussed in section 1.1 of this thesis.
2. Such a system will be beneficial to institutions such as mines, as it would save on electricity bills.
3. The introduction of automation will reduce the number of control operators and therefore result in a decrease in labour costs.

4. A system that incorporates a variety of automated control and alarm systems will improve mine safety.

1.2.4. Current methodologies and systems for mine water pumping

Due to the substantial savings in electricity costs that can be achieved in the industry and the funding made available by ESKOM for this purpose, a number of ESCOs have been formed. For the same reason, systems have been developed that claim to save running electricity cost. In spite of this, no system that combines all of the following, has yet been implemented on any South African deep level mine:

1. **Simulation.** These systems have the capability to simulate a water pumping system. The simulation or simulated model is used for optimisation, testing and potential investigations.

2. **Optimisation.** These systems have the ability to optimise the build-up of an integrated system. The optimisation is done to improve the overall performance or efficiency of the system, or to lower electricity consumption and/or cost.

3. **Load shifting**. These systems have the capability to compile an optimised operation schedule for a system that will result in load shifting.

4. **Reduces running cost**. These systems have the capacity to compile an optimised operation schedule for a system that will result in reduced running cost. These systems take real time electricity cost and pricing structures into account to schedule workload to low cost periods.

5. **Control**. These are systems capable of control. These systems have the ability to, in one way or the other, control the components of a system with a defined goal in mind without human assistance.

6. **Automated operation**. These systems have the ability to complete designated tasks unassisted and without the need for 24-hour human assistance. Packages

and systems like these must have the ability to deal with emergency situations and continue normal operation in any event.

7. **Monitor**. These systems are designed as data and information tools. They are used to automatically log and manage data.

8. **Water pumping**. The solution sought for in this thesis is aimed at water pumping. Water pumping systems are systems that can be applied to water pumping systems in the industrial sector. Many pump control systems that are not applicable for the industrial sector are available.

The following table summarises most of the available systems that claim one or more of the above functionalities. The table also shows which of the functionalities each system is capable of:

Requirements	1	2	3	4	5	6	7	8
System	**Simulation**	**Optimisation**	**Load Shifting**	**Reduce Running Cost**	**Control**	**Automated Operation**	**Monitor**	**Water Pumping**
G2 [78]	●	●	●	●				●
Flownex [79]	●	●	●	●				●
VUMA [80]	●	●	●	●				
Mine Toolbox [84]	●	●	●	●				
U.S. Patient No. 6178393 Irvin et al [72]		●	●	●	●		●	●
SA Patent No. 2004/1173 by Temm Int (Pty) Ltd. [83]	●	●	●	●				●
U.S. Patent No.6366889 by Zalloom [69]	●	●	●	●				●
U.S. Patent No. 6178362 by Woolard et al. [70]	●	●	●	●				●
U.S. Patent No. 5963458 by Cascia et al [71]			●	●	●			●
H2ONET Scheduler [74]		●	●	●	●			●
MISER-PS [75]		●	●	●	●			●
Derceto 3.0 [76]		●			●			●
RTP ControlTM by Honeywell Inc [77]			●	●	●	●		
SA Patent No. 2004/1172 by Temm Int (Pty) Ltd. [82]					●			●
IST Otokon Pty (Ltd) [73]							●	●
TAS Online [81]		●					●	●
Adroit [85]					●	●	●	●
Wonderware Intouch [86]					●	●	●	●
WinCC [87]					●	●	●	●
PLC Programming					●	●		●
Crouzet, C-Lynx, Pump and Level Control [103]					●	●	●	●
MultiTrode, MultiSmart Pump Controller [104]					●	●	●	●
Commander-M, Pump Automation System [105]					●	●		●

CEE – Pump System Optimisation [106]		●					●	●
Pump System Matter ™ [107]		●		●				●
Pipe-Flo – Fluid Flow Analysis Software [108]	●							●
Pump-Flo – Pump Sizing and Selection Software [108]		●		●				●
Aquifier-Test – Pumping system Simulator [109]	●	●		●				●
On-line Pump System Design [110]	●	●						●
PCSM-2000 Pump Control System [111]					●	●	●	●

Table 1-3 Current Available systems

A system truly applicable to the South African mining industry that will achieve reduced running costs and load reduction, must meet all the requirement as set out in Table 1-3. As seen from this table there is currently no system available that comply with all these specifications.

