RESEARCH INTO REAL-TIME ENERGY MANAGEMENT ON OLD GOLD MINES

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ABSTRACT

Title: Research into real-time energy management on old gold mines

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Key words: DSM, ESCo, load shifting, mine water pumping system, Eskom, REMS

The South African Electricity Supply Industry is one of the backbone industries in South Africa. During 2003, it became clear that the demand for electricity in South Africa was increasing at a rate that had not been predicted nor recognised before. This was a clear indication that Eskom, the national electricity supply utility, would have to invest in additional generating capacity before 2007.

Eskom envisioned these problems and introduced a DSM programme, which is aimed at reducing the national peak power demand. In so doing, the immediate need for additional power generating capacity will be postponed. A major part of this program is the concept of electrical load shifting.

In 2000 mining in South Africa consumed 29% of the total quantity of electricity generated, of which the gold-mining industry consumed more than half. Electricity is the exclusive power source for the application of vital health and safety-related requirements in gold mines. In some cases, these consume in excess of 55% of the total electricity used on a mine. Water-pumping systems are a major part of these important applications.

This dissertation presents a study of certain aspects of real-time energy management on old gold mines, by focusing on electrical load shifting on underground water pumping systems. Old gold mines use old, proven and energy-intensive methods that were not designed to conserve energy. This study also researches the challenges associated with the implementation of energy management strategies on old gold mines.

Research was done on three old gold mines to determine the potential for load shifting on the underground water pumping systems of old gold mines. Integrated simulations were used as the main method of establishing this potential as well as the financial savings potential for the client. The simulation results showed large amounts of load-shifting potential for all three case studies and substantial financial savings potential for the clients.

Real-time, load-shifting strategies were implemented on the three systems analysed in the case studies. The results generated by these strategies showed that load shifting could be realised on these systems, and confirmed the potential calculated in the simulations. Further research into the results however showed that the old infrastructure in the old mines caused many problems and influenced the sustainability of these strategies.

From this study, the conclusions were made that; (a) there exists a potential for energy management on old gold mines, (b) there exists large potential for the implementation of sustainable energy management strategies on old gold mines, and (c) it is feasible to implement energy management strategies on old gold mines.

SAMEVATTING

Titel: Navorsing oor in-tyd energie bestuur op ou goudmyne

Outeur: N.L. de Lange

Promotor: Dr. M.F. Geyser

Sleutelwoorde: DSM, ESCo, lasverskuiwing, myn waterpompstelsel, Eskom, REMS

Die Suid-Afrikaanse elektrisiteitsvoorsienings-industrie is een van die rugsteun industrieë in Suid-Afrika. Gedurende 2003 het dit duidelik geword dat die aanvraag vir elektrisiteit in Suid-Afrika vermeerder teen 'n spoed wat nie voorheen voorspel is nie. Hierdie was 'n duidelike aanduiding dat Eskom, die nasionale elektrisiteitsvoorsiener, sal moet belê in addisionele elektrisiteits voorsienings kapasiteit voor 2007.

Eskom het egter hierdie probleme voorsien en het 'n "DSM" program bekendgestel, met die doel om die nasionale piek-periode kragverbuik te verminder. Daarmee kan die onmiddelike behoefte aan addisionele kragopwekkings kapasititeit uigestel word. Elektriese lasskuif vorm 'n groot deel van hierdie DSM program.

In 2000, het mynwese in Suid Afrika, 29% van die totale voorsiende elektrisiteit verbruik, waarvan die goudmyn industrie meer as die helfte hiervan verbruik het. Elektrisiteit is die eksklusiewe kragbron vir belangrike veiligheid en gesondheid verwante toepassings in goudmyne. In sommige gevalle, verbuik hierdie toepassings meer as 55% van die totale elektrisiteit wat gebruik word op 'n myn. Waterpompstelsels maak 'n groot deel uit van hierdie belangrike toepassings.

Hierdie verhandeling is 'n studie, aangaande sekere aspekte van intyd energiebestuur op ou goudmyne, deur te fokus op elektriese lasskuif op die ondergrondse waterpompstelsel. Ou goudmyne gebruik ou, beproefde en energie-intensiewe metodes wat nie ontwerp is

om energie te bespaar nie. Hierdie studie ondersoek ook van die unieke uitdagings wat gepaard gaan met die implementering van energiebestuur strategieë op ou goudmyne.

Drie gevallestudies is ondersoek om die potensiaal vir lasskuif op die ondergrondse waterpompstelsels van ou goudmyne te bepaal. Geintegreerde simulasies is gebruik as die hoofmetode om hierdie potensiaal te bepaal, sowel as die finansiële besparings potensiaal vir die kliënt. Die simulasie resultate het groot potensiaal vir lasskuif op al drie gevalle studies gewys asook groot potensiaal vir finansiële besparings vir die kliënt.

In-tyd lasskuif strategieë is geïmplenteer op die drie stelsels wat geanaliseer is in die gevallestudies. Soos wat verwag kan word, is dit gevind dat die meestal ou infrastruktuur in die ou myne verskeie probleme veroorsaak het wat die volhoubaarheid van hierdie strategieë beinvloed het.

Vanuit hierdie studie is die volgende afleidings gemaak; (a) daar bestaan 'n potensiaal vir energiebestuur op ou goudmyne, (b) daar bestaan groot potensiaal vir die implementering van volhoubare energiebestuur strategieë op ou goud myne, en (c) dit is gangbaar om energiebestuurs projekte op ou goudmyne te implementeer.

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- Finally, all thanks to my Creator, without whom none of this would have been possible.

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LIST OF ABBREVIATIONS

DME	-	Department of Minerals and Energy
DSM	-	demand side management
EE	-	energy efficiency
EMS	-	energy management system
ESCo	-	energy services company
ESI	-	electricity supply industry
GW	-	giga watt
GWh	-	giga watt hour
IEP	-	integrated electricity planning
kW	-	kilowatt
kWh	-	kilowatt hour
MW	-	megawatt
NERSA	-	National Energy Regulator of South Africa
NEP	-	national electrification programme
PLC	-	programmable logic controller
REMS	-	real-time energy management system
SCADA	-	supervisory control and data acquisition
SSM	-	supply side management
TOU	-	time of use

1. INTRODUCTION

This chapter gives an overview of the current electricity situation in South Africa and introduces the Eskom generating capacity problem. Electrical load shifting as part of the Eskom DSM process is analysed as a solution to this rising problem. Old gold mines are outlined as big electricity consumers and the concept of load shifting is proposed for critical, energy-intensive water pumping systems on these mines.

1.1 Background

Energy is critical to every aspect of the economic and social development of a country [1]. South Africa has always been seen as a developing nation throughout the world and the South African energy sector has always been at the centre of the country's development [2].

The South African Electricity Supply Industry (ESI) is one of the backbone industries in the country's energy sector and is therefore a major component of this growing South African economy [3]. As shown in *Figure 1-1*, electricity contributed 26% of the total amount of energy consumed in South Africa during 2003 [4].

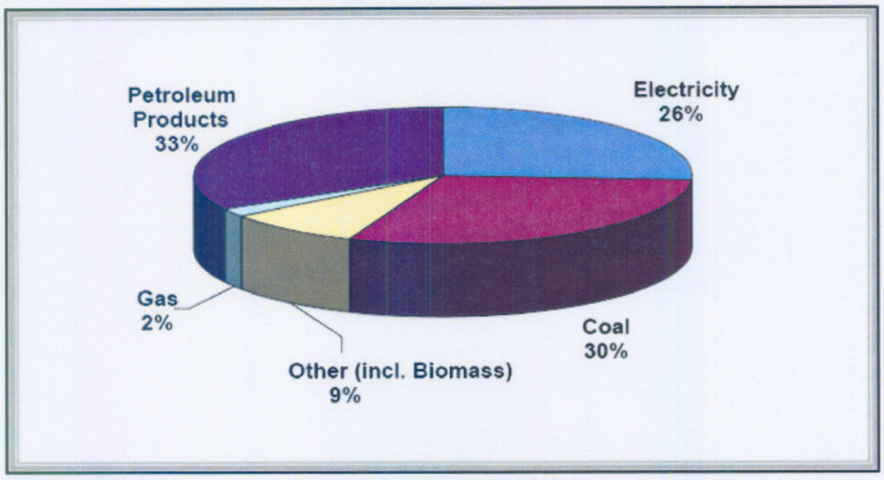


Figure 1-1: Energy consumption in South Africa [4]

The main resource utilised in the generation of electricity in South Africa is coal [3]. Shown as a percentage in *Figure 1-2*, coal contributes 93% of the total energy used. Based on this fact, the assumption can be made that electricity and the generation thereof contribute more than half of the total energy consumed in South Africa.

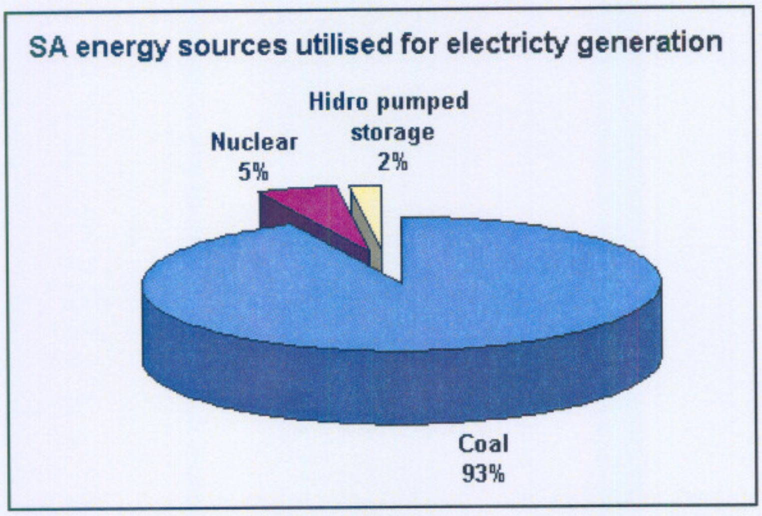


Figure 1-2: Energy sources used in electricity generation [3]

The significance of the South African ESI is that the main focus of the industry lies in improving the quality of life for the previously disadvantaged majority as well as supporting large-scale industrial development [5]. This is confirmed by the fact that the production and distribution of energy contributes 15% to South Africa's gross domestic product (GDP), creating more than 250 000 jobs [6]. These figures truly emphasise the importance of this major industry in South Africa.

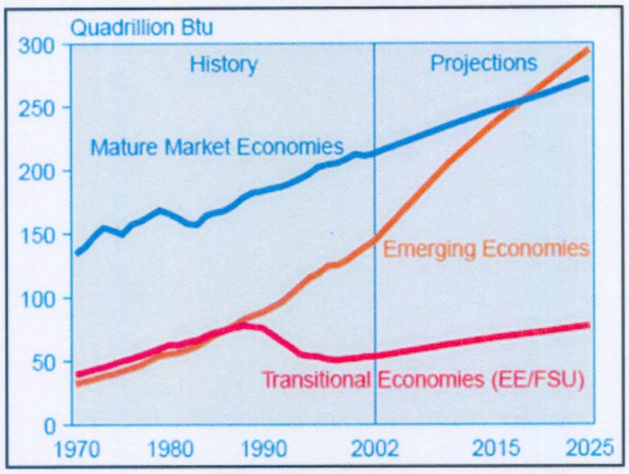


Figure 1-3: World energy requirements [5]

According to forecasts by the Energy Information Administration (EIA), the energy requirements of emerging economies such as South Africa will increase dramatically during the next 20 years [5]. These forecasts are illustrated in *Figure 1-3.*

From the figure, it is evident that great focus has to remain on South Africa's energy sector to ensure the economical growth that is required, not only in this country, but also in the greater continent of Africa.

1.1.1 Electricity in South Africa

South Africa consumes almost 40% of all the electricity used in Africa [2] and produces more than half of the electricity generated on the continent [6].

Eskom is South Africa's national power generation utility. As the primary utility, it has historically assumed the responsibility of ensuring adequate supply capacity [7], and generates most of South Africa's electricity. Currently Eskom is one of the top seven utilities in the world regarding generating capacity, and among the top nine in terms of sales [8].

a) History of electricity in South Africa

"The origins of the electricity supply industry in the first years of the twentieth century were driven by the needs of the booming mining industry." [2]. This statement is easily confirmed throughout the history of the South African ESI and Eskom. In the booklet *"Eskom - Empowering the nation and beyond!"* [9] it is shown that almost all of the earliest development by power companies in South Africa came to pass due to the growing electricity demand by gold mines.

Although the main forms of energy at the inception of electricity were gas, compressed air, and coal, the low cost of electricity from central power stations quickly made it the dominant energy resource for mining and industries [10]. During the next 80 years economics and mining drove electrification.

During the 1980s Eskom invested in a very large construction program, erecting a large number of coal power stations. Unfortunately, during this same period the South African economy was starting to stagnate because of international sanctions against "apartheid". This brought about a large excess in capacity. Old power stations were mothballed and their capacity receded as a priority [11].

In 1987, the South African ESI was restructured and Eskom started focusing its efforts on bringing affordable electricity to all of South Africa. In 1994, the Integrated Electricity Planning (IEP) approach was adopted to meet the obligations of the "electricity for all" policy [7]. As part of this policy, Eskom embarked on electrifying 1.75 million houses by 2001 and this was achieved during 1999 [11]. Yet by the end of 2003, 31% of the houses in South Africa still had no electricity available [3].

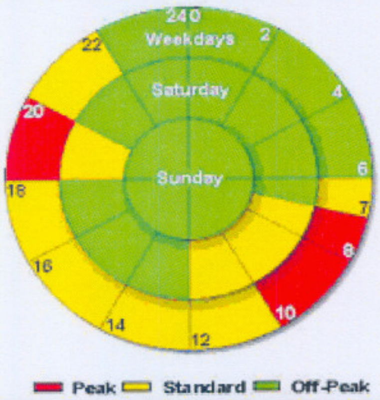
b) Cost of electricity in South Africa

During the early 1990s, Eskom determined that a reduction in the price of electricity would stimulate the South African economy to revive its former growth [9]. As a result of this price reduction, Eskom had the lowest industrial electricity tariffs in the world during 1997 [12]. Eskom currently generates the second cheapest electricity in the world [13].

This privileged position is mainly due to: (a) the abundance of coal in South Africa, allowing power stations to be constructed near coal mines [14], (b) the fact that municipal distributors and large industrial and mining customers contribute more than 80% of Eskom's sales [1], and (c) Eskom's early investments in the power sector which allowed them to pay off debts and reduce financing costs on new developments [2].

c) Current pricing structures

Eskom provides various pricing structures for large consumers of electricity. The five main tariffs available are NightSave, MegaFlex, MiniFlex, RuraFlex and Wholesale Electricity Pricing (WEP). MegaFlex is the tariff that is most suitable for large energy consumers and mines. The times of use for this tariff is depicted in *Figure 1-4*.



High-demand season (June - August)		Low-demand season (September - May)
49,69c + VAT = 56,65c/kWh	Peak	14,10 + VAT = 16,07c/kWh
13,14c + VAT = 14,98c/kWh	Standard	8,75c + VAT = 9,98c/kWh
7,15c + VAT = 8,15c/kWh	Off-peak	6,20c + VAT = 7,07c/kWh

Figure 1-4: Megaflex times of use and Eskom's electricity tariffs (2005/2006) [15]

This tariff is ideal for large consumers capable of scheduling their electricity usage and is used by most of the mines in South Africa.

d) Current demand situation

The South African economy is currently very energy-intensive, with every rand of value added consuming a large amount of energy [16]. Eskom's low electricity rates provide little or no incentive for energy conservation strategies on the part of the consumer. For this reason, industries in South Africa have made only limited investments in energy conservation strategies and remain very inefficient in energy saving [17].

Eskom presently has a total generation capacity of 37 gigawatt (GW) as seen in *Table 1-1*. Also shown in this table is a categorised breakdown of Eskom's generating capacity.

Eskom's main producers are the large number of coal-fired power stations, with a single nuclear power station, two gas turbine facilities, six hydroelectric plants and two pump storage stations, adding a few extra GW [19]. These producers supply one of the most extensive and effective electricity supply grids in the world [11].

Table 1-1: South Africa's electricity generation capacity [18]

Energy Source	Capacity / MWe
Coal	32,202
Nuclear	1,840
Pumped Storage	1,580
Hydro	667
Gas Turbine	662
Bagasse	105
TOTAL	***37,056***

1.1.2 Envisioned electricity supply problems

The demand for electricity is increasing all over the world, both in developed and emerging countries. The IEA forecasts that the world's electricity demand in 2030 will be more than 50% higher than the current demand [20]. *Figure 1-5* illustrates the current expected net electricity consumption of the world. In the figure, it is clear that electricity consumption of emerging economies such as South Africa will rise dramatically.

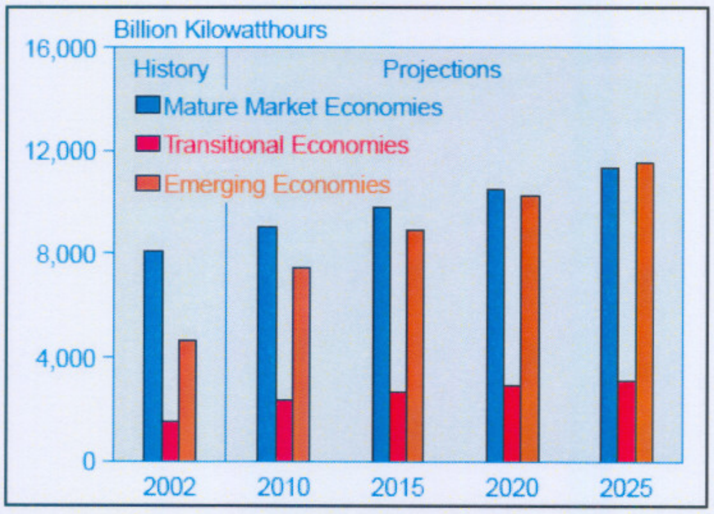


Figure 1-5: World's net electricity consumption by region [5]

In South Africa, most people use electricity during Eskom's peak demand periods [21]. This places a definite strain on the country's electricity resources. The typical electricity load profile for an average day in South Africa is depicted in *Figure 1-6,* in which two definite peaks are visible.

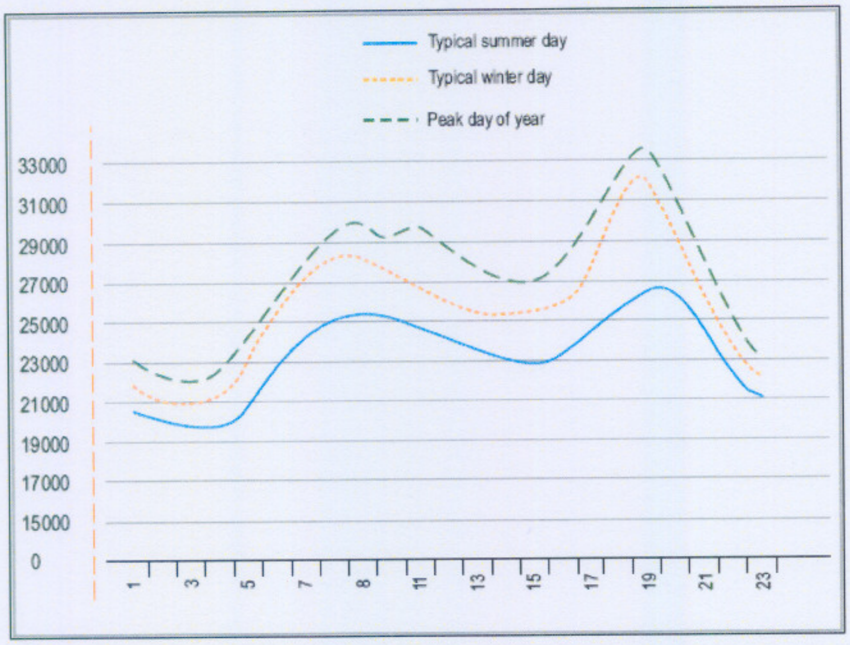


Figure 1-6: Weekday electricity demand profile for South Africa [3]

Eskom defines peak demand periods in South Africa as the periods between 7 a.m. and 10 a.m. as well as 6 p.m. and 8 p.m. Also visible from the figure is the increase in the demand profile during winter times, due to higher residential heating requirements [3].

During 2003 it became clear that the demand for electricity in South Africa was rising faster than had been recognised by any predictions [11]. With today's current usage levels and projections pertaining to the National Electrification Program (NEP), there will be a need for Eskom to invest in new generation capacity before 2007 [22]. This is illustrated in *Figure 1-7,* where the generation capacity of Eskom is shown as a function of time.

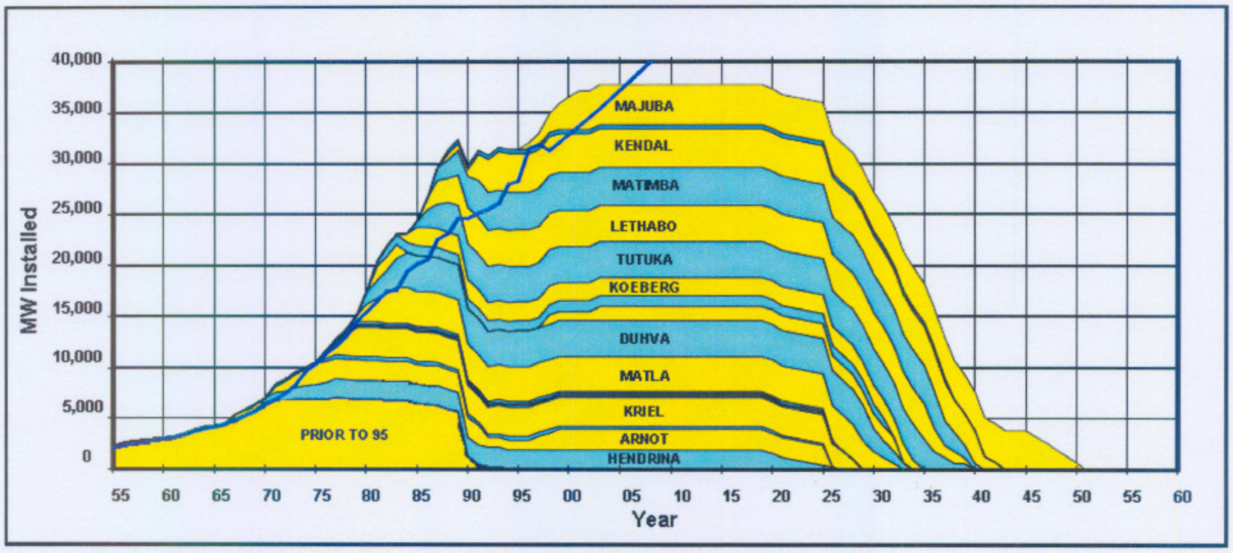


Figure 1-7: Eskom's electricity generation capacity [18]

The line in the figure indicates the current demand predictions. Note that it passes through the summit of the generation capacity by 2007.

As further increases in demand are encountered in the future, the load profile will become increasingly peaky as estimated in *Figure 1-8*. The base load has also increased dramatically over the past few years, making it even more difficult to counteract the peaks during peak demand periods [23][11].

