RESEARCHING THE LONG-TERM IMPACT OF LOAD MANAGEMENT PROJECTS ON SOUTH AFRICAN MINES

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ABSTRACT

Title: Researching the long term impact of load management projects on South African mines

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Keywords: DSM, ESCO, load shift, clear-water pumping system, Eskom, EMS.

Eskom is currently facing an energy crisis due to the limited operational electricity generating capacity in South Africa. The historically low electricity price, the rapid growth in economy and the energy intensive nature of South African industries are the most common reasons for the peak supply problem.

Various supply and demand technologies have been identified to address this energy crisis. Due to the lengthy process of building new peaking load power stations, Eskom has initiated the Demand-side Management (DSM) programme as a solution to the short-term supply problem.

The National Energy Regulator (NER) has set targets to Eskom DSM to reduce the evening peak demand by 153 MW per annum and 4 255 MW over a 20-year planning horizon. Due to the energy intensive nature of the mining industry, it has been targeted for DSM savings. To date there have been a number of DSM projects implemented on the clear-water pumping systems of various mines, with a large potential for DSM savings identified on future projects still unrealised.

The generation benefit of DSM load-shifting projects is twofold; firstly Eskom's evening load capacity increases due to the reduction in demand during these periods and secondly, the mine receives electricity cost savings due to load management practices. Because Eskom DSM is dependent on the client consumer to accept and roll-out the DSM programme, client satisfaction is of paramount importance. Due to the fact that load-shifting efforts require from the mine to change their normal operating schedules, there is uncertainty on the impact and knock-on effects of DSM projects on a mine.

Therefore, the purpose of this study is to investigate and thereafter quantify the overall impact of DSM load-shifting on the clear-water pumping system of South African mines. A generic model was developed by performing case studies on existing DSM projects. This model was then applied to future DSM projects to validate the findings made throughout the research study.

The case studies performed on existing DSM projects, as well as the results obtained when modelling the overall impact of DSM on future mines, proofs that DSM definitely benefits a mine. The total annual cost saving on the four future DSM projects is predicted to be in the order of R 7.64 million instead of the R 4.27 million when considering only the electricity cost savings to the mine.

SAMEVATTING

Titel: Ondersoek die langtermyn impak van lasbestuur projekte op Suid-Afrikaanse myne

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Sleutelwoorde: DSM, ESCO, las verskuif, myn waterpompstelsel, Eskom, EMS

Suid-Afrika se energie-reus, Eskom, staar huidiglik `n energiekrisis in die oë as gevolg van die beperkte energie-opwekkingskapasisteit in die land. Die beperkte toevoerkapasiteit gedurende piektye van die dag kan hoofsaaklik toegeskryf word aan die lae prys van elektrisiteit in die velede, vinnige ekonomiese groei en die energie-intensiewe aard van Suid-Afrikaanse industrieë. Verskeie tegnologiese voorstelle rakende die vraag en aanbod na energie is reeds geidentifiseer om die energiekrisis aan te spreek. Omdat die oprigting van nuwe kragopwekkingstasies so 'n tydrowende proses is, het Eskom die DSM (Demand-side Management) program geïnisieer met die doel om die korttermyn elektrisiteitstekort aan te spreek.

Die NER (Nasionale Enegie Reguleerder) bestuur, reguleer en stel doelwitte vir Eskom se DSM inisiatief. Die hoofdoelwit van die NER is om die vraag na elektrisiteit gedurende aand piek-tye met 153 MW per jaar te verlaag (4 255 MW oor `n periode van 20 jaar). DSM fokus spesifiek op die industriële sektor vir energiebesparings as gevolg van die energie-intensiewe aard van hierdie sektor. Alhoewel daar tans reeds `n groot aantal DSM projekte geimplimenteer is op skoon-water pomp stelsels van verskeie myne, is daar nog baie potensiaal in toekomstige projekte wat nog nie gerealiseer is nie.

Die tweeledige voordeel van geimplimenteerde DSM lasskuif projekte op myne is as volg; eerstens word die Eskom piekkapasiteit verhoog deur die vraag na elektrisiteit te verlaag en tweedens ontvang die myn elektrisiteits koste-besparings deur middel van lasbestuur. Omdat Eskom se DSM inisiatief afhanklik is van die kliënt om die doelwit energiebesparings te bereik, is dit noodsaaklik dat die kliënt se belange ten alle tye eerste gestel word. Omdat die huidige operasionele skedules op die myn deur `n outomatiese stelsel beheer word om energiebesparings te realiseer, is daar onsekerheid oor die impak en gevolge van DSM projekte op die myn.

Om die ware impak van DSM projekte op skoon-water pomp stelsels in Suid-Afrikaanse myne te bepaal, word alle faktore wat deur DSM beïnvloed word geidentifiseer, ondersoek en gekwantifiseer. Uit gevallestudies op bestaande DSM projekte is `n "generiese" model opgestel. Om die geldigheid van hierdie studie te bewys is hierdie generiese model toegepas om vooruitskattings te maak oor moontlike toekomstige DSM pomp projekte.

Gevallestudies op bestaande DSM projekte, asook die resultate wat verkry is deur die totale impak van DSM op die moontlike toekomstige projekte te modelleer, bewys dat DSM werklik `n voordeel vir die myn inhou. Die totale vooruitskatte jaarlikse koste-besparing op die vier toekomstige DSM projekte is in die orde van R 7.64 miljoen in plaas van R 4.27 miljoen wanneer slegs die elektrisiteit koste-besparing vir die myn in ag geneem word.

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LIST OF ABBREVIATIONS

DME	Department of Minerals and Energy
DOL	Direct on-line
DSM	Demand-side Management
EE	Energy Efficiency
EMI	Electromagnetic interference
EMS	Energy Management System
ESCO	Energy Services Company
GDP	Gross Domestic Product
GWh	Giga Watt Hours
HMI	Human Machine Interface
HT	High Tension
HVAC	Heating Ventilation & Air Conditioning
IEP	Integrated Energy Plan
IRP	Integrated Resource Planning
ISEP	Integrated Strategic Electricity Plan
kVA	Kilovolt-ampere (Standard Unit for Peak Demand)
kVAh	Kilovolt-ampere Hours
kVAR	Kilovolt-ampere Reactive (Reactive Power)
kW	Kilowatt
kWh	Kilowatt-hour
l/s	Liters per second
LM	Load Management
LR	Load Reduction
LT	Low Tension
M&V	Measurement and Verification
MD	Maximum Demand
ML	Mega Liters
MW	Megawatt
MWh	Megawatt-hour
NER	National Electricity Regulator

PLC	Programmable Logic Controller
RDP	Reconstruction and Development Programme
REMS	Real-time Energy Management System
SCADA	Supervisory Control and Data Acquisition
SSM	Supply-side Management
TOU	Time-of-use
VRT	Virgin Rock Temperature
VSD	Variable Speed Drive

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CHAPTER 1: INTRODUCTION

This chapter presents the literature overview and background of the current energy situation in South Africa. The purpose of this chapter is to ensure the successful understanding of the peak electrical demand problem facing Eskom, which led to the Demand Side Management (DSM) initiative.

1.1 THE ENERGY CRISIS IN SOUTH AFRICA

1.1.1 Preamble

"By 2007 Eskom's surplus peaking load capacity will run out" [1]-[4]. This prediction appears in many articles currently published with regard to the electricity situation in South Africa. Operational generating capacity in South Africa currently (2006) totals 36 398 MW [4] with the reserve capacity narrowing down to below 10% [5]. To align its reserve margin with international norms, Eskom has planned for a capacity of 15% on the long-term [4]. Eskom's generating capacity, assuming a 50-year life per plant, is indicated in Figure 1-1 [6]:

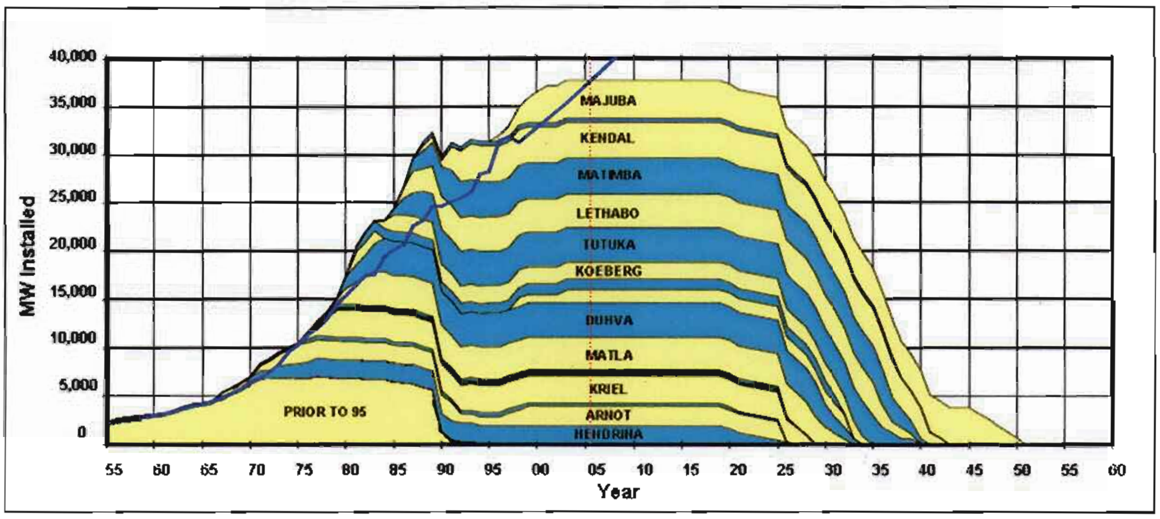
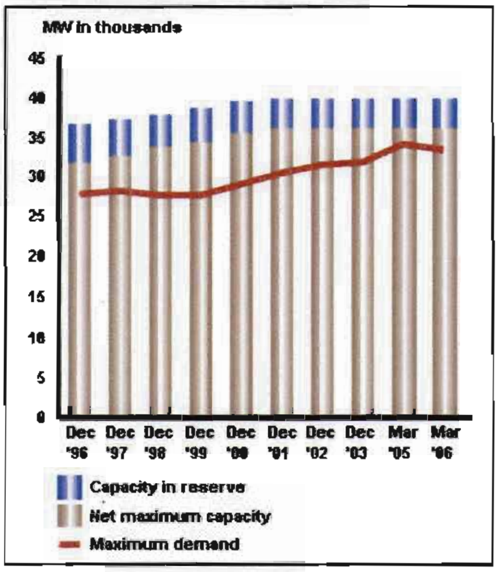


Figure 1-1: Eskom's electricity generating capacity as a function of time

The generating capacity is primarily coal-fired and the graph indicates that the current generating plants will only be in operation until at least the year 2020. The blue line in Figure 1-1 illustrates the electricity demand over time, while the red line indicates that further generating capacity will be required by the year 2007.

Furthermore, it is sobering to think that whilst current concerns relate to additional capacity to accommodate growth in demand, after the year 2020 generating capacity will be required to replace the existing 36 398 MW. Current concerns seem trivial when compared with the task foreseen post 2020.

Figure 1-2 on the following page shows trends in generation plant capacity by Eskom and peak demand for electricity, indicated by the red line, for the period 1996 to 2006 [4]. Although the peak demand shows an upward trend from 2000, the operational generating capacity remained unchanged. The average growth in peak demand over the period 1990 to 2004 is 4,0% [7]. In other words electricity demand in South Africa is currently estimated to be growing by approximately 1 000 MW per annum [3].



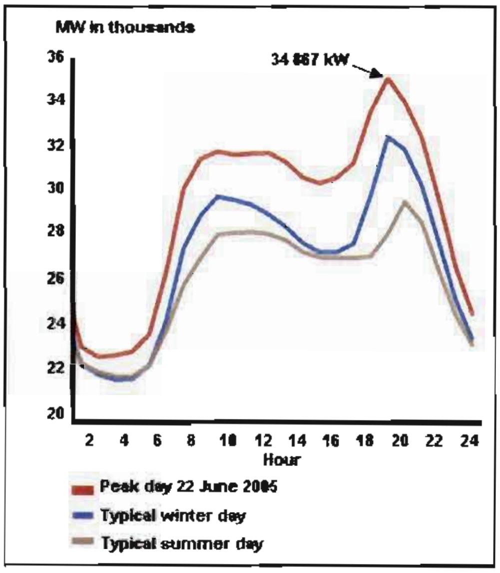


Figure 1-2: Generation capacity and maximum demand

Figure 1-3: Electrical demand profile for 2005 - 2006

From Figure 1-3 it can be seen that the highest recorded peak demand up to now is 34 867 MW (22 June 2005) [4]. This is substantially higher than the previously highest peak demand of 34 195 MW recorded on 13 July 2004 [7][8]. The next highest peak demand recorded was 31 928 MW (2003) [9]. This means that there was a significant decrease in the generation reserve margin from 12,2% in 2003 to 4,2% in 2005. Given a forecast peak demand for winter 2006 of 35 100 MW, there is sufficient capacity to meet demand and operational reserve requirements for this period [4]. System stability will be of paramount importance with generation and transmission networks operating at full capacity.

Referring back to Figure 1-3, it is also clear how electricity demand by customers in South Africa changes during a 24-hour period. During the winter months (blue profile), the average demand is higher than the summer months (gold profile). During winter, both the morning and evening peak demands are more prominent, since there is a significant increase in the evening peak demand with the need for heating.

Eskom, which produces 95.9% of South Africa's electricity requirements, is currently devoting a great deal of their attention on the supply issues [4]. If South Africa is to experience a colder-than-ever winter in 2007, the possibility exists that the peak demand will exceed the generating capacity. Due to the cost and lengthy process to restore the 15% reserve margin, Eskom has a number of short-term supply options in place for the winter of 2007 [5].

With the electricity demand closing down on supply, Eskom has been criticised for being in a national electricity crises. Steve Lennon, Eskom's Resources and Strategy Managing Director, explained that the Western Cape issues have to be separated from the national picture for the purpose of future generating capacity shortages. He admits that Eskom is going through a difficult period, but guarantees that there are strategies in place to increase supply so it matches demand. The national situation points to an increase in growth of demand for electricity of 2,5% a year and it is anticipated that this figure will grow to about 4,5% if the country attains the targeted gross domestic product (GDP) growth of 6%. This growth in electricity demand will lead to an expectation of 65 000 MW in generating capacity in 2024, which requires huge investments in new power stations and new transmission lines [10].

1.1.2 Reasons for the electricity crisis

South Africa has a history of overcapacity in electricity, which made its power cheap and reliable. The historically low electricity price in conjunction with the rapid growth in economy and the energy-intensive nature of the South African industry are the most common factors for the energy crisis.

Together with these factors, Eskom determined in 2002 that the restructuring process of the South African electricity industry is far more complex and was taking much longer than originally anticipated. As time went on and demand began catching up with supply, the point of realisation was later reached that the responsibility for newly built capacity will also fall on the shoulders of Eskom. Consequently, Eskom's focus shifted to the construction of these new plans, by conducting feasibility studies and by investing millions of rands in the supply field. Although the government prohibited engagement in these kinds of activities (because of the anticipated restructuring of the South African electricity industry), Eskom still took the risk and followed through with the investigation.

Starting in 2000, Eskom however was the only organisation doing studies on the entire energy industry, calculating the additional capacity that South Africa would require in future and estimating when this additional capacity would need to be introduced in order to meet the demand. With the reasonable growth in electricity demand up to 2002, Eskom estimated that additional capacity would only be needed in 2012. However, this expected date changed to 2007 due to the following reasons [11]:

- The current energy crisis is related to activities in three load sectors, namely the residential, commercial and industrial sectors. The biggest contributor being the residential sector, mainly due to the rising numbers of newly electrified households. Although these rising numbers meet the requirements of government policy, it puts a strain on the utility's resources.

- Until approximately 1992, the electricity reserve margin was well above the 15% level, although the electricity demand slowly grew by approximately 2,5% per year. The drastic change South Africa experienced in 1994 had a significant influence on the electricity situation in the country. Spare capacity is rapidly being eroded by the mass housing and electrification programme of the Reconstruction and Development Programme (RDP) forming a part of the National Electrification Programme initiated by the new government in 1994. Between 1994 and May 2000 around 1,75 million homes had been connected to the national grid, while the proportion of rural homes with electricity grew from 12% to 42% [12].

- The industrial sector also contributes to the rapid growth in electricity demand in South Africa. Research has shown that the industrial sector grew at a rate of approximately 5.5% and 3.6% during 2004 and 2005 respectively [13]. Therefore it can be said that the electricity demand of the industrial sector grew at approximately the same rate as the overall growth, which contributes to the earlier need for extra supply capacity.

1.1.3 Present and future impact on the country

South Africa recently experienced the impact of power shortages and blackouts. Power failures of this magnitude have a significant impact on the various economic sectors and could lead to huge financial losses.

Power failures typically force daily consumers to buy non-electrical appliances to make a living, which cannot be afforded by the whole population. Major industries in the Cape region came to a complete standstill, which had a considerable impact on the production of such an industry. It is estimated that the losses due to power cuts in the Cape Province from 20 November 2005 to May 2006, are in the order of R 500 million [14].

It is foreseen that the same power shortages will soon occur in the Johannesburg area, with the demand exceeding the power capacity. This would not only lead to large financial losses to the country, but economic growth is also influenced by the limited supply capacity.

1.2 POSSIBLE SOLUTIONS TO INCREASE SUPPLY CAPACITY

1.2.1 Overview

Various supply and demand technologies have been identified to address the growing demand for electricity and limited generating capacity in South Africa. Eskom, in conjunction with the government, is addressing this challenge by expanding the supply options. The two supply options are the Return-to-service programme of mothballed power stations and the Demand-side Management (DSM) initiative.

According to Eskom's most recent studies, building a new peaking-load power station could take up to seven years at a cost of R16 billion [5]. In addition, it could take up to three years to return mothballed power stations to service. It is therefore clear that there will be a potential peak demand supply shortage if no drastic measures are taken soon. At the very least, the price for electricity, especially during the peak periods, will become much higher due to the higher long-run costs resulting from the investment in new generation plants.

Research has shown that Eskom will need to expand the national capacity by approximately 2000 MW per annum over a 20-year period to meet the growing demand [4]. Thus, as growing power shortages in South Africa threaten its continued economic growth, it becomes more important than ever to find ways to use energy more efficiently. Therefore, short- and long-term plans and targets are set to satisfy anticipated demand to avoid potential capacity shortfalls. The programmes put in place to achieve the targets set by the government to ensure sufficient peaking capacity as soon as 2007, and base capacity as soon as 2010, are discussed in the following two paragraphs.

1.2.2 Short-term solutions

In order to increase the supply capacity of the country, the most obvious solution to the problem is to build extra power stations. Because this is a lengthy and costly exercise and also due to the fact that the shape of the demand profile during certain time periods of the day is more of a problem than the base supply capacity, the main focus is on developing and implementing short-term solutions.

Short-term capacity expansion and network stabilisation plans lead to continued measures to increase peak demand supply capacity. Programmes put in place to meet the immediate electricity needs of the country are firstly the Demand Market Participation (DMP) programme where Eskom has an interruptible-supply contract with large energy intensive companies, i.e. metal smelters. This option equates to an additional electricity supply of 612 MW for any instance in time [5]. Secondly, the Demand-side Management (DSM) initiative aims to reduce the peak demand with 153 MW per annum for the next 25 years. This initiative started in 2003.

The other options currently in development are the two open-cycle, gas-turbine power plants, at Atlantis and Mossel Bay, which will come on-line before the winter of 2007 and the return to service of the three mothballed power stations. The above mentioned mothballed power stations are Gamden in Ermelo, Grootvlei in Balfour, and Komati, between Middelburg and Bethal. The power stations have a combined generating capacity of 3 800 MW [5]. The first two units of Gamden are already in a working condition, while Grootvlei is expected to return to service during 2007 and Komati during 2008 [15].

1.2.3 Addressing long-term needs for the country

In order for Eskom to align its reserve margin with international norms, Eskom has planned for a capacity reserve margin of 15% over the long term. The long-term refers to the next 5 to 25 years. Eskom's longer term projects are firstly aimed at increasing peaking capacity and secondly at increasing base capacity.

Given that coal-fired power stations contribute nearly 90% of the total generating capacity in the country, Eskom has long-standing contracts with the coal mining industry to produce and supply coal solely for Eskom. The various contributions made by Eskom to the national generating capacity are illustrated in Figure 1-4:

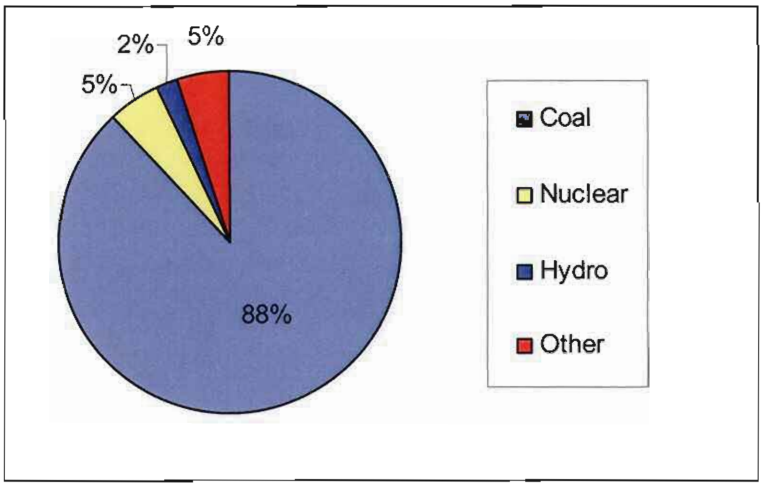


Figure 1-4: Eskom's primary energy sources

Eskom is currently doing research into further power technologies and energy sources under the integrated strategic electricity plan (ISEP) [10]. ISEP has been adopted by Eskom to integrate and expand on existing supply-side and demand-side planning activities.

Apart from the targets set for the DSM programme, which could be seen as a "virtual power station" increasing the availability of peak load capacity, Eskom will embark on a programme of building new generating plants to increase the base load capacity. Projects contributing to the base load capacity, including the return of mothballed power plants, accounts to 8 391 MW and will be completed within the next 7 years [5].

Additionally, the government wants to produce between 4 000 MW and 5 000 MW of nuclear power from the Pebble Bed Modular Reactor (PBMR) in South Africa. Estimates are showing that the first contribution of these modular reactors will only be in 2010 [16].

Furthermore, government has also set the target for renewable energy to contribute 10 000 GWh of the final energy consumption by 2013 [4]. An example of a renewable energy source already operating is the wind energy pilot plants. Research and development still continues on solar, ocean current and bio-gases technologies.

Because of the DSM programme's short- and long-term benefits of the supply capacity expansion, this initiative contributes significantly in solving the electricity crisis in South Africa. DSM is described in more detail in the next section.

1.3 DEMAND-SIDE MANAGEMENT

1.3.1 Background on DSM

The term 'Demand-side Management' (DSM) refers to a process by which electric utilities, in collaboration with consumers, achieve predictable and sustainable changes in electricity demand with the desire to change the utility's load-profile [17]. These changes are effected through a permanent reduction in demand levels (Energy Efficiency) as well as time-related reductions in demand levels (Load Management). In other words, DSM changes the current load shape by reducing the electricity demand during times when Eskom's reserve capacity is at a minimum.

The following programmes all emphasise the importance of the Eskom DSM programme; (i) the Department of Minerals and Energy's (DME) White Paper on Energy Policy [18], (ii) the Department's energy efficiency strategy, and (iii) the National Energy Regulator's (NER) energy efficiency and DSM policy [19]. The White Paper identifies the DSM programme as one of the areas that needs to be developed and promoted whilst the NER is mandated to ensure sufficient installed generation capacity to meet the needs of future electricity demand. Thus, the DSM initiative extends the point at which new power generation utilities are necessary. It therefore buys valuable time during which power stations can be built.

As the existing energy demand will increase over the years, DSM will play an important role in reducing the actual energy consumption in a developing country such as South Africa. Thus, the electrical energy made available by the DSM programme, could be used for development in the country. The involvement of DSM in contributing to the availability of additional electricity for development can be seen in Figure 1-5.

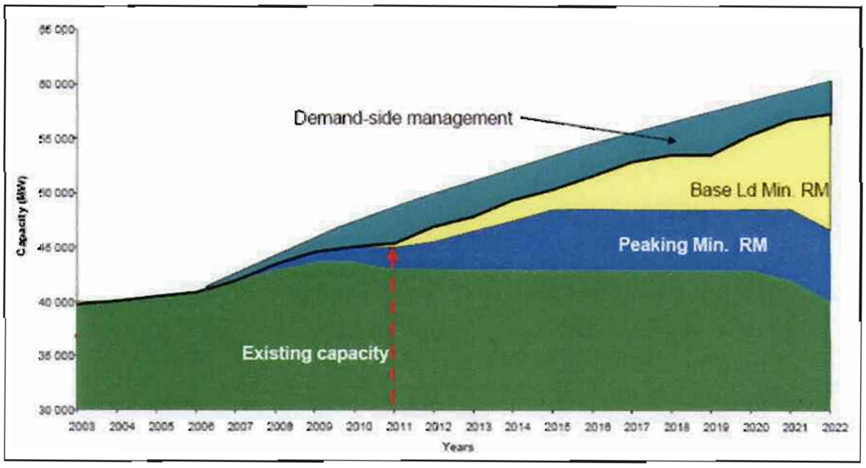


Figure 1-5: Capacity development plan

According to Figure 1-5, DSM is expected to increase its contribution until 2011, and from then onwards the contribution of DSM will remain rather constant although it plays an important role as an additional "source" [3]. It has been said: "Energy conserved is energy generated". Energy conservation and efficiency measures are the best alternative to power generation utilities.

The solid profiles seen in Figure 1-6 represent the load curves for a typical weekday. This is the demand that the utility has to supply to the customer. The two main areas of focus with regard to DSM are Load Management (LM) and Energy Efficiency (EE). A graphical explanation of these concepts is given in Figure 1-6 on the following page [17].

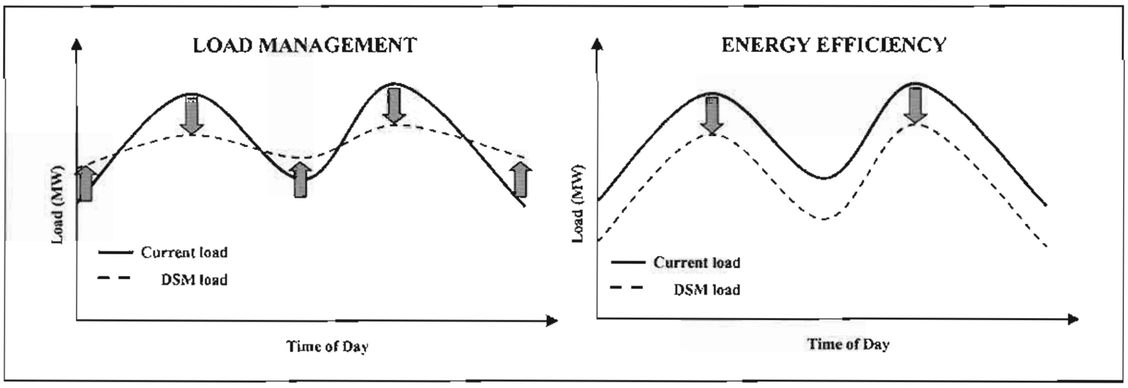


Figure 1-6: Load Management (LM) and Energy Efficiency (EE) through DSM

I) Load Management

Load Management (LM) is achieved by implementing activities to influence the time-pattern and manipulate the electricity load profile of the consumer, while maintaining customer satisfaction. Load Management is also known as "load shifting" or "peak-clipping and valley-fitting". This implies that by optimised planning and scheduling, the electricity usage is moved to some of the lower demand periods, which will decrease peak demand. It is very important to note that with load shifting the electricity load is moved and not reduced, therefore, the area under the load profile remains unchanged.

Although load Management programmes are largely short-term responses, they contribute largely to the long-term solution of the electricity problem in the country.

II) Energy Efficiency

In the case of Energy Efficiency (EE), the load curve is reduced evenly by the same amount, reflecting a reduced consumption of energy due to improved efficiency operations. This implies that less energy will be consumed, and therefore the area under the load profile will decrease.

Investing in energy efficiency is often cheaper, cleaner, safer, faster and more reliable than investing in new supply. This reduces the need to construct new generation, transmission and distribution facilities, which are associated with costly risks. The major advantage of Energy Efficiency is that it can be implemented much faster than expanding the energy supply, without any problems of surplus or shortage. Retrofitting motors and pumps, adding insulation to buildings, or changing light bulbs, take much less time than constructing a new power plant [11]. Energy Efficiency also means a loss in revenue for Eskom's Supply-side Management (SSM) programme. This is mainly why Eskom funds only 50% of the DSM Energy Efficiency projects.

1.3.2 DSM on the international front

DSM started in the United States of America (USA) and has made a significant contribution to the economic growth since the oil crisis in 1973 [20]. DSM has evolved tremendously in the early stages of the 1980s to become an entity of large value to the developed country.

In the USA, more than 500 utilities implemented DSM programmes from 1985 to 1995, saving more than 29 GW of peak load. The average upfront cost of implementing this energy savings was only 2 to 3 cent (US) per kWh, which is less than one-half of the cost of building new power plants [21].

Over the last two decades in the USA, many states used Integrated Reduction Planning (IRP) to compare the benefit and cost of DSM with the cost of additional generation. A whole network of utility DSM programmes avoided the need for about 100 power plants adding up to 300 MW.

DSM, as an alternative to system expansion as well as a tangible means of providing customers with a valuable service, was later adopted in the United Kingdom, Europe, and Australia. Today, DSM-associated initiatives are practiced worldwide, although not necessarily referred to as "DSM programmes".

1.3.3 The adoption of DSM for the South African situation

In South Africa DSM is still a relatively new concept. Although Eskom formally recognised DSM in 1992 when Integrated Electricity Planning (IEP) was first introduced, the actual need for Energy Efficiency and specifically Load Management became critical during the recent five years. The DSM programme mainly started in 2003 when the NER mandated Eskom to be the administrator of the DSM programme in South Africa [22].

The major difference between a developed and developing country considering energy consumption is the rate at which the economy and then also the demand for electricity grows. Due to the intensity of the industrial sector and the rapid economic growth and development plans set in place by the new government, there exist plenty of DSM opportunities in South Africa. The DSM programme originally developed and used in the US has been adopted and customised by South Africa to suit the energy needs of a typical developing country.

Due to the rapid increase in economic growth and the limited electricity capacity, especially during the evening peak period, the need for energy conservation is of high priority. The DSM programme adopted by South Africa has a number of targets being set by the NER.

I) DSM targets

The NER has set a target to Eskom to reduce the evening peak demand by 153 MW per annum, which started in 2003 [23]. Over a 20-year planning horizon, DSM is scheduled to save an accumulative total of 4 255 MW, which contributes a saving equivalent to a six unit coal-fired power station [3]. In 2003 the DME has outlined the following sectorial targets [24]:

- Nationally – Net energy demand reduction of 12% by 2015.
- Industry and mining sectors – Net energy demand reduction of 15% by 2015.

Further sector-specific targets for the Eskom DSM programme are shown in Table 1-1 [17]. The accumulative target saving to be achieved for the period from 2003 to 2005 is 459 MW.

Table 1-1: Annual DSM targets

Programme Category	Annual Peak Load Reduction (MW)
Residential EE	33
Residential LM	49
Industrial & Mining EE	16
Industrial & Mining LM	41
Commercial EE	14
Annual Total	**153**

Thus, it is crucial that these targets are met to ensure that the future of the initiative is sustainable and accepted by all stakeholders involved.

II) Achievements by implementing the DSM initiative

Measurement and Verification (M&V), the independent monitoring and evaluation body for Eskom DSM projects, has indicated that an accumulated total of 296.3 MW load is intended to be shifted by the end of 2005. As indicated by the red columns in Figure 1-7, the DSM programme only reduced 270.7 MW (59%) of the targeted 459 MW up to 2005. The above-mentioned results as illustrated in Figure 1-7 are extracted from M&V's quarterly report for 2005 [24] and the Eskom's Annual Report for 2006 [4].

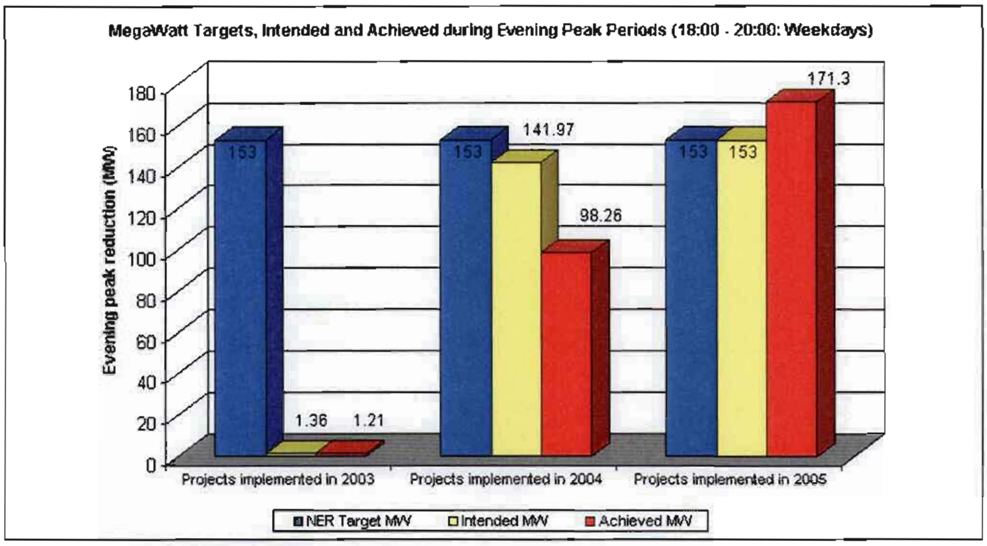


Figure 1-7: Eskom DSM target and results since 2003

Although the DSM initiative started in 2003, it took a while for the projects to be implemented and for the results to become observable. The 12% overperformance of DSM during 2005 clearly indicates that the DSM initiative has proved to be successful in South Africa with expectations to perform even better in the future and contributing even more to the peak demand capacity.

1.3.4 Objectives of DSM

Based on the Integrated Strategic Electricity Planning (ISEP) and the NER guidelines, the objectives of Eskom's DSM department are to [17]:

- Add value to the South African economy by initiating DSM programmes that comply with sound business principles.

- Concentrate on DSM programmes that provide win-win situations for the customer and Eskom.
- Create the opportunity for Eskom to improve supply-side planning, which results in lowered risks in implementing supply-side solutions.
- Achieve market transformation and ensure DSM sustainability. This should ensure that the market does not regress to lower levels of efficiency after active participation of the utility has ceased.
- Reduce the energy consumption and maximum demand by changing the configuration or magnitude of the load shape. Eskom will therefore be able to accommodate the system-demand growth using existing capacity. This flexibility means that in the event of market transformation or market deregulation, Eskom will be competitive in the market and remain one of the cheapest energy suppliers in the world, thus creating value for customers.

Furthermore, the DSM initiative over the next 10-year rollout period will be more cost-effective than the Supply-side Management (SSM) alternatives. This will prevent investments in potential stranded assets, thus adding value to Eskom's business. In addition, the DSM projects will prevent the need to provide more than 5 600 MW of peak generating capacity and Eskom will ultimately save the national economy, and itself, R5 billion over the next 25-year implementation period.

1.3.5 Role of an Energy Services Company

The business of an Energy Services Company (ESCO) is to sell energy services by achieving the following [26]:

- Carry out a comprehensive energy audit service to the client
- Develop and design energy efficiency and load management projects
- Install and maintain the control equipment involved
- Measure, monitor, and verify the project's energy savings
- Ensure sustainable performance of energy saving projects

ESCOs are private companies that help Eskom to achieve DSM goals. They make use of DSM programmes, technologies and optimisation packages to determine and realise DSM results at the electricity consumer. The ESCO is the party responsible for implementing and maintaining the project in order not to burden the client with committing additional resources to the initiative. It is the client's prerogative to decide if he wants to act as the ESCO, or to appoint an ESCO [27].

Normally the ESCOs operate in a three-way partnership between themselves, the electricity supplier (or regulatory body responsible for DSM) and the electricity consumer. The parties must be contractually bound to define the roles and responsibilities of everyone in order to avoid any confusion and penalties if one party does not perform in line with the requirements. The actual energy and financial savings will be measured by an independent Monitoring and Verification (M&V) body and distributed to all parties concerned.

1.4 DSM IN THE INDUSTRIAL SECTOR

1.4.1 Opportunities and needs for Load Management in South African mines

DSM focuses on the industrial, commercial and residential sector, with the industrial sector accounting for more than two-thirds of the national electricity usage [28]. Figure 1-8 on the following page illustrates that the industrial sector, which includes mining, agriculture and other industries, contributes 71% to the country's annual consumption and 52% to the maximum demand of the country during 2003 [3].

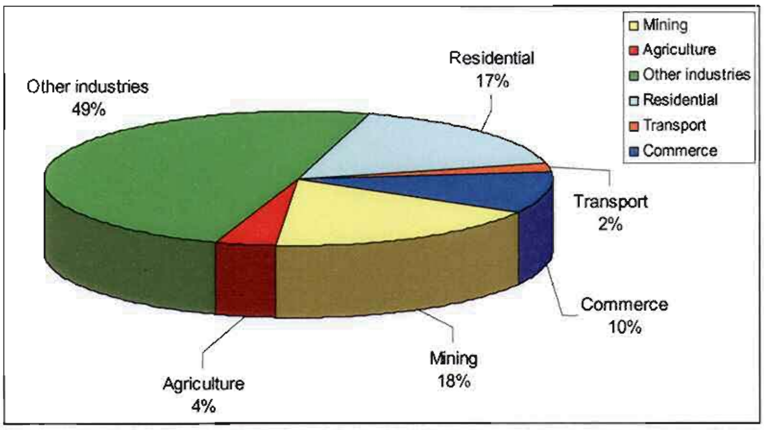


Figure 1-8: Electricity consumption per sector (2003)

Within the industrial sector of South Africa lies the potential for the largest Load Management saving by replacing old technologies with new ones. The wide variety of energy-intensive equipment and the large savings possible, welcomes effective Load Management practice.