To illustrate the beneficial capabilities and shortcoming of these available systems further, a short discussion is given on the capabilities of each. Also discussed are the capabilities each system lacks to make it truly applicable for this specialised application.

Simulation packages

i) G2 [78]

G2, a simulation package developed in Germany, can simulate a wide variety of systems. This includes production lines, traffic congestion or internal stress factors in designed components [78]. G2 can be applied to simulate a mine water pumping system, but the aim of the simulation is to give a representation of the pumping system for study and observation purposes. No focus is put on control. G2 further offers no features regarding automated, unassisted control, as it is designed as a simulation, and not a control tool.

ii) Flownex [79]

Flownex, a simulation package like G2, was developed in South Africa. It is focussed on simulating pipe networks and intricate thermal-fluid systems. Flownex is used worldwide for the simulation of compressed air, water and gas pipe networks and other large thermal-fluid systems. Flownex will be able to accurately simulate the intricate details of the water pumping system of a mine. The focus of the simulations and Flownex is the detailed physical properties of the fluid in the network. It can be used to optimise a pump system, but it can be a lengthy and difficult exercise.

Furthermore, Flownex cannot be used for controlling a system. Due to the intricate simulations capabilities, Flownex simulations are iterative. This means that with certain simulation parameters no clear answer can be guaranteed in one attempt. This makes it unsuitable, if not impossible, to adopt for automated control because of the instability of the iterative simulation.

iii) VUMA [80]

VUMA (Ventilation of Underground Mine Atmospheres) is a software package developed in South Africa. VUMA aids the development and management of mine ventilation and cooling systems. VUMA was not developed as an automated pump control system. The tools aid in decision making, but is unable to automatically control the components of a water pump system with the goal of reduced running costs and load shifting.

iv) Mine Toolbox [84]

Mine Toolbox is a simulation tool used to simulate the cooling system of a mine. Mine Toolbox, despite its wide range of capabilities, is not feasible for automated, optimised control of water pump systems. The reasons for this are the following:

1. Mine Toolbox was developed as an engineering tool and is user driven as is other applications such as G2 or Microsoft Excel. No features are automated, which implies that Mine Toolbox does not have the ability to automatically complete tasks without user request or input. For automated control a system is

needed that is capable of automatically driving itself and completing designated tasks without user request or input.

2. Mine Toolbox has only one input source. The information available to this system, is supplied by the user. Mine Toolbox has no communication capabilities to monitor components via a direct data chain. This implies that this tool will have no way to observe the level of a dam or the status of a pump without this data coming from the user. The ability to observe system statuses is essential for any control strategy.

3. Mine Toolbox cannot monitor the components of a system as mentioned in the previous point. Mine Toolbox also does not have the functionality or communication chain to send commands to the system components. Mine Toolbox is therefore unable to directly start or stop a pump.

4. As Mine Toolbox has no direct communication capabilities to directly communicate data to and from any system, this package lacks the ability to respond to real-time actual status and condition changes in the system, as these changes can not be automatically monitored.

5. Mine Toolbox was developed with many intricate tools focussed on the simulation and efficiency of cooling system components such as chillers and bulk air coolers. The system offers little functionality on optimised control and simulation of water pump systems.

6. Although the system is capable of simulation, its simulation capabilities cannot be integrated and used in a final solution to realise the goals that are set by this thesis. This is because the simulation is a complex and involved task that can be performed by only a highly trained engineer.

Optimisation packages

i) U.S. Patient No. 6178393 Irvin et al [72]

The goal of this patent is to optimise the total energy cost of integrated components and/or systems and to serve as a measurement tool to aid in reporting. This patent is focused on the control of constant and variable speed pumps. In short, this system takes into account the real-time operating cost for each pump and calculates the optimum combination of pumps that should be running and, if applicable, at what speed. This schedule is passed on to a human controller who is responsible for the execution thereof.

The shortcomings of this system, and others like it, are as follows:

1. This system only takes into account the immediate cost. It does not take into account what the cost in the near future will be. This implies that this system is unable to optimise for a period of time but only for an instant in time.