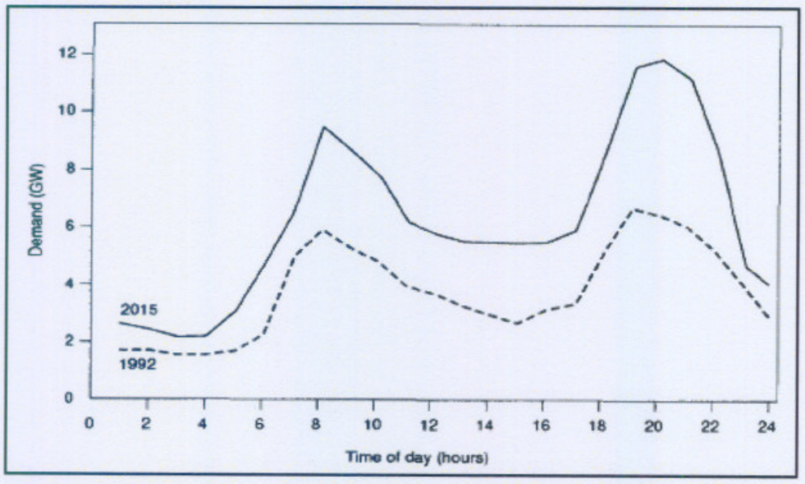


Figure 1-8: Estimated peak growth from 1992-2015 [13]

One way of counteracting the high demand in peak times would be to build additional power stations. The drawback to this idea is that the additional power stations would only be required during peak times, and will thus be idle for the rest of the time. Consumers would then in any case have to bear the investment costs [21]. Further expansions in generation capacity will also place additional strains on the transmission and distribution network [13].

In 2005 Eskom's full operational capacity was 37,5 GW. Peak demand was 36,1 GW during the same period [11]. The average annual growth of peak demand from 1990 to 2003 was 3,3% and this is illustrated in *Figure 1-9* [3]. Early estimates suggest that R107 billion would be required between 2005 and 2009 to solve the problem and meet the country's growing energy needs [6].

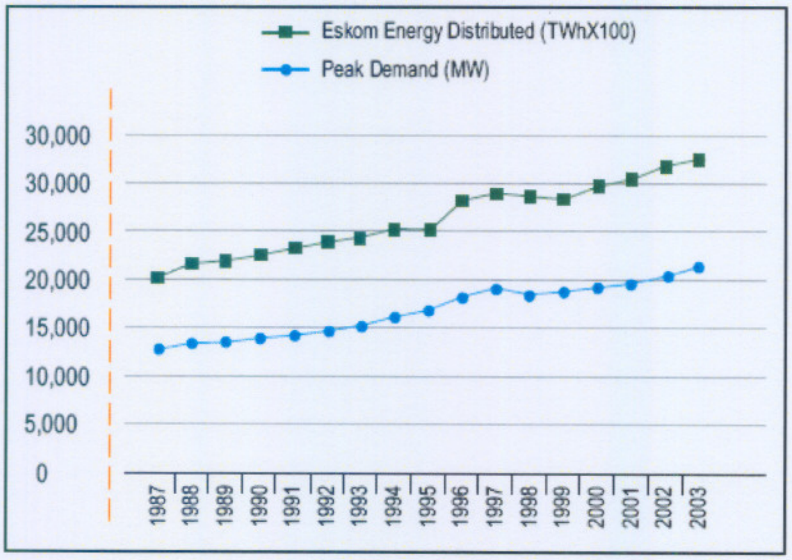


Figure 1-9: Rise in Eskom's distributed energy and peak demand [3]

Eskom envisioned these problems. They realised that improvements in energy efficiency (EE) could contribute to the reduction in future peak demand. However, this meant that they had to start managing the demand side of the ESI, something that had never been done in Africa before.

These envisioned problems were some of the main reasons why Eskom adopted the IEP approach in 1994. As part of this approach, Eskom made provision for the inclusion of demand side management (DSM) interventions where economically viable; this included 7,3 GW of peak load reduction [7].

1.1.3 Eskom's DSM and ESCos

To ensure a stable and reliable electricity market, a balance between the electricity supply and demand is a necessary factor [12]. This balance can be created by either SSM or demand side management (DSM). Considering that, SSM solutions require large amounts of lead time, and realising the shortage of time available to implement a working solution, DSM was the natural choice for Eskom.

a) The theory behind DSM

"DSM refers to a process whereby electric utilities in collaboration with consumers achieve predictable and sustainable changes in electricity demand [24]." Or to put it quite simply: DSM is the process whereby a supplier influences the way electricity is used by customers [21].

The term DSM was first used in the United States of America (USA) in the early 1980s, and was later adopted in the United Kingdom, Europe and Australia [21]. While Eskom formally recognised DSM in 1992, South Africa's first DSM plan was only produced in 1994 [25].

Demand side management interventions can generally be broken down into four broad subcategories. These are (1) strategic load growth; (2) load shifting; (3) interruptibility; and (4) EE interventions [12]. These are illustrated in the following figure:

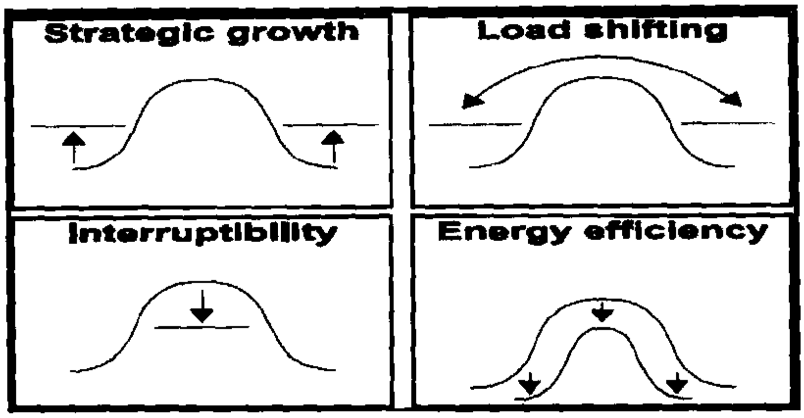


Figure 1-10: DSM options [12]

The first subcategory, namely strategic load growth, can be defined as increasing an energy demand profile uniformly to a higher average level. This intervention is normally utilised when there is an excess in capacity.

The other alternatives can be utilised when there is a shortage of generating capacity. Load shifting can be described as moving demand from peak times to lesser demand times [24]. Energy efficiency can be defined as uniformly reducing the demand curve, and interuptibility may be defined as reducing the demand curve at a specific time by shutting down a large energy consumer.

Eskom's DSM programme is aimed at reducing the national peak power demand, thereby postponing the immediate need for additional power generation capacity [26]. Load shifting, EE and interruptibility are therefore utilised in South Africa to achieve this aim.

b) Advantages of DSM

The key benefit of DSM is efficient use of electricity, without influencing the customer's production and satisfaction levels [21]. This also results in large cost savings for the provider as well as for the customer. Tariff decreases and savings on transmission and distribution networks are subsequently possible.

A few other advantages of DSM are:

- DSM initiatives can be implemented quickly.
- DSM results can be generated at low cost compared to the capital required for constructing new power stations.
- DSM reduces electricity grid congestion and thus increases the system's reliability.
- DSM is a possible method of meeting the regulations of the Kyoto Protocol for green house gas emissions [28].

To summarise, DSM encompasses economic, environmental and system reliability advantages.

c) Implementing DSM in South Africa

Since their formal recognition of DSM, Eskom has spearheaded many DSM initiatives, continuing to lead the way in promoting the efficient use of electricity on the African continent [21]. Of the R107 billion required for meeting South Africa's energy requirements, Eskom will invest R84 billion overall [6].

In 2004, the Department of Minerals and Energy (DME) set a target for a reduction in energy demand by 14% during the next eight years, relative to a reference scenario [16]. This was seen as a summons to all industries to start working together on DSM.

Currently all major industries are taking part in various DSM initiatives with the help of energy services companies (ESCos).

d) ESCos

Eskom has adopted the ESCo methodology to implement DSM strategies [4]. ESCos are private companies that help utilities and consumers all around the world to realise DSM goals [29].

Eskom, as the national utility, finance all DSM projects by channelling the funds through the ESCo industry. The amount of funding depends on the type of DSM project and the amount of energy that can be saved on a project. These funding programmes have played a major role in creating and supporting the ESCo industry, and will help South Africa into an energy-efficient future [30].

Eskom's CEO, Mr Thulani Gcabashe, said the following in his speech at the official opening of EE month in May 2005: "ESCos play an important role in implementing EE. International experience has indicated that it is imperative to have a strong infrastructure in the private sector for effective delivery of EE-DSM programmes." [31].

In 2004 there were already 80 registered ESCos in SA, realising demand reductions of 187,2 MW [4]. The target with DSM is to create and maintain an annual decrease of 153 MW of demand with the help of ESCos.

1.1.4 Electrical load shifting

Due to South Africa's large demand peaks, the DSM concept of electrical load shifting is the perfect DSM initiative to reduce these peaks as much as possible in the shortest time available. The concept of load shifting has already been touched upon in *section 1.1.3*, but will now be discussed in more detail.

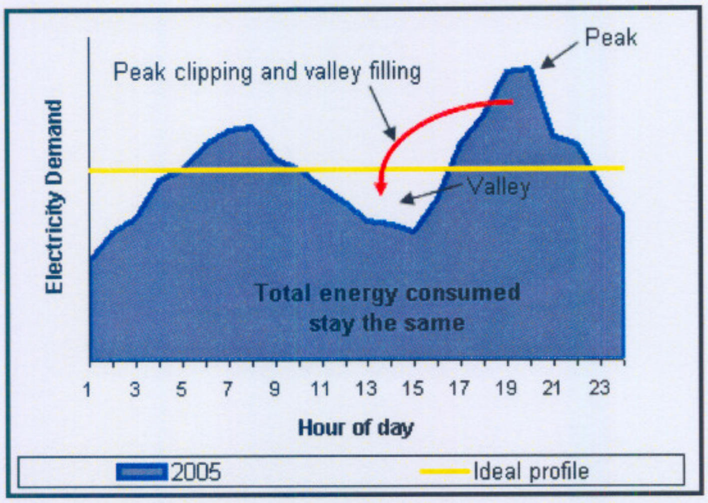


Figure 1-11: Principles of peak clipping and valley filling

The concept of load shifting can be described in more detail by the principles of peak clipping and valley filling as shown in *Figure 1-11*. The blue area depicts a typical electricity demand profile in South Africa. By rescheduling the use of electrical load, the profile can be adjusted to the yellow line and a uniform state. Thereby the peaks are removed and the valleys filled. The importance of these principles is that the total energy consumption does not change. The product output of the consumer therefore stays unchanged.

With the DSM initiative of electrical load shifting, the main aim is to move energy demand from peak periods to off-peak periods during the same day. The ideal load-shifting profile for any load is shown in *figure 1-12*.

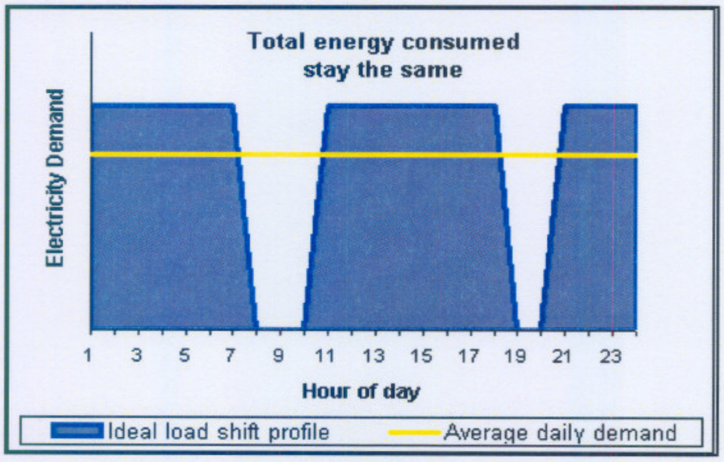


Figure 1-12: Ideal load-shifting profile

The aim of shifting as much energy as possible out of peak time and into off-peak times is shown by the blue area. The yellow line illustrates the average daily electricity consumption that remains unchanged.

1.2 Mining in South Africa

1.2.1 Background

As stated earlier, the origins of the South African ESI were driven by the needs of the booming early mining industry [2]. The discovery of diamonds and gold towards the end of the nineteenth century fundamentally changed the history of South Africa's economy and became the start of the long dominance of mining in the country's industry [14].

The industrial and mining sectors are the biggest electricity consumers in South Africa, accounting for more than two thirds of the national electricity usage [4]. In 2000 mining was one of the largest consumers of energy in the industrial sector, utilising 11,4% of the total energy and 29% of the total electricity consumption [14]. The influence of the industrial sector on the daily South African demand profile is illustrated in *Figure 1-13.*

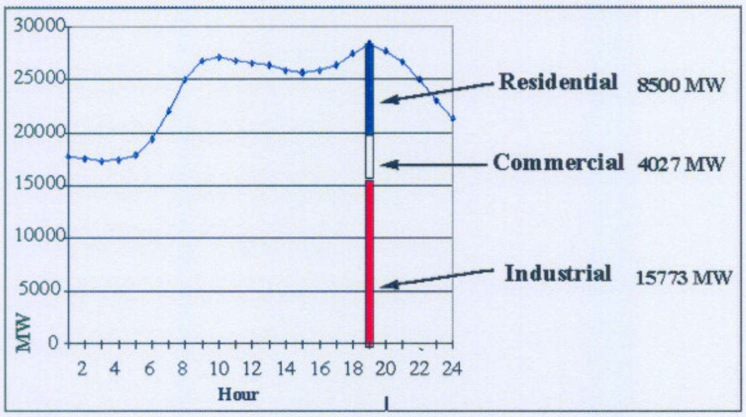


Figure 1-13: Demand profile for different sectors [7]

During 1999 mining consumed 31,352 GW/h or 18,4% of the electricity sold in South Africa [32]. Statistics supplied by the National Electricity Regulator of South Africa (NERSA) for 1999 revealed that there were 1 039 mining electricity consumers in South Africa. With such a large demand in mining, it is clear that there exists a large potential for employing DSM strategies [4]. In line with the targets set out in the South African EE strategy, the local mining industry also has to reduce its energy demand by 10%-15% by 2015, which signifies the need for these strategies to be implemented promptly [33].

Electricity is a major energy source for all forms of mining and is used in various applications such as transportation of personnel, material and ore, production machinery and processing of minerals. It is also used for critical health and safety operations in deep gold mines, such as water pumping, ventilation and cooling which constitute a large part of the mine's total energy consumption.

1.2.2 Old gold mines – large electricity consumers

The attractive colour, bright lustre and high malleability and durability of gold has endeared it to humans throughout history [34]. Since the origin of mining in South Africa, there have been many additions and expansions to the mining industry due to the large quantities of natural resources and precious metals found in this country.

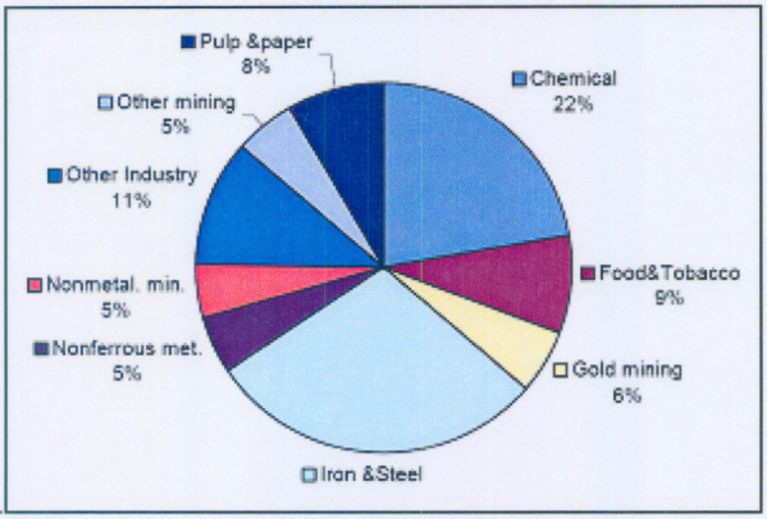


Figure 1-14: Industrial energy demand per sector

With the increase in establishing different mining industries, the percentage of electricity used for gold mining has, however, declined in respect of the total amount of electricity used by mining. Gold mining nevertheless still uses more energy than all other types of mining put together, as illustrated in *Figure 1-14*. In 1996, gold mining still used 12% of the total amount of electricity consumed in South Africa [14].

During the 1990s industry analysts estimated that South Africa had produced more than 43 000 tons of gold during the past century, and that at least that amount still remained in underground reserves [35]. This initially pointed to a bright future for the industry.

Unfortunately, the gold mining industry in South Africa is currently on a steady decline owing to a number of reasons. The first reason is that the richest underground ore deposits have been worked through during the early years of the industry. As a result of weakening ore grades, increasing mine depths and the recent low gold price, it was impossible for the industry to show any signs of growth [36][37].

Added to this, most of the gold mines in South Africa are old. They use old, proven and energy-intensive mining methods. Due to the above-mentioned reasons, production levels of the mines remain of the highest priority, with limited capital being spent on upgrading and maintaining mining systems.

Electricity is also the exclusive power source for vital health and safety-related applications in gold mines, such as pumping of water, ventilation and refrigeration. In 1993, 15% of all electrical energy consumed in South Africa was used by deep-level gold mines [38]. In these extremely deep gold mines, these applications become exceedingly important and in some cases consume in excess of 55% of the total electricity used on a mine [6]. This electrical energy seems, however, not to be managed in any clearly defined way in the mining industry [39].

Currently the demand for energy in gold mining is still on a steady increase, as more energy is required to produce each ton of gold [4]. This warrants the development of a suitable strategy for energy management in the South African mining industry [39].

1.2.3 Water-pumping systems at gold mines

The mine environment is hostile to both machinery and men in the underground portion of the mine [40] and there is a strong reliance on electrical energy, which goes beyond mere production [39].

Some of the deepest mines in the world are found in South Africa, where gold is mined at depths of up to four kilometres [41]. Mining companies are forced to mine ever deeper since the shallower and more accessible gold deposits were mined out in the earlier days of gold mining in South Africa.

These depths present a host of operational problems, including ambient underground temperatures of 50 °C and more, occasional rock bursts, groundwater seepage and the ever present danger of flooding [41]. Massive water refrigeration systems are used to make working conditions possible at these depths. These large quantities of water together with the natural groundwater and mining water have to be pumped out of the mine's workings and back to surface on a daily basis [42].

Underground water pumping systems, consisting of massive high-pressure pumps, fulfil these pumping operations. The significance of these systems is that they are critical mining systems, which could influence production, or claim lives if their operation is halted or interrupted for extended periods. *Table 1-2* shows that the underground water pumping systems in typical gold mines consume 17,7 % of the mines' total electricity consumption.

Table 1-2: Energy consumption of gold mining systems[43]

Load End-user group	Energy Consumption as a % of total electricity bill
Ventilation system	4.1%
Fridge plant	3.8%
Underground water pumping system	17.7%
Compressed air system	21.3%
Underground mining system	18.9%
Mine winding system	14.2%
Mineral processing plant	13.7%
Hostels and essential services	6.3%

The importance of these systems to DSM is that the high-pressure pumps require massive electric motors to drive them, which are extremely energy intensive. By using a pump efficiency equation [44] it was calculated that 3,6 MW worth of electrical energy is required to pump a volume of 1 megalitre (Mℓ) from a depth of 1 km in an hour. This is at an efficiency of 75% with a well-maintained pump [45]. As was already mentioned, some mines in South Africa are 4 km deep and pump 20 Mℓ of water out of the mine on a daily basis. If it should be possible to manage this demand, massive energy savings can be realised.

1.2.4 Automatic load shifting through intelligent control

The principle of load shifting has already been discussed in *section 1.1.3*, therefore the application of load shifting on a water-pumping system will now be briefly discussed.

To schedule the pumping of a simple system is relatively easy. If a dam is overflowing, a pump is started. If the dam is almost empty, a pump is stopped. This means that by bringing a time scale into consideration, it would be possible to stop a pump during a certain time of the day. If this time happens to be during Eskom's peak demand period, it can be defined as load shifting. Load shifting on a pumping system can therefore be achieved by switching pumps off during Eskom's peak demand periods, and scheduling more pumping during off-peak periods.

Deep mines are, however, intricate systems, each having its own individual system constraints and preferences, which in turn complicate the manual scheduling of pumps. Although it is possible, it is usually not sustainable. An automatic system is therefore required to schedule the pumping.

The system must be able to take all of the system's constraints into account and schedule the pumping in such a way that it does not influence production levels. As pumping systems are critical life-sustaining equipment, the energy management strategies implemented by the system must take this into careful consideration to reduce chances of punitive legal action being brought against its implementer [39]. This means the system also has to be an intelligent system.

In a case study done in an Australian mine a 36% improvement in electrical energy efficiency was obtained. Critical to the success of the project was the use of a real-time measurement and load-forecasting system. Without such a system, the substantial savings at the mine would not have been realised. A successful electrical load management strategy in the South African mining industry would thus also benefit from the application of such a system [39].

1.3 Problem statement and objectives of study

In this study, research into real time energy management on old gold mines is done to determine the following:

a) *the potential for energy management on old gold mines*

b) *the potential for the implementation of sustainable energy management strategies on old gold mines*

c) *the challenges associated with the implementation of energy management strategies on old gold mines*

d) *the feasibility of implementing energy management strategies on old gold mines*

Three old gold mines are considered in studying these aspects.

1.4 A brief overview of the thesis

Chapter 1 gives an introduction to the dissertation. Eskom's electricity supply problem is outlined and the influence of the mining industry and specifically the gold mining industry on the South African ESI is discussed. Thereafter DSM, through automatic load shifting on mine water pumping systems, is proposed as a temporary remedy for the supply problem.

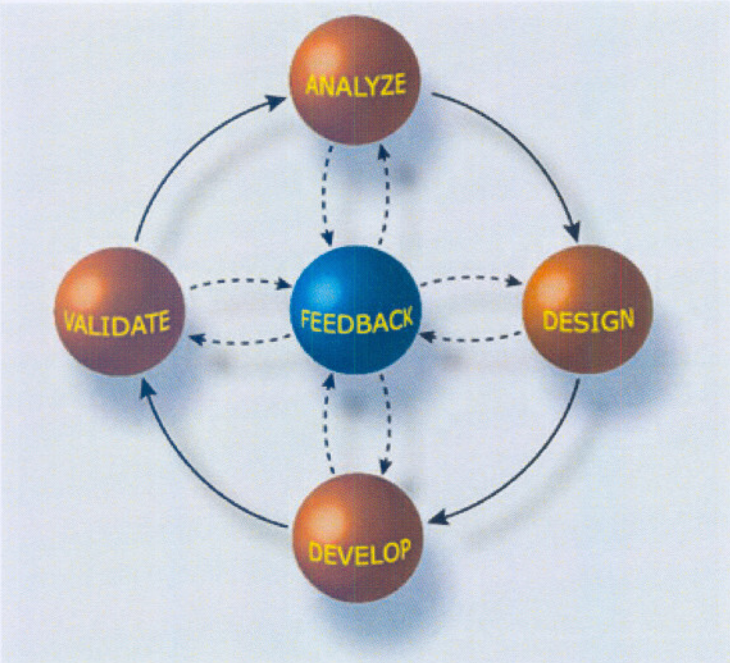
In Chapter 2 the theory of investigating DSM potential is discussed. Simulation is outlined as the method by which load-shifting potential will be evaluated in the study and the process is discussed in much detail.