Load Management is done by switching off energy intensive equipment during Eskom's peak demand periods and rescheduling the equipment to operate during the low demand periods of the day. For example, switching off a motor with an installed capacity of 4 000 kW for one hour is equivalent to the savings generated by switching off 400 household geysers for one hour. In practice it makes more business sense to switch off the one industrial motor than switching off 400 geysers for a certain period of time.

1.4.2 Focusing on the mining industry for DSM

South Africa is a world-renowned leader in the mining industry; this gives a good indication of the size of such an industry. The mining sector in South Africa used 32 372 GWh (or 18%) of all the electricity generated in the country during 2003 [29]. Deep level mines (most gold and platinum mines) accounted for 28 559 GWh (or 15%) of all electrical energy consumed during 2003 [30]. Up to 30% of this electricity is consumed in the pumping of water [31]. It therefore makes sense to focus one's attention on the potential electricity cost savings that could be realised by operators of deep, hot mines, and in doing so assist Eskom in their objective of shifting load, primarily away from the evening peak period.

Several ESCOs mainly focus on the gold mining industry due to the energy intensive equipment used in the deep level mining process. The total amount of electricity used for gold mining increased between 1967 and 1988, thereafter declining slightly. The electricity used in gold mining as a percentage of the electricity used in all mining declined from 88% in 1967 to 67% in 1995. Since then it has declined even further. However, it still uses more electricity than all other types of mining put together [30].

Although there still exists more or less the same amount of gold reserves as were mined in the past, these resources are well below the current working levels. The gold price compared to the operational costs will determine the potential for further mining development and operation. Thus, with more efficient energy consumption and energy management practices (resulting in decreased operational costs) the gold mining industry will certainly consider further development to mine gold from even deeper levels.

In 2003, the local mining industry bought 33 372 GWh of electricity generated by Eskom at an average cost of 15,07 c/kWh, which amounts to R 5 billion per annum. In 2005 the industry's electricity consumption increased to 40 557 GWh at an average cost of 15,36 c/kWh [29]. As mentioned in Section 1.2, the price per unit electricity during Eskom's peak demand periods will increase even faster in future, which emphasises the need for Load Management to reduce the peak consumption.

A typical gold mining operation uses electricity mainly for drilling (compressed air), cooling (fridge plants), ventilation (fans), hoisting of ore, pumping and lighting. The contribution of the various electricity users on a typical mine could be illustrated as shown in Figure 1-9 [29]:

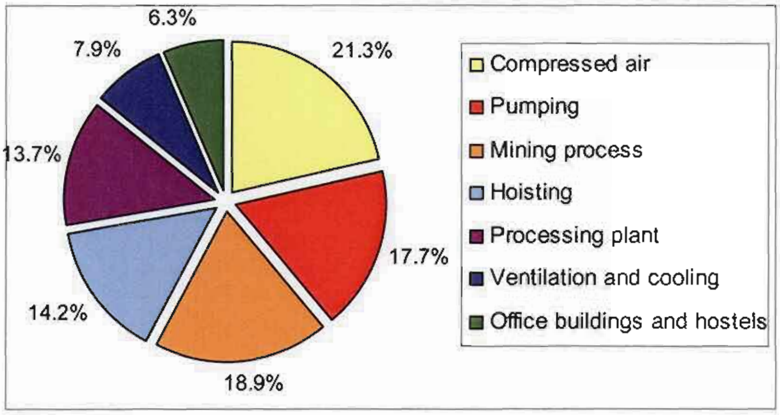


Figure 1-9: Contribution of main electricity users in a mining operation

Due to the energy intensity of specifically the compressed air, pumping, hoisting and cooling systems, these systems offer an ideal business opportunity if they are utilised correctly. Many mines are not fully aware of the energy saving opportunities and the possible benefits they could receive from the DSM programme. A case study conducted in 1996 on a typical deep level mine in South Africa showed that 27% reduction in system peak demand could be achieved by using optimised scheduling of the various systems [31]. Although potential exists for electricity savings on all the above-mentioned systems, Load Management was first attempted on the underground clear-water pumping system.

1.4.3 Clear-water pumping systems of deep level mines

The clear-water pumping system consists of pumping stations with dams on certain underground levels. The water being pumped from underground is water already used for mining purposes. Due to the high Virgin Rock Temperature (VRT) on the deep working levels, the excess hot water collected in the bottom dam gets pumped up to surface where the water gets cooled down and again sent down to underground levels for mining purposes. Thus, a continuous cycle of pumping water from underground to surface and back exists throughout the day. A typical layout of the clear-water pumping system is illustrated in Figure 1-10.

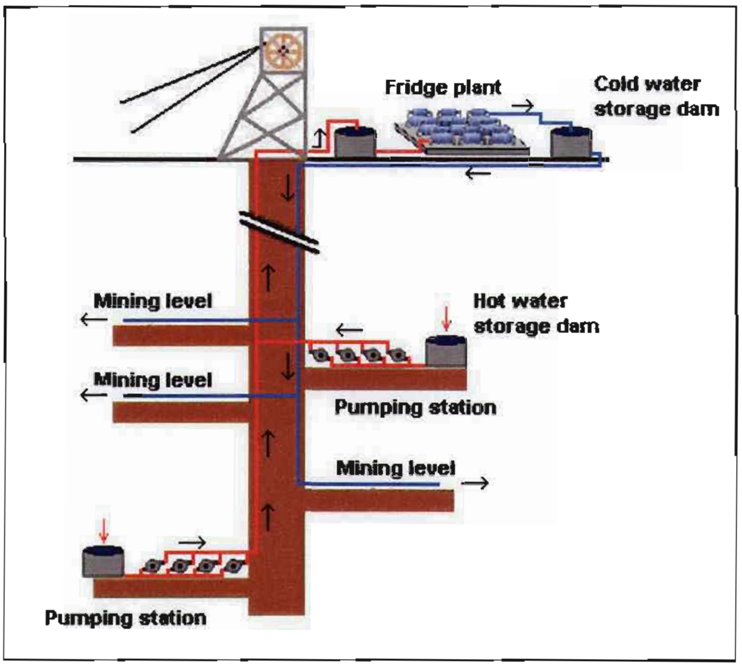


Figure 1-10: Typical layout of a clear-water pumping system

The main reason why Load Management (load shifting) was first attempted on the clear-water pumping system is because the pumping of water is not directly linked to the production of the mine. Another characteristic of the clear-water pumping system that makes it ideal for load shifting is that the pumps are frequently stopped and started due to the dynamic nature of the system, which is also required to do load shifting.

In order to realise load shifting, pumps and storage dams are needed to reschedule the pumping activities over a 24-hour period. The philosophy is that dams in clear-water pumping systems are used to store the continuous incoming water during Eskom's peak periods, so that the electrical-intensive pumps can be switched off during these periods. After peak time the pumps can be restarted to pump out the stored underground water to attain water balance in the mine.

By rather using the electrical pumps outside Eskom's peak period, a reduction in the current peak load is obtained. Although the mine consumes the same amount of electrical energy with load shifting, the mine realises electricity cost saving due to the lower electricity tariff in the standard and off-peak periods of the day. Thus, the mine uses more energy in the less expensive tariff periods and less energy during the more expensive peak periods.

The major factors determining the load shift potential as well as the cost saving to the mine are the storage capacity of the dams as well as the rate at which the dam fills up during peak time.

1.4.4 Load Management opportunities on clear-water pumping systems

Prior to the DSM programme being implemented on clear-water pumping systems of various mines, the pumping activities were controlled by human factor. Although on some mines load-shifting has been attempted by the human factor, it was done with little satisfaction. To realise sustainable DSM (load shift) results on the clear-water pumping system, the operational schedule followed by the human factor had to be changed.

Due to the high risks involved with load shifting when dam levels rise to levels higher than usual, a fully integrated control system, taking all the system constraints into consideration, should replace the human factor. This control system not only decreases the risk involved in manual load shifting, but it also increases the reliability and sustainability of the DSM results.

A tool that could achieve maximum load shift results in a reliable and sustainable manner was developed and installed on a number of deep level mines in South Africa. This tool, called the Energy Management System (EMS) proved to be successful on all the various types of mines, which are [31]:

- Type 1: Mines with an intricate pump system
- Type 2: Mines with a pumping system that includes a 3-Chamber Pipe Feeder System (CPFS)
- Type 3: Mines with a pumping system with no control infrastructure and/or no 24-hour manned control room.

This automatic control approach is now applicable to any clear-water pumping system on a South African mine. A number of deep level mines were approached and investigated for DSM potential on their clear-water pumping systems. Although more than 20 mines with sufficient DSM potential exist, only a small number of mines have the EMS system already implemented. The remaining mines will implement this EMS system in the near future.

The pumping projects successfully implemented and currently contributing to the DSM programme are as follows [33]:

Table 1-2: Current DSM pumping projects

MINE	CONTRIBUTION (MW)	TYPE OF PUMPING SYSTEM
Kopanang	3.0	Type 1
Elandsrand	3.1	Type 1
Bamabanani	5.8	Type 1
Masimong 4#	3.9	Type 3
Harmony 3#	3.8	Type 3
Mponeng	6.2	Type 1
Target	1.8	Type 1
Tshepong	3.1	Type 2

1.5 NEED FOR THIS RESEARCH STUDY

On all of the above-mentioned mines certain measures have been followed and put in place to realise sustainable DSM results. The direct benefit of load-management projects installed on the clear-water pumping system is twofold: to Eskom the load being shifted resulted in a reduction in evening peak demand of the country. Secondly, to the client (mine) electricity cost savings are realised, which decreases the operational cost of pumping water.

During the project feasibility study the ESCO determines the MW load shift potential as well as the expected cost saving to the mine. The first priority of a typical DSM load shift project is to realise the promised MW load shift savings on a sustainable basis, although experience shows that this "virtual power station" is roughly only 85% effective.

The 85% availability mentioned above results from the dynamic nature of the mining operation, which leads to system down-time and missed saving opportunities. Missed opportunities of this kind are accepted by Eskom and these days are not considered by the Measurement and Verification team when determining the average monthly MW load shifted.

Due to the system downtime saving opportunities are lost, which means that the actual electricity cost saving to the mine is less than anticipated. This gives the mine an incorrect indication of the possible saving offered by DSM. Thus, the need exists to make a more accurate estimation of the expected electricity cost saving potential to the mine.

Furthermore, the significant changes made to the clear-water pumping system to accommodate load shifting also influence the actual impact of DSM on the mine. The impact of DSM is much more extensive than the electricity cost saving achieved through load shifting. The need exists to determine the total impact of a DSM clear-water pumping project on the mine.

During this study, the various effects of DSM on the mine are identified, investigated and quantified to determine the actual impact of DSM. By determining the impact of DSM on the mine, the results could be presented to the management of the mine, who is unfamiliar with the DSM concept, in order to encourage the acceptance of DSM on the clear-water pumping system of a mine.

1.6 OVERVIEW OF THIS DISSERTATION

As seen in ***Chapter 1*** Eskom may be running out of supply capacity as early as 2007. Although Eskom is currently in the process of building new generating plants, additional capacity will only be available as early as 2012. The main concern to Eskom is not the base load capacity, but rather the high-demand peaks of the daily national electricity profile.

Due to the short rollout period of a Demand-side Management (DSM) project, the DSM initiative is the ideal solution to the current supply problem. In Section 1.4.2 it is shown that the clear-water pumping system is the ideal application to shift load out of Eskom's peak demand periods. The load shift pumping projects already implemented are also stated in Chapter 1.

The problem statement of this study flows from Chapter 2. Due to the change in system operation to perform load shifting on the clear-water pumping system of a mine, an uncertainty exists regarding the knock-on effects of such a project on the overall mining operation. Thus, apart from the electricity cost saving obtained through load shifting, the overall impact of DSM on a mine is researched.

Chapter 2 includes the methodology followed to perform the research study as well as a background study on each of the roll-playing factors identified to have an impact on the mine.

In ***Chapter 3*** the various DSM pumping projects currently running were used as a case study to quantify the overall impact of DSM on the mine. Each role-playing factor is categorised according to certain characteristics in order to develop a criteria to perform risk analysis on load shifting projects implemented on clear-water pumping systems.

Furthermore, this chapter concludes the research study by identifying input parameters to a generic model used as a tool to determine the overall impact of a DSM load-shifting project on a mine.

Chapter 4 proves the validity of the research study, by applying the generic model developed to existing as well as future DSM projects. The results obtained by the modelling process are compared to determine the realistic DSM savings.

Chapter 5 concludes this thesis by discussing the findings made throughout the study as well as making recommendations for further study.

CHAPTER 2: RESEARCHING THE FACTORS THAT DETERMINE THE IMPACT OF DSM ON A MINE

In this chapter the process of identifying a typical DSM load shifting project is briefly discussed in order to generate electricity cost savings to the client. Current DSM pumping projects are investigated to identify the possible effects of load shifting on the mine.

2.1 INTRODUCTION

The characteristics of the gold mining industry are of such nature that all systems within the mining operations are closely integrated. A change in the existing operating conditions of a single project could have a knock-on effect onto other mining systems. Due to the dynamic style of the mining industry and the way each mine is different from the other, there are various points to consider when the impact of DSM on the clear-water pumping system of a deep level mine is determined.

Since 2004, more than ten DSM projects were implemented on the clear-water pumping systems of various mines. Although the outcome of each project is the same, with Eskom receiving the megawatt (MW) load-shift saving and the mine (client) receiving electricity cost savings, the technical work done differs due to different characteristics of each mine. Thus, the impact of DSM on the mine also differs from one mine to the next. Although the effects of DSM projects could be either positive or negative, it is important to firstly identify the various role-playing factors.

Throughout the implementation phase of a typical DSM project, a great deal of time is spent with engineers and artisans of the mine. This is done in order to overcome uncertainty caused by the intended method of controlling the underground pumping system. The idea is to replace the existing human factor controlling the pumps manually by an intelligent fully automatic control system. This new method of pumping requires a complete change in the current operating schedule of the clear-water pumping system.

In general, mine personnel fear the uncertainty of changing from a manual control system to an automatic control system. Due to the high risks involved with pumping water from underground, the uncertainty is mostly associated with a failure on the automatic control system, which relates directly to safety and production on the mine. Uncertainty in this regard may lead to a negative perception of taking on an energy savings project, which will have a direct impact on the intervention of the DSM programme on the mining sector. Eskom DSM is dependent on the mining sector to meet their DSM targets.

Before a DSM project is welcomed by a mine, many questions are being raised with regard to the impact that such a project could have on the current system as well as on the employees currently working on the system. The most frequently asked questions are stated as follows:

- What is the expected annual electricity cost savings to the mine?
- Will the automatic control system take all system constraints into account?
- What are the risks involved due to load shifting on the de-watering system?
- Will the pump attendant or control room operator still be able to control the pumps manually during emergency situations?
- Is there potential for cutting down on labour numbers with an automatic system taking over the control responsibilities?
- What is the effect of load shifting on the Maximum Demand (MD) of the mine?
- What are the risks involved when taking on a DSM load shifting project?
- What is the overall benefit of a DSM load-shifting project to the mine?

All the above-mentioned questions are discussed later in this chapter in order to identify the effects of a DSM project on the mine.

2.2 OVERVIEW OF IDENTIFYING A TYPICAL DSM PROJECT

2.2.1 Preface

A DSM load-shifting project has a number of phases to be completed before the project proposal can be presented to the mine. The incentive to the mine for taking on a DSM project with a certain amount of risk involved is strongly motivated by the electricity cost saving potential. These phases are briefly discussed in this section, as it is not the main focus of this study.

2.2.2 Technical audit on the clear-water pumping system

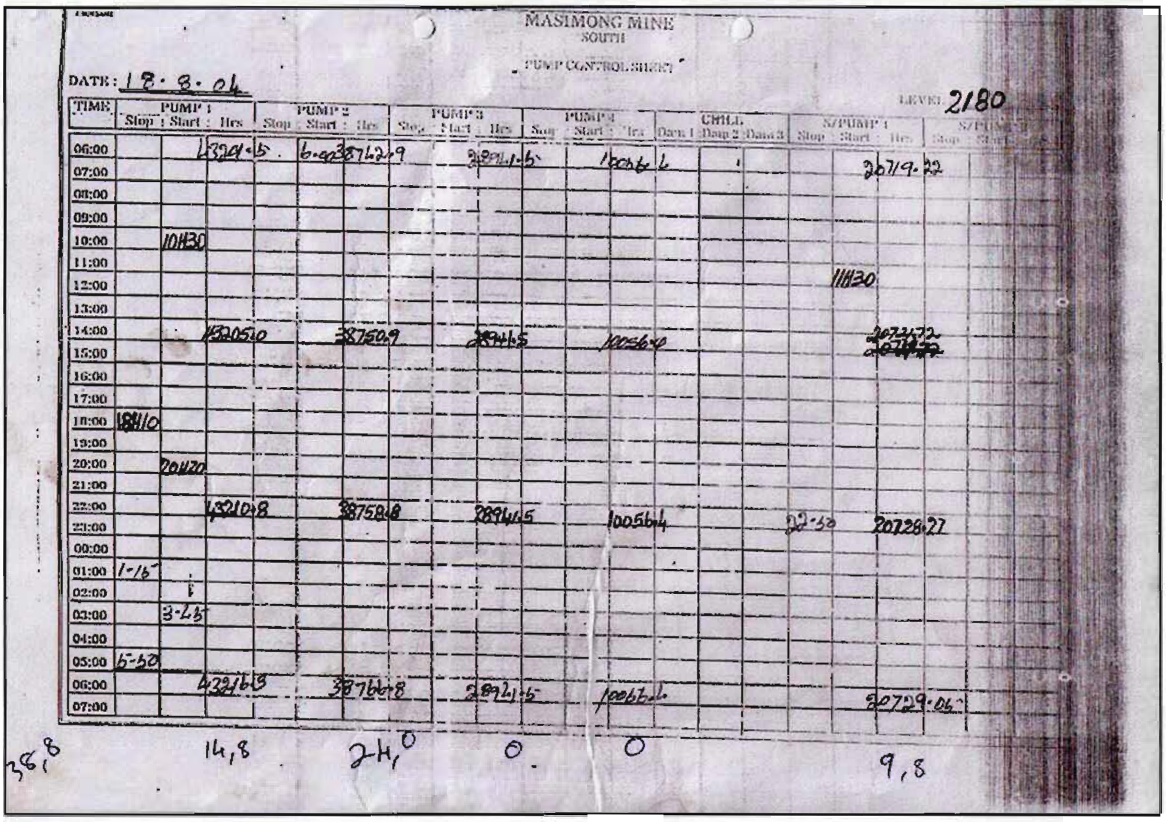
In order to determine the DSM potential of a clear-water pumping system, an on-site investigation is conducted. Certain specifications and constraints regarding the current control and operation of the pumping system are needed to do a feasibility study. The information required to perform the feasibility study with the help of a real-time simulation model is as follows:

- Number of pumping stations
- Number of pumps per pumping station
- Installed capacity of the pumps
- Flow rate of pumps
- Running statuses of pumps (logged data)
- Control infrastructure needed for automatic control
- Understanding the overall system operation

2.2.3 Determining the megawatt load shifting potential

In order for an ESCO (Energy Services Company) to determine whether a project is feasible, a power baseline should be established. A baseline is a power profile that represents the actual energy consumed (measured in megawatts) versus time (measured in hours). The actual energy consumed is obtained from logged data. This data can be either electronic data, obtained from the SCADA (Supervisory Control and Data Acquisition) system, or hardcopy data logged manually by the pump attendants on the various pumping stations.

Filling in log sheets is a standardised procedure used on all mines to keep a record of all the actions of main electrical equipment, e.g. pumps, compressors, etc. The mine mainly uses this information for maintenance purposes. It is very important to the mine to know the exact running hours of the equipment, as well as to monitor the actions for optimum performance. A typical hardcopy log sheet representing the daily running statuses of all the pumps on 2180 Level pumping station of Masimong 4# is shown in Figure 2-1.



MASIMONG MINE
SOUTH

PUMP CONTROL SHEET

DATE: 18·8·04

LEVEL 2180

TIME	PUMP 1			PUMP 2			PUMP 3			PUMP 4			CHILL			S/PUMP 1			S/PUMP 2	
	Stop	Start	Hrs	Stop	Start	Hrs	Stop	Start	Hrs	Stop	Start	Hrs	Dam 1	Dam 2	Dam 3	Stop	Start	Hrs	Stop	Start
06:00			43201·5	6·00		38742·9			28941·5			10056·6						20719·22		
07:00																				
08:00																				
09:00																				
10:00		10H30																		
11:00																				
12:00																	11H30			
13:00																				
14:00			43205·0			38750·9			28941·5			10056·0						20724·72		
15:00																				
16:00																				
17:00																				
18:00	18H10																			
19:00																				
20:00		20H20																		
21:00																				
22:00			43210·8			38758·8			28941·5			10056·4				22·30		20728·27		
23:00																				
00:00																				
01:00	1-15																			
02:00																				
03:00		3-25																		
04:00																				
05:00	5-50																			
06:00			43216·3			38766·8			28941·5			10056·6								
07:00																		20729·06		
38,8			14,8			24,0			0			0						9,8		

Figure 2-1: Log sheet for 2180 level pumping station at Masimong 4# mine

As illustrated in Figure 2-1, the stop and start status as well as the running time of each pump is logged on an hourly basis. These log sheets, which represent the hourly performance of the pumps, are analysed in order to determine the energy consumption baseline for the pre-implementation period. The pre-implementation data, used to determine the energy baseline, should be for a minimum period of three months.

The energy baseline is directly proportional to the number of pumps running for each day over this period. The power baseline of Masimong 4# as calculated in a spread sheet programme (Microsoft Excel^{TM}) for this period is shown in Figure 2-2 on the following page:

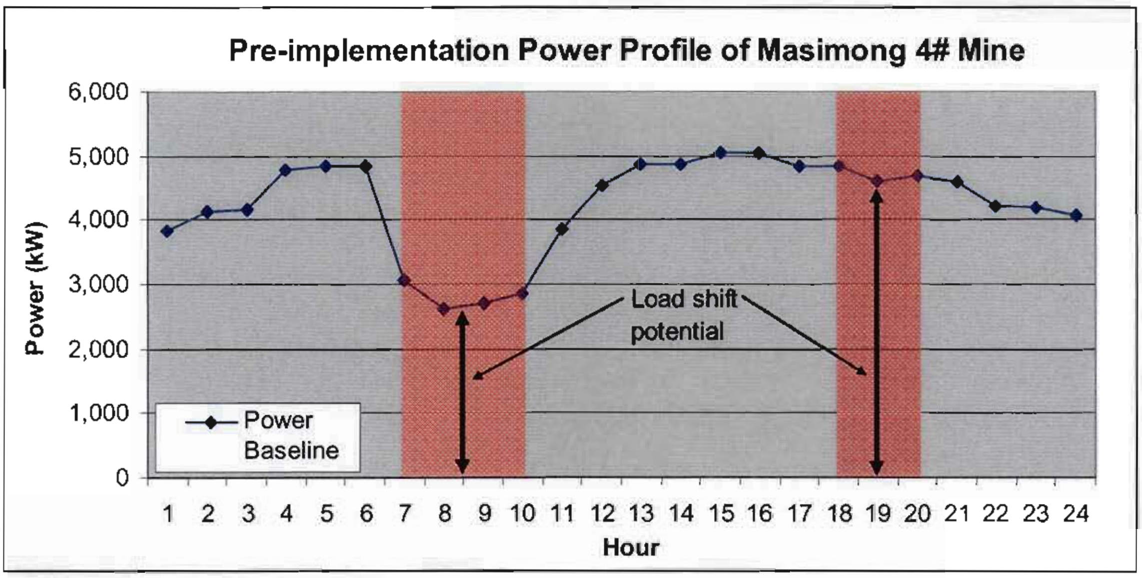


Figure 2-2: Energy consumption baseline for the pre-implementation period

The baseline shown in Figure 2-2 represents the average hourly kilowatt (kW) power consumed for a period of one day, over the minimum period of three months. From Figure 2-2, an estimation regarding the maximum load-shift potential during the peak demand times can be made. In this case, the maximum load-shift potential, if all the pumps are stopped during evening peak, is approximately 4.2 MW. The load shift potential for the morning peak period is much lower. It is reasonable to say that the mine itself has attempted load shifting during the morning peak. An energy management simulation tool is then used to determine the actual load shift potential, taking into consideration all system constraints.

2.3 METHODOLOGY USED TO DETERMINE THE TRUE EFFECT OF A DSM PUMPING PROJECT

After identifying the need for the study, the first step is to do a research study on the various aspects in the existing mining operation, identified to be affected due to DSM. After completing the research study, these effects are quantified by using performance-tracking records and information obtained from the mine on the existing load shift projects. The methodology used to carry out the two above mention steps is discussed as follows:

Step 1: Identifying the true effects of DSM on the mine

Before taking on this research study, the only known benefit to a mine when taking on a DSM project is electricity cost savings calculated and presented to the mine on a monthly basis by the Measuring and Verification (M&V) team [34]. These performance-tracking reports are interpreted to identify the basic cost impact of DSM on a mine and use it as a foundation to expand the study upon.

The process of identifying the additional effects of DSM on a mine entails an investigation on the performance of existing DSM projects. This is done by comparing the circumstances of the pumping operation before and after DSM implementation. This investigation was guided to a large extent by the experience obtained working in this field as well as questions being raised by mine personnel during the investigation process. After identifying the possible effects of DSM, research on each of the system components will be done to determine the possible contribution to the overall DSM savings' pool.

Each of these system components identified as effects of DSM are categorised according to certain characteristics and contributions made to the overall system. These system components are categorised under *cost benefits*, *additional benefits* and *possible (hidden) costs* to the mine.

Step 2: Quantifying the effects using actual information

After the identification process has been completed, the various effects are quantified by using real-life information obtained from existing load shift projects. Data capturing and system performance analysis on each of the system components identified in Step 1 has to be done. Obviously, not all of the effects are relevant to each mine due to the varying nature of clear-water pumping systems. Thus, an average of the findings made on the relevant mines was calculated to determine the true impact of each system component having an effect on a mine.

All of these effects contributing to the true impact of DSM on the mine are then interpreted and quantified to draw up a generic model. This model then requires input parameters derived from the quantification process in order to determine the true overall impact of a DSM load-shifting project on the clear-water pumping system of a mine.

Both the above-mentioned steps (followed during the methodology used to determine the true impact of a DSM pumping project) are illustrated in Figure 2-3 on the following page.

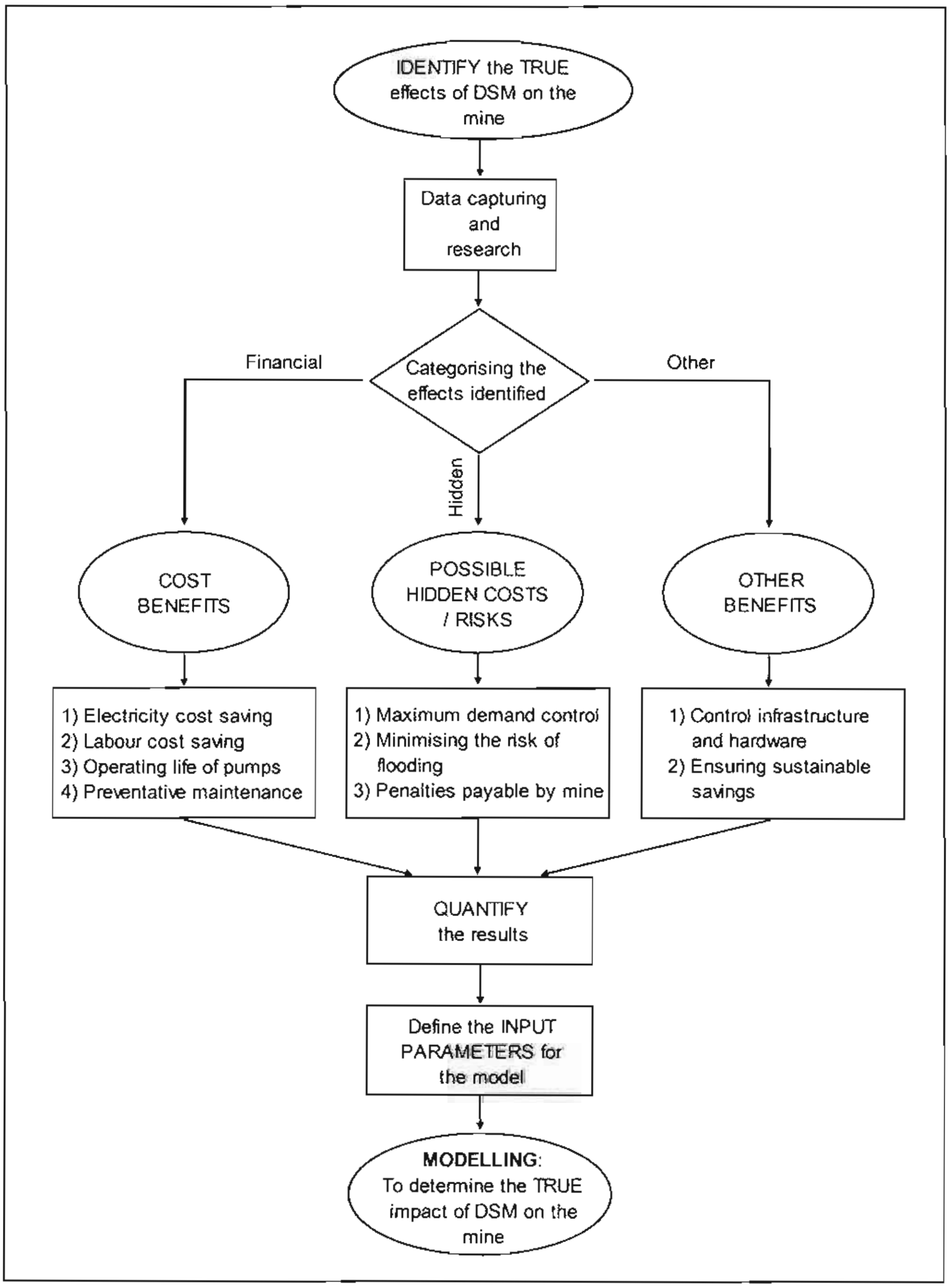


Figure 2-3: Flow diagram for the research methodology

2.4 COST BENEFITS OF DSM

2.4.1 Calculating the electricity cost savings

Although the DSM programme entails both energy efficiency and load shifting, the focus of this research study is on load shifting. It is important to note that with load shifting, the daily energy consumption remains exactly the same as before DSM implementation. This is because energy consumed to pump the water during peak time, is now rather consumed during the standard or off-peak periods of the day. Thus, the amount of water being pumped on a daily basis remains unchanged.

The question could be asked whether load shifting qualifies as energy savings regarding the load reduction campaign. The answer to such a question is no. Although the client receives large energy cost savings by reducing the energy consumption during the expensive peak demand times of Eskom, the total daily energy consumption remains the same.

Although the mining industry is showing good profit due to the high gold price, management continuously try to cut down on operating costs. The DSM load shifting projects currently installed on various clear-water pumping systems have proven to generate considerable electricity cost savings. The incentive of consuming energy during standard and off-peak demand (less expensive) periods of the day, rather than the peak demand (more expensive) periods of the day, is emphasised in the figure on the following page. Figure 2-4 on the following page represents the Eskom Megaflex tariff structure, applied to industrial consumers with a Notified Maximum Demand (NMD) of more than 1 MVA [35].

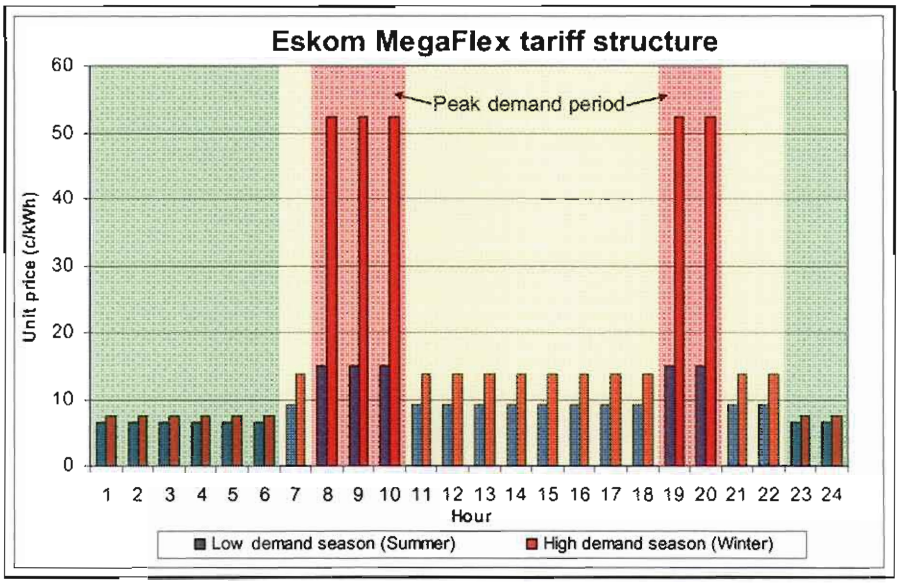


Figure 2-4: Megaflex tariff structure for the high and low demand season

Figure 2-4 shows the price per unit electricity (c/kWh) consumed for the different hours of the day, according to the tariff charges for the period from April 2006 to March 2007 [35]. The red columns indicate the tariff per unit electricity consumed during the high-demand season while the blue columns indicate the tariff of the low-demand season. The high-demand season consists of the winter months (June to August), while the low-demand season consists of the summer months (September to May). For both seasons, it is clear that the price varies for different times of the day. The peak demand hours (7:00 – 10:00 and 18:00 – 20:00) are highlighted by the red blocks seen in Figure 2-4. The tariffs for the various seasons, as well as the different periods of the day, are given in Table 2-1.

Table 2-1: Megaflex tariff structure for 2006/2007

Low-demand season (September - May)	Magflex Tariff Period	High-demand Season (June - August)
6.52 c/kWh	Off-peak	7.51 c/kWh
9.20 c/kWh	Standard	13.81 c/kWh
14.82 c/kWh	Peak	52.22 c/kWh

Thus, for any client to obtain optimal cost savings on their electricity bill, it is important to schedule the operational hours of the energy-intensive equipment, to operate only during the standard and off-peak times of the day.

During the feasibility study of DSM projects, the expected electricity cost savings to be realised by the mine are determined by the ESCO. The outcome of this study is proposed to the mine as an encouragement to take on the project. Experience gained on previous DSM load-shifting projects showed that the actual electricity cost savings, realised by DSM, are less than the expected (proposed) cost savings. The main reason for this is that system breakdowns, common to the mining process, affect the load shifting performance.

Missed opportunities, due to unavoidable breakdowns in the mine affecting the load-shift results, are accepted by Eskom as condonables, and are not considered by M&V in the performance-tracking reports [36]. Thus, due to the fact that the total energy consumed by the mine is continuously monitored and billed by Eskom, high energy consumption due to system breakdowns is taken into consideration when determining the monthly electricity bill for the pumping operation. This will be discussed in Section 3.3.1 on the hand of a case study.

2.4.2 Reducing labour cost

Labour costs range from 40% to 50% of the total expenses of a typical mine, and thus contribute significantly to the operating costs of a mining company [37]. It is obvious that labour numbers cannot be cut down on the production department without cutting down on production volumes. By implementing an automatic control system on the clear-water pump system, which is not directly linked to production, there exists a potential to cut down on labour numbers.

Pump attendants working on the pump stations are mainly used to stop and start pumps manually according to certain orders from the engineer in charge. The pump attendants are also responsible for housekeeping and other routine jobs. Usually there are three pump attendants per shift, working on a pumping station performing the various routine jobs. Two pump attendants are used to stop and start the pumps and to monitor the dam levels while a third is used to constantly monitor the oil and temperatures of the pumps and to do various other small jobs.

There is no longer a need for three pump attendants, with an automated control system stopping and starting the pumps according to specified dam levels and also monitoring the status of the field instrumentation. Since all pumping actions are done from one centralised point on the shaft, the number of pump attendants working per pump station could be cut down to a single pump attendant.

Some mines go as far as installing cameras on the pumping stations to monitor the pumping station from the control room and therefore, the only remaining pump attendant could also be removed. This can only be done if the mine has enough spare storage capacity available for the responsible person to get down to the pumping station should a breakdown on the pumping system occur.

The pump attendants no longer needed on the pump stations could be re-allocated in vacant positions on the mine instead of the mine assigning external people. There are several advantages, other than the capital cost savings on wages, by cutting down on some labourers due to the automatic control system installed.

Firstly, due to the underground safety aspects of people working in the mining industry, each mine has a certain level of risk measured against the number of people working underground. This is quantified as the "at-risk behaviour" of the mine. If the number of people working underground could be cut down, the at-risk behaviour of the mine will decrease. By replacing the human factor, working under high risk circumstances with an automatic control system, the mine in general will benefit from the DSM project.

The second advantage is that less people have to travel to their working areas underground. Due to the decreased number of people having to be transported to the working level underground, less shaft time is taken up. Shaft time is very limited in a high production mine, due to the equipment used in the mining purpose that has to be transported to the various working levels. This equipment includes explosives, cars carrying support beams used in the stopes and empty cars hoisted to surface again. The more shaft time is available, the more production can increase.

2.4.3 Increasing the operating life of pumps

The impact of load shifting on the operating life of a pump varies from mine to mine. This could be seen as either a benefit or a drawback depending on the situation before the DSM project implementation. Some mines allocate a duty pump to run 24-hours a day with a standby pump available for stop and start when required. In this case the EMS will stop and start pumps more frequently, which will decrease the operating life of the pump.

On other mines without DSM, the opposite happens while the pumping operation is controlled manually. On these mines, the pump attendants are not knowledgeable of what the effects of frequent stopping and starting of pumps are. On some of the mines pumps are switched on and off more than 6 times a day. For this application the EMS will benefit the mine by optimising the use of pumps and in turn decrease the life-cycle cost of the pumps. There is no specific literature available on the direct cost effect of switching a pump on and off on a more frequent basis.

The life-cycle cost of any piece of equipment is the total cost of purchase and operation over its entire service life. These costs of any piece of equipment may include purchasing cost, installation and commissioning cost, energy cost, maintenance and repair cost, down-time cost, environmental cost and decommissioning and disposal cost [38].

This section only focuses on the life-cycle cost components affected by load management in order to determine if load management has a positive or negative impact on the life-cycle cost of a pump and motor. Only energy cost, maintenance and repair cost were considered. The other life-cycle cost components will remain unaffected for load-shifting purposes.

