A NEW APPROACH TO ENSURE SUCCESSFUL IMPLEMENTATION AND SUSTAINABLE DSM IN RSA MINES

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Thesis submitted in partial fulfilment of the requirements for the degree of Philosophiae Doctor in Mechanical Engineering at the North-West University, Potchefstroom Campus.

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November 2005
Potchefstroom
In this study a new tool was developed that made new approaches possible for the successful implementation of Demand Side Management (DSM) projects. The new approaches are incorporated into a generic tool that makes it possible for Energy Services Companies (ESCos) to undertake DSM projects that were previously not possible with currently available technology. Through these new approaches, maximum results can be obtained on a sustainable basis on the clear water pumping systems of South African mines.

The author was responsible and participated in four different investigations and implementations of DSM projects. These were grouped into three case studies. Each of these studies required different new innovations.

The innovations described in this thesis include the adaptation of the Real-time Energy Management System (REMS) that was developed and marketed by HVAC International, to mines with intricate pumping systems, mines without any instrumentation and control infrastructure, as well as to mines that make use of a Three Pipe Water Pumping System.

The tool developed and applied in these projects was part of Eskom's DSM programme. In this programme, large electricity clients who wish to shift electrical load out of peak periods, are assisted by having the total costs of such projects funded by Eskom. The fact that the clients will most likely enjoy substantial electricity cost savings, (by not having to pay the high peak prices), is a major attraction of this programme. Nevertheless, the programme is not moving as fast as it should.

The National Energy Regulator (NER) has set an annual target of 153 MW load to be shifted since 2003. By the end of 2005, the accumulated target load to be shifted will be 459 MW. However, Eskom has indicated that an accumulated total of only 181 MW load will have been shifted by the end of 2005. This means that the Eskom DSM programme has actually only achieved 39% of its target.

The innovations described in this thesis will help ESCOs to address this shortfall more effectively.
'n Nuwe benadering om suksesvolle implementering en volhoubare DSM in RSA te verseker.

Danie le Roux

Prof. M. Kleingeld

DSM, ESCo, las verskuif, myn waterpompstelsel, Eskom, REMS

In hierdie studie is 'n nuwe hulpmiddel ontwikkel om nuwe benaderings moontlik te maak vir die suksesvolle implementering van aanvraagkant elektrisiteitsbestuursprojekte (DSM projekte). Die nuwe benaderings is omvat in 'n generies hulpmiddel en sal Energie Diensverskaffer Maatskappye (ESCos) help om DSM projekte te onderneem, waar dit met die huidige tegnologie vir hulle voorheen nie moontlik was nie. Deur van hierdie nuwe benaderings gebruik te maak kan Suid-Afrikaanse myn waterpompstelsels maksimum resultate bereik en handhaaf.

Die outeur was verantwoordelik en het deelgeneem aan vier verskillende ondersoeke en implementasies van DSM projekte, wat in drie verskillende gevallestudies verdeel is. Elkeen van hierdie ondersoeke het nuwe en unieke innovasies geverg.

Die innovasies wat in hierdie tesis beskryf word, sluit die aanpassing in van die Intydse Energie Bestuur Stelsel (REMS), wat deur HVAC Internasionaal ontwikkel en bemark is, in myne met ingewikkelde water pompstelsels, myne sonder enige instrumentasie en beheer infrastruktuur en myne waar 'n Drie-pyp Water Pompstelsel tans gebruik word.

Die hulpmiddel wat hier ontwikkel en toegepas is, het deel uitgemaak van Eskom se DSM program. Hierdie program ondersteun groot elektrisiteitskliënte, wat elektriese las buite die piekperiode wil verskuif, deurdat Eskom die volle koste van sulke projekte dra. Die program is besonders aantreklik aangesien kliënte heel moontlik 'n aansienlike elektrisiteitsbesparing sal ondervind (deurdat hulle nie die hoë piektyd tarief hoeft te betaal nie). Ten spyte hiervan het die program tot dusver nog nie groot byval gevind nie.

Die Nasionale Energie Beheerliggaam (NER) het sedert 2003 'n jaarlike doelwit gestel om 153 MW las te verskuif. Die totale lasverskuwing aan die einde van 2005 is dus 459 MW. Eskom het egter aangedui dat die totale lasverskuwing slegs 181 MW sal wees, wat beteken dat die Eskom DSM program slegs 39% van die oorspronklike doelwit sal bereik.

Die innovasies wat in hierdie tesis ontwikkel is, sal ESCos help om hierdie tekortkominge meer effektief aan te spreek.
The author would like to thank the following people:

- Prof EH Mathews,
- Prof M Kleingeld,
- Dr C Swart,
- Mr DLW Krueger,
- Mr D van Rhyn,
- Mr W Rautenbach,
- The rest of my colleagues at the Centre of Research and Commercialisation for their input,
- Mine management and personnel of the four mines used as case studies.

- A very special thanks to my wife and family, for their continuous love and support.

- Finally, all thanks to my Creator, without whom none of this would have been possible.
This thesis describes the evolvement of a new approach to control clear water pumping systems in the mine industry. The progress of the new approach is described with the aid of actual case studies on four different gold mines in South Africa.

The case studies are grouped and described in three separate chapters. These chapters describe the clear water pumping systems of the case study mines, the shortcomings to the new approach and the new enhancements that were incorporated to the approach.

After the evolvement of the new approach is described it is evaluated to ensure that all clear water pumping systems in the mine sector in South Africa can be controlled consistently at an optimum point and contribute to the South African peak demand problem.

The thesis concludes with a final generic implementation procedure of the new approach as well as further work and recommendations.
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>3CPFS</td>
<td>Three Chamber Pipe Feeder System</td>
</tr>
<tr>
<td>BTU</td>
<td>British Thermal Unit</td>
</tr>
<tr>
<td>CBL</td>
<td>Customer Base Line</td>
</tr>
<tr>
<td>CFL</td>
<td>Compact Fluorescent Lamp</td>
</tr>
<tr>
<td>DME</td>
<td>Department of Mineral and Energy</td>
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<tr>
<td>DSM</td>
<td>Demand Side Management</td>
</tr>
<tr>
<td>EE</td>
<td>Energy Efficiency</td>
</tr>
<tr>
<td>EE-DSM</td>
<td>Energy Efficiency Demand Side Management</td>
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<tr>
<td>EMS</td>
<td>Energy Management System</td>
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<tr>
<td>ESCo</td>
<td>Energy Services Company</td>
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<tr>
<td>EST</td>
<td>Energy Saving Trust</td>
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<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GWh</td>
<td>Giga Watt Hours</td>
</tr>
<tr>
<td>HMI</td>
<td>Human Machine Interface</td>
</tr>
<tr>
<td>HT</td>
<td>High Tension</td>
</tr>
<tr>
<td>IEP</td>
<td>Integrated Energy Planning</td>
</tr>
<tr>
<td>IRP</td>
<td>Integrated Resource Planning</td>
</tr>
<tr>
<td>kW</td>
<td>Kilowatt</td>
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<tr>
<td>kWh</td>
<td>Kilowatt-hour</td>
</tr>
<tr>
<td>l/s</td>
<td>Litres per second</td>
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<tr>
<td>LT</td>
<td>Low Tension</td>
</tr>
<tr>
<td>M&amp;V</td>
<td>Measurement and Verification</td>
</tr>
<tr>
<td>Mi</td>
<td>Mega Litres</td>
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<tr>
<td>MVA</td>
<td>Mega Volt Ampere</td>
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<tr>
<td>MW</td>
<td>Megawatt</td>
</tr>
<tr>
<td>NER</td>
<td>National Energy Regulator</td>
</tr>
<tr>
<td>PC</td>
<td>Personal Computer</td>
</tr>
<tr>
<td>PLC</td>
<td>Programmable Logic Controller</td>
</tr>
<tr>
<td>RDP</td>
<td>Reconstruction and Development Programme</td>
</tr>
<tr>
<td>REMS</td>
<td>Real-time Energy Management System</td>
</tr>
<tr>
<td>RTP</td>
<td>Real-time Pricing</td>
</tr>
<tr>
<td>SCADA</td>
<td>Supervisory Control and Data Acquisition</td>
</tr>
<tr>
<td>SSM</td>
<td>Supply Side Management</td>
</tr>
<tr>
<td>TOU</td>
<td>Time-of-Use</td>
</tr>
<tr>
<td>TWh</td>
<td>Terra Watt Hour</td>
</tr>
<tr>
<td>VCB</td>
<td>Vacuum Circuit Breaker</td>
</tr>
<tr>
<td>VCP</td>
<td>Ventilation, Cooling and Pumping</td>
</tr>
<tr>
<td>WEP</td>
<td>Wholesale Electricity Pricing</td>
</tr>
</tbody>
</table>
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South Africa is fast running out of electricity supply. New ways have to be found to supply to the
 growing electricity demand as well as to replace base load capacity. New generation projects are in
 progress, but the results will arrive too late. DSM is one of the solutions that will be able to extend
 the point when demand will exceed supply. Pumping systems on mines are large electricity
 consumers and are ideal to achieve load shift out of peak demand periods. But there exists no
 technology in the mine industry today to achieve maximum, sustainable DSM results.
1.1 BACKGROUND TO THE ENERGY SITUATION

1.1.1 A world wide problem

Energy will be one of the defining issues of this century. One thing is clear: the era of easy energy is over. What we all do next will determine how well we meet the energy needs of the entire world in this century and beyond. Demand is soaring like never before. As populations grow and economies take off, millions in the developing world are enjoying the benefits of a lifestyle that requires increasing amounts of energy [1].

Worldwide, total energy demand trends from 1970 to 2002 have increased from 207 quadrillion British thermal units to (Btu) to 412 quadrillion Btu [2]. It is projected that world energy consumption will increase by 57% from 2002 to 2025, an increase of almost 2.5% per year over the 23 year forecast. For instance, it took 125 years to use the first trillion barrels of oil. It is said that the next trillion will be used in 30 years [3].

Emerging economies account for much of the projected growth in marketed energy consumption over the next two decades, with energy use in the group more than doubling by 2025. Strong projected economic growth drives the demand for energy use in the region. Economic activity, as measured by Gross Domestic Product (GDP) in purchasing power parity terms, is expected to expand by 5.1% per year in the emerging economies, as compared with 2.5% per year in the mature market economies and 4.4% per year in the transitional economies [2].

Increased energy use is a natural consequence of economic growth and improving living standards in emerging countries. Where people once burned wood for heating and cooking, oil furnaces, stoves, and refrigerators are now more available and affordable. In many Asian cities, bicycles are being replaced by automobiles, increasing mobility and convenience (as well as congestion and pollution), and providing more options for employment and leisure [4]. At the same time, soaring business activity and industrial output are also boosting demand.

Rising energy demand in developed countries will add to the pressure on supply. The USA, for example, is home to 4% of the world’s population but is consuming 25% of the world’s energy [5]. As wealthier countries in general continue to prosper, their energy needs will continue to grow accordingly [6]. Houses are getting bigger, and are increasingly "wired" with computer and audio
and video equipment. And people are driving their cars, which in many cases are no more fuel efficient than cars of 20 years ago, more kilometres each year [7] [8].

It is in the interests of all stakeholders — energy producers, industrial users, governments and consumers — to make the energy sources we have, go as far as they can go. The challenge is to provide the clean, affordable energy necessary for rapid economic growth and rising living standards in emerging economies, while also fulfilling demand in the world’s more developed economies [9]. This will require a combination of increasing conservation, expanding and diversifying our energy supply, and improving Energy Efficiency (EE) [10].

1.1.2 Electricity supply and demand in SA: Another energy problem

In South Africa a large portion of the primary energy is transformed into the generation of electricity. The most important are coal (87%), hydro pumped storage (6%) and nuclear (5%). This can be seen in Table 1. (These figures exclude imported electricity, for example from the Cahora Bassa hydro scheme).

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Capacity / MW</th>
</tr>
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<tbody>
<tr>
<td>Coal</td>
<td>32,202</td>
</tr>
<tr>
<td>Nuclear</td>
<td>1,840</td>
</tr>
<tr>
<td>Hydro Pumped Storage</td>
<td>1,580</td>
</tr>
<tr>
<td>Hydro</td>
<td>667</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>662</td>
</tr>
<tr>
<td>Bagasse</td>
<td>105</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>37,056</strong></td>
</tr>
</tbody>
</table>

Table 1: South Africa electricity generation capacity [11].

Sufficient capacity in this sector, including a provision for planned and unplanned outages, is critical for the balance between supply and demand. For instance, the pumped storage unit is a net energy loss system, its purpose being to store energy generated during off-peak periods for conversion back to electricity during peak periods. Therefore, a pumped storage system could make the overall system more efficient by the judicious storage of energy during low cost periods for use during high cost periods. This is done to conform to the unique daily profile of the demand side.

Eskom produces 95.9% of South Africa’s electricity requirements [12], the remainder being provided through local authorities, industry and imports via the South African Power Pool. Eskom’s generation capacity, assuming a 50 year life per plant, is indicated in Figure 1.
The capacity is primarily coal-fired and the graph indicates that current plant is scheduled to be operational until at least the year 2020. The red demand line in the figure indicates that further electricity generation plants will be required approximately at the year 2007 [13][14].

It is pertinent to note that whilst current concerns relate to new capacity to accommodate growth in demand, after the year 2020 and for the following three decades, generating capacity to replace the existing 37 000 MW will need to be addressed. Current concerns may seem trivial when compared with the foreseen task after the year 2020.

Figure 2 shows the trends in generation plant capacity by Eskom and the peak demand for electricity during the period 1995-2005 [15]. Peak demand showed an upward trend from 2000 onwards after being depressed since 1997. The average growth in peak demand over the period 1990 to 2003 was 3,3% [16]. This means that electricity demand in South Africa is currently estimated to be growing by approximately 1 000 MW per annum [17].

However, when looking at Figure 2 it is interesting to note that the highest recorded peak demand for the period 2004 to 2005 was 34 195 MW (13 July 2004). This was substantially higher than the previously highest peak demand of 31 928 MW that was recorded in 2003. This meant that there was a substantial decrease in the generation reserve margin from 16,9% in 2003 to 8,5% in 2004 [18].

Figure 3 shows how the electricity demand by all customers in South Africa simultaneously changes depending on the time of day. During the winter months the average demand is higher.
than during the summer months. During winter both the morning and evening peak demands are more pronounced than during summer, since there is a significant increase in the evening peak demand due to the need for heating. At night, the demand decreases to on average about 69% of the peak demand (78% in summer and 70% in winter) [15].

From Figure 3 it is evident that there is a problem with electricity supply in South Africa. The spare capacity is rapidly being eroded by the steep increase in the peak demand over the last 2 – 3 years. One of the main reasons for this is the mass housing and electrification programmes of the Reconstruction and Development Programme (RDP). More than 1.3 million new electricity connections have been established between 1994 and 1996, bringing urban electrification to 79% at the end of 1996 [19]. Since then, 450 000 additional houses have been electrified per year [20].

Electricity demand in low-income urban areas, however, tends to be heavily skewed toward the peak periods of power demand in the mornings and evenings, although total electricity usage per household is often low. Moreover, the poor quality of RDP homes means that much of the energy used for space heating is wasted. The rapid increase in electrified homes soaks up much of the current surplus capacity in South Africa, especially during the peak times [21]. Therefore, Eskom
estimates that a high-growth scenario might require new generating capacity by the year 2007 [13] [14].

Given the time to commission new plant, the current electricity generation system could soon be viewed as vulnerable. As more frequent power shortages in South Africa threaten its continued economic growth, it becomes more important than ever to find ways of consuming energy more efficiently.

1.2 BACKGROUND TO DSM

1.2.1 Introduction

DSM refers to measures sponsored, funded, and/or implemented by utilities that modify end-use electrical energy consumption, either reducing overall consumption through EE or using load management to reduce demand at times when the cost of reducing demand is less than the cost of servicing it. Cost-effective efficiency and load management measures could significantly improve the reliability of national electric systems and close the gap between supply and demand, while lowering the economic and environmental costs of electric service [22].

1.2.2 History of DSM in the world

More than 30 countries around the world have successfully applied DSM to increase energy savings, reduce the need for new power plants, improve economy and reliability in power network operation, control tariff escalation, lower customer electric expenses, save energy resources, and improve environmental quality [23]. DSM has become an important strategy for achieving sustainable energy and electricity development. Specific applications differ in each country according to local conditions.

The United States – a master in DSM

DSM has made a tremendous contribution to the economic growth of the United States since the Arab oil embargo of 1973. Total USA primary energy use per capita in 2000 was almost identical to that of 1973. Yet over the same time period, economic output (GDP) per capita increased 74% [24]
By 2000, reduced "energy intensity" (compared with 1975) was providing 40% of all USA energy services.

This made DSM (EE) America's largest and fastest growing energy resource—greater than oil, gas, coal, or nuclear power. Since 1973, the United States has received more than four times as much new energy from savings as from all net expansions of domestic energy supply combined [25].

In 2000, USA consumers and businesses spent more than US $600 billion for total energy use. Had the United States not dramatically reduced its energy intensity since 1973, they would have spent at least US $430 per capita more in energy purchases in 2000 [24].

Over the last two decades in the United States, many states used Integrated Resource Planning (IRP) to compare the benefits and costs of DSM with the costs of additional generation. These IRP programmes led states to generate a network of utility DSM programmes that together avoided the need for about 100 power plants with 300 MW [26].

The average initial cost of efficiency was less than one-half the cost of building new power plants. Utilities report that their average cost of implementing electricity savings of all kinds has been about 2 cents (US $) per kWh. In comparison, each kWh generated by an existing power plant costs more than 5 cents. Delivered power from a nuclear plant can cost as much as 20 cents per kWh [25].

In the late 1980s, more than 1 300 DSM programmes were conducted in the United States, which together curtailed 0.4% - 1.4% of peak load, corresponding to a demand growth rate of 20% - 40%. Between 1985 and 1995, more than 500 utilities conducted DSM programmes, curtailing large portions of peak load. Up to the mid 1990s, USA utilities increased their investment in DSM each year, from US $900 million in 1990 to US $2 700 million in 1994, corresponding to 0.7% - 1.0% of average sales revenue.

A total of US $1.4 billion was spent on utility EE programmes in 1999, due primarily to the adoption of system benefit charges [27]. A number of other new approaches to DSM have emerged since restructuring. Texas, for example, is pioneering the idea of an "EE portfolio standard," analogous to a renewable portfolio standard, whereby utilities are required to derive a certain percentage of their energy from renewable sources, such as solar or wind. Texas requires regulated utilities to acquire EE equivalent to 10% of each year's growth in electricity demand.
Other countries with DSM programmes

**European Union.** The Council of the European Union is in the process of drafting a Directive on Energy Efficiency - Demand Side Management (EE-DSM). This directive would require each member state to achieve a certain minimum level of EE improvements through EE-DSM.

Each state would be free to determine which policy mechanisms to adopt to meet that target. The draft directive recommends a minimum target energy savings level of one percent per year below the consumption in each member state the previous year, expressed in Terra Watt hour per year per member state.

The target also includes a recommended minimum level of investment for EE-DSM programmes from each member state of 2% of the total net revenue in that member state from electricity and natural gas sales to final customers.

The EE-DSM programme investments must be additional to EE activities financed from the state budget at present. The member states should also support the development of a market for EE-DSM services [28].

**United Kingdom.** In 1992, following electric sector restructuring, the UK established an independent, non-profit Energy Saving Trust (EST) to design and oversee DSM programmes. Its primary mandate was to reduce carbon dioxide emissions through DSM and EE.

During the first four years of the DSM programme, the UK power sector collected US $165 million from a wires surcharge, or system benefit charge, and invested it in more than 500 EE projects. Estimated electricity savings totalled more than 6 800 Giga Watt hours (GWh), which is equivalent to the annual electricity consumption of 2 million UK households.

Under the UK Utilities Act of 2000, both gas and electricity suppliers are required to meet specific EE targets and encourage or assist domestic customers to implement EE measures. The overall energy savings target (known as the EE Commitment) is 62 TWh, with half of the savings targeted at customers receiving benefits or tax credits.

The government regulator is responsible for administering the commitment, apportion the overall target to each supplier and monitor suppliers' performance against their targets [29]. Table 2 lists most of the countries that successfully apply DSM programmes [23].
<table>
<thead>
<tr>
<th>Country</th>
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<td>Argentina</td>
<td>Hong Kong</td>
<td>Netherlands</td>
<td>Spain</td>
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<td>Australia</td>
<td>India</td>
<td>New Zealand</td>
<td>Sri Lanka</td>
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<td>France</td>
<td>Malaysia</td>
<td>South Africa</td>
<td>USA</td>
</tr>
<tr>
<td>Greece</td>
<td>Mexico</td>
<td>South Korea</td>
<td>Vietnam</td>
</tr>
</tbody>
</table>

Table 2: List of countries with DSM programmes.

1.2.3 DSM in South Africa

The need for DSM in South Africa

On the supply side, Eskom has announced an investment programme of at least R 200 billion over the next 25 years that will ensure that South Africa has enough electricity to power its fast growing economy [30]. This programme is divided into two phases. The first one deals with the immediate electricity needs for the next five years, which will require Eskom to add 1 000 MW of capacity every year from 2005 to 2009 to avoid shortages during peak times.