In Chapter 3 three mines are identified as potential DSM candidates to be used in this study. All of these mines conform to the criteria for being old gold mines. The process discussed in chapter 2 is used to analyse the load-shifting potential of the water-pumping systems on these mines.

In Chapter 4 the results of the real-time load-shifting strategies as implemented on the real-life systems are discussed. The results are also compared to the simulated results found in chapter 3.

Chapter 5 concludes this dissertation by summarising all conclusions reached regarding the objectives of the study.

2. METHODOLOGY



In this chapter the processes that will be used during the investigation of the load-shifting potential on water-pumping systems is discussed in detail. The approach followed to implement load-shifting strategies on real mine systems is also discussed.

2.1 Introduction

The most important part of successfully implementing a DSM load-shifting strategy on a mine is to establish the savings potential of the particular system. One of the methods to investigate load-shift savings potential is through the use of integrated simulations. To be able to complete the integrated simulations of such a project, the steps outlined below must be followed.

The first step is to analyse the system to obtain all system characteristics, and then to construct a theoretical model according to these system characteristics. Following this, the simulation model can be constructed by incorporating the mathematical model of each system component into the theoretical model.

The simulation model also has to be verified and validated to test whether it is an accurate representation of the real-life pumping system. This is a necessary step before the results of the simulation model can be used to estimate the savings potential of the system.

If a feasible amount of potential exists, it will be possible for the ESCo who completed the investigation to implement the project. The implementation of the project consists of investigating automation infrastructure requirements, submitting a project proposal to Eskom, and physically implementing the project if the proposal is approved. Although the project proposal is a process of many steps, it is of little importance to this study and will not be discussed. This also applies to the physical implementation of the project.

Finally, the results of the implemented strategy must be verified and validated against the results generated in the simulation models to successfully complete the project.

2.2 *System analysis*

2.2.1 Baseline acquisition

The analysis of a pumping system starts by examining the system's electricity usage for a certain period. As most industries operate on a day-to-day basis, this period is divided into 24-hour increments, allowing the average usage profile to be presented by a single 24-hour profile. In electrical energy, the system's electricity usage is characterised in kilowatt-hours (kWh). This refers to the integrated kW usage within a single hour.

There are three main methods of analysing the electricity usage of a pumping system, namely by using (a) paper log sheets, (b) a supervisory control and data acquisition (SCADA) system, or (c) data logging equipment.

Option (a) is present in even the most modern of mines. The paper sheets are used to log the pump motor's running time statistics and are stored for reference. Although the system is very old, it is reliable.

Option (b) is mostly present on relatively new mines only and is used as a representation of all the processes inside the mine. Depending on the complexity of the SCADA, these systems can give second-by-second representations of the processes in the mine, including that of the pumping system. With both these options, the pump's running time statistics can be multiplied by the motor's kW rating to acquire a daily kWh profile.

Option (c) is used when neither of the above-mentioned options are available. Data loggers have to be installed on the electrical feeders that provide electricity solely to the pumping system. This method is the most accurate and a true kWh profile for each day can be acquired. It is, however, an expensive and time-consuming option.

When all the raw data for pump running times have been obtained, a baseline for the pumping system can be calculated. A typical baseline for a mine is that of AngloGold Ashanti's Mponeng mine, as depicted in *Figure* 2-1.

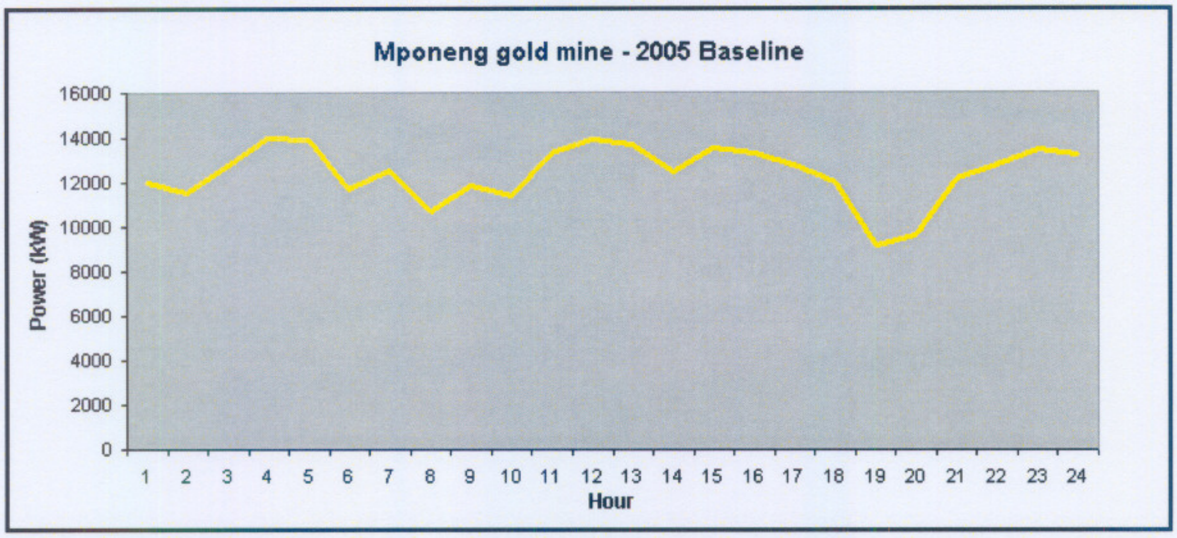


Figure 2-1: Typical daily energy usage profile of a mine pumping system

A quick estimation of load-shifting potential can be made by analysing the demand values of a profile during peak periods. The profile in the upper figure shows that as much as 10 MW can be shifted out of the morning peak period and as much as 9 MW can be shifted out of the evening peak period. The assumption can therefore be made that the system has a large potential for load shifting.

To obtain a realistic profile, an extensive amount of data must be analysed. This is because the quantities of water utilised in a mine is greatly influenced by seasonal changes as well as changes in production levels. Less mine cooling is required during winter, and therefore less water is required underground, whereas when production increases, more water is required underground for mining operations. Wintertime is recognised by Eskom as high demand season and summertime as the low demand season.

To counteract the effect of seasonal changes, sufficient data must be collected to calculate a separate baseline for winter and summer. The average baseline can then be calculated by the summation of the winter baseline multiplied by 3/12 and the summer baseline multiplied by 9/12. This is as the months of June, July and August are regarded as high demand season, while the rest of the year is regarded as low demand season [15].

2.2.2 Obtaining system characteristics

In addition to gathering information regarding the system's electricity usage baseline, the physical characteristics of the system have to be obtained together with the characteristic of all the factors that influence the system. The detail of the specific characteristics required for the study will be discussed in the next two sections.

2.3 Constructing theoretical models

All theoretical and scientific studies of a situation are centred around a model [46]. When engineers analyse a system, they often use mathematical models [47] since these provide the most accurate predictions of system behaviour [48]. A model may be defined as a simplified version of a real-world system that approximately simulates the relevant responses of the real-world system [49].

The first step in a modelling process is to construct a conceptual model consisting of a set of assumptions that describes the system's characteristics. A conceptual model is basically a simplistic verbal representation of a system. As real-world systems are mostly very complex, relevant assumptions must be made to simplify the system.

This is done through the analysis of all of the system's characteristics. This is a very important process, since oversimplification may lead to a model that lacks important information. Contrary to this, under simplification may lead to a model that requires more data than can be obtained [49].

A very simplified conceptual model of a pumping system can be described by examining the following figure:

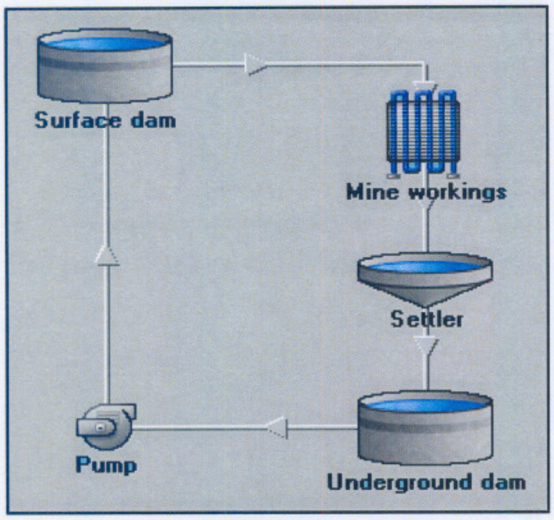


Figure 2-2: Simplistic conceptual model of a mine's pumping system

In a mine, water is used for various mining operations. After use, the water collects in settlers, from where it flows downwards into the underground dam. The water is pumped out of the dam to the surface dam. The cycle is completed when the water from the surface dam is once again used underground. Several assumptions were made to simplify the model so far, but in reality, there are many more variables required to give a realistic representation of the real system.

The next step in the modelling process is to express the conceptual model in mathematical form by structuring the mathematical models for each individual system component in a sequential form. The response of this model must then yield the predicted response of the conceptual model in reply to certain input variables.

Unlike the conceptual model, all input to the system are modelled and variables such as fissure water inflow and motor efficiency must also be considered. The main components of any pumping system are the dams and the pumps.

The characteristics of the components that are required are the following:

- inflow of water into each dam, from the settlers, for a 24-hour profile
- volume of water that each pump can pump, in litre per second (ℓ/s)

- 24-hour electricity demand profile of the system
- maximum and minimum dam level limit values
- maximum number of pumps that can be run simultaneously on pump station
- capacity of the dam and pump motor ratings
- maximum demand the system may produce
- friction losses induced in the columns
- losses induced by the column head
- efficiency of the pump motor
- efficiency of the pump

As water is pumped by an underground water-pumping system, water flow is the most important input variable in the mathematical representation of the theoretical model. By further utilising the system constraints and control strategies, assumptions can be made to once again simplify the model. Finally, as this is an energy management study, the output of the model has to be the energy used to cycle the water through the system.

On completion of the modelling, the model can be used in integrated simulations to estimate the load shifting or DSM potential of the system. This concept is discussed in the next section.

2.4 Integrated simulations

Modelling and simulation play an important role in modern life by contributing to our understanding of worldly systems and are essential to the effective design, evaluation and operation of new products and systems [50].

Simulation is a very powerful tool used by most engineers and many other professions all over the world. As modelling is used to set up a realistic model of a system, simulations are also used to test a model's correctness, and finally to make important decisions. Surveys have shown that simulation is the most widely and quantitative modelling technique employed as a system analysis tool by industry and the government in the USA [43].

There are various methods of doing a simulation and many packages available to aid in this process. Most mathematical packages such as Matlab and Microsoft Excel are capable of the process. Another capable package is a new technology that has been developed by TEMMI (Pty.)(Ltd.), named Real-time Energy Management System (REMS). It is an end-user system control package that is utilised on mines to optimise automatic load shifting. Also built into the package is a functional simulation tool, the REMS simulator that will be utilised during this study.

As the simulations during this study will only be performed to evaluate load-shifting potential, assumptions can be made regarding many system constraints as a method of simplifying the simulation. In more precise simulations, the number of assumptions must be kept as low as possible to enhance the credibility of the simulation results

The simulations in this study will be done in Microsoft Excel and REMS simulator by considering the following system characteristics:

The reduced input to the system:

- flow into each dam from the settlers in the mine
- Eskom's electricity tariff per hour

The reduced system constraints used:

- maximum/minimum number of pumps allowed to run per pump station
- maximum/minimum allowable levels for all dams
- capacities of the dam
- maximum electricity demand allowed for the system
- volume of water in the system
- total energy usage for the load-shifting optimised profile must be equal to the total energy usage of the baseline.

The reduced number of variables:

- number of pumps running on a pump station

- amount of flow generated by the pumps into the dams.

The output of the simulation is then the kW usage for the system over a 24-hour period.

Some of the assumptions made in these simulations are that the efficiency of the pump motors, the friction losses and losses due to the amount of head in the columns are modelled inside the flow rate produced by the pump.

As seasons have an impact on the water usage of a water-pumping system, this fact must be taken into account during the simulation process. The reduced water consumption is because less mine cooling is required during winter. Two separate models are, however, not required since this factor can be remedied by scaling the baseline according to the total amount of electrical energy used in a day. This process is known as normalisation and is discussed in *section 2.6*.

2.5 Verification and validation of models

From the earliest days of modelling and simulation, model developers have been concerned with the accuracy of the model and the simulation and the credibility of their results. These concerns are still justified as modelling and simulation provide vital information for decisions and actions in many areas of business and government.

A dynamic simulation is required to ensure that neither the safety of mine personnel nor the mine's production are compromised by any load control strategy [39]. To ensure the correctness and reliability of a simulation or model, verification and validation of the model are required.

a) Verification

During the verification process, the questions should be asked whether the simulation model was built correctly and according to the specification of the conceptual model, and whether it fully satisfies the developer's intent.

For the purposes of this study, the verification process can be performed by analysing the response of the simulation model to certain inputs and comparing it to the response of the real mine system with the same inputs. If the simulation model responds within the system constraints and the system characteristics remain the same, the simulation model can be regarded as verified.

b) Validation

During the validation of a model, the questions should be asked whether the correct model was built and whether the model and simulation will be able to support its intended use.

To simplify the validation process it can be divided into two concepts: (a) conceptual validation, when the assessment is made whether the model is a valid representation of the real system [46], and (b) results validation, when the simulation results are compared with the real system results to demonstrate that the model or simulation can support its intended use [43].

The conceptual validation can be done on the simulation, but the results validation as described will only be completed later in the process after the real system results are available.

In reality, it is impossible for a simulation model to be an exact representation of a real-life system. With the validation process, it can be reduced to a valid representation. By comparing the response of each system component to the mathematical model of the component, the conceptual validation can be done. In this way, the validation of the simulation can be used to increase the confidence in the model accuracy.

There have been many paradigms on the relationships among verification and validation activities during model and simulation development. One such paradigm, depicted in *Figure 2-3*, is called the Sargent circle and was named after its creator. This was created as a verification and validation guide for engineers and model builders.

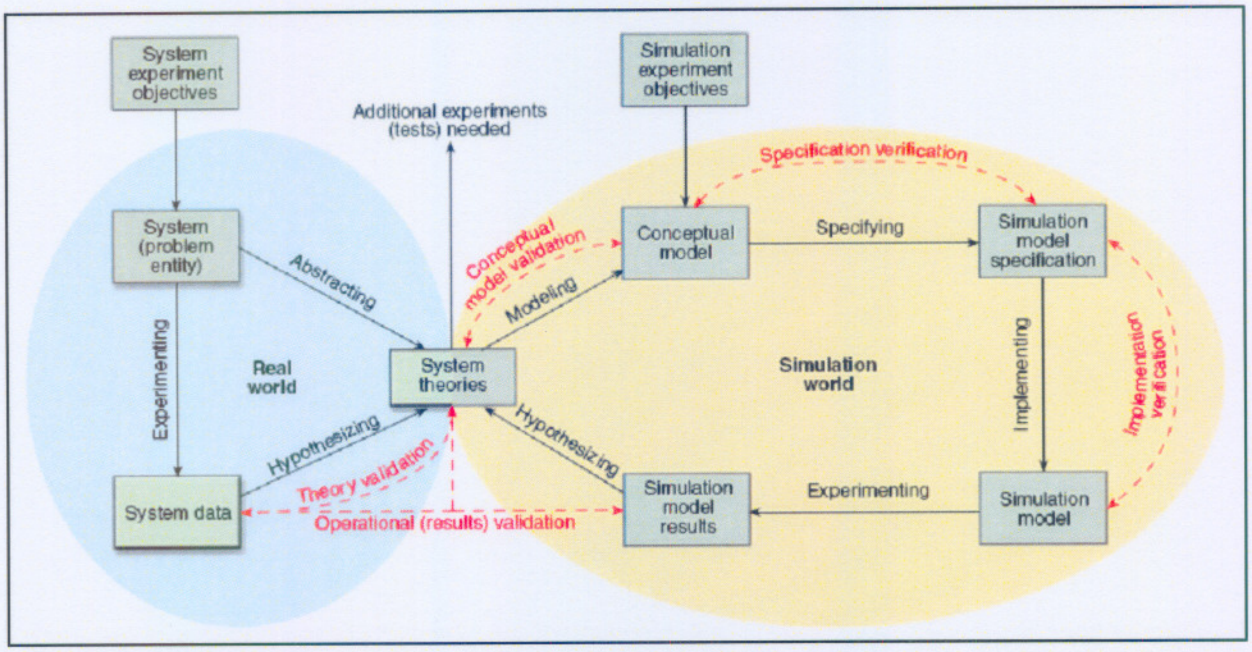


Figure 2-3: Sargent circle as utilised during model verification and validation [43]

By repetitive use of the simulation model in real-time applications confidence in the simulation can be built up to the point where the modeller is happy that the results can be used for decision-making purposes [46].

2.6 Calculating savings potential

2.6.1 Normalising baselines

As was previously mentioned, the energy usage for a pumping system changes daily. This is due to system influences that change continually throughout each day.

For this reason, the energy profile for a day may be much different from the baseline energy profile, in regard to total energy usage. This may in the end influence the performance of an energy management strategy. Such a difference in energy usage is illustrated in *Figure 2-4*.

To be able to compare the two profiles in any regard, one of them has to be normalised (adjusted) so that the total energy usage of both profiles are equal. The baseline becomes the normalised profile so that the performance of the system can be evaluated with regard to the amount of energy used during each specific day and with all system changes taken into account.

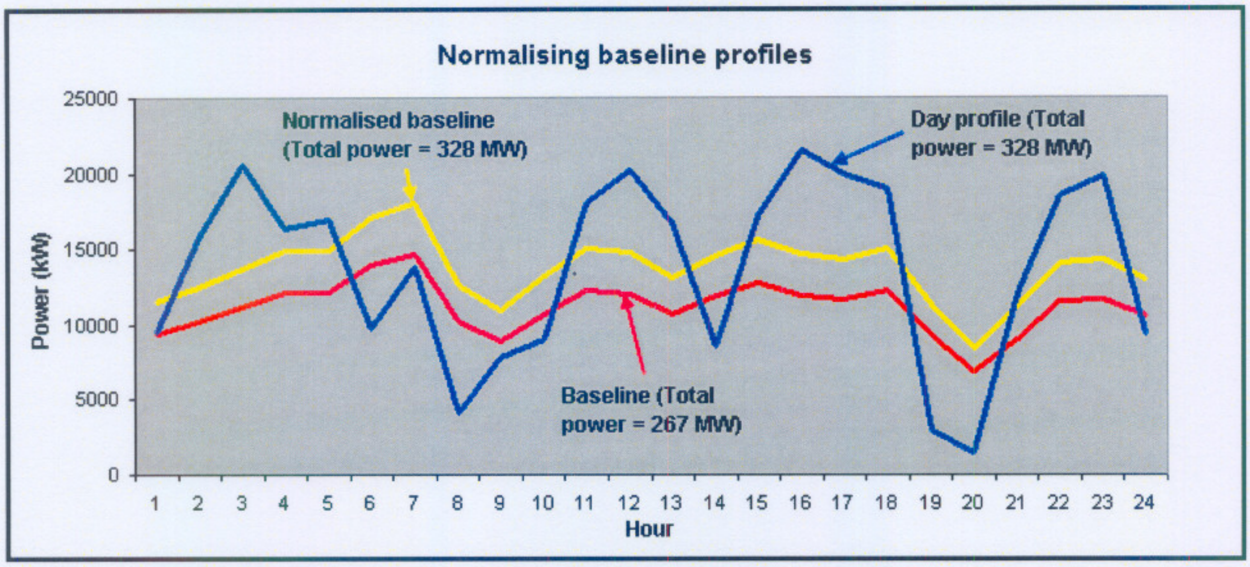


Figure 2-4: Example of baseline normalising

The method of normalising the baseline can be explained by the following equation:

$$Normalised\ baseline\ profile_{Hour(i)} = (Total\ energy_{Day\,Profile} \div Total\ energy_{Baseline}) \times baseline\ profile_{Hour(i)}$$

The total power consumption for the normalised baseline and the day profile are equal and can therefore be compared. This principle is, however, only required during the calculation of real-system savings results. This is as it is a simulation constraint for the total power consumption of the optimised profile to be equal to the total power consumption of the baseline profile.

2.6.2 Calculating load-shifting savings potential

Once the optimised profile of a system has been established through the simulation process, it is relatively easy to calculate the load-shifting savings potential of a system. The result of such a simulation is shown in *Figure 2-5*.

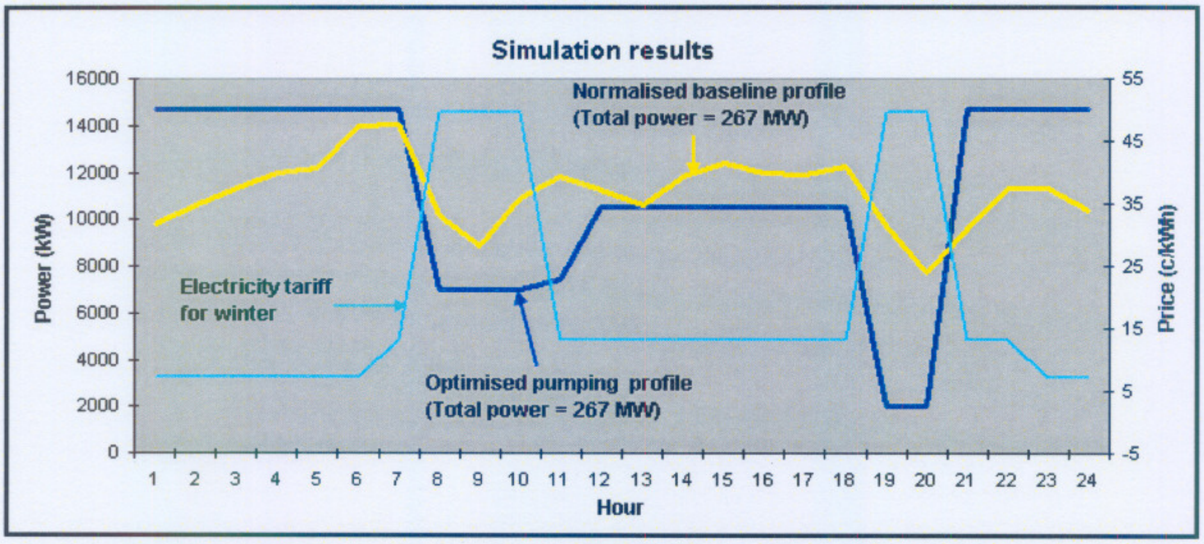


Figure 2-5: Possible results of simulation

For the purpose of this explanation, the load-shifting potential can be calculated by subtracting the peak period values of the optimised profile in the figure from the corresponding values of the normalised baseline profile. The potential for each individual peak period can be calculated in this manner.

Table 2-1: Calculating morning and evening load-shifting potential

Hour	Optimised profile (kW)	Normalised baseline (kW)	Difference (kW)
8	7000	10156	3156
9	7000	8853	1853
10	7000	10876	3876
Morning load shift potential =			2962
19	2000	9703	7703
20	2000	7724	5724
Evening load shift potential =			6713

The calculation of the load-shifting potential from the results shown in *Figure 2-5* is demonstrated in *Table 2-1*. In the table the values of the peak periods of the optimised profile are subtracted from the corresponding values of the normalised baseline. The averages of the values are then calculated, depending on the specific peak period. This same process is followed during the calculation of real system savings.