I) Higher stop / start frequency due to DSM load-shifting

The idea of load shifting is to reduce the demand for energy consumption during the two peak demand periods per day. The simplest way of performing load shifting is by switching off the motor during the peak demand periods and rather run the motor during standard or off-peak hours.

In order to perform load shifting on the clear-water pump system of a mine, the pumps have to be switched on and off more often. The main reason being is that pumps are stopped before peak time and restarted right after peak time.

Switching motors off can be a very simple way of saving energy, but has a number of drawbacks on the mechanical and electrical parts of pumps and motors. Standard motors are rated for continuous duty; in other words, the load remains relatively constant for long periods of time.

A rule-of-thumb indicates that the oil in the bearings should be replaced after every 80 start-up actions. It is also included that frequent switching of industrial pumps contributes to between 15% and 25% of the overall maintenance cost of a pump [39]. The extra heating due to the high start-up current could also shorten the life of the motor insulation system. Another rule-of-thumb indicates that for every 10°C rise above the limit of the motor, insulation life is halved [40].

Figure 2-5 on the following page illustrates the more frequent switching on and off of pumps, in order to do load shifting, compared to the old method of running the duty pumps for long periods without stopping. The blue lines indicate the running statuses of the pumps prior to the DSM project, while the green lines indicate the statuses of the pumps while doing load shifting. The red blocks indicate Eskom`s two peak demand periods, which are also the most expensive time to consume electricity.

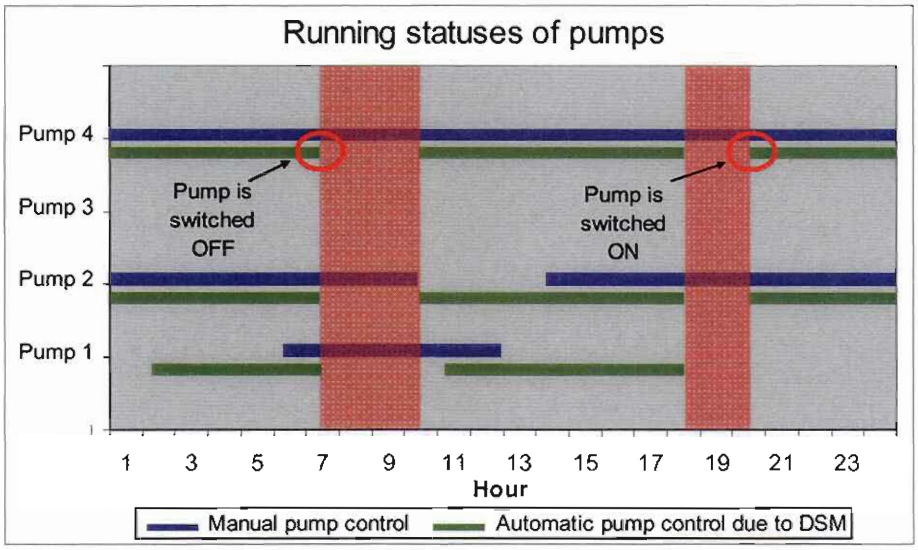


Figure 2-5: Switching pumps on and off more frequently due to Load Management

From Figure 2-5, it could be seen that the pumps in total are switched off only twice a day with the old method (blue lines) of pumping, while the switching off of the pumps (to realise load shifting) increased to 5 times per day. Note that with load shifting, the total energy consumed per day remains the same for both methods of pumping. Although the operating cost may decrease significantly, the increase in stopping and starting the pumps may increase the maintenance costs of the pumps.

II) Optimisation of the cycling of pumps with automatic control

As mentioned earlier, at some mines pumps are stopped and started on a frequent basis. The reason being that the pump attendants are unfamiliar with the maintenance issues involved with starting-up a pump. Their only concern is to get the water pumped out of the mine as soon as possible. Another reason is that the pump attendants on the specific pumping station only know what is happening on their own working level, and then pump according to the change in the specific dam level. Due to the fact that the number of pumps running on the various levels is not the same, the inflow and outflow of the dams are not equal and thus the pumping actions on the two levels cannot be synchronised. For example, the pump attendant develops a culture to start two pumps in order to get the dam level low and to stop both pumps again until the dam level reaches a certain high level before he starts the same two pumps again.

The ideal way of pumping in this case would be to run the same number of pumps as on the pumping station below, in order to keep the dam level constant without switching the pumps continuously. Due to the fact that controlling the pumping system at an optimum point is very complex, an intelligent control system considering all system constraints is needed. The effect of this control system will be quantified in Section 3.3.3.

2.4.4 Enhancing preventative maintenance

Maintenance plays a critical role in ensuring sustainable performance of any operation [41]. Properly maintained equipment is necessary to keep the process functioning at its optimum capability. Unfortunately, the maintenance program is often one of the first victims of any cost-cutting effort. It is often the case that preventative or scheduled maintenance is cut back whilst the maintenance efforts are directed more towards repairing and replacement.

Maintenance has a significant impact on operational costs of equipment and should be an integral part of any energy management program. Preventative maintenance is essential to ensure sustainable performance of an automatic energy management system. Energy savings due to maintenance could escalate as the installed capacity of the equipment in the process is increasing. Sufficient maintenance leads to the following [42]:

- Avoid early pump failures.
- Helps keep energy costs savings within reason.
- Helps prevent excess capital expenditure.
- Ensures availability of more efficient equipment.
- Is frequently necessary for safety purposes.

Prior to the DSM intervention on some of the clear-water pumping systems, preventative maintenance could not be done effectively due to the limited information available on the system devices and equipment. By enabling automatic control on the clear-water pumping system, all system devices and equipment have to be monitored by a Programmable Logic

Controller (PLC). The information is not only used for control purposes by the PLC, but it also gets sent to the SCADA computer where all the information is saved in a database. This data is then made available to the person in charge and could easily be analysed on a frequent basis to encourage preventative maintenance.

The clear-water pumping system of a deep level mine typically consists of storage dams, pipe work, valves, pumps and motor drives. A breakdown on any of these will have a negative effect on the load shift performance of the DSM project. The functionality set available by the SCADA system as well as the EMS system could benefit the mine as follows:

I) Optimised storage capacity

In the load shifting process, storage dams are used to store water during Eskom`s expensive peak demand periods. The capacity of these storage dams is the critical factor in the clear-water pumping system that determines the potential for load shifting and electricity cost savings. With the aim on reducing electricity consumption during the peak demand periods of the day, it is important to have maximum storage capacity during these periods of time. The cost per unit electricity consumed only during the peak demand hours of the day, amounts to 33% of the total price per weekday during summer and 55% per weekday during winter [34].

Storage dams do not require maintenance on a daily basis and would rather be maintained on an annual basis. Maintenance on storage dams involves removing excess mud to increase the storage capacity in order to maximise load shift savings. Prior to DSM, there was no need for maximum storage capacity. The dams were always controlled within small control ranges.

Due to the limited manpower available to ensure high levels of maintenance on system devices as well as the cleaning of storage dams, storage dams are left running full of mud for periods as long as five years. The energy savings lost due to the limited storage capacities amounts to thousands of rands per annum. By keeping the dams clean the load shift savings during Eskom`s peak demand periods could be maximised. The scenarios for both, limited and maximum storage capacity are given in Figure 2-6:

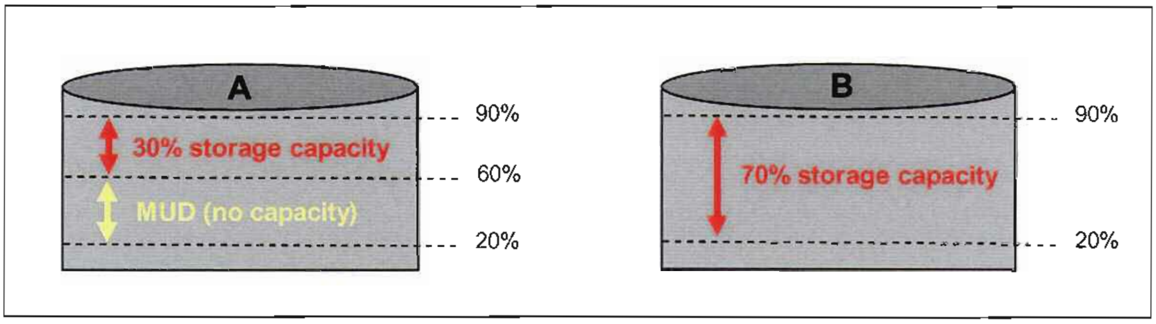


Figure 2-6: Increased storage capacity due to frequent maintenance on storage dams

Figure 2-6 clearly shows that the storage capacity of Dam A is only 43% (30% of 70%) of the designed capacity given by Dam B. Thus, with the limited storage capacity of Dam A, the potential for load shifting is 57% less than with Dam B.

Typically, in order to get the mine management to fund the dam-cleaning process on an annual basis, the expected savings could be used as an incentive. Due to the high risk of flooding involved with running dams at full capacity, it is not viable to perform a physical test to determine the expected savings.

The EMS simulation tool enables the user to determine the expected savings by simulating the clear-water pumping system for various storage capacities. The savings obtained could now be used as an incentive to pay for the dam-cleaning process. The savings expected will determine the duration of the payback period involving the dam cleaning process.

II) Efficiency of pumps and motors

Energy management on the clear-water pumping system is directly related to the amount of electricity consumed by all the motors in the system during a certain period of time. The less electricity consumed for a certain amount of water being pumped, the higher the electricity saving is. In other words, the higher the efficiency of the pump, the higher the electricity cost saving when operating the pump [43].

In the load shifting process, electricity cost savings are related to the storage capacity available during the evening peak demand period. With the varying water situation in the de-watering operation, the storage capacity differs from day to day. During the four to five hours before peak time it is important to prepare the dams for maximum storage capacity. During the preparation phase of load shifting, efficiency of a pump plays a big role in getting the storage dams as empty as possible in a certain period of time.

Note that there is a fine line between a high-efficiency pump and a high availability of a pump. Although availability and high efficiency of pumps are directly related, it is important to have your most efficient pumps available at all times. In order to increase the availability of the most efficient pumps and in turn increase load-shift potential, predictive maintenance of pumps and motors using condition monitoring is essential [44].

The basic principle of calculating the efficiency of a pump is explained on the hand of basic pump characteristic curves. Curve B in Figure 2-7 represents the pump performance curve. For this calculation, the system curve (Figure 2-7, curve A) remains the same, whilst the flow (indicated with red lines) decreases relevant to the pump efficiency. With a lower flow through the pump and a constant head, it is clearly seen that the electric power of the motor has to be increased to restore the existing system performance. Thus, due to the decreasing efficiency of the pump (see curve D), the motor has to draw more power (see curve C) to transfer the same amount of water, given that the head and flow remains unchanged. Equation 2-1 is used to calculate the pump efficiency [38]:

$$\eta = \frac{\rho * g * Q * H}{P} \qquad \textbf{(2-1)}$$

Where,

- η = efficiency (%)
- ρ = density of water
- g = gravity (9.81 m^2/s)
- Q = rate of flow (m^3/s)

- H = Head (m)
- P = $\text{Power}_{\text{Electric}}$ (Watt)

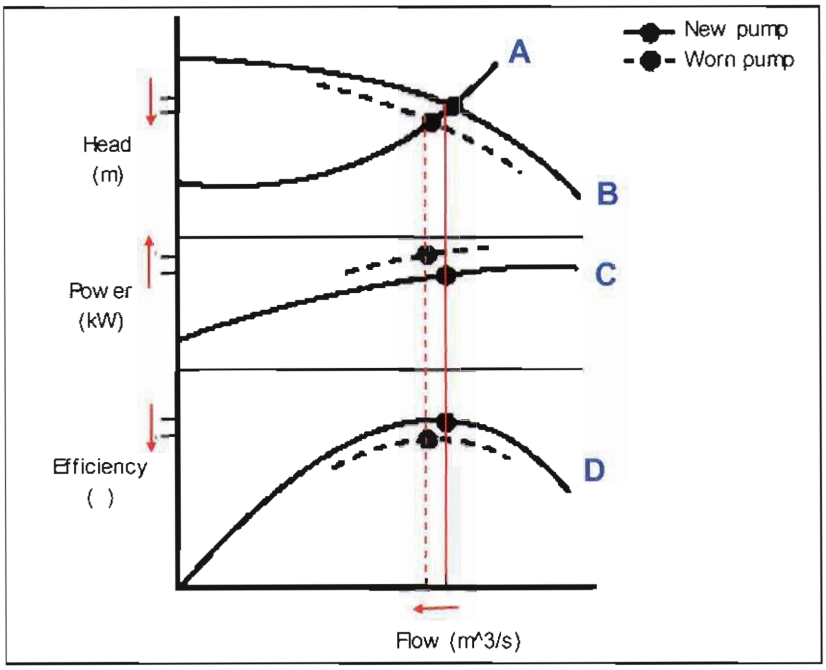


Figure 2-7: Effect of deterioration on pump characteristics

Prior to DSM, preventative maintenance on pumps was not possible due to the limited information available. Efficiency tests were only conducted once in six months by specialised companies [45]. Maintenance done by mine personnel was limited to repair and replacement of small parts, which caused pumps to run at poor efficiencies for long periods of time. As previously stated, the efficiency of a pump is directly related to the electrical cost to run the pump, thus inefficient pumps have led to huge electricity expenses in the past. A case study carried out on underground multi-stage pumps has shown that electricity costs makes up 86% of the life-cycle cost of a pump [46]. It is therefore important to run the most efficient pump and rather service or replace the less efficient pump. The typical information required to determine the efficiency of a pump is as follows:

- Motor current
- Running hours of pump
- Flow rate of pump

- Vibration on pump
- Bearing temperatures (motor and pump)
- Balance disk flow on pump
- Delivery pressure

As part of the automation process of the DSM pumping project, all the information obtained from the PLC is logged on the SCADA system. The information is used to monitor the system's performance and to analyse the condition of the pumps and motors that are displayed on the SCADA system. A graphical representation of the information being monitored and viewed on the SCADA system is shown in Figure 2-8:

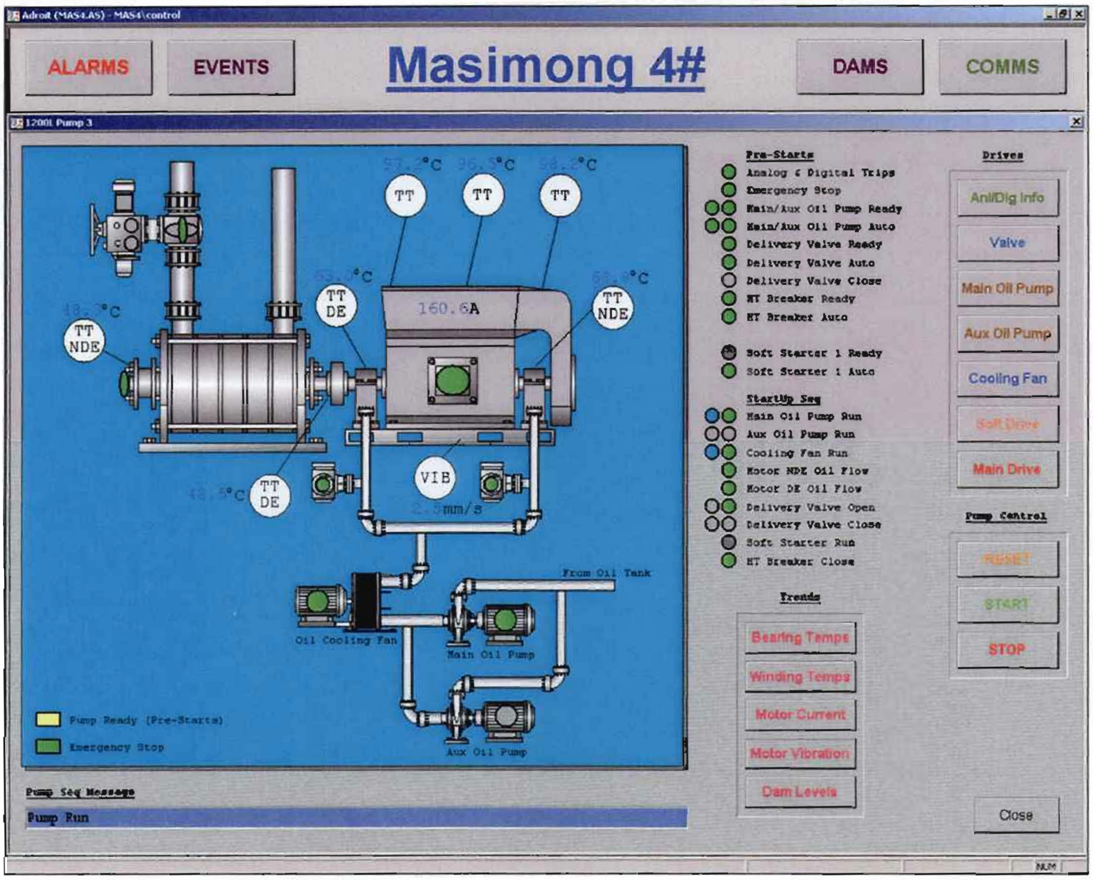
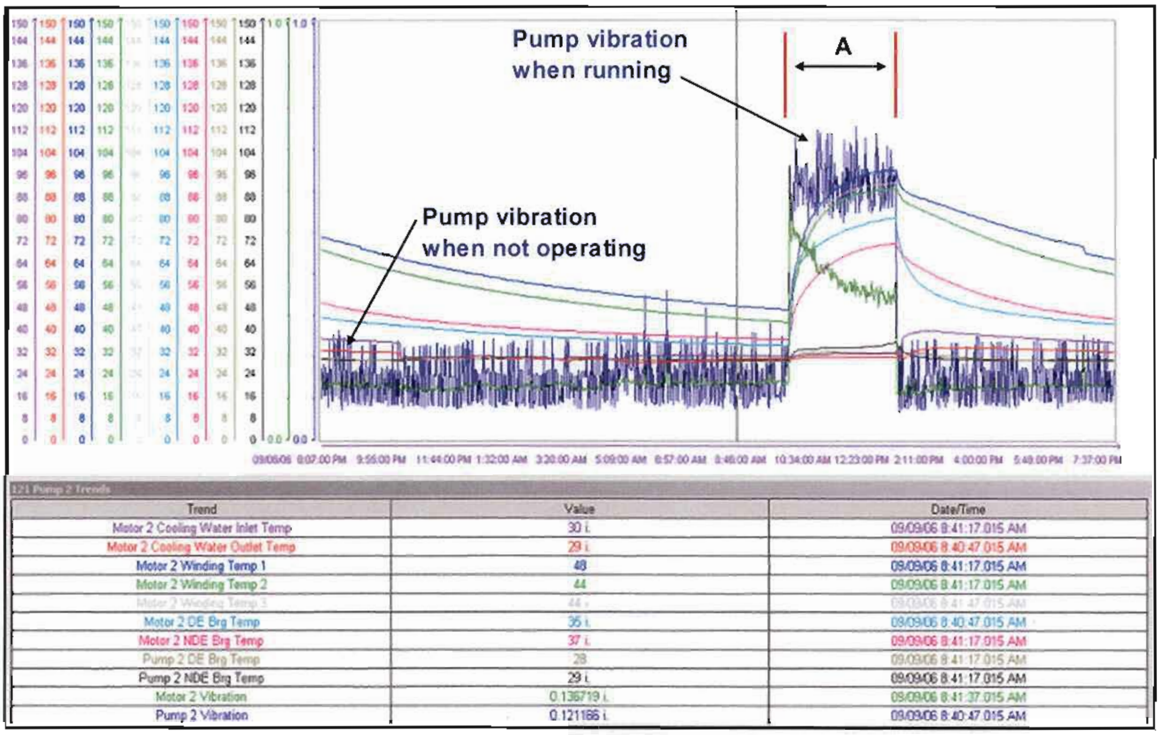


Figure 2-8: Condition monitoring of motor and pump components on Masimong 4# mine

This above figure indicates the various components on the motor and pump being monitored over time. A graphical representation of the typical trends drawn to analyse the condition of the pump is shown in Figure 2-9 (see the following page). Point A indicates the period when the pump was running. The bearing temperatures and winding temperatures increased during these periods. The vibration of both the pump and motor is also displayed on a scale from 0 to 1 mm/s Root Means Square (RMS) [47]. The above-mentioned information, together with the motor current and pump flow readings, could be used to determine the efficiency of a pump.



Trend	Value	Date/Time
Motor 2 Cooling Water Inlet Temp	30 i	09/09/06 8:41:17.015 AM
Motor 2 Cooling Water Outlet Temp	29 i	09/09/06 8:40:47.015 AM
Motor 2 Winding Temp 1	48	09/09/06 8:41:17.015 AM
Motor 2 Winding Temp 2	44	09/09/06 8:41:17.015 AM
Motor 2 Winding Temp 3	44 i	09/09/06 8:41:47.015 AM
Motor 2 DE Brg Temp	35 i	09/09/06 8:40:47.015 AM
Motor 2 NDE Brg Temp	37 i	09/09/06 8:41:17.015 AM
Pump 2 DE Brg Temp	28	09/09/06 8:41:17.015 AM
Pump 2 NDE Brg Temp	29 i	09/09/06 8:41:17.015 AM
Motor 2 Vibration	0.136719 i	09/09/06 8:41:37.015 AM
Pump 2 Vibration	0.121186 i	09/09/06 8:40:47.015 AM

Figure 2-9: Typical trends of pump and motor logged on the SCADA system

This information set available by the DSM project, enables the artisan to proactively maintain the pump and to determine the efficiency of the pump on a more frequent basis. Predictions based on this information could further be used to determine how long the pump should possibly still be used before the next service is due. A pump with an insufficient efficiency could be serviced or replaced by a more efficient pump, which cost less to operate. By performing preventative maintenance on the pumps, the availability of the more efficient pumps will increase and a sustainable load shift performance will be ensured.

III) Benefit of a maintenance contract between the client and the ESCO

The DSM project enters into a performance assessment period after the implementation phase is completed. During the performance assessment period the ESCO is responsible for delivering the contractual megawatt (MW) load-shift savings. It should be noted that after the performance assessment period is completed successfully, the ESCO is no longer responsible to meet the contractual MW load shift target. From this point in time the mine is responsible for the delivery of the contractual MW load shift savings to Eskom.

A mine can enter into a maintenance agreement with the ESCO in order to reduce the risk of not meeting the DSM targets,. The ESCO, who specialises in the energy savings field, has all the necessary tools and expertise to ensure sustainable DSM performance. The following services are provided by the ESCO to improve the system performance of the client and to ensure sustainable results:

- The ESCO has the function of monitoring and analysing the system performance on a day-to-day basis in order to ensure optimal savings.
- Reports containing the savings achieved as well as the savings lost due to missed opportunities are available to the management.
- The mine receives a 24-hour standby service.
- Constant system support and system updates are available to the mine.
- The ESCO will carry the responsibility of shifting the required minimum load.
- The ESCO will handle the correspondence with Eskom regarding project operation.

The benefit to the mine of having all these monitoring and support systems provided by the ESCO, is that the mine personnel involved with the project remains informed about the system performance. Due to the negative impact of system breakdowns on the load-shift performance, mines without constant monitoring miss out on large savings. With a maintenance contract, the ESCO monitors the system on a continuous basis and informs the mine as soon as the problem is identified. This enables the mine to immediately address the problem in order to minimise system downtime. The financial impact of a maintenance contract between the client and the ESCO is quantified in Chapter 3.

2.5 OTHER BENEFITS OF DSM

2.5.1 Control infrastructure

We are currently in the era where intelligent communication and control systems are the norm of the day. With the control systems available on the market nowadays, the industrial sector is rapidly changing over from human factor controlling the system, to an automated control system.

The main advantage of having an automated control system is to improve the efficiency of the system by managing the system devices. A more efficient system is only possible when the inputs are minimised relevant to the output. The functionality of monitoring and measuring the system devices, due to an automated system, ensures a more sustainable system. The law of metrics states the following: "If you cannot measure, you cannot manage, if you cannot manage, you cannot improve" [48].

Although the mines are familiar with the energy saving possibilities, it is not always feasible for them to replace human factor with an automatic control system due to the high costs involved. Although some small-scale automated systems are put in place by the mine, it is too expensive for the mine to automate a system as big as a clear-water pumping system.

Manual operation of critical dewatering systems, where the main focus is to avoid the mine from flooding, currently costs mines thousands of rands each year in electricity costs. It is clear that the pump attendants, controlling the pumps, are not cost-savings driven or load-shift orientated, and therefore do not mind starting the pumps during Eskom`s peak (high priced) demand periods. Without an automated control system the mine is dependent on the human factor to intelligently schedule and optimise the pump system within the system constraints. Due to the complexity of the system when considering Load Management, the mine management cannot expect an unschooled pump attendant to control the pumps in such a way as to obtain electrical cost savings on a sustainable basis.

With the Eskom DSM programme requiring sustainable load-shift results and a consistent reduction in electrical demand during the peak hours of the day, the clear-water pump system in this case has to be automated. Eskom will fund the capital expenditure on equipment that leads directly to load shifting or energy reduction as well as the installation and commissioning of such equipment.

For load-shifting projects, such as the clear-water pumping projects, Eskom funds 100% of all costs and the client will not be required to contribute to the capital expenses involved with the project [17]. Although the client will assume ownership of all infrastructure immediately after installation, the client will be responsible for the insurance of the assets and maintenance of such assets in accordance with the Eskom DSM agreement.

Although the infrastructure required is so diverse from mine to mine due to the various system layouts, the most common equipment to be installed remains standard. Some mines already have the required infrastructure in place to control the pumps from a centralised point on site, therefore Eskom does not fund any infrastructure not directly related to automatic control.

An automated pump system is a system where the pumps can be controlled from a centralised point on the mine. For this to be realised, all switchgear, field instrumentation and manual valves should be upgraded and automated in order to be controlled by a PLC.

The infrastructure funded by Eskom to realise automatic control of the pumping system could be divided into three categories, (i) infrastructure installed on the pumping stations, (ii) network and communication equipment and (iii) optional equipment.

I) Infrastructure installed on the pump stations

Prior to DSM, the pump attendants working on the pumping station performed the switching operation of pumps. This is an all-manual process where the pump attendants had to follow a certain procedure before a pump could be stopped or started. The start-up procedure of a typical clear-water pump is described in the following steps:

Step 1: Open up the suction valve and make sure that the spindle opens.

Step 2: Open small taps on each pump stage to get rid of air. Close when water is coming out.

Step 3: Check that there is oil in the bearings and no water in the bearings.

Step 4: Make sure the delivery valve is closed. Open delivery valve slowly.

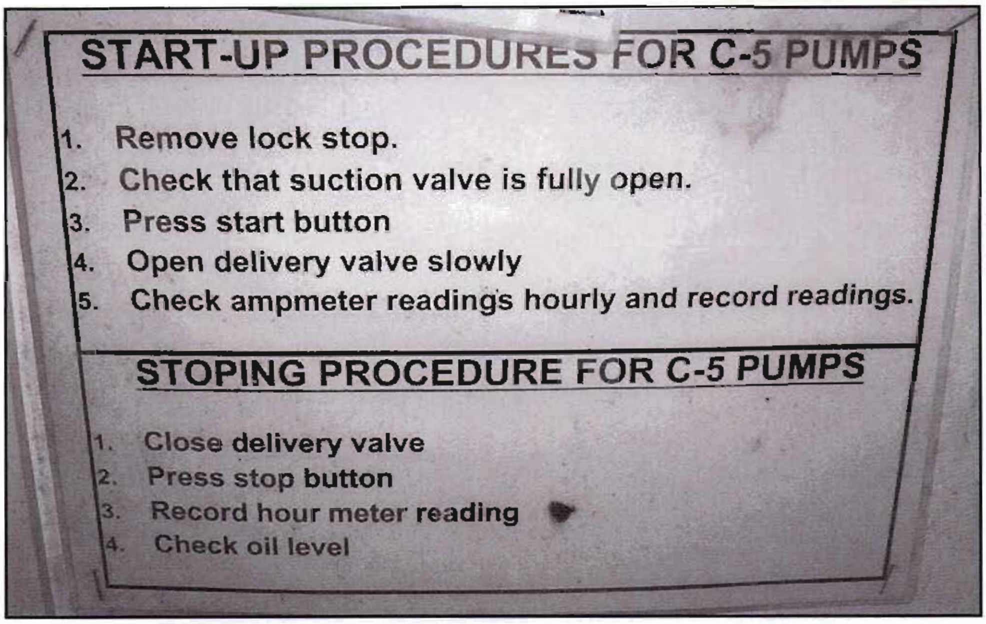
Step 5: Now the pump is ready to start. Push the start button on the electrical 6,6 kV switchgear.

Step 6: Open the delivery valve slowly until fully open. Make sure that the motor current is synchronised at the required amperes.

Step 7: While the pump is running, certain checks have to be done on a frequent basis to monitor the pump and motor, which includes the following:

- Check the ampere meter reading of the motor.
- Check that the oil rings are turning in the pump.
- Check that the motor bearings are not overheating.
- Check the vibration of the pump.

It is clear that the start-up procedure is complex and unwieldy. It takes two pump attendants approximately 10 to 15 minutes to start a pump. Another interesting fact is that when pump attendants change shifts, the pumps are unattended for a dead period of roughly 30 minutes. The cumbersome manual start-up procedure and the unattended period make it difficult to execute a 24-hour optimised schedule to realise sufficient peak load shifting and electricity cost savings.



START-UP PROCEDURES FOR C-5 PUMPS

1. Remove lock stop.
2. Check that suction valve is fully open.
3. Press start button
4. Open delivery valve slowly
5. Check ampmeter readings hourly and record readings.

STOPING PROCEDURE FOR C-5 PUMPS

1. Close delivery valve
2. Press stop button
3. Record hour meter reading
4. Check oil level

Figure 2-10: Start-up and stopping procedure for the pumps (photograph taken at Harmony 3# mine)

Not only do the pump attendants have to stop and start the pumps manually, they also have to monitor the dam level constantly. In order to have a fully automated control system taking over the duties of the pump attendants, various infrastructure on the pumping station has to be changed. The manual stop / start procedure, as illustrated in Figure 2-10, is replaced by installing the following control infrastructure on the pumping system underground to enable automatic control:

Automatic dam level indicators

The most common manual dam level indicator used prior to DSM was a floating ball, indicating the level on the outside of the dam. The only way of knowing what the dam level is, is to physically look against the wall of each dam. This floating ball dam-level indicator is shown on the left of Figure 2-11 (next page).

For automatic control purposes this manual dam level indicator is replaced by an ultrasonic level indicator located on top of the dam, measuring the dam level constantly. This information is then communicated to the PLC giving a live indication of the dam level.

Figure 2-11: Old dam level indicator and actuated control valve (Masimong 4#)

An alternative way of measuring the dam level is by installing a pressure transmitter onto the suction column between the pump and the dam from which the water is drawn. The pressure measured in the pipe is a reflection of the amount of water in the dam (measured by the head) and could be converted to percentage volume water in the dam.

Automatic control valves

Each pump has a valve positioned on both the suction as well as the delivery side of the pump, which is opened and closed manually according to the actions of the pump. During manual operation, these actions are done by hand.

To enable automatic stopping and starting of pumps, the manual valves are automated by installing an actuator controlling the opening and closing process of the valves. The automatic valve with actuator is shown on the right hand side of Figure 2-11.

Field instrumentation

As described earlier in this section, there is a list of checkpoints to be performed by the pump attendants before a pump is started up and also while the pump is running. Although the same procedure is followed before a pump is started manually, this procedure has to be automated for remote controllability. For this procedure to be automatically performed by the PLC, the field instrumentation is linked to the PLC.

The field instrumentation commonly installed on each pump is a vibration transmitter, bearing temperature transmitter, flow switch, pressure switch and electric actuator. The field instrumentation gets installed on each pump and connected to a junction box via single pair cables. The junction box is then connected via a multi-core cable to the PLC for interlock, tripping, remote monitoring and controlling.

Field instrumentation is hardware components physically installed onto the pump and motor, constantly measuring the state of the specific device. A picture of the field instrumentation connected to the bearings of the pump and motor is shown in Figure 2-12:

Figure 2-12: RTD probes measuring the bearing temperature and vibration on the shaft

High-tension (HT) and instrumentation cable

Usually, high-tension (HT) cable, from the supply panel to the motor, is already in place. Only if the existing HT cable is damaged or absolute, new cable will be installed. HT cable always gets connected through a circuit breaker to avoid electrical faults from damaging the electrical equipment.

Instrumentation cable connects the field instrumentation to junction boxes. From the terminals in the junction boxes, the instrumentation cable is connected to the PLC.

II) Network and communication equipment

Programmable Logic Controller (PLC) equipment

The PLC installed for each pump, is the device used to perform automatic stopping and starting of the pumps. The PLC is a digital software package programmed to communicate through analog signals with the pumps. Each PLC rack consists of a Central Processing Unit (CPU), Ethernet module (device for a specific communication language), analog-to-digital input and output modules communicating to the field instrumentation. A picture of a typical PLC with its modules is shown in Figure 2-13:

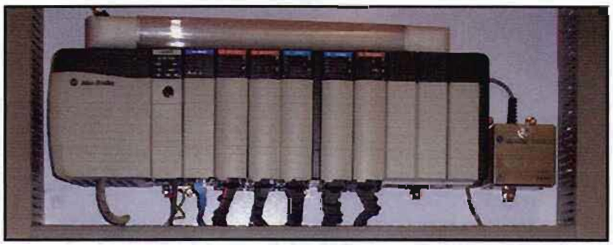


Figure 2-13: Allen-Bradley PLC

All low-tension (LT) and high-tension (HT) drives are interfaced with the PLC to facilitate remote control and monitoring of the pumps from a surface control room. A Human Machine Interface (HMI) is mounted onto the panel of the PLC to enable local control and indication on the pump station. A picture of a typical HMI is shown in Figure 2-14:

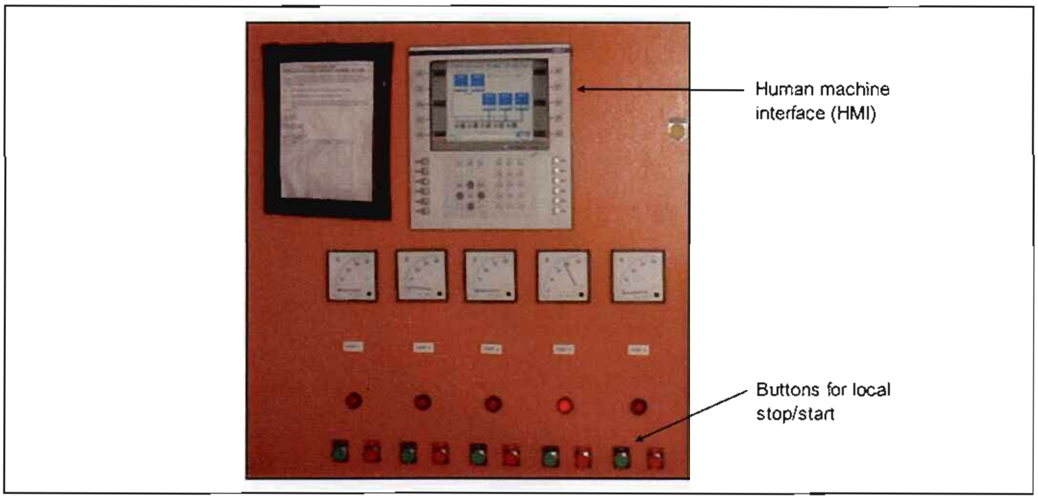


Figure 2-14: HMI which enables local stop and start of pumps

Communication cable between pump stations and surface

Some mines already have a communication backbone transferring data between underground and surface. Until recently, the most common method of communicating over great distances was with the use of copper cable. Using copper cable for communication purposes has a number of drawbacks. Some drawbacks include high losses of signal strength over long distances, which require amplifiers or repeaters to strengthen the signal [50]. Copper is a very good conductor and requires sufficient electrical isolation to eliminate differences in earth potential. For data transfer purposes copper also has a low immunity to electromagnetic interference (EMI), which makes the communication medium unreliable.

Fibre optic communication has proven to be more reliable and successful in a wide variety of applications. The benefits of using fibre optic cable over copper cable for communication purposes are given as follows [51]:

- Optic losses are significantly small. Data can be transferred over a distance of more than 2 km without the use of repeaters.
- Fibre optic is light and has a small cable size.
- Immunity to electromagnetic interference.
- High electrical resistance, making it safe to use near high-voltage equipment.
- By using multiplexers, one fibre could replace hundreds of copper cables.

Fibre optic cable is the ideal solution for the purpose of communicating data from the pumping station to the surface control room enabling remote control of the pumps. The main reason for using fibre optic cable is because of the reliability of communicating data between the control system and the PLC. If communication to the pumping station was to be lost every now and again, the risk involved in controlling the pumps remotely from surface will be very high.

By installing a graded index multi-mode fibre optic cable in the shaft for the communication purposes of the DSM project, additional equipment could also be connected to the fibre optic cable to be monitored at a remote station. Fibre optic cable is dynamic and can be used to transfer multiple signals at a time.

Supervisory Control and Data Acquisition (SCADA) system

In order for the Load Management system to remotely control the pumps, a SCADA system with two-way communication to the PLC is needed. The SCADA system is located in the control room on the surface and acquires all the information from the PLC. It is important to note that the SCADA system does not control the pumps according to a certain schedule; it only serves as the master system, obtaining all information required by external control systems communicating to the PLC. The purpose of the SCADA system is stated as follows:

- The SCADA system visually presents the layout of the complete system monitored by the PLC. In this case, it is the clear-water pumping system.
- It enables Ethernet communication needed to stop and start the pumps remotely.
- It has the functionality to draw historical trends of the equipment monitored over time.

The status of each pump and the dam level readings is illustrated on the SCADA system and changes according to the real-life actions of the de-watering system. The typical display on the SCADA system installed on Masimong 4# is shown in Figure 2-15 (next page). The picture on the left illustrates the measurements taken by the field instrumentation while the picture on the right shows the layout of the clear-water pumping system.