2. This system does not have the ability to automatically control equipment, but relies on a human operator to execute the optimised schedule.

ii) SA Patent No. 2004/1173 by Temm International (Pty) Ltd. [83]

This Temm International (Pty) Ltd. invention claims the ability to simulate and calculate optimised schedules for HVAC system components. If the HVAC components are controlled according to these schedules, cost savings would be realised. This system incorporates simulation and optimisation elements that function with intricate mathematical models.

The patent document of this invention [83] claims the ability to create an optimised control schedule for the components of an industrial system. These optimised schedules are focussed on running-cost reductions and load shifting. This principle of *load shifting* and optimised control is not a new and novel principle devised from this invention, but was already applied before in the ESCO industry [60]. The system is able to incorporate any system-constraints during the creation of the optimised schedule as claimed by the patent document.

This patented system was successfully used to shift load on a South African mine during the period September 2003 to March 2004. The application of this system resulted in 6 MW load shift in the evening peak. This exercise highlighted the sustainability problem of this invention. After implementation of the system the amount of load shifted deteriorated from 6 MW to 3 MW over a period of seven months.

The reason for this deterioration of the load shifted, and other shortcomings of invention are the following:

1. This package is able to simulate any HVAC system from any initial status. This initial status could include dam levels, pump statuses, water temperatures etc. This information or data describing the initial status of the HVAC system are supplied by human operators. This invention has no structure or functionality to automatically monitor system status data, making the system unable to do automated, unassisted simulation.

2. All simulation and optimisation are done on user request. The system has no functionality to automate tasks. This system is therefore unable to perform automated, unassisted optimisation.

3. The system is unable to control HVAC system components, such as valves or pumps. The optimised schedules calculated by this invention have to be implemented by human operators or other software. This invention therefore lacks the ability to automatically and directly control HVAC system components.

4. The system simulation and build-up needed for optimisation is done by utilising and connecting intricate, mathematical simulation algorithms. This is a

complicated and involved task and can only be performed by highly trained users. This implies that the system is not user friendly and feasible for the industrial control sector.

5. The optimised schedules are calculated from simulations that represent the actual system. The simulations are built on system statuses that are hand fed into the system. Once the actual system statuses deviate from the statuses used for the simulation, the optimised schedules are no longer relevant. This illustrates the inability of the system to incorporate real-time data into the calculation of the optimised schedules to, in real-time, update schedules as system conditions change.

Control systems

i) U.S. Patent No.6366889 by Zalloom [69] and U.S. Patent No. 6178362 by Woolard et al. [70]

These patents claim the ability to optimise energy costs in HVAC systems in mines, buildings and industries. They enable the users to analyse energy consumption trends. The goal of this software is to help the user determine operating errors, equipment faults and billing errors. Both of these systems, as well as many others, have extensive Internet based communication capabilities in order to connect the user to real-time data.

The shortcomings of these two systems, and others like it, are as follows:

1. They do not cut out human operation and therefore do not qualify as a fully automated system.

2. They are not continuously optimising tools. After extensive information input, a once-off optimisation is done and an answer is given.

3. This software does not have the capability to self-ascertain the information needed for the optimisation.

4. This software does not do active automated control in accordance with the optimised schedule that has been calculated.

ii) U.S. Patent No. 5963458 by Cascia et al [71]

This patent follows a real-time, low-level control approach. With this approach a controller is used to control an electrical component that can be a part of any cooling, heating or hoisting system.

In the patent by Cascia, a digital controller is used to control different electrical components. The controller for the specific component calculates an optimal set point and is then controlled according to this set point. This is done in real-time. Following this strategy, the controller optimises the energy consumption of the components for that specific point in time.

The shortcomings of this system, and others like it, are as follows:

1. This system only optimises for a single electrical component. It is therefore not possible to optimise an integrated network of components in parallel systems.

2. As control is performed via individual controllers. A single human interface that gives access to the control platform is not possible.

3. This approach seeks to optimise power usage (i.e. promote energy efficiency). Thus, it strives to save electricity rather than shift load.