The second phase deals with the replacement of old power plants with new generating possibilities that will add to the base load of its network. This is the long term phase of its programme, where the big investment decisions are required. Most of Eskom’s current power plants will only be operational until 2020 and new generating possibilities will have to replace them [11].

Amongst Eskom’s long term projects to meet the base load capacity, are included the Braamhoek pumped storage scheme, the Steelpoort pumped storage scheme, a new gas turbine near Coega, adding three power units to the existing six at Mathimba power station, as well as a new greenfields coal fired power station. However, electricity is only expected to be delivered from these by 2012 [30].

Because of the length of the lead time required for Supply Side solutions, and the urgency of reducing peak demand, DSM can be seen as an immediate solution to the problem. DSM can reduce peak loads and projects can deliver results in a fairly short time.
The Application of DSM in South Africa

DSM aims to reduce electricity demand during peak periods, when Eskom’s supply capability is limited. The greater the co-operation between Eskom and customers in reducing demand during peak periods, the longer Eskom will be able to delay investment in new power stations and the accompanying price impact for energy users [31].

The key benefit of DSM is efficient use of electricity, without influencing the customer production and satisfaction levels, resulting in significant cost savings for the provider and thus the consumer as well. DSM is an important mechanism that can complement and extend government, private sector, and international assistance efforts to help electricity end users capture the full range of efficiency opportunities available today in South Africa and induce the development of next-generation EE procedures and technologies.

A number of barriers stand in the way of implementing effective DSM programmes in South Africa. These barriers are similar to those facing most other countries: a traditional tariff rate design that provides a built-in disincentive to utility DSM programmes; the lack of a sustainable mechanism to generate necessary funding for DSM programmes; and a lack of positive incentives that would motivate utilities to maximise energy savings.

Yet as South Africa restructures its electric power industry, it has a valuable opportunity to take advantage of the lessons learned (both positive and negative) in other countries in order to harness the benefits of demand-side resources in a manner that will suit South Africa’s particular circumstances and fulfil its own goals.

From the Minister of Minerals and Energy [32]

In the foreword to the March 2005 EE Strategy of the RSA, former Minister of Mineral and Energy, Phumzile Mlanbo-Ngcuka states:

"In South Africa we take energy for granted, with the consequence that our energy consumption is higher than it should be. Whilst our historically low electricity price has contributed towards a competitive position, it has also meant that there has been little incentive to save electricity.

So in many respects we start with a clean slate with little EE measures having taken place, apart from many years of work by universities and other research institutions that have pointed the way."
The White Paper on Energy Policy (1998) recognized that standards and appliance labelling should be the first measures to put in place in implementing EE. Indeed such perspective-type measures provide the framework on which EE strategy is based. At the same time consumers of energy also need to perceive the cost benefits they can derive from energy savings measures and it is here that demonstrations are essential. The Industrial and Mining Sector are the heaviest users of energy, accounting for more than two-thirds of our national electricity usage. Here lies the potential for the largest savings by replacing old technologies with new, and employing best energy management principles.

1.3 EXISTING DSM PROGRAMMES AND TECHNOLOGIES

1.3.1 Two legs of DSM

DSM is achieved through implementation of activities to influence the time-pattern and amount of electricity usage in such a way that it produces a change on the electricity load profile of the industry, while still maintaining customer satisfaction [33]. This will assist the supply utilities to reduce or shift electricity peaks and therefore reduce the cost of generation.

Existing programmes and technologies can be categorised into the two legs of DSM namely: load management and EE. Some of the programmes and technologies are specific to a DSM leg and some are overlapping. First the differences between the two DSM legs are discussed.

Energy Efficiency

It is said that energy conserved is energy generated. Energy conservation and efficiency measures are the best alternative energy sources Figure 4 shows DSM through increasing EE. This implies that less energy will be consumed and therefore the area under the load curve will decrease.

There are various opportunities and techniques available for reducing energy consumption such as efficient lighting, variable speed drives, solar hot water systems etc. These technologies reduce demand, help in lowering high peak prices and also reduce greenhouse gas emissions due to less stress on generating plants.
Investing in EE is often cheaper, cleaner, safer, faster, more reliable, and more secure than investing in new supply [25]. In addition to reducing the need to construct new generation, transmission and distribution facilities, improving efficiency also reduces maintenance and equipment replacement costs, as many efficient industrial technologies have longer lifetimes than their less efficient counterparts.

Relying on efficiency also avoids a number of costly risks associated with generation, such as lack of demand, cost overruns, interest rate risk, volatile fuel costs, technological obsolescence, catastrophic failure, and political and national security risks. Efficiency can come online much faster than expanding energy supply, without any problems of surplus or shortage. Retrofitting motors and pumps, adding insulation to buildings, or even changing a light bulb takes much less time than constructing a new power plant [22].

Load management

Load management programmes involve reducing loads on a utility’s system during periods of peak power consumption or allowing customers to reduce electricity use in response to price signals. Figure 5 depicts DSM through load shifting / clipping. This implies that by optimised planning (scheduling) the electricity usage is moved to some of the lower demand periods which will decrease peak demands. It is very important to note that with load management the electricity load is moved and not reduced, therefore, the area under the profile will remain the same.

Load management programmes use mechanisms like interruptible load tariffs, Time-of-Use rates (TOU), Real-time Pricing (RTP), direct load control, and voluntary demand response programmes. Although load management programmes are largely short-term responses it has a major impact on the reduction of peak load, which in turn helps to reduce utility construction costs as well as lower electric rates. Load management also extends the point when new power generation utilities will be necessary due to increasing demand, therefore it buys valuable time for power stations to be build.
1.3.2 DSM programmes and technologies

The DSM programmes and technologies can be described by the “Push-Pull” concept in Figure 6. The first step is the “Push” that represents programmes and structures that are set in place by regulatory bodies to promote DSM incentives as clients participate in the programmes. The “Pull” represents the benefits clients receive by participating in these programmes. The result is the advancement of DSM technologies as it evolves into affordable, reliable, sustainable and competitive products. These efforts play an essential role in developing the market for DSM technologies.

Figure 6: The “push – pull” development of DSM technologies.
Regulatory programmes

DSM programmes can increase compliance with regulatory programmes such as new building or appliance standards by helping customers bear the costs. These programmes can also help develop the market for efficient DSM technologies more quickly, demonstrate the feasibility of tightening existing efficiency standards and induce next-generation DSM measures once the current generation has been broadly commercialised and is understood [34].

For example, refrigerators were the largest residential user of electricity in 1972 in the United States, but their energy consumption declined fourfold over the next 30 years as a result of policy at the same time that the size and features were increasing and the price to the consumer decreasing in real dollars. Much of the momentum for this improvement came from regulatory DSM programmes [35].

Another example is energy efficient lights in South Africa. The compact fluorescent lamps (CFLs) were originally priced between R60 and R80 per lamp and in 2004 it was able to drop the price to between R13 and R20 [36] [37]. This was possible because of a jointly funded programme between the Global Environmental Facility and Eskom.

In South Africa the Department of Mineral and Energy (DME) has outlined the following targets [32]:
- Nationally — final energy demand reduction of 12% by 2015.
- Industry and Mining sector — final energy demand reduction of 15% by 2015.

Electricity tariffs

In many cases, load management can be encouraged with properly designed and progressive tariffs, such as TOU and interruptible tariffs. These tariffs work on the “supply and demand” concept. During a 24 hour profile, the electricity price is high when the demand is high and low when the demand is low. Some tariff structures also vary seasonal if the demand is higher during certain seasons of the year.

To improve load management, utilities must further expand the price differential between the peak and valley hour tariffs in order to encourage load shifting. This means greater electricity cost savings for those clients that participate in load management and more electricity costs for those clients that still use electricity load during the peak times. In South Africa the MegaFlex tariff structure is available to electricity intensive industrial clients. The price difference in high demand

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season (winter) between peak and off-peak times varies almost 7 times and between high
demand season - peak and low demand season - peak, 3.5 times [38].

ESCos

Experience in a number of countries, including the United States, New Zealand, Chile and
Argentina, indicates that neither a restructured electricity sector nor the market itself will
automatically deliver EE. In fact, DSM will generally be a casualty of restructuring unless active
steps are taken to include it [23].

When the United Kingdom began to restructure its electric industry, for example, no special
provisions were made for EE-DSM. It was assumed that market forces would meet demands for EE
measures as they arose. Experience proved otherwise, and three years later the United Kingdom
established an independent Energy Saving Trust (EST) which, with the help of ESCos, realised
DSM targets [39].

ESCos are private companies that help to realise DSM goals. Normally they operate in a three way
partnership between themselves, the electricity supplier or regulatory body responsible for DSM
and the electricity consumer [40]. They make use of DSM programmes, technologies and
optimisation packages to determine and realise DSM results at the electricity consumer.

Typically an ESCo will approach a client and offer to carry out a no-cost energy survey to determine
whether a DSM project is feasible. If the survey has positive results, the ESCo will draw up a
project proposal, which will indicate clearly the DSM results to be delivered as well as the turnkey
cost of the project. The proposal is submitted to the electricity utility, or regulatory body responsible
for DSM and they determine if funds will be made available to the ESCo to implement the project
and deliver the proposed DSM targets.

The role of ESCos proves to be successful. Currently the ESCo industry in North America facilitates
$2 billion annual investment in EE [41]. Yet experience in other countries has shown that while the
ESCo industry provides a very valuable role in delivering DSM results to large industrial and
commercial markets, it has been less successful in serving other market segments, particularly
residential and small commercial and industrial customers. In market segments where ESCos have
been most successful, DSM funding programmes have played a major role in creating and
supporting the ESCo industry, and continue to do so today [42].

Chapter 1: Introduction
In South Africa, Eskom’s CEO, Mr Thulani Gocabashe stated his speech at the official opening of EE Month, in May 2005 that:

“ESCos play an important role in implementing EE. International experience has indicated that it is imperative to have a strong private sector infrastructure for effective delivery of EE-DSM programmes.” [43]

On reflection, it is clear that Eskom’s EE-DSM programme has no hope of succeeding, without the existence of a strong ESCo industry to make it happen.

1.3.3 Technologies used by ESCos

A lot of work has been done to the development of DSM technologies. There are numerous references in literature to technologies and software for energy cost optimisation through load management and EE. Most of these technologies are available in the residential and commercial (buildings) sectors. Fewer are available in the industrial sector because of the complexity of the systems, sometimes, directly linked to production.

Technologies and products for DSM should be able to offer the following benefits to clients: peak shaving to optimise grid operation and minimise electricity costs, improving energy used (more energy efficient), reducing environmental pollution and delivering the same or enhanced output. They can all be categorised into the following categories [44]:

- Power load management technologies;
- Heat and cold energy storage technologies;
- Green lighting technologies;
- Energy-efficient home appliances;
- Heat pump and gas and steam combined cycle power generation technologies;
- Ultra-infrared, microwave, or high-power/mid-frequency inducted heating technologies;
- High-power/low-frequency electric source metallurgical technologies;
- Variable Speed Drives technology for alternate current electric motors;
- High efficiency fans, water pumps, electric motors, and transmitters;
- Heat treatment, electric plating, moulding, and oxygen production technologies;
- Non-power automatic supplement technology;
- High efficiency batteries; and
- Renewable energy power generation technologies.
1.4 CURRENT ESKOM DSM PROGRAMME IN SOUTH AFRICA

1.4.1 Governance of the Eskom DSM initiative

South Africa is in a fortunate position where it could learn from over thirty years of experience of developed markets. They are still faced with the challenge of tailor-making an initiative for their unique environment.

DSM is implemented through collaboration with the DME and the National Electricity Regulator (NER). It also includes the DME’s White Paper on Energy Policy, the department’s EE Strategy and the NER’s EE and DSM Policy. The White Paper identifies EE as one of the areas that needs to be developed and promoted whilst the NER is mandated to ensure the installation of sufficient generation capacity to meet the needs of future electricity demand [31].

In South Africa Eskom’s DSM strategy comprises a dual approach: to reduce electricity demand at peak periods (07:00-10:00 and 18:00-20:00) by shifting load to off-peak periods and by overall electricity consumption reduction (24-hour reduction) by installing energy efficient equipment and optimising industrial processes. Sustainable DSM projects often involve a combination of both methods. The framework of the DSM supporting mechanisms that have already been established in South Africa include:

- Integrated Energy Planning (IEP) with DSM as part of the integrated energy supply portfolio.
- Government support to drive DSM and EE from a national benefit perspective irrespective of the industry structure, in particular through periods of industry transformation.
- Clear legal framework to regulate, promote and enforce DSM implementation, clarify roles of varied stakeholders, set targets, determine technology requirements and provide environmental conservation legislation, among other things.
- Introduction of a policy framework for guiding and promoting efficient technology use and appliance labelling, and enabling spot trading.
- A viable funding mechanism for overcoming disincentives to utilities for implementing DSM.
- Agreement on set price structures that convey to consumers the implications of the timing of energy consumption.
- Establishment of 106 ESCos to effectively realise DSM [17].
- Ongoing education and awareness campaigns to maintain public participation and market transformation, among other things.
- Research and development focusing on the successful application of technologies and programmes within the South African context.
- Independent monitoring and evaluation to assess and evaluate sustainability and influence informed decision-making for the future.

**DSM activities**

The DSM programme is comprised of the following various programme themes which include:

- Residential, commercial and industrial programmes: The main objective of this programme is to transform the South African electricity market into creating an EE industry.
- Public education: The primary objective of this programme is to increase awareness about EE. The programme includes a broad range of marketing and public relations activities, and feeds directly to programmes in different income segments as well as residential, commercial, industrial and institutional programme activities.
- Schools programme: The objective of this programme is to highlight the benefits and importance of using electricity efficiently to school pupils. DSM seek to increase the awareness of students and faculties on energy efficient measures through providing participating institutions with resources packs, including teacher and learners and electricity audit guides.

**DSM benefits:**

- Reduced electricity demand during peak periods, thus delaying additional capital investment to further increase electricity supply.
- Improved value of electricity service to customers by reducing costs - customers have a wide range of energy efficient options and financial benefits.
- Conservation of the environment by reducing emissions and water consumption at power stations.
- Support of macro-economic development through job creation and improved productivity.

**DSM funding:**

The DSM profitable partnership programme offers financial assistance for approved projects.

- For viable load management projects; designed to shift electricity consumption to off peak periods in order to reduce peak loads; Eskom funds all capital expenditures.
For viable EE projects; designed to make businesses and buildings more electricity efficient and reduce electricity consumption; Eskom will make a 50% contribution towards the project implementation cost.

1.4.2 Eskom's time of use tariffs [37]

Eskom supplies the cheapest electricity in the world [45]. For large electricity consumers they provide alternative pricing structures. The five main tariffs available to them are NightSave, MegaFlex, MiniFlex, RuraFlex and Wholesale Electricity Pricing (WEP). RTP was available as a sixth tariff until April 2004 after it was decided to stop this tariff. WEP is still in the testing phase with various pilot sites being used.

NightSave is a tariff that rewards consumers able to shift load to the time, between 22:00 and 6:00 during the week. This is known as the off-peak period. The TOU component for NightSave can be seen in Figure 7 (left). This tariff is not very cost reflective since it doesn't really specifically take Eskom's peak demands (7:00 – 10:00 and 18:00 – 20:00) during the day into account.

<table>
<thead>
<tr>
<th>Time of Use</th>
<th>Cost per kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>49.69c + VAT = 56.85c/kWh</td>
</tr>
<tr>
<td>Off-Peak</td>
<td>13.14c + VAT = 14.98c/kWh</td>
</tr>
<tr>
<td>Standard</td>
<td>7.15c + VAT = 8.15c/kWh</td>
</tr>
</tbody>
</table>

**Figure 7:** Time-of-use for NightSave (left) and MiniFlex, RuraFlex and MegaFlex (right).

MiniFlex is for medium sized consumers with different charges for the different TOU periods for different seasons. Figure 7 (right) shows the TOU periods for MiniFlex. MiniFlex is more cost reflective, but very static. The consumer must be able to shift load for a substantial period of time to be able to profit from this tariff. The consumer pays for peak demands, which is kW and energy used, which is kWh.
RuraFlex is much the same as MiniFlex but is more specifically aimed at consumers with three phase supplies from a rural reticulation network. The TOU is exactly the same as MiniFlex as seen in Figure 7 (right).

MegaFlex is more suitable for large consumers that need a supply of 1 MVA and above. The TOU period is exactly the same as MiniFlex as seen in Figure 7 (right). This is ideal for large consumers capable of shifting load for long periods (4 to 5 hours per day). The only negative is that this tariff is very rigid with little room for innovative scheduling. Most of the mines in South Africa make use of this tariff.

WEP basically works on the principle of MegaFlex. It has a time-of-use tariff component, closely corresponding to the levels of MegaFlex. WEP is mainly for clients that have an annual consumption of electrical energy of more than 100 GWh at a single site over the last three years.

1.4.3 DSM targets and results

Eskom has set an annual target of 153 MW load shift out of the evening peak period since 2003 [18]. Thus, at the end of 2005 the accumulated target load to be shifted will be 459 MW. The aim over the next 20 years is to save an accumulative total of 4 255 MW, representing the capacity of one six-unit coal-fired power station [17].

Measurement and Verification (M&V), the independent monitoring and evaluation team for Eskom DSM projects, has indicated that an accumulated total of 181 MW load will be shifted at the end of 2005. This means that since 2003 the Eskom DSM programme only achieved 39% of the targeted 459 MW. These results can be seen in Figure 8, extracted from M&V’s quarterly report for 2005 [46].
1.5 MINING AND DSM IN SOUTH AFRICA

1.5.1 The role of mining in the SA electricity economy

The discovery of diamonds and gold towards the end of the Nineteenth Century fundamentally changed the history of the South African economy and began the long dominance of mining in the industry. South Africa has vast mineral wealth, including the world’s largest reserves of gold, chromium, manganese, platinum, titanium and vanadium, and huge amounts of copper, iron ore, lead, silver, fluorspar, uranium and coal [47].

The mining sector as a whole used 18% of South Africa’s electrical energy in 2003 [17]. Deep level mines (most gold and platinum mines) accounted for 15% of all electrical energy consumed in 2003 [48]. Thus, total electrical energy for gold and platinum mines were 28,559 GWh in 2003. The electricity is i.a. used for hoisting, milling, cooling, pumping and ventilation.
Gold is still the most important mineral mined in South Africa, earning R40,9 billion in 2002 from export sales, compared with R30,5 billion for the next most important, platinum [49]. Gold is also by far the biggest energy user in mining.

Although the tonnage of South African gold production is decreasing, the energy needed for each ton of gold is increasing. This is because the gold mines are going deeper and deeper, needing more energy for pumping, cooling, lifting and transporting. As the gold content of the ore available decreases, more tons of ore have to be dug, lifted and processed for each ton of gold recovered, resulting in more energy used [50].

The total amount of electricity used for mining gold increased from 1967 to 1988 and after that declined 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 further. However, it still uses more electricity than all other mining put together [48].

South Africa has an abundance of mineral reserves for which there will be international demand and nearly 80% of earnings from minerals come from exports. So, for the indefinite future mining is unlikely to decline and may even slightly increase. In the special case of gold, production is likely to decline but with increasing depths and poorer ores the amount of energy required will stay the same or increase.
The one possibility that could change the future for gold mining is ultra-deep mining, to depths down to 5 000 m, which could extract again almost as much gold as has been mined in the past [51]. This is only likely to happen with a large and sustained increase in the price of gold.

1.5.2 Why mine pumping systems are ideal for peak load reduction

Many mines make use of ventilation, fridge plants and underground pumping systems. These can typically contribute in the order of 25% of the electricity used in underground mines [52]. The industrial sector contributes 52% to Eskom’s peak demand and the contribution of pumping to this is 13% [17]. This means that pumping alone contribute approximately 2 300 MW to the 34 000 MW electricity peak in South Africa [18]. Figure 10 lists the processes in the industrial sector and their contribution to Eskom’s peak demand.

Clear water pumping systems can usually be well controlled with storage built into the entire system through the use of dams. Therefore these systems offer an ideal business opportunity if they can be utilised correctly. A case study by Lane in 1996 on a typical deep mine in South Africa showed that a 27% reduction in coincident system peak demand could be achieved by using optimised scheduling of energy systems on a typical deep mine [52].

Figure 10: Contribution by process in the industrial sector to Eskom's peak demand, (2003 data).
Load shift on clear water pumping systems can be achieved without influencing the mining operations, because the pumping of water is not directly coupled to the production of the mine. Because of the dynamic nature of the system, the pumps are frequently started and stopped. This reduces the risk in rescheduling the system over a 24-hour period.

The clear water pumping system consists of a pumping station with dams on certain underground levels. The water pumped is used for cooling air, ventilation as well as for mining operations. The excess water from mining operations in the surrounding area as well as the ground water underground is caught-up in dams. Normally, this hot water is cleaned, pumped out to surface and cooled, to be used again in underground mining operations. Thus, a continuous water cycle from shaft bottom to surface, back to shaft bottom again, exists throughout the day.