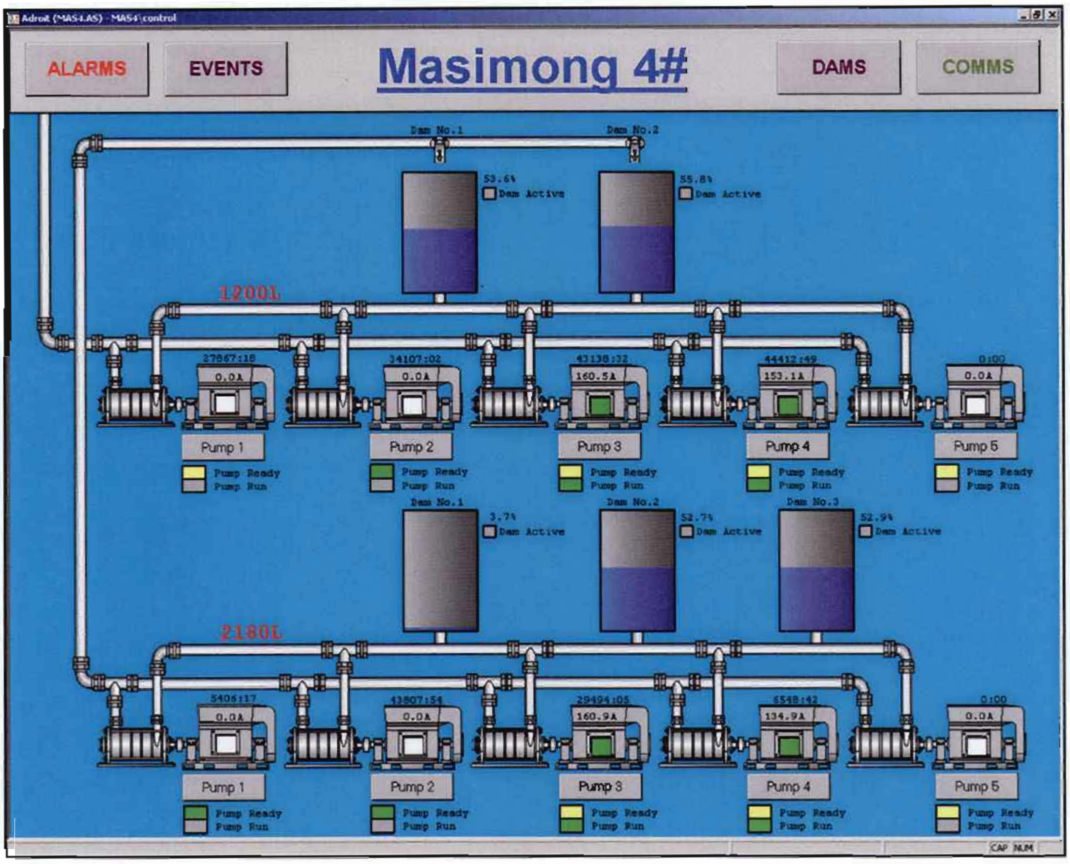


Figure 2-15: Typical illustration of the Adroit SCADA system installed at Masimong 4# mine

All the information received by the SCADA system gets logged and saved into a database. In order to promote preventative maintenance, trends of the historical data logged for each system device could be drawn. This information could then be analysed to see what the status of the specific devices is in order to repair or replace it at the most suitable time.

The Energy Management System

The Energy Management System (EMS) is an on-site information system controlling the pumps from a centralised point on the surface via the SCADA system. The EMS optimises the pumping actions in order to prepare the dam levels to enable load shifting during the Eskom peak demand periods.

Before the EMS system is implemented on site, a simulation model is built to model the water pumping system of the mine according to the real-life application. Mathematical models are used to model each system component individually before the whole system gets integrated. The component models link inputs to the basic variables in the system. These are based on simplified fundamental principles combined with correlation coefficients derived from discrete empirical data [52].

The models are fully component-based and allow simulation of a wide range of operating conditions. The calculation of the energy consumption of each component is included in each model.

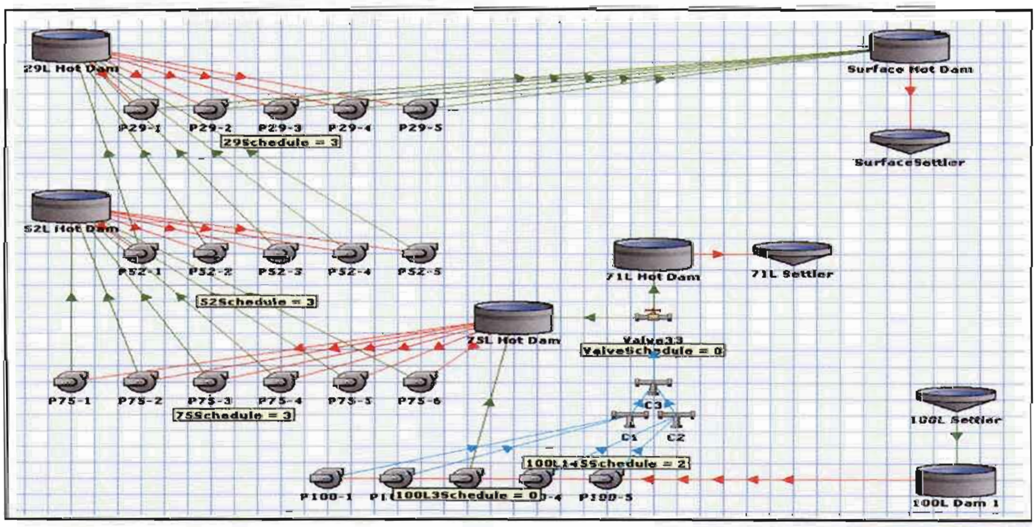


Figure 2-16: A typical mine water pumping simulation model

Figure 2-16 shows a typical layout of the clear-water pumping system in a mine as it is built up in the simulation software package. Once the simulation model of the system has been completed, this creates the opportunity to build an optimisation engine. The output of such an optimisation process is a component scheduler, which is an operation schedule for every controllable component in the system. Since energy consumption figures and costs are inherent elements of the simulation model, the optimised operations schedule will result in an overall minimum cost of electricity. The operation of the EMS system and its relation to other components in the overall system can be seen in Figure 2-17 on the following page.

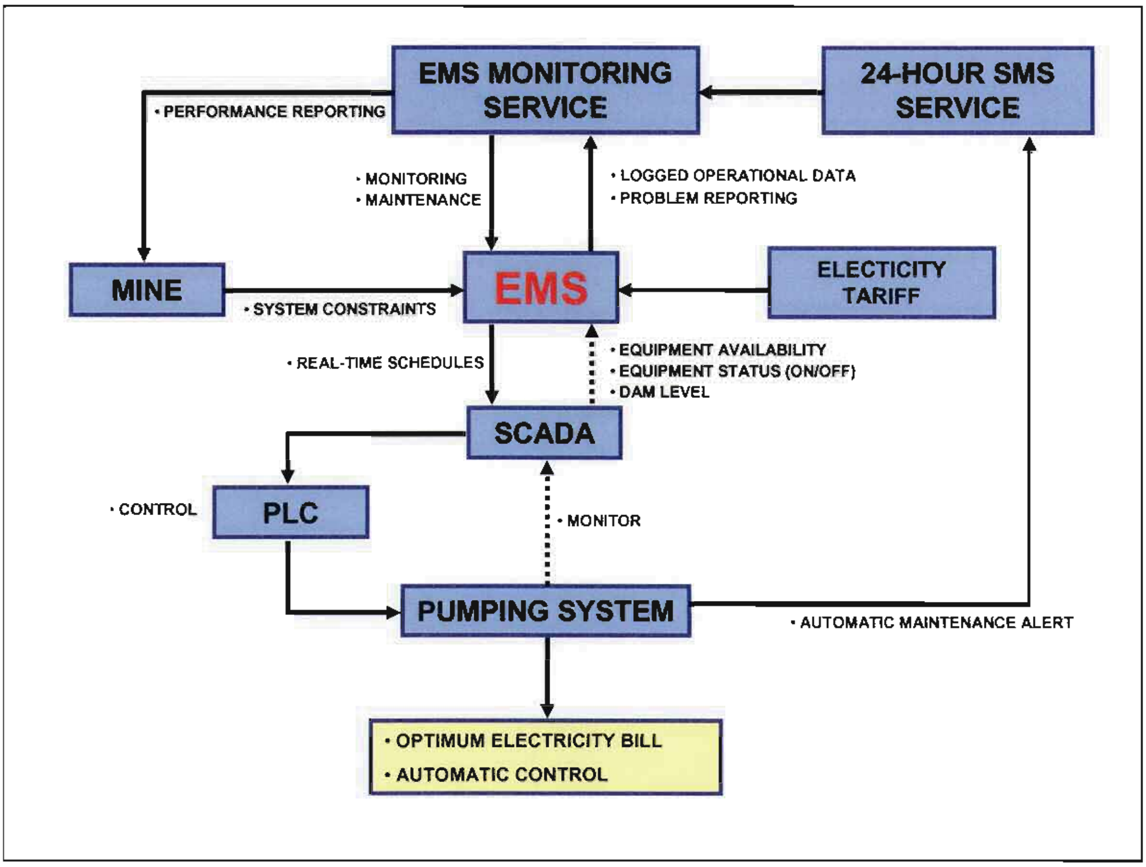


Figure 2-17: Schematic diagram of the Energy Management System (EMS)

The EMS unit will typically be located in the control room on the mine, where it is connected to the SCADA system. It controls the pumps and valves through the SCADA system, which is connected to the relevant mine systems by means of communication hardware and software.

III) Optional equipment

In load-shifting projects on pumping systems it is often required for pumps to be switched on and off more frequently than before. This deterioration of the pumps' efficiency due to constant on and off switching could be considered a problem, and may be an undesirable feature to the client. However, soft starters (which eliminate the problem) can, and should, be included in the DSM project and will in this case also be funded by Eskom.

Soft starters

It has become a common concern that, when starting high-voltage Alternating Current (AC) motors, the torque developed in the starting phase of the motor is excessively more than the torque required at full speed [53]. The consequence is that the excess stress, which is transferred to the mechanical transmission system, results in excessive wear and premature failure of chains, belts, gears, mechanical seals, etc. Additionally, rapid acceleration also has a massive impact on electricity supply charges with high in-rush currents drawing up to 600% of the normal run current.

Soft starters are designed to provide controlled starting and stopping of high voltage AC electric motors, employing the latest Digital Signal Processors (DSPs) to accurately control the ramp voltage supplied to a motor over an optimum time period as set by the user. The voltage is adjusted by making use of power electronic devices controlled through a firing signal generated by the DSP, which consequently alters the voltage phase. Figure 2-18 illustrates how the voltage amplitude and strain are dampened by making use of soft starters, in comparison with the direct-on-line approach.

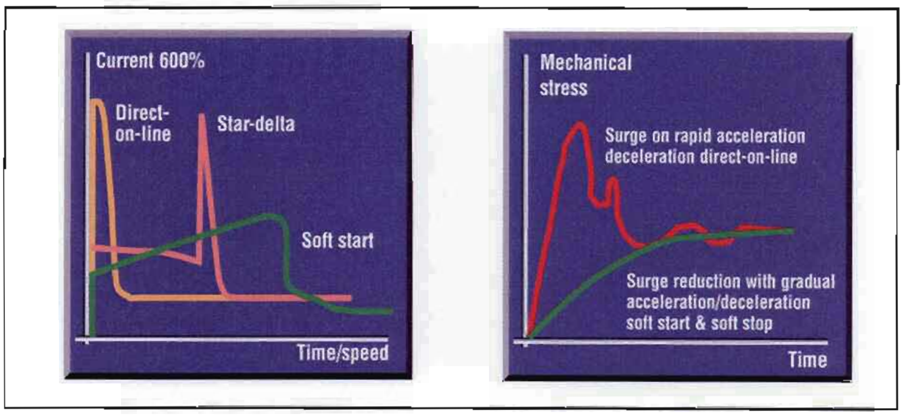


Figure 2-18: Effect of a soft starter on the current and stress of a motor

The benefits of having soft starters installed are as follows:

- The sudden impact at start-up of uncontrolled starting, followed by the rapid acceleration to full speed, causing problems across a wider range of equipment types, could be minimised.

- Pumps that were previously left running due to concerns about it restarting (shafts that get sheared and bearings which fail) could now be stopped to enable load shifting.
- Multiple current or voltage ramp-up curves are used during the start-up to reduce peak torque and further mechanical stresses.
- Electricity cost savings is achieved due to a higher availability of the more efficient pumps. (The actual benefit of this is briefly discussed in Section 2.4.4).
- The stresses from water hammering on the pipe system are minimised due to the soft-stop functionality of the soft starters.
- By controlling and limiting the stresses on the mechanical and electrical equipment, real savings in energy and maintenance costs could be achieved.

2.5.2 Ensuring sustainable savings

The idea of having a control room on the mine was initially put in place to have a centralised point on site. The control room is used mainly for communication purposes between underground and surface activities as well as from outside areas. The control room operators are on duty 24-hours a day attending to telephones calls.

As technology improved and operational systems from various places on site could all be displayed on a single computer screen, the control room operators had to monitor these systems. Slowly the duties of a control room operator expanded to being more of a system's co-ordinator, and at the same time, ensuring reliable performance of the systems being monitored. This also applies for the EMS controlling the clear-water pumping system underground.

Although the EMS system is a fully automatic control system optimising the energy consumption, it is not recommended to run without the supervision of a human being. This is mainly due to the dynamic style and the fast-changing circumstances of the clear-water pump system. In other words, this means that the water flowing into the system varies with time and a breakdown on any of the system devices could have a vital effect on the system performance. Due to the limited control options during emergency situations the automatic system could malfunction. Not only could a malfunction of the automatic control system lead to loss of energy savings but it could also lead to the loss in production and life of people working underground.

Safety of the personnel working on site is of utmost importance to any engineer. By putting a control room operator in place monitoring the system, safety of people as well as energy savings could be ensured.

Performance measurements have shown that by having a control room operator that monitors the actions of the EMS system, the sustainability of DSM results achieved has been more than satisfactory. Due to the continuous changes in the water balance and the amount of system breakdowns having an impact on the system constraints, the fully automated control system in this case has to be bypassed and controlled manually by the control room operator.

System breakdowns occur on a daily basis which requires the control room operator to take over the control responsibilities until the system is under control again. During this period of time the preparation for load shift could be spoiled, which directly affects the load shift results. The EMS system enables the control room operator to see the whole scenario of the pumping system, and proactively manually control the pumps from the surface to ensure maximum savings during peak time.

Mines without a control room are more commonly the mines that struggle to succeed in reaching their energy saving targets. This is because nobody can take over the control responsibilities during a breakdown in order to get the system variables within system constraints for the EMS to control the pumps automatically again.

2.6 POSSIBLE HIDDEN COSTS OF A DSM PROJECT

2.6.1 Controlling the maximum demand

Electricity tariffs dictate how consumers are billed for their electrical energy usage. The main costs associated with supplying electrical energy are the costs of generating the energy and the cost of getting it to the customer (transmission, distribution and reticulation cost). The tariff for large consumers consists of two components. Firstly, it comprises a charge for the energy consumed (charged in kWh units) as discussed in Section 2.4.1 and secondly, a charge for the maximum demand (MD) incurred during the billing month (charged in kW units) [54]. The focus of this section is on the latter.

Due to the huge impact that various sectors in the economy have on the electricity demand network, large industries have to perform better demand control on their total energy profile. The reason being that Eskom as the utility, has to do planning and has to control the generation capacity according to long term demands in order to ensure availability of electrical energy at any period in time. This system or charge put in place by Eskom is called Notified Maximum Demand (NMD). NMD is a written demand by the company given to Eskom on the level at which the company foresee their maximum demand usage [55].

As a customer does not always draw a constant power from the supply network during each half hour of the day, peaks and troughs result in a consumption profile. This consumption profile is monitored by Eskom and the integrated power (kVA) for every half hour determines the maximum demand of the customer. The highest measurement for the day is known as the MD of the day, while the highest daily Maximum Demand (MD) measured over a period of one month is used to determine the monthly maximum demand. This principle is better illustrated by an example as seen in Figure 2-19:

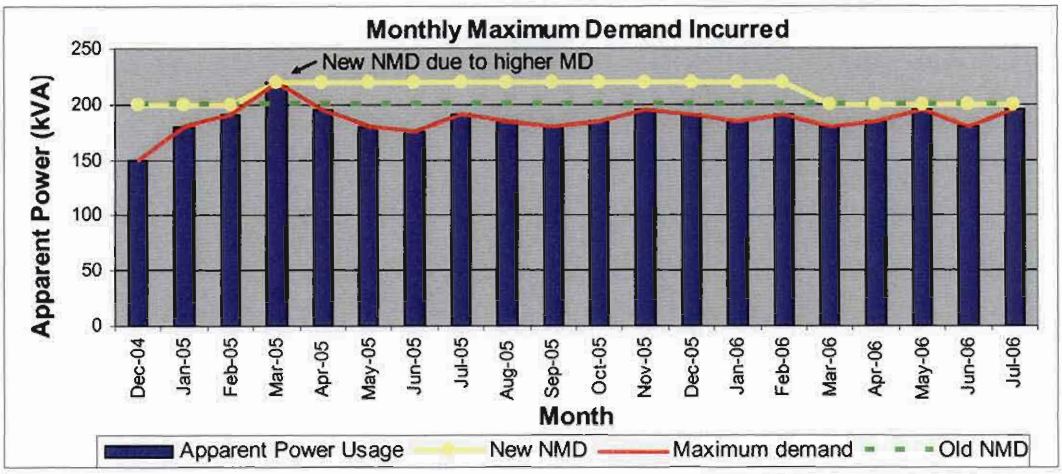


Figure 2-19: Maximum Demand (MD) due to higher apparent power usage

Figure 2-19 illustrates how the maximum demand (MD) tariff is charged onto the consumer. The blue columns illustrate the maximum apparent power consumed (kVA) at any half hour during the standard or peak demand times per day for each month. The red line represents the highest MD for each month. The green dashed line represents the written NMD the company gave to Eskom, while the yellow line indicates the NMD on which the customer gets charged by Eskom.

DSM load shifting has a tendency to increase the MD, especially directly after peak time in an attempt to restore the dams to a safe operating level. A simple example of a higher MD and also NMD is used to show the financial impact of an increased MD as well as NMD, see Figure 2-19.

It is clear that the apparent power consumption exceeded the written NMD in March 2005, thus the NMD increased from 200 kVA to 220 kVA. From March 2005, the company will continue to pay a monthly demand charge based on this higher NMD peak until either a higher peak is recorded or until a new demand is calculated after twelve months. The network charges involved with a higher MD is calculated in the following table.

Table 2-2: Cost regarding higher network demand

Charge	Cost/kVA	NMD charged		MD measured		Actual cost		Extra monthly cost
		Previous NMD (kVA)	New NMD (kVA)	Previous MD (kVA)	New MD (kVA)	Previous	New	
Network access charge (NMD)	R 5.91	200	220	-	-	R 1,182	R 1,300	R 118
Network demand charge (MD)	R 6.69	-	-	190 (<200)	220	R 1,271	R 1,472	R 201

From Table 2-2 it can be seen that the network access charge, or NMD, increased by 10% and the network demand charge, or MD, increased by 15.8%. The higher network access charge is charged for the next 12 months and the higher network demand charge is only charged for the specific month, with 190 kVA taken as the average measured MD over a period of time [34]. Thus, the extra annual cost due to the higher MD is calculated to be 10.4%. This calculation is shown below:

Extra network charge due to the higher MD in March 2005:

$$\text{Extra Network Charge} = \left(\frac{\text{Higher NMD}}{\text{Previous NMD}}\right) + \left(\frac{\text{Higher MD}}{\text{Previous MD}}\right)$$

$$= \left(\frac{220\,\text{kVA}}{200\,\text{kVA}}\right) + \left(\frac{200\,\text{kVA}}{190\,\text{kVA}}\right) \tag{2-2}$$

$$= 25.8\%$$

Annual extra network charge due to the higher MD

$$\text{Percentage Extra Annual Cost} = \frac{\left(\frac{\text{Higher NMD}}{\text{Previous NMD}} \times 12\text{ months}\right) + \left(\frac{\text{Higher MD}}{\text{Previous MD}} \times 1\text{ month}\right)}{13\text{ months}}$$

$$= \frac{\left(\frac{220\,\text{kVA}}{200\,\text{kVA}} \times 12\right) + \left(\frac{200\,\text{kVA}}{190\,\text{kVA}} \times 1\right)}{13} \tag{2-3}$$

$$= 10.4\%$$

Now, the consumer will ask why the NMD can't be increased to levels where it won't be exceeded by a sudden peak in the apparent power consumed. Eskom already put a system in place where the demand charges are being changed in South African electricity tariffs, so that a customer will be penalised for reserving a portion of the network capacity but not using it as reflected by the monthly demand incurred. This is called the "Utilised Capacity" and is expected to become one way of charging consumers for their use of the network.

By having a Load Management system installed on the energy intensive equipment, the MD of the mine could be controlled [56]. This is done in order to avoid an exceeded NMD and also to minimise the excess system expenses by not paying network charges for unnecessary capacity made available.

2.6.2 Risk of flooding

Dewatering systems play a critical role in the typical mining cycle due to the mining activities mainly taking place at levels far below surface. Underground water consists of both fissure water, continuously flowing into the system, as well as cold water sent down the shaft for cooling purposes and various other mining activities. After the water has been used, it is constantly flowing into the bottom level dam from where the water gets pumped out to surface level where it gets cooled down again.

Pumping water from underground seems rather simple, but has lead to major losses in production as well as in lives in the past. The human factor controlling the pumps has a high amount of risk involved. The only way of stopping or starting pumps with a manual control system is on the station itself, which limits the control of the pumps to the pump attendant. With the limited control options, illiterate pump attendants and fast changing water balances, the risk of flooding the mine especially when attempting load shifting, is very high.

It is the duty of the engineer on the specific mine to set the minimum and maximum dam levels taking into account the safety factors regarding the dam capacities. During normal pumping operations, the pumps are controlled within the limits set by the engineer with a low level of risk. During emergency situations resulting from breakdowns or a high inrush of water into the system, the pump attendant is not authorised to make decisions regarding the safety of workers and thus the need for a more senior person exists. During times like this, the engineer will give the necessary instructions until the system is under control again. If the competent person required in an emergency situation is not available, the risk of flooding increases significantly.

The EMS system installed on the mine eliminates the human factor which in turn decreases the risk of flooding the storage dams. The low risk automatic control system takes into consideration all the safety hazards and has an alarm system in place notifying the person in charge about potential risks.

The biggest advantage of having an automatic control system in the control room is that the entire pumping system can be seen as a whole. With the necessary measurements and indications displaying the system variables, an accurate forecast of possible risks could be made. Being able to proactively identify the potential risks, these risks could be managed and turned into safe operational measures.

2.6.3 Possible costs to the client when taking on a DSM project

Before taking on a DSM project, the first contract to be signed is a DSM contract between the client and Eskom. This contract consists of penalties clauses stipulating the financial costs involved to the client for a lower performance as contracted, or an early termination of the project. These two types of penalties are discussed as follows:

I) Costs involved due to the underperformance of the load shifting project

Once the Energy Services Company (ESCO) has completed the implementation of the DSM intervention, Eskom DSM issues a certificate of completion. The project then enters into a performance assessment phase where the ESCO is responsible for achieving the intended MW load-shift saving. The ESCO will be penalised if the intended load-shift saving is not met, and the target will then drop to the maximum achieved MW saving by the ESCO during this period [57].

After the performance assessment phase, the project enters into a performance-tracking phase where the mine is responsible to sustain and maintain the contractual MW saving.

During this phase the client gets penalised for underperformance of the system. DSM projects perform, underperform or overperform during this phase. The penalties involved with underperformance will be discussed in this section. Figure 2-20 on the following page graphically presents the penalty and banking structure for DSM projects [36].

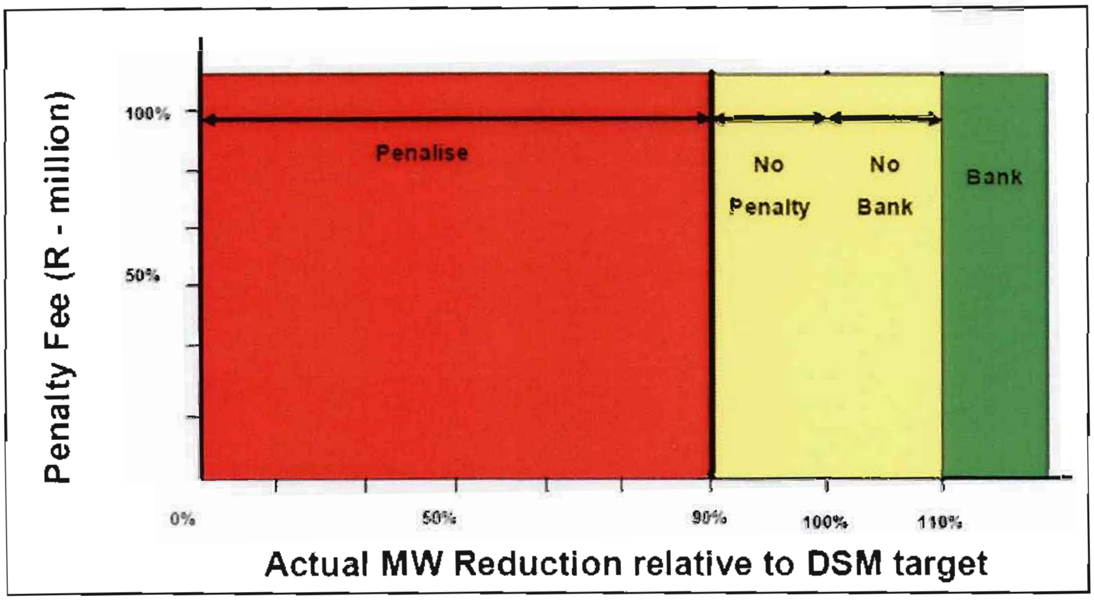


Figure 2-20: Underperformance penalties and banking

As illustrated by Figure 2-20, the client will only start paying penalties for achieved savings smaller than 90% of the contractual saving. If the client overperforms the extra megawatt hours (MWh) will be saved in the bank. Only when the penalties exceed the total banked MWh, the client has to pay a specified amount to Eskom for the monthly underperformance. The penalties to be paid by the client are given in Table 3-2:

Table 2-3: Penalty structure for underperformance of a DSM project

PERCENTAGE OF CONTRACTUAL SAVING ACHIEVED	PENALTY TO CLIENT (R/MWh)
Above 90%	R 0
Between 80% and 90%	R 526
Between 70% and 80%	R 546
Between 60% and 70%	R 620
Less than 60%	R 846

This penalty structure will be discussed in more detail later in the study in order to quantify the risk of taking on a DSM project for the mine.

II) Costs involved with early termination of a DSM project

A second risk to the mine, when taking on a DSM project, is the costs involved with an early termination of the DSM load-shifting project. The costs involved for an early termination of a DSM project is due to the infrastructure Eskom funded to accommodate the automatic control system used for load shifting. The amount payable to Eskom is calculated by the following formula [57]:

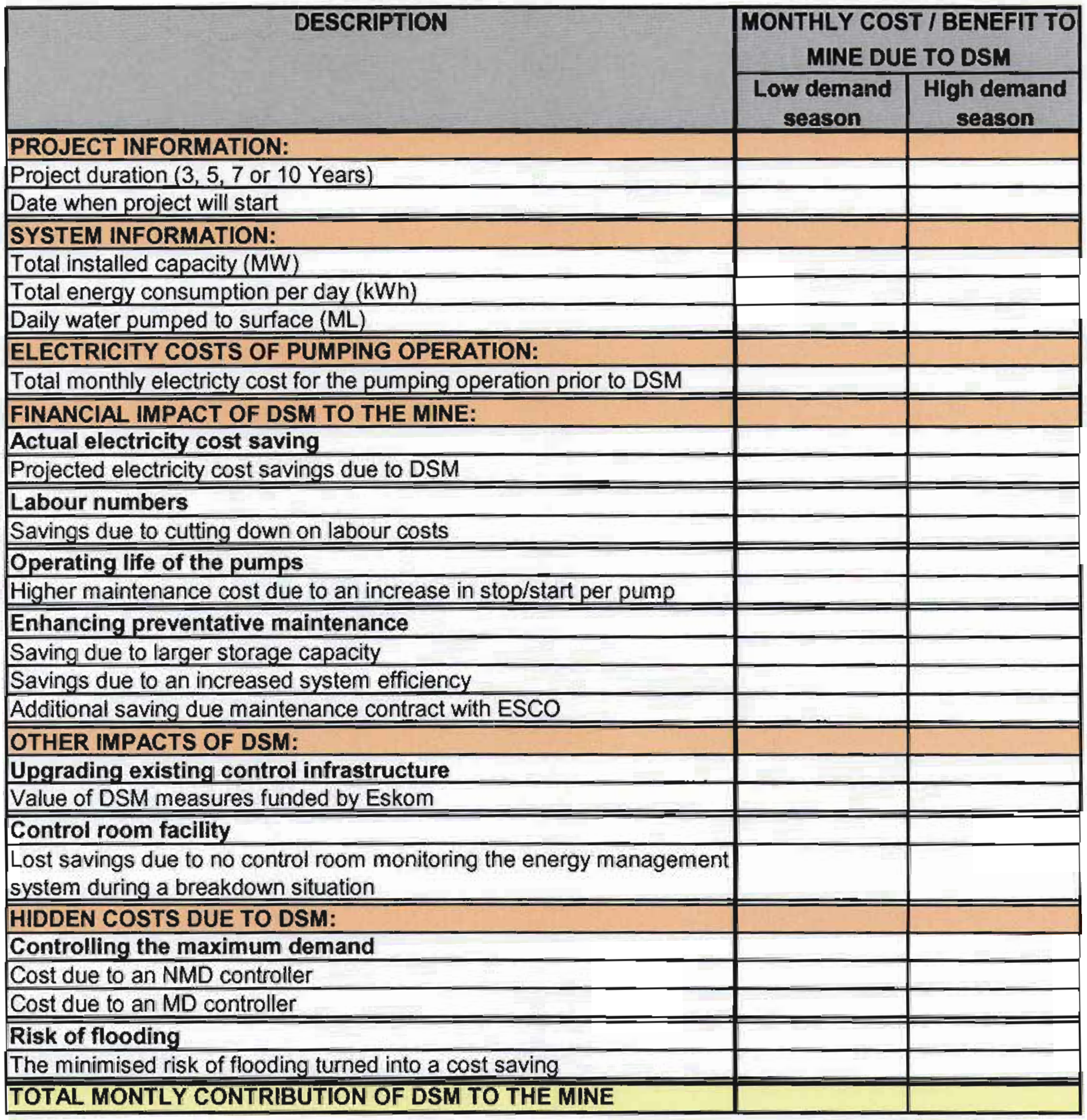
$$\text{Termination penalty (TP)} = \left(\frac{\text{Total cost of DSM measures (T)}}{365\ \text{days} \times 5\ \text{(contractual period) years}}\right) \times \left(\text{Number of days falling short of the 5 year period (D)}\right) \qquad \textbf{(2-4)}$$

By using this equation the mine could determine what the termination penalty (TP) would be at any stage during the contractual project duration. Taking all the cost savings realised due to DSM into consideration, the break-even point when terminating the DSM project could be determined. This will be discussed in Section 3.5.3.

2.7 PRELIMINARY REQUIREMENTS FOR THE MODEL

After identifying the effects of DSM that contributes to the overall impact on the mine, a preliminary model is drawn up. This model entails all effects discussed throughout this chapter and could be used as a guideline when identifying the input parameters to the final model. These input parameters to the model will be determined after quantifying the effects of DSM identified in Chapter two. The preliminary model is given in Table 2-4 on the following page.

Table 2-4: Preliminary model to determine the effect of DSM on a mine



DESCRIPTION	MONTHLY COST / BENEFIT TO MINE DUE TO DSM	
	Low demand season	High demand season
PROJECT INFORMATION:		
Project duration (3, 5, 7 or 10 Years)		
Date when project will start		
SYSTEM INFORMATION:		
Total installed capacity (MW)		
Total energy consumption per day (kWh)		
Daily water pumped to surface (ML)		
ELECTRICITY COSTS OF PUMPING OPERATION:		
Total monthly electricty cost for the pumping operation prior to DSM		
FINANCIAL IMPACT OF DSM TO THE MINE:		
Actual electricity cost saving		
Projected electricity cost savings due to DSM		
Labour numbers		
Savings due to cutting down on labour costs		
Operating life of the pumps		
Higher maintenance cost due to an increase in stop/start per pump		
Enhancing preventative maintenance		
Saving due to larger storage capacity		
Savings due to an increased system efficiency		
Additional saving due maintenance contract with ESCO		
OTHER IMPACTS OF DSM:		
Upgrading existing control infrastructure		
Value of DSM measures funded by Eskom		
Control room facility		
Lost savings due to no control room monitoring the energy management system during a breakdown situation		
HIDDEN COSTS DUE TO DSM:		
Controlling the maximum demand		
Cost due to an NMD controller		
Cost due to an MD controller		
Risk of flooding		
The minimised risk of flooding turned into a cost saving		
TOTAL MONTLY CONTRIBUTION OF DSM TO THE MINE		

2.8 CONCLUSION

Chapter 2 started off by discussing the procedure followed when performing a feasibility study for a typical DSM project. The main outcome of a DSM project is to reduce the peak load demand of a customer to increase Eskom`s generation capacity during this period. As an incentive to the client (mine) for taking on a DSM project, the ESCO provides the mine with expected cost savings in order for the mine to join into a DSM agreement with Eskom by taking on the project. When attempting load shifting the existing operating schedule has to be changed. This in turn proved to have various effects on the clear-water pumping system.

Thus, throughout this chapter, the methodology followed to identify the true effects of DSM on a mine was developed. By using this methodology, an investigation into each of the effects was done to develop a preliminary model to determine the true impact of DSM load shifting projects.

In Chapter 3, the effects identified and discussed throughout Chapter 2 will be quantified by performing a case study on the various mines with load-shifting projects installed on their clear-water pumping systems.

CHAPTER 3: QUANTIFYING THE OVERALL IMPACT OF A DSM PUMPING PROJECT

Throughout this chapter the results of the current DSM pumping projects are interpreted in order to quantify the impact of a typical DSM project implemented on the clear-water pump system of a mine. A case study is performed on each of the mines to investigate for the various factors identified in Chapter 2.

3.1 INTRODUCTION

The DSM initiative has been successfully implemented on a number of South African mines. The clear-water pumping systems of deep level mines were first targeted for DSM load shifting with the first project implemented on Kopanang mine during June 2004.

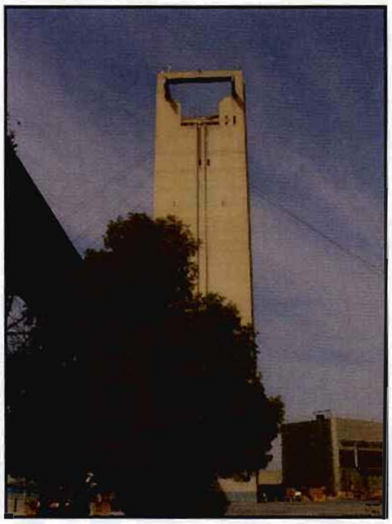
After the DSM load shift project on Kopanang mine proved to be reliable and safe, similar load shift projects were implemented on a number of other mines. Due to the dynamic style and the different characteristics of the various dewatering systems, the impact of DSM load shifting varies from mine to mine. The true impact of DSM load shifting is quantified by performing case studies on all the existing DSM projects implemented on clear-water pumping systems.

The mines where DSM load shift projects on the clear-water pumping systems were implemented and currently operate are Masimong 4#, Harmony 3#, Bambanani, Elandsrand, Kopanang, Mponeng and Tau Tona. These mines are used as case studies in this chapter.

3.2 BACKGROUND ON EXISTING DSM PUMPING PROJECTS

Masimong 4# (Number four shaft) and ***Harmony 3#*** are Harmony Gold mines, situated near Virginia in the Free State province of South Africa. The Masimong mine complex comprises of two shafts: Masimong 4 shaft and Masimong 5 shaft. This complex has been one of the first Harmony Gold mines on which mining activities took place in the early 1950s.

The Masimong mining project is primarily a development project with the major emphasis on 5 Shaft, while Masimong 4 shaft is considered as an ‘essential services’ mine. The term ‘essential services’ means that the main operation in the mine is to pump underground water in order to avoid excess water flowing to the surrounding mines. With the amount of resources left to be mined at 5 Shaft, the Masimong complex has a life span in excess of 15 years.



Masimong 4 shaft is approximately 2250 meters deep with a number of levels underground on which they have been mining over the years. The mine only consists of two pumping stations, one on the bottom level, which is 2180 m below surface and the other only 1200 meters below surface. Masimong mine pumps approximately 11 ML water each day from underground and has a total installed capacity of 18,8 MW.

Harmony 3 shaft is mainly used as a pumping shaft although a small amount of mining activities is still taking place. It pumps the water from Merriespruit 1, Merriespruit 3 and Harmony 2 shafts to the surface. The Masimong 4# and 5# operations are dependent on the pumping operations of Harmony 3# since there is an underground water table that connects these mines. If Harmony 3# were to stop pumping, Masimong 4#, Masimong 5#, Merriespruit 1# and Merriespruit 3# would flood.