The following four software packages that are discussed are focused on the distribution of municipal water. These packages claim to minimise the electrical costs of the municipal water distribution system. Because these systems are designed for the distribution of water in a city, it is crucial to emphasise the differences between such a distribution system and mine water pumping systems. The differences are as follows:

1. Municipal water reservoirs are much larger than the reservoirs used in mine applications. The smaller the reservoir, the faster its level will change. Thus, a system that is intended to control a network containing smaller reservoirs must be capable of faster reaction and control. Another danger of rapidly changing dam levels is that it could result in pumps cycling.

2. The bill for city water distribution is much higher than the cost of mine water pumping. As a result of this, the cost of these software packages is also very high in comparison to the savings that could be realised in a mining situation.

Consequently, these systems are not feasible for the mining industry. Yet they are still discussed as one can still identify characteristic that will be necessary for the mining industry.

i) H2ONET Scheduler [74]

This system has been developed for the municipal water distribution market. Its focus is the calculation of optimised operating schedules for water pumps for both maximum performance, and energy saving. This system can also be used to optimise the design of a municipal water distribution network. The operating schedule is calculated on a daily basis. This system has the capability to take into account hydraulic operational constraints such as pressure, velocity, head loss, and desired tank trajectory curves.

ii) MISER-PS [75]

MISER-PS is yet another application focused on municipal water distribution. This application is used to calculate day-to-day pump operational schedules to optimise electrical costs and efficiency. This application can also be used to plan emergency procedures in the event of a pump failure. The schedule is calculated in half-hour intervals and contains on-off statuses for all the pumps that are taken into account. The operator can specify constraint limits, for example the number of pumps running simultaneously, flow parameters, and reservoir levels.

iii) Derceto 3.0 [76]

Derceto is focused on larger water distribution networks. It aims to deliver a certain demand of water to specific points. It has online data collection capability, which means that it can find the cheapest water source and deliver the water to points where it is needed. The water is distributed via a pump system that is automatically controlled. This whole process is optimised in real-time to minimise the operational costs. This is the only application that is capable of scheduling pumps for minimal electrical cost in real-time. This application is very flexible and can be applied to a wide range of fields. Its drawback is that it needs a specialist to install and maintain and costs approximately US$ 500 000 per installation. This is beyond the reach of smaller operators.

iv) RTP ControlTM by Honeywell Inc [77]

This system is used to enable commercial and industrial systems to respond to real-time pricing. It was tested and verified in a case study at the Marriott Marquiss Hotel in New York. The system has the right load shifting approach, but it does so by thermal energy storing. It can therefore not be used in the controlling of a system that includes components such as pumps and/or electrical motors.

v) SA Patent No. 2004/1172 by Temm International (Pty) Ltd. [82]

This patented system was developed by Temm International (Pty) Ltd. The invention claims the ability to control the components of an HVAC system with the goal of minimising running costs. The invention includes tools that control the components of a HVAC system in accordance to an optimised schedule.

The claims in patent document [82] summarised, claim:

1. An innovative approach towards optimised system element control.
2. Workload distribution between the pumps in the water pump system.

These are not new discoveries made by this patented system. These principles were already applied with the birth of the ESCO industry [60]. This patent has proved helpful in controlling a water pump system on a South African mine by introducing automated control and workload distribution between pumps.

The shortcomings of this patented system are the following:

1. The system provides for control of water pumps in accordance to an optimised schedule. The schedule is not calculated by the invention itself. The schedule is calculated by software that is not part of the patented invention. This patent does therefore not incorporate the ability to generate an optimised control schedule for the components of a water pump system.

2. The optimised schedule that is needed for the control of HVAC system components is sent to the patented system from a central control point. This step is not automated and is done by human operators. This implies that the system is not fully automated and unable to control without human intervention.

3. The invention incorporates real-time data logging. The logging is done on given time intervals and gathers data regarding dam levels, pump statuses etc. The system does not have the functionality to react to this data. The data is later available to the user, but the system is not able to process the data itself to report on progress or control performance.

4. The patented system does not directly control the components of HVAC systems, but relies on a Citect SCADA to control the components to its instructions. The patented system communicates to this Citect SCADA via a programming language called Cicode, a language unique to Citect. This means that the patented invention is only capable to communicate to this specific SCADA. It furthermore implies that the system will not have the ability to control any HVAC components where the Citect SCADA is not implemented.