Many mines are not fully aware of opportunities available on their systems and the possible benefits to them with regard to the DSM programme. By optimising mining systems according to Eskom’s TOU tariffs huge electricity cost savings can be realised through load management.

Underground dams which are part of the clear water pumping system can be used cleverly as storage capacity in order to realise DSM (load shift) during peak periods of the day. This is almost similar to pumped storage systems used in Supply Side Management (SSM). A good example of this is the Drakensberg, Palmiet and soon to come Braamhoek pumped storage schemes where water is pumped to high level dams in off-peak times and the water’s potential energy is used to generate electricity in peak times [53].

In mines, if the dams in clear water pumping systems can be used to store the continuous incoming water during Eskom’s peak periods, electrical intensive pumps can be switched off. Then, after peak periods, the pumps can be started up and the stored water will be pumped out to attain the water balance in the mine.

The use of the electrical pumps outside Eskom’s peak periods results in peak load reduction. Because the electricity tariff is lower in off peak periods, the mine realises electricity cost savings through rescheduling their pumps out of peak times. Thus, the mine uses more, cheap, off-peak electricity and less, expensive, peak electricity.

The capacity of the dam and the flow rate into the dam determine how long the pumps can remain switched off. Higher dam levels on shaft bottom also mean higher risk for the mine. (What if a pump
fails to start and the dam is already at a high level?) Because the clear water system is a complex system with many variables, mine managers will not stop pumps during peak times.

Unless technology is available, in which they can put their confidence, which automatically controls the clear water pumps out of Eskom's peak times, DSM (load shift) results for Eskom and electricity cost savings for the mine can be achieved.

1.5.3 Technologies available to realise peak load reduction on pumping systems

To achieve DSM (load shift) potential on the clear water pumping system on a mine, the operation schedule have to be changed from its current one. Mines will only change their operations if there is a very high level of confidence that these changes will not affect the safety and production of the mine. To gain the confidence of the mine it is very important to prove beyond any doubt that there will be no negative influence as a result of any DSM (load shift) suggestions.

This can only be achieved if the full integrated operation of the mine's clear water pumping system can be simulated in exact detail and extensively verified through historic detailed operational data. After the simulation model have proved that DSM (load shift) results can be obtained at the particular pumping system, true sustainable results can only be achieved with real-time, on-site, automated technology.

A literature survey was conducted on load management technologies on pumping systems that claim the ability to simulate, optimise and automatically realise sustainable DSM (load shift), which results in electrical cost savings for the client. Such a detailed integrated, dynamic, simulation and control system for the full mine pump operation could not be found, in South Africa and internationally. Similar systems and their differences are discussed next.

Current systems

A good example of a company that provides a system for automated energy metering and reporting in the mining environment is IST Otokon (Pty) Ltd in South Africa [54]. The IST Otokon system does remote energy metering via a data collection network. A user can access the data with their ecWin™ software. The system is used to:

- Reconcile the readings from the various energy meters of the installation with the reading of the utility that supplies the energy.
- Allocate energy costs to sub-sections of an installation.
- Identify billing problems.
- Identify overall trends.
- Warn users of peak prices.

The *IST Otokon* system only does energy metering in the mine industry and not simulation, optimisation and realisation of electrical load shift. Recently they have extended the metering system to control the pumping system of *Midvaal Water Company* and reduce the peaking energy used [55]. *Midvaal* supplies portable water to municipalities and have large reservoirs and pumps that serve an area of around 900 km² [56]. *IST Otokon* has not implemented a load management system on a clear water pumping system in the mine industry.

Another company that claim to do load management on clear water pumping systems in mines is *National Power Contractors cc* [57]. However, their approach is to do the optimised control software inside the Programmable Logic Controller (PLC) of each pump station. Although the PLC has achieved great success across a wide range of process control applications, including certain pumping systems, it is almost impossible to cater for all the different specifications that a complex integrated pumping system consisting of various pump stations may have.

The reasons for reconsidering the PLC as the control device can be categorised as follows:
- Software development, commissioning and maintenance costs are too high.
- Reliability of the "one-off" software (software that is hard coded) in a critical environment.
- No user interface – still need additional wiring to indicator lights and control switches.
- Additional functions like alarms require extra, expensive components.

A ladder logic implementation of 2 pumps alternating in a dam with common fault inputs is very straightforward and this often leads to the conclusion that a PLC will be ideal for a pump station. However, consider some of the specifications that mines usually want with load management implementation:
- Maximum pump run-time (to reduce inefficient pumps running continually) – where the next pump to run cuts in after this time.
- Duty and stand by pumps to run only. Emergency pumps only to be used in emergencies. The duty, stand-by and emergency pumps may differ every week and must be selected by a person from a central point.
Maximum pumps to run (usually due to hydraulic constraints) – with the standby pump taking over from the duty pump at the standby level.

Fault inputs configurable for critical (lockout until operator reset) or non-critical (pump becomes available when fault clears, but unacknowledged alarm condition still visible until reset by operator).

Adaptive dam level control to minimise station starts in peak periods.

To keep the water balance intact, the total water of complete system (various levels) must be considered before certain pumps may run.

Alarms must go off at a central point when a combination of certain scenarios occurs.

Only certain combination of pumps can run at one stage (maybe pumps on different columns, or from different electrical panels).

From practical experience it is thus clear that optimised automatic control of a complex pumping system, to realise load shift results, is practically impossible by programming the PLCs at each pump station. It must be said that National Power Contractors cc has not yet implemented a load management project on a clear water pumping system.

Software

There are numerous companies that provide software for the optimisation of energy cost of water pumping systems. These software packages were developed specifically for large city water distribution systems. The water distribution systems differ from the pumping systems of deep mines in the following respects:

- City water reservoirs are much larger than the reservoirs of deep mines. A typical underground clear water dam can be emptied in a matter of hours or minutes. This implies that the control of the underground pumps have to be executed relatively rapidly. Care has to be taken that the frequency at which the switching of pumps takes place is not excessive since it strains all the components in a pumping system.

- The total energy bill of city water distribution systems is much higher than deep mine pumping systems. This means that expensive optimisation and control software are more affordable to cities.

The first software system for the optimisation of water distribution systems is H20NET Scheduler [58]. This system is part of a larger suite of programmes that is used by several water utilities to analyse and optimise the design and operation of residential water distribution systems. The
specific aim of *H2ONET Scheduler* is to optimise daily pump operations (daily pump scheduling) for maximum performance and energy savings. The programme uses generic algorithms to determine the lowest energy cost on a daily basis. It also takes hydraulic operational constraints into account like pressure, velocity, head loss and desired tank trajectory curves.

A second system is *MISER-PS* [59]. It is used for the derivation of least-cost pumping schedules for optimisation of energy usage and the exploitation of electricity tariff structures. It is used to plan day-to-day system operation, to identify emergency responses to failures and for tariff management, with the potential for on-line pump scheduling to deliver further cost-savings.

The pump schedule describes the times and settings of all pump and valve operations over a specified horizon. The programme uses half-hour intervals. Constraints can be built into *MISER-PS* to limit the number of pump switches, flow changes and so on and to control reservoir levels to ensure schedules meet a wide range of operational constraints.

A third system is *Derceto 3.0 by Beca Technologies* of New Zealand [60]. *Derceto* optimises pump schedules to minimise distribution costs of large water distribution networks. On-line data collection allows *Derceto* to choose the lowest cost source of water. By predicting future consumption, it calculates the thousands of possible pump schedule combinations to meet the day's evolving demand, in real-time.

This software is very flexible but it needs to be custom-engineered by a team of specialists for every new application. *Derceto* is probably the most flexible and powerful software available for optimising pump scheduling. It is also the only software that does the optimisation in real-time. However, it is expensive, in the order of US $500 000 per installation.

A fourth system is *PumpView by MultiTrode Industrial Solutions* [61]. This system is a web-based pump station management system that provides control and monitoring of a network of water and wastewater pump stations. As most systems it was specifically designed for municipality pump stations.

*PumpView* allows monitoring and control of pump station faults and problems over the Internet. If a problem occurs, specific alarm notification is sent via mobile phone Short Message System (SMS) or e-mail to each user on the alarm list in turn, until the alarm is acknowledged. Most problems can be addressed over the Internet from home or office Personal Computer (PC) or laptop. Because of
the information provided by PumpView. Customers achieve savings on reduced call outs and an effective preventative maintenance programme.

Remote energy management system (EMS)

TEMM International has developed an Energy Management System (EMS) that was implemented on Kopanang mine [62]. This system was a “one-off” system, specifically developed for the clear water pumping system of Kopanang mine. Chapter 2 investigates the performance of this system at Kopanang mine and the shortcomings it has to extend this system to other mines in South Africa.

1.6 OVERVIEW OF THIS THESIS

It is seen in Chapter 1 that Eskom may be running out of supply capacity as early as 2007. Due to the two peaks of the national daily electricity demand profile, Eskom may not be able to supply electricity between 7:00 to 10:00 and 18:00 to 20:00. Although they have a number of new generation projects going on, the earliest additional capacity will not be delivered before 2012.

Therefore a solution to the current supply problem could be electricity load shifting out of peak periods, through the Eskom DSM initiative. In section 1.5.2 above it was shown that the possibility exists to shift load out of peak demand periods on the clear water pumping systems in the mine industry. However, there is no technology currently available to achieve this DSM potential, in a way that will reliably contribute to the solution of the supply problem.

In Chapter 2 the author looks in detail at the current state of the art technology that was implemented on the clear water pumping system of Kopanang gold mine. Through this investigation it was seen that the technology only achieved approximately 50% of its potential. Because of the limited approach that was followed, the full results could not be obtained and those that were, could not be maintained on a sustainable basis.

Out of this chapter flows the problem statement. Prior to this project, there existed no technology in South Africa that could be successfully applied to any type of clear water pumping system on a South African mine, which would achieve the maximum possible DSM results on a sustainable basis. Therefore, technology had to be developed that would follow a different and new approach, rather than the old approach that was followed at Kopanang mine. This is therefore the
problem that was addressed in this study: how to modify and/or design an energy management system that could be applied to every configuration of clear water pumps on any South African mine and shift load reliably and on a sustainable basis.

A new DSM tool, (called REMS) was therefore developed. This tool was used to implement new approaches that ensured maximum, sustainable DSM results. Chapter 3 discusses the process of implementation of REMS for the first time on an intricate pumping system. New and novel innovations were made to the system, in order to accommodate specific user constraints. This new modified REMS was first used on Bambanani mine. Results proved that the implementation was hugely successful. This extended the market for REMS to other complex pumping systems and ensured the wider penetration of Eskom's DSM initiative.

Chapter 4 describes a further extension of the application of REMS. After further innovations were made to the REMS controller, it was now able to be implemented on a pumping system that included a Three Chamber Pipe Feeder System (3CPFS). This had never before been possible. The reason was because no technology existed to simulate and optimise a 3CPFS to achieve load shift on the entire system. Once again, new markets were opened up where the potential for load shift projects could be successfully explored.

Previously mines without adequate infrastructure had never been considered for DSM projects, since automated load shift required an intensive investment in capital infrastructure. Therefore, mines that did not have this capacity did not even consider the possibility of engaging in load shift projects. Chapter 5 discusses the necessary changes made to REMS to address this further virgin market. It discusses the implementation and results achieved at two mines with no control infrastructure prior to the implementations.

To satisfy the national electricity supply problem, load shift results have to be produced continually and reliably. In Chapter 6 the author evaluates the new approaches that have been incorporated into REMS over the duration of this project. Since DSM projects are viewed as a virtual power station, it had to be established whether the DSM results achieved so far could be sustained consistently over a long period. In order to establish the user-acceptability of the new technology, it was evaluated through two types of questionnaires, the results of which are reported in this chapter.

Chapter 7 concludes this thesis by listing the contributions made by implementing the novel and unique innovations recorded in this thesis. It was seen that REMS achieved maximum, sustainable
DSM results on each of the three possible types of pumping systems that exist on South African gold mines. It can therefore safely be stated that the new and improved REMS technology can now be implemented on any deep level hard rock mine in the country.

A study into the DSM potential of the clear water pumping systems of the entire gold mine industry gave an estimate of the possible national impact of REMS.

1.7 CONTRIBUTIONS OF THIS STUDY

The main contribution of this research project was that an energy management system, which had previously been successfully used only in a limited way in one installation, was modified systematically to include novel and unique features, which finally catered for every possible configuration of pumping systems on SA mines.

It was established that all water pumping systems on SA mines could be divided into one of three possible categories, i.e. simple systems without control infrastructure, complicated systems with sophisticated instrumentation and control, and systems containing 3CPFS. This study systematically analysed each of these systems in a generic way and formulated technical and operational solutions to the problem.

In each case, the proposed solution was applied as a case study and tested on a real mine. Results showed that the technology is indeed generically applicable to all such underground water pumping systems and can make a major contribution to the SA peak demand problem.
CHAPTER 2

CURRENT STATE OF THE ART LOAD MANAGEMENT TECHNOLOGY IMPLEMENTED AT KOPANANG MINE

An energy management system was developed specifically for the water pumping system of Kopanang mine. However, the DSM results so obtained would not be sufficient and sustainable to contribute to the national electricity supply problem if replicated elsewhere. By investigating the development of REMS and the implementation procedures, new approaches were identified that would ensure adequate and reliable results.
2.1 INTRODUCTION TO THE REMOTE ENERGY MANAGEMENT SYSTEM (EMS)

2.1.1 Evolution of the remote EMS

Towards the end of the 1990s and early in this century a need was identified in the mining industry to improve and promote the use of energy management systems. Electricity constitutes a substantial part of the operating expenses incurred by an underground mine, therefore managing this part will make a major contribution to cost saving initiatives. Since about 25% of the electricity consumed on an underground mine is used for the Ventilation, Cooling and Pumping (VCP) systems, these formed the basis of the management system described in this thesis [52].

When Kopanang mine management first approached TEMM International, the following needs were identified that were not satisfied by any other device available at that time:

- A control system that scheduled VCP equipment 24-hours in advance. It had to optimise the total electricity cost of an installation. The optimisation had to be based on predicted electrical loads and electricity prices in a 24-hour forward horizon.
- A control system that did the optimisation of the VCP schedules remotely from the installation. The Optimised Schedule was sent daily to the mine via any suitable communication network.
- A control system that could easily be implemented.
- A control system that could be incorporated with any existing control or monitoring installation.
- A control system that did not change the set points of the VCP system, but that primarily used the inherent spare capacity in the system to shift electricity load.
- A control system that could be used for any one of the several VCP systems installed in underground mines.

The original intention was to develop the remote EMS generically for any VCP system on any mine, but as will be seen in Section 2.2, in the end it was developed only for the clear water pumping system at Kopanang mine.

Firstly, a procedure was developed where daily control schedules, that optimised the electricity cost of mine cooling systems, was developed. This procedure used novel simulation models and a specific simulation technique that allowed for the mathematical optimisation of large cooling systems. The objective function of the optimisation procedure was the daily electricity cost of the
cooling systems. By making use of the inherent storage capacities in the cooling system, the electrical load was shifted from peak to off-peak (cheaper electricity) periods. The final result of the optimisation procedure was an Optimised Schedule, which indicated the optimum running statuses of VCP components on an hourly basis for the following 24-hours.

The inputs for the optimisation procedure were the predicted chilled water demand and the hourly electricity prices for the following day. The procedure assumed that all dams were 65% full at the start of each day. Constraints on the optimisation procedure included dam level limits. If it was assumed that all these predictions were true, then the human operators were able to follow the Optimised Schedule for 24-hours without regard to dam levels.

However, as expected, the actual conditions deviated from the predicted conditions due to the following factors:

- VCP equipment, like pumps, became unavailable for unscheduled maintenance reasons.
- The water demand changed from day to day.
- The human operators were not always able to ensure that all dam levels were 65% full at the end of each day.

Therefore, automation was taken one step further. A partly automated system was developed and deployed. This system implemented the Optimised Schedules. The result was the so-called remote EMS. The motivation for automating part of the system was to ensure consistency in the control actions and to have remote control access to the cooling system.

The remote EMS comprised of four components. The first component was the Optimised Schedule. Second was a means of communicating the schedule from a remote computer to a Supervisory Control and Data Acquisition (SCADA) system at the mine. The third part was the remote EMS software itself. This software generated discrete control signals for the pumps and turbines based on the Optimised Schedule and certain VCP and dam constraints. The last component provided an interface between the remote EMS software and the SCADA system.

2.1.2 System layout of the EMS

The EMS was a computer and software system containing the four main components. Figure 11 shows the flow of information in the EMS. It also shows the relationship between the four

Chapter 2: Current state of the art load management technology implemented at Kopanang mine 33
components of this invention. The information flow started with the Optimised Schedule Software that produced a daily Optimised Schedule (1) for all VCP equipment in a specified installation.

This Optimised Schedule (1) had to be communicated daily from the remote control computer to the remote EMS Software (3) on the SCADA computer. A commercial PC communication package (called PcAnywhere version 10.5) together with two modems and a land-based telephone line (2) was used to transfer the Optimised Schedule (1) between the two computers. Human operators conducted the daily file transfer actions.

Component three of this system was the remote EMS Software itself (3). The inputs for this software were the Optimised Schedule (1) and the operational parameters of dams and all VCP equipment. From the SCADA inputs were dam levels, on-off statuses of VCP equipment and ready-to-start statuses of VCP equipment. The output for the remote EMS Software (3) was control signals for all the VCP equipment. Control signals were generated every two minutes.

The last component of this invention was the EMS User Interface (4) between the EMS Software (3) and the SCADA computer. This interface formed an integral part of the SCADA software. Most SCADA software packages offered several different data interface options to the user. Citect 5.4, a SCADA software package, had an integrated compiler and programming language called Cicode. This option was used to construct the remote EMS User Interface (4).

The User Interface (4) simply read and wrote text files that had been shared with the EMS (3). Control signals were conveyed with a single text file. This file was updated by the EMS and was read by the User Interface every two minutes. There was a six second phase change between the read and write actions to prevent clashing. The control signal file contained an integer for every piece of VCP equipment that was controlled by this invention. A zero signified that no control action should take place; a one told the SCADA to switch the specific equipment on while a minus one told it to switch it off. In a similar way dam levels, on-off statuses and ready-to-start statuses of all relevant equipment were updated in three separate text files.

Control signals and operational information were transferred internally between the SCADA and the remote EMS User Interface (4). The SCADA software translated the control signals to electronic pulses that were sent via a data network to the PLCs that performed the local control of the individual VCP components.
The EMS Software itself, the third component of this system, will be looked at in more detail in the following paragraphs.

The EMS Software (3) focussed on the calculation of discrete control signals for pumps and turbines that formed part of a VCP system of an underground mine. On a daily basis the EMS received an ideal Optimised Schedule (1) for pumps and turbines for the next day. The Optimised Schedule minimised electricity cost through load management and ensured that minimum and maximum dam levels were not violated.

The calculation of the schedule assumed a certain water demand profile and that all pumps and turbines would be available throughout the day. Another assumption was that the dam levels at the start of the day (00h00) were between 60% and 70% full. Obviously, these assumptions were not always true. The EMS attempted to adhere to the Optimised Schedule as far as possible, but it deviated from the ideal schedule as soon as one of the dam level limits was threatened. The deviated schedule was then called the Realistic Schedule (See Figure 11, between 3 and 4).
The EMS was programmed with Borland Delphi 6.0 [63]. It had a very simple one-page graphical user interface (see Figure 16). There were only three options on the user interface: to start and stop the control, to switch the focus to the SCADA programme (which was also running on the computer) and to close the EMS. The user interface showed a diagram of all the relevant pumps, turbines and dams. Dam levels and pump statuses were also shown.

2.1.3 The EMS: Determining the Realistic Schedule

The first step in describing the calculation of the Realistic Schedule is to discuss the basic underground water system layout that was assumed for the remote EMS (see Figure 12).

It was assumed that the mine had dams and/or pump stations on a number of underground mining levels. The number typically ranged from 1 to 5, depending on the mine size and depth. Figure 12 shows levels i-1 and i, which were the same. A typical level had a hot dam (item 1) and a cold dam (item 2). Water from the hot dam was pumped to the level above with a pump station that consisted of electrical pumps (item 4) and turbine pumps (item 3). The turbine acted as a valve that allowed cold water to flow into the cold dam (item 2).

The following aspects were considered in the calculation of the Realistic Schedule: the maximum and minimum limits of the dam levels could not be violated and turbine pumps could not be preferred above electrical pumps since it represented “free” energy. These aspects were embodied in a number of control dead bands (Figure 13). The main purpose of a dead band was to prevent pump cycling. The specific placement of the dead band on dam level scale signified a certain control aim. A brief description of the purpose of each band follows.