2.6.3 Calculating financial savings potential

By utilising the optimised profile from the simulation or from the real system results, the estimated savings for a client can be calculated. This process is illustrated in *Table 2-2*.

Table 2-2: Calculation of estimated Megaflex savings during summer

Optimised profile (kW)	Baseline (kW)	Normalised baseline (kW)		Hour	Weekday Price (c/kWh)	Saturday Price (c/kWh)	Sunday Price (c/kWh)	Average weekly price (c/kWh)		Savings/ hour (c/kWh)
14700	9295	9773		1	6.20	6.20	6.20	6.20		-30546.41
14700	10103	10623		2	6.20	6.20	6.20	6.20		-25275.30
14700	10787	11342		3	6.20	6.20	6.20	6.20		-20817.20
14700	11356	11940		4	6.20	6.20	6.20	6.20		-17112.52
14700	11580	12176		5	6.20	6.20	6.20	6.20		-15651.32
14700	13281	13965		6	6.20	6.20	6.20	6.20		-4558.70
14700	13364	14051		7	8.75	6.20	6.20	8.02		-5202.74
7000	9659	10156		8	14.10	8.75	6.20	12.21		38528.08
7000	8420	8853		9	14.10	8.75	6.20	12.21		22623.29
7000	10344	10876		10	14.10	8.75	6.20	12.21		47316.59
7439	11212	11789		11	8.75	8.75	6.20	8.39		36473.03
10500	10706	11257		12	8.75	8.75	6.20	8.39		6346.04
10500	10049	10566		13	8.75	6.20	6.20	8.02		527.89
10500	11219	11797		14	8.75	6.20	6.20	8.02		10401.93
10500	11773	12379		15	8.75	6.20	6.20	8.02		15073.27
10500	11362	11947		16	8.75	6.20	6.20	8.02		11603.20
10500	11280	11860		17	8.75	6.20	6.20	8.02		10911.59
10500	11669	12269		18	8.75	6.20	6.20	8.02		14193.70
2000	9228	9703		19	14.10	8.75	6.20	12.21		94028.10
2000	7346	7724		20	14.10	8.75	6.20	12.21		69870.22
14700	9087	9555		21	8.75	6.20	6.20	8.02		-41269.79
14700	10738	11291		22	8.75	6.20	6.20	8.02		-27348.54
14700	10795	11350		23	6.20	6.20	6.20	6.20		-20768.77
14700	9889	10397		24	6.20	6.20	6.20	6.20		-26675.96
267639	254541	267639		Summer			Savings per day			R 1,426.70
Factor	1.05						Savings per month			R 42,800.90

First the Eskom Megaflex tariffs for the applicable season are entered into a sheet, as shown in the table. The historical electricity demand baseline for the given system as well as the load-shifting optimised profile for the system are also inserted into the same sheet.

The process to normalise the baseline according to the total energy usage of the optimised profile was already discussed earlier, and is utilised during the calculation of the financial savings and the financial savings potential.

To calculate the estimated savings that could be realised if the system performed according to the optimised profile, the electricity usage per hour for the simulated profile is subtracted from the corresponding value of the normalised baseline and multiplied by the average price for that hour. The total savings per day is then calculated at the bottom of the table.

These calculations have to be done in respect to the applicable season, which influences the amount of savings. The total estimated savings for a year can be calculated by multiplying the daily savings by the number of days in a month and then by the number of winter or summer months in the year. With Eskom Megaflex tarrifs for South Africa, calculations are done with three winter months and nine summer months [15].

2.7 Implementation

After the theoretical work has been completed and the potential for load shifting has been attained, a feasibility study has to be done on the respective investigated system. Although a large potential may sometimes exist, this will not ensure the feasibility of such a project on a mine. This is because the infrastructure that will be required to maintain sustainable load management has a major influence.

As most underground water reticulation systems are usually very complicated, it is difficult to shift a sustainable amount of load manually. Therefore infrastructure has to be installed to automate the load-shifting process. An energy management strategy that makes a mine operationally more efficient should not, as a result of the implementation of that strategy, cause the mine to become less safe [39].

The focus of sustainable load shifting must therefore be on automated real-time management. All actions performed in a system must consider all system constraints, characteristics and the implications of the actions. Therefore a real-time system is required that is able to analyse the main system characteristics and control the system within its original constraints so as not to influence the system negatively by load shifting.

Full automatic control of any system entails the centralised control of the system without any human intervention. As was already stated, this can be arrived at by automation of the system. To automate a pumping system there are various requirements. These are: (a) pump automation equipment for automatic switching, (b) various monitoring instrumentation, and (c) a centralised supervisory control system.

a) Pump automation equipment

A high-pressure water pump inside a mine is regarded as a unit; therefore a pump as named in this dissertation actually consists of the pump motor, the pump, the control system and the pump valves.

To automate a pump, instrumentation first has to be installed to monitor all of the characteristics of the motor and pump. Secondly, control infrastructure must be installed for each individual pump. Most of the time this involves programmable logic controller (PLC) control, as this is the only way of acquiring automated control. Thirdly, the valves of the pump have to be automated as required.

b) Monitoring equipment

Although monitoring equipment has already been mentioned in the previous section, this monitoring equipment entails the equipment that is not focused on an individual pump, such as the dam level sensors and column pressure sensors.

c) Supervisory control system

Thirdly, a central supervisory control system such as a SCADA system must be installed and connected to each pump through fibre-optic cable or instrumentation cable. It has been shown that the integration of technological tools such as an energy management system and the SCADA system would greatly improve the successful sustainability of a load management system [39].

Most new mines already have much of the infrastructure required for automatic load shifting. This greatly simplifies the implementation of a possible strategy, as the lower the infrastructure requirements, the faster the implementation can be followed through.

On mines that have none of the required infrastructure, it has to be installed to make a load-shifting philosophy possible. This usually acts as a major pulling factor since a mine can receive most of the infrastructure free due to DSM capital funding from Eskom.

2.8 Validation and verification of implemented system results

As was already mentioned, the verification and validation of processes are very important in modern life. For the particular application of real-life system results, it is equally important and is used to ensure that decisions based on the investigations are always correct.

The verification of the real system results are done to ensure that the ESCo performs according to the values proposed to Eskom. There are companies known as measurement and verification companies that are also employed by Eskom and verify the results generated by the implemented systems.

Except for the formal verification of the implemented results, the real system results also have to be validated according to the generated simulation results. This is called the results validation as mentioned in *section 2.5.*

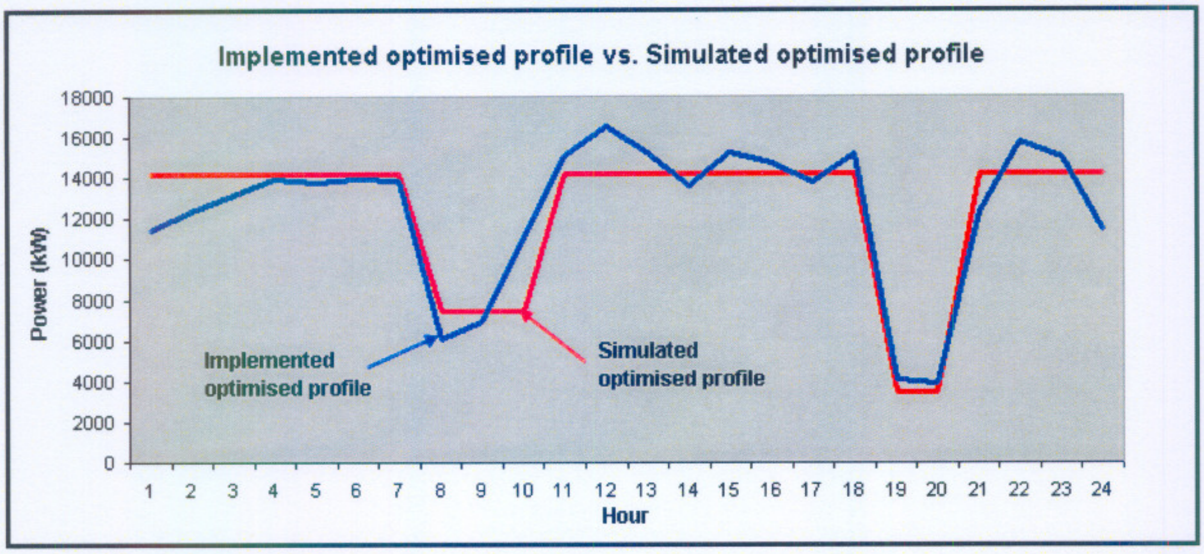


Figure 2-6: Comparison between simulated and implemented results

This process is completed in this study by comparing the results from the simulation profile to the results of the real-time implemented strategy. If the results correspond, the conceptual model and simulation model work can be seen as correct, and the simulation can be used in further studies. In this way it is shown that the simulation supports its intended use and the results generated by the simulation are true and viable to be used for decision-making purposes.

2.9 Conclusion

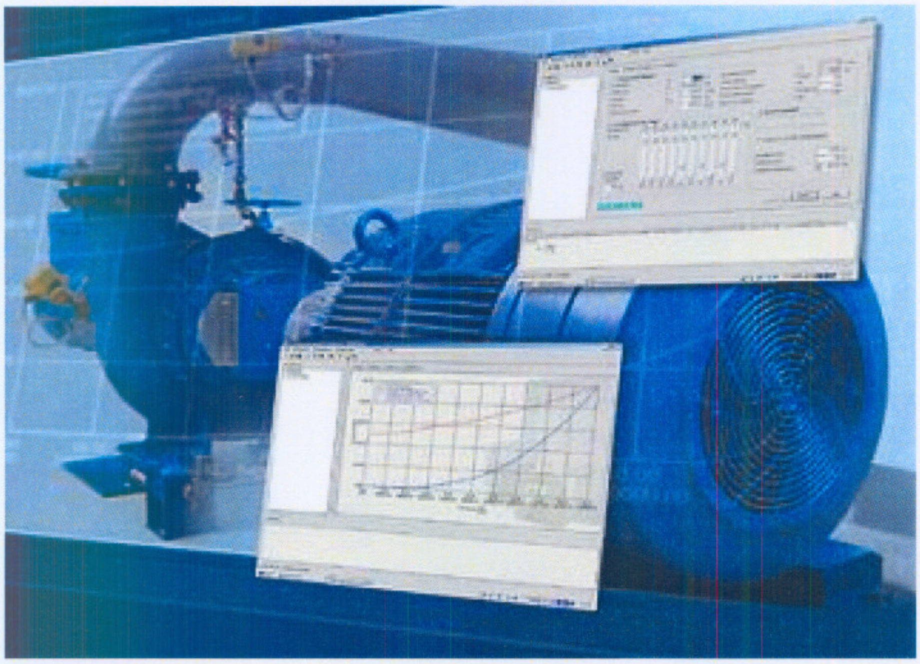
The methods of investigating load-shifting potential on old mines are of great importance to this study and are summarised in the following points:

Firstly, the entire system under investigation is analysed and all system characteristics are acquired from the mine. From this data the baseline energy usage profile and the conceptual model of the system can be prepared. The conceptual model can then be transformed into a system simulation by using the mathematical models for each particular system component.

Once the system simulation has been constructed, it must be verified and validated by comparing the simulation results to real system behaviour. After this, the simulation model can be used to calculate the load-shifting potential, by optimising the pump scheduling. By using the optimised profile, the estimated financial cost savings can also be calculated very easily and be used in project proposals to the client.

The feasibility of such a project not only relies on the load-shifting potential, but also on other factors. Because of the intricate systems used on mines, an automatic load-shifting system is required for ultimate project sustainability. The system must be able to optimise pumping according to real-time data and system characteristics. For an automatic system to control a system, all of the system components have to be automated.

3. SIMULATING SAVINGS POTENTIAL



In this chapter the load-shifting potential and financial savings potential for three different underground water-pumping systems are determined by following the processes outlined in chapter 2. Conclusions are made regarding the potential for implementing the strategies on the real systems.

3.1 Introduction

The South African gold-mining industry has always been one of the largest industries in terms of energy usage in the country. This industry has, however, dwindled due to low ore grades and an extremely low gold price in comparison with earlier periods.This has caused many mines to minimise production, which in turn reduced the electricity usage and the potential for DSM projects.

Since the start of gold mining in South Africa the focus of most mines have naturally reverted to maximum production levels. With the low cost of electricity and the steady drop in the gold price since the sixties, the mindset remained that energy-saving strategies would influence production levels negatively.

For this reason there exists massive energy savings potential on most gold mines and especially on old gold mines, as the old and proven technologies from the past are mostly very much energy intensive. The focus of this study is therefore to research real-time energy management strategies on old gold mines.

Three mines will be investigated in this study. These are Harmony Gold's Harmony 3 shaft (Harmony 3#) mine, Anglogold Ashanti's Tau Tona mine and Goldfields' Beatrix mine. (All of the above are subscribers to the Eskom Megaflex tariff, which promotes and increases the potential for financial savings resulting from energy-saving strategies.)

3.2 Case study 1 – Harmony 3# mine

3.2.1 Background

Harmony 3# is situated near the town of Virginia in South Africa. It is owned by Harmony (Pty.)(Ltd.) (Harmony) and is utilised primarily as a water-pumping shaft. The headgear of Harmony 3# is shown in *Figure 3-1*.

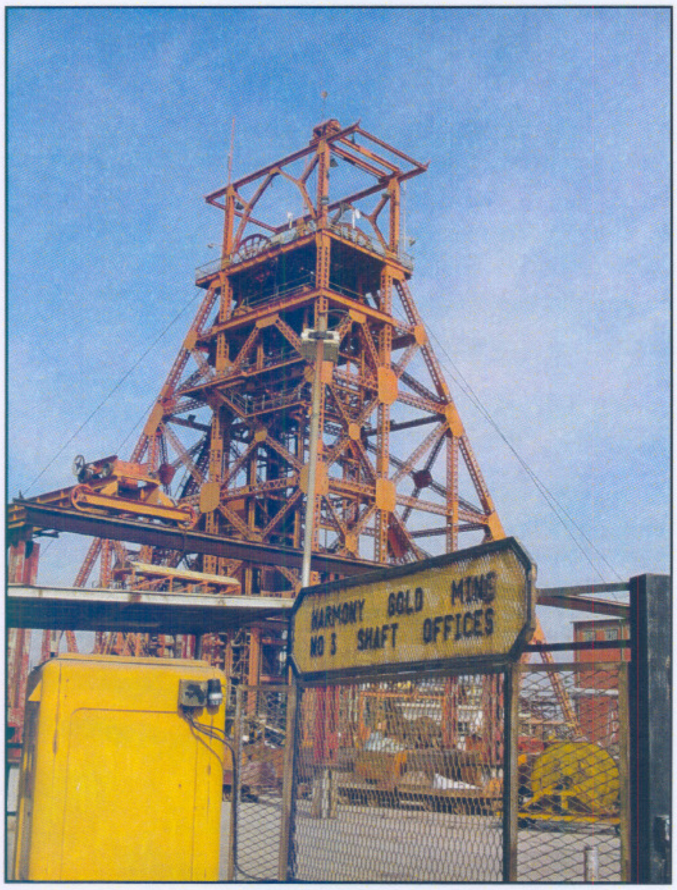


Figure 3-1: Harmony 3# headgear at site of mine

Harmony 3# is a very old mine and was part of the original Harmony owned mines established before 1950. During the past few years, Harmony has purchased most of the mines situated in the region around Welkom and Virginia.

As a measure of reducing the cost of water pumping operations Harmony 3#, together with Masimong 4#, were assigned to pump the water of much of the region. The reason for this was that these two mines already had the water-pumping infrastructure in place.

3.2.2 System analysis

a) Analysing system characteristics

Harmony 3# mine is a special type of gold mine. The mine is primarily utilised as a water pumping shaft. No major mining operations take place on the mine except for a small amount to cover the operational cost of the shaft. In addition, the adjacent Harmony 2# is interconnected with Harmony 3#, allowing the reef to be extracted there.

Harmony 3# pumps water that is utilised by Merriespruit 1#, Merriespruit 3# and Harmony 2#, as well as the region's groundwater to the surface. The Masimong 4# and 5# operations are also dependent on the pumping operations of Harmony 3# since the underground water table between these mines is interconnected. This means that if Harmony 3# were to stop pumping, Masimong 4#, Masimong 5#, Merriespruit 1#, Merriespruit 3# and Harmony 2# would be flooded, causing major repercussions for the production side of the mine. This highlights the importance of this shaft's continuing operation.

The pumping system at Harmony 3# consists of two main pumping stations: (a) 4/3 pump station situated on level 4 (4L), and (b) 14B pump station situated on level 27 (27L). There are also sub-pump stations on 27L and 29L that feed the settlers on 25L. As in all mines, the collected water flows to a central point, which in this case is the main pumping system settlers on 25L. From there it flows into the return water dams on 26L.

At present, the pumping system at Harmony 3# pumps 18 megalitre (Mℓ) water on average out of the 26L dams a rate of 62 ℓ/s, throughout the day. This water ends up in the dams situated on 4L, from where it is again displaced to the surface dam.

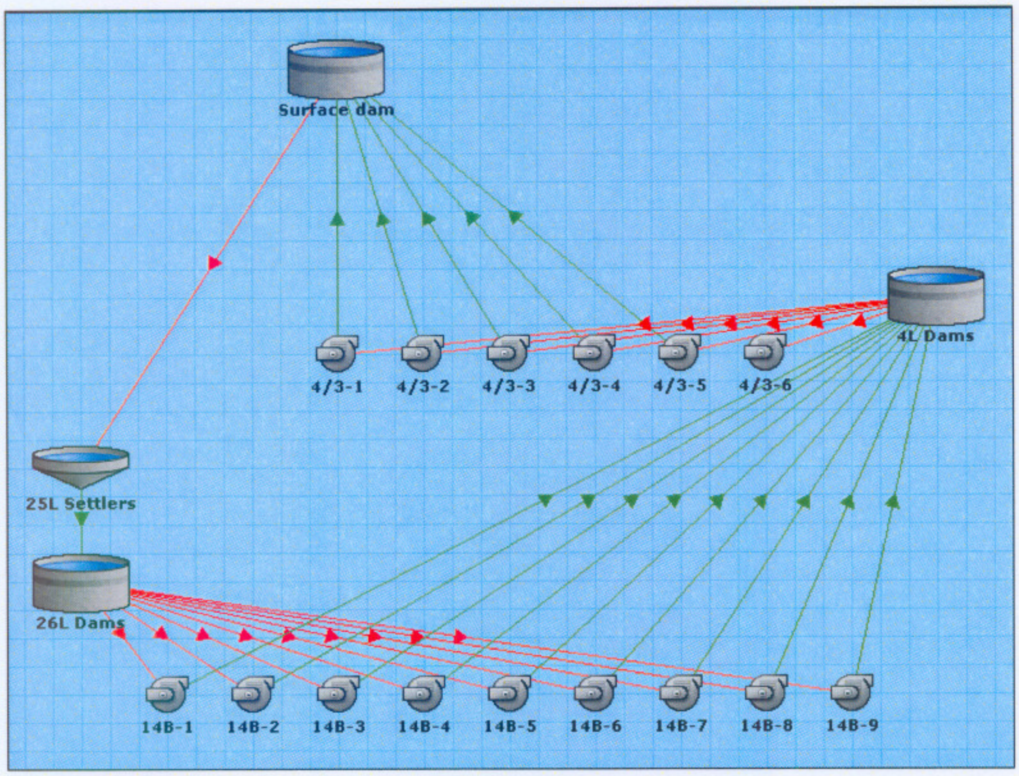


Figure 3-2: Pumping system configuration at Harmony 3#

The configuration of the Harmony 3# pumping system is shown in *Figure 3-2*. From the figure it is noticeable that 14B pump station has nine pumps and 4/3 pump station has six pumps. 14B pump station only has 1 200 kW pump motors, whilst 4/3 pump station has three 1 200 kW pump motors and three 900 kW pump motors. This results in a total installed capacity of 17 100 kW. A 10-inch and a 12-inch pipe column also interconnect the pump stations. A summary of the system characteristics is shown in *Table 3-1.*

Table 3-1: Harmony3# pumping system characteristics [51]

Level	Pump station	Average (Mℓ/day)	Peak (Mℓ/day)	Calculated Settler flow (Mℓ/day)	No. of 1200 kW pumps	No. of 900 kW pumps	Pump delivery flow (ℓ/s)	Dam Capacity (Mℓ)	Spare Dam Capacity (Mℓ)
Surface	-	-	-	-	-	-	-	9	0
4	4_3	18	19	0	3	3	100	10	0
27	14B	18	19	18	9	0	100	12.5	2.5

From the table it is clear that the dam capacities at Harmony 3# are extremely large. This enables pumping operations to be halted for long periods without negatively influencing the water pumping operations. According to this, the estimation can be made that a large potential exists for load shifting.

b) Baseline acquisition

At Harmony 3# there is no electronic data acquisition system, and therefore the paper log sheet system is still operational. This means that the pump operators log the operating schedules of the pumps daily on paper log sheets. Data was collected from the mine for the entire year of 2004 and the system demand baseline was prepared by calculating the average daily electricity demand profile for the period. The final baseline is shown in *Figure 3-3.*

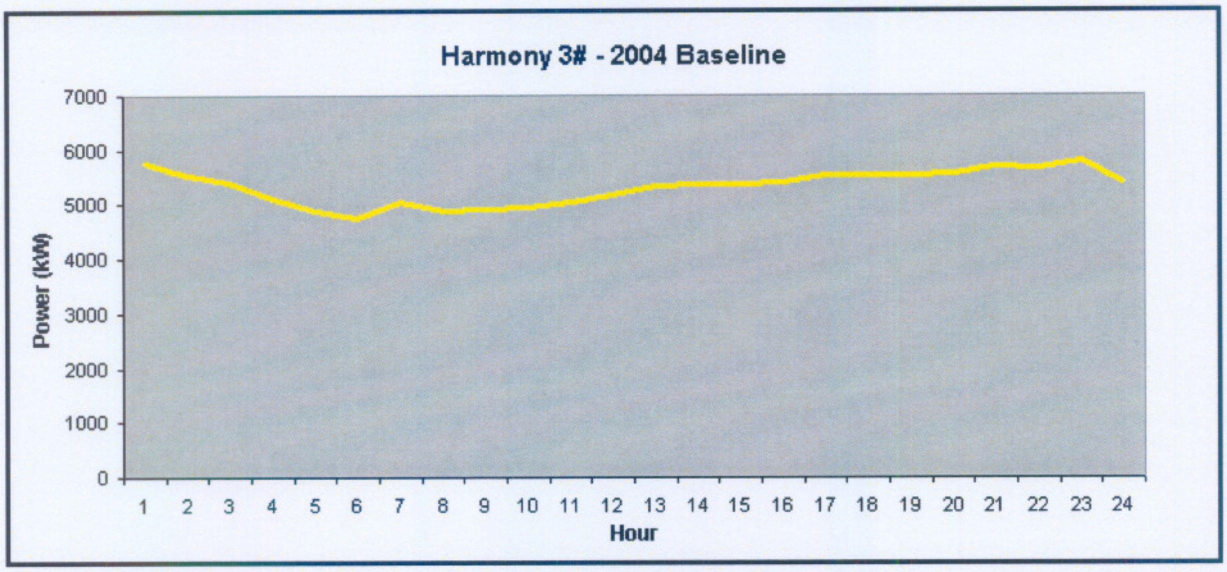


Figure 3-3: Harmony 3# baseline calculated from 2004 data set [52]

From the baseline it is noticeable that the mine pumped at an almost constant rate throughout the day during 2004. It is also clear that no efforts were made during this period to decrease pumping in peak periods. This leaves the opportunity for large load-shifting savings during peak periods.