At present Harmony 3 shaft pumps an average of 19 ML water from the bottom level (14B level) via 4/3 Level pump station to surface. The installed capacity of the pump system is 11 MW. A simple schematic illustration of the water cycles at the Masimong 4 and Harmony 3 shafts can be seen in Figure 3-1:

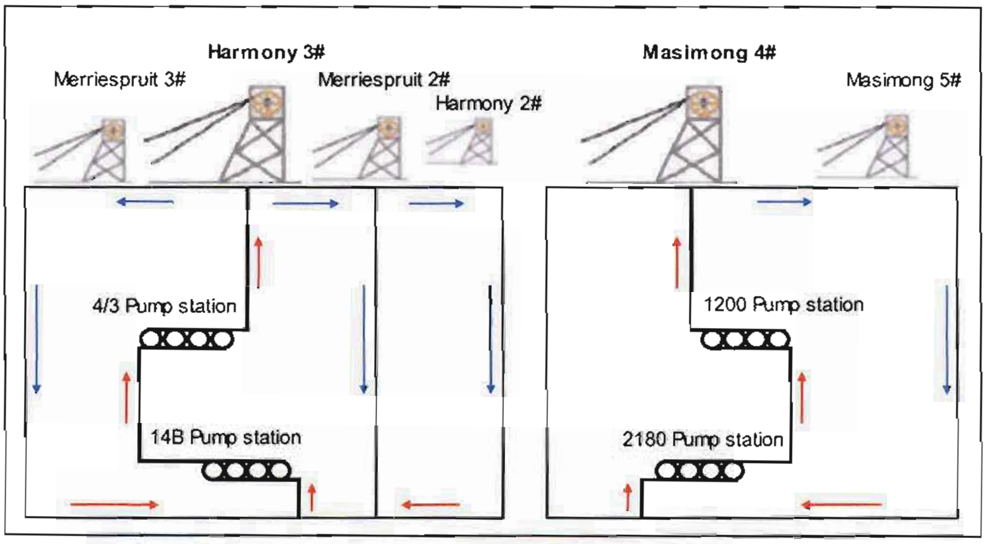


Figure 3-1: Schematic illustration of water cycles at Harmony 3# and Masimong 4# mines

Elandsrand mine is also owned by the Harmony Gold group and is situated close to Carletonville in the North West province. Elandsrand is the main shaft with production taking place at the old Deelkraal mine as well as on Elandsrand mine. Elandsrand mine is busy with a deepening process with mining activities starting in 2007 on these newly developed levels.

The clear-water pumping load is one of the biggest contributors to the mine's electricity costs. A daily amount of approximately 22 ML water gets circulated as far down as 3 km below surface.

The Elandsrand clear-water pumping system consists of four pump stations and two fridge plants (The fridge plants are used to cool down the hot water pumped from underground). The pump stations are located on 100 Level, 75 Level, 52 Level and 29 Level, with the fridge plants on 75 Level and on the surface. The installed capacity of the pumping system is 27.2 MW.

Bambanani mine is located south of Welkom in the Free State province and is also one of Harmony Gold's largest production mines. The water reticulation of Bambanani is intricate with an independent closed-loop system within the main pumping system. This mine pumps a total volume of 65 ML water per day.

The closed-loop pumping system consists of three levels with a pump station on 105 Level (bottom level), 91 Level and an underground fridge plant on 73 Level. The water used for mining purposes gets cycled in this closed-loop system, while the excess water gets pumped out to surface via 73 Level, 52 Level and 41 Level. The total installed capacity of the clear-water pumping system of Bambanani mine is 23 800 kW.

Mponeng mine situated close to Carletonville in the Gauteng province is currently the leading production mine in South Africa. Mponeng mine is also one of the deepest gold mines in the world with a total depth of 3 372m. This flagship mine owned by AngloGold Ashanti, with its 5 455 employees produced as much as 14 tons of pure gold during 2005 [58].

In order to exploit this amount of gold the mine pumps an average of 45 ML water per day with a total installed capacity of the pumps adding up to 47.2 MW. This rather high installed capacity is needed on Mponeng mine due to the depth of the mine, which requires the pumps to pump water a high head. Mponeng mine has four pump stations with 121 Level at the bottom and 110 Level, 85 Level and $45^1/_2$ Level higher up.

Prior to the DSM intervention the technology was already in place to monitor the statuses of the pumps from the control room on the surface, although the pumps could only be controlled manually by the pump attendants underground. Due to the high volumes of water being pumped out on a daily basis and the fast changing water balance, load shifting efforts were obstructed.

Kopanang mine originally formed part of Vaal Reefs Exploration and Mining Company and is situated on the border of the Free State province of South Africa. Shaft sinking at No 9 shaft began in 1978 before reaching a final depth of 2 240 m. The first gold from this shaft was produced in 1984. Today AngloGold Ashanti owns Kopanang gold mine. The word Kopanang is a Sotho word meaning "Come Together". The mine forms part of the AngloGold Vaal River operations, which comprises of four mines. The mine hoists approximately 226 000 tons of material per month at an average grade of 6 g/ton. In 2002, it cost the mine R 55 000 for each ounce of gold produced.

The clear-water pumping system of Kopanang mine consists of two pump stations, one on 75 Level and one on 38 Level. There are four pumps installed on 75 Level, and three pumps and one turbine pump installed on 38 Level. The turbine pump installed on 38 Level could put as much as 4000 kW back into the grid and is also used to pump out the hot water to surface. In order to pump a daily average of 23 ML out from underground, a total installed capacity of 26 MW is available.

3.3 FINANCIAL IMPACT OF DSM ON A MINE

3.3.1 Actual electricity cost savings

As discussed in Chapter 2, the DSM load-management programme sets the necessary technologies available to change the current pumping schedule by intelligently optimising the electricity consumption according to the TOU (Time-of-use) tariff structure. Table 3-1 gives the monthly electricity cost of the clear-water pumping process before the DSM project was installed. The actual electricity cost savings achieved due to the DSM initiative on the various clear-water pumping systems are also shown.

Table 3-1: Electricity cost savings due to DSM

MINE	INSTALLED CAPACITY (MW)	MONTHLY OPERATIONAL COST BEFORE DSM		EVENING LOAD SHIFT POTENTIAL (MW)	AVERAGE MONTHLY COST SAVINGS DUE TO DSM (ACTUAL)			
		LOW DEMAND SEASON	HIGH DEMAND SEASON		LOW DEMAND SEASON	% SAVING	HIGH DEMAND SEASON	% SAVING
Kopanang	26.0	R 341,811	R 626,942	4.5	R 16,971	5%	R 103,812	17%
Elandsrand	27.2	R 642,961	R 1,196,637	3.5	R 14,556	2%	R 102,137	9%
Bambanani	23.8	R 714,061	R 1,398,010	7.0	R 32,407	5%	R 160,263	11%
Masimong 4#	18.8	R 237,218	R 430,104	4.0	R 20,405	9%	R 111,964	26%
Harmony 3#	24.2	R 318,309	R 605,802	3.8	R 15,651	5%	R 72,801	12%
Mponeng	47.2	R 984,241	R 1,878,697	11.0	R 46,641	5%	R 448,971	24%
Average	**27.9**	**R 539,767**	**R 1,022,699**	**5.6**	**R 24,439**	**5.0%**	**R 166,658**	**16.4%**

As seen in Table 3-1, the average monthly electricity cost saving to the mine is approximately 5% of the total electricity cost during the low-demand season and 16% of the total monthly electricity cost during the high-demand season. The reason for the higher saving during the high-demand season is due to the price difference per unit electricity between the peak periods of the two different seasons.

Before taking on a DSM project, the ESCO presents the mine with an expected monthly, as well as annual cost saving. As previously discussed in Section 2.4.1, the expected cost saving varies from the actual cost saving due to the system breakdowns affecting load shifting performance. By comparing the expected electricity cost saving to the achieved cost savings, the average underperformance of the EMS system can be estimated.

Table 3-2: Expected versus actual electricity cost saving realised through load shifting

MINE	AVERAGE MONTHLY COST SAVINGS DUE TO DSM (EXPECTED)		AVERAGE MONTHLY COST SAVINGS DUE TO DSM (ACTUAL)		ACTUAL VS. EXPECTED COST SAVING	
	LOW DEMAND SEASON	HIGH DEMAND SEASON	LOW DEMAND SEASON	HIGH DEMAND SEASON	LOW DEMAND SEASON	HIGH DEMAND SEASON
Kopanang	5.9%	17.8%	5.0%	16.6%	**85%**	**93%**
Elandsrand	3.6%	11.0%	2.3%	8.5%	**63%**	**77%**
Bambanani	5.6%	15.4%	4.5%	11.5%	**81%**	**75%**
Masimong 4#	5.3%	17.2%	8.6%	26.0%	**162%**	**151%**
Harmony 3#	8.0%	22.2%	4.9%	12.0%	**62%**	**54%**
Mponeng	4.2%	12.5%	4.7%	23.9%	**113%**	**191%**
Average	**5.4%**	**16.0%**	**5.0%**	**16.4%**	**94.3%**	**106.8%**

From Table 3-2 it is evident that the average actual electricity cost saving to the mine is lower than the expected cost saving. Masimong 4 shaft and Mponeng mine could be taken out of the equation because these projects performed better than expected. The reason being is that Masimong 4 shaft is an essential services mine with no production influencing the clear-water pumping system, while Mponeng mine is still a fairly new mine with fewer breakdowns affecting the action of the pumping system. The performance-tracking report of Mponeng mine can be seen in Appendix A.

By taking Masimong 4 shaft and Mponeng mine out of the equation when determining the average actual electricity cost savings in comparison to the expected cost savings, the percentage saving during the low-demand season and the high-demand season is 72.7% and 74.8% respectively. It is also possible to make the assumption that breakdowns occur approximately 26% of the day. Therefore, it could be said that the actual electricity cost savings on a production mine, where pumping is not the main priority, will only be approximately 73% of the expected electricity cost saving.

The input parameters to model the actual electricity cost savings to the mine more accurately, are as follows:

- Current monthly electricity cost to mine.
- Pre-implementation energy profile of the clear-water pumping system.

- Any production activities running at the mine or otherwise specifying if the mine is a pumping only (essential services) mine.

3.3.2 Benefit of cutting down on labour cost

The underground-water pumping operation is a liability to each mine and is mainly seen as an operational expense. The pumping operation will always play a significant role in any deep-level mine, but to a varying extent. The fact is that this essential part of the mining operation is very costly and additional operational cost savings could be achieved by cutting down on the number of pump attendants operating the pumps.

The DSM load shift initiative implemented on the clear-water pumping systems of deep-level mines also encourages savings apart from electricity cost savings. Due to the automatic control system being implemented to replace the duty of the human factor, labour cost savings have been realised in the past.

Kopanang mine was one of the first mines where a load shift project on the clear-water pumping system was implemented and also one of the first mines where pump attendants were reduced. Kopanang mine had two pump attendants per shift working on each of the two pump stations. These pump attendants were all taken out of their jobs and have been trained and successfully reallocated to other vacant positions.

This was possible because the automatic control system proved to be reliable. The automatic control system completely replaced all the duties previously done by the human factor. Some mines even install video cameras on the various pumping stations to monitor the pumping activities from the surface control room. A picture of the 75 Level pump station at Kopanang mine, with live camera footage, as displayed on the SCADA computer in the control room, is shown in Figure 3-2 on the following page.

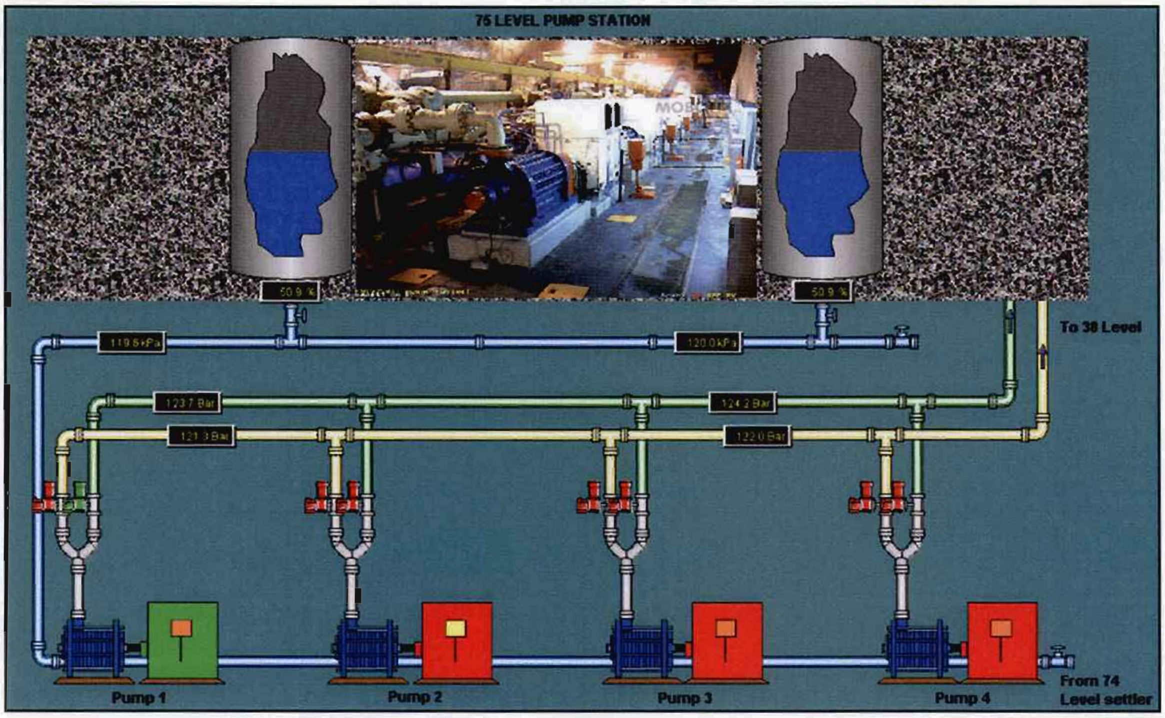


Figure 3-2: Camera installed on Kopanang mine's 75 Level pump station displayed on the SCADA system

Kopanang mine, Masimong 4# and Harmony 3# are the only mines where the number of pump attendants could be reduced. No pump attendants were re-allocated at Mponeng, Elandsrand and Bambanani mines, because of the high water volumes and limited storage capacity. This is a precautionary measure in the event of a system breakdown. Due to the limited system down time available before the mine will start flooding, it is critical to have a person on the pumping station to take over the pumping responsibility in case of an emergency.

The reduced labour costs on Kopanang mine, Masimong 4# and Harmony 3#, where the number of employees changed due to DSM, are given by Table 3-3:

Table 3-3: Labour cost saving as a result of DSM

MINE	TOTAL NUMBER OF PUMP ATTENDANTS		MONTHLY COST PER PUMP ATTENDANT	TOTAL LABOUR COST SAVING (MONTLY)	PERCENTAGE CUT DOWN ON LABOUR COST
	BEFORE DSM	DUE TO DSM			
Kopanang	6	0	R 4,550	R 27,300	100%
Masimong 4#	12	6	R 3,800	R 15,300	50%
Harmony 3#	18	12	R 3,650	R 21,900	33%
Average	**12**	**6**	**R 4,000**	**R 21,500**	**61.1%**

It is also important to consider the fact that DSM may require additional labourers. For example, some mines did not have any automatic systems before DSM and will have to employ an artisan to maintain the new control equipment. Between Masimong 4# and Harmony 3# one extra technician is employed at a monthly expense of approximately R8 000 to the company.

From Table 3-3 it can be seen that the circumstances regarding the risk of operating the pumps determine the possibility of reducing the number of pump attendants. However, the 61% average cut down on labour numbers for the three above-mentioned mines is not an accurate indication of potential labour savings for future mines. Thus, the circumstances on each mine will determine to what extent the labour numbers could be cut down.

In order to quantify the impact of the DSM programme on the labour cost of the mine, the following information should be available:

- How many pump attendants are there in total?
- What is the monthly labour cost per pump attendant to the mine?
- What is the minimum number of pump attendants per shift needed to monitor the system with an automatic system controlling the pumps?
- Are there additional labourers required due to the DSM initiative?

3.3.3 Impact of load shifting on the operating life of pumps

As discussed in Section 2.4.3, load-shift projects implemented on pumping systems often require pumps to be started and stopped more frequently than before. The same also appears when pumps are manually switched on and off too many times per day due to the human factor controlling the pumps. In this case, the Load Management (LM) system optimises the pumping activities by stopping and starting (switching) pumps less, which increases the operating life of pumps.

Prior to the DSM initiative implemented on the clear-water pumping system of Tau Tona mine, the pumps were all controlled manually by the pump attendants underground. The pumps on Tau Tona mine were switched on and off on a frequent basis due to the complexity of the dewatering system. Not only is it impossible for a pump attendant to see how much water gets pumped into the dams so that enough pumps could be run to pump out the same amount of water in order to keep the dam levels fairly constant, but water is also drawn from the dams for mining purposes. This increases the rate at which the circumstances in the clear-water pumping system change and it also increases the complexity of controlling the system.

The main priority of the pump attendant is to stop and start pumps to prevent dams from flooding or running empty without violating the system specifications and constraints. On top of this, it is not reasonable to rely on the pump attendant to do load shifting on a sustainable basis. Most of the pump attendants are unschooled and can only follow a simple start / stop procedure.

At Tau Tona mine, the pump attendants got into the habit of starting two pumps at times when the dam level becomes high and to run both of these pumps until they automatically trip at a specified lower level. These pumps will then remain switched off until the dam level increases to a specified high level before the two pumps are started up again.

Figure 3-3 shows the above-mentioned method of running two pumps at a time until the pumps trip on a specified lower level. The red dashed line (marked as A) indicates the minimum dam level where the PLC automatically trips the pumps. Point B indicates that the dam level sometimes decreases to a level below 40% due to water being drawn from the dam for mining operations, although the pumps may not run at levels below 40%.

Figure 3-3 on the following page illustrates the status of the pumps as well as the dam level for both 3000 Level and 67 Level on Tau Tona gold mine. The dam level is given on the primary (left-hand) axis while the number of pumps running are given on the secondary (right-hand) axis. The water gets pumped from 67 Level to 3000 Level. It can clearly be seen that the pump attendants run either zero or two pumps at a time.

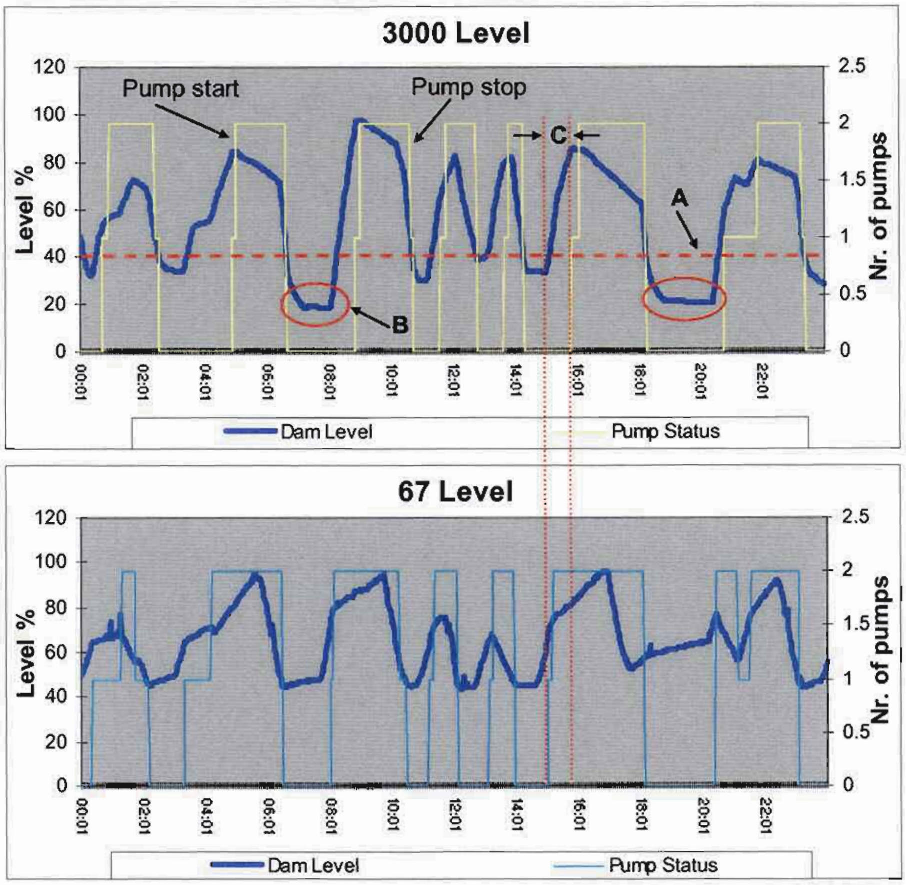


Figure 3-3: Daily stop/start of pumps with manual control

On the above figure that displays the information for 3000 Level, it can be seen that the dam level rises very fast due to the two pumps that pump water from 67 Level. Due to the fact that no pumps are running on 3000 Level, the dam level on 3000 Level increases rapidly. Only when the dam level reaches a specified high level, two pumps on 3000 Level are started up manually to handle the high inflow of water into the 3000 Level dam. In the meantime, while the two pumps are running on 3000 Level, the pumps on 67 Level are stopped due to the minimum dam level being reached, which leads to a rapid decrease in dam level on 3000 Level. This method of pumping continues and results in a high cycling frequency of the pumps, which leads to a reduction in the operating life of the pumps. The fact that the pumps are running out of phase by more than an hour is indicated by point C in Figure 3-3.

Because the EMS system uses the information of the complete pumping system to intelligently calculate the inflow and outflow on each storage dam, calculated predictions are made to determine how many pumps should run at any given point in time. By intelligently rescheduling the pumps and synchronising the number of pumps running on each pump station, the dam levels will remain constant for longer periods of time, which means that the pumps will remain switched on/off (depending on the circumstances) for longer periods of time. The optimised pumping profile obtained by applying the EMS controller on the clear-water pumping system of Tau Tona mine is shown in Figure 3-4:

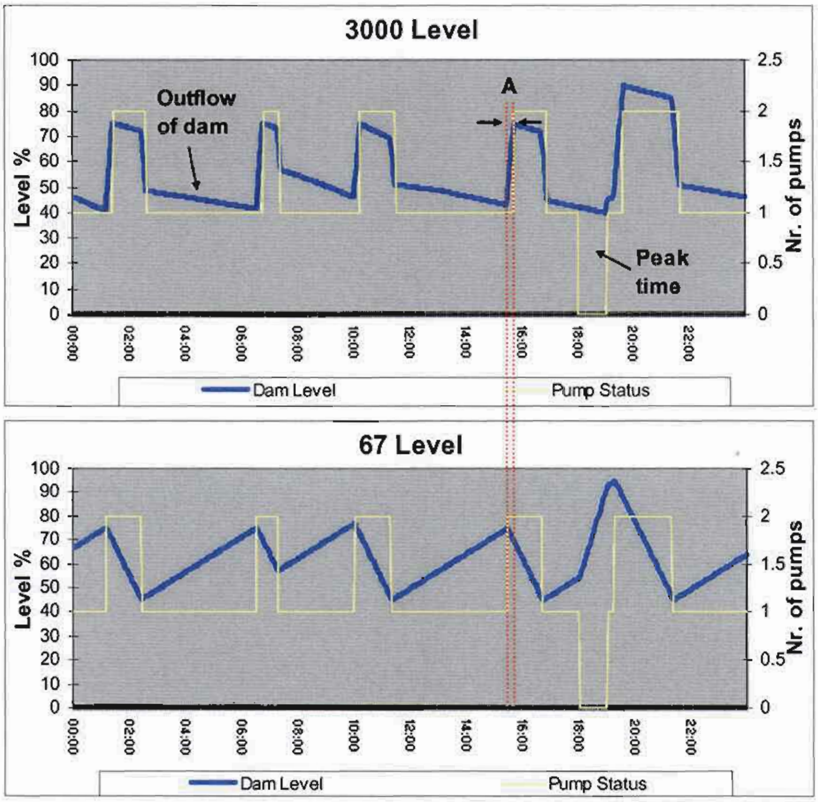


Figure 3-4: Optimised stop/start with the energy management system

Figure 3-4 clearly indicates that the excessive cycling of the pumps, as previously illustrated in Figure 3-3 (with manually control), is minimised by applying the automatic energy management control system. The following strategy was built into the EMS to minimise the cycling and in turn increase the operating life of the pumps:

- Synchronising the pumping activities on both the pumping stations (Figure 3-4, Point A).
- Running a minimum of one pump at all times except during the following two situations:

  1) When the dam level is below 40%.

  2) During the evening peak period.

Thus, the total amount of cycling on 3000 Level has decreased from 14 times per day, with manual control, to 6 using the automatic controller. With four pumps on 3000 Level and only two of the four pumps allocated to be the duty pumps, the cycling per pump decreased on average from 7 to 3 times per day.

By having an automatic control system in place, the cost regarding the cycling of each pump will decrease by 57%. Because cycling of pumps contribute approximately 15% to the maintenance cost during the operating life of a pump, it could be said that the maintenance cost per pump will decrease due to the fact that the operating life of the pump between services increases by approximately 8.5%. With the monthly maintenance cost per pump on Tau Tona mine in the order of R 30 000, the cost saving due to the automatic control system is calculated as follows:

$$\begin{aligned}\text{Annual maintenance cost} &= \text{R } 30\,000 \times 12 \text{ months}\\ &= \text{R } 360\,000 \text{ per pump}\end{aligned} \tag{3-1}$$

The monthly reduced maintenance cost due to the 8.5% increase in operating life of the pump is calculated as follows:

$$\begin{aligned}\text{Monthly maintenance cost} &= \text{R } 360\,000 \times 13.2 \text{ months } (8.5\% \text{ increase in operating life})\\ &= \text{R } 27\,650 \text{ per pump}\end{aligned} \tag{3-2}$$

Thus, the annual cost saving is as follows:

$$\begin{aligned}\text{Annual cost saving} &= (\text{R } 30\,000 - \text{R } 27\,650) \times 12 \text{ months}\\ &= \text{R } 28\,200 \text{ per pump}\end{aligned} \tag{3-3}$$

The input parameters needed to determine the cost saving due to the changing operating life of a pump caused by DSM, are as follows:

- Total monthly maintenance cost per pump.
- The contribution of cycling to the overall maintenance cost per pump.
- Number of stop/starts per pump before load shifting was attempted.
- Number of stop/starts per pump due to load shifting as determined by the simulation model.
- Number of duty pumps in the system.

3.3.4 Impact of preventative maintenance on system performance

The three critical maintenance factors contributing to the load-shift performance, as discussed in Section 2.4.4, are quantified in this section. The advanced system information, being available to the mine, could be used to perform preventative maintenance on the identified pumping system devices.

I) Optimising storage capacity

Storage capacity is a key element in determining the load-shift potential on a dewatering pumping system. Over time, storage dams fill up with mud, which minimises the storage capacity and also the load-shifting potential. Prior to the DSM load-shifting initiative, the mines were not too concerned about storage capacity, since the pumping method was based on the simple principle that the amount of water flowing into the dam should also be pumped out of the dam. No intelligent load-shifting efforts were attempted prior to the DSM project implementation.

Since the DSM implementation, storage capacity has become one of the main focus areas in the load-shifting environment. The need arose for maintenance on storage dams to be increased in order to ensure larger storage capacity and higher load-shift potential.

Due to the high maintenance and labour costs involved with cleaning of dams, management are not eager to set funds available for dam cleaning. As discussed in Chapter 2, the savings and payback period due to the cleaner dams will have to be used as a motivation to fund the cleaning process. In order to determine the potential savings due to the extra storage capacity available with cleaner dams, physical tests have to be conducted on the real-life system. Due to the high risk of running dams at full capacity, it is not viable to perform tests on the real-life system.

Due to the EMS simulator technology made available by the DSM programme, the impact of extra storage capacity on the pumping system could be determined at no risk. Real-life information on the system is used to build a simulation model and to accurately determine the potential savings. The payback period of the dam cleaning project can also be predicted. This practice was conducted on Elandsrand mine with the simulation models discussed as follows. The following three scenarios were simulated for:

- Scenario 1: Savings with current storage capacity.
- Scenario 2: Savings with improved storage capacity.
- Scenario 3: Savings with maximum (ideal) storage capacity.

Scenario 1: Expected savings with current storage capacity

Elandsrand gold mine has not cleaned their dam for a period of eight years, which resulted in a situation where the storage capacity became insufficient to meet the load-shift targets. As seen in Table 3-4, the current average storage capacity of the dams is 20% (top four levels) and 35% (bottom level) of the ideal capacity. These figures are very low and affect the load shifting results significantly.

Table 3-4: Specifications of storage dams with current capacity

Dam level	Dam volume (m^3)	Storage capacity (m^3)	Storage capacity available	Minimum (%)	Maximum (%)
29 Level	1700	340	20%	80	100
52 Level	3000	600	20%	80	100
71 Level	4000	800	20%	90	110
75 Level	3000	600	20%	80	100
100 Level	9000	3150	35%	40	75

The optimised baseline determined from the simulation model is given in Figure 3-5. Point A clearly shows that the pumps are switched off during the initial stages of the evening peak demand period. Point B indicates that some pumps had to be started during the second hour of the evening peak-demand period due to the increasing dam levels. This had a direct impact on the load-shift potential.

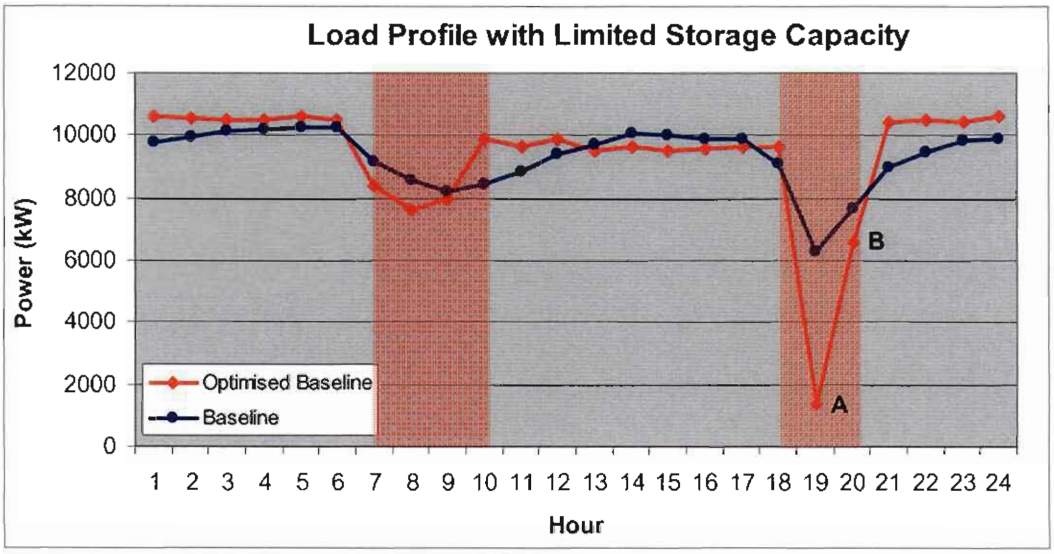


Figure 3-5: Electricity consumption profile with limited storage capacity

Scenario 2: Expected savings with improved storage capacity

The second simulation model was built with improved storage capacity. The storage capacity simulated in Scenario 2 is a realistic increased dam capacity over a prolonged period of time after the dams have been cleaned. The storage capacity being simulated in Scenario 2 is given in Table 3-5:

Table 3-5: Specifications of storage dams with improved storage capacity

Dam level	Dam volume (m^3)	Storage capacity (m^3)	Storage capacity available	Minimum (%)	Maximum (%)
29 Level	1700	595	35%	55	90
52 Level	3000	1050	35%	55	90
71 Level	4000	1800	45%	65	110
75 Level	3000	1050	35%	55	90
100 Level	9000	4500	50%	40	90

The optimised baseline as simulated in Scenario 2 is given in Figure 3-6. This figure illustrates that the pumps are switched off during the first hour of the evening peak-demand period. The figure also illustrates the larger storage capacity of the dams that allow the pumps to remain switched off for longer periods during the second evening peak-demand hour. It is also shown that more pumps are switched off during the morning peak demand period with the improved storage capacity of the dams.

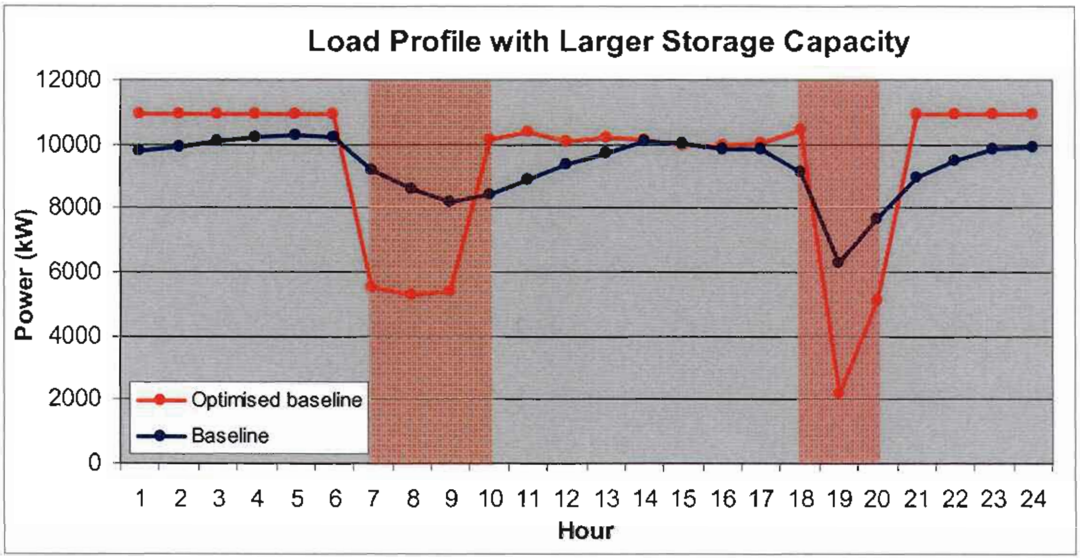


Figure 3-6: Improved electricity consumption profile with larger storage capacity

Scenario 3: Expected savings with maximum storage capacity

The simulation model built for Scenario 3 involves the maximum storage capacity as initially designed. Note that a specified low and high limit on the dam levels exist. These low and high levels specified by the mine form part of the system constraints and may not be exceeded at any time. The average storage capacity available (as simulated for in Scenario 3) is 82% of the design capacity. The storage capacity being simulated for in Scenario 3 is given in Table 3-6:

Table 3-6: Specifications of storage dams with extreme capacity

Dam level	Dam volume (m^3)	Storage capacity (m^3)	Storage capacity available	Minimum (%)	Maximum (%)
29 Level	1700	1020	60%	35	95
52 Level	3000	1800	60%	35	95
71 Level	4000	3000	75%	35	110
75 Level	3000	1800	60%	35	95
100 Level	9000	5400	60%	35	95

The profile seen in Figure 3-7 is obtained from the simulation model with maximum storage capacity. As illustrated, the load-shift potential during the evening peak period is 5.7 MW in comparison with the 2.98 MW load shift potential obtained in Scenario 1.

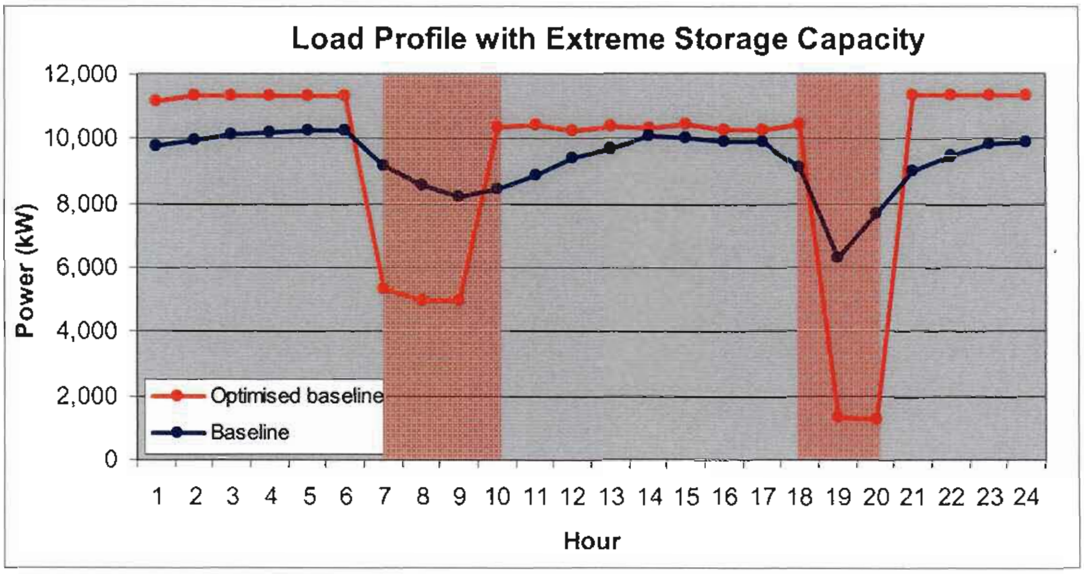


Figure 3-7: Energy profile as simulated with extreme storage capacity

The expected savings obtained for the three different scenarios are given in Table 3-7. The cost savings obtained with the larger storage capacity are sufficient to fund the dam cleaning process on a more frequent basis. The expected electricity cost savings calculated from Scenario 2 are almost twice the amount currently saved by the mine. The additional R 228 859 expected annual cost savings obtained with Scenario 2 could cover the costs of the dam cleaning process, which is estimated to be R 280 400 (R 80 per m^3 @ 3505 m^3). The payback period of this project is estimated to be 15 months. Apart from the electricity cost savings the mud taken out of the dams also contains a certain low-grade gold content, which will be put through the processing plant to increase the final savings.

Table 3-7: Expected savings for various storage capacities

SCENARIO	AVAILABLE STORAGE CAPACITY	MW SAVINGS		ELECTRICITY COST SAVING		
		Morning load shift (kW)	Evening load shift (kW)	Summer month	Winter month	Annual
Scenario 1	22%	675	2,982	R 9,340	R 53,180	R 243,597
Scenario 2	40%	3,284	3,351	R 18,043	R 103,356	R 472,456
Scenario 3	63%	3,563	5,701	R 26,374	R 151,335	R 691,375

In order to determine the net impact of larger storage capacity, the following input parameters to the model should be known:

- Realistic storage capacity as designed for.
- Actual existing storage capacity.

- Consultant cost for cleaning process (R/m^3).
- Volume to be cleaned (m^3).
- Expected duration of the cleaning process.

II) Monitoring the system efficiency for optimal savings

Due to the high electricity costs associated with pumping water, it is critical to optimise the system performance in order to cut down on operating costs. It is known that the pump efficiency plays a big role in system performance and could lead to high operating costs if preventative maintenance is not applied.

Until recently, no functionality existed to do a quick and accurate estimation of the quality and efficiency of the pumps and motors. The solution to this shortcoming in system information has been solved by the DSM initiative as part of the load-shift project. This functionality provides the customer with all the system information to proactively maintain the system to ensure optimal and sustainable load-shift performance.