Band 2 prevented the pumps on level i to flood the hot dam (item 5) on level i-1. Band 3 forced the pumps on level i to come on to ensure that the turbine pumps on level i-1 did not have to be stopped when the dam (item 5) became empty. Band 6 allowed for the starting of all pumps on level i to prevent the flooding of the hot dam (item 5) on level i. Band 7 was only applicable during the last two hours of the day. All pumps on level i were switched on if the dam level was above this band and all pumps were switched off when it was below the band.
Figure 12: Schematic diagram of a typical underground pumping layout in a mine.

The reason for this band 7 was to ensure that the dams started each day on a predictable level. If the dam level fell below band 8 all electrical pumps were switched off to protect it from pumping dirt and ultimately air. Similarly, band 9 specified when the turbine pump on level i should be switched off to prevent the same problems as for the electrical pumps. Band 9 was situated below band 8 in keeping with the aim to let the turbine pumps ran as long as possible. All turbine pumps on level i had to be switched off when band 12 was transgressed.
Any combination of dam levels on the three dams could occur in practice. Therefore the control logic described thus far was inadequate since it could prescribe conflicting actions. It was therefore a matter of prioritising the various control actions. In general the priorities were as follows:

- Prevent any pump and turbine pump from pumping dirty water.
- Prevent any dam from overflowing.
- The turbine pumps were preferred above electrical pumps.

The complete control logic algorithm could be summarised by saying that it took the Optimised Schedule for the pumps and turbines on level i and then used it to calculate the Realistic Schedule based on the dam levels of the cold and hot dams on the same level as well as the hot dam level on level i-1. If all the relevant dam levels were within limits the Realistic Schedule was identical to the Optimised Schedule.
2.2 IMPLEMENTATION PROCEDURE OF THE EMS AT KOPANANG MINE

2.2.1 Background to Kopanang mine clear water pumping system

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 the shaft was produced in 1984 [64].

![Figure 14: Location of Kopanang mine.](image)

Today Kopanang gold mine is an Anglogold Ashanti mine. The word Kopanang is a Sotho word meaning “Come Together”. The mine is part of the Anglogold Vaal River group, which comprises of four mines. It is an underground mine with 7 206 employees, including contractors. The mine hoists approximately 226 000 tons of material per month at an average grade of 6 g/ton. In 2002 the cash cost to mine an ounce of gold was R 55 000 per kilogram [64].

The rock temperature of Kopanang is relatively high; therefore cold water is used to cool the underground atmosphere. Water is also used to cool the rock drills (machine water). Chilled water is gravity fed from the surface cold water confluence dam through the water turbine on level 38 to the chill water dam on level 38. The chilled water flow of ± 250 l/s is enough to drive the turbine driven pump that is used in conjunction with the electrical pumps on level 38. The cold water is gravity fed to all the working areas where it is used for the cooling of the pneumatic rock drills and the rock face.
This water together with the spilled drinking water gravitates down along gullies to the settler dam at level 74. At the settler the silt is gravitated out of the hot water. The clear, hot water is fed to the hot water dam on level 75. This dam has a capacity of ± 9MI.

Four electrical pumps are available on level 75 to pump the hot water to level 38. These pumps deliver a flow of approximately 120 l/s. All four pumps can be used in emergencies but normally one is on standby.

![Flowchart of water management system](image)

**Figure 15: Kopanang mine underground pump system.**

On level 38 the water from level 75 flows into the hot water dam with a capacity of approximately 5.5 MI. There are three electrical pumps on this level. Only two are normally used. The turbine pump is also used constantly during the week. These pumps deliver an average flow of 115 l/s. The turbine is only turned off for maintenance to the fridge plants during Sunday mornings. The water from level 38 is pumped into the surge dam on surface. This is graphically illustrated in Figure 15.
2.2.2 Implementation of the EMS at Kopanang

It was intended originally to implement the EMS on the total VCP system of Kopanang mine, but in the end it was only implemented on the clear water pumping system.

During September 2001, optimised pumping schedules were faxed to Kopanang mine from the remote, off-site control room for the first time. This faxing procedure continued for 7 months until March 2002, when the partly automated remote EMS was implemented. The implementation of this EMS consisted of the following:

- Whilst studying the working of the control of the underground pumping system, it was noted that human operators controlled individual pumps via a SCADA system. The operators had to use their own judgment to schedule the pumps to ensure that dam levels were not violated and that the pumps did not operate during times of peak prices.

- During the study of the system certain control parameters were noted that had to be implemented in the EMS. Some of these parameters were gathered from the way the human operators were operating the system in the past, while others had to be determined by means of trial-and-error. The dam level limits were selected so that they did not overlap and thereby caused interference in the control logic. Furthermore, they were selected to avoid pump damage due to frequent switching.

- The existing PLCs at the pump stations would act to protect the dams and pumps in the event of a failure by the EMS.

- The study of the system included an investigation into the configuration of the existing SCADA system. This had to be done to enable the interfacing between the EMS and the SCADA system. In the end the SCADA's build-in programming language was used to write a suitable data interface between the two systems.

- The operators were trained in the working of the EMS. This consisted of a short training session with the four operators. Thereafter 24-hour telephone support was given for approximately two weeks after implementation. At that time the operators were sufficiently comfortable with the system so that the support service could be limited to office hours.

From the remote control room in Pretoria, a daily optimisation for the clear water pumps had to be done to calculate the optimum operating strategy for the following day. This schedule was then sent to the EMS computer on the mine by human operators. The EMS computer used this Optimised Schedule as an input. Considering the pump and dam constraints it tried to stay at this Optimised Schedule for as long as possible.
The daily RTP signal was available from Eskom from 14:30 on the previous day. This meant that the optimum Operating Schedule for the next day could only be generated after this and sent to the operators. The generation of the optimum operating schedule for the clear water pumps consisted of the following steps which had to be executed by human operators in Pretoria on a daily basis:

1. **Downloading price information**
   The RTP signal was downloaded daily, anytime after 14:30, from the following website: www.enerweb.co.za/ftp/pub/ftp/rtp2p/latest_rtp2p.csv. This data then had to be combined into one file to facilitate its use in the optimisation process.

2. **Optimisation**
   All the variables were then reset to zero and the optimisation of each of the clear water pumps was done. The newly calibrated boundary and component data was fed to a commercial solver for the optimisation [65]. After the optimisation process, the number of components active every hour needed to be rounded down or up to integer values.

3. **Transfer of the final operating schedule**
   This calculated number of components active every hour was then summarised in an electronic format and sent to the remote EMS on the mine. The file was a comma-delimited text file. Columns one to five represented five equipment groups while the rows correspond to the hours of the day. The number of columns depended on the number of equipment groups at Kopanang mine. The integer numbers indicated the number of units in each equipment group that were active during that specific hour.

   The EMS User Interface for Kopanang mine is shown in Figure 16 below. The mine control room operators could see this interface on the SCADA computers. An outlay of the cooling and pumping systems was shown on the right while the statuses of the components were shown on the left.

   The control room operators could also see any deviations from the Optimised Schedule on the user interface. Red rectangles indicated deviations while green rectangles meant that there were no deviations (Optimised Schedule = Realistic Schedule). Deviations would occur if there were not enough pumps in working order to meet the demands of the Optimised Schedule.
2.3 EVALUATION OF THE EMS

2.3.1 Load shift: Unrealised Potential

For the 7 month period when optimised pump schedules were faxed to the mine, Kopanang mine managed to shift daily an average of 2.06 MW load out of Eskom’s evening peak period. The control room operator at the mine received the Optimised Schedule for the following day from the remote control room and had to do his best to follow the schedules on an hourly basis.

In Figure 17 below the daily average load profile for the clear water pumping system at Kopanang mine is shown. This is for the period Sep 01 – Mar 02, when the fax system was in operation. When comparing the Kopanang baseline (blue line) to the EMS profile (fax, red line) it can be seen that just over 2.00 MW load was shifted out of the peak period 18:00 – 20:00. When comparing the...
EMS profile (Optimised Schedule, yellow line) with the baseline it can be seen that the unrealised potential is a further 2,60 MW.

Figure 17: Kopanang mine average daily pumping profile for the fax system period.

After the partly automated remote EMS was implemented on the mine the evening load shift increased to 2,52 MW. The Optimised Schedules for the following day were sent daily to the remote EMS on the mine. The EMS computer used this Optimised Schedule as an input. Considering the pump and dam constraints it tried to stay at this Optimised Schedule for as long as possible. The outcome was the Realistic Schedule.

In Figure 18 below the daily average load profile for the clear water pumping system at Kopanang mine is shown. This is for the period when the partly automated remote EMS system was working. When comparing the Kopanang baseline (blue line) to the EMS profile (Realistic Schedule, red line) it can be seen that just over 2,50 MW load was shifted out of the period 18:00 – 20:00. When comparing the EMS profile (Optimised Schedule, yellow line), it can be seen that the unrealised potential is a further 2,14 MW.
In both cases, if it were possible to follow the Optimised Schedules precisely, every hour, the daily average load shift would have been 4,66 MW out of the evening peak. It can thus be said that the fax system realised 44% and the partly automated remote EMS system, 54% of the maximum load shift potential.

2.3.2 Monetary saving: Unrealised Potential

Because electricity was shifted from high-priced periods to low-priced periods Kopanang mine achieved an electricity cost saving. The saving was based on the fact that the mine used less expensive electricity and more inexpensive electricity.

At the time when the EMS was working, the mine was on the RTP tariff structure. This tariff consisted of a Customer Base Line (CBL), load cost and a RTP cost. The CBL load was calculated from historic measured data. This load was then used to calculate the unit cost of electricity if the mine was still on the NIGHTSAVE tariff. The CBL cost was a fixed cost if no electricity was used.

The RTP part of the tariff had a debit and credit price for every hour of every day. This price was calculated by Eskom every day for the following day. The RTP cost was calculated as follows: If the mine used more electricity than the CBL they were billed on the amount exceeding the CBL with the RTP debit price. When the mine used less than the CBL load they were credited with the amount of load less than the CBL times the RTP credit price.

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*Chapter 2: Current state of the art load management technology implemented at Kopanang mine*
The average daily RTP price for 2002 is shown (red line) together with the average daily optimised load profile as suggested by the EMS (yellow line) and the historical baseline (blue line) for the pumping system. From this illustration it is possible to see that electricity load was shifted from the high-priced periods to the low-priced periods.

Figure 19: Kopanang mine average daily pumping profile together with RTP prices.

Table 3 shows the electricity cost savings realised for Kopanang mine in 2002. It can be seen that a total of R 252 854 had been saved for the mine from a possible R 512 603 savings potential. Thus, in monetary terms the EMS system realised 49% of the maximum savings possible.

<table>
<thead>
<tr>
<th>MONTH</th>
<th>ELECTRICITY COST SAVING</th>
<th>MAX SAVING POSSIBLE</th>
<th>UNREALISED POTENTIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan-02</td>
<td>R 11,672</td>
<td>R 11,672</td>
<td>R 0</td>
</tr>
<tr>
<td>Feb-02</td>
<td>R 8,581</td>
<td>R 8,581</td>
<td>R 0</td>
</tr>
<tr>
<td>Mar-02</td>
<td>R 9,288</td>
<td>R 18,208</td>
<td>R 8,920</td>
</tr>
<tr>
<td>Apr-02</td>
<td>R 39,132</td>
<td>R 64,444</td>
<td>R 25,312</td>
</tr>
<tr>
<td>May-02</td>
<td>R 21,680</td>
<td>R 43,838</td>
<td>R 22,158</td>
</tr>
<tr>
<td>Jun-02</td>
<td>R 66,176</td>
<td>R 86,944</td>
<td>R 20,768</td>
</tr>
<tr>
<td>Jul-02</td>
<td>R 71,491</td>
<td>R 85,130</td>
<td>R 13,639</td>
</tr>
<tr>
<td>Aug-02</td>
<td>R 26,865</td>
<td>R 26,865</td>
<td>R 0</td>
</tr>
<tr>
<td>Sep-02</td>
<td>R 11,296</td>
<td>R 29,135</td>
<td>R 17,840</td>
</tr>
<tr>
<td>Oct-02</td>
<td>R 3,658</td>
<td>R 74,014</td>
<td>R 70,357</td>
</tr>
<tr>
<td>Nov-02</td>
<td>-R 7,078</td>
<td>R 57,483</td>
<td>R 64,561</td>
</tr>
<tr>
<td>Dec-02</td>
<td>-R 9,906</td>
<td>R 6,287</td>
<td>R 16,193</td>
</tr>
<tr>
<td>Total</td>
<td>R 252,854</td>
<td>R 512,603</td>
<td>R 259,749</td>
</tr>
</tbody>
</table>

Table 3: Summary of electricity cost savings at Kopanang mine for 2002.
2.4 THE NEED FOR AN ENHANCED ENERGY MANAGEMENT SYSTEM

2.4.1 Problems and shortcomings of the EMS

It is important to note that the EMS, as was developed for and implemented at Kopanang mine, was dependant on human operators. Because the Optimised Schedule was obtained by human operators completing three lengthy steps, as described earlier, and because it was obtained off site and then sent to the mine, several undesirable situations occurred.

Firstly, the Optimised Schedule was calculated for the following day, assuming ideal situations on the mine. The next day when the Optimised Schedule had to be executed on the mine, something different from the ideal situation might have occurred. For example, pump equipment might become unavailable or dams had to be cleaned. This caused the Realistic Schedule to deviate from the Optimised Schedule, resulting in poor load shift and saving performances.

Secondly, because the Optimised Schedule was calculated off site, certain assumptions about the water balance had to be made. Two important assumptions were firstly that the water demand stayed constant from day to day and secondly that the control room operators on the mine were able to ensure that all dam levels were 65% full at the end of each day. If one of these two conditions were not true, the Realistic Schedule also had to deviate from the Optimised Schedule, resulting in poor load shift and saving performances.

The performance of the EMS was very dependant on the daily involvement of human operators in Pretoria and the hourly involvement of the control room operators on the mine. Therefore, it could be said that the load shift and electricity cost savings were not sustainable. It should also be pointed out that although the initial intention was to develop an energy management system for any VCP system on any mine in SA, the EMS was specifically developed for the clear water pumping system and circumstances at Kopanang mine.

Below follows a list of shortcomings of the remote EMS:

- During the project, the mine control room operators frequently had to disable the EMS due to maintenance on the pumps. This was because the EMS was not programmed to handle maintenance downtime on pumps. The EMS had to be changed to a real-time system that...
re-calculated the Optimised Schedule hourly, or whenever a certain change of circumstances occurred e.g. when a certain pump or dam needed maintenance.

- During the project, pump flows and dam capacities were re-calculated on a weekly basis by using the past week’s data of the system. This calculation had to be done automatically and much more frequently. The updated values had to be used whenever a new Optimised Schedule was calculated.

- The EMS had to update the water demand automatically when it detected a deviation from the predicted water demand. This information had to be used in real-time in re-calculating a new Optimised Schedule.

- The modem-based communication with the remote EMS was cumbersome and unreliable. An internet-based communication system had to be developed, or even better, an on-site management system had to be developed.

- The remote EMS was "once-off" developed for Kopanang mine consisting of a 24-hour control room on the clear water pumps. Therefore the system was largely dependant on these operators. This system would not function on a mine where there was no control room.

- The system had no alarms. What if a control room operator did not detect an emergency situation, or what if there was no control room operator? There existed a need to insert alarms to the enhanced system that would warn a person (on or off the mine) when an emergency occurred.

The above-mentioned problems and shortcomings were largely responsible for the fairly poor results of 54% load shift performance and 49% cost savings performance. Besides this, the EMS would probably not perform on any mine with a different layout and operating practices than Kopanang mine. There was definitely a need to further develop the system in order to obtain better load shift and cost savings results.

2.4.2 Problem statement and need for this study

From the literature study it was seen that there existed no generic system that could be successfully implemented on any pumping system in the mine industry. TEMM International had developed the EMS that was implemented at Kopanang mine, but the system was solely developed for the circumstances of this mine. Because there were many shortcomings in this system, it would not have reached maximum, sustainable results on any other pumping system.
Therefore there existed a need to develop a new approach to ensure successful implementation and sustainable DSM (load shift) results in South Africa. This approach had to be applicable to any clear water pumping system on a South African mine.

2.4.3 The requirements and specifications for a new enhanced energy system

From the problems and shortcomings mentioned it was clear that there existed a need to improve the EMS. The shortcomings of the EMS served as a guideline for the specifications of the system envisaged. An energy management system had to be developed that achieved the full potential of load shift and electricity cost savings.

It could be said that the mission statement of the new enhanced energy management system would be the following: “A system that achieved maximum, reliable load shift and electricity cost savings potential without jeopardising operational, safety, health and maintenance constraints in any way.”

To solve the problem, and address the need pointed out in the previous section, a system had to be developed with the requirements and specifications as discussed below:

1. The system had to control any clear water pumping system on a South African mine within operational, safety health and maintenance constraints.

2. To ensure that no assumptions were made about the condition of the mine pumping system, it had to be on-site to receive real-time system data as an input. This would ensure that the Optimised Schedule was always realistic for the specific system conditions.

3. The system should continually calculate the Optimised Schedule to adapt to different mine situations in real-time.

4. To ensure reliable results the system should be empowered to automatically execute the Optimised Schedule as soon as it changed. Human operators should not be responsible to execute the new schedule.

5. The system should maintain and regulate dam levels at minimum and maximum values as supplied by mine personnel. No user constraints should be violated.

6. The system should access and manage data through an integrated database system to generate operational reports on the actions and performance of mine equipment and itself.

7. The system had to warn or notify any designated persons on or off the mine in case of an emergency.
8. The User Interface of the new system had to be user friendly and logical. Because the system was intended to be introduced into a mine environment, it had to be accessible, usable and understandable by the average mine artisan.

9. The interface had to be powerful enough to enable the higher-level users to manipulate the application to comply with their more complex and specific requirements.

10. The system had to be easy to maintain.

11. The system should be easy to install.

12. The system had to be stable and robust. It was going to be designed to control critical processes of production. It was therefore essential that the working process had to be reliable and robust.

2.5 CONCLUSION

The EMS was first implemented in the form of a fax system at Kopanang mine. This system consisted of the following:

- An optimised 24-hour future schedule of the pumping system was generated off site.
- The Optimised Schedule for the following day was then faxed to Kopanang mine.
- The control room operators received the fax. It was their responsibility to follow the Optimised Schedule on an hourly basis the next day.

It was seen that this fax system was much too dependent on the human operators in Pretoria and the control room operators on the mine. Because they were not always in a suitable situation to execute the optimised schedule hourly, the fax system was soon replaced by a partly automated remote EMS. The partly automated remote EMS consisted of the following:

- The Optimised Schedule for the following day was generated off-site.
- It was sent in an electronic format to the remote EMS on Kopanang mine.
- The remote EMS took the Optimised Schedule, combined it with VCP and dam constraints and determined the Realistic Schedule.
- The Realistic Schedule was then put into electronic pulses and sent via the communication network of the mine to the underground PLCs, controlling the VCP equipment.

Although plenty of assumptions were made, the EMS was partially successful at Kopanang mine. This was the first time that load shift results were recorded on any pumping system in South Africa, even before the Eskom DSM initiative was in full action [66]. It was seen that the system annually
saved the mine more than R 250 000 in electricity costs. This saving was based on the fact that the EMS enabled the mine to use less high-priced electricity and more low-priced electricity. The system shifted a daily average of 2.5 MW electricity load out of Eskom’s evening peak (18:00 – 20:00).

However, it was also seen that the full potential was not achieved. Load shift wise, the EMS achieved between 44% (fax system) and 54% (partly automated system) of the maximum possible load shift available. In monetary terms, the system accomplished 49% of the theoretically maximum electricity cost savings.

From the shortcomings of the prototype EMS, the requirements and specifications of a new enhanced system were born. The main purpose of the new enhanced system would be to achieve full load shift and cost savings potential on a reliable basis, without jeopardising operational, safety, health and maintenance values on any pumping system in the SA mine industry.

The development, implementation and performance monitoring of such a new enhanced system is further discussed in Chapter 3.
A new DSM tool was developed. This tool implemented new approaches that ensured maximum, sustainable DSM results. In this chapter REMS was implemented on an intricate pumping system. New innovations were made to the system to accommodate specific user constraints. The results proved that the implementation of REMS at Bambanani mine was successful. This opened up the market for REMS to achieve successful load shift results on complex, intricate pumping systems.
3.1 THE DEVELOPMENT OF THE ON-SITE REMS

3.1.1 Product Description & Control Philosophy

In Chapter 2, a list of requirements and specifications for the new energy system was discussed. This list was compiled from the shortcomings of the EMS installed at Kopanang mine. The requirements and specifications were used as boundaries and guidelines from which REMS was developed.

The information flow and working philosophy of REMS are discussed in this section. In terms of attributes and the control philosophy, the system has a few similarities to the EMS. However, a lot of enhancements and unique extensions were made that changed the daily working operation on the mine. The system also accomplished superior results.

REMS does not have the disadvantage of having to make assumptions about the mine system, because the Optimised Schedule is calculated on-site. REMS has the ability and inputs to calculate the Optimised Schedule in real-time, on-site. Unlike the previous energy management systems, the new REMS is fully automated. The daily working operations totally exclude human operators.