3.2.3 System simulation

Before the simulation model for the Harmony 3# system could be constructed, the conceptual model had to be constructed according to the system characteristics, as shown in *section 2.3*. The mathematical model of each system component was inserted into the conceptual model to construct the simulation model.

The completed simulation model was then verified and validated to ensure that the simulation model forms a true representation of the real-life system. This was done by inserting real system values into the model and analysing whether the output results were similar to that of the real-life system.

After the simulation model had been verified and validated, a simulation had to be performed to estimate the potential for load shifting on the system. The system constraints were inserted into the model and the load-shifting potential was simulated. Some of the system constraints are shown in *Table 3-2*.

Table 3-2: Harmony 3# system simulation constraints [52]

Level	Pump station	Max. dam level (%)	Min. dam level (%)	Max. running pumps	Min. running pumps
Surface	-	-	-	-	-
4	4_3	90	40	3	0
27	14B	70	35	3	0

Another important system constraint is that the total amount of energy used in the simulation must be equal to the total amount of energy used during the 24-hour baseline profile. This is to ensure that the load-shifting potential is calculated for an average day on the mine.

As can be seen in the table, the maximum and minimum levels for the 26L dam is 70% and 35% respectively. It is, however, very important that the level be controlled between these levels, as flooding may influence the production of all of the surrounding shafts.

As Harmony 3# is just a pumping shaft and no mining is done, no water is required for mining operations or cooling. No fridge plants are present, so the dams do not have to be at a required level throughout the day.

The surface dam at the shaft is an evaporation dam. This means that water is not stored in the dam for further mining operations, but is allowed to evaporate. As much water as is required can be pumped to the surface, as these dams can also overflow without causing any problems.

Another large constraint on the system is the maximum number of pumps that are allowed to run simultaneously, per pump station. This is very important since the columns in the mine are very old and can in many cases only handle a certain amount of pressure. The constraint on the mine's side lies therein that only one pump may pump into the 10-inch column and two pumps may pump together into the 12-inch column.

3.2.4 Simulation results

By completing load-shifting optimised simulation and including all the system constraints, the potential for load shifting was calculated as 3,8 MW during evening peak periods and 2,9 MW during morning peak periods. A graph of the simulation results is shown in *Figure 3-4*.

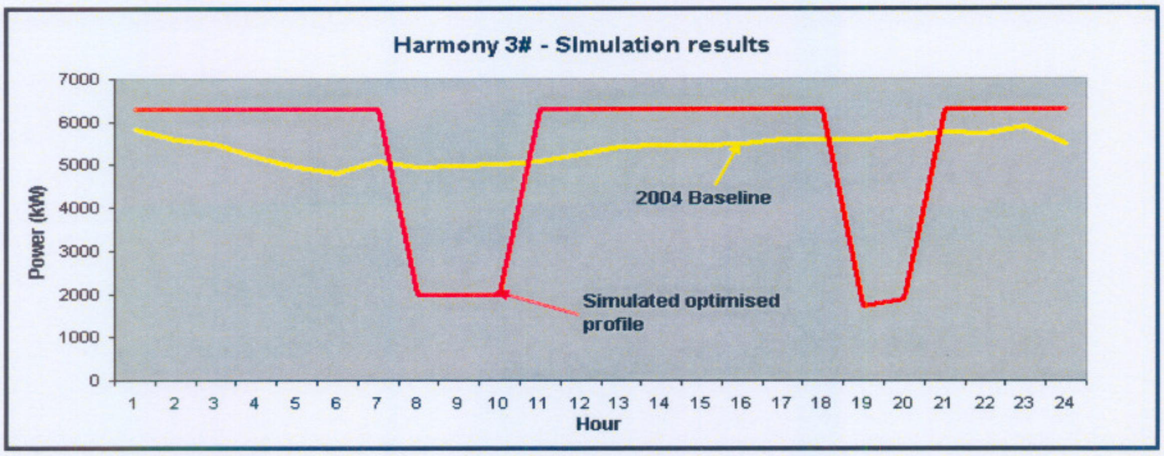


Figure 3-4: Harmony 3# simulation results

In the figure it is clear that there remains much potential during both peak periods, but due to the elevated system constraints and the relative importance of the mine, not all of the potential can be utilised.

With the current Eskom Megaflex rates as shown in *section 1.1.1*, the potential for financial savings of a system that can be optimised according to load shifting is greatly improved. By utilising the method demonstrated in *section 2.6.3*, the financial savings potential was calculated. The optimised profile in the figure shows large potential for load-shifting savings during peak periods, which also results in good financial savings potential.

The estimated financial savings potential for a summer month at Harmony 3# was calculated as R25 000. For a winter month the potential was calculated as R133 000, which results in a total potential saving of R 624 000 for a period of a year. The summary for the Harmony 3# potential is shown in *Table 3-3.*

Table 3-3: Summary of savings potential at Harmony 3#

Harmony3# Load-shift potential	Daily electricity usage (MW)	Morning Load Shift (MW)	Everning Load Shift (MW)	Estimated financial saving
Summer	127	2.9	3.8	R 25,000
Winter	100	2.9	3.8	R 133,000

3.3 Case study 2 –- Tau Tona gold mine

3.3.1 Background

Tau Tona is a gold mine located on the West Wits gold line near the town of Carletonville in South Africa. At more than 3,5 kilometres (km) deep, it is currently home to the world's second deepest mining operations. *Figure 3-5* shows a photograph of the Tau Tona mine property.

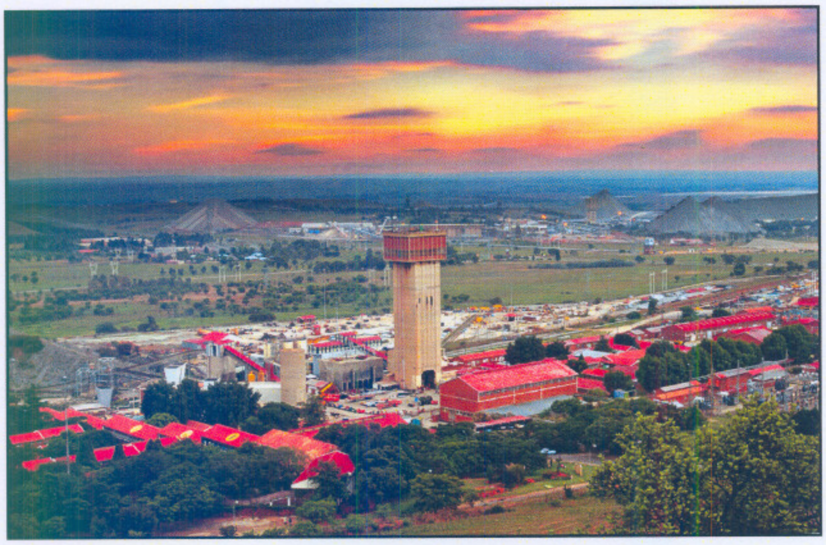


Figure 3-5: Photograph of the Tau Tona headgear and mine property

Construction on the mine started in 1950 and in 1957 the chairperson of Anglo American Corporation (AAC), Sir Ernest Oppenheimer, set the pregrouting drills in motion. The new shaft established the mine and Anglo American as world leaders in ultra-deep level mining [53]. The mine started producing in 1962 and is one of the more efficient South African mines that remains in continuous operation, even during periods when the price of gold is low [55].

Work is currently under way to extend the mine's depth to 3,9 km underground. This new shaft is set to be completed by 2009 and will extend the mine's life to 2015. The mine today has some 800 km of tunnels and employs approximately 5 600 miners [55].

3.3.2 System analysis

a) Analysing system characteristics

At Tau Tona mine, water is used to cool the underground mining conditions and for drilling and cleaning operations. The water is cooled via three different fridge plant stations on different levels. Fridge plants are situated on the surface, on 87 level and on 100 level. From the fridge plants the cold water is utilised in various mining operations, after which it flows into the settlers just above the pump-station dams. The water flows through the settlers to remove all excess mud, and into the clear-water dams on each pumping station level. From there the water is pumped by the clear-water pumping system to the surface dam to complete the cycle.

The configuration of the main pumping system at Tau Tona mine is shown in *Figure 3-6*.

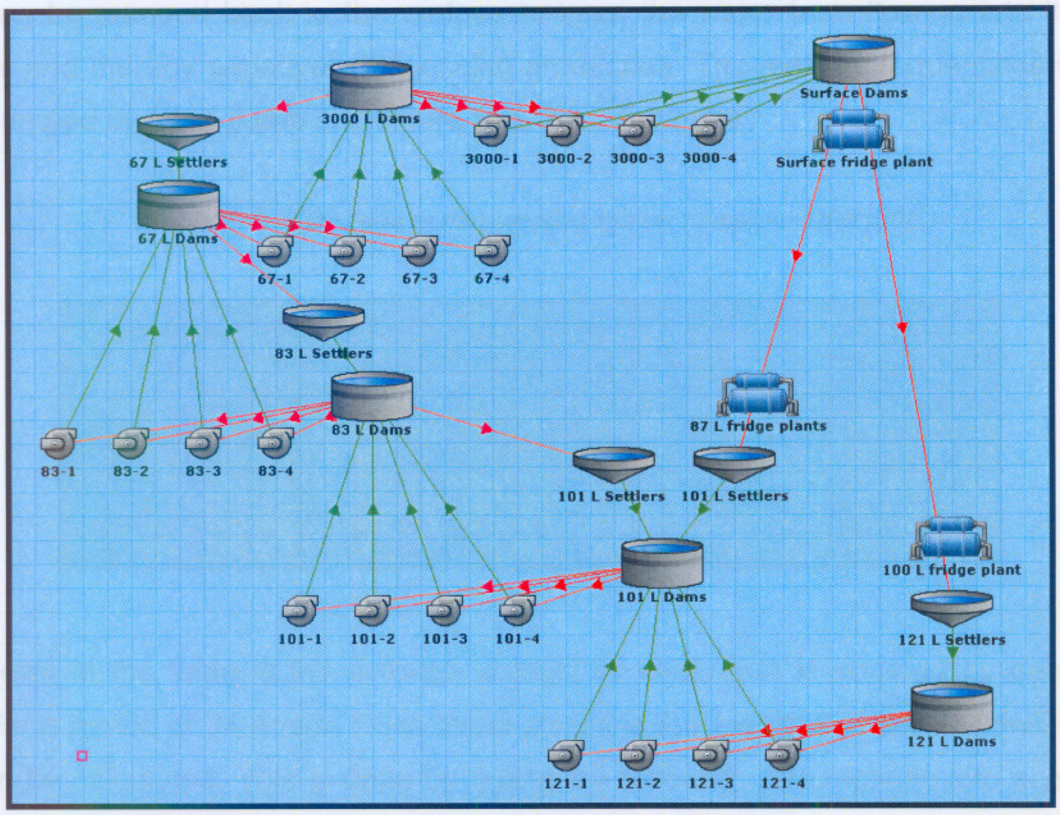


Figure 3-6: Undergound water pumping system configuration at Tau Tona mine

As can be seen in the figure, Tau Tona mine's water reticulation system consists of five main pump stations. These are: a) 121L pump station, which pumps its water to the 101L dams, b) 101L pump station, which pumps its water to the 83L dams, c) 83L pump station, which pumps its water to the 67L dams, d) 67L pump station, which pumps its water to the 3000L dams, and e) 3000L pump station, which pumps its water to the surface dams. Two 350 mm pipe columns interlink each pump station.

There are also sub-pump stations that feed the main pump stations. These pump relatively small amounts of water and have small pump motors. Because of this, the potential to save energy is limited and is therefore excluded from this study. The main pump stations in comparison have very large motor ratings, as they drive high-pressure pumps.

The significance of this mine system is that Tau Tona is an ultra-deep levels mine. For this reason, greater quantities of water are required for cooling throughout the mine. This water must then be pumped back to the surface to keep the water from flowing into the mine workings and thereby negatively influencing production. The maximum quantities of water that is pumped by each pump station are shown in *Table 3-4.*

Table 3-4: Tau Tona main pumping system characteristics [56]

Level	Average pumped (Mℓ/day)	Peak pumped (Mℓ/day)	Calculated Settler flow (Mℓ/day)	Pump delivery flow (ℓ/s)	Pump motor rating (kW)	Dam 1 Capacity (Mℓ)	Dam 2 Capacity (Mℓ)
3000	18	24	-	215	2580	0.62	0.31
67	19	26	1.0368	210	2580	4.7	2.47
83	22	24	2.9376	230	1875	1.52	1.89
101	25	27	15.12	220	1875	1.78	2.27
121	10	17	10.368	220	1875	2.63	3.54

Also shown in the table is the average amount of water that is pumped by each pump station for a period of 24 hours. From these statistics the volumes of settler flow into each dam can be calculated. This is done by taking the following assumptions into account: a) all water that flows into a return water dam originates from the settlers, and b) a pump station must pump out the amount of water that it receives on a daily basis.

An important system characteristic that was witnessed at Tau Tona mine is that water is extracted from the 67L, 83L, and 101L dams used in mining operations, and then flows back into the system through the settlers of the underlying pump station. This fact was also incorporated into the calculation of the settler flows.

The pump delivery flow rate per pump is also shown in the table. An average per pump station is given since the pumps are identical and are maintained to run at a high efficiency. As was mentioned in the previous chapter, the friction losses in the columns as well as head losses are already taken into account in each pump delivery flow rate, as the design rates are much higher than the actual rates. The pump motor ratings are also shown in the table

Each pump station at Tau Tona has two dams. One of the dams is utilised at any given time by the pumping system. The other dam is used as a spare dam. The dams are switched around on a monthly basis to allow for dam cleaning operations.

The surface dams at Tau Tona do not play a major role in the system and therefore are not discussed in much detail. They are very large, with little chance for overflowing, and feed the surface fridge plants and cooling towers. When the water reserves become exhausted, clean water is acquired from Randwater.

b) Baseline acquisition

The pumping system electricity demand baseline of the Tau Tona water-pumping system was acquired from data that was automatically logged by the mine system. The data is seen as very reliable and acccurate since the measurements were done with industrial loggers on the Eskom main incomer cables for the pumping system. The only drawback of this is that the true power utilised by each separate pump station cannot be determined.

Data was collected for the period of one year to take into account the effect that seasonal changes may have. The data was also filtered for weekdays. This was done as the pumping demand profile changes drastically over weekends due to the change in production levels. Also, due to the Eskom Megaflex structure, there is not much opportunity for energy savings on weekends. The data that is used in this study was gathered for the year 2004.

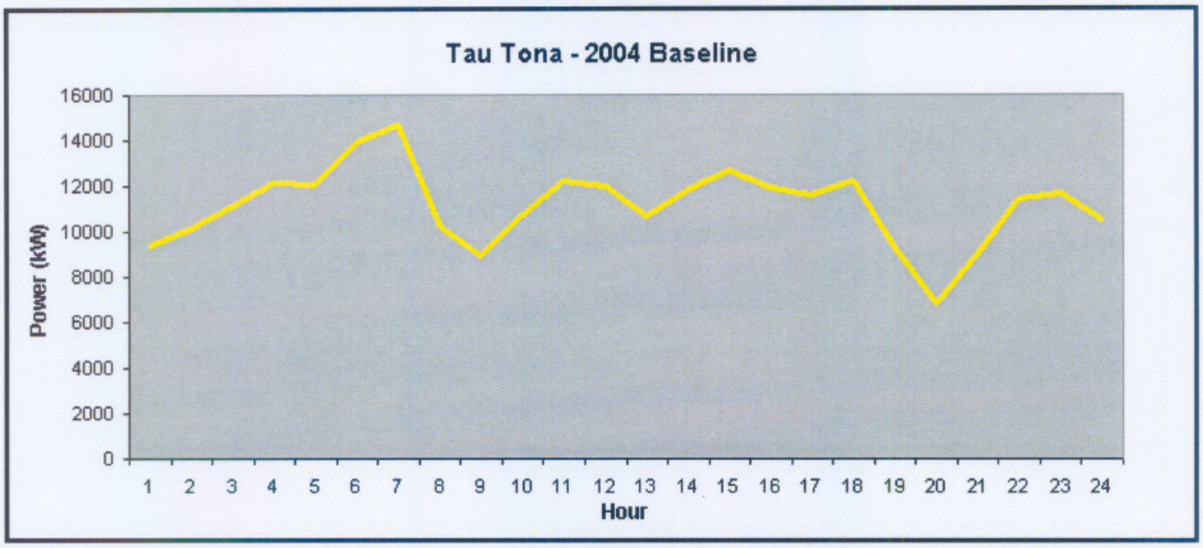


Figure 3-7: Weekday baseline profile for Tau Tone mine [57]

The weekday baseline profile that was determined is shown in *Figure 3-7*. As is noticeable from the figure, previous work had been done by the mine to try and minimise pumping during peak periods. Unfortunately it was not very successful and the potential to shift large amounts of load remains. The full potential will be estimated by this study.

The baseline can be verified by evaluating the system demand data for a prolonged period. Naturally the baseline was found by taking a weighted average over a certain number of months. For this specific baseline the period was from September 2004 until the end of December 2004.

3.3.3 System simulation

The method of simulation that was described in *chapter 2* and was used for the simulation of Harmony 3# is also used in this case study. The simulation of the system was completed with the help of Microsoft Excel and REMS simulator. All of the system characteristics that were gathered in the previous section were used in the integrated simulations.

Each simulation was run for a period of 24 hours or longer. The dam levels were required to be at the same level at the end of each day, to ensure that the simulation remains realistic on a daily basis and does not apply for a single day only.

In a complete analysis of the system it was found that Tau Tona has an extremely complex system. One reason for this is that the dams on all the pump station levels have small capacities that constrain maximum load-shifting performance. It was found that water from all of the pump station dams except on 3000L is used for mining operations. The water then flows back into the settler on the underlying pump station. If no pumps are running at any given time, the dam level will therefore decrease. This very important system characteristic was also input into the simulation.

The normal strategy for load shifting is to get all the dam levels as low as possible before peak periods. The ultimate strategy would actually be to pump as much as possible during the periods with the lowest Eskom Megaflex rates. Unfortunately this strategy would not work at Tau Tona since the dam capacities are small and do not have the required storage capacity.

The system constraints as used in the simulation are shown in *Table 3-5*.

Table 3-5: Constraints applied on Tau Tona system during simulation [58]

Level	Max. dam level (%)	Min. dam level (%)	Max. nr. of pumps	Min. nr. of pumps
3000	90	40	2	0
67	90	40	2	0
83	90	40	2	0
101	90	40	2	0
121	90	40	2	0

Another constraint on the system is the maximum demand of the pumping system. The maximum number of pumps that are allowed to be on at any given time is ten. This is due to capacity constraints of the feeder cables. Therefore the maximum demand of the pumping system results to 21 570 kW.

With this characteristics and constraints taken into account, the simulation was run for 24-hour periods at a time. The simulation was completed by ensuring that all of the system characteristics stay within the constraints set out onto the system.

3.3.4 Simulation results

As was mentioned in the previous section, the simulation was completed with the help of Microsoft Excel and the REMS simulator. The profile shown below is the potential that exists to shift load at Tau Tona mine by automatic control of the main pumping system.

The maximum potential for load shifting was calculated as 7 MW during evening peak periods and 5 MW during morning peak periods. The simulated profile is illustrated in *Figure 3-8*. Although this was calculated with all the system constraints taken into account, there are still many factors that can influence the system on a daily basis.

Note that the load-shifting potential is greatly influenced by the quantity of water that needs to be pumped, and therefore the load shifting may increase or decrease with the increase in daily pumping as discussed in *section 2.6.1*.

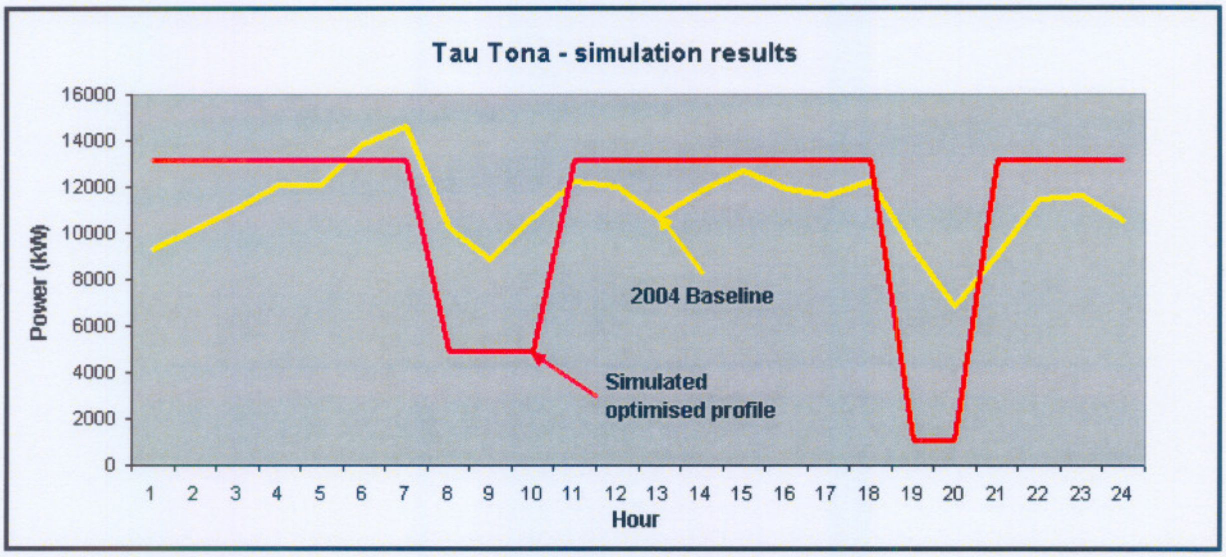


Figure 3-8: Results of the Tau Tona simulation

By once again utilising the method shown in *section 2.6.3*, it was calculated that the estimated financial savings for a summer month amounts to R55 000. These calculations also showed a winter month saving potential of R315 000. This amounts to an estimated annual financial saving potential of R1 440 000. From this total, it is clear that large financial savings are again possible even though Eskom's tariffs are of the lowest in the world. The summary of the savings potential on the Tau Tona pumping system is shown in *Table 3-6*.

Table 3-6: Summary of savings potential Tau Tona

Tau Tona Load-shift potential	Daily electricity usage (MW)	Morning Load Shift (MW)	Everning Load Shift (MW)	Estimated monthly financial saving
Summer	267	5	7	R 55,000
Winter	267	5	7	R 315,000

3.4 Case study 3 – Beatrix 1#, 2#, 3# mine

3.4.1 Background

Goldfield's Beatrix mine is also a special type of mine in that it has three different mine shafts situated not more than 2 km apart. Beatrix 1# and 2# started production in 1984 and Beatrix 3# was commissioned just after 2000. Although this is not an old mine in the true sense of the word, the mine is still operated with age old and proven technologies. In this regard the mine can be considered an old gold mine.