The benefit of preventative maintenance on motors and pumps was be quantified by performing a case study on one of the pumps on Masimong 4# mine. The system specifications, efficiency of the pump and motor as well as the cost implication are discussed below:

System specifications:

The number 2 pump on 2180 Level pump station was used to perform the efficiency calculations on. The design specifications of the system as well as the pump and motor are given in Table 3-8.

Table 3-8: Design specifications of the pump

Pump Specifications: Toshiba BS 2213 (1970) 3-Phase Induction Motor		
Installed capacity	1500	kW
Voltage supply	6600	V
Amperes	149	A
Total discharge head (TDH)	980	m
Flow rate	95	l/s
Design efficiency (practical)	61	%

Determining the pump efficiency from SCADA information:

The deterioration in the efficiency of a motor and pump could be determined in more ways than one. The basic information set available by the SCADA system that could be used to determine the efficiency of a pump and motor is as follows:

- the flow rate of the pump;
- motor current, and
- the vibration on the pump.

The information logged by the SCADA system to determine the actual efficiency of the pump and motors should be used as follows:

Option 1: Change in the flow rate of the pump

From the SCADA information it is given that the actual flow rate of the pump is 82 l/s compared to the design specification of 95 l/s. The standard rule in most cases is that the mine will service or replace any pump with efficiency below 52%. With all the system specifications remaining the same, the pump efficiency could be calculated as follows (same as Equation 2-1):

$$\begin{aligned}\eta &= \frac{\rho \times g \times Q \times H}{P_{electric}} \\ &= \frac{1000 \times 9.81 \times 0.082 \times 980}{1500 \times 10^3} \qquad \textbf{(3-4)} \\ &= 52.5\%\end{aligned}$$

Thus, for a decrease in flow rate of 13 l/s (13.7%), the efficiency of the pump dropped by 8.5%. The electricity cost for the pump operating at lower efficiency will be discussed later in this section.

Option 2: Change in motor current

It is important to note that a decrease in motor current could be an indication of a decrease in either the pump or motor efficiency. The calculation for determining the pump and motor efficiency is discussed as follows:

I. *Measuring a lower motor current due to a decrease in pump efficiency:*

According to the system specifications given in Table 3-8 the motor current drawn for a high efficient pump is in the region of 149 A. According to the SCADA data, the motor current being drawn due to the worn pump is 142 A. Thus, the motor current decreases as the efficiency of the pump drops. The main reason for this is that the mechanical load of the pump increases as the efficiency of the pump decreases. It is said that when this happens the flow through the pump is not that turbulent anymore. The following calculation illustrates how the motor current decreases as the pump efficiency drops.

$$P_{electric} = I^2 \times R \qquad \textbf{(3-5)}$$

Where,

- $P_{electric}$ = Electric Power (Watt)
- I = Motor Current (Ampere)
- R = Resistance (Ohm)

Thus, with the resistance (R) increasing as the load increases due to the deterioration of the pump's efficiency, the current (I) will decrease to keep the input power ($P_{electric}$) unchanged. Although the decrease in motor current does not clearly indicate what the pump efficiency is, it gives the artisan an indication that the pump efficiency has deteriorated.

II. *Measuring a lower motor current due to a decrease in motor efficiency:*

The decreasing motor current will have a direct impact on the efficiency of the motor. The lower motor efficiency has an impact on the complete pumping system, and will thus pump less water in a certain period of time. For example, if the motor current decreases from 149 A to 142 A, the electric power will also decrease as follows:

$$\begin{aligned} P_{electric} &= \sqrt{3} \times V \times I \times \cos\theta \\ &= \sqrt{3} \times 6600 \times 142 \times 0.88 \qquad \textbf{(3-6)} \\ &= 1428\,\text{kW} \end{aligned}$$

For a decrease in motor current of 7 A (4.7%), the power drawn by the motor decreases from 1500 kW to 1428 kW (9.5%).

Impact of pump efficiency on the electricity cost of the mine

The electricity costs involved for the various pump efficiencies are explained below by considering the cost per unit electricity consumed (c/kWh) for a certain amount of water being pumped.

Table 3-9: Average electricity cost to pump a megalitre (ML) water

Installed Capacity (kW)	Pump efficiency	Flow rate of pump (l/s)	Average cost per hour	Hourly water pumped (ML/hour)	Average cost per ML
1500	60.9%	95	R 437.8	0.34	R 1,280.24
1500	52.6%	82	R 437.8	0.30	R 1,483.21

From Table 3-9 it is evident that a pump with an 8.3% less efficiency costs the mine 15.8% more to operate. Say for instance the pump has to pump 200 ML per month; the electricity cost for the less efficient pump will be R 40 594 more than that of the more efficient pump. Thus, it makes good business sense to rather run the more efficient pump instead of the less efficient pump. The financial impact of running the more efficient pump instead of the less efficient pump is discussed as follows:

Suppose Pump A is 8.3% more efficient than Pump B, but Pump A is only available 70% of the time. Suppose Pump A is ideally available 90% of the time for pumping duty. The installed capacity of the pump is 1500 kW and the pump is running 6 000 hours per year.

Note that the operating cost for Pump A is R 437.80 per hour (Table 3-9), while Pump B amounts to R474.14 (8.3% less efficient) per hour. Thus, the difference in electricity costs for the two pumps are as follows:

Amount of hours that pump B runs instead of Pump A:

- Hours = 20% x 6000h = **1200 hours**

Annual electricity cost of the two pumps:

- Pump A: 1200 hours @ R 437.80/hour = **R 525 360**

- Pump B: 1200 hours @ R 474.14/hour = **R 568 964**

It is clearly seen that preventative maintenance leads to a higher availability of the more efficient pump and that amounts to an annual electricity cost saving of R 43 600. The input parameters needed to improve pump and motor efficiency are as follows:

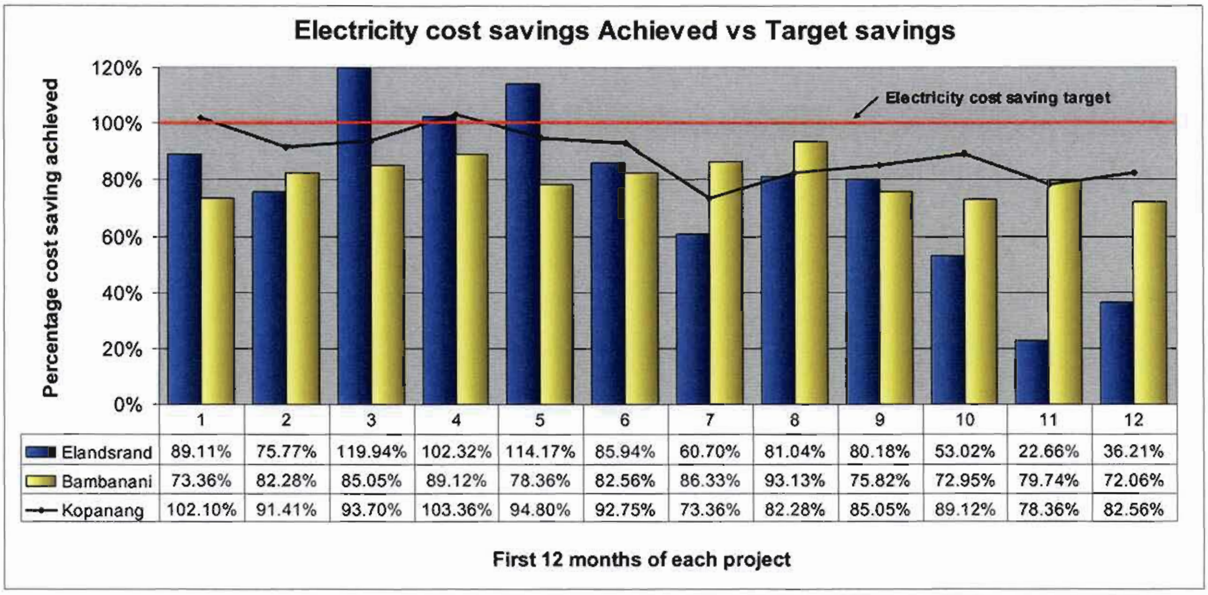
- Average pump and motor efficiency before DSM.
- Time intervals that efficiency of pumps and motors were determined and monitored.
- Increase in efficiency due to continuous monitoring.

III) Maintenance contract between the client and the ESCO

The clear-water pumping project on Kopanang mine has proven to be one of the best performing projects with a consistent load-shift record. The main reason for this is because the management team of the mine is extremely driven to increase energy savings and requires constant feedback on the performance of the DSM project. The management then decided to join into a maintenance agreement with the ESCO.

One of the main reasons for having a maintenance contract with the ESCO is to receive constant feedback on the performance of the project. A daily report gets sent to all the mine personnel involved with the project, keeping them informed on the savings achieved and also to notify them on system breakdowns leading to missed opportunities. A copy of this report can be seen in Appendix C.

The DSM performance of a project with a maintenance contract between the mine and the ESCO was compared to DSM projects where the mine does not have a maintenance contract with the ESCO. Figure 3-8 on the following page illustrates the percentage actual electricity cost saving achieved during the first twelve months of each project compared to the target (expected) electricity cost saving.


Electricity cost savings Achieved vs Target savings

	1	2	3	4	5	6	7	8	9	10	11	12
■ Elandsrand	89.11%	75.77%	119.94%	102.32%	114.17%	85.94%	60.70%	81.04%	80.18%	53.02%	22.66%	36.21%
▭ Bambanani	73.36%	82.28%	85.05%	89.12%	78.36%	82.56%	86.33%	93.13%	75.82%	72.95%	79.74%	72.06%
—•— Kopanang	102.10%	91.41%	93.70%	103.36%	94.80%	92.75%	73.36%	82.28%	85.05%	89.12%	78.36%	82.56%

Figure 3-8: DSM performance due to maintenance contract with the ESCO

Figure 3-8 clearly shows that the Kopanang project has the highest achieved savings over the 12 month period. Table 3-10 illustrates the average of all the percentage savings achieved per month compared to the expected savings.

Table 3-10: Summary of electricity cost savings with and without a maintenance contract

MINE	MAINTENANCE CONTRACT	TOTAL ELECTRICITY COST SAVING FOR THE FIRST 12 MONTHS OF EACH PROJECT	
		EXPECTED	AVERAGE PERCENTAGE OF MONTHLY SAVING
Elandsrand	No	R 603,138	76%
Bambanani	No	R 1,011,629	80%
Kopanang	Yes	R 495,352	89%

Table 3-10 shows that the percentage cost saving for a project with a maintenance contract is approximately 10% higher than the saving achieved on projects without a maintenance contract. Thus, the 10% extra cost saving to Kopanang mine accumulates to an annual saving of R 44 500. The only input parameter needed to determine the true impact of having a maintenance contract with the ESCO is the 10% higher cost saving achieved.

3.4 OTHER IMPACTS OF DSM ON A MINE

3.4.1 Mine benefits from upgrading of control infrastructure

In order to perform load shifting on a clear-water pumping system, the original pumping schedule has to be changed. To ensure sustainable DSM load-shift results, the pumping system should be automated in order to take over the control activities previously done by the pump attendants on the pump station. To accommodate automatic control of the pumps, control infrastructure is put in place.

Table 3-11 illustrates the control infrastructure the various mines received as part of the DSM initiative. Some mines already had the required control infrastructure and thus did not benefit from getting any further automation equipment. Thus, Eskom only funds the infrastructure needed for sustainable load management. All mines receive the intelligent Energy Management System (EMS) performing the optimisation of the clear-water pumping system and reducing electrical consumption during the peak demand periods.

Table 3-11: Infrastructure installed due to the DSM initiative

MINE	HARDWARE INSTALLED				NETWORK COMMUNICATION EQUIPMENT			SOFTWARE INSTALLED	
	Automatic dam level indicators	Automatic control valves	Field instrumentation	New switchgear	PLC equipment	Instrumentation cable	Fibre optic cable	SCADA computer	REMS system
Kopanang									x
Elandsrand									x
Bambanani			x				x		x
Masimong 4#	x	x	x	x	x	x	x	x	x
Harmony 3#	x	x	x	x	x	x	x	x	x
Mponeng			x	x	x	x			x

As seen in Table 3-11, ***Kopanang***, ***Elandsrand*** and ***Bambanani*** mines already had all the infrastructure required to accommodate automatic control of the pumping system. The functionality to stop and start the pumps from the control room already exists, although the pumps were manually controlled by the pump attendants on the various pumping stations.

Mponeng mine had infrastructure in place to monitor the clear-water pumping activities from the control room, although the one-way communication did not allow the control room operators to control the pumps from the surface. A system upgrade was needed to enable remote stop and start from the surface control room. Field instrumentation, new switchgear and instrumentation cable formed part of the infrastructure funded by Eskom.

Masimong 4# and ***Harmony 3#*** had no control infrastructure prior to the DSM project and needed a complete system upgrade. These two mines are both old mines with no infrastructure to stop and start the pumps remotely from a central point on site. The manual method of controlling the pumps does not accommodate sustainable DSM results, which is another reason why Eskom is funding 100% of the infrastructure needed for automatic control of the pumping system.

With the two mines consisting of the same limited infrastructure, similar control infrastructure was needed on both the pumping systems. The hardware and software installed on each of the above mentioned mines, as discussed in Chapter 2, become the property of the mine immediately after implementation.

As part of the DSM project Eskom also provided Masimong 4# with soft starters on the motors. These soft starters were funded on request from the client due to the condition of the old pumps considering the mechanical stresses when performing load shift. Apart from the electricity cost savings obtained through DSM, the modern technological equipment funded by Eskom increases the assets of the mine, which is a definite benefit to the mine.

The cost involved with the automation of the pumping system of Masimong 4# is given in Table 3-12. The total cost of this infrastructure is a capital benefit to the mine for taking on a DSM load shifting project. See Appendix B for the list of control and infrastructure equipment installed on Masimong 4# mine as part of the DSM initiative.

Table 3-12: Cost of control infrastructure funded by Eskom DSM

Hardware installed (2 Pump stations with 4 pumps per station)	Quantity	Unit price	Total cost
Communication cable from surface to each pump station level	2000m	R 40	R 80,000
SCADA system for monitoring and remote controlability of REMS	1	R 70,000	R 70,000
Network equipment	2	R 25,000	R 50,000
PLC equipment	2	R 220,000	R 440,000
Automatic control valves	8	R 50,000	R 400,000
Field instrumentation aquiring system device information	2	R 150,000	R 300,000
HT and instrumentation cable	2	R 30,000	R 60,000
Soft starters	4	R 400,000	R 1,600,000
Total			**R 3,000,000**

For the purposes of the model, it is important to know what control infrastructure is needed to enable remote controllability in order to determine the total cost of the DSM project. The feasibility of a DSM project is determined by the infrastructure cost of the project as a function of the MW load shift potential.

3.4.2 Sustainable results due to 24-hour control room

Due to the automatic EMS system taking over the pumping responsibilities, the physical human related work previously done by the pump attendants is reduced by approximately 90%. The remaining 10% workload is shifted from the pump attendant to the control room operator, monitoring the system from a central point on site. This 10% of work to be done by the control room operator includes taking over the control responsibility of the pumps during a breakdown situation to ensure sustainable load-shift results.

The whole idea of load shifting is to prepare the storage dams for maximum capacity by pumping during the standard and off-peak periods of the day. The slightest of breakdowns could easily affect the preparation process, which results in insufficient load shifting. Thus, the contributions made by the control room operators during a breakdown situation are vital in assuring successful load shift results.

The benefit of having a control room operator receiving warning messages from the EMS system in time, enables the operator to proactively address the problem and turn the possible "missed opportunity" into a load-shift saving. In this case, the duration of the system downtime is equivalent to the loss of savings.

At Harmony 3 mine there is no control room functionality, which requires from the pump attendants to take over the pumping responsibility during breakdown periods. Because the unschooled pump attendants are not competent to proactively attend to a problem, it takes longer to get the artisan down to the point of the breakdown. Thus, instead of the problem being solved within an hour, it could take up to three hours. This extended system downtime affects the load-shift preparation and could result in pumps running during the peak hours due to high dam levels. This has a definite negative affect on the sustainability of load shift results.

Figure 3-9 (next page) illustrates the difference in savings achieved due to the downtime of only one hour and the downtime being three hours long. Figure 3-9 (A) illustrates the savings achieved for the downtime limited to only one hour during the preparation period, while Figure B illustrates the lost savings due to the extended downtime.

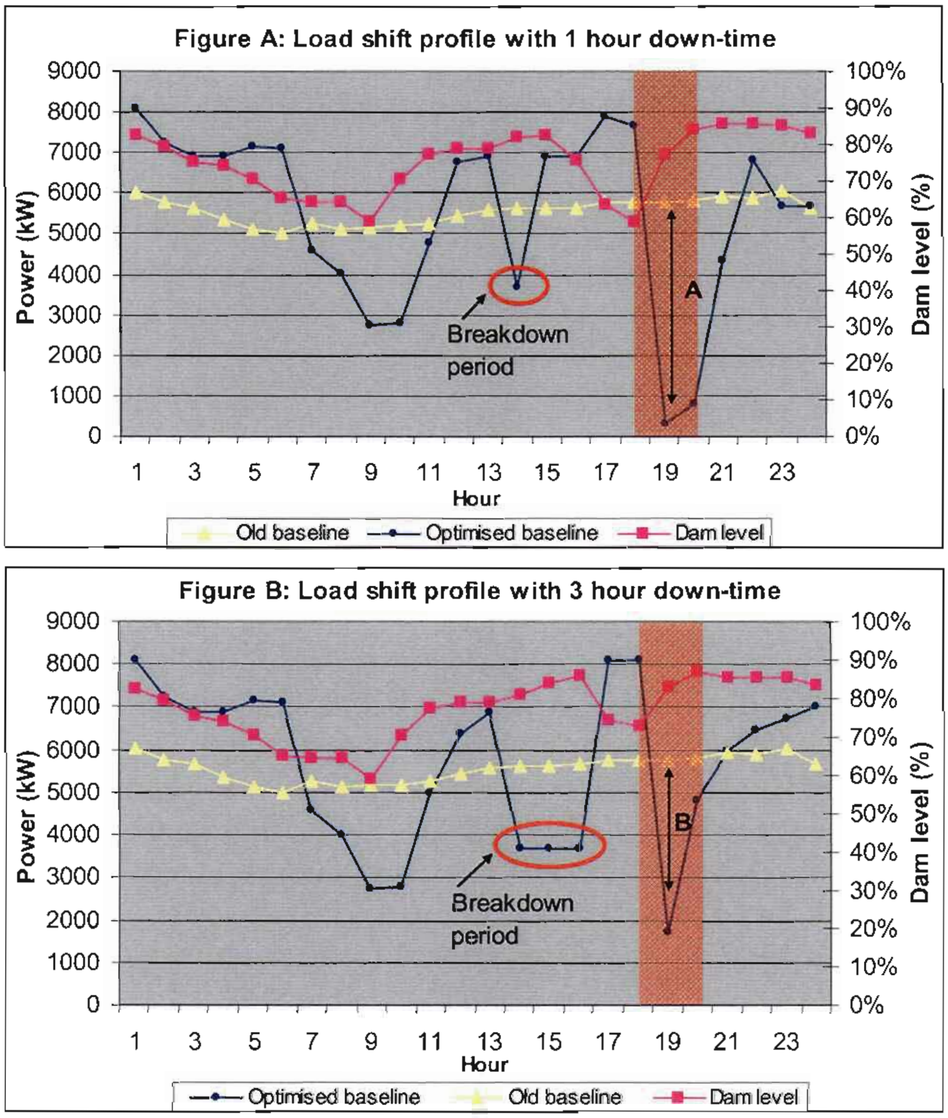


Figure 3-9: Lost savings due to extended system downtime

Point A in Figure 3-9 (A) shows that the load-shift saving during the evening peak period is 5.2 MW, while the load shift saving due to the extended downtime is only 2.5 MW. The evening load shift target of Harmony 3# is 3.8 MW. The daily electricity cost savings lost due to the extended downtime period is calculated to be R 2 116 per winter weekday and R 324 per summer weekday. This lost saving could be minimised by having a competent control room operator monitoring the system and proactively addressing the problem.

By comparing the performance records of all the load-shifting projects, it is evident that the contribution made by the control room operators during a breakdown situation is critical in assuring sustainable results. This assumption can be confirmed by the following table:

Table 3-13: Achieved savings due to a control room

MINE	CONTROL ROOM FACILITY	ACTUAL VS. EXPECTED COST SAVING	
		LOW DEMAND SEASON	HIGH DEMAND SEASON
Kopanang	Yes	**85%**	**93%**
Elandsrand	Yes	**63%**	**77%**
Bambanani	Yes	**81%**	**75%**
Masimong 4#	Yes	**162%**	**151%**
Mponeng	Yes	**113%**	**191%**
Harmony 3#	No	**62%**	**54%**
Average saving without Harmony 3# savings		**100.8%**	**117.4%**

Thus, the electricity cost saving achieved on Harmony 3#, during the low- and high-demand seasons, is respectively 39% and 63.4% less than the savings achieved on the mines with control room operators. It is therefore necessary to have a control room operator on duty to take over the system control responsibilities during breakdown periods.

3.5 POSSIBLE COSTS ASSOCIATED WITH DSM PUMPING PROJECTS

3.5.1 Benefit of controlling the Maximum Demand

As mentioned in Section 2.4.2, load-shift potential on clear-water pumping projects is directly related to the storage capacity of the underground dams. During load shifting, it is fundamental to make the dam level increase to a maximum before starting a pump to empty the dam again. In order to shift maximum load, pumps have to be stopped during the peak-demand hours. With no water flowing out of the dams during these times, the dam level increases to a level higher than the normal operating level (still within the system constraints). With the high dam levels and the risk of flooding the dams, more pumps than usual are started after peak time to get the dam level within the safe operating boundaries.

The higher than usual number of pumps being started up after peak time have previously led to a new maximum demand (MD) on Mponeng mine. The financial penalties involved with an exceeded MD is very high and the mine will carry the higher cost for the following twelve months. These additional costs could be managed by implementing a control system limiting the apparent power consumption of the pumping system.

Due to the energy intensity of the industrial pumps used in the dewatering system, it is not very effective to stop and start pumps in order to manage the MD of the mine. Rock winders hoisting the rock from underground are the ideal system to perform MD control with [59]. Although the dewatering pump system is not the essential application for MD control, the start-up actions of pumps at any time of the day could be manipulated according to the live MD measured for the mine. The exceeded MD caused by the load shift project implemented on Mponeng mine is better illustrated by Figure 3-10:

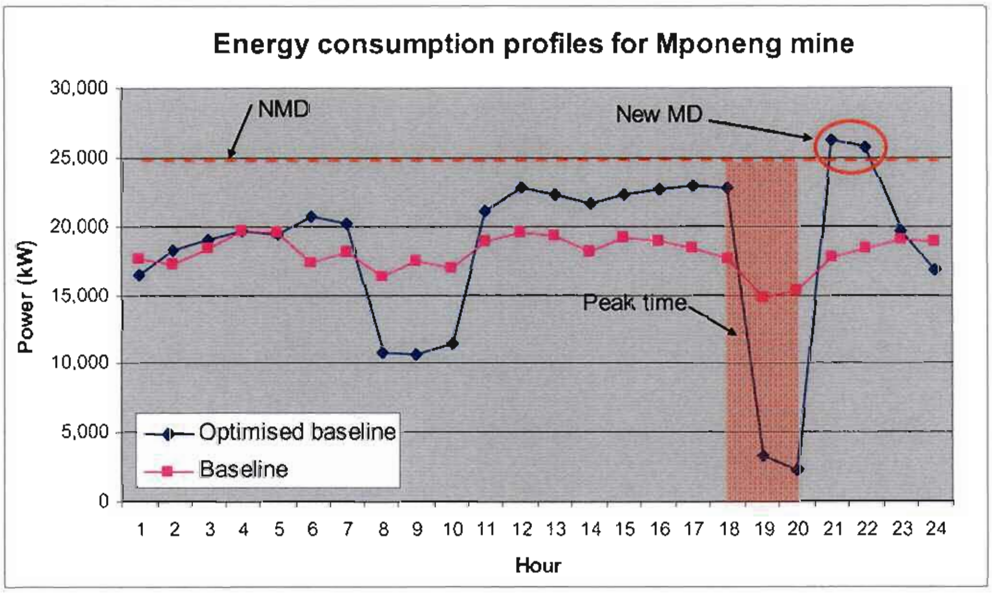


Figure 3-10: New MD after peak time due to DSM load shifting

Figure 3-10 shows the exceeded MD recorded due to the high number of pumps being started directly after peak time. This exceeded (new) MD recorded for Mponeng mine happened on 21 November 2005. Figure 3-11 on the following page illustrates the MD profile for Mponeng mine for this specific day. The blue line indicates the NMD of the mine, while the red line indicates the MD of the mine. The green line represents the total power consumption of all the electrical equipment (base load and pumping load) on Mponeng mine.

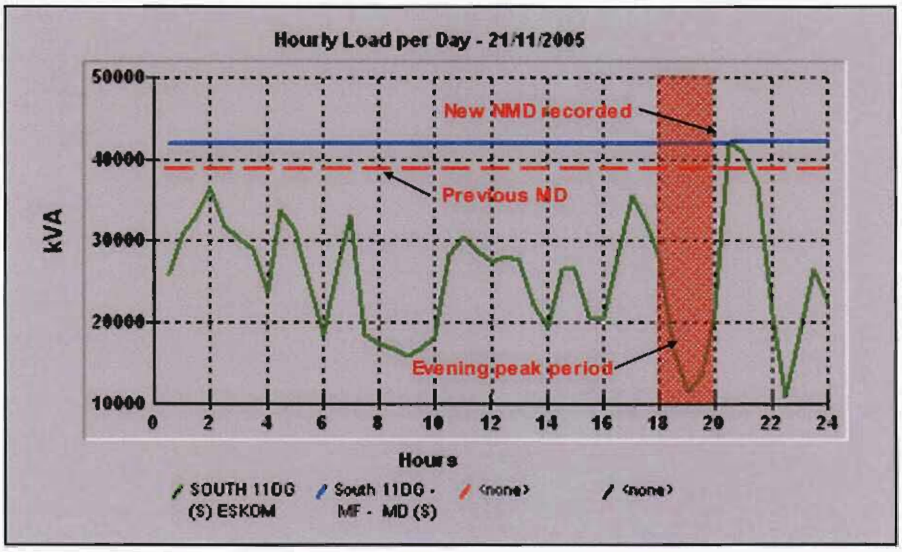


Figure 3-11: New MD recorded on Mponeng mine

The NMD on Mponeng mine increased from 41 758 kVA to 42 789 kVA, while the MD increased from 39 275 kVA to 42 789 kVA. The additional charges for November 2005 due to the exceeded NMD are given in Table 3-14:

Table 3-14: Higher network charges due to new NMD

Charge	Cost/kVA	NMD Charged		MD measured		Actual cost		Extra monthly cost
		Previous NMD (kVA)	New NMD (kVA)	Previous MD (kVA)	New MD (kVA)	Previous	New	
Network access charge (NMD)	R 5.91	41,758	42,789	-	-	R 246,790	R 252,883	R 6,093
Network demand charge (MD)	R 6.69	-	-	39,275	42,789	R 262,750	R 286,258	R 23,509

The higher network demand charge are only payable for one month and will be recalculated for all the future months, while the higher network access charges of R 252 883 is payable for the next 12 months or until a higher NMD is obtained. As seen in Table 3-14, the total extra network charge due to the new NMD is estimated to be R 29 602 for the month of November 2005.

By implementing the EMS system to perform load shifting, the MD on the pumping system could be controlled within a certain limit in order to avoid exceeding the existing MD of the mine. As mentioned before, the EMS will not stop a pump if a new MD would be reached, the EMS will only prevent a pump from starting up if the MD is close to maximum.

Because the MD of the mine could be managed to a certain extent, the risk involved when exceeding the MD of the mine could be changed into a cost saving opportunity to the mine. The input parameters to the model for determining the risk of exceeding the existing NMD or only the MD are as follows:

Managing the Notified Maximum Demand (NMD):

- What is the NMD ***before*** taking on DSM?
- What is the expected NMD when performing load shifting ***without*** MD control?
- What is the expected NMD when performing load shifting ***with*** MD control?
- What is the network access charge for an increased NMD (R/kVA)?

Managing the Maximum Demand (MD):

- What is the MD ***before*** taking on DSM?
- What is the expected MD when performing load shifting ***without*** MD control?
- What is the expected MD when performing load shifting ***with*** MD control?
- What is the network demand charge for an increased MD (R/kVA)?

3.5.2 DSM minimises the risk of pumping underground water

Manual control of the clear-water pumping system may not only increase the electricity cost to the mine, but it also involves some amount of risk. The human factor is not always fault-proof and has previously led to severe damage of underground operations due to flooding. The pump attendants have a lot of duties and are the only eyes monitoring the dam levels when controlling the system manually. The most common incident often happens when the pump attendant does not notice the high inrush of water into the dams. This usually goes hand-in-hand with pumps which can not start up due to mechanical problems or power failures that the pump attendants weren't aware of.

Production is not directly linked to the pumping of water, but could be affected by the flooding of pumping stations and mining levels. It is practically impossible to predict the financial impact when flooding a mine, although an incident like this could lead to a loss of production, or even loss of life.

Prior to implementing the load shift project on Masimong 4# and Harmony 3# mines, one of the biggest concerns to the engineer was the risk of flooding dams due to the limited operational options with a manual control system [60]. Masimong 4# is a very critical pumping shaft and the flooding of the shaft will affect production on the surrounding shafts. The first mine to be affected is Masimong 5 shaft. Because mining activities at Masimong 4 have been closed down, Masimong 5 shaft was investigated to determine the financial impact for a complete loss of production if the mine would flood.

The monthly production volumes at full production on Masimong 5 shaft are approximately 128 000 tons of rock per month at an average recovery grade of 5.5 grams of gold per ton [61]. The average daily loss of production is calculated as follows:

$$\begin{aligned} \text{Daily Production Loss} &= 4\,266 \text{ tons / day (mine working 7 days a week)} \\ &= 23\,466 \text{ grams / day } (1\text{ g} = 0.03527 \text{ ounces}) \\ &= 827.65 \text{ ounces / day (gold price as on 3 June 2006 : R 617.10 / ounce)} \\ &= \text{R } 502{,}463 \end{aligned} \tag{3-7}$$

Thus, a failure on the clear-water pumps resulting in a flood of underground working areas at Masimong 5# will lead to a loss in production costs of approximately R 502 500 per day. By implementing an automatic control system informing the responsible person about the problem in time, the problem could be addressed to prevent the mine from flooding. By applying the automatic control system on the pumps, the potential expense could be turned into a cost saving opportunity to the mine. The input parameters to the model in order to determine the risk associated with a manual control system are as follows:

- What will the financial implication be when the mine floods?
- Will the dam flooding affect the production of the mine?
- If yes, what are the production figures per day?

3.5.3 Financial risk to the client when taking on a DSM project

As discussed in Section 2.6.3 there are hidden costs to the client for underperformance as well as for early termination of a project. A case study will be conducted to determine the financial implication of the penalties involved.

l) Penalties due to underperformance

During the performance-tracking phase of the DSM project, the client is responsible for the sustainable delivery of the MW load-shift savings. As discussed in Section 2.6.3, the client has to pay penalties for a performance less than 90% of the contractual load-shift savings. The performance measured at Kopanang mine over the duration of the DSM load-shifting project is used to quantify the impact of an underperforming system to the mine. Because Kopanang mine has a maintenance contract with the ESCO, the ESCO carries the responsibility of paying the penalties if required.

The results of the Kopanang load shifting project during the performance-tracking phase for the last 12 months of the project are shown in Figure 3-12. The project overperformed consistently over this period, except for the month of July 2006. The insufficient load shifting is mainly due to limited storage capacity as a result of the dam cleaning process.

During the 12-month period, Kopanang mine managed to bank 196.5 MWh in overperformance. The intended DSM impact is 3 MW for each month and the corresponding achieved DSM impacts are shown below.

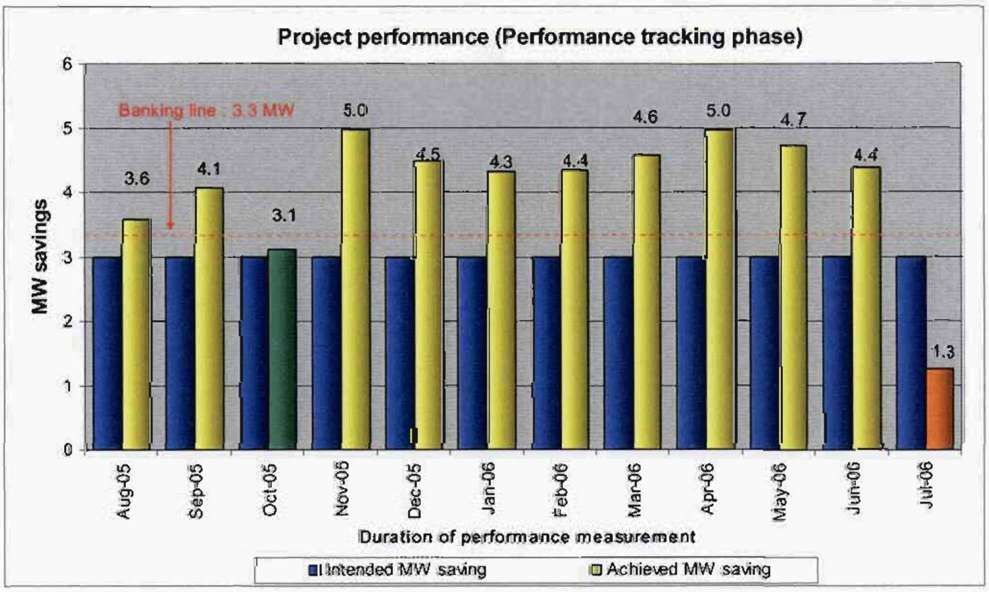


Figure 3-12: Monthly performance of the Kopanang project during the performance-tracking phase

From Figure 3-12 it can be seen that the DSM impact for July 2006 was less than the minimum 90% of the intended DSM target. The project performance is also given in Table 3-15, where the bankable balances and penalties are calculated from the data.

Table 3-15: Summary of Kopanang DSM performance

MONTH	NUMBER OF WEEKDAYS	INTENDED IMPACT (MW)	INTENDED IMPACT (MWh)	ACHIEVED IMPACT (MW)	ACHIEVED IMPACT (MWh)	OVER / UNDER PERFORMANCE (MWh)	ACCUMULATED PERFORMANCE (MWh)	COST DUE TO UNDER-PERFORMANCE
Aug-05	23	3	69	3.6	82.3	6.4	6.4	N/A
Sep-05	22	3	66	4.1	89.8	17.2	23.6	N/A
Oct-05	21	3	63	3.1	65.5	0	0	N/A
Nov-05	22	3	66	5.0	109.6	37.0	37.0	N/A
Dec-05	22	3	66	4.5	99.0	26.4	63.4	N/A
Jan-06	22	3	66	4.3	95.3	22.7	86.0	N/A
Feb-06	20	3	60	4.4	87.0	21.0	107.0	N/A
Mar-06	23	3	69	4.6	105.6	29.7	136.7	N/A
Apr-06	20	3	60	5.0	99.6	33.6	170.3	N/A
May-06	23	3	69	4.7	108.8	32.9	203.2	N/A
Jun-06	22	3	66	4.4	96.4	23.8	226.9	N/A
Jul-06	21	3	63	1.3	26.3	-30.5	196.5	R 79,059

This table presents the intended MWh impact compared to the achieved MWh impact. The project had to achieve a 3 MW saving during the two evening peak hours on weekdays. The number of weekdays determines the total monthly intended impact of the project, because DSM load shifting only applies for weekdays. Furthermore, note that only an overperformance of 110% of the MW target is considered for banking, and only a performance below 90% of the intended target is classified as underperformance.

As seen in Table 3-15, the project overperformed every month of the 12-month performance-tracking period, except for October 2005, and July 2006 when the project underperformed. The underperformance in July 2005 would have cost Kopanang mine R 79 059 if it was not for the accumulated bank balance of 226.9 MWh after 11 months. Thus, the banked overperformance could be used to offset the underperformance during July 2006.

Thus, it is important to the client to be aware of the hidden cost associated with a DSM project before taking on a project of this magnitude. By being informed, the mine could avoid hidden costs by maintaining the system or join into a maintenance contract with the ESCO.

II) Termination penalties

A case study of Masimong 4# was performed to determine the costs involved would the mine consider an early termination of the DSM project. The information needed to determine the termination penalty payable to Eskom is given in Table 3-16 on the following page.

Table 3-16: Information required when determining the termination cost of a project

DESCRIPTION	PROJECT RELATED INFORMATION
Total cost of DSM measures (T) (Infrastructure cost funded by Eskom)	R 3,000,000
Contractual duration of DSM project (Years)	5
Contractual date when project started	1 August 2005
Contractual date when project terminates	31 July 2010
Date of early termination	31 December 2006
Number of days falling short of the 5 year period (D)	1260

The termination penalty payable by Masimong 4# for an early termination of the load shifting project on the clear-water pumping system is calculated as follows:

$$\text{Termination penalty (TP)} = \left(\frac{\text{Total cost of DSM measures (T)}}{365\text{ days}\times 5\text{ (contractual period) years}}\right)\times$$

$$(\text{Number of days falling short of the 5 year period (D)}) \tag{3-8}$$

$$= \left(\frac{3000{,}000}{365\times 5}\right)\times 1260$$

$$= \text{R}2{,}071\text{ million}$$

The termination penalty payable by the mine 17 months into the project is illustrated in Figure 3-13. By accurately determining the true impact of a DSM project on the mine, the break-even point where the savings generated by the DSM project and the termination penalty is equal, could be determined. This point could rather be considered if the mine plans on an early termination of the project. This break-even point will be given in Section 4.2, where Masimong 4# is used as a case study to determine the long-term impact of DSM.