It was already stated that to achieve any electricity load shift and cost savings on a mine, the operation schedule has to be changed from its current one. Mines will only change their operations if there is a very high level of confidence that these changes will not affect the safety and production of the mine.

To gain the confidence of the mine it was very important to prove beyond any doubt that there would be no negative influence as a result of any load shift suggestions by REMS. This could only be achieved if the fully integrated operation of the mine could be simulated in exact detail and verified through historic detailed operational data.

When building the simulation model for Bambanani mine operations, every element in the mining process was simulated in exact detail. For each element a mathematical model was built, which accurately represented that specific component. The model for the component was verified to ensure that it reacted in exactly the same way as the actual component on the mine.
All the simulated components were combined into one integration model, which represented the integrated clear water pumping system of the complete mine. The full control system was then integrated with this model to arrive at a "real life" simulation of the mine.

This fully integrated dynamic system and control model for the mine was verified with detailed measured data. The necessary update of the integrated model was done until perfect verification proved to the Bambanani mine personnel that a successful computer model of the mine was achieved.

The verification process provided the necessary assurance that the simulation model correctly represented the integrated operation on the mine. Figure 20 shows the clear water pumping simulation model for the Bambanani mine.

Once the simulation model was completed and the confidence of the client was obtained, the model was integrated with the SCADA control system of the mine. Other daily varying influences on the final electricity bill, which were incorporated into the system, included the maintenance schedules and the availability of equipment.
The Bambanani system users supplied the model with operational constraints that did not change daily, such as the upper and lower limits for the dams, the equipment on and off limits, as well as the TOU electricity tariff for the mine. All this information was integrated into the system before the simulation model could be optimised for maximum load shift and minimum electricity costs.

Production and operating constraints that were taken into account are the following:

1. Maximum number of pumps active daily
2. Minimum and maximum dam levels and dam capacities
3. Underground water usage
4. Safety constraints
5. Maintenance constraints
6. Allowable on/off switch periods for all elements

A dynamic optimisation procedure was integrated with all the aforementioned to arrive at the Optimum Schedule of all the elements to ensure maximum load shift and minimum electricity costs. It took into account all the safety, health, operation, maintenance or other constraints. The optimised solution interacted with the SCADA system on the mine and controlled the operations via PLCs.

This new integrated technology is called REMS and the information flow is demonstrated in Figure 21.
The Optimised Schedule was calculated on-site every two minutes and was automatically executed as it changed through the mine communication system to the PLCs. Real-time data about the operations of the pumping system from the various pump levels was communicated back to REMS and was immediately taken into consideration for the next Optimised Schedule calculation.

It is important to note that the Optimised Schedule was only calculated once all user operational and maintenance constraints were incorporated into the simulation model. This was not the case with the Kopanang EMS, where the Optimised Schedule was calculated off-site, assuming the abovementioned constraints. This difference was important because the Optimised Schedule and Realistic Schedule (i.e. the schedule that was executed) would always be the same.
3.2 THE IMPLEMENTATION OF REMS AT BAMBANANI MINE

3.2.1 Identify preliminary DSM potential

This section describes the execution of the first DSM potential study as it was done at Bambanani mine. Only if the results of this process were positive, was it meaningful to continue with the implementation process.

Bambanani mine was approached within terms of a questionnaire with fifteen questions about the clear water pumping system. This questionnaire was sent to the Engineering Manager. It was not supposed to take more than 30 minutes of his time, but the information obtained from it was sufficient to form a preliminary idea of the DSM potential.

The fifteen questions focused on the amount of hot water that had to be pumped out of the mine per day, the depth below surface from which it had to be pumped and the electricity consumption of the mine. From these questions, a preliminary idea could be formed about the electricity usage on the clear water pumping system. From the answers, it could be decided if a further DSM potential study would have to be conducted.

The questionnaire that was emailed to the Engineering Manager of Bambanani mine is given in Table 4. The answers that were filled in and sent back are indicated in bold text in the right hand column.
Table 4: The questionnaire that was sent to Bambanani mine.

<table>
<thead>
<tr>
<th>QUESTION</th>
<th>ANSWER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Name of the mine engineer</td>
<td>Lourens Steynberg</td>
</tr>
<tr>
<td>2. How deep is the mine?</td>
<td>2500m</td>
</tr>
<tr>
<td>3. How much water do you pump daily?</td>
<td>65 Megaliters per day</td>
</tr>
<tr>
<td>4. How much pump stations do you have on the mine?</td>
<td>4 pump stations</td>
</tr>
<tr>
<td>5. What are the levels on which the pump stations are?</td>
<td>105L, 91L, 73L, 40L</td>
</tr>
<tr>
<td>6. What types of pumps do you have on the mine?</td>
<td>Sulzer</td>
</tr>
<tr>
<td>7. How much water do they pump per second?</td>
<td>Between 100 and 120 litre/second</td>
</tr>
<tr>
<td>8. Is the SCADA system connected to the pump system?</td>
<td>Yes, to all pumping levels except 73L pump station</td>
</tr>
<tr>
<td>9. Is the pumps controlled by the SCADA system?</td>
<td>No, they are controlled by pump attendants on each pump station</td>
</tr>
<tr>
<td>10. What kind of communication backbone do you have in the mine?</td>
<td>The only communication is via telephone</td>
</tr>
<tr>
<td>11. On which electricity tariff are you?</td>
<td>Nightsave</td>
</tr>
<tr>
<td>12. What is the total electricity usage for summer and winter</td>
<td>We used 49,688,256 kWh electricity last summer and 47,283,952 kWh last winter</td>
</tr>
<tr>
<td>13. Do you control the valves with PLC or manually?</td>
<td>Manually</td>
</tr>
</tbody>
</table>

From the answers, information was obtained to make the following important conclusions:

1. The mine pumped 65 000 000 litres of water per day from almost 2 500 m depth. This was more than 750 litres of water per second. By using first order mathematical calculations it could be said that more or less 21 MW of electricity was consumed to pump that amount of water out of the mine.

2. The mine had an intricate clear water pumping system layout, since there were 4 interconnected pumping stations, each of which had a head of roughly 625 m. Compared with the two pumping stations at Kopanang mine, this mine had a far more intricate layout.

3. Question 8 asked about the current pumping schedule of the mine. They answered it by saying that they switched off the pumps during peak times, if possible. From this answer it could be reasoned, that since they had an intricate pumping layout, which was responsible to pump more than 750 litres of water per second, it was humanly impossible to manually operate the pumping system at the optimum point of cost savings.

4. Question 15 asked about the electricity usage of the mine. When their answer was compared to that of other mines, it was seen that Bambanani mine used the most electricity in the entire Harmony group.
All conclusions that were made indicated that a more detailed investigation had to be conducted. It was seen that they used a lot of electricity on the clear water pumping system. The important question was whether they used it at the optimum point where the maximum electricity cost savings and load shift could be achieved. The answer could only be obtained from examining the baseline of the mine.

The baseline of a mine is a daily average of the historical way/trend in which the mine operated the clear water pumps. By investigating this baseline, it could be seen, on average, over a historic period how much electricity was used during every hour of the day. By focussing on the amount of electricity used during Eskom's peak periods (7:00 - 10:00 and 18:00 - 20:00) it could be determined whether there was any possibility of improving the operation.

The author examined two historical months of daily log sheets for each pumping station. These log sheets consisted of tables that were filled in by the pump attendant on each pumping station every time a pump was switched on or off. By taking the average running time per hour, over a 24 hour profile, for each pump, and multiplying this with the rated electricity reading, and then adding up every pump in the clear water pumps system, a daily average electricity profile was obtained. This is called the baseline of the clear water pumping system. The baseline so obtained for Bambanani mine was for two consecutive months and is shown in Figure 22 below. More information about the calculation of the baseline can be seen in Appendix A.

![Bambanani mine: Electricity profile of the clear water pumps](image)

**Figure 22:** Electricity baseline for clear water pumps at Bambanani mine.
From the baseline in Figure 22 it could be seen that no attempt had been made by the mine to switch off the electrical pumps during Eskom’s peak times. Almost 14 MW of electricity was used per hour during the evening peak periods. The next question to be answered was whether the current profile could be modified to achieve load shift and therefore electricity cost savings. This modification and optimisation could, however, only be done after the simulation model was completed. The simulation model could only be built to simulate the mine system if the real life system was understood completely. This is discussed in the next section.

3.2.2 System layout of Bambanani mine clear water pumping system

Pump capacities

At Bambanani, water is used to cool the underground mining conditions and operations. This water is cooled via two underground refrigeration plants. From these plants the water flows to the mining operations and then back to the settlers. From the settlers the water is pumped via the clear water pumping system and again flowed back to the two fridge plants. The water completes this cycle continually throughout the day. A minimum amount of ground water is also pumped to the surface to keep the water balance intact.

Bambanani mine pumps an average of 650 l/s water from the lowest pump station at 105 level, throughout the day. The water from 105 level (pumps 5,6,8,9 in Figure 20) is pumped to the next pumping station on 91 level and from there to the 75 level hot water dams. 75 level hot water dams supply the underground refrigeration plant on that level with sufficient water.

The fridge plant on 75 level cools the water down from 28 °C to 4 °C. This cold water is used to cool down the mining operations and feeds mining levels downwards to the shaft bottom. On 105 level, the water flows into the settlers where it is separated from mud, before the clear water is pumped up again to 91 level. This internal water cycle continues throughout the day.

Pumps 1,2,3 of the 105 level pump station pump water to 73 level hot dams. From the 73 level dams water is either pumped to 40 level hot water dam or the 58 level dam which supplies the second underground fridge plant with sufficient water. From 40 level hot water dam water is pumped to surface. The only reason why water is pumped to surface is when too much water is in the system, due to ground water seepage into the mine.
On 105 level there are seven electrical pumps (4 x 800 kW and 3 x 1800 kW motors). On level 91 there are seven electrical pumps of 800 kW ratings. There are five 1200 kW electrical pumps on 73 level and on 40 level there are another three 1200 kW electrical pumps installed. The current total installed capacity of the clear water pumps at Bambanani mine is almost 24 MW.

The clear water dam levels and other warm water dam levels are kept between 40% and 90% at all times as per client constraints. To keep the water balance intact the clear water pumping system supplies the dams that feed the fridge plants with sufficient water. A simplified schematic diagram of the clear water system at Bambanani mine can be seen in Figure 20.

3.2.3 Expected load shift and cost saving results

After the system layout of the clear water pumping system was understood completely, a preliminary simulation model of the system could be developed. This was first calibrated and verified so that it could be optimised to obtain the optimum operational point of the pumping system.

The expected load shift results for the Bambanani DSM project are shown in Figure 23. This predicted result was given to mine personnel before the project started. The new optimised pump profile (red line) assumed that equipment was always available and that the clear water system reacted immediately to the Optimised Schedule, as calculated by REMS. The calculations took the operational, safety, health and maintenance constraints of the mine into consideration.
The possible performance of the new on-site REMS technology could be demonstrated by comparing the baseline (blue line) with the recommended optimised profile (red line). There existed more than 5,8 MW load shift potential between 18:00 and 20:00.

The area under each load profile represented the average daily energy use on the pumps. The amount of energy consumed for each profile, however, was the same. As the peak time energy was more expensive, a load shift resulted in an energy cost saving. A load shift of 5,8 MW would result in an electricity cost saving of R 363 000 during the 9 summer months and R 649 000 could be saved during the 3 winter months. This meant an annual electricity cost saving of R 1,012 million.

The abovementioned expected results were documented in a Scope of Work and extracts can be seen in Appendix B. After this was discussed with the management of Bambanani mine, they gave permission to continue with the DSM project.
3.3 LOAD MANAGEMENT AND COST SAVINGS ASSESSMENT

3.3.1 Performance assessment

After approval was obtained from the management of Bambanani mine, REMS was implemented on the mine and the first load shift and electricity cost savings results were obtained. The first DSM results at Bambanani mine are shown in Figure 24.

![Figure 24: DSM results at Bambanani mine from February - July.](image)

A few interesting conclusions can be drawn from Figure 24:

1. The average load shift result for the first three months was 4,19 MW (as indicated by the red circle), compared to the last three months with an average of 6,12 MW. The reason for this was that operators at the mine at first did not have confidence in the fully automatic REMS system. REMS first had to win their confidence. Proof of this can be seen in the percentage of time that the system was in manual control mode. During the first three months REMS was put into manual control mode 53% of the time. During the last three months, however, it was put into manual control mode only 14% of the time.
2. Of the expected result of 5.8 MW load shift that was promised, only 72% was achieved during the first three months. During the next three months, 106% was achieved. This showed that once the control room operators obtained confidence in the automatic system and it was left in auto control mode, an improvement of 34% load shift was obtained.

3. During the four summer months (Feb. – May) an average monthly monetary saving in excess of R 30 000 was achieved. During the 2 winter months (Jun., Jul.) the average monthly saving was R 157 000. From this, it can be said that the electricity cost saving due to load shift is 5 – 6 times smaller during summer months. Over a 12 month period two thirds of the annual saving is gained from the three winter months and the other third is obtained form the nine summer months. This is due to the MegaFlex electricity tariff structure.

4. If a projection for the second half of the year is made, it can be seen that the annual saving will be close to R 750 000. This is, however, only 74% of the expected cost saving of R 1,012 million, which was calculated by means of the simulation model and promised to management of Bambanani mine prior to the commencement of the project.

3.3.2 Operational evaluation

Safety aspects
With the REMS technology, the safety aspects of the mine were fully integrated into the system. It scheduled the equipment on/off control signals according to the safety constraints set by the mine and the equipment manufacturers. Furthermore, it also limited equipment cycling to a specified minimum to ensure a better maintenance performance.

Installation and maintenance
The installation of the REMS technology could be somewhat complex as it is an involved system. However, the system was being further improved to simplify its implementation. After installing the REMS technology, it was maintained and monitored from the remote monitor room in Pretoria.

General appearance
Figure 25 (right) shows REMS in the control room of Bambanani mine. The image on this monitor shows the simulation model of the fully integrated processes. Figure 25 (left) is a photograph of the remote monitor room in Pretoria. The different computer screens, as seen in the figure, show the simulator, SCADA, operation status, optimised schedule etc. From this monitor room the daily
optimum mine operation was managed. Any problem could immediately be detected and acted upon.

Figure 25: Remote monitor room and REMS at Bambanani mine.

3.4 INNOVATIONS DESCRIBED IN THIS CASE STUDY

3.4.1 Operational contributions

It was seen in Chapter 2, that the EMS was dependant on human operators. Because the EMS was so dependant on human operators, on-site and off-site, it had a very high level of maintenance. To obtain load shift and cost savings results, control room operators on the mine had to be contacted every day to ensure that they followed the Optimised Schedule.

It was also seen that because the Optimised Schedule was calculated off-site and then sent to the mine, assumptions had to be made which resulted in undesired situations. This resulted in missed load shift and electricity cost savings opportunities.

In this chapter it was seen that REMS operated automatically on the mine. The simulation and optimisation models of REMS were built into the system that was put on-site. Therefore, it was possible to execute the simulation and optimisation processes in real-time as the clear water pumping system changed throughout the day. If a pump was made unavailable, REMS automatically picked it up and adjusted the Optimised Schedule accordingly. Because REMS was connected to the mine SCADA, it was able to execute the adjusted schedule immediately.
Since REMS was independent of any human operators (they were only responsible for monitoring the system), it had a much lower maintenance level than the EMS. Maintenance still had to be done, but not on a daily basis any more. The remote monitoring room enabled human operators in Pretoria to update any changes on the pumping system from the remote site. This minimised travelling to the mine for maintenance and saved many man-hours.

The operational contributions made to REMS made it possible to obtain much more sustainable results without putting in a high level of maintenance. Once mine control room operators gained confidence in the system, they kept it in auto control mode, without having trouble to keep to an Optimised Schedule on an hourly basis.

3.4.2 Contributions made to the REMS controller

Because the system layout of the clear water pumping system at Bambanani mine was much more complex than other mines, enhancements had to be made to the REMS controller. These enhancements were necessary for the REMS controller to be able to handle the complexity of Bambanani mine. These enhancements are listed below:

Valve Controller

Bambanani mine has three dumping valves in the clear water pumping system. They are normally used only in emergency situations, when pumps are not able to supply water to the hot water dams which are placed before the refrigeration plants. There are two dumping valves between 73 and 75 levels and one dumping valve between 40 and 58 levels dams.

In order to enable REMS to control the complete clear water pumping system correctly, these valves had to be included into the controller. The valve controller controls the minimum and maximum levels of the dams to and from which the water flows, and determines whether the valve is to be opened or closed. It was seen that by controlling the valve between 40 and 58 levels cleverly, an extra 1.2 MW load shift could be moved out of Eskom's evening peak. The valve controller is shown in Figure 26 below.
"Minimum / Maximum Pumps" Controller

Mine constraints for hot dams on 91 and 75 levels were to keep them anytime of the day as full as possible. The maximum and minimum level constraints for these dams were 100% and 80% respectively, meaning they should not be emptier than 80%. Another constraint by the mine was to reduce the number of start/stop operations per pump station.

To keep these dam levels as full as possible without stopping and starting the pumps too frequently, required a controller to specify the minimum and maximum number of pumps that should, or could, be run. This controller enabled the person that implemented REMS on the mine to accurately calculate the optimum amount of pumps to run over the longest period to keep the dam levels intact. Various inputs from the clear water system were used in this controller and the output was then the minimum and maximum number of pumps to run. This minimised the start/stop operations of the pumps.

"Total amount of water in system" Controller

All the water used in the pumping system at Bambanani mine was internally recycled. Only ground water seepage from underground had to be pumped out of the mine through the 40 level pumps.
Because of this unique situation, a further controller was developed and added to the REMS controller that calculated the total amount of water in the water pumping system.

This controller received the dam percentages of all the dams as inputs and calculated the instantaneous amount of water in the system. It then compared this value to a preset maximum amount of water and decided if, and for how long, the 40 level pumps should be run. All the other pumps in the system reacted to this controller to pump the correct amount of water out of the mine. It was very important to keep the water balance intact and thus to enable REMS to use the dams to their full capacities when electrical load was needed to be shifted.

3.5 CONCLUSION

Out of the shortcomings of the partly automated, off-site, EMS a fully automated, on-site REMS was developed. REMS did not have the disadvantage of making assumptions about the mine system, because it calculated the Optimised Schedule on-site. The control philosophy of REMS involved fully automated control and not partly automated control, like the EMS. Human operators were not necessary to transfer the Optimised Schedule from a remote control room and control room operators on the mine were not necessary to execute the Optimised Schedule.

After preliminary DSM potential was identified at Bambanani mine, the baseline of the clear water pumping system was determined. From the baseline, it was seen that there existed potential to shift electricity load out of Eskom’s evening peak. A clear water pumping system simulation model was built and optimised in terms of lowest electricity price. The results were documented and presented to the management of the mine.

After their approval had been obtained, the new REMS was implemented at Bambanani mine. At first, the control room operators on the mine did not have complete confidence in the system. REMS first had to prove itself. This was demonstrated by the fact that the system was only 47% in auto control mode for the first three months. This resulted in a poor load shift and electricity cost savings record.

However, once the operators gained confidence in the system, they kept REMS in auto control mode almost permanently. During months 4, 5 and 6, REMS was 86% in auto control mode, resulting in excellent results. REMS achieved 106% of the expected load shift results and obtained
74% of the expected electricity cost savings. Compared with the remote Kopanang EMS, the improvement in load shift and cost savings were 54% and 49% respectively.

From this case study it was seen that the new REMS was easily able to handle an intricate pumping system such as Bambanani mine. However, this was not only achieved with extensions and enhancements that were made to REMS. The most important innovation was to build the simulation and optimisation models into the system that was installed on the mine. This enabled REMS to independently (without the help of human operators) update and execute the optimised schedule in real-time, as changes were made to the pumping system.

Although the pumping system at Bambanani was far more complex than the simple one at Kopanang, the new REMS achieved better results than the remote EMS. The following case study in Chapter 4 shows how these enhancements were put to good use in a mine with yet another unique type of pumping system.
CHAPTER 4

USING REMS ON A MINE WITH A THREE CHAMBER PIPE FEEDER SYSTEM (3CPFS)

Never yet have load shift results been achieved on pumping systems that included a 3CPFS. The reason for this is that no technology has existed so far that can simulate and optimise a 3CPFS according to load shift results. In this chapter, the working operations of a 3CPFS are described. A simulation model was developed and incorporated into the real-time REMS controller to operate the complete pumping system at the optimum point. The DSM results for Tshepong mine were successful. Once again, new markets were opened where load shift potential could be successfully explored on pumping systems in mines.
4.1 HOW DOES A 3CPFS WORK?

4.1.1 Background

This chapter describes a further development of REMS, the objective of which was to reduce the electricity running costs of a pumping system that also included a 3CPFS. This improved REMS software system had to be able to carry out an optimisation of the system components by means of a simulation model of those components.

The author was part of a project team that became aware that a load management possibility might exist at Tshepong mine. However, this mine operated a 3CFPS and it was well known that there has never yet been an energy management system installed on a pumping system that included a 3CPFS. The reason for this is that no technology existed at present that could accurately simulate the working operations of a 3CPFS.