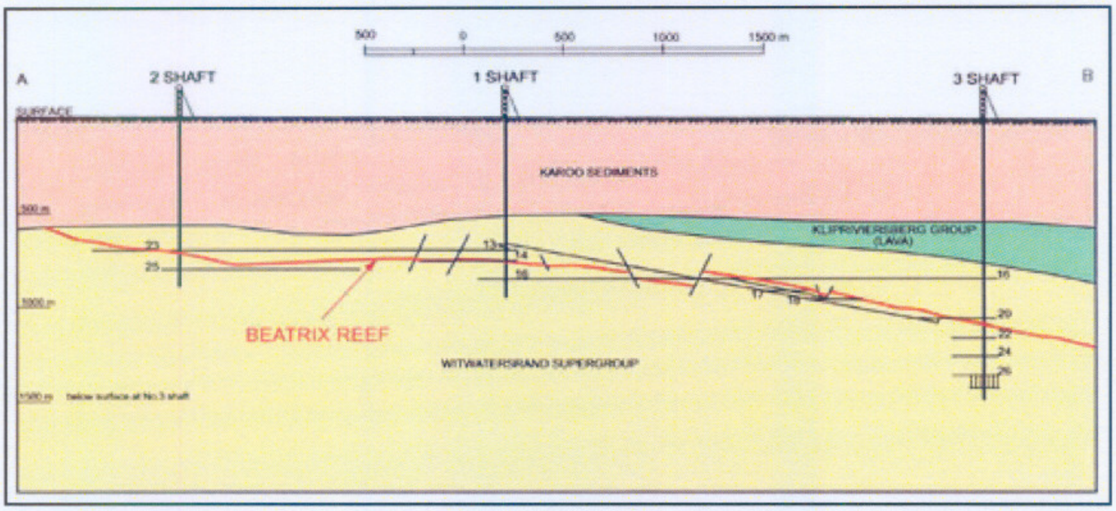


Figure 3-9: Configuration of the Beatrix mine shafts [53]

The mine is situated near the town of Virginia in South Africa and exploits the Beatrix gold formation as seen in *Figure 3-9*. The shafts vary between a depth of 500 and 2 300 metres and 12 000 people are employed. This mine annually produces more than 650 000 ounces of gold [53].

3.4.2 System analysis

a) Analysing system characteristics

At Beatrix mine water is used to cool the underground mining conditions and for mining operations. This water, together with fissure water (better known as groundwater) gather in the underground settlers [54]. The water flows through the settlers and collects in the underground dams. The clear-water pumping system reticulates the required service water throughout the mine and pumps the excess water to surface.

The mine pumping system consists of pumping stations on the three different shafts: (a) Beatrix 1#, (b) Beatrix 2#, and (c) Beatrix 3#. At present, only the pump stations at Beatrix 1# and Beatrix 2# are fully operational. Beatrix 3# is still being developed and currently only has three pumps and a very small dam cavity. Although this development is scheduled to be finished in the near future, the current system characteristics will be evaluated in this study.

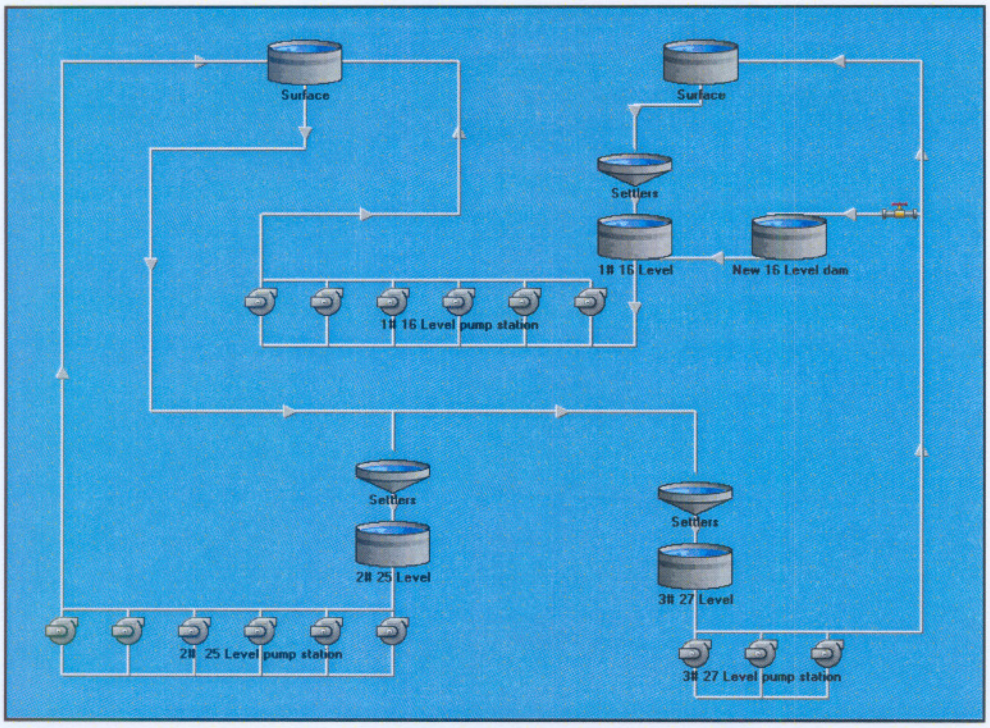


Figure 3-10: Configuration of pumping system at Beatrix 1#, 2# and 3# shafts

The configuration of the current pumping system that interconnects the different shafts is shown in *Figure 3-10*. Currently Beatrix 3# pumps an average of 9 Mℓ per day from the 27 level pump station to either the new clear-water dam on 16 level or back to the surface. From the new dam, water is transferred to the mining operations while the excess water is pumped via the existing 16-level pump station to the surface.

The pump station at Beatrix 2# (level 25) pumps approximately 15 Mℓ water per day to the surface. Other excess water is transferred to Beatrix 1#'s clear-water system. An estimated 20,5 Mℓ is pumped to the surface via the 16-level pump station of Beatrix 1# per day. The current total installed pumping capacity for the complete system is ± 26 MW. More system characteristics are shown in *Table 3-7*.

Table 3-7: Beatrix mine's system characteristics [59]

Level	Shaft	Average pumped (Mℓ/day)	Calculated Settler flow (ℓ/s)	Pump delivery flow (ℓ/s)	Dam Capacity (Mℓ)
Surface	1 & 3	-	-	-	19.5
16	1	9	307	170	4
25	2	15	424	140	8
27	3	20	280	90	4.5

b) Baseline acquisition

The baseline for the Beatrix mine pumping system was calculated by evaluating the historical pumping data for each separate shaft. This was done by analysing log sheets for the year 2004. The decision was made to use the period from October 2004 to December 2004, as the profile was most constant during this period. Although this is the profile for summer months, the profile will be normalised during winter months to cater for months with lower energy usage. The procedure for normalising the baseline was discussed in *section 2.6.1*.

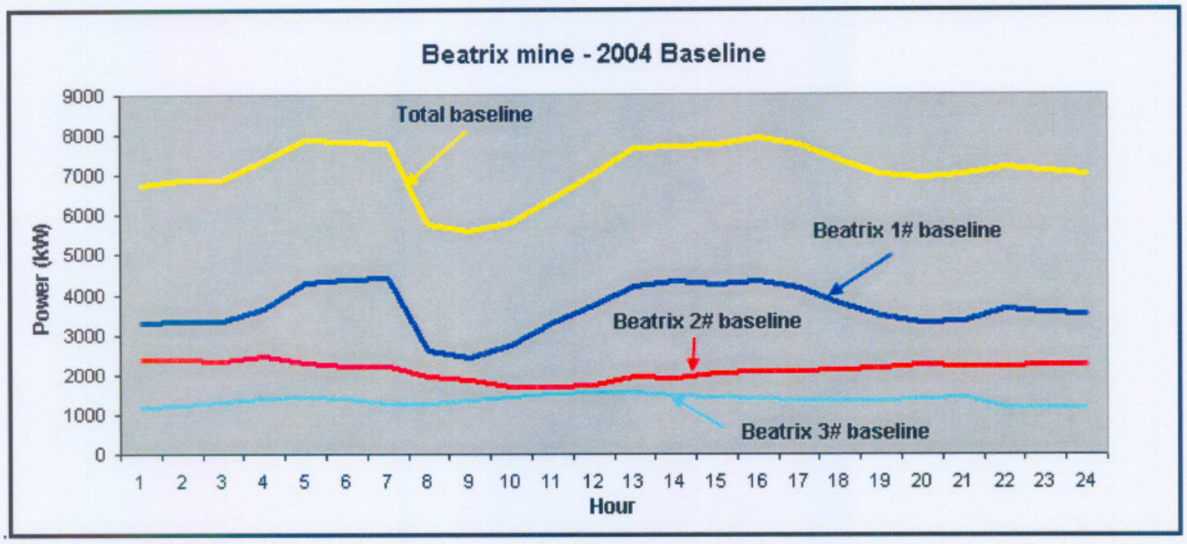


Figure 3-11: Calculated baseline profiles for Beatrix 1#, 2# and 3#

The baselines as derived from the above-mentioned data for the separate shafts are shown in *Figure 3-11*. The total energy usage baseline for the pumping system is also shown. From this, the large potential for load shifting during the evening peak period can be identified. The total baseline profile also shows a major dip during the morning peak period. This can be attributed to the settler flow that declines during this period of the day, due to a decrease in mining activities.

3.4.3 System simulation

There are two types of constraints applicable to this system. These are the maximum pumps allowed to run at a specific time and the minimum and maximum dam level constraints. The 27L underground dam is controlled between a minimum level of 10% and a maximum level of 40% at all times. This is because it is the deepest pump station and chances are great of the mine flooding if problems are encountered. Extra precaution is therefore required for this pump station.

On level 16 there are six electrical pumps. The hot water dam levels on the level will be kept between a minimum of 10% and a maximum of 60%. On level 25 there are six electrical pumps. The hot-water dam level on level 25 will be controlled between a minimum of 10% and a maximum of 60%.

To keep the water balance intact the clear-water pumping system must supply the surface hot dam and fridge plant with sufficient water. Therefore the surface dam also has level constraints of a minimum of 40% and a maximum of 95%. Another constraint is that only three pumps may run simultaneously at the Beatrix 1# and Beatrix 2# pump stations, while only two pumps may run simultaneously at the Beatrix 3# pump station. All of these constraints are shown in *Table 3-8*.

Table 3-8: Beatrix mine's system constraints [60]

Level	Max. dam level (%)	Min. dam level (%)	Max. running pumps	Min. running pumps
Surface	95	40	-	-
16	60	10	3	0
25	60	10	3	0
27	40	10	2	0

As with the simulation for Tau Tona and Harmony 3#, the simulation was done for a period of 24 hours, with all of the system characteristics and constraints taken into account. The simulation was also done with the current system water volumes and energy used by the pumping system.

3.4.4 Simulation results

The results of the simulation shows that the pumping system at Beatrix mine has the potential of shifting 5,3 MW out of evening peak periods and 3 MW out of morning peak periods. This is the maximum load-shifting potential. The results of the simulation are shown in *Figure 3-12*.

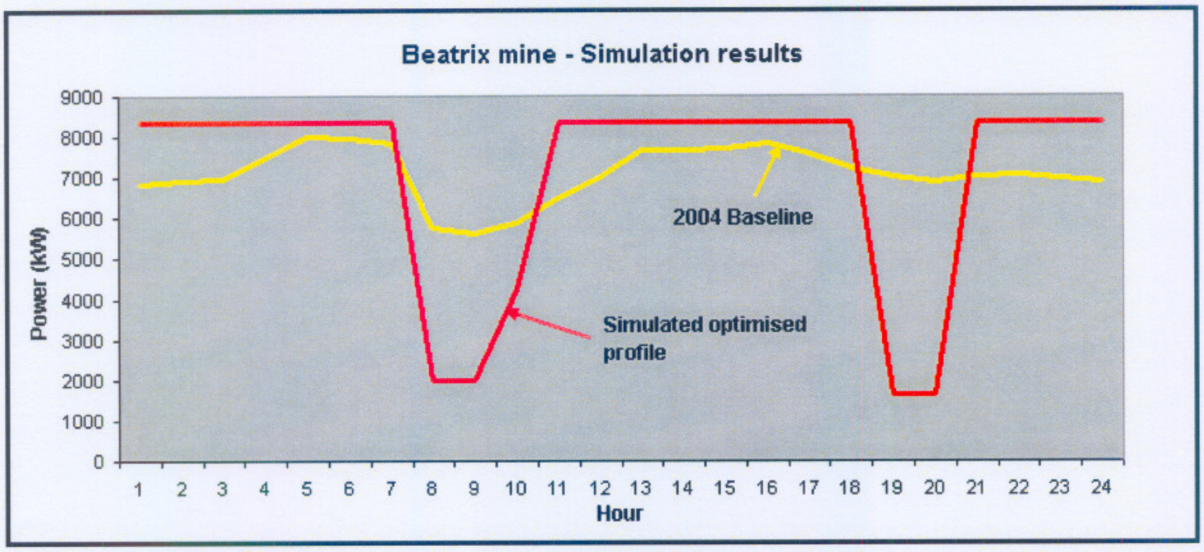


Figure 3-12: Results of Beatrix simulation

The calculation of the estimated annual financial savings that could be realised through this optimised pumping profile, amounted to a total of R1,25-million. The method outlined in *section 2.6.3* was again utilised to determine this total by calculating the estimated savings for summer and winter months individually.

The break down for summer and winter months individually is shown in *Table 3-9.* Also shown in the table is the summary of the load shift potential at Beatrix mine. This summary shows that Beatrix mine can save large amounts of money by applying these strategies.

Table 3-9: Summary of Beatrix mine savings potential

Beatrix Load-shift potential	Daily electricity usage (MW)	Morning Load Shift (MW)	Everning Load Shift (MW)	Estimated monthly financial saving
Summer	153	3	5.3	R 29,000
Winter	153	3	5.3	R 170,000

3.5 Conclusion

In this chapter, the load-shifting potential on three old gold mines was researched, through the use of case studies. The methods as outlined up to *section 2.6.3* of *chapter 2* was utilised in determining this potential. Each case study showed positive results.

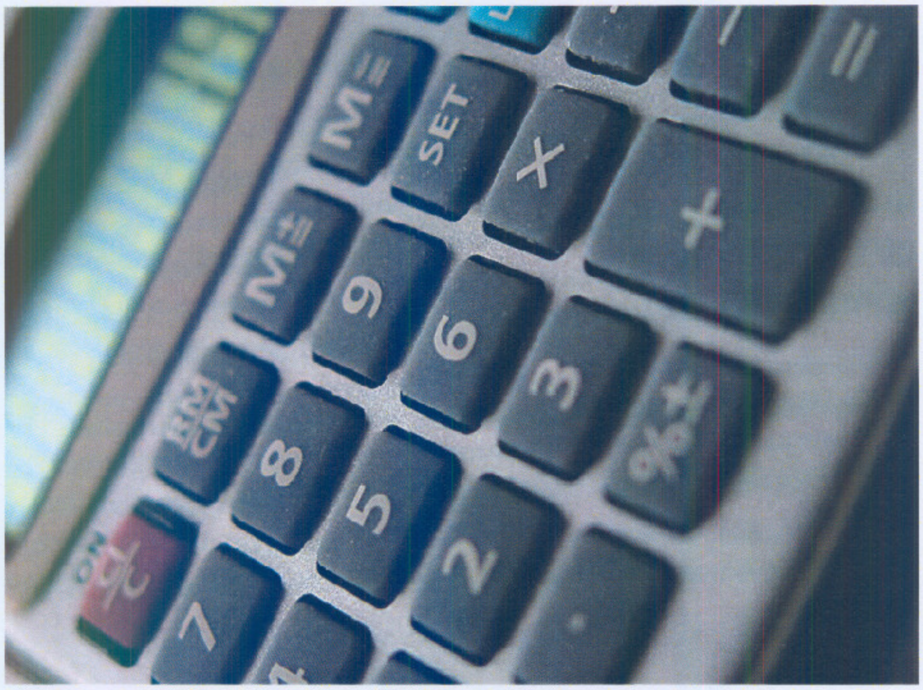
The case study for Harmony 3# shaft showed that large potential exists for load shifting. The fact that the system has large dam capacities and a major number of spare pumps greatly reduce the complexity of the system and the risk involved with load shifting. The fact that the shaft is primarily a pumping shaft and is truly very old, is unfortunately a worrying factor, as most of the infrastructure on the mine is in bad shape and may greatly influence real load-shifting performance.

The case study for Tau Tona mine also showed that there exists large potential for load-shifting and financial savings for the mine. The mine system is much more complex and complicated than the system at Harmony 3# and relies on very small dam cavities in the pumping system. The infrastructure in the mine is also very old. Nonetheless, the potential shows that load shifting can bring about large financial savings to the mine.

The case study for Beatrix mine showed that large potential for savings exists if the three different shafts are controlled collectively. The distance between the shafts and the changes on Beatrix 3# might, however, have a major effect on the sustainability of a project on the mine.

This chapter has also shown that old mines are actually some of the simple candidates for Eskom's DSM strategies. This is since the mines are mostly in dire need of the capital investment brought about by the Eskom DSM process. With the advantage of extra savings brought about by load shifting and other DSM strategies, this should motivate the mines to pay more attention to energy management.

4. REAL SAVING RESULTS



In this chapter the results obtained from the implementation of the load-shifting strategies on real mine system are compared with the simulation results of the case studies analysed in chapter 3. The unique challenges associated with the implementation of these strategies are also discussed.

4.1 Preamble

In the previous chapter the potential for energy savings through load shifting was calculated for each separate case study mine system. Through proposals, Eskom DSM approved these strategies as feasible load-shifting projects.

With capital funding from Eskom, load-shifting strategies were implemented on the mines by:

1. automating the pumping systems, so that automatic control could be achieved from a centralised control room.
2. installing a real-time energy management system on each mine to control the pumping systems in real time.

The challenges associated with the implementation of these strategies will be discussed in this chapter as well as the solutions that were engineered. The real load-shifting results of these projects will also be evaluated against the proposed potential as shown in *chapter 3.*

4.2 Challenges associated with real-time energy management on old gold mines

During the implementation of the above-mentioned strategies, there were several challenges that had to be overcome to successfully complete the implementation and produce sustainable results. These were mostly challenges that were unique to old gold mines and had not been encountered on other, newer gold mines.

These unique challenges are discussed throughout the section along with the solutions that were engineered to overcome the challenges.

a) Old infrastructure

The age of a gold mine has a large effect on the age of the infrastructure in the mine. As was already mentioned most of the old gold mines proceed in using old and proven technologies, while newer mines upgrade their infrastructure more often. Due to this, challenges arose that caused many problems and delays during the implementation of the strategies mentioned in the case studies.

During the investigations at Harmony 3# and Beatrix mine it was found that the very old water columns in the mines would not be able to withstand the constant hammering of water caused by continuous pump switching. This hammering is caused when the upwards moving water in a column changes direction, starts moving downwards and comes to a standstill against the pump station valves. This occurrence is at its most powerful when all of the pumps on a pump station are stopped simultaneously and no force is available to keep the water moving upwards.

As a solution to this problem, additional non-return and isolation valves had to be installed at critical positions in the shaft columns. In addition, the sequencing of each pump's stop procedure had to be optimised. By closing the automatic pump delivery valve at a certain stage in the pump stop sequence, the water hammering was dramatically reduced.

Another problem encountered was the reliability of the old electrical infrastructure in the mines. Because of the age of the components and in some cases the lack of maintenance on the components, their reliability raised questions. At all three mines this posed problems and the decisions were made to replace as much of the unreliable system components as possible. This turned out to be a very costly exercise.

One of the components that could not be replaced at Harmony 3# was an electrical switchgear that was designed for minimal switching and was installed in the pump station due to the unavailability of alternatives. Because of the forceful mechanical switching enforced by the switchgear, the increase in pump switching reduced the lifetime of the contactors. This caused large amounts of system down time, but was remedied by optimising the pump scheduling, so that a minimum number of pumps are stopped and started daily.

b) The absence of control infrastructure

Most of the systems on old gold mines still use old control techniques. These techniques include manual relay switching and valve operation by the pump operators, which proves to be rather time consuming. This was found to be the standard on old gold mines, while complex techniques associated with PLC control were found to be the standard on newer gold mines.

The absence of PLC control infrastructure on the mines was seen as a challenge, as automatic control of the systems was not possible. This problem was solved by redesigning the control system of each pump and installing automatic PLC control infrastructure. This, however, also entailed large costs.

c) Absence of control centre

On most mines, a control centre (control room) is the gathering point of all of the information on a mine. It acts as an imitation of all of the systems on the mine and is used to monitor and supervise the systems. A SCADA system is therefore also situated in the control room of a mine.

As Harmony 3# is only a pumping shaft, the main process running at the shaft is that of pumping water. Because of the old infrastructure inside the mineshaft, it was never possible to monitor the systems from the surface. Therefore there was never in the past the requirement for a control room to assess and supervise any systems.

With the installation of the load-shifting strategy a SCADA system also had to be installed, which required a 24-hour control room. This was a major problem, as the mine did not have the resources to operate a control room. This situation was remedied by converting a room next to the shaft into a small control room. The person originally stationed in the room was appointed to supervise and monitor the system.

At Beatrix mine, only one of the shafts had a control room. As the systems on all three shafts were automated and had to be controlled by a single management system from a central point, the decision was made to link the individual SCADA systems on each mine shaft to the control room on Beatrix 2#, where a control room operator was present for the entire day.

The purpose of real-time energy management is to be able to control the particular mining system according to system changes for every second of the day. With system breakdowns, the energy management system has down time in which it cannot optimise the pumping for that specific amount of time.

If the down time of the system is longer than a certain amount of time, depending on the time of day, this may greatly influence the load-shifting results for the day. The presence of a control room with a dedicated control room operator reduces the periods of system down time since he can notify the maintenance teams to repair problems as soon as possible.

d) Mine workers' unions

The transition from manual control to automatic control of a system usually results in cuts in labour cost. This was seen on a large scale in the automotive industry where massive labour cuts were made when plants were automated.

At all three mines in this study the implementation of the load-shifting strategies raised questions from the mineworkers' unions. This was because the proposal of automatic system control raised the question of whether cuts in labour would be required.

On most of the main pump stations with an average of four high-pressure pumps there are three labourers set to operate the pumps and maintain the pump station. On a relatively new mine with new and reliable infrastructure, the potential exists to cut this labour down to one person, as only one person would be required to clean and maintain the pump station.

On old mines this is, however, impossible as the risk of system failure due to the unreliable infrastructure remains high. For this reason, a trained pump operator must always be on hand to take over the manual control of a pump if the situation should arise. For this reason, a maximum of one labour cut can be made due to the automation process.

e) Influence of load shifting on production

Except for the physical challenges associated with the implementation of load-shifting strategies, there are also challenges regarding the production side of any mining operation. All the systems inside a mine work together to maintain certain gold production levels. If the operation of one of the mine systems is changed, the possibility is high that the production levels of the mine could be influenced. For this reason special care had to be taken not to influence production on the mines in question.