5. During maintenance of the HVAC components that are being controlled by this patented system, the system has to be stopped or switched off. This is to prevent the system from sending control signals to the components. This will cease all control over components and/or equipment undergoing maintenance.

6. The optimised schedules for the HVAC components are calculated daily. The optimised schedule is compiled allowing for the status of the system at the beginning of the day. The changing statuses of the system during the day are not taken into account. This implies that the system is unable to react to real-time data. For example, the sudden unexpected inrush of underground fissure water into the mine or the breakdown of a pump cannot be accounted for. During situations like these, the system has to be disabled, and control of the water pump system has to be done manually by human operator.

Monitoring systems

i) IST Otokon Pty (Ltd) [73]

IST Otokon PTY (Ltd) is a South African company that provides systems that can be used to achieve automated energy readings in the industrial environment. This data is logged into a database and is available to the user via their ecWin^{TM} software. This system does not focus on control at all and therefore cannot be used directly for load shifting or automated control.

ii) TAS Online [81]

TAS Online, a system developed in South Africa, is focused on monitoring industrial pumps. The system helps in scheduling maintenance and reports on the efficiency of pumps. It can also reduce the power usage of a pumping system by helping increase the efficiency of the pumping system. The information this system provides can help in load shifting projects, but the system is not focussed on load shifting itself.

iii) SCADA packages

SCADA packages offer programmability components to the user, in which control algorithms can be written. Therefore, in theory, SCADAs could be used to control individual pumps according to specific criteria. The problem is that no integrated simulation is possible that take all system components into account.

In addition SCADA programming is very difficult. An extremely high level of coding knowledge is needed. SCADAs also do not allow for optimisation. This means that load shift through SCADA programming will lead to serious problems such as pump cycling, a system that may eventually become clogged with too much water etc.

Investigations done on South African mines found no instance where this functionality was utilised to realise optimised control and load shifting. SCADAs that were commonly found on these mines were Adroit [85], Wonderware Intouch [86] and WinCC [87].

iv) PLC Programming

PLC (Programmable Logic Controller) programming was also applied in the past. This approach does not offer the advantage of integrating a whole system. The disadvantages of this approach are the following:

1. PLC logic programming does not offer the same mathematical and simulation capabilities found in a computer system environment. This lowers or inhibits the capability of this approach to do optimised control.

2. PLCs do not offer a database capability. Long term information cannot be stored in a PLC. Computer systems have this advantage. Having access to this data enables the system to better optimise the control.

3. PLCs offer poor human interface devices, compared to that of a computer system.

4. PLC logic programming is very complex and involved and can only be performed by a highly trained technician.

1.2.5. The need for this study

Section 1.1 discussed the benefits that can be gained from shifting load. In section 1.2.4 a number of existing control systems that help to shift load in some way were discussed. Also discussed are simulation tools able to simulate intricate set-ups such as water pumping systems. The advantages, drawbacks and field of application of these systems were highlighted.

By investigating these systems and technologies a series of attributes and properties were identified that are needed for automated optimised control. The list consists of the following, but no system mentioned above combines all these properties into one integrated system:

1. Simulation: The ability to simulate a set-up such as a water pumping system.
2. Optimisation: The ability to optimise certain outputs by a set of preferred criteria.
3. Automated control: The ability to achieve unassisted control of a system based on the simulation and optimisation results.
4. Communication to system components: The ability to communicate to system components such as dams and pumps, to directly monitor component statuses and to send control commands.
5. Real-time control: The system must firstly be able to incorporate real time live data, and secondly react to that data. The control system must be able to incorporate live data into the control and/or simulation philosophy to immediately react to changes in the controlled system.

During the literature review no mention or link could be found of a system which integrates all these aspects. One explanation for the lack of literature may be that information is withheld to protect intellectual property.

The literature study was therefore taken further. A detailed survey found no such system on any South African mine. It therefore seems safe to state that no such system exists.

1.3. Contributions of this study

The contributions of this research can be summarised as follows:

1. This thesis presents research into an automated optimisation control system for large water pumping configurations in underground mines. For the first time a solution is presented that integrates simulation, scheduling, automated control, and reporting in real-time. All constraints such as maintenance, production, safety and health issues are automatically taken care of with the new system.