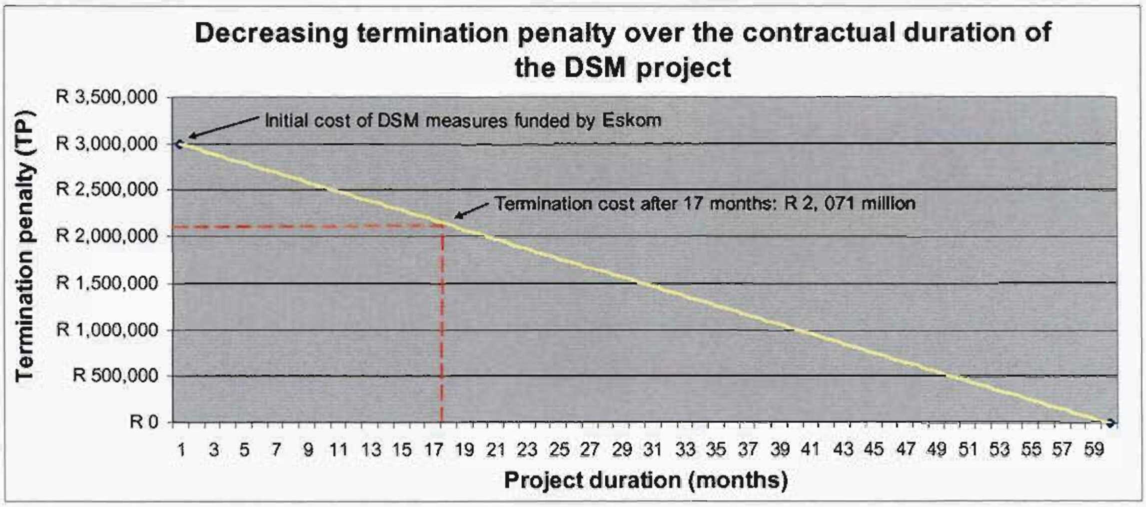


Figure 3-13: Decreasing termination penalty for the duration of the DSM project

3.6 CONCLUSION

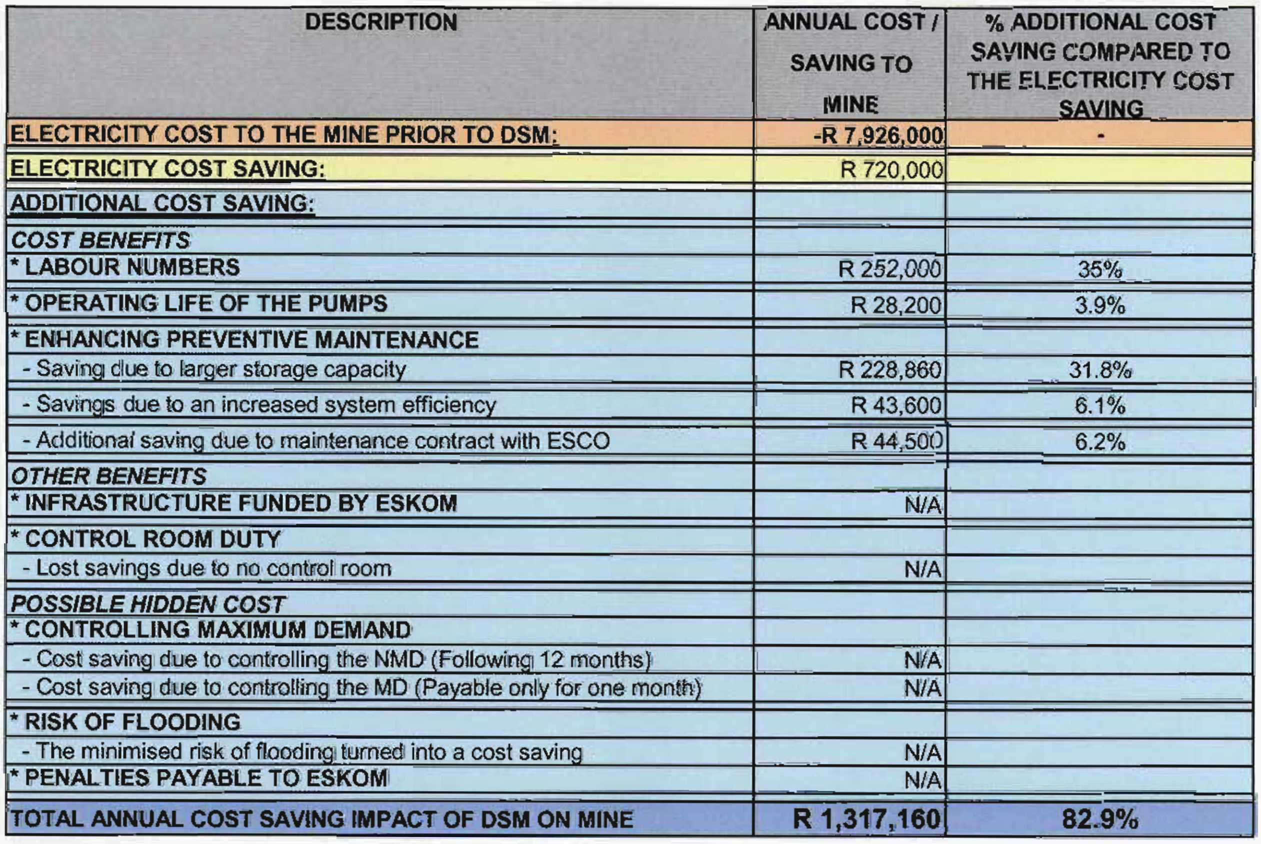
Throughout this chapter all effects identified in Chapter 2 were quantified by performing case studies on existing load shifting projects. This is done to predict the effect of the overall impact of DSM on a mine. During the quantification process, performance-tracking reports and logged data were analysed.

From the performance-tracking reports, it was found that the actual electricity cost savings of the various mines are approximately 73% of the intended cost saving and the missed savings are mainly due to system breakdowns. This figure increases to well over 100% on mines with new pumping equipment. Furthermore, labour cost savings, costs savings regarding the operating life of pumps as well as the cost savings associated with preventative maintenance increased due to DSM.

Other benefits of DSM are the upgraded infrastructure the mines receive from Eskom as part of the project. Secondly, the importance of having a control room operator monitoring the system is also emphasised by determining the missed savings on mines without a 24-hour control room facility.

Possible hidden costs to mines, when taking on a DSM project, were identified with an exceeded maximum demand (which is common to load shifting), risk of flooding and also penalties payable to Eskom for underperformance as well as an early termination of a DSM project. By controlling the above-mentioned risks of DSM, these hidden costs could be turned into saving opportunities. Due to the difficulty to predict the impact of these hidden costs, it is not possible to accurately predict the hidden cost-savings obtained due to a controlled system. Table 3-17 represents the annual cost saving for each of the additional effects (excluding the electricity cost saving) of DSM, determined throughout the quantification process, compared to the electricity cost saving only.

Table 3-17: Annual additional cost saving compared to the electricity cost saving



DESCRIPTION	ANNUAL COST / SAVING TO MINE	% ADDITIONAL COST SAVING COMPARED TO THE ELECTRICITY COST SAVING
ELECTRICITY COST TO THE MINE PRIOR TO DSM:	-R 7,926,000	-
ELECTRICITY COST SAVING:	R 720,000	
ADDITIONAL COST SAVING:		
COST BENEFITS		
* LABOUR NUMBERS	R 252,000	35%
* OPERATING LIFE OF THE PUMPS	R 28,200	3.9%
* ENHANCING PREVENTIVE MAINTENANCE		
- Saving due to larger storage capacity	R 228,860	31.8%
- Savings due to an increased system efficiency	R 43,600	6.1%
- Additional saving due to maintenance contract with ESCO	R 44,500	6.2%
OTHER BENEFITS		
* INFRASTRUCTURE FUNDED BY ESKOM	N/A	
* CONTROL ROOM DUTY		
- Lost savings due to no control room	N/A	
POSSIBLE HIDDEN COST		
* CONTROLLING MAXIMUM DEMAND		
- Cost saving due to controlling the NMD (Following 12 months)	N/A	
- Cost saving due to controlling the MD (Payable only for one month)	N/A	
* RISK OF FLOODING		
- The minimised risk of flooding turned into a cost saving	N/A	
* PENALTIES PAYABLE TO ESKOM	N/A	
TOTAL ANNUAL COST SAVING IMPACT OF DSM ON MINE	**R 1,317,160**	**82.9%**

Due to the fact that the impact of the *other benefits* and *hidden costs* cannot be predicted, it was not included in the above table. From the above table it can be seen that the additional cost saving is roughly 83% of the electricity cost saving only.

CHAPTER 4: VALIDATION OF THE RESEARCH STUDY

Throughout this chapter the validity of the research study is proved by applying the generic model developed to existing as well as future DSM projects. The effect of extrapolating the model to all mines with DSM potential on their clear-water pumping systems is also mentioned.

4.1 INTRODUCTION

After quantifying the various effects of load shifting by using the track records and performance information of existing DSM projects, the results have been interpreted to determine the true impact that each of the effects have on a mine. The findings made throughout the study, as well as the input parameters identified, have been incorporated into building a generic model.

The generic model built in Microsoft Excel^{TM} basically consists of a questionnaire, requiring operational information on the clear-water pumping system of the specific mine. To prove the validity of the research study, this generic model was applied to the existing load-shift project on Masimong 4# mine and thereafter to future DSM projects.

4.2 MODELLING THE IMPACT OF DSM ON THE PUMPING SYSTEM OF MASIMONG 4# MINE

4.2.1 Input parameters to the model

I) System information needed to determine the proposed electricity cost savings

The general information on the clear-water pumping system needed to perform a DSM feasibility study is given in Table 4-1 (next page). This information is sufficient to estimate the MW load shift potential, as well as the expected electricity cost savings promised to the mine.

The values highlighted in green in Table 4-1 are the input parameters to the model used for calculating the projected electricity cost saving due to the load-shifting project. Considering this information, a more realistic prediction regarding the electricity cost savings of a DSM project could be made by using the average achieved saving on existing mines, as determined in Section 3.3.1.

Table 4-1: General information on the operation of the clear-water pumping system

	DESCRIPTION	SYSTEM INFORMATION
	PROJECT RELATED DETAIL:	
	Project name	Masimong 4#
	Duration of project (Years)	5
	Date when project will start	Aug-05
	SYSTEM INFORMATION:	
	Total installed capacity (MW)	18.8
	Total energy consumption per day (kWh)	135.36
	Daily water pumped to surface (ML)	14
	TOTAL ELECTRICITY COSTS:	
	Low demand season (Monthly)	R 240,000
	High demand season (Monthly)	R 430,000

II) Modelling the additional benefits of DSM

To determine the overall impact of the load-shifting project on Masimong 4#, the information as given in Table 4-2 was obtained from the shaft engineer. This information was also used to calculate the financial impact of each of the DSM effects on the overall saving of the load shifting project.

Table 4-2: Additional information regarding the Masimong 4# clear-water pumping system

	DESCRIPTION	SYSTEM INFORMATION
A	LABOUR NUMBERS	
	Monthly cost per labourer to mine	R 4,500
	How many pumping stations?	2
	How many pump attendants per station?	2
	How many shifts per day?	3
	Current total number of pump attendants	12
	Number of pump attendants DUE TO DSM	6
B	OPERATING LIFE OF THE PUMPS	
	Total monthly maintenance cost of pumping system	R 300,000
	Total number of pumps in system	8
	Daily amount of stop/start per pump BEFORE DSM	3
C	ENHANCING PREVENTIVE MAINTENANCE	
	STORAGE CAPACITY	
	Ideal (expected) storage capacity per level (m^3)	14,700
	*Maximum dam level	90%
	*Minimum dam level	20%

	Current total storage capacity per level (m^3)	14,700
	*Maximum dam level	90%
	*Minimum dam level	35%
	SYSTEM EFFICIENCY	
	Motor (manufacturing specifications):	
	Motor type	Induction
	Installed capacity (kW)	1500
	Supply voltage to motor (kV)	6.6
	Motor ampere (A)	149
	Power factor	0.88
	Pump (manufacturing specifications):	
	Pump name	Sulzer
	Design flow rate (l/s)	95
	Design efficiency (%)	64%
	MAINTENANCE CONTRACT	
	Maintenance contract between the client and ESCO?	No
D	**CONTROL ROOM DUTY**	
	Does the mine have a control room?	Yes
E	**CONTROL INFRASTRUCTURE**	
	Does the mine need infrastructure?	Yes
	Total DSM measures funded by Eskom	R 3,000,000
F	**CONTROLLING MAXIMUM DEMAND**	
	What is the current NMD of the mine? (kVA)	35400
	What is the current MD of the mine? (kVA)	33000
G	**RISK OF FLOODING**	
	Which surrounding mines will be affected due to flooding?	Masimong 5#
	Total daily average of rock being mined (tons)	4266
	Recovery grade (g/ton)	5.5
	Gold price (R/ounce)	R 617.10
	Daily production loss if the shaft would flood	R 510,675
	Downtime time available before a mine would flood (hours)	2

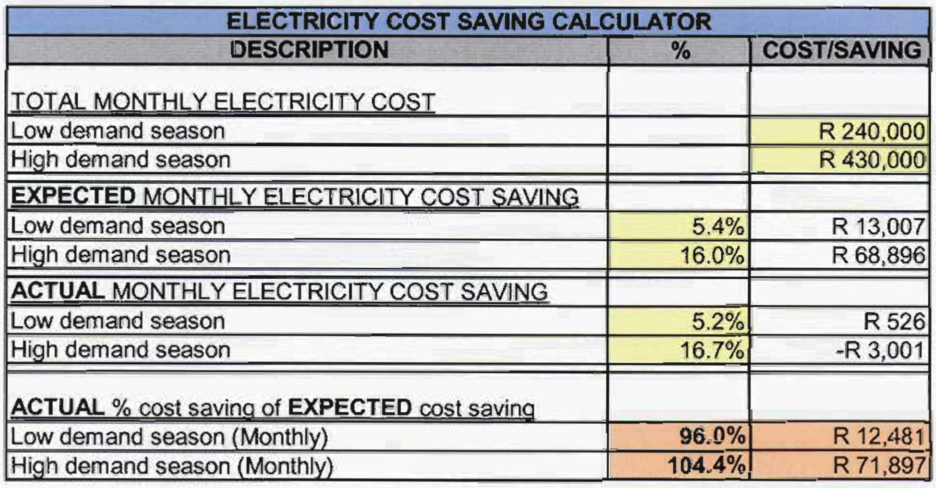
The monthly contribution for each of the additional aspects to the overall impact of DSM on the mine is discussed in the following section.

4.2.2 Results obtained from the model

I) Proposed electricity cost savings to the mine

Section 3.3.1 showed that the actual monthly electricity cost saving is 5.2% and 16.7% of the total electricity cost of the pumping operation, for the low-demand (summer) and high-demand (winter) seasons respectively. The projected electricity cost saving to Masimong 4# when taking on the load-shift project, is calculated to be approximately R 12 500 for a summer month and R 71 900 for a winter month. Thus, the annual electricity cost saving proposed to the mine by using pre-implementation information is calculated to be in the order of R 328 000. The model used to determine the electricity cost saving is given in Table 4-3.

Table 4-3: Calculator used to predict a realistic electricity cost saving to Masimong 4#



ELECTRICITY COST SAVING CALCULATOR		
DESCRIPTION	**%**	**COST/SAVING**
TOTAL MONTHLY ELECTRICITY COST		
Low demand season		R 240,000
High demand season		R 430,000
EXPECTED MONTHLY ELECTRICITY COST SAVING		
Low demand season	5.4%	R 13,007
High demand season	16.0%	R 68,896
ACTUAL MONTHLY ELECTRICITY COST SAVING		
Low demand season	5.2%	R 526
High demand season	16.7%	-R 3,001
ACTUAL % cost saving of **EXPECTED** cost saving		
Low demand season (Monthly)	**96.0%**	R 12,481
High demand season (Monthly)	**104.4%**	R 71,897

Table 4-3 uses the monthly electricity costs before attempting load shifting as well as the expected saving to predict a more realistic electricity cost saving when attempting load shifting. Thus, performance-tracking reports used in Section 3.3.1 illustrated that the actual electricity cost saving is 96% and 104.4% of the expected cost saving for summer and winter months respectively.

II) Additional impact of DSM on Masimong 4# mine

Each of the additional effects that contribute to the overall impact of DSM on Masimong 4# will be discussed in order to explain the output of the model.

Table 4-4: Monthly contribution of the system components due to DSM

	DESCRIPTION	MONTHLY COST IMPACT DUE TO DSM		ANNUAL IMPACT DUE TO DSM
		Low demand season	High demand season	
E	INFRASTRUCTURE COST FUNDED BY ESKOM:	R 3,000,000		
A	LABOUR NUMBERS:	R 27,000	R 27,000	R 324,000
B	OPERATING LIFE OF THE PUMPS:			
	Higher maintenance cost due to an increase in stop/start per pump	-R 2,813	-R 2,813	-R 33,750
C	ENHANCING PREVENTIVE MAINTENANCE:			
	Saving due to larger storage capacity	R 6,867	R 53,551	R 222,453
	Savings due to an increased system efficiency	R 3,819	R 22,001	R 100,375
	Additional saving due to maintenance contract with ESCO	R 0	R 0	R 0
D	CONTROL ROOM DUTY:			
	Lost savings due to no control room	NA	NA	NA
F	CONTROLLING MAXIMUM DEMAND:			
	Cost saving due to controlling the NMD (Following 12 months)	NA	NA	NA
	Cost saving due to controlling the MD (Payable only for one month)	NA	NA	NA
G	RISK OF FLOODING:			
	The minimised risk of flooding turned into a cost saving	NA	NA	NA
	TOTAL IMPACT OF DSM ON THE MINE	**R 34,874**	**R 99,739**	**R 613,079**

A) Labour numbers

From Table 4-2 it could be seen that the number of pump attendants working on the pumping system of Masimong 4# were reduced from 12 to 6 people. This is mainly due to the automatic control system which replaced the human factor. The monthly expense to the mine per pump attendant is R 4 500, thus the monthly cost saving due to the reduction in the number of pump attendants employed is calculated to be R 27 000 per month.

B) Operating life of the pumps

According to the shaft engineer, the total monthly maintenance cost for the clear-water pumping system is R 300 000. Thus, the average maintenance cost per pump is approximately R 37 500, with the pumping system consisting of eight pumps. During the research study it was found that the percentage maintenance cost due to the frequent switching on and off of the pumps is in the order of 15% to 20% of the total maintenance cost. At Masimong 4# this contribution is approximately 15%. Thus, from the logged data it was found that the duty pumps were stopped and started 3 times per day compared to the 2 times when not attempting load shifting. With this average daily increase in the number of cycles per duty pump when attempting load shifting, the net monthly expense to the mine is calculated to be R 2 812.

C) Enhancing preventative maintenance

Larger storage capacity

From Table 4-2 it is given that the design (ideal) storage capacity of the complete pumping system is 14 700 m^3. Over the years this storage capacity reduced from 70% to 55% of the design capacity. This is because the minimum dam level limit needed to be raised from 20% to 35% due to the excessive mud volume.

Calculations have shown that the cleaning process to restore the ideal storage capacity of 2 205 m^3 will take approximately 6 months at a total expense in the order of R 176 400.

By simulating the pumping system for the two scenarios, the net monthly electricity cost saving due to the increased storage capacity is calculated to be R 6 870 and R 53 550 for the summer and winter months respectively. Thus, the payback period for the dam cleaning process is approximately 8 months.

Increased system efficiency

Due to the functionality put in place by the DSM initiative in order to improve preventative maintenance by continuous monitoring of the pumps and motors, the overall system efficiency could be increased. From Table 4-2 it can be seen that the design efficiency of the pumps is in the order of 64%, while the average operating efficiency is approximately 51%. It is assumed that the system efficiency is also 51%.

If the efficiency of the pumps and motors could be determined on a more regular basis, the less efficient pumps could be replaced by the more efficient pumps. By managing the duty pumps according to their efficiency, the overall system efficiency could be restored to approximately 60%. This increase in system efficiency leads to an additional monthly net electricity cost saving of R 3 800 during the low-demand season and R 22 000 during the high-demand season.

Maintenance contract between the ESCO and the mine

From Chapter 3 it was found that by having a maintenance contract with the ESCO, the electricity cost savings of DSM load shifting increases by approximately 10%. Note that Masimong 4# does not have a maintenance contract with the ESCO, and in turn does not benefit from the higher saving.

D) Control room duty

Masimong 4# has a control room in place that monitors the EMS system performance and takes over the pumping responsibilities during a breakdown period. Because the control room operator gets notified immediately when a system breakdown occurred, the responsible person could be informed about the problem in order to address the problem before it affects the load shift savings. This leads to a shorter down-time period of the EMS system and limits the lost savings to a minimum. Due to the fact that there are no unnecessary lost savings due to system down-time, the mine has no additional expenses due to the DSM project.

E) Infrastructure cost funded by Eskom

During the investigation phase of the project, it was found that the mine did not have the needed infrastructure to accommodate automatic control of the clear-water pumping system. The total DSM measures funded by Eskom to enable automatic control of the pumping system are R 3 million.

F) Controlling the Maximum Demand

As discussed in Section 3.5.1, the MD of the mine is likely to be exceeded when attempting load shifting. Although the MD of the mine could be controlled by using the EMS, it is not possible to predict when the MD would have exceeded the previous MD and by what margin. Due to the complexity of determining the cost saving impact of controlling the MD when a profile baseline of the MD is not available, this impact could not be determined. Thus, the effect of MD on Masimong 4# is rather seen as a possible loss to the mine.

G) Risk of flooding

The financial impact on a mine due to the lower risk of flooding when replacing the human factor with an automatic control system could be regarded as a cost savings to the mine. As explained in Section 3.5.2, when controlling the risk of flooding, the cost impact on the mine could only be determined if the financial cost of a flooding was known. Thus, it is also not possible to predict when a flooding would occur and what the effect would be.

Although it is calculated that a loss in production of one day on Masimong 5# could lead to a financial loss of R 510 000, the monthly cost saving to the mine when controlling the risk of flooding, in this case could not be calculated.

4.2.3 Summarising the results obtained from the Masimong 4# model

It is calculated that the projected total monthly cost saving due to DSM is approximately R 47 355 (R 12 481 + R 34 874) and R 171 636 (R 71 897 + R 99 739), for low- and high-demand seasons respectively. The R 12 481 and R 71 897 is the electricity cost saving initially proposed to the mine. The annual additional cost saving due to DSM is R 613 079 compared to the electricity cost saving only of R 328 020, which gives a total annual cost saving of almost R 1 million.

The extra monthly cost saving when considering the above-mentioned factors were added together to give an overall expected cost saving to the mine for the duration of the DSM project. Figure 4-1 on the following page gives the accumulative cost saving for Masimong 4# for the duration of the DSM project. Note that no inflation was considered when the projected cost savings for the duration of the project were calculated.

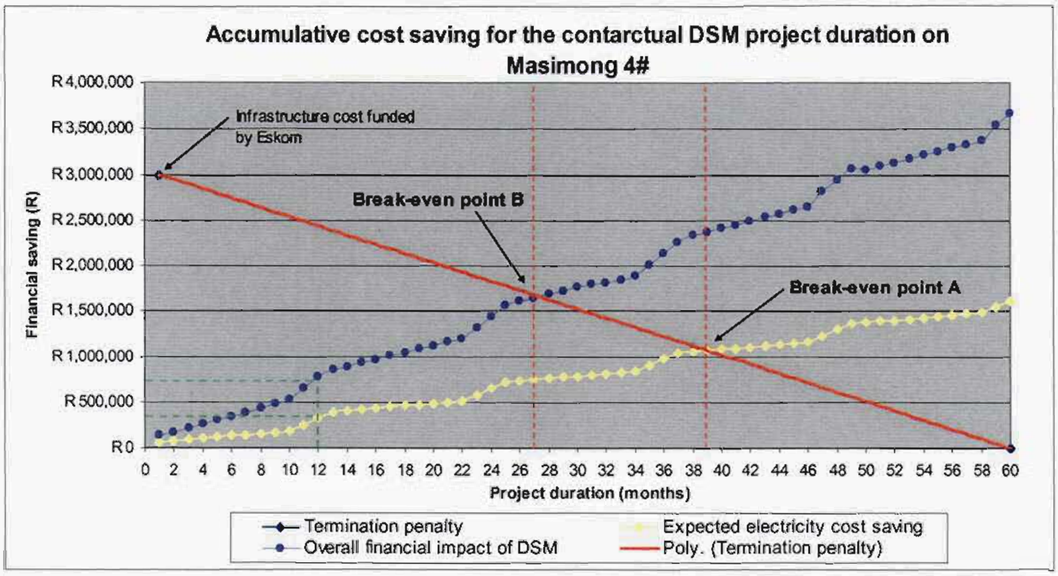


Figure 4-1: Accumulative cost saving to Masimong 4# for the duration of the project

As seen in Figure 4-1, the electricity cost saving initially proposed to the mine adds up to approximately R 1.6 million (yellow line) over the five-year period. After considering the overall impact of DSM on the mine, the predicted net cost saving accumulates to approximately R 3.7 million after five years.

The green lines in Figure 4-1 indicates that after the first 12 months of performing load-shifting on the clear-water pumping system of Masimong 4#, the mine already saved up to R 750 000. This is approximately R 300 000 more than initially proposed, when only the electricity cost savings were considered.

The red line represents the termination penalty payable to Eskom over the duration of the DSM project. The break-even points where the financial risk to the mine for an early termination of the project is zero, are given by point A and point B. Point A indicates the break-even point when only the electricity cost savings were considered. By considering the overall impact of DSM compared to electricity cost saving only, it was found that the break-even point advanced from 36 months into the project to 23 months.

4.3 APPLYING THE GENERIC MODEL TO FUTURE DSM PROJECTS

4.3.1 Overview of future DSM clear-water pumping projects

The model used in Section 4.2 to determine the overall DSM impact on Masimong 4# was also used on future DSM projects. The model was applied to the following mines:

- Ezulwini mine
- Cooke 1#
- President Steyn 3# and 9#
- Kloof 7#

The input parameters for the various clear-water pumping systems are given in Table 4-5 on the following page. These input parameters obtained from the mine will be put into the generic model to determine the overall long term impact of DSM projects on the mines.

Table 4-5: Input parameters for future load-shifting projects

INPUT PARAMETERS TO MODEL				
DESCRIPTION	**INPUT PARAMETERS**			
PROJECT RELATED DETAIL				
Project name	**Ezulwini Mine**	**Cooke 1#**	**Pres Steyn 3#&9#**	**Kloof 7#**
Duration of project (Years)	5	5	3	5
Date when project will start	Jul-07	Aug-07	Jul-07	Dec-07
SYSTEM INFORMATION				
Total installed capacity (MW)	56	8.28	20.648	33.6
Total energy consumption per day (kWh)	438	60	66	443.52
Daily water pumped to surface (ML)	65	14.3	12	30
ELECTRICITY COSTS				
Low demand season (Monthly)	R 1,200,000	R 165,000	R 180,000	R 1,161,000
High demand season (Monthly)	R 2,550,000	R 346,800	R 396,000	R 2,193,600
LABOUR NUMBERS				
Monthly cost per labourer to the mine	3,850	3,670	4,000	4,200
How many pumping stations?	3	1	5	4
How many pump attendants per station?	10	1	3	3
How many shifts per day?	3	3	3	3
Current total numer of pump attendants	30	3	45	36
Number of pump attendants DUE TO DSM?	21	3	30	24
OPERATING LIFE OF THE PUMPS				
Total monthly maintenance cost to pumping system	R 550,000	R 75,000	R 255,000	R 560,000
Total number of pumps in system	22	3	17	16
Daily amount of stop/start per pump BEFORE DSM	2	1	6	1
ENHANCING PREVENTIVE MAINTENANCE				
STORAGE CAPACITY				
Ideal (Expected) storage capacity per level (m^3)	16,500	9,200	5,300	39,000
*Maximum dam level	90%	90%	95%	90%
*Minimum dam level	40%	30%	45%	30%
Current total storage capacity per level (m^3)	16,500	9,200	5,300	39,000
*Maximum dam level	90%	90%	95%	90%
*Minimum dam level	30%	30%	55%	30%
SYSTEM EFFICIENCY				
Motor:				
Motor type	Induction	Induction	Induction	Induction
Installed capacity (kW)	2,716	2,760	1,100	2,000
Supply voltage to motor (kV)	6.6	6.6	6.6	6.6
Motor ampere (A)				
Power factor	0.89	0.87	0.86	0.88
Pump:				
Pump name	Sulzer	Siemens	Toshiba	Sulzer
Design flow rate (l/s)	213	90	75	190
Design efficiency (%)	67%	65%	64%	68%
MAINTENANCE CONTRACT				
Maintenance contract between the client and ESCO?	Yes	No	Yes	Yes
CONTROL ROOM DUTY				
Has the mine got a control room?	Yes	Yes	No	Yes
CONTROL INFRASTRUCTURE				
Does the mine need infrastructure?	Yes	Yes	Yes	Yes
Total DSM measures	R 4,877,605	R 674,714	R 3,067,069	R 4,900,000

4.3.2 Outcome of the generic model

I) Ezulwini mine

Ezulwini mine (formerly known as Randfontein Estates Number Four Shaft) is currently owned by Simmer and Jack Mines Limited and is situated in the Western Area region south-west of Johannesburg. As seen in Table 4-5, this mine pumps a large amount of water to the surface on a daily basis, which results in a large electricity bill to operate the pumping system. Table 4-6 shows the high electricity cost savings possible when implementing the DSM load-shifting project. The additional cost savings possible when implementing DSM are also given in the table below.

In Table 4-6 it could be seen that the only expense to the mine when implementing the DSM initiative is the cost associated with the operating life of the pumps. This is because of the more frequent switching of the pumps to realise load shifting, compared to the constant running of the duty pumps when not attempting load shifting.

Table 4-6: Overall monthly impact of DSM on Ezulwini mine

DESCRIPTION	MONTHLY COST IMPACT DUE TO DSM		ANNUAL IMPACT DUE TO DSM
	Low demand season	High demand season	
INFRASTRUCTURE COST FUNDED BY ESKOM:	R 4,877,605		
PROPOSED ELECTRICITY COST SAVING:	R 62,407	R 426,368	R 1,840,765
LABOUR NUMBERS:	R 34,650	R 34,650	R 415,800
OPERATING LIFE OF THE PUMPS:			
Higher maintenance cost due to an increase in stop/start per pump	-R 28,000	-R 28,000	-R 336,000
ENHANCING PREVENTIVE MAINTENANCE:			
Saving due to larger storage capacity	R 6,734	R 67,395	R 262,794
Savings due to an increased system efficiency	R 21,281	R 145,391	R 627,701
Additional saving due to maintenance contract with ESCO	R 6,241	R 42,637	R 184,077
CONTROL ROOM DUTY:			
Lost savings due to no control room	NA	NA	NA
CONTROLLING MAXIMUM DEMAND:			
Cost saving due to controlling the NMD (Following 12 months)	NA	NA	NA
Cost saving due to controlling the MD (Payable only for one month)	NA	NA	NA
RISK OF FLOODING:			
The minimised risk of flooding turned into a cost saving	NA	NA	NA
TOTAL IMPACT OF DSM ON THE MINE	**R 103,313**	**R 688,441**	**R 2,995,137**

The total monthly impact of DSM on the mine, with the additional effects also taken into account, is compared to the electricity cost saving initially proposed to the mine. Figure 4-2 clearly indicates the two break-even points when comparing the savings to the termination penalties associated with the DSM project. When considering the overall impact of DSM on the mine, the break-even point advanced from 19 months into the project to 13 months into the project.

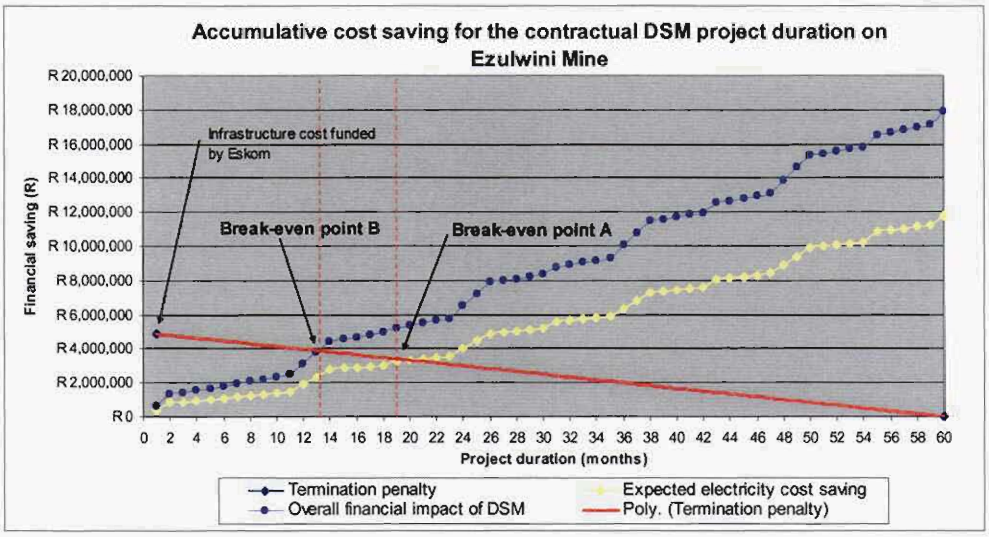


Figure 4-2: Accumulative cost saving to Ezulwini mine for the duration of the project

II) Cooke 1#

Cooke 1# is also located in the Western Area region and is owned by Harmony Gold. The underground pumping system of Cooke 1# has only one pumping station and pumps an average of 14.3 ML water per day. Table 4-7 indicates that the proposed monthly electricity cost saving due to DSM is R 8 581 and R 57 986 for the low- and high-demand seasons respectively.

The additional benefits of DSM as given in Table 4-7 indicate that the number of pump attendants working per shift will remain the same. The reason for this is that the functionality already exists to stop and start the pumps automatically, which includes the opening and closing of the valves. According to the engineer, the single pump attendant working per shift will remain working on the pumping station to monitor the system at all times.

Furthermore, it could be seen that the cost regarding the operating life of the pumps will increase, because the pump attendants previously ran the pumps for a whole day without stopping the pumps. It is also seen that the cost saving associated with the maximum demand (MD) is calculated to be R 2 208. This effect could be quantified because the 24-hour MD profile of the mine was available and the effect of load shifting on the MD could be simulated. Because the MD of the mine would have been affected when attempting load shifting, the MD can be controlled by the EMS system. Thus, the potential costs involved with an exceeded MD could be changed into a cost-saving opportunity to the mine. The overall net monthly impact of DSM load shifting on the clear-water pumping system of Cooke 1# is approximately R 8 628 during the low-demand season and R 71 501 during the high-demand season.

Table 4-7: Overall monthly impact of DSM on Cooke 1# mine

DESCRIPTION	MONTHLY CONTRIBUTION DUE TO DSM		ANNUAL IMPACT DUE TO DSM
	Low demand season	High demand season	
INFRASTRUCTURE COST FUNDED BY ESKOM:			**R 674,714**
PROPOSED ELECTRICITY COST SAVING:	R 8,581	R 57,986	R 251,187
LABOUR NUMBERS:	NA	NA	NA
OPERATING LIFE OF THE PUMPS:			
Higher maintenance cost due to an increase in stop/start per pump	-R 4,583	-R 4,583	-R 55,000
ENHANCING PREVENTIVE MAINTENANCE:			
Saving due to larger storage capacity	R 0	R 0	R 0
Savings due to an increased system efficiency	R 2,339	R 15,807	R 68,473
Additional saving due to maintenance contract with ESCO	NA	NA	NA
CONTROL ROOM DUTY:			
Lost savings due to no control room	NA	NA	NA
CONTROLLING MAXIMUM DEMAND:			
Cost due to an NMD controller	R 0	R 0	R 0.00
Cost due to an MD controller	R 2,208	R 2,208	R 26,492.40
RISK OF FLOODING:			
The minimised risk of flooding turned into a cost saving	NA	NA	NA
TOTAL IMPACT OF DSM ON THE MINE	**R 8,544**	**R 71,417**	**R 291,152**

When considering the overall impact of DSM on the mine, the break-even point advanced from 22 months into the project to 19 months into the project. This can be seen in Figure 4-3 on the following page.

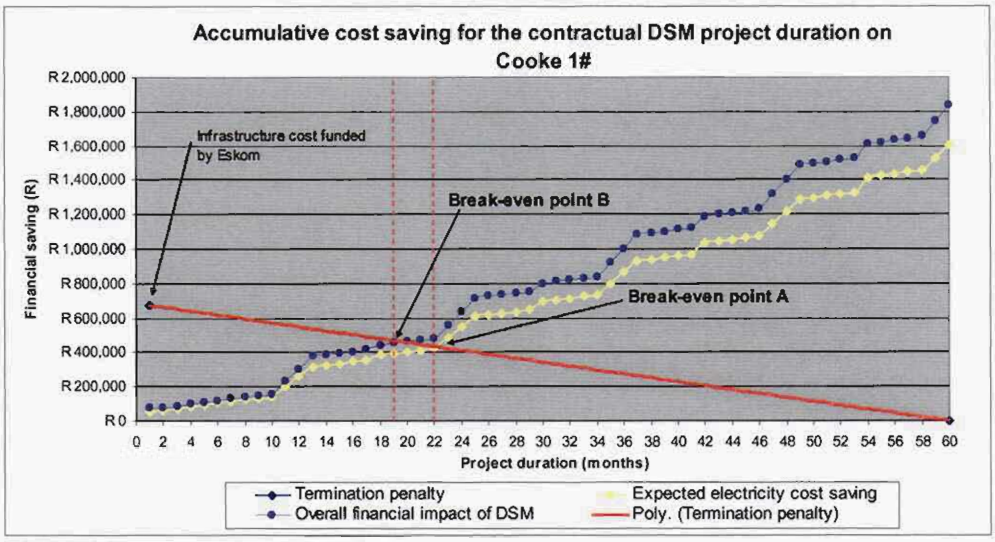


Figure 4-3: Accumulative cost saving to Cooke 1# for the duration of the project

III) President Steyn 3# & 9#

President Steyn mine is located north-west of Odendalsrus in the Free State province and belongs to the Disselgroup Company. The DSM initiative will be implemented at two shafts, although it is seen as one DSM project. In total, the project consists of five pumping stations and pumps an average of 12 ML water per day.

The monthly electricity bill of the mine is calculated to be in the order of R 180 000 and R 400 000 for the low and high-demand seasons respectively. As seen in Table 4-8, the monthly electricity cost saving due to the DSM initiative proposed to the mine is approximately R 26 000 and R 100 000 for the respective seasons.