The findings of the case study in this chapter have been published by Rautenbach, Krueger and Mathews [67].

4.1.2 Working philosophy of a 3CPFS

A 3CPFS is widely used in the mining industry to circulate water from the mine surface (ground-level) to designated points inside the mine itself. This water is mostly used for the cooling of air. Normally, the water is cooled on the surface and then channelled down into the mine. After its use in mining operations, the water must be pumped out of the mine again.

The 3CPFS is so popular because it uses very little electrical energy to achieve this cycling [68]. In principle, a 3CPFS extracts potential energy that is transformed into kinetic energy as the water goes down into the mine and uses this energy to pump the used water out of the mine.

A mathematical model for the 3CPFS was constructed to simulate its overall working. Since it was not the focus of this study to go into an in-depth investigation of the valves and flow dynamics that govern the internal workings of a 3CPFS itself, this was therefore not included into the mathematical model.
An explanation on how a 3CPFS works is given with the aid of Figure 27, which is a schematic representation of a 3CPFS, installed in a typical mine.

![Figure 27: Energy Principles (left) and schematic representation (right) of a 3CPFS.](image)

Column B is cold water being channelled down into the mine where it will be used for cooling, drilling, etc. Column A is hot, used water being pumped out of the mine where it will be cleaned and re-cooled. The 3CPFS uses potential energy derived from the water in column B to pump the water in column A. This energy is obtained from $\Delta h_1$ and $\Delta h_2$ and this give power to the 3CPFS.

The energy that is necessary to produce $\Delta h_1$ and $\Delta h_2$ can be described by

$$E_p = mgh$$

where:
- $E_p$ – Potential energy,
- $m$ – Mass,
- $g$ – Gravitational constant,
- $h$ – Height.

In a typical mine, $\Delta h_1$ is created by pumping the water that is to be channelled down into the mine, into a reservoir several meters above the ground. The water coming out of the mine goes into a dam build at ground level. $\Delta h_2$ is obtained by letting the water in column B flow to the bottom of the mine. The dam, out of which water is pumped, is deeper than this.
The 3CPFS can be considered as a closed energy system. The energy going into the system is obtained through $\Delta h_1$ and $\Delta h_2$ as explained above. The energy that is consumed inside the system is that used to overcome the flow losses and the kinetic and potential energy that ends up in the water itself.

This is described by the equation

$$E_{\text{in}} = E_{\text{out}}$$

where:
- $E_{\text{in}}$ – Energy going into the system,
- $E_{\text{out}}$ – Energy going out of the system.

Equation (2) can therefore be expanded to

$$mg(\Delta h_1 + \Delta h_2) = E_{\text{in}} + E_x$$

where:
- $E_{\text{in}}$ – Head/flow loss as result of flow,
- $E_x$ – Kinetic energy loss that ends up in the water.

The kinetic energy in the water can be described by

$$E_k = \frac{1}{2}mv^2$$

where:
- $m$ – Mass,
- $v$ – Speed.

The head loss is as a result of friction during flow. The head loss in the piping and in and around the valves, elbows, links, etc. is calculated using the Hazen-Williams head loss equations [69].

$$h_f = SL$$

where:
- $h_f$ – Head loss,
- $L$ – Length,
- $S$ - Head loss $/ \text{length of pipe}$.

$S$ is calculated

$$S = \left(\frac{v}{kC R_h^{0.63}}\right)^{\frac{1}{6.54}}$$

where:
- $k$ = Minor loss coefficient,
- $C$ = Table of Hazen-Williams coefficients,
- $R_h$ = Hydraulic radius.
Rₙ is specific to the shape of the ducting. Rₙ for circular tubing can be calculated as

\[ Rₙ = \frac{D}{4} \]  \hspace{1cm} (7)

where: \( D \) – Inside diameter of the tubing.

The values for \( k \) and \( C \) can be obtained from the Hazen-Williams Coefficient tables in Ref [69].

The 3CPFS consists of three chambers, marked C, D and E, which link column A and B. During the pumping process, these three chambers go through the same cycle, but in sequential phases.

For clarity, a section cut has been made into the chamber marked E. The cycle that each chamber goes through is as follows. Let's assume the chamber is filled with used hot water. The first stage of the cycle will be when valves open in such a way that cold unused water can flow, because of \( \Delta h₁ \), out of column B into this chamber. This cold unused water will then push the hot used water up into column A.

The chamber is now filled with cold water. The second stage will be when certain valves open in such way that this cold water is pulled, due to \( \Delta h₂ \), further down into column B. This will result in used hot water being sucked out of column A into the chamber. After this phase the chamber is again filled with used hot water and the cycle is completed, ready to start all over again.

There is no physical separation between the used and unused water in the chambers, but there is a huge amount of water being pumped compared to the amount of mixing. The mixing is tolerated because this system can pump water out of the mine without using any electricity.

However, there are many problems associated with this system. Experience has show that the biggest problem is the maintenance of the valves that govern the flow inside the 3CPFS. These valves undergo extreme stresses when opening and closing. This hammering on the valves can cause substantial downtime of the system, which can be costly and time consuming.

The simulation model of the systems creates the opportunity to build an optimisation engine. The heart of the optimisation engine is the system simulation upon which a component scheduler is build. The output of the component scheduler is an operation schedule for every controllable component in the system.
4.2 CAN REMS CONTROL A PUMP SYSTEM THAT INCLUDES A 3CPFS?

4.2.1 Control Approach on the pumping system

It is important to start by saying that if a 3CPFS is a stand-alone system, it will not be financially feasible to implement an energy management system. There will be little or no load shift and electricity cost savings potential because of the little electricity being used by a 3CPFS [68].

However, in the mine industry most 3CPFS are not stand-alone systems. In a clear water pumping system a 3CPFS is normally supported by electrical pumps on the same and other pumping stations. This is because the pumping of water is one of the most important operations on a mine. Enormous financial losses, as well as human losses, can be suffered if the pumping of water out of the mine fails. On any mine, there are normally not less than 2 emergency back up electrical pumps on a pumping station. If a 3CPFS is installed on a pumping station, emergency back up pumps must also be provided.

As was seen in the previous section, the 3CPFS works on the following principle: “For every litre of water that is moved through the 3CPFS out of the mine, a litre of water must go down.” Therefore, the surface chill dam, bottom chill dam, surface hot dam and bottom hot dam must have sufficient capacities to handle the amount of water. These four dams must always be at the right levels to enable the 3CPFS to move the water from the bottom hot dam.

If a situation occurs where the surface chill dam is empty and the bottom hot dam is full, the 3CPFS cannot be used to move water out of the bottom hot dam. In such a situation, where the bottom hot dam needs to be emptied, electrical pumps will have to be used to pump the water to the surface hot dam. See Figure 27 for clarification.

With an energy management system, load shift and electricity cost savings are the objective. To guarantee this it is important that the dams of the 3CPFS are at the correct levels before Eskom’s peak times. This is to make sure that the 3CPFS is used to its full potential during peak times with the intention for electrical pumps to be switched off.

The control approach will be to include the 3CPFS, together with all its constraints (surface and bottom dams) as well as the electrical pumps on other pump stations, in an integrated simulation model. This will then be optimised to ensure maximum load shift and minimum electricity cost on the clear water pumping system.
It is thus seen that a clear water system, which includes a 3CPFS, can be controlled by REMS. The difference is that a separate simulation model for the 3CPFS must be developed. This will include all the normal safety, health, maintenance and production constraints, as well as the specific 3CPFS constraints. Once this standalone 3CPFS simulation model is calibrated and verified, it is integrated into the clear water pumping system simulation model. From there the optimisation is exactly the same as any other DSM project on clear water pumping systems.

4.2.2 Simulation and Optimisation model

Simulation model

Based on the results of previous studies, the simulation tool QUICKcontrol was used to perform the required simulations [70]. The model on which the simulation tool is based is briefly discussed in this section. The programme has been verified in over 100 case studies, which illustrates the value, and verifies the capability, of this simulation tool.

Mathematical equations are used to model the water pumping system of the mine as accurately as possible. The component models link inputs to the basic variables in the system. These are based on the simplified fundamental principles combined with correlation coefficients derived from discrete empirical data.

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. The correlation coefficients for a specific make and model of equipment can be derived from data obtained during measurements or manufacturer's data sheets.

To simulate dynamic effects, a simple time constant approach is used. The user is responsible for supplying the time constants. The approach is as follows:

\[ \frac{d\varphi}{dt} = Function \times \frac{1}{\tau} \]

(model input parameters), with \( \tau \) the time constant of the model and \( \varphi \) one of the output parameters of the model. The relevant psychometric relationships are employed in all models, including the 3CPFS, dealing with the clear water pumping system.
The simulation model makes provision for proportional, integral, derivative, on/off and step controllers. These controllers are used in many control applications. With these controllers any measurable condition can be controlled from a sensor. Water flow rates, dam levels and electricity consumption of the system are controllable variables.

Controller output at each step is only dependent on the previous step values. This considerably reduces the complexity of the solution algorithm. From a system point of view, this implies that the controller acts like a controller that has a sampling rate corresponding to the system integration time step size.

There are also energy management systems included in the simulation tool. With these, system energy consumption can be reduced by more energy-efficient control. The simulation tool provides a series of energy management strategies.

The simulation model is build up out of modular mathematical models. Each model represents a different component of the water pumping system. These models are developed with the goal of portraying the effect that this specific component will have on the systems as a whole.

Each mathematical model was developed with a standard interface. This was done to enable the models to exchange data based on a set standard. The data that is conveyed between these models includes flows, temperatures, statuses, etc.

The models were all linked and run on a simulation platform that is built on the principles as described above. The function of the platform is to control and extract information from the mathematical models and present this in a usable format to the user.

Simulations can also be used to predict the future status of a system. The simulation can be run at faster-than-real-time to reach a simulated system condition or status of the system. This principle was also used in this study.

As this simulation model is to be used in a control system, it must be designed to be unconditionally stable. The control system is to be used on a mine, and a financial loss results if the control system should fail. A simulation model that, under certain conditions and input values, does not come to an answer, will therefore not work for this application.
This implies that the mathematical models that are used to create the individual components must be explicit. An implicit equation does not always yield an answer, or it can yield more than one answer. This is not acceptable, as this will cause the simulation model to be unstable.

The mathematical models were therefore created in such a way that a solution is always reached. All recursive and loop functions are created in such a way that they stop after a number of cycles have been completed. This can lead to a certain amount of inaccuracy, but the error made is small compared to the duration for which the simulation is run.

In order to verify the simulation, it must run for a couple of days where the simulation status is synchronised with the real-life status at the beginning of each day.

Figure 28 shows the actual and simulated levels of one of the dams of the Tshepong mine system. (The correspondence between the actual and simulated levels of the other dams were very much the same and are not reproduced here to avoid duplication.) These figures give results for a 24-hour period and show that, on average, a less than 3,5% deviation accumulated in a 24-hour time period. This gives an indication of the accuracy of the simulation.
Optimisation model

The simulation model of the systems creates the opportunity to build an optimisation engine. The heart of the optimisation engine is the system simulation upon which a component scheduler is build. The output of this component scheduler is an operation schedule for every controllable component in the system.

This operation schedule consists of on/off, open/close and set point instructions for every controllable component in the system, for the next 24-hours. Controllable components can be pumps, valves and 3CPFS. The controllable components in this case study are electrical pumps and the 3CPFS.

The optimisation philosophy is based on a feedback principle. The effect of every action is tested in a feedback loop. Every conceivable action can be tested by repeating this feedback loop. The best, or optimised, actions are found by selecting the action that results in the best outcome.

The optimisation process is not at fixed cycle, but a generic, dynamic procedure. The procedure is developed in such a way that it can, on its own accord, skip, re-run or back-run any of the steps in the optimisation procedure. This dynamic process adapts itself to the problem and gives a more reliable and faster way to reach an answer.

Figure 29 shows the optimisation cycle that is used for the component scheduling and control. During steps one, two and three the components and their operation schedules are handled individually. The system and the complete operation schedule are handled as a whole in steps four to six.
1. Investigate components effect of system

2. Compute primary schedule for component

3. Test if schedule comprises to system constraints

4. Optimise and incorporate changes

5. Test all component schedules as a whole

6. Optimise and incorporate changes

Figure 29: Optimisation cycle.

The first step of the optimisation uses the simulation model of the system. Simulations around the specific components are conducted to investigate the effect that each one's operation will have on the system as a whole. This information is needed in the steps that follow.

At this stage the information of how each component will affect the systems is known. This information is then used to compute a primary schedule for each component individually. This is done during step two of the optimisation cycle. This schedule is computed to obtain the most ideal future for the system.

In this case, the specified ideal future for the system is where the electricity cost is the lowest. This is calculated by finding the electricity usage by running a simulation of the system. The cost is then calculated by multiplying the electricity usage by the electricity pricing profile.

Step three in the optimisation cycle will test the schedules that have been calculated for the individual components against the systems constraints. Systems constraints include maximum and minimum dam levels, maximum number of pumps running at any one time, etc. If any constraint is broken, the cycle will go back to step two where the schedule will be altered to remedy the problem.

This test procedure is done by running the simulation while the component schedule is applied. The simulation is started with the real-world system's status as start values. The simulation is then run...
at faster-than-real-time speed. This gives an almost immediate prediction of the effect that the tested schedule will have on the system.

Optimisation is done during step four. After the schedules for the individual components have been calculated, they are put together. The system will alter the schedules of each component to make sure that all the schedules work together. Conflicting actions are eliminated.

During step 5 all the schedules are put together and again tested in the simulation model. All the operation constrains, as given by the operators, are tested and confirmed. If any of these should be violated, the optimisation cycle will go back to step 4 where the schedules will be altered to remedy the problem.

Step 6, like step 4, takes all the schedules together and eliminates any conflicting actions, if present. If changes are made, the cycle goes back to step 5 where the schedules are again tested again.

4.3 TSHEPONG MINE: A CASE STUDY

4.3.1 Tshepong mine system layout

During a preliminary DSM potential study it was found that Tshepong mine has a 3CPFS included in their clear water pumping system. At first one would think that there is little or no need to implement REMS at such a mine. However, after further investigation it was seen that there existed scope to manage the 3CPFS together with the electrical pumps at an optimum point to realise load shift and cost savings.

Tshepong mine is a Harmony Gold mine, situated near Odendalsrus in the Free State province of South Africa. The mine has two pumping stations, 66 level pump station situated 2200 m below surface and 45 level pump stations situated 1 500 m below surface.

The 3CPFS is situated on 45 level pumping station and is responsible for delivering used, hot water in the mine from 45 level pumping station to the surface dams. The hot water is then cooled and again channelled down into the mine where it is used to cool air, prevent dust and in mining...
operations. From there it is collected, cleaned and again fed into the clear water pumping system, thus completing the water cycle. This cycle can be seen in Figure 30.

![Figure 30: Tshepong water cycle.](image)

The clear water pumping system starts with dams 1, 2, 3 and 6 on 66 level. Together they have store capacity of 9 MI. All the used, hot water in the mine is channelled through open drains to these dams where it is cleaned from mud in the settlers. The pumps labelled '66-1' to '66-7' pump the water out of these dams to the next two dams in the system on 45 level pump station.

From there the water is pumped / moved via pumps '45-1' to '45-3' and / or the 3CPFS to the surface Pre-cool dam. From the Pre-cool dams the water is cooled through the refrigeration plants and channelled down the mine again.

The 3CPFS is responsible for delivering 30 240 m³ water out of the mine every day. The 7 pumps on 66-level are each driven by 1 500 kW motors, capable of delivering 120 l/s. The 3 pumps on 45 level are each driven by 2 500 kW motors, capable of delivering 120 l/s. The current installed electricity capacity to pump the water out of the mine is 18 MW (excluding the 3CPFS).
4.3.2 The DSM potential

There are two types of constraints applicable to this system. These are the available number of pumps and the minimum and maximum dam levels. On level 66, there are seven electrical pumps. The level 66 hot water dam must be kept between 15% and 100% at all times.

On level 45, there are three electrical pumps. The hot water dam level on level 45 must be kept between 15% and 100% as per client constraints. To keep the water balance intact the clear water pumping system must supply the surface hot dam with sufficient water.

It is important to point out that load shift can only be achieved if there is adequate storage capacity for the water during peak periods. This was indeed the case at Tshepong where the 66 level hot water dams were large enough to accommodate all the water flowing into the dam during the peak period when pumps are switched off.

Through the simulation and optimisation models it was seen that there existed load shift potential on 66 level pumps. This would be possible to achieve if the 3CPFS was controlled with the REMS 3CPFS controller. There existed 3,1 MW load shift potential and an estimated electricity cost saving of R 200 000 per year for Tshepong mine. The result of the simulation and optimisation models is given in Figure 31.

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**Figure 31: Expected load shift results that can be realised by REMS for Tshepong mine.**
No other operational parameters of the mine were affected by shifting load in the hot water pumping system. The water-flow used for cooling the workings continued exactly the same as operational schedules demanded (with or without load shift). There was also no net energy consumption saving, since the same amount of energy required to pump the water remained unchanged. The only factor that generated energy cost savings was the fact that water was pumped mainly during off-peak hours, and not during the peak demand (high tariff) hours.

4.4 CALCULATING LOAD SHIFT AND COST SAVINGS

4.4.1 New approach to determine the baseline for a system that includes a 3CPFS

In order to be able to calculate any savings or load shift of the new system after implementation, it was first necessary to determine the historic electricity consumption baseline / trend of the pumping system before REMS was implemented.

In Chapter 3 the definition of a baseline was discussed. It is a 24-hour profile that describes the average electricity usage over a certain period. Each value gives the accumulated kW electricity used for that specific hour that was consumed by a system.

A clear water pumping system that includes a 3CPFS differs from a normal system. To determine the correct baseline, three different baselines were required. The first, baseline A, was the baseline for the system when the 3CPFS was fully operational on a 24-hour basis. The 3CPFS carried a part of the electrical workload, but without using any electricity.

The second, baseline B, was the baseline for the system when the 3CPFS was not operational. The electrical pumps were therefore solely responsible for carrying the full workload. Two pumps on 45 level pumping station had to be started to compensate for the workload that the 3CPFS usually carries. The pumps on 45 level are 2500 kW each. Baseline B must therefore allow for the additional 5 000 kW, as this is the extra amount of energy needed to compensate for the 3CPFS not working.

The third, baseline C, was a baseline for the system when the 3CPFS was operational for only a certain time or periods of the day. This base line is a combination of sections of baseline A and
baseline B, depending on whether the 3CPFS was working or not. Thus, baseline C varies between baseline A and B, depending on the working operation of the 3CPFS.

Figure 32 shows a typical example of baselines A and B. It also shows an example of how baseline C can look when the 3CPFS is not operational, say, between the hours 4:00 - 6:00 and 13:00 - 16:00.

During the case study, baseline C was inevitably used, as there were only a few days during which the 3CPFS was either fully operational or totally out of order. As the 3CPFS experiences significant down time because of maintenance, the operation of the 3CPFS was therefore carefully logged to make the calculation of every day’s base line possible.

4.4.2 Results for test period

A new electricity usage profile was drawn up during the period when the clear water pumping system, together with the 3CPFS was controlled by REMS. As with the baseline profile, this current usage profile was drawn up using empirical measurements.
Figure 33 shows the average results achieved for the month of August. It can be seen that the electricity usage dropped below the baseline during the periods when the electricity tariff was the highest.

The total saving recorded during August was approximately R 42,000. The average saving was close to R 1,400 per day. It is also clear that the average electricity consumption was below the base line during peak hours. This resulted in an average of 3.9 MW load shifting per day.

![August Summary Graph](image)

Figure 33: Summary results for August.

Figure 34 shows the average results for September.

There are three winter and nine summer months in the MegaFlex pricing structure. The predicted savings for one year was approximately R 186,000. Since the study had not yet run for a full year, this prediction could not be verified. A predicted 3.9 MW could be shifted on average each month.

4.6 CONCLUSION

The installation of REMS at Telpong mine was successful. Of the 3.1 MW load shift that was predicted 3.9 MW and 3.4 MW were actually achieved during August and September respectively. The mine continues to this day to perform well above expectations.

Chapter 4: Using REMS on a mine with a Three Chamber Pipe Feeder System
The total saving realised in September was R 7 150. This related to an average savings of R 238 per day. Since September fell under the summer period of the MegaFlex pricing structure (which is more lenient, since peak demand in summer is not such a big problem for Eskom), the savings in September were far less than during August (winter). However, the load shifted on average was still significant at a calculated 3.4 MW per day.

There are three winter and nine summer months in the MegaFlex pricing structure. The predicted savings for one year was approximately R 195 000. Since the study had not yet run for a full year, this prediction could not be verified. A predicted 3.6 MW could be shifted on average each month.

4.5 CONCLUSION

The installation of REMS at Tshepong mine was successful. Of the 3.1 MW load shift that was predicted, 3.9 MW and 3.4 MW were actually achieved during August and September respectively. The mine continues to this day to perform well above expectations.
This is the first time that an energy management system has been installed on a pumping system that includes a 3CPFS.