2. Before this research was rolled out, some attempts were made on about 10 % of South African mines to shift load through manual control of pumps. These manual load shift attempts resulted in low savings. Proper control of large pumping systems is difficult enough with attendants and operators having to worry about serious threats such as flooding. By implementing this new solution, maximum load shift was achieved resulting in reduced electricity costs on several mines. The results are summarised in chapter 4.

3. This invention introduces a faster and cheaper way to investigate possible project potential for a given pump system. This invention, independent of the pumping system itself, is capable of predicting the load shift and savings potential of any pumping system. This eased investigations to find feasible projects viable for load shift control. Traditional control systems have no way to achieve this and can therefore yield no forecast on the success it will have. Other simulation packages could be used to simulate the proposed project systems, but these simulation packages require highly skilled personnel and a great deal of information on the pump system. This is time-consuming and expensive.

4. Previously, training of pump control operators and attendants was done on actual pump systems. These lengthy training periods are risky as human error could lead to flooding, loss of life etc. This new system with its simplified simulation capabilities is a unique training tool.

   Operators can be trained on virtual water pumping systems built in a simulated environment. No risk is involved and the virtual system can be built to represent any known water pumping system. Other simulation packages could be used for this purpose, but the operation and set-up of these systems are complex, time-consuming, and expensive.

5. Traditional maintenance on pumps and water pumping systems include scheduled replacement of critical system parts and the distribution of workload between components. The workload distribution was managed and executed by human control room operators. This invention improves and automates this workload distribution by scheduling pump operations in accordance with maintenance planning. This leads to a well managed and more reliable maintenance system.

6. This invention automatically monitors pumps, records flows, power usages etc. This information is processed to produce suggested maintenance schedules. It raises alarms in the event of eminent pump failure or performance deterioration. Acting on these alarms prevents serious pump failures and the threat of mine flooding. It also provides for a safer pump system, because of minimum potential for human error.

7. Safety and evacuation procedures in mines are based on many assumptions on how and when, life-threatening situations occur. For example, much guesswork is involved on how fast dams can overflow during power failures etc. This invention can be used to simulate emergency scenarios in order to develop optimal safety procedures. Should circumstances in the mine change, procedures can easily be adapted with the new and easy to use simulation tool.

8. This invention can be used to develop and optimise new water pumping systems. The simulation capability can be used to investigate various scenarios. Through simulation, the impact of each component can be seen, which makes the design process effective and quick.

1.4. Outline of this document

This document consists of 5 chapters. They are:

Chapter 1 - Introduction

This chapter contains the literature study, an in-depth look at the electricity demand trend in the world, as well as a more focused look at the South African situation. This chapter also describes the mining situation in South Africa and to what degree it contributes to the total electricity demand in South Africa. Also stated are the problems we face in the electricity demand of our country and what needs to be done to mend these problems.

This chapter also proposes the development of a solution that can help the electricity demand crisis in South Africa. The solution is the development of an automated control system that shifts electrical load and realises electrical cost savings in the South African mining environment.

Chapter 2 - Engineering a novel solution

This chapter gives an overview of the development stages of the novel solution proposed in chapter one. The stages were discussed and presented as they were tackled in real life. This chapter elaborates on the requirements set to the proposed solution and describes the engineered philosophies and algorithms that answer to these requirements.

Chapter 3 – Building the novel solution into a feasible system

Chapter three fully describes the development specifications drawn up for the proposed system that will incorporate and roll out the developed solution. This chapter explains the assembly of a system feasible for the industrial environment, capable of fulfilling the set goals.

Focus was placed on the reliability aspects of the systems. The reliability of systems that will be linked to the production of industries, such as gold mines, is of paramount concern.

Chapter 4 – Verifying the new system

This chapter is dedicated to testing and proving the successful development and implementation of the system proposed in chapter one. The system was tested by implementing it on several mines and carefully monitoring its progress.

This chapter also describes how success was measured. Some of the case studies were fully discussed and presented with daily results to prove that the system did yield real and positive results.

Chapter 5 - Conclusions

This chapter concludes the thesis summarising the final verdict on the development of the system that was proposed in the chapter one. Is also lists recommendations for further study.