The additional effects of DSM contributing to the overall impact on the mine are also given in Table 4-8. Firstly, due to the cut down in the number of pump attendants needed to operate the pumps, from 45 to 30, the mine will save in the order of R 60 000 per month. The optimised controlling regarding the operation of the pumps also contributed to a monthly cost saving of approximately R 1 650. Thus, the operating life of the pumps between services will increase due to less cycling of the pumps.

Note that the maintenance contract between the mine and the ESCO will roughly have a 10% higher electricity cost saving to the mine. This higher saving is mainly due to the constant feedback on the non-performance of the DSM project, which makes the mine more aware of the problems causing missed saving opportunities. Thus, the ESCO points the problems out to the mine in order for the mine to address the problem as soon as possible.

The fact that there is no control room facility at President Steyn mine, the monthly missed saving is approximately R 2 800 during a low-demand month and R 19 200 during a high-demand month. This major loss in cost savings could be presented to the mine as an incentive to put a control room facility in place to monitor the system in order to minimise the down-time that results into lost savings.

Table 4-8: Overall monthly impact of DSM on President Steyn 3# & 9# mine

DESCRIPTION	**MONTHLY CONTRIBUTION DUE TO DSM**		**ANNUAL IMPACT DUE TO DSM**
	Low demand season	**High demand season**	
INFRASTRUCTURE COST FUNDED BY ESKOM:			R 3,067,069
PROPOSED ELECTRICITY COST SAVING:	R 26,100	R 101,772	R 540,216
LABOUR NUMBERS:	R 60,000	R 60,000	R 720,000
OPERATING LIFE OF THE PUMPS:			
Higher maintenance cost due to an increase in stop/start per pump	R 8,250	R 8,250	R 99,000
ENHANCING PREVENTIVE MAINTENANCE:			
Saving due to larger storage capacity	R 3,453	R 18,588	R 86,843
Savings due to an increased system efficiency	R 7,034	R 27,428	R 145,588
Additional saving due to maintenance contract with ESCO	R 2,610	R 10,177	R 54,022
CONTROL ROOM DUTY:			
Lost savings due to no control room	-R 2,845	-R 19,219	-R 83,260
CONTROLLING MAXIMUM DEMAND:			
Cost saving due to controlling the NMD (Following 12 months)	NA	NA	NA
Cost saving due to controlling the MD (Payable only for one month)	NA	NA	NA
RISK OF FLOODING:			
The minimised risk of flooding turned into a cost saving	NA	NA	NA
TOTAL IMPACT OF DSM ON THE MINE	**R 104,602**	**R 206,996**	**R 1,562,409**

Note that the contractual DSM project duration with President Steyn mine is only 3 years (30 months). The break-even point when only considering the electricity cost savings is only reached after 24 months (see point A in Figure 4-4 on the following page) into the DSM project. When considering the overall impact of DSM on President Steyn 3# and 9#, the break-even point of the project advanced to approximately 15 months into the project.

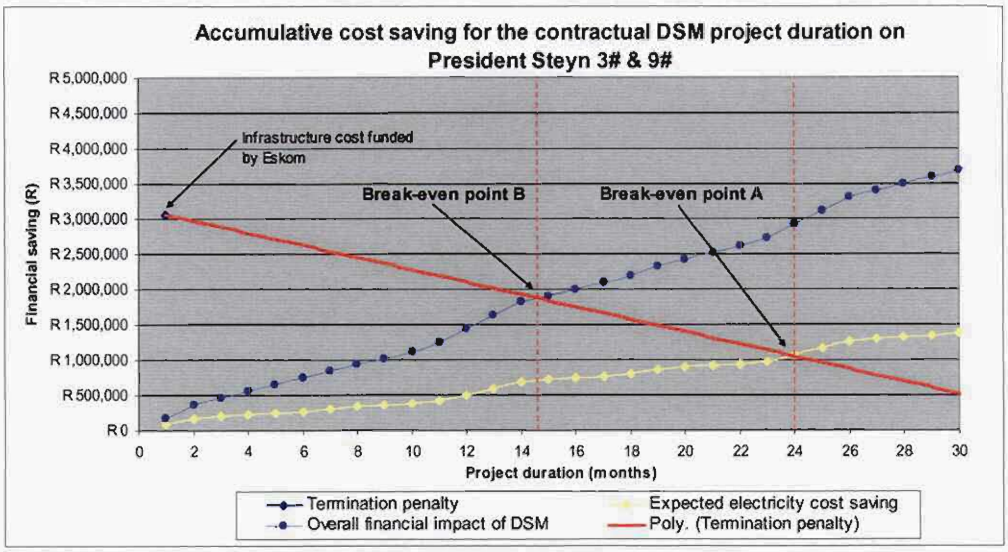


Figure 4-4: Accumulative cost saving to President Steyn 3# & 9# for the duration of the project

IV) Kloof 7# mine

Kloof 7# forms part of the Kloof Operations, which takes place in the Carletonville region and is owned by Gold Fields Limited. This is a high production mine and consists of three pumping stations. Kloof 7# pumps in the order of 30 ML water from 3000 m below collar per day. As seen in Table 4-5, the monthly electricity bill for the pumping operation is approximately R 1.1 million and R 2.2 million for the respective low- and high-demand seasons. The net monthly electricity cost saving proposed to the mine is calculated to be in the order of R 60 400 and R 366 800 for the summer and winter respectively.

By cutting down the number of pump attendants needed to operate the pumping system, the mine will save approximately R 50 000 per month. The maintenance cost due to more frequent switching of the pumps is in the order of R 14 000 per month. The total contribution of DSM due to preventative maintenance is calculated to be R 41 500 for a low-demand season month and R 253 000 for a high-demand season month. Thus, the overall net cost saving to the mine due to DSM is calculated to be R 85 584 and R 603 110 for the respective summer and winter months.

Table 4-9: Overall monthly impact of DSM on Kloof 7# mine

DESCRIPTION	MONTHLY CONTRIBUTION DUE TO DSM		ANNUAL IMPACT DUE TO DSM
	Low demand season	High demand season	
INFRASTRUCTURE COST FUNDED BY ESKOM:			R 4,900,000
PROPOSED ELECTRICITY COST SAVING:	R 60,379	R 366,777	R 1,643,738
LABOUR NUMBERS:	R 50,400	R 50,400	R 604,800
OPERATING LIFE OF THE PUMPS:			
Higher maintenance cost due to an increase in stop/start per pump	-R 61,600	-R 61,600	-R 739,200
ENHANCING PREVENTIVE MAINTENANCE:			
Saving due to larger storage capacity	R 10,063	R 61,129	R 273,956
Savings due to an increased system efficiency	R 25,504	R 154,926	R 694,315
Additional saving due to maintenance contract with ESCO	R 6,038	R 36,678	R 164,374
CONTROL ROOM DUTY:			
Lost savings due to no control room	NA	NA	NA
CONTROLLING MAXIMUM DEMAND:			
Cost due to an NMD controller	NA	NA	NA
Cost due to an MD controller	NA	NA	NA
RISK OF FLOODING:			
The minimised risk of flooding turned into a cost saving	NA	NA	NA
TOTAL IMPACT OF DSM ON THE MINE	**R 90,784**	**R 608,310**	**R 2,641,982**

Figure 4-5 illustrates that the break-even point when considering only the electricity cost savings due to DSM is 23 months into the DSM project, compared to the 16 months when the overall impact of DSM on the mine is taken into calculation.

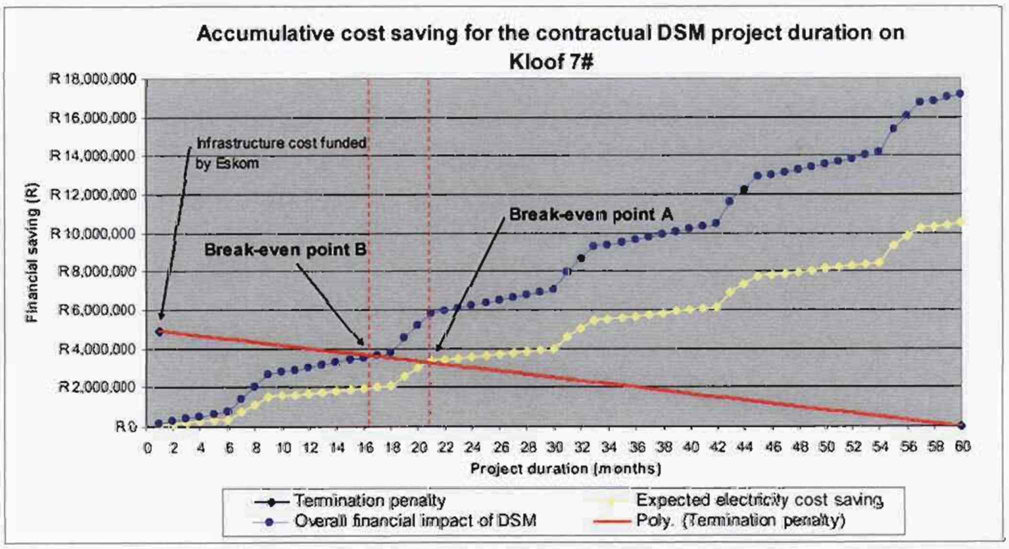


Figure 4-5: Accumulative cost saving to Kloof 7# for the duration of the project

4.3.3 Summarising the predicted results

The results obtained from the case studies performed in the above section are summarised in the Table 4-10. This table illustrates the annual cost impact of DSM on each of the four future load management projects as calculated by the generic model.

Table 4-10: Annual cost impact of DSM on a mine

MINE	ANNUAL COST IMPACT OF DSM			% INCREASE IN OVERALL DSM SAVING
	Only electricity cost savings	Additonal cost saving	Overall cost saving due to DSM	
Ezulwini	R 1,840,765	R 1,154,372	R 2,995,137	**63%**
Cooke 1#	R 251,187	R 39,966	R 291,152	**16%**
President Steyn 3# & 9#	R 540,216	R 1,022,193	R 1,562,409	**189%**
Kloof 7#	R 1,643,738	R 935,845	R 2,579,582	**57%**
Average	**R 1,068,976**	**R 788,094**	**R 1,857,070**	81.2%

From Table 4-10 it can be seen that the net average cost saving to the mine, when considering the overall impact of DSM, is approximately 81% more that the electricity cost saving only proposed to a mine. It is seen that the increase in overall cost saving to each of the mines varies significantly. This is mainly due to the varying circumstances of the pumping operation.

Furthermore, Table 4-11 illustrates the change in the break-even point for each of the DSM projects to the various mines. Due to the financial risk involved when taking on a DSM project, managements of mines are hesitant and therefore the break-even point to a mine is of great importance.

Table 4-11: Financial risk of a DSM project to a mine

MINE	PROJECT DURATION (Months)	EARLY TERMINATION BREAK-EVEN POINT		TIME DIFFERENCE OF BREAK-EVEN POINT	% INCREASE IN BREAK-EVEN TIME OF DSM PROJECT
		Only electricity cost savings	Overall impact of DSM		
Ezulwini	60	19	13	6	**10%**
Cooke 1#	60	22	19	3	**5%**
President Steyn 3# & 9#	36	24	15	9	**25%**
Kloof 7#	60	23	16	7	**12%**

It is clearly seen from Table 4-11 that the break-even point of a DSM project advances when considering the overall impact of DSM on a mine compared to the break-even point when only considering the electricity cost savings. When only taking the electricity cost saving due to load management into calculation, the early termination break-even point with regard to the DSM project is approximately 43% of the total project duration into the project. When taking all the effects discussed throughout the study into calculation the early termination break-even point advanced by approximately 12.6%. Thus, the risk to the mine when taking on a DSM project decreases by 12.6% when considering the overall cost impact of DSM compared to the electricity cost savings only.

4.4 CONCLUSION

By applying the model on Masimong 4# mine, it was found that the annual electricity cost saving initially proposed to the mine is approximately R 328 024. This gives an accumulated cost saving of R 1.64 million over the five year project duration. When considering the overall impact of DSM on a mine, this saving increases by approximately R 613 079. The total net cost saving due to DSM accumulates to R 5.2 million after five years. (Note that only an annual increase in electricity price was taken into account and no inflation or annual increase in labour cost).

The results of the Masimong 4# model shows that the cost benefit of the additional effects of DSM is approximately 200% of the electricity cost saving only. The reason for the high additional cost saving is mainly because the mine has never optimised the expenses involved with the pumping operation.

By applying the generic model on future DSM projects, predictions can be made regarding the overall benefit of DSM. These predicted results were compared to the results obtained when applying the generic model on an existing DSM project. This is done in order to validate the research study. As discussed in Section 4.3.3, the cost benefit when considering the additional effects of DSM is on average 81% of the electricity cost saving only.

By comparing the additional cost saving of Masimong 4# (200%) to the 81% as predicted on the future DSM projects, it became evident that the overall impact of DSM varies from one mine to the other. The main factor influencing the additional saving is the status of the pumping operation before and after DSM implementation.

The 81% additional cost saving predicted for the future DSM projects corresponds to the 83% additional cost saving determined in Chapter 3. Therefore, the generic model is of value and should be applied specifically to a mine in order to accurately determine the overall impact of DSM on a mine.

Furthermore, this model could be used to determine the accumulated cost saving over the project duration in order to see where the break-even point with regard to the early termination penalty payable to Eskom is. This break-even point also determines the risk involved to the mine when taking on a DSM load-shifting project.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

This chapter outlines the conclusion of the research study as well as the recommendations for future study in DSM clear-water pumping systems.

5.1 CLOSURE

When attempting DSM load shifting on the clear-water pumping systems of deep level mines, it is often required that the current system operation be changed. Due to the uncertainty of the impact and knock-on effects of DSM on a mine, the client could decide not to take on a DSM project.

With the purpose of this research study being to investigate and furthermore identify and quantify the possible effects of DSM on clear-water pumping systems, the overall impact of DSM could be determined. The increased benefit, when considering the overall impact of DSM, could be used as an incentive to mines to take on DSM projects by making an informed decision and in turn benefit the DSM programme.

During the identification phase of the research study it was found that the overall impact of DSM could be divided into three sections e.g. cost benefits, other benefits and possible hidden costs to the mine.

Under cost benefits, electricity cost savings due to DSM are identified as the main benefits of DSM on a mine. During the quantification phase it was found that the actual electricity cost saving achieved is approximately 98% of the intended electricity cost saving proposed to the mine. This cost saving varies from approximately 70% to 170% of the intended cost saving depending on the quality of the pumping system. The quality of the pumping system determines the number of system breakdowns affecting the DSM savings. Due to the fact that most mines have old pumping equipment, the net achieved electricity cost savings are generally less that the intended saving. This fact led to the need to determine the overall long term impact of DSM on a mine.

By considering all the other effects investigated during the study, it was found that the additional benefits amount to an average higher net cost saving of approximately 81% of the electricity cost saving only.

The final conclusion could be made that a mine definitely benefits from the DSM programme. Although the varying circumstances in the pumping operations are different from each mine to the other, the overall benefit when considering the additional benefit of DSM almost doubles.

It could be said that the net annual cost saving to a mine (due to DSM) is approximately 9% (electricity cost saving only) of the annual operational electricity costs and 7.2% due to the additional cost. Therefore, the overall net cost saving due to DSM increased form 9% to 16.2% of electricity cost to operate the pumping system before DSM implementation.

5.2 RECOMMENDATIONS FOR FURTHER WORK

With the purpose of this study to research the long term impact of a DSM project on a mine, by identifying and quantifying the various effects of DSM, the need for further study exists.

Work could be done by researching the various effects of DSM in much more detail. By performing detailed tests on these effects, the certainty of the findings made throughout this study could be determined. With a higher certainty and accuracy of the results obtained from the investigation, the existing model could be improved to determine the overall impact of DSM with even more certainty.

This model could then be expanded to determine the overall impact of DSM projects on other mining systems, e.g. rock winders, compressed air, ventilation fans, fridge plants and gold plants.

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APPENDIX

APPENDIX A: PERFORMANCE-TRACKING REPORT FOR MPONENG MINE

THE EMS PERFORMANCE-TRACKING REPORT FOR MPONENG MINE: JULY 2006

ANGLOGOLD ASHANTI

1 August 2006

1 INTRODUCTION

The purpose of this report is to inform the reader of the savings the REMS 2 system realised at Mponeng mine. A period of one year is described (December 2005 to November 2006).

2 PERFORMANCE MEASUREMENT

REMS 2 has been operational for seven months. See Table 1 for the savings achieved.

Month	Maximum monthly savings possible	Monthly savings achieved	Unrealised potential / Over performance	Accumulated maximum savings possible	Accumulated actual savings
December 2005	R 42,258	R 44,245	R 1,987	R 41,545	R 44,245
January 2006	R 41,545	R 51,691	R 10,146	R 83,090	R 95,936
February 2006	R 38,028	R 45,652	R 7,624	R 121,118	R 141,588
March 2006	R 43,304	R 44,775	R 1,471	R 164,422	R 186,363
April 2006	R 38,741	R 37,513	R 1,228	R 203,163	R 223,876
May 2006	R 43,304	R 55,973	R 12,669	R 246,467	R 279,849
June 2006	R 240,097	R 479,005	R 238,908	R 486,564	R 758,854
July 2006	R 231,162	R 418,937	R 187,775	R 717,726	R 1,177,791
August 2006	R 250,706				
September 2006	R 40,500				
October 2006	R 41,545				
November 2006	R 41,545				

Table 1: *Actual savings for July 2006*

For July 2006 REMS 2 has saved Mponeng mine R418 937. From December 2005 to July 2006 the REMS2 system has saved Mponeng mine R 1 177 791.

3 SAVINGS FOR THE MONTH

Detailed daily savings for July 2006 is outlined in Figure 1.

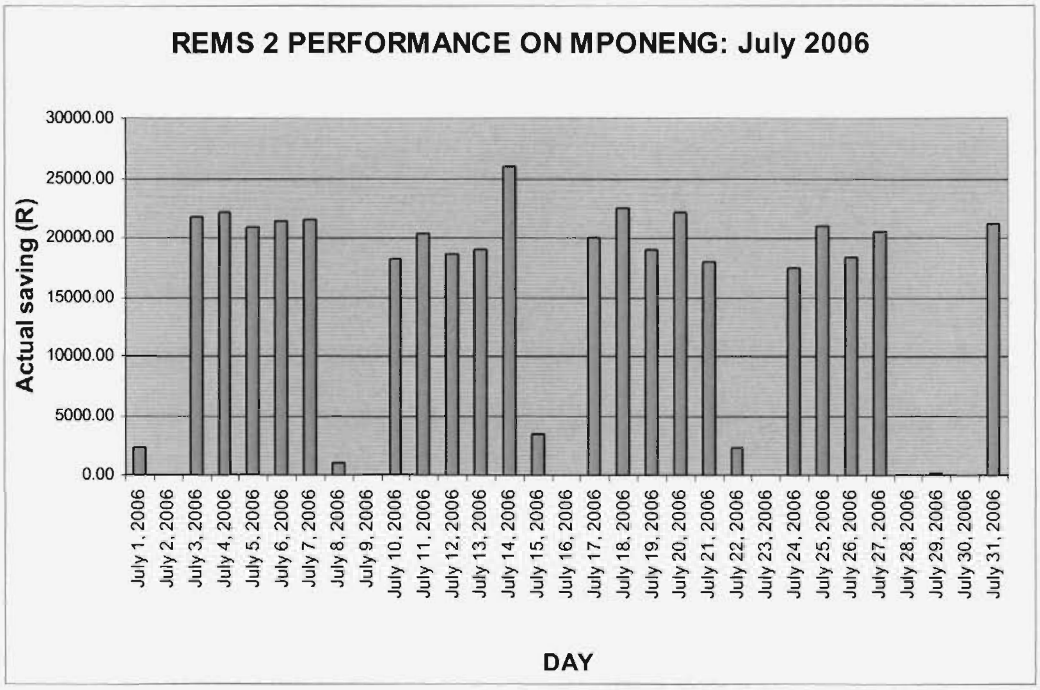


Figure 1: *EMS Performance for July 2006*

4 REASONS FOR LIMITED LOAD SHIFT

Date	Reason
NA	All fine

5 TOTAL PUMPING-ENERGY USED AND PEAK TIME LOAD SHIFT

The average load profile for July 2006 is compared to the baseline in Figure 2. Load shift (in MW) for the morning and evening is outlined in Figure 3.

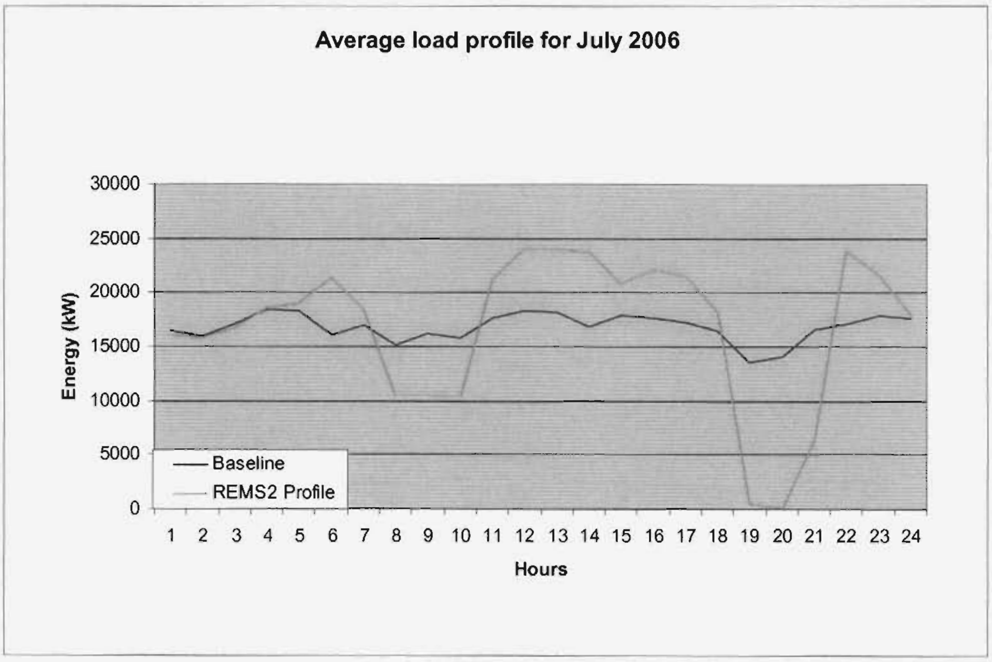


Figure 2: Average load profile for July 2006

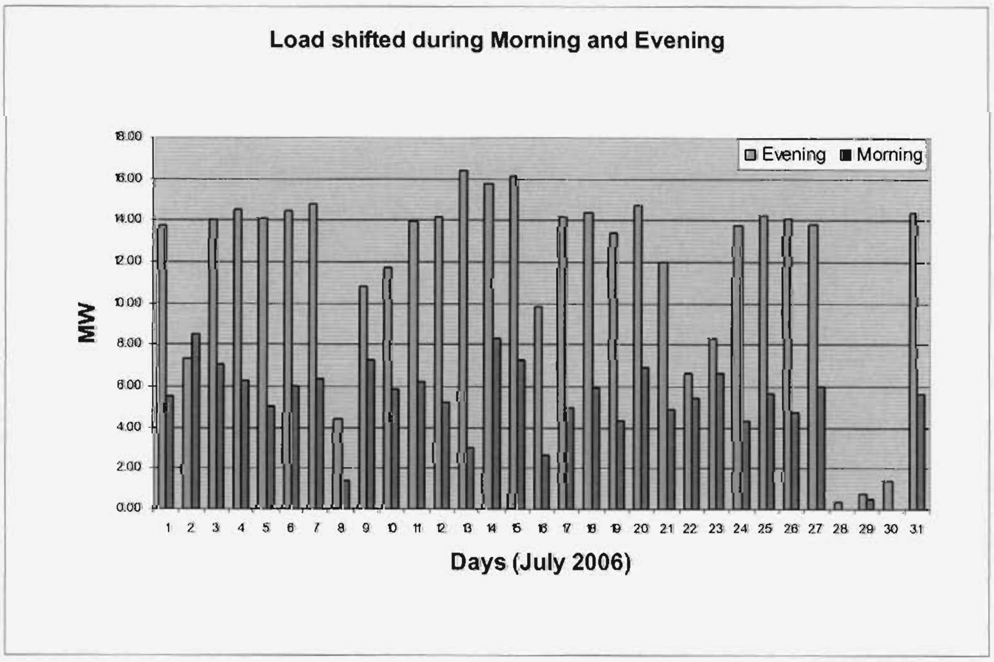


Figure 3: Load shifted during morning and evening peaks for July 2006

6 CONCLUSION

For July 2006 REMS 2 has saved Mponeng mine R418 937. From December 2005 to July 2006 the REMS2 system has saved Mponeng mine R 1 177 791.

APPENDIX B: CONTROL AND INSTRUMENTATION EQUIPMENT INSTALLED ON MASIMONG 4# MINE

LIST OF QUANTITIES

QTY	**Main PLC 1280 level consisting of the following:**
1	CPU 512K
1	AC Power supply 115/230V
1	Backplane 16 slot
4	AC input 4 x 8 Channel 115 V ac
3	Relay output 16 x 1 NO
3	Analog input module 16 channel
1	Ethernet module
1	Magelis 10.4" colour operator interface panel
	Panel for PLC 1280 level:
1	Panel consisting of a PLC section (1800 x 1200 x 300) and an electrical section (1800 x 800 x 300)
1	Wiring of PLC and operator panel including terminals, wire, rail, trunking, wire numbers, 24V power supply
1	Wiring of electrical panel including 12 x 2.2 kW contactors, thermal overload, local stop start push buttons
	Field instrumentation 1280 level:
6	Pressure switches
6	Flow switches
6	Vibration sensors
7	Junction boxes including terminals, trunking, wire numbers
1	Installation of field instrumentation underground, installing cable and termination, junction boxes
6	Electric actuators
	Main PLC 1200 level consisting of the following:
1	CPU 512K
1	AC Power supply 115/230V
1	Backplane 16 slot
4	AC input 4 x 8 Channel 115 V ac
3	Relay output 16 x 1 NO
3	Analog input module 16 channel
1	Ethernet module
1	Magelis 10.4" colour operator interface panel
	Panel for PLC 1200 level:
1	Panel consisting of a PLC section (1800 x 1200 x 300) and an electrical section (1800 x 800 x 300)
1	Wiring of PLC and operator panel including terminals, wire, rail, trunking, wire numbers, 24V power supply
1	Wiring of electrical panel including 12 x 2.2 kW contactors, thermal overload, local stop start push buttons
	Field instrumentation 1200 level:
6	Pressure switches
6	Flow switches
6	Vibration sensors
7	Junction boxes including terminals, trunking, wire numbers
1	Installation of field instrumentation underground, installing cable and termination, junction boxes
6	Electric actuators

QTY	**Network: Fibre optics**
2500m	Fibre mine shaft cable
400m	Heavy duty duct cable
	Other components
1	19" wall mount rack
	Network: SCADA
1	Mecer PC with 17" monitor
1	Adroit 5.0 Standalone System - 5000 scanned points unconfigured with all configuration tools and drivers
	Network: Software
1	Development of HMI data panel
1	Development of PLC software
1	Development of SCADA software
	Variable Speed Drives
4	6.6 kV, 250 A Soft starter for sequenced starting of three 1.5 MW pump motors
2	Soft starter panel

APPENDIX C: DAILY PERFORMANCE REPORTS (MAINTENANCE CONTRACT)

REMS Daily report for Kopanang Pumps

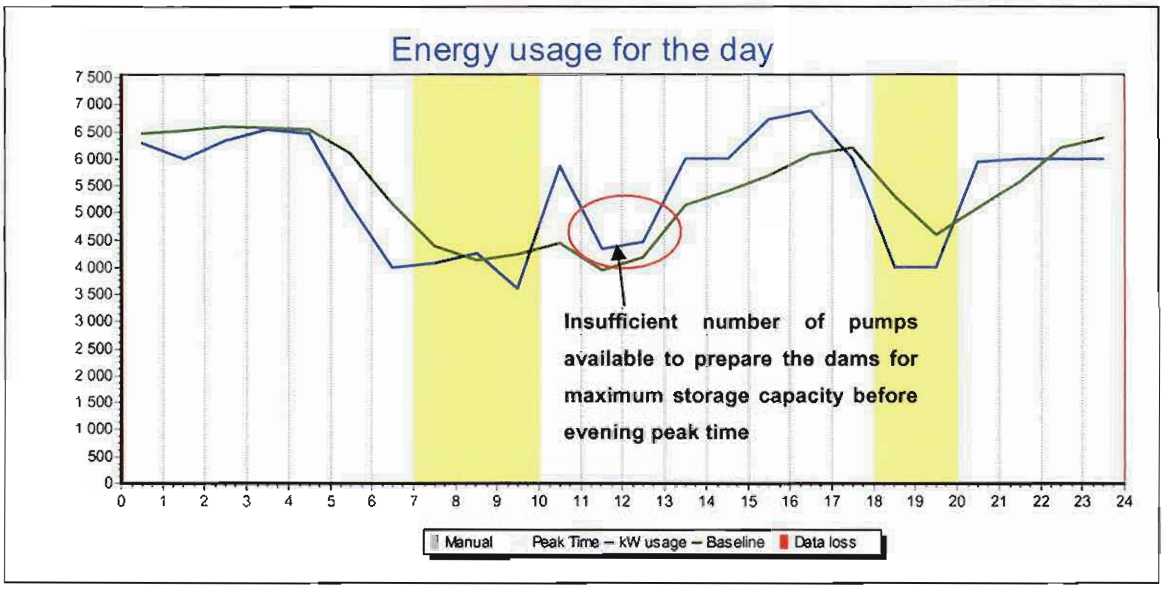
2006-09-07

8 September 2006

7 LOAD SHIFT RESULTS FOR KOPANANG PUMPS FOR 7 SEPTEMBER 2006

Parameter	Value
Morning peak	0.27 MW
Evening peak	0.95 MW
Average evening peak for month	4.47 MW
Contractual	3.00 MW
Cost saving	R 83
Energy usage	130.88 MWh
System on manual	0 % of the day

***Table 1:** Summary of day*



Insufficient number of pumps available to prepare the dams for maximum storage capacity before evening peak time

***Figure 1:** kW usage profile*

The above graph shows the energy usage profile for the day with manual overrides and data loss overlays.

8 SUMMARY FOR 38 CONTROLLER

The figure below shows the detail description for 38 Controller for the day. The status is the actual amount of pumps running and the schedule is the amount of pumps requested by REMS.

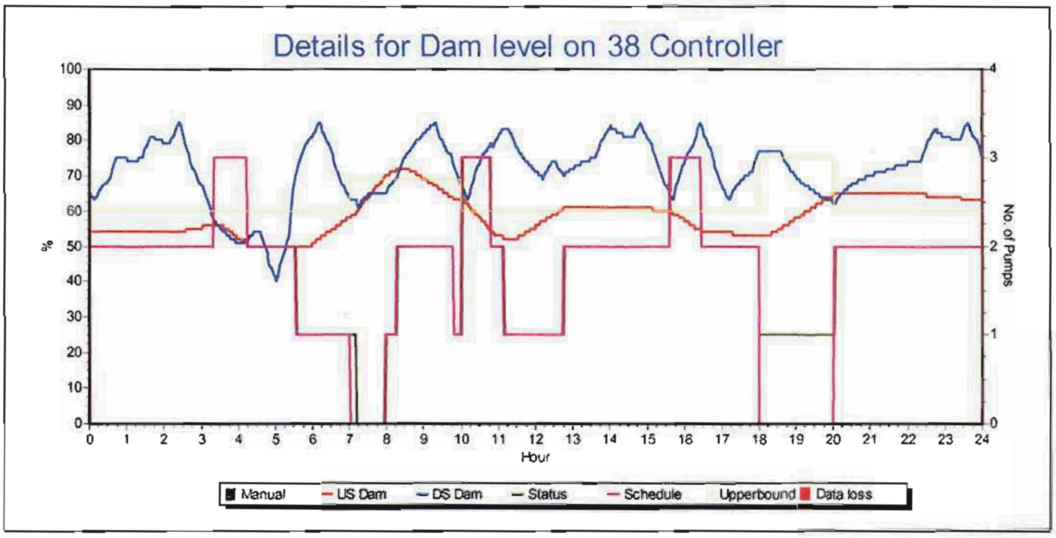


Figure 2: *Dam levels, status and schedule for 38 Controller*

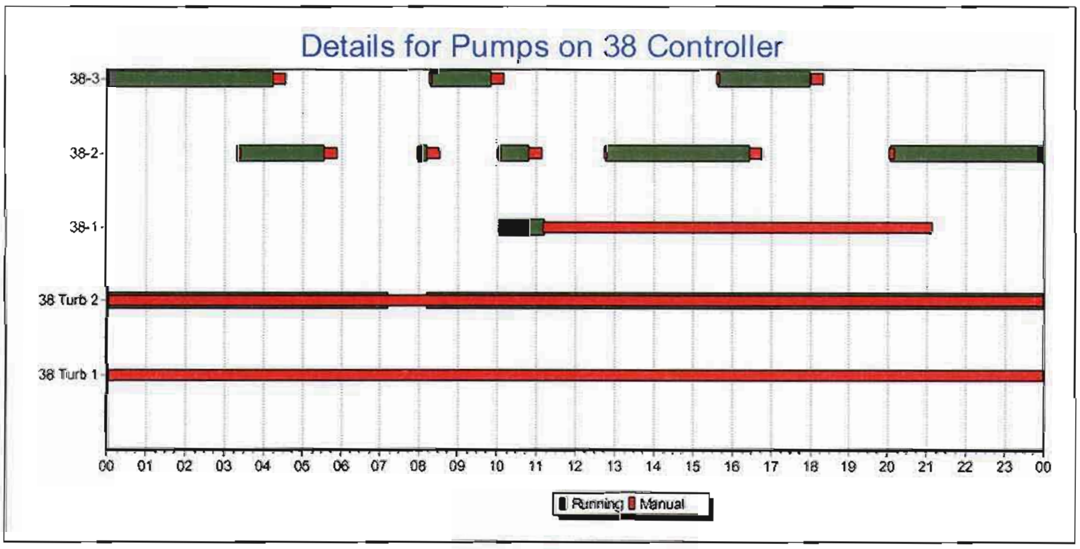


Figure 3: *Runtimes for 38 Controller*

The above figure shows the actual runtimes for the pumps in this level.

9 SUMMARY FOR 75 CONTROLLER

The figure below shows the detail description for 75 Controller for the day. The status is the actual amount of pumps running and the schedule is the amount of pumps requested by REMS.

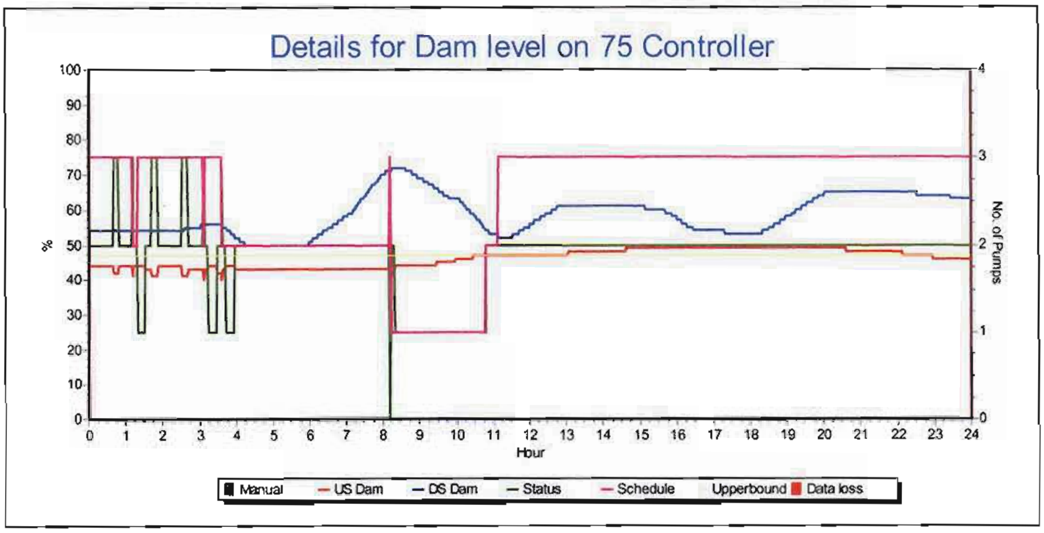


***Figure 4:** Dam levels, status and schedule for 75 Controller*

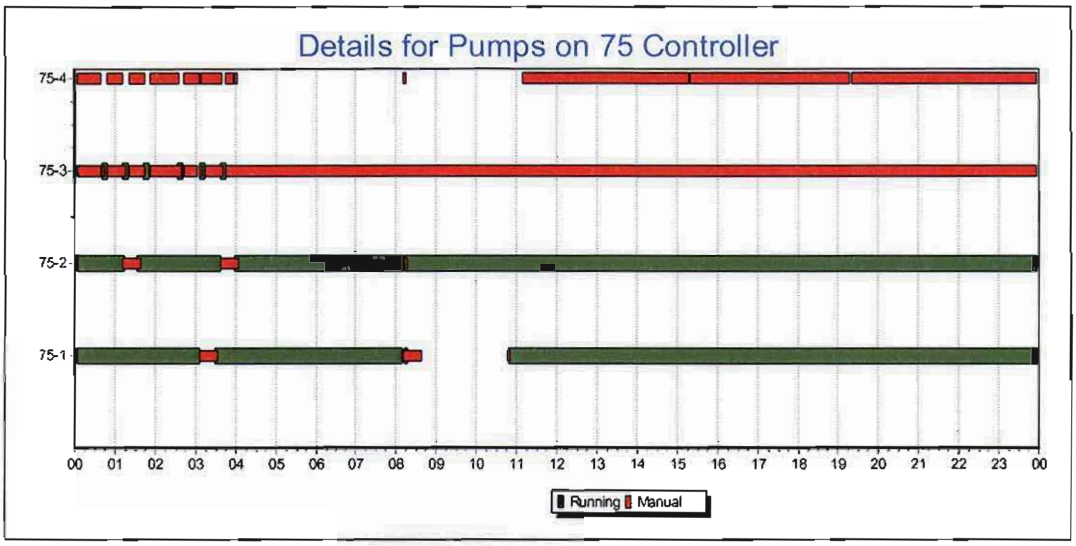


***Figure 5:** Runtimes for 75 Controller*

The above figure shows the actual runtimes for the pumps in this level.

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