This was accomplished by designing a separate 3CPFS-simulator and including this into the REMS controller. The complete pumping system could be simulated and was then optimised for maximum results.

Although the 3CPFS is not currently installed on many mines in South Africa it is becoming more popular. The author knows of three gold mines that are adding 3CPFS to their pumping systems. Therefore, the successful implementation of REMS on a mine with a 3CPFS enhances the marketability of REMS. REMS can now be applied to a larger range of mines in the South African mine industry.
Previously, mines without adequate instrumentation and control infrastructure had not been considered for DSM projects. Automated load shift requires an intensive investment in capital infrastructure. Therefore, mines that did not have this capacity did not even consider the possibility of engaging in load shift projects. In order to address this additional market, REMS was adapted so that it could operate with minimum infrastructure. This was then incorporated into the REMS product range for DSM proposals.
5.1 SITUATION ON THE MINE BEFORE A DSM PROJECT

5.1.1 Current control philosophy on mines without infrastructure

Masimong 4 and Harmony 3 shafts are Harmony Gold mines, situated near Virginia in the Free State province of South Africa. The author approached the mine management and asked them to complete simple questionnaires with questions about the clear water pumping systems. These questionnaires indicated that pump attendants manually controlled the pumps on these two shafts.

No instrumentation infrastructure existed that enabled the mine to control the pumps from a central point on the mine. All the mines in the previous case studies were equipped with the necessary instrumentation and software to monitor and control the operation of the clear water pumping system from a central control room on surface.

At Masimong 4 and Harmony 3 shafts pump attendants manned the pumping stations 24-hours per day, 7 days a week. They had the responsibility to keep the dam levels between certain safety values by starting and stopping the pumps. If the store dam on the pumping station was filled and reached a certain high level, they started a pump. If it reached a higher level they started the next pump and so forth. Conversely, when it became empty and reached a certain low level a pump was stopped. When it became emptier and reached a lower level, they stopped the next pump, and so on.

The engineer on Masimong 4 shaft had made this procedure very simple for the pump attendants. Below is a picture (Figure 35, left) that was taken on one of the pump stations of the mine. The instructions in this picture were strict guidelines by which the pump attendant had to stop and start the pumps according to the dam reading from the pressure gauge (Figure 35, right).

It is important to note that these instructions would work under normal circumstances. It made no provision for any emergency conditions. For example, when one pump was running and the dam reached 55%, the second pump should be started. But the instructions stopped there. What happened when two pumps were running and the dam volume still rose? At what percentage should the pump attendant had started the third pump? In such a scenario the engineer would be called out to the mine to give emergency instructions.
The only responsibility of these pump attendants was to keep the dam levels between two safe values. It was clear that they were not cost savings driven or load shift orientated and therefore did not mind starting the pumps during Eskom's peak (high priced) electricity periods. This was clear from the baselines of Masimong 4 and Harmony 3 shafts.

The baselines for these two mines were obtained from log sheets, filled in by the pump attendants on an hourly basis every day. Figure 36 and Figure 37 show typical baselines for these mines.

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![Figure 36: Baseline profiles for the clear water pump system of Harmony 3 shaft.](image-url)
From these baselines, it was evident that no attempt had been made at these two shafts to try to keep their pumping operations out of Eskom's evening peak period. At Masimong 4 shaft, some electrical load was shifted out of the morning peak, especially on Sundays. But since the MegaFlex tariff structure does not differ for peak hours on Sundays, no substantial electricity cost saving was achieved.

It was not reasonable from the management of a mine to expect the pump attendants to stop the pumps on each pump station during the high priced periods. It must be remembered that a clear water pumping system has to be prepared for a whole day to be able to stop pumps at certain periods during the next day. A mine like Bambanani pumps on average 650 litres of water every second of the day. To leave the responsibility of energy management to the pump attendants might result in fatal accidents. It was therefore far too much of a safety risk to expect pump attendants to stop pumps during peak periods.

5.1.2 Current start up procedure

Masimong 4 and Harmony 3 shafts had similar manual procedures that had to be followed to start a pump. This start up procedure is described in the following steps:

- Step 1: Open up suction valve and make sure that spindle opens. The suction valve has a ratio of 19:1, meaning for a 12 inch column it has to be turned 228 times. Two persons are necessary to do this.
• 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 bearings and no water in bearings.
• Step 4: Make sure the delivery valve is closed. Open delivery valve 5%. (Approximately 12 turns.)
• Step 5: Now pump is ready to start. Push the start button on electrical 6,6 kV switch gear.
• Open delivery valve slowly until fully open (approximately 216 turns). Make sure motor current is synchronised at 100 A.
• Step 6: While pump is running, continuously check that oil ring is turning in pump and that motor bearings are not overheating.

It was clear that the start up procedure is complex and unwieldy. It took two pump attendants approximately 10 – 15 minutes to start a pump and then to continuously check the bearing temperature while it was running. Another interesting fact was that when pump attendants changed shifts, the pumps were unattended for a dead period of roughly 30 minutes.

The cumbersome manual start up procedure, and the unattended period, made it difficult to execute a 24-hour optimised schedule in order to obtain peak load reduction and minimum costs. (However, when the above start up procedure is automated; it takes REMS no more than 2 minutes to start a pump.)

5.1.3 Why remote control is essential for REMS

In order to shift load, the operation schedule on a mine has to be changed from its current one. REMS shifts load through switching off the clear water pumping system during peak times, and switching them on again during off-peak hours. The correct schedule for the pumps is sent to the pumping system from the REMS computer. This equipment is situated in the control centre on the surface.

The Kopanang study showed that merely instructing operators to switch off the pumps manually at certain times did not work. This is because the inter-relationship between dam-levels, pumps and water flow rates on most mines is far too complex for manual optimisation. REMS calculates the best times to do this and by switching the pumps on and off automatically, eliminates the human element. This is the primary advantage of REMS.
REMS manages this on/off switching of the pumps from the remote control centre. However, to enable it to do this, certain infrastructure has to be installed. This infrastructure essentially consists of a control room, a SCADA located in the control room, instrumentation sensors at the equipment that must be controlled, and communication to the electric switchgear at that equipment. Without this infrastructure, REMS does not have the ability to control the equipment.

Fortunately, certain mines like Kopanang and Tshepong already have the necessary infrastructure in place for remote control of the pumping system. However, most of the gold mines in South Africa need additional instrumentation and/or other equipment to be able to operate the clear water pumping systems from surface. In such cases, the required infrastructure has to be put into place prior to REMS being able to do its work.

Remote control from one central point on the clear water pumping system is thus essential for REMS. Without this REMS will not be able to automatically execute the Optimised Schedules.

5.2 IDENTIFYING LOAD SHIFT POTENTIAL

5.2.1 System layout of Masimong 4 and Harmony 3 shafts

Harmony 3 shaft

This mine is currently used as a pumping shaft. It pumps the water from Merriespruit 1, Merriespruit 3 and Harmony 2 shafts to the surface. The Masimong 4 and 5 operations are dependant on the pumping operations of Harmony 3 since the underground water table between these mines is connected. If Harmony 3 were to stop pumping, Masimong 4, Masimong 5, Merriespruit 1 and Merriespruit 3 would flood. This mine pumps a daily average of 19 MI water.

At present Harmony 3 shaft pumps an average of 162 l/s water from 14B level throughout the day. This water ends up at the hot water dam on level 4/3. It is then pumped via the 4/3 level pump station to the surface dam. The current installed capacity to pump this water is 11 MW.
Masimong 4 shaft

The expected life of this mine is at least 16 years. It pumps water for its own use and for its neighbouring mine, Masimong 5 shaft. Masimong 4 is approximately 2 250 m deep with a number of levels underground on which they have been mining over the years. The mine only contains two pumping stations, one on the bottom level, (which is 2180 meters below surface) and the other only 1 200 m below surface.

Masimong 4 shaft pumps 11 Ml of water each day from underground. The water to cool the underground mining is cooled by a surface refrigeration plant. From this it flows to mining operations and then to settlers. From here, it is pumped to the surface dam in a cycle that is repeated constantly. The current installed capacity to pump this water is 11 MW.

A simple schematic illustration of the water cycles at the Harmony 3 and Masimong 4 shafts can be seen in Figure 38.

![Figure 38: Schematic illustration of water cycles at Harmony 3 and Masimong 4 shafts.](image)
5.2.2 DSM simulation models and expected results

Different simulation model scenarios

After the system layout of the clear water pumping systems had been intensively studied, preliminary simulation models of the systems were developed. These were calibrated and verified until they could be optimised to obtain the optimum operational point of the pumping systems. The outputs of the optimised models were maximum load shift and electricity cost savings.

The same simulation tool that was used for Tshepong and Bambanani mines, namely quickcontrol, was used for the simulation of Harmony 3 and Masimong 4 shafts. For these simulation models to have any effect and accurate results, it was built according to the real-world applications. This process was thoroughly described in section 4.2.2. In Figure 39 the viewer simulation model of Masimong 4 shaft is illustrated.

![Figure 39: Simple presentation of the simulation model of Masimong 4 shaft.](image-url)
Because the mine is a dynamic system and certain variables cannot be predicted, the simulation model was built to simulate all the different scenarios for the unpredictable variables. The model was then simulated for every possible value of the unpredicted variable. The predicted variables were used as inputs together with the different possibilities of the unpredicted variables. The simulation was necessary to ascertain that the system could handle the scenarios without compromising on the results. Only then it was possible to present the load shift results with certainty and to confidently implement REMS on those results.

One of these uncertainties was the varying inflow of water into the shaft bottom dams per day. Due to this unpredictability, the water capacity in the system varied from day to day. Because the daily water capacity in the system was directly related to the load shift potential, the need for simulation of the different possible scenarios was of utmost importance.

Below is a description of different scenarios that were simulated at Masimong 4 shaft. Three different scenarios for the inflow of water were assumed. Scenario one was done for a normal water balance in the system. Scenario two and three were done for a high water balance in the system. The question was if the high water balance meant that the pumps and dams in the system still had spare capacity to shift electric load out of peak times, without violating the maximum dam level constraints. This could be answered once the simulation models were built and optimised.

**Simulation scenario 1: Normal water inflow**

Scenario 1 was done to illustrate the potential for electric load shift when the water balance in the system was normal. As illustrated by point B in Figure 40, all the pumps at Masimong 4 were stopped during the morning peak period (7:00 – 10:00), with the 2180 dam level rising 23% to a level of 69%.

After the morning peak 2180 dam level was still low enough to prepare for evening peak period (18:00 – 20:00). The dam level before the evening peak was 51% and with a rise of 16% during this period, the dam level would be 67% after peak time. This was still well within the maximum dam level constraint of 85% as specified by the mine. This is illustrated by point A in Figure 40.
Thus, with a normal water balance it was possible to achieve maximum load shift during the morning peak without influencing the potential of maximum load shifting during the more important evening peak. This simulation model had shown that through optimisation, the maximum load could be shifted during both peak periods of the day for a normal water balance.

**Simulation scenario 2: High water inflow compromising evening peak load shift**

Scenario 2 was specified to determine the impact on load shift for a high water balance. This high water balance could be caused by the continuous rapid inflow of water into the system. As illustrated in Figure 41, the yellow line represents the electricity usage of all the pumps running on an hourly basis, while the blue line shows 2180 dam level. With all the pumps switched off during the morning peak (marked B), the dam level had increased by 30%. (Note that this increase was higher than scenario 1 because a higher inflow of water was assumed.)

After the morning peak period, the maximum number of two pumps on 2180 level were started up to prepare the level of the dam in order to shift maximum load during the evening peak. The dam level before evening peak was 68%. When all the pumps were switched off, 2180 dam level rose at 10% per hour. The need for starting pumps during the second hour of the evening peak arose when the maximum dam level of 85% was reached. This is shown in point A.
Scenario 2: High inflow of water

Max dam limit = 85%

Optimised baseline (kW) - 2180 Dam level status - 2180 Maximum dam level

Figure 41: Simulation results with high inflow (comprising evening load shift).

Thus, the load shift during the morning peak influenced the maximum potential for load shift during the evening peak if the water balance in the system was very high. Because the evening peak was more of a concern for Eskom, it would be more practical not to shift optimal load during the morning peak and rather to prepare for optimum load shift during for the evening peak. This possibility was investigated in scenario 3.

Simulation scenario 3: High water inflow and still obtaining an evening peak load shift

Scenario 3 was also simulated to determine the impact on load shift of a high water balance. The difference was that the morning peak period was not used for maximum load shift, but rather as preparation of the 2180 dam levels for maximum load shift during the evening peak.

As seen in Figure 42 point B, not all the pumps were stopped during the morning peak in order to prevent 2180 dam level to rise to high. The dam level only increased with 13%, which was low enough to effectively prepare the dam level for the evening peak. With the dam level at 61% before the evening peak period, and the increase in the dam level still being 10% per hour with all the pumps switched off, the maximum dam level of 85% would not be reached. This meant that the
pumps would remain switched off, obtaining optimal load shifted. Point A in Figure 42 illustrates that all the pumps were switched off during peak time.

---

**Scenario 3: High inflow of water**

![Graph of Scenario 3](image)

**Figure 42: Simulation results with high inflow (realising full evening load shift).**

The simulation model showed that when the water inflow was high, all the pumps should not be switched off during morning peak. This would cause the 2180 dam level to rise too high, and the system would not be able to prepare enough for the evening peak. In this scenario, it was better to compromise some load shift during the morning peak to ensure maximum load shift during Eskom’s important evening peak.

**Expected Results**

After all the different scenarios were simulated, verified and optimised, the predicted results could be documented and presented in a Scope of Work for management at the different mines. Extracts of the complete Scope of Works can be seen in Appendix B. The expected results were as follows:

- **Masimong 4 shaft**
  
  It was predicted that REMS would be able to shift 3.9 MW electricity load out of Eskom’s evening peak period. Because the mine was on the MegaFlex tariff structure, the load shift would result in an average electricity cost saving of R 74 000 during winter months and
This added up to an annual cost saving of R 335 000 for Masimong 4 shaft.

- **Harmony 3 shaft**
  At this mine, REMS was expected to shift 3,8 MW electricity load out of Eskom's evening peak period. This mine was also on the MegaFlex tariff structure, and the load shift would achieve an average electricity cost saving of R 136 000 during winter months and R 25 000 during summer months. This resulted in an annual cost saving of R 638 000 for Harmony 3 shaft.

### 5.3 IMPLEMENT ADDITIONAL INFRASTRUCTURE AND REMS

#### 5.3.1 Remote control of pumps

It was described in Section 5.1 how the pumps at Masimong 4 and Harmony 3 shafts were controlled manually by pump attendants before REMS was implemented. New control instrumentation therefore had to be installed in order to control the clear water pumping system from one central point on each mine. The manual control situation on the two mines was almost the same, except that Harmony 3 did not have a control room.

Normally the control room on a mine is the central point from where different operations are controlled. At Bambanani and Tshepong mines, the REMS system was implemented in their control rooms. Part of the REMS project at Harmony 3 was to identify a suitable place where all the network points from the underground pumping stations could come together and where the REMS control system could best be implemented.

The additional infrastructure that had to be installed and commissioned before remote control on the clear water system could be done is discussed below. These steps had to be done at Harmony 3 and Masimong 4 shafts to enable remote control. Only after these steps were completed and tested, the REMS implementation could start.

For both the mines a SCADA had to be supplied and installed. This Adroit SCADA (Figure 43) would be linked to the pumping stations (1280 level and 2100 level at Masimong 4 and 14B and 4/3 at Harmony 3) via a new fibre optic network for communication. The network would comprise of an
Ethernet switch in the surface control room mounted in a 19" rack cabinet and connected to the SCADA via Ethernet.

The fibre in the shaft was connected on each level to a switch that in turn was connected via Ethernet to a Quantum Schneider Ethernet module in each PLC rack. Each PLC rack consisted of a CPU, Ethernet module, analogue and digital input and output modules. A vibration transmitter, flow switch, pressure switch and automatic valve that consisted of an electric actuator was installed on each pump and connected to a junction box via single pair cables (Figure 43). The junction box was then connected via a multi-core cable to the PLC for interlock, trip and remote monitoring and controlling.

All Low Tension (LT) and High Tension (HT) drives were interfaced with the PLC to facilitate remote control and monitoring of the pumps from a surface control room. Each PLC was mounted in an enclosure with a Human Machine Interface (HMI) that had to be installed in the panel door to facilitate control and indication on the pump station. The system was then commissioned and tested on a pump-by-pump basis, to ensure minimum interruption of the day-to-day operation of the mine. All fibre optic cable was spliced and tested prior to commencing with commissioning. All loop drawings for panels and junction boxes were supplied.

A breakdown of the main equipment items for Harmony 3 and Masimong 4 is given in Appendix F. For the two projects, the above described work was subcontracted to a control and instrumentation company but the specifications and project coordination were done by the author.

Figure 43: Readings of field instrumentation concerning a pump and the complete pump system as represented by the SCADA at Masimong 4 shaft.
5.3.2 Unique innovations added to REMS to accommodate these mines

With the implementation of REMS at Harmony 3 and Masimong 4 shafts, several shortcomings became evident that required further modifications to REMS to accommodate these mines. The main reason for these shortcomings was that this was the first time that REMS was implemented on mines that had no remote control infrastructure prior to the REMS installation. Thus, mine personnel were not used to operating the clear water system from a central control point.

Because Harmony 3 does not have a 24-hour manned control room, it was decided to use the bank room next to the head gear of the shaft as a place where all the control points came together. The bank is the room where the person operating the winder cage is situated. This person is responsible for the vertical transportation of people and equipment into and out of the mine. This room was chosen because it was the only room that was manned for 24-hours daily on the shaft and was equipped with an external telephone line.

Because REMS was installed in the bank, a few extensions were made for this unique situation. One of these was security settings on the interface of REMS. Because the bank room is not a control room where a control room operator takes responsibility for the control actions, security settings were built into REMS that enabled only specified users with unique passwords to carry out control actions from REMS. One can imagine the consequences when an electrician does maintenance work on a pump underground and someone entering the bank room starts that pump from surface. Therefore, user logins were created in REMS giving certain users privileges to change setting on REMS.

Another situation that was unique to the Harmony 3 implementation, was the two columns in which the pumps pumped the water. Certain pumps pumped water out into the 12 inch column and other pumps into the 10 inch column. User specifications were given regarding the start and stop sequence and the maximum amount of pumps running on a column. The specifications were as follow:

- Because the friction loss is less in the 12" column, the first pump to be started on a pump station must be a pump pumping into the 12" column. The second pump must be a 10" column pump. The third a 12" pumps and the fourth a 10" column pump.
- When the pumps are stopped, a 10" column pump should be stopped first and then a 12" column pump.
• The maximum number of pumps running on a pump station is three, but if something is wrong, for example, with the 10” column pumps, a maximum of two pumps on the 12” column may be started. Thus, the maximum number of pumps running per pump set (column) is two, while the maximum number of pumps running per pump station is three. The reason for this is that more than two pumps per column put too much pressure strain on the column and may result in a column burst. This can cause a lot of damage and is very dangerous.

These new specifications were programmed into REMS. A user could specify within a pump station different pump sets in REMS and the pumps associated with the pump sets. Every pump station had its own maximum number of pumps, but after the modification, the pump sets also had their own maximum number of pumps. In Figure 44 the two different pump sets can be seen.

![Figure 44: REMS on Harmony 3 shaft with pumps on 10" and 12" column.](image)

Other additions that had to be made to REMS are the following:

• Manual stop / start from REMS by users with that privilege. Previously this could not be done from REMS but from the SCADA. But because no certified control room operator was
present at Harmony 3, the functionality of manual stop / start of pumps had to be implemented into REMS.

- Indication of the total running hours per pump.
- Indication of the maximum and minimum dam levels where REMS will control the dams.
- Block out of a pump if maintenance is done on it. This block out means that REMS does not take the availability of the pump into account when doing the real-time simulation for the mine. The block out of pumps can be seen in Figure 44. The blocked out pumps are those with a red cross through.
- The REMS actions history was shown in a separate window on the REMS screen. This is necessary for an operator to see how long REMS is trying to execute a certain action. For example if it takes longer than two minute to start or stop a pump the operator knows that something might be wrong and then he can take action on that.

Before automatic control could be handed over to the REMS these new functionalities were programmed into REMS. It is seen that the extensions that were made to REMS does not improve the real-time calculation of the Optimum Schedule, but the working performance of the system on that specific type of mine.

From previous case studies it was seen that the real-time simulation and calculation of the Optimum Schedule by REMS is attainable, but the practical operation of REMS must be extended to cater for any type of mine. If REMS was not acceptable to the mine personnel, control will not be handed over to REMS. This will result in missed load shift and electricity cost saving opportunities. All the modifications described in this thesis were unique, novel, innovative and had never been done before.

5.4 EVALUATION OF PROJECTS

5.4.1 Evaluating load shift and electricity cost savings

The average profiles obtained by REMS on the pumping systems for Masimong 4 and Harmony 3 shafts are shown below. It can be seen that the load shift out of peak times was successful. At Masimong 4 shaft the target of 3,9 MW load shift for the evening peak exceeded and 4,2 MW was
achieved. At Harmony 3 shaft the target of 3.8 MW was exceeded and 4.0 MW was achieved. This can be seen in the two figures below.