The production of a shaft can directly be influenced if the dams in the clear-water pumping system are flooded. This causes excess mud in the mining areas, which in turn make it difficult to do work. Another obstacle occurs when too much water is pumped out of a dam and no water is available for the underground fridge plants or mining operations.

By ensuring that the dams of the water-pumping system at the mine never overflow and their levels never recede below a required minimum level, the production of the mine will not easily be influenced. As the real-time energy management systems control the pumping systems in real time and continuously take all of the system's constraints into account, it ensures that production levels on a mine will not easily be influenced.

This may also be seen the other way around. Production levels may influence the load-shifting results produced by the strategy. At the end of the year 2005, the price of gold all over the world increased to the highest level that it had ever been. For many mines this meant increased production levels, and some mines even started with continuous operation mining (conops mining), whereby the mine remains in production for the entire day.

In the case of Harmony 3#, the production of all of the mines around the shaft increased dramatically. This had a major influence on the volume of water utilised for mining operations and therefore the volume of water pumped by Harmony 3#. This greatly affected the potential for load shifting, as the maximum number of pumps had to run continuously to remove the water from the mine and keep the dam levels at a reasonable level.

As a remedy for this situation, the load-shifting control strategy had to be optimised to only shift load during the evening peak periods. This slightly affected the financial savings, but the system managed to shift the required load during the evening peak periods.

f) Mine resource shortages

Due to the old and outdated infrastructure on the mines used in the study, there was never much maintenance required on instrumentation. For this reason, the labour force required to maintain these systems were also minimal. This caused another unforeseen challenge, as the installation of the new systems required much labour input from the mine.

At all three mines this caused major delays since the mine's personnel were unable to fit all of the required work into their normal schedules. The only way that this problem could be remedied was to improve and optimise the project planning and hire extra contractors to complete specific tasks.

On completion of the automation of the systems, another challenge was encountered. This time it was due to the mine's personnel not being skilled in maintaining the systems. The solution for this specific problem was to set up a maintenance contract between the mine and the original contractor, which entailed all maintenance on the new control systems to be done by the contractor.

g) Sustainable load shifting

One of the biggest challenges that were encountered with DSM load-shifting strategies on old mines was that of actually realising sustainable load-shifting results. All old mines have major maintenance problems due to the age of the infrastructure. Changing the operation of the system in any way may cause even more breakdowns and system down time. This makes it difficult to maintain constant results.

To solve this problem an intensive process of constant system result monitoring was undertaken. By analysing the results for each day, updating, and refining the system control strategy according to changes in the system, it was possible to achieve sustainable results at these mines.

4.3 Measured results for Harmony 3#

To allow the load-shifting potential that was calculated in *chapter 3* to be realised, the pumping system at Harmony 3# had to be automated. This allowed an automatic real-time load shift strategy to be implemented. The installation of the automation infrastructure was completed in August 2005. The measured results for the period from September 2005 to October 2006 will be discussed.

4.3.1 Real load-shifting results

The implemented load-shifting strategy at Harmony 3# officially started generating results during September 2005. Since then it has continually produced load-shifting results and energy savings for the mine.

Table 4-1: Results generated by the load-shifting strategy at Harmony 3#

Month	Average Daily electricity usage (MWh)	Average Morning Load Shift (MW)		Average Evening Load Shift (MW)	
		Potential	Obtained	Potential	Obtained
Sep-05	96	2.90	1.77	3.80	4.14
Oct-05	108	2.90	1.54	3.80	4
Nov-05	104	2.90	1.22	3.80	4.16
Dec-05	106	2.90	1.26	3.80	4.98
Jan-06	99	2.90	1.80	3.80	3.8
Feb-06	104	2.90	2.88	3.80	4.18
Mar-06	99	2.90	3.16	3.80	4.05
Apr-06	107	2.90	2.86	3.80	4.06
May-06	113	2.90	0.00	3.80	0
Jun-06	129	2.90	1.22	3.80	4.14
Jul-06	130	2.90	1.34	3.80	3.81
Aug-06	138	2.90	0.56	3.80	5.33
Sep-06	148	2.90	0.54	3.80	5.14
Oct-06	134	2.90	0.14	3.80	4.04
Average	115	2.90	1.45	3.80	3.99

The performance of the real-time load-shift strategy from September 2005 is shown in *Table 4-1.* As can be seen from the table, more than 3,8 MW of load was shifted at a sustainable rate out of the evening peak periods.

Unfortunately, it is not the same case with the morning peak periods, as the average target of 2,9 MW was only achieved once throughout the year. This can however be attributed to the fact that water usage increases during morning peak periods due to mining activities. Allowing for this, the morning load shift was neglected to ensure a higher average for the more important evening load shift.

As can be noted in the table, the average daily electricity usage for the mine pumping system shows a drastic increase from September 2005 until September 2006. This is due to a large production increase on the mines surrounding Harmony 3#, which increased overall water consumption. This further influenced the morning load shift results, as the original load-shift strategy had to be changed to only allow for the more important evening load shift.

However, more factors also played a role in the load-shifting results. These factors mostly had a negative influence on the load-shifting results and could not be controlled by the real-time strategy. As a manner to exclude the influence of these factors, a procedure was devised to exclude any day's results from calculations, if unforeseen and uncontrollable factors had a negative effect on the results. Such a day is then defined as a condonable day. The amount of weekdays in the month in which load shift can be realised, the amount of condonable days recorded in each month and the main reasons for condonable days are shown in *Table 4-2.*

Table 4-2: Influence of condonable days at Harmony 3# [61]

Month	Weekdays	Condonable days	Main reason for condonables
Sep-05	22	3	Fibre communication problems
Oct-05	21	7	Burst water column and broken transformer
Nov-05	22	12	Broken motor and transformer
Dec-05	22	20	Maintenance on shaft water columns
Jan-06	22	7	Maintenance on shaft water columns
Feb-06	20	6	Pump maintenance and communication problems
Mar-06	23	11	Dam cleansing processes
Apr-06	17	7	Dam cleansing processes
May-06	23	23	Burnt out feeder cable reducing electrical capacity
Jun-06	21	13	Sudden increase in water usage
Jul-06	21	9	Pump maintenance and communication problems
Aug-06	23	3	Burst water columns
Sep-06	20	2	Pump maintenance and continual power failures
Oct-06	22	6	Increase of water during critical periods of day
Average	21	9	

From the table is clear that there is a certain amount of condonable days during any month. Throughout the year an average of 9 condonable days per month were recorded at Harmony 3#. This showed that load shifting was only possible during 60% of the weekdays in a month. Because of this, the effectiveness of the load-shift principle in terms of sustainability is reduced greatly.

From the column showing the main reasons for condonable days, it is clear that most of the condonable days were caused by the unreliability of the old infrastructure in the old mine. As also mentioned earlier, there were also cases where the water consumption increased so dramatically, that the system could not be controlled according to the original strategy. These days were also marked as condonable days.

Nonetheless, the days in which sufficient load was shifted showed good performance by the real-time, load-shift strategy. The average optimised consumption profile of these days can be compared with the simulated, optimised consumption profile in *Figure 4-1*.

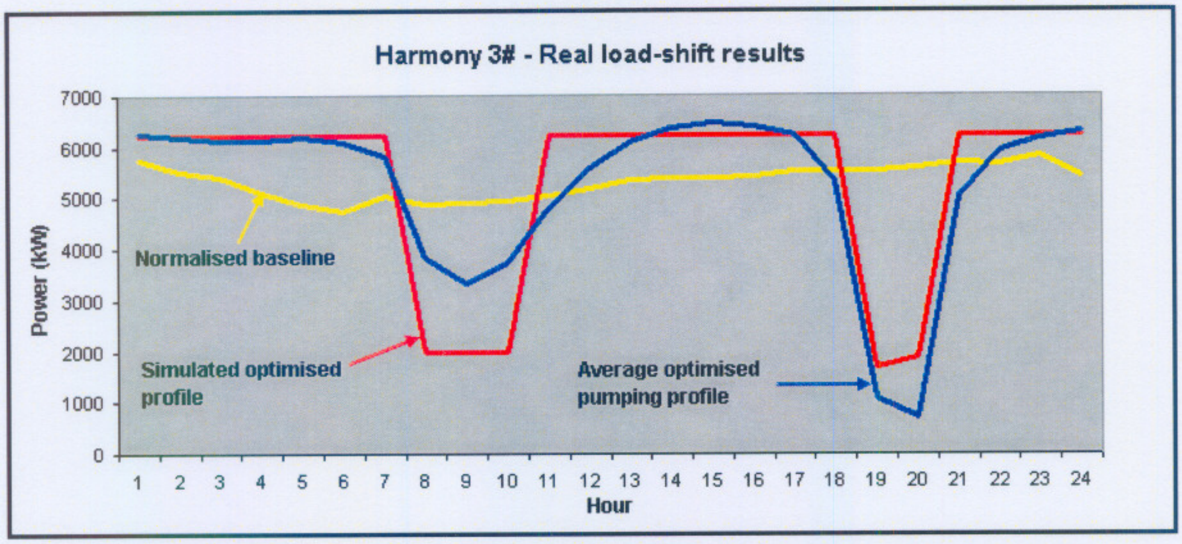


Figure 4-1: Real load shift results for Harmony 3# mine

The comparison of these two profiles shows that although the simulated morning load shift could not be attained, this lost potential was converted into a larger evening load shift potential and overall performance.

The normalised baseline profile is also shown in the figure. By comparing the baseline profile with the optimised consumption profile, the true effect of the real-time, load-shift strategy that was implemented on the Harmony 3# pumping system, is demonstrated.

4.3.2 Electricity cost savings

The estimated electricity cost savings for the project was calculated according to the process shown in *chapter 2*. A summary of the estimated cost savings together with the predicted cost savings is shown in *Table 4-3*.

Table 4-3: Estimated financial savings realised at Harmony 3#

Month	Average Morning Load Shift (MW)	Average Evening Load Shift (MW)	Estimated Monthly Financial Saving	
			Potential	Obtained
Sep-05	1.77	4.14	R 25,000	R 18,882
Oct-05	1.54	4	R 25,000	R 15,896
Nov-05	1.22	4.16	R 25,000	R 14,517
Dec-05	1.26	4.98	R 25,000	R 8,186
Jan-06	1.8	3.8	R 25,000	R 15,376
Feb-06	2.88	4.18	R 25,000	R 18,241
Mar-06	3.16	4.05	R 25,000	R 21,254
Apr-06	2.86	4.06	R 25,000	R 22,395
May-06	0	0	R 25,000	R 0
Jun-06	1.22	4.14	R 133,000	R 81,508
Jul-06	1.34	3.81	R 133,000	R 92,677
Aug-06	0.56	5.33	R 133,000	R 127,507
Sep-06	0.54	5.14	R 25,000	R 19,315
Oct-06	0.14	4.04	R 25,000	R 11,839
Total			R 674,000	R 467,593

The effect of the condonable days is clearly visible in the estimated obtained savings column. The obtained savings are much less than the potential savings that was calculated according to the simulation results. The reason for this is easily recognisable in *Figure 4-2.*

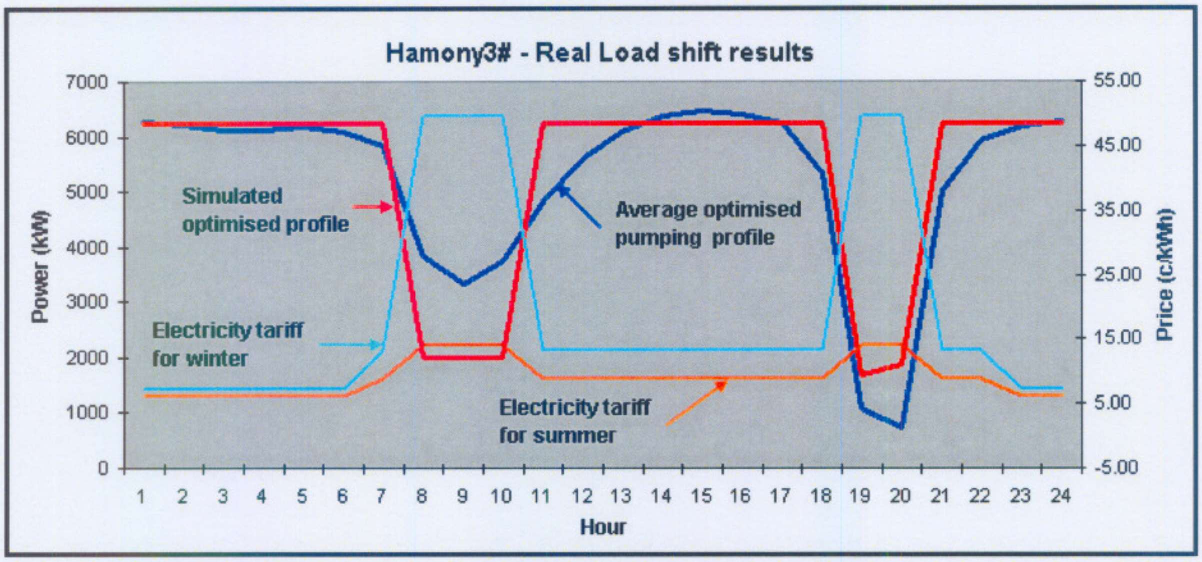


Figure 4-2: Financial saving results for Harmony 3#

During winter and summer months, a substantial amount of savings was lost due to the unrealised morning load shift potential. Although more evening load shift was realised because of this, the amount of lost load-shifting potential still had a larger effect.

The condonable days during each month logically also influenced and reduced the obtained savings dramatically. This is because the financial savings potential is more sensitive to any small changes in a system. It is important to realise that the financial saving potential is more sensitive to changes in a system than overall load-shift savings potential.

4.3.3 Change in system control strategy

In the past the mine's control strategy was to run three pumps on 14B pump station throughout the day and control the 4_3 pump station dam according to the volume of water that flows in from 14B. Pump-station pump would run continuously for days on end.

On implementing the strategy, the mine had special requests regarding control of the dam levels. This was different from their original strategy of only controlling the dam level of the 4_3 pump station between 40% and 85%, and the dams for 14B pump station between 40% and 60%. Their request is shown in *Table 4-4* below.

Table 4-4: Dam control strategy as requested by mine [61]

	Dam Levels (4_3)	Dam levels (14B)
Start 3rd pump	91%	55%
Start 2nd pump	87%	50%
Start 1st pump	50%	45%
Stop 1st pump	43%	35%
Stop 2nd pump	41%	33%
Stop 3rd pump	39%	31%

The new control strategy that was incorporated by the real-time energy management strategy is not distinctively different from the original that was used in the past. Mostly the maximum allowable number of pumps are utilised on 14B pump station to keep the 25 level dams as low as possible throughout the day. As the head losses on 4_3 pump station are less than for 14B pump station, the 4_3 pump-station pumps are able to pump water more efficiently.

The new control strategy for the 4_3 pump station is therefore also set to control the pumps according to the volume of water that flows in from 14B pump station, and the dam level specifications as were provided by the mine in *Table 3-2*. This also ensures that the lowest amount of pump switching is performed.

4.4 Measured results for Tau Tona

As with Harmony 3#, a load-shifting strategy used to achieve the savings potential calculated in chapter 3 had to be implemented on the Tau Tona water pumping system. The automation of the system was, however, a massive operation and is currently still under way, owing to many delays.

For this reason, no results as generated by automatic, real-time load shifting can be shown. Fortunately, a manual load-shifting strategy was undertaken, to maximise energy savings during the high demand season. The results of this strategy are given in the next section.

4.4.1 Real load-shifting results

The load-shifting results for the period since the load-shift strategy was implemented are shown in *Table 4-5*. It is important to note that the manual load-shifting strategy had no negative effect on the pumping system or any other system that relies on the pumping system for water, during this period.

The results that were realised prove that the load-shift potential calculated in *chapter 3* can be realised at such a complex system as Tau Tona mine. The results show that an average amount of more than 6 MW can be shifted out of the evening peak period with the help of a manual load shift strategy. Unfortunately, the full load-shift potential, as calculated in *chapter 3*, was only attained during a single month, and shows that a manual load shift strategy cannot utilise the full savings potential of the system.

Table 4-5: Results generated by load-shifting strategy at Tau Tona mine

Month	Average Daily electricity usage (MWh)	Average Morning Load Shift (MW)		Average Evening Load Shift (MW)	
		Potential	Obtained	Potential	Obtained
Jun-06	295	5.00	4.50	7.00	6.88
Jul-06	299	5.00	0.94	7.00	7.05
Aug-06	312	5.00	4.72	7.00	6.35
Sep-06	318	5.00	2.60	7.00	6.32
Oct-06	260	5.00	1.19	7.00	5.18
Average	297	5.00	2.79	7.00	6.36

The load shift that was realised during the morning peak period was, as with Harmony 3#, not close to the potential that was calculated in *chapter 3*. This can also be attributed to the fact that more water is utilised during the morning periods in comparison with the evening peak period. For this reason, it is also more difficult to schedule the pumping during this period.

The average daily system energy usage of the system baseline was calculated as 267 MWh in *chapter 3*. In the table, this average changes at an inconsistent rate. This can be seen as a reason for the lower than required load shift performance. The fact that Tau Tona is also a very complex system with limited underground dam capacities, also explains the inconsistent results shown in the table.

During this performance evaluation period, there were also problems encountered due to the old infrastructure in the mine, which caused condonable days. As can be seen in *Table* 4-6 an average of 7 condonable days per month was recorded due to the reasons also supplied in the table. These reasons were mainly due to the old infrastructure in the mine, which takes longer than normal to repair.

Table 4-6: Influence of condonable days at Tau Tona mine

Month	Weekdays	Condonable days	Main reason for condonables
Jun-06	22	2	Pump maintenance
Jul-06	21	5	Pump maintenance
Aug-06	23	4	Large increases in water usage
Sep-06	21	8	Broken settlers influenched pump scheduling
Oct-06	22	15	Burst water columns
Average	22	7	

The average manual, load-shift optimised pumping profile that was realised during the evaluation period is shown in *Figure 4-3.* This profile excludes condonable days and is compared against the normalised baseline profile and the simulated optimised profile in the figure.

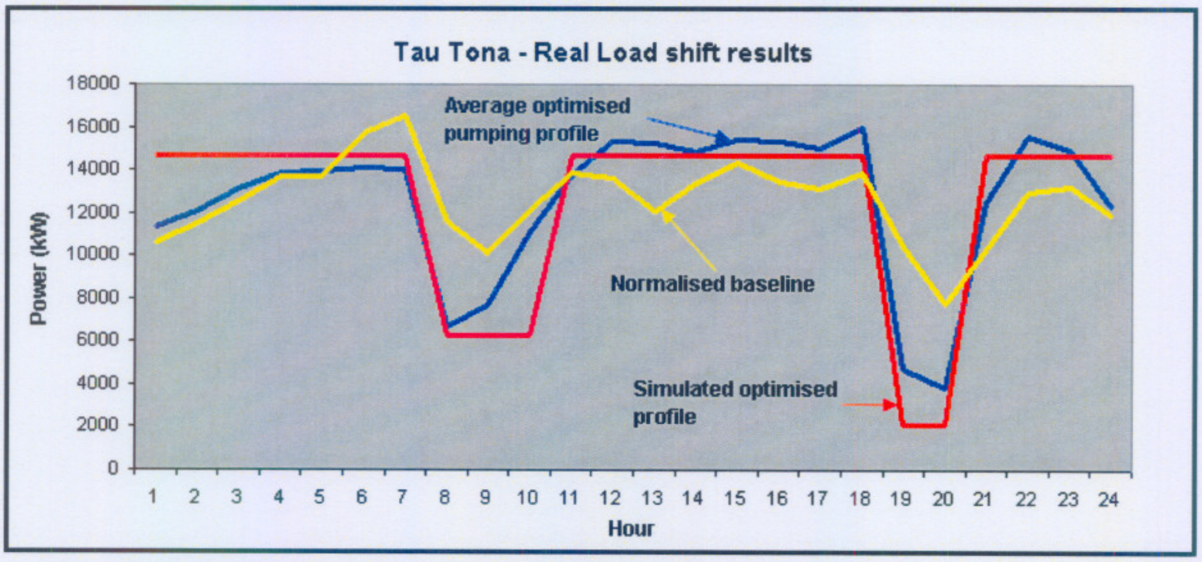


Figure 4-3: Load shift profile that was realised at Tau Tona mine

The average optimised profile in the figure is very similar to the simulated optimised profile. This shows that the potential that was calculated in *chapter 3* can be realised if more preparation work is done before peak periods, and less pumping is done during peak periods. If the average optimised profile is compared with the normalised baseline profile, the true influence of the load-shifting strategy can be observed.

4.4.2 Electricity cost savings

The financial savings brought about by the load-shifting strategy is shown in *Table 4-7*. The estimated saving results show that a large financial saving was realised through the implementation of the load shift strategy.

Table 4-7: Estimated financial savings realised for Tau Tona mine

Month	Average Morning Load Shift (MW)	Average Evening Load Shift (MW)	Estimated Monthly Financial Saving	
			Potential	Obtained
Jun-06	4.50	6.88	R 315,000	R 237,580
Jul-06	0.94	7.05	R 315,000	R 115,156
Aug-06	4.72	6.35	R 315,000	R 201,695
Sep-06	2.60	6.32	R 55,000	R 16,394
Oct-06	1.19	5.18	R 55,000	R 9,094
Total			R 1,055,000	R 579,920

The full potential was however not realised due to the reduced load shift performance during both morning and evening peak periods. For this reason, the financial saving was not nearly as much as the calculated potential for each month. The big effect of condonable days can again be seen by examining the financial savings for October 2006. There were 15 condonable days during this month, which played a large role in not realising the estimated potential savings.

The average optimised pumping profile is again shown in *Figure 4-4*, together with the simulated optimised profile. By comparing the average optimised profile with the electricity tariff structures, which is also seen in the figure, the reason can very easily be identified why the maximum savings potential was not realised. From this figure, it is also clear that more preparation has to be done before peak time, to ensure that the maximum amount of dam capacity is available for load shifting during peak periods.