![Graph of Masimong 4 Shaft](image1)

**Figure 45: Average load shift profile for Masimong 4 shaft.**

![Graph of Harmony 3 Shaft](image2)

**Figure 46: Average load shift profile for Harmony 3 shaft.**

The electricity cost savings associated with the load shift are the following:

Masimong 4 shaft: Based on the results achieved a projected annual saving of R 419 000.

Harmony 3 shaft: Based on the results achieved a projected annual saving of R 385 000.
5.4.2 Evaluating technical specifications of REMS

It was seen earlier that the system layouts of Harmony 3 and Masimong 4 shafts were very similar to each other, with two pumping stations each. This is also very similar to that of Kopanang mine. Therefore, REMS had no problem to handle the layout of these two mines. However, many shortcomings were still identified which could explain the poor results.

Because it was the first time that a system like REMS had ever been implemented on any mine without remote control on the clear water pumping system, several shortcomings became apparent. In the previous case studies operators were used to controlling the clear water system from a control room. In this case study, it is the first time that control and instrumentation equipment was put in place to enable remote control.

Many of the shortcomings were also identified because of the fact that Harmony 3 does not have a 24-hour manned control room from where operations on the mine could be controlled. It was decided to use the bank room next to the head gear of the shaft as a point where all the control systems could come together. This was also used as the place where REMS could be implemented. Because of this unique situation several functionality extensions had to be made to REMS.

These unique extensions were discussed in section 5.3.2. They were implemented and tested before REMS could be implemented on the mines. Only after this was done REMS could be given permission to automatically control the clear water pumping system. If these extensions were not made it could result in serious consequences.

It is important to note that the shortcomings that were identified had nothing to do with the ability of real-time simulation and calculation of the Optimum Schedule for the clear water pumps. As was said earlier, REMS could easily have handled the layout of the mines. The shortcomings that were identified were unique to mines which had no remote control infrastructure prior to the REMS implementation.

It must also be said that if these shortcomings had not been implemented into REMS, the users on the mine would not have accepted the system. This would have resulted in the mine putting REMS on manual control, which would have resulted in missed load shift opportunities. It is thus of utmost
importance to enable REMS with the functionality that is required by the clear water pumping system and the personnel occupied with the working operation of REMS. Once all the user defined functionality was implemented into REMS, they had the necessary faith in the system and were prepared to keep it in automatic control mode. The result is maximum load shift and electricity cost savings.

5.5 CONCLUSION

The implementation of REMS at Masimong 4 and Harmony 3 shafts was successful since the project achieved the maximum load shift and electricity cost savings theoretical possible. No mine without the necessary control and instrumentation infrastructure had ever before been able to implement a load shift project.

The installation of REMS on these shafts represented a further milestone in the development of the REMS product. It consisted of several new and unique modifications and additions to the REMS software.

In South Africa, because of the age of many gold mines and the shortage of funds for capital projects, (in view of the low gold price in Rand), many mines do not have control and instrumentation equipment, similar to Masimong 4 and Harmony 3 shafts. Therefore, the further development of REMS to cater for these mines has opened up a significant market segment for sustainable load shift projects.
In the previous chapters it was shown that REMS was implemented successfully at four mines. However, to contribute to the national electricity supply problem, load shift results have to be produced continually and reliably. In this chapter REMS is evaluated on the DSM results, as well as the ability to achieve these results over a prolonged period.
6.1 EVALUATION OF PEAK LOAD REDUCTION

In Chapters 3 - 5 the implementation of REMS was discussed at Bambanani, Tshepong, Masimong 4 and Harmony 3 mines. The new pump profiles accomplished with REMS was then compared with the baselines of the different mines to determine the evening peak load reduction.

In Table 5 the achieved peak load reduction for every mine is compared with the expected MW load shift, as was determined with the mine specific simulation model. The predicted load shift result is that load shift quantity that was promised to Eskom and the mine before the project started. The ratio between the promised and the actual peak load reduction is expressed as the DSM performance of REMS and can be seen for each mine in Table 5.

![Table 5: Evaluation of peak load reduction for the different type of mines.](image)

It is encouraging to note that at every mine where REMS was implemented, a performance higher than 100% was achieved. This means that the peak load reduction obtained was more than the potential peak load reduction that was calculated through optimising the simulation models.

When this is compared with the peak load reduction performance of the remote EMS, as was described in Chapter 2, the new REMS achieved almost double the peak load reduction performance at every mine.

All four mines described in this thesis were able to reduce Eskom’s peak load with a total of 17.6 MW. This is 0.9 MW higher than the expected results of the simulation models, resulting in an average performance of 106%. From this peak load reduction evaluation table it is thus clear that the new DSM tool, namely REMS, is successful regarding DSM results on pumping systems in mines.
6.2 EVALUATION OF ELECTRICITY COST SAVINGS

With the MegaFlex tariff, (as was used by all four of the case study mines), the effect of peak load reduction is electricity cost savings. The new optimised pump profile achieved through REMS enabled the mines to reduce their consumption of expensive electricity and to rather increase their consumption of less expensive electricity. In this way, an electricity cost saving was obtained for each month. One can now compared the promised cost saving with those actually achieved.

In those cases when REMS has not yet been operating for a full year, the achieved cost saving have been projected for the remainder of the year. The expected and actual electricity cost savings can be seen in Table 6. Again, the ratio between the expected and actual savings, expressed as a performance percentage, is shown as the electricity cost savings performance.

<table>
<thead>
<tr>
<th>MINE</th>
<th>EXPECTED (R/c)</th>
<th>ACTUAL (R/c)</th>
<th>PERFORMANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bambanan</td>
<td>R 996,753</td>
<td>R 695,546</td>
<td>70%</td>
</tr>
<tr>
<td>Tshepong</td>
<td>R 324,169</td>
<td>R 280,209</td>
<td>86%</td>
</tr>
<tr>
<td>Masimong 4#</td>
<td>R 335,307</td>
<td>R 414,784</td>
<td>124%</td>
</tr>
<tr>
<td>Harmony 3#</td>
<td>R 630,158</td>
<td>R 384,605</td>
<td>61%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>R 2,286,386</td>
<td>R 1,775,144</td>
<td>78%</td>
</tr>
</tbody>
</table>

Table 6: Evaluation of the electricity cost savings for the different type of mines.

From Table 6 it can be seen that the electricity cost savings performance is not as high as the DSM performance. For all four mines a total of R2.286 million saving was expected and only R1,779 million was achieved. This results in an average cost saving performance of 78%.

The reason for this lower performance in the electricity cost saving for the mine is because the cost factor was calculated based on the morning peak load reduction as well as the evening peak load reduction. Through the optimised simulation profile for each mine it was calculated that potential existed for both morning and evening peak load reduction.

However, because the national electricity demand profile's evening peak is approximately 10% higher than the morning peak, Eskom DSM is only interested in evening peak load reduction [15] [71]. Therefore, with the implementation of DSM technologies on these mines, a higher priority was put on achieving an evening peak load reduction, than a morning peak load reduction. The evening
peak load shift achieved was higher than the optimised simulation model’s results, but the morning peak load shift achieved was less, thus resulting in lower than expected monetary savings.

Every mine in the case studies had different operating procedures. Through the optimised simulation model, it was known that potential for morning load shift existed, but it was only acted upon if it did not put the achievement of the evening load shift at risk. For instance, at Masimong 4 shaft, more peak load reduction than was forecasted was achieved both in the evening as well as in the morning. The morning peak was only acted upon once it was ensured that it would not put the results of the evening load shift at risk. This resulted in 125% electricity cost savings performance.

At Harmony 3 shaft it was different. It was established during implementation that the pumps were not allowed to be stopped nor started more often than absolutely necessary. This was because the electrical switchgear on the pumps was very old. If the pumps were stopped and started too frequently, the Vacuum Circuit Breaker (VCB) of the switchgear took too much breaking-load and had to be replaced.

Due to the system layout of the mine it was possible to obtain evening peak load reduction, but because morning peak load reduction would mean one extra stop and start per running pump per day, it was decided to ignore the morning load shift potential. The optimised simulation model, however, still took the morning load shift potential into consideration and therefore this resulted in the poor electricity cost savings performance of 61%.

Despite the lower than expected electricity cost savings results of REMS, it is still higher than the results achieved by the remote EMS that was implemented on the pumps at Kopanang mine. On the four mines described in this thesis, the electricity cost saving performance for REMS was 78% whereas the remote EMS had only 49% performance. Thus, despite the lower than 100% performance of REMS it can still be said that it was successful regarding electricity cost savings obtained for the mines.
6.3 CONSISTENCY OF THE DSM RESULTS

To help solve the national electricity supply problem as was described in Chapter 1 it is important that the DSM technology developed must maintain sustainable peak load reductions. When Eskom invests in a DSM project, they expect the project to deliver the promised MW peak load reductions consistently for a period of at least five years [72].

Peak load reduction on a specific project will only contribute to the solution of the national electricity supply problem if Eskom can depend on it, meaning that the peak load reduction must be sustainable on a daily basis. Peak load reduction projects can be seen as virtual power stations that supply the necessary electricity in Eskom’s peak times, that is, when Eskom needs it most. Therefore the peak load reduction results must be consistent and sustainable.

One of the main requirements of the new approach developed in this thesis was to develop a DSM tool that achieves maximum DSM results on a sustainable basis on pumping stations on mines. Because of the nature of a mine pumping system, it is a highly dynamic system. Once DSM results have been achieved during the implementation period, it does not mean that these results will necessarily be achieved on a daily basis.

For instance, a DSM lighting project in a building is different. Once the lights have been identified on each floor to be switched off during Eskom’s peak times, the possibility that these results will be achieved every day is fairly high. This is because the situation in the building does not change every day, or even every month.

A clear water pumping system on a mine changes daily. Normally there are between 8 – 24 electrical pumps that require maintenance on a daily basis. The flow rate of the pumps is dependant on the mechanical efficiency of the pumps, as well as on the motor that rotates the pump. If the efficiency of a pump is too low the pump has to be logged out of the system and maintenance has to be done on the pump.

Because that pump is not part of the system any more, it may result in the shaft bottom dam level to rise, depending on whether there are backup pumps for the pump, or not. The same situation occurs if a column in the shaft bursts or leaks water. Then all the pumps that pump through that column have to be logged out of the system and can not be used to regulate the dams at the correct level, ideal for peak load reduction.
The water balance of the pumping system is also very critical. Due to ground water seepage into the mine there can be too much water in the system. When this happens the spare capacity of the dams is not sufficient to enable the system to stop pumps during Eskom's peak times. On the other hand, if there is too little water in the system, critical mining operations cannot be supplied with cold water and have to be stopped, resulting in lower production. Therefore the water balance in the system must also be perfect before DSM results can be attempted.

Situations as mentioned above can happen on a daily basis on a mine and are the reason why the pumping system is extremely dynamic. These situations have nothing to do with the fact that REMS controls the pumps. They are normal pumping system maintenance situations. But if they are not repaired quickly by mine personnel, it can result in poor DSM performance. The fact is, if the shaft bottom dam level is too high before peak time, safety constraints are at risk, resulting in missed load shift opportunities.

Because REMS has a built-in simulation and optimisation model it can, in real-time, automatically adapt to the undesired situation and schedule the pumps in the best way for that specific situation. Thus, in undesired situations it still obtains the maximum possible DSM results for that specific situation. This can be seen in Table 7 where the REMS performance for peak load reduction during Eskom's evening peak is shown since implementation.

<table>
<thead>
<tr>
<th></th>
<th>TSHEPONG</th>
<th>BAMBANANI</th>
<th>MASIMONG 4#</th>
<th>HARMONY 3#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month 1</td>
<td>123%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Month 2</td>
<td>104%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Month 3</td>
<td>128%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Month 4</td>
<td>131%</td>
<td>68%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Month 5</td>
<td>106%</td>
<td>85%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Month 6</td>
<td>98%</td>
<td>83%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Month 7</td>
<td>92%</td>
<td>112%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Month 8</td>
<td>101%</td>
<td>104%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Month 9</td>
<td>76%</td>
<td>100%</td>
<td>105%</td>
<td>-</td>
</tr>
<tr>
<td>Month 10</td>
<td>75%</td>
<td>101%</td>
<td>103%</td>
<td>102%</td>
</tr>
<tr>
<td>Month 11</td>
<td>100%</td>
<td>106%</td>
<td>116%</td>
<td>109%</td>
</tr>
<tr>
<td>Month 12</td>
<td>99%</td>
<td>124%</td>
<td>122%</td>
<td>107%</td>
</tr>
<tr>
<td>AVG</td>
<td>103%</td>
<td>100%</td>
<td>112%</td>
<td>106%</td>
</tr>
</tbody>
</table>

Table 7: Peak load reduction performance for REMS since implementation.

This table proves that REMS delivers sustainable DSM results on the 4 mines which represent the 3 different types of pumping systems. The mine where REMS has been controlling the pumping
system automatically for the longest time is at Tshepong mine. Here REMS has delivered successful DSM results for over 12 months. REMS has managed to constantly shift, on average, more than 3.2 MW electricity load out of the 2 hour evening peak period, every day for 12 months.

It is interesting to note that during July and August 2005 the peak load reduction performance for Tshepong was only 76% and 75%. The reason for this is that no remote monitoring was done during those months. For the first few months after implementation, daily reports were generated about the working operations of REMS. These reports were studied at the remote monitor room and it was possible to supply feedback to the mine, as well as to REMS.

When dynamic changes within the pumping system were detected, adjustments to the REMS controller were made to adapt to the changed mine scenario. When poor mechanical performances of the pumps were detected, feedback was given to mine personnel, enabling them to act fast on maintenance. All this resulted in a performance of well above 100% for the first 5 months.

After this period, it was believed that remote monitoring was not necessary any more. It was thought that the studying of daily operational reports could be terminated and that REMS would automatically adjust to any changed pumping system scenario. For the first three months without remote monitoring, REMS still performed well. The average performance for these months was 97%. This was not as good as the first five months, but it was still reasonably good, when taking into account that no level of remote monitoring was applied.

During the forth and fifth month with no level of REMS maintenance, the performance fell to 76% and 75%. After daily reports were drawn for the two months it was seen that the pumping system of Tshepong mine slowly changed during the five months with no maintenance. The changes occurred because the mechanical performance of the pumps was not as good as it has been.

For instance, the response of the 3CPFS to REMS schedules was in a poor condition. If REMS tried to start the 3CPFS according to the optimised schedule, it had a very tardy reply. Or when it eventually was running it tripped after a short while. This forced REMS to start the electrical pumps and resulted in poor peak load reduction and electricity cost savings results.

After the poor mechanical performance of the pumps was mentioned to mine personnel they could focus on the problems and fix it. REMS was able to execute the optimised schedule again without trips and errors from the mechanical pumps and good performance results were achieved again. This can be seen in the performances of months 11 and 12, which are 100% and 99% respectively.
For all the mines it was decided to draw up daily reports on a weekly basis to give feedback to mine personnel and the REMS controller. This is necessary to continuously update REMS according to the situation on the mine system and to report to mine personnel on the performance of their pumping system. This form of maintenance is essential for sustainable DSM results on pumping systems. In Appendix G examples of daily operational reports for the mines as discussed in this thesis are shown.

It is seen that good peak load reduction results can only be delivered continuously on a mine if there is good teamwork between the mine and the ESCo. It is only possible to achieve continuous DSM results if the mine pumping system is in good working condition. Only then can DSM technology be applied to reduce peak load. If this is not the case, the working operation of the pumping system must be updated with new technology before sustainable DSM results can be realised. This was seen at Masimong 4 and Harmony 3 mines.

6.4 USER ACCEPTANCE

6.4.1 Evaluation of management level users

Questionnaires were given to the engineering managers of the mines where REMS was implemented. The objective of the questionnaires was to test the pre-implementation, implementation and after implementation processes of each project. A copy of the management level questionnaire can be seen in Appendix D.

It was seen that the engineering managers were satisfied with the pre-implementation process. All the managers indicated that the gathering of mine information and data for the simulation models was not time consuming and they were satisfied with the presentation of the preliminary results. Most of them (especially at Tshepong) were not confident that DSM results would be achieved on a sustainable basis, without interfering with the production water requirements.

However, the managers were impressed with the implementation procedure. They were satisfied with the technology that was being implemented and agreed that REMS controlled the pumps in a smarter way than their control room operators/pump attendants could. They were pleased with the fact that an automatic control system was controlling their pumping system at the optimum point.
Concerning the sustainability of the load shift and the cost saving results, they were also positive. They were satisfied with the after-implementation REMS support from the remote monitoring room and were optimistic about the fact that weekly reports about the working operations of the pumps as well as DSM results were sent to them.

6.4.2 The importance of operator level users

Although the management level users gave permission for REMS to be implemented on their mines, it was the operator level users that worked every day with the new system. Therefore, they were the persons that could make or break the DSM project. The real user acceptance test came when evaluating the operator level user acceptance of REMS. Therefore, a separate questionnaire was given to the operators of the mines to test their acceptability of REMS. The operator level questionnaire can also be seen in Appendix D.

At mines with control room operators, it is their responsibility to start and stop pumps and keep the storage dams at safe levels. Therefore, these control room operators could easily feel insulted by implementing new technology that took over one of their daily tasks. This could cultivate a dislike in the system and could boycott the DSM project. Thus, special care was taken to explain the real-time simulation and optimisation process of REMS, and particular stressing the fact that it could not be calculated by humans.

During the implementation process when the REMS controllers were configured, the pump operators were consulted to share their experience of how the system worked. It was made a team effort to setup the REMS controller according to the mine pumping system. With this approach they felt part of the project.

When they were asked about the inclusion of pump operators in the configuration of REMS, they reacted positively. All indicated that the purpose and objective of REMS was explained before the project started. Some of them thought it was possible to obtain DSM results without REMS, but most agreed that new, automatic technology was necessary to achieve DSM results continuously.

After REMS was implemented they agreed that the pumps were controlled in a smart way and that REMS helped them with their daily tasks. They felt that the REMS project was a team effort.
between the mine and REMS personnel. They were also satisfied with the remote support and the alarm system that warned them of any constraint violations.

6.5 EVALUATION OF IMPLEMENTATION POSSIBILITIES OF THE NEW PROCEDURE

6.5.1 Introduction: SA gold mines with load shift opportunity

This section describes a comprehensive study which was carried out to identify possible gold mines where this new approach could be implemented. This study was later extended to platinum mines, but because of the energy intensive mining method of gold mines, and the depth at which gold is exploited, most peak load reduction potential lies in gold mines. Below is a short description of the pumping system and the current control method of some of the gold mines with peak load reduction potential in South Africa.

6.5.2 Mines in the AngloGold Ashanti Group

Mponeng: This mine has 4 pump stations which are situated on 45½ level (1 060 m), 85 level (2 183 m), 110 level (3 083 m) and 121 level (3 483 m). The last pumping station is one of the deepest in the world [73]. On average they pump 40 MI of water per day with 19 electrical pumps, totalling an installed capacity of 56.6 MW electricity consumption. They supply an average of 12 MI of cold water to their neighbouring mine, Tau Tona from 85 level.

The mine has old instrumentation equipment installed on the pumps. They have the ability to monitor the statuses of the pumps and dam levels from the surface control room, but do not have the facility to start and stop the pumps from there. At present shift foremen operate the control room 24-hours a day and on their order pump attendants on each level start and stop the pumps.

Tau Tona: At present this mine pumps up to 12 MI water per day from 121 level hot water dam, and up to 20 MI water per day at 101 level hot water dam. From 101 level water is pumped to 83 level. From 83 level water is pumped to 67 level. From there water is pumped to 33 level and from there the water is pumped to the surface. The maximum number of pumps that can run at one stage are 10 because of the limitation on the electric panels.
The mine has very old instrumentation equipment installed on the pumps and dams from which they can only monitor the statuses from the surface control room. They have pump attendants on each pump station that start and stop the pumps on the command of the control room operators.

**Savuka:** This mine and Tau Tona mine have identical pumping system layouts. The mine pumps 12.3 MI water from a depth of approximately 3 700 m below surface. It has 18 electrical pumps with a combined installed capacity of 40 MW electrical power. The mine has a control room from where start / stop commands are given to pump attendants on the various pump stations. Although there is rumour that the mine will close down in the near future, the water has still to be pumped out to keep the underground water table at a required level for the neighbouring mine Blyvooruitzicht.

**Great Noligwa:** There are 4 pump stations that pump an average of 15 MI hot water per day. The water is pumped by 11 electrical pumps with combined installed power of more than 25 MW. The mine has a 24 hour manned control room, but pumps are started by pump attendants on the various levels.

**Kopanang:** The mine has two pump stations on 75 and 38 levels. It has a total of 8 pumps and 2 turbines to pump a daily average of 21 MI of water to surface. The instrumentation equipment on the pumping system is modern and in very good condition. At present this mine is one of few mines in South Africa with no pump attendants on the pump stations. The pump