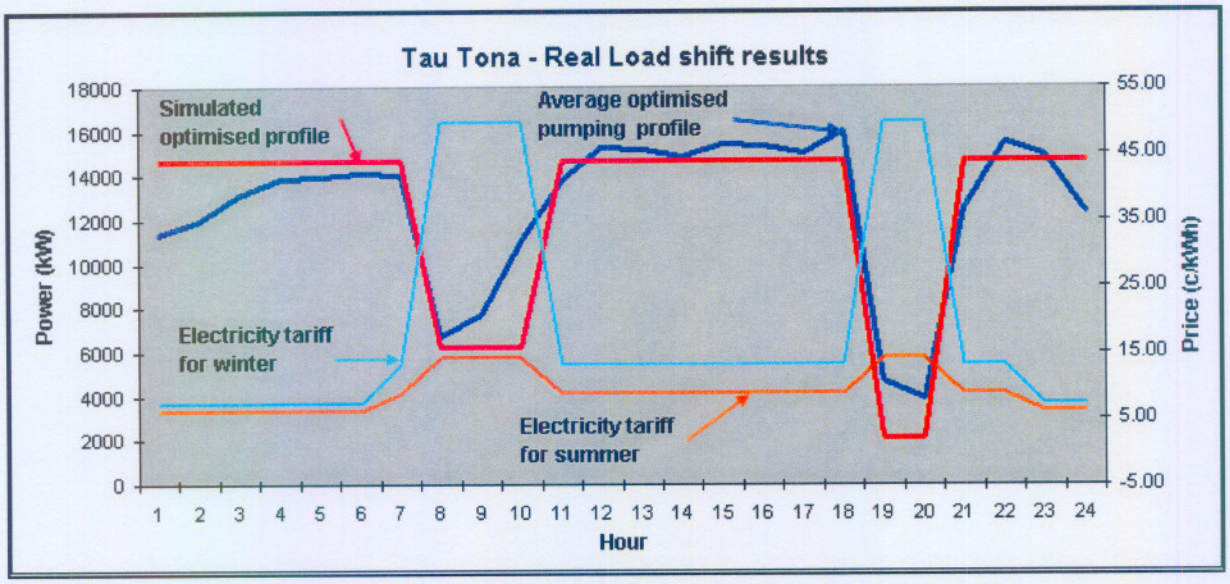


Figure 4-4: Real load shifting results for Tau Tona mine

4.4.3 Change in system control strategy

A strategy was devised to control the Tau Tona pumping system to shift load by manual operator control. This was done by controlling the system as in the past with a few alterations. The following methodology was used to incorporate load shifting into the original control strategy:

1. An automatic alarm is issued in the control room, warning the control room operator (CRO) that a peak period will start in two hours.
2. CRO notifies PO on each pump station to start a maximum number of pumps, to prepare for peak time.
3. PO on each pump station start the maximum number of pumps.
4. An automatic alarm alerts CRO that peak time has started.
5. CRO alerts POs to stop all available pumps.
6. POs stop all pumps.
7. Automatic alarm alerts CRO that peak time is over.
8. CRO notifies the POs that they may start pumps and commence as normal.

The automatic alarm was used to remind the CROs at Tau Tona mine as they have other important tasks that may overlap with this load-shifting strategy. Except for the steps that are followed during this strategy, the CROs and POs must always be aware of the system's characteristics and make sure that there are no chances of flooding during peak periods.

For this reason, the following changes to the strategy were made: (a) if the dam levels rise above a certain level, a PO is allowed to start a pump, and (b) the CRO supervises the process from the control room and has to be aware of all of PO operations at all times.

4.5 Measured results for Beatrix 1#, 2#, 3# mine

As with both other case studies, implementation of the proposed load-shifting strategy relied on the automation of the collective Beatrix mine pumping system. The installation of a real-time energy management system was also required. This process was completed during June 2006 and the results for the period thereafter are discussed below.

4.5.1 Real load-shifting results

The results that will be discussed were generated by automatic, real-time control of the Beatrix 1#, Beatrix 2# and Beatrix 3# pump stations. As these three shafts were analysed as a single water pumping system, the results will also be discussed and analysed collectively. The results generated by the load shift strategy are shown in *Table 4-8*.

Table 4-8: Real load-shifting results for Beatrix 1# shaft

Month	Average Daily electricity usage (MWh)	Average Morning Load Shift (MW)		Average Evening Load Shift (MW)	
		Potential	Obtained	Potential	Obtained
Jul-06	154	3.00	0.53	5.30	5.57
Aug-06	137	3.00	0.77	5.30	5.06
Sep-06	159	3.00	0.85	5.30	5.52
Oct-06	168	3.00	0.48	5.30	5.16
Average	155	3.00	0.66	5.30	5.33

As can be seen in the table, an evening load-shift average of more than the potential was realised during two of the four months, while the average for the other two months were just below the potential. This shows that the evening load shift can be realised at a sustainable rate. The average daily electricity usage also stayed constant, except for August 2006. During this month, this may have had an effect on the overall load shift performance.

The morning, load-shift performance was however not satisfactory during any month. The average performance is little more than a third of the actual potential for morning load shifting. This can however again be attributed to the increase in water usage due to mining activities during these periods. As the dams at Beatrix 3# are also very small, they cannot handle any excess water if sufficient load must be shifted.

Table 4-9: Influence of condonable days at Beatrix mine

Month	Weekdays	Condonable days	Main reason for condonables
Jul-06	21	4	Pump maintenance and communication problems
Aug-06	23	10	Burst columns
Sep-06	20	6	Pump maintenance and power failures
Oct-06	22	7	Increase of water during critical periods of day
Average	22	7	

There were again a certain amount condonable days recorded for each month. These and the main cause of condonable days during each month are shown in *Table 4-9.* Again, there was an average of seven condonable days during a month, caused mostly by unreliable infrastructure.

The profile of the average optimised results, generated at Beatrix mine, is shown in *Figure* 4-5. By comparing the average optimised profile with the simulated optimised profile, a distinct difference can be noted before the morning peak period. This shows that the preparation for the morning peak period by the strategy is not sufficient to allow the maximum down time during morning peak periods.

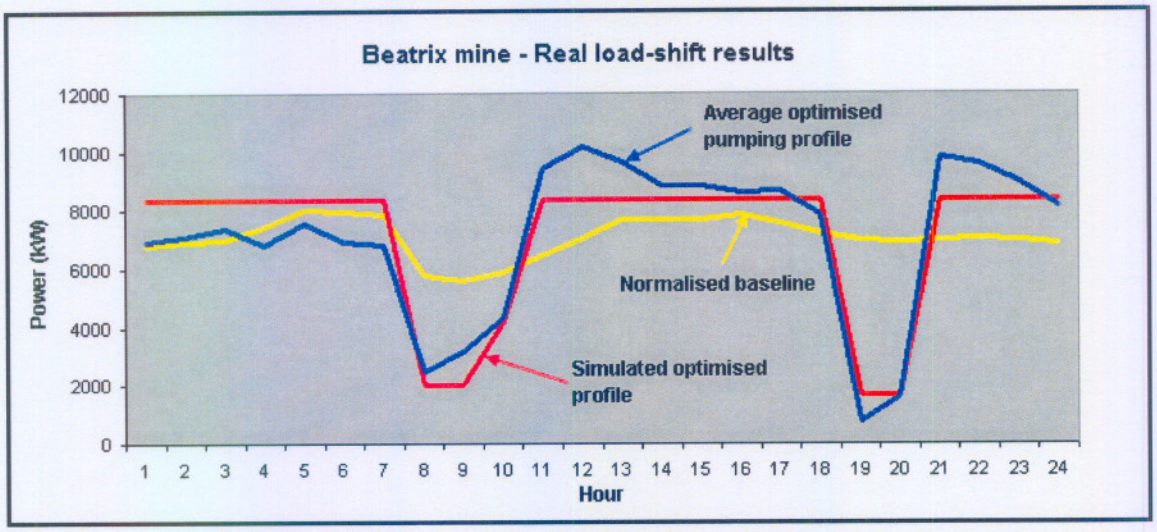


Figure 4-5: Real load shift results at Beatrix mine

In addition, the slight dip before the evening peak period, can explain the need for pumps to start pumping before the evening peak period is over. The fact that the baseline is also so low during morning peak periods complicates the process to shift the maximum potential of load.

4.5.2 Electricity cost savings

The estimated financial savings that were realised by the load shift strategy at Beatrix mine is shown in *Table 4-10*. The financial saving potential that was calculated for Beatrix mine was not fully realised. The loss in savings can be attributed to the bad morning load-shift performance, compared to the potential, and the large amount of condonable days that was recorded.

Table 4-10: Financial savings generated at Beatrix project for period of analysis

Month	Average Morning Load Shift (MW)	Average Evening Load Shift (MW)	Estimated Monthly Financial Saving	
			Potential	Obtained
Jul-06	0.53	5.57	R 170,000	R 100,449
Aug-06	0.77	5.06	R 170,000	R 98,021
Sep-06	0.85	5.52	R 29,000	R 22,192
Oct-06	0.48	5.16	R 29,000	R 18,354
Total			R 398,000	R 239,016

The average, load-shift optimised, pumping profile for Beatrix mine is again shown in *Figure 4-6.* By comparing this profile with the simulated optimised profile, the reason can easily be seen why the obtained savings is lower than the potential savings. This is as the average optimised profile is higher than the simulated profile during periods with high electricity tariffs, and below the same profile during periods with a lower tariff.

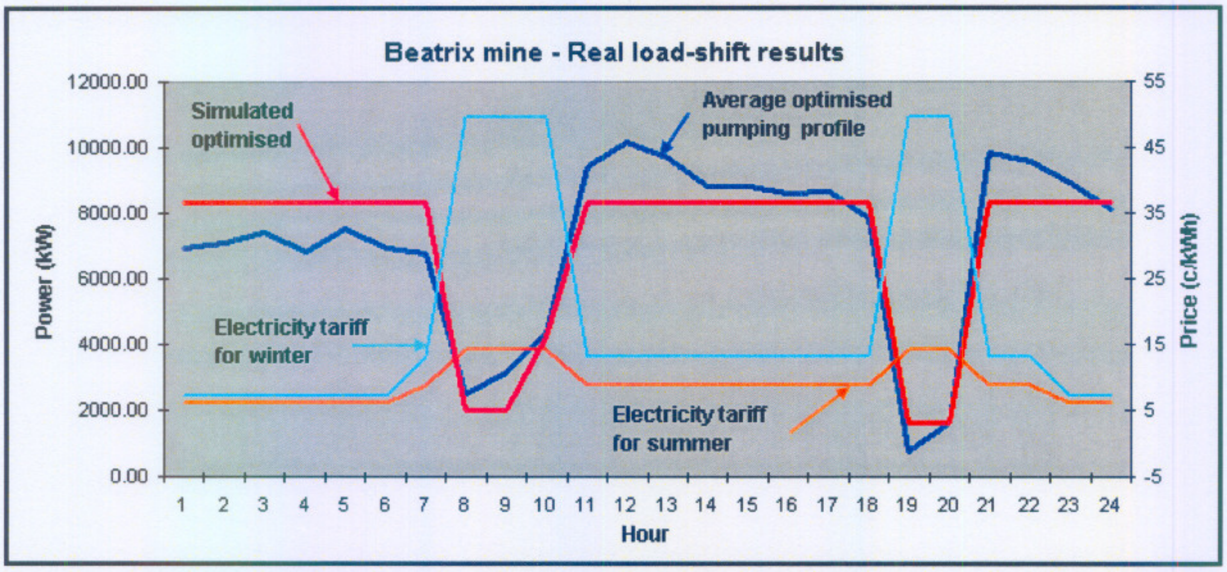


Figure 4-6: Cost saving results for Beatrix system

4.5.3 Change in system control strategy

With the implementation of the project on the collective Beatrix mineshafts, a few changes were made in the control strategy of the system.

a) Beatrix 1#

As is already known there are six pumps in the Beatrix 1# pumping station. In the past, there were only two pipe columns for pumping the water from the station to surface level. As three pumps were the average number of pumps that were utilised during the calculation of the baseline, two pumps had to be used in a parallel configuration on one pipe column. Because of the interrelationship between the systems pressure head, the pump flow rates and the system curves; it proved an inefficient strategy.

The pumping efficiency of a pump station can be improved by reducing the number of pumps that pump into a column.

When pumps run in parallel and pump into a single column [44]:

- the produced flow is increased
- the pressure head produced stays approximately the same as for a single pump.

The produced flow does not, however, increase proportionally to the increase of pumps that pump into the same column. This is illustrated in *Figure 4-7.* Each pump will operate at the same pressure head, but will share the flow rate with the other pumps. Because of the slope of the system curve, the pumps in this arrangement will each operate at a lower flow rate when operating together than would have been the case if they operated alone on the same system [62].

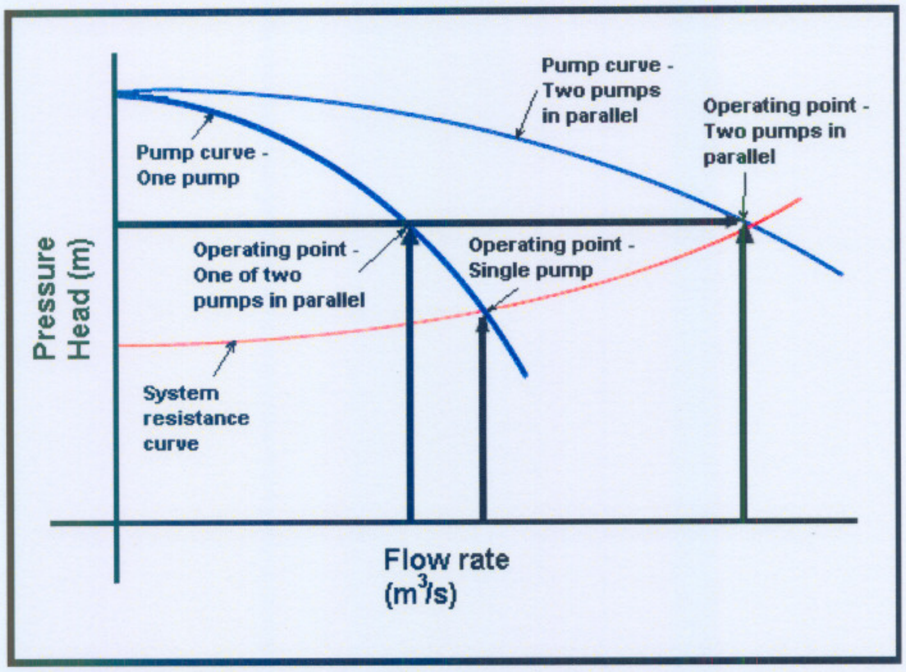


Figure 4-7: Parallel pumping operation

On implementing the load-shifting strategy, the decision was made to install a third column. Owing to this, it is currently possible to have three pumps running simultaneously, each pumping into a separate column. All of the pumps can therefore now pump closer to their rated flow rates, which makes the pumping on the pump station much more efficient.

b) Beatrix 2#

At Beatrix 2#, the control strategy also remained as in the past, with only the real-time energy management strategy having an influence on the scheduling of the pumps. The dam level is still being controlled between 10% and 60% with a maximum of three pumps allowed to run at any one time.

c) Beatrix 3#

Currently Beatrix 3# has three pumps - one with a 1 600 kW pump motor and the remaining two with 800 kW motors. In the past the 1 600 kW pump was operated continuously with one of the 800 kW pumps running as a second pump. Both of the pumps pumped into a single column.

The 1 600 kW pump generates a much larger flow rate than the smaller pumps. This also caused inefficient pumping, as the maximum flow rate that could be generated by the 1 600 kW pump and the 800 kW pump together was 130 ℓ/s. By allowing the two smaller pumps to pump together, a flow rate of 112 ℓ/s was generated. This can be explained by the relationship shown in *Figure 4-7*.

When the two small pumps pump together, the real collective flow rate is only reduced by 14% from the designed collective flow rate, whilst the kW usage is reduced by 36%. This resulted in more efficient pumping and was made part of the new control strategy.

4.6 Conclusion

Throughout this chapter, the real load-shifting results have illustrated the reality of load shifting potential at three different old mines. The realised financial savings also show the reality of possible financial savings due to energy management at old mines.

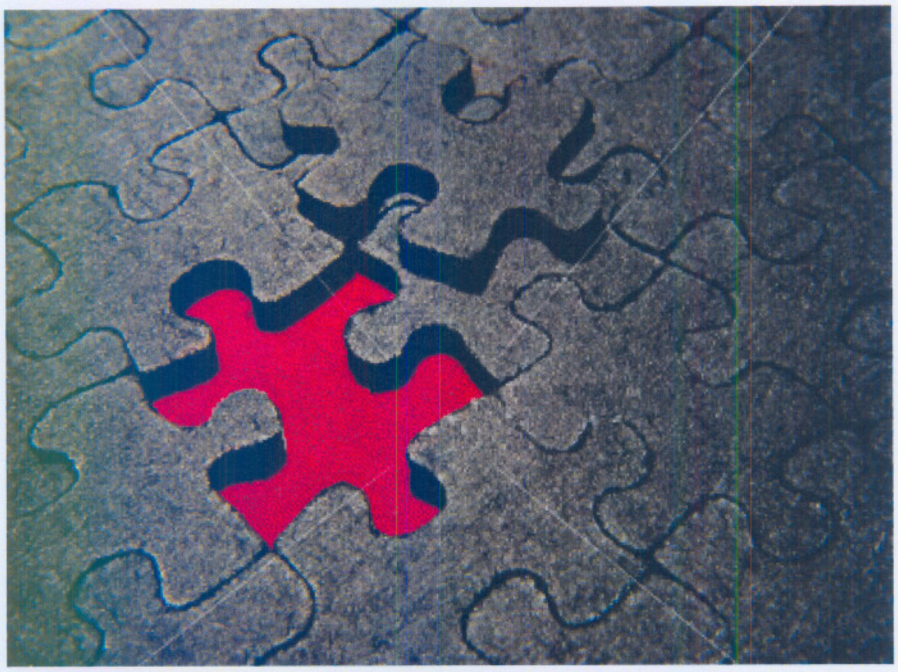
At Harmony 3#, the implemented load-shifting strategy has generated results that is higher than the potential, at a constant rate. The estimated savings have unfortunately not been realised due to many problems with old infrastructure, causing many condonable days. Most of these issues cost major amounts of system downtime and labour to correct.

A manual load shift strategy was implemented at Tau Tona mine, as the automation infrastructure, required for the real time energy management system is still underway. The strategy produced constant results, but due to the complexity of the system, the results were mostly lower than the true potential. This signifies the importance of a real time energy management system for a complicated system as the Tau Tona water pumping system.

The implementation of the real time energy management strategy at the collective Beatrix mineshafts also generated sufficient load-shift results. This verified the potential that was determined in *chapter 3*.

With all the case studies, a large amount of condonable days was recorded during each month. This greatly influenced the financial savings that could be realised and also in some case the overall load shift performance. Most of these condonable days were caused by the unreliable and old infrastructure in the mines, which caused large amounts of system down time.

5. CLOSURE



This chapter gives an overview of the dissertation, and subsequently derives a conclusion based on the comparison of the simulated results with the real system results for each case study. Recommendations for further research in this field of study are also made.

5.1 Conclusion

The purpose of this dissertation was to research certain aspects of real-time energy management on old gold mines. These aspects were listed in *section 1.3* and are now discussed based on the results and conclusions made in the previous chapters.

a) The potential for energy management on old gold mines

Chapter 1 of this study showed that gold mines were always and are still today very large electricity consumers. Due to the very low cost of electricity in South Africa, the industrial and mining sectors developed in a very energy inefficient manner. On gold mines, in particular, the high price of gold during the 1970s, made the cost of electricity inferior to the profits of high but energy intensive gold production levels.

Today, because of the age of the gold mining industry, most gold mines are old and still use old, proven and energy-intensive methods and infrastructure. The large drop in the gold price during the nineties, which lowered investments into new energy efficient infrastructure upgrades on the then on old gold mines, even further worsened this situation.

Due to this, there are major opportunities for energy savings on old gold mines. This research has substantiated this statement through the load-shift potential that was calculated in *chapter 3* for three old gold mines, and was later verified through the real saving results shown in *chapter 4*. The fact however remains that to save energy, energy consumption must be managed correctly. This sheds light on the large potential for energy management on old gold mines.

b) The potential for the implementation of sustainable energy management strategies on old gold mines

The research into the potential for load shift at the three old gold mines in *chapter 3* has shown the large potential for energy savings at these mines. Through the Eskom DSM process, strategies were implemented on the mines, without influencing the mining or production levels in any manner. The results as discussed in *chapter 4* confirmed this potential.

There were however factors that influenced the sustainability of the strategies. Through research into the main reasons for condonable days on each mine, it was found that the old infrastructure in the old gold mines, were mostly unreliable due to age and lack of maintenance. This caused major amounts of time in which the load-shift strategies could not be executed, which resulted in reduced load-shifting performance and reduced the realised electricity cost savings for the mine.

Another factor that played a role on Tau Tona mine was the absence of a real time energy management system. As discussed in *chapter 4*, the full load shift and cost savings potential on the mine could not be realised by a manual load shift strategy, which is reliant on human intervention.

The complexity of the Beatrix system results showed that sustainable load shifting can be realised collectively over a three-mine shaft system with a real time energy management system that controls the full system. The importance of the pumping operation at Harmony 3#, and the relative importance that a pumping system is controlled within certain system constraints as researched on all three mines, further substantiates the need for an automatic real time energy management system.

The last factor that has an impact on the sustainability of energy management strategies on old gold mines is the commitment from the mine to realise sustainable savings. From the results shown in *chapter 4*, it was seen that if maintenance on even newly installed infrastructure required by the strategies is not done promptly and frequently by mine personal, major amounts op saving opportunities can be missed.

According to these findings, the following conclusion can therefore be made. The potential for the implementation of sustainable energy management strategies on old gold mines is large if:

- Most of the unreliable infrastructure required by the load shift strategy can be upgraded or repaired
- An automatic real time energy management system controls the system and implements the strategy
- The mine offers commitment to the strategy and maintains the systems required by the strategy

c) Challenges associated with the implementation of energy management strategies on old gold mines

Through the research into the challenges associated with implementation of energy management strategies on old gold mines, the following challenges were identified:

1. The old unreliable infrastructure in the mine
2. The absence of system control infrastructure
3. The absence of a centralised control centre
4. Problem with mine workers unions due to possible labour cuts
5. Influence of load shifting on production
6. Mine resource shortages
7. Sustainable load shifting

Although all of these challenges were overcome, it must be made clear that any of these challenges can delay or prevent the implementation of an energy management strategy on an old gold mine. An analogy can however be found between these challenges and the requirements for the implementation of a sustainable energy management strategy on an old gold mine as shown in the previous section. This is that all of these challenges were overcome by fulfilling the abovementioned requirements.

d) The feasibility of energy management strategies on old gold mines

A conclusion regarding the feasibility of energy management strategies on old gold mines can be made at the hand of the conclusions made in the previous sections. There exists potential for energy management on old gold mines. There exists large potential for the implementation of sustainable energy management strategies on old gold mines if certain requirements are fulfilled. All of the challenges associated with the implementation of such strategies on old gold mines during this study can be overcome by the above-mentioned requirements.

Eskom DSM, through the process of a DSM project can fulfil all of the above-mentioned requirements with the capital funding available for especially such projects. According to this, the conclusion can therefore be made that energy management strategies on old gold mines are definitely feasible with the help of Eskom DSM.

5.2 Recommendations for further studies

There are endless recommendations that can be made for further studies in the field of energy management, but only a few that are thought to be in line with the view of this thesis. One of these is an analysis of methods for changing current mining systems or designing new mining systems to maximise EE and simplify energy management.

Another recommendation is to analyse the effect on a mine if all the mine's processes are controlled by a real-time energy management system. To be able to prove the extent to which energy management (if correctly implemented) influences the processes and production on a mine, will be of great service to society. Weighing up the advantages and disadvantages of load shifting and energy management will be the first step.

The clear-water pumping system is only one electricity-intensive process on a mine. There are many other industrial and mining processes where load shifting could be successfully implemented. The primary requirement for such processes must be sufficient surge capacities so that equipment can be switched off during peak times [63].

Such situations are found in other mining processes, such as:

1. mine refrigeration plants
2. mine ventilation fans
3. mine vertical rock winders
4. mine as well as industrial compressed air machines

5. cement plants.

A further recommendation is for further research to be done on other large energy consumers and their capability of implementing energy management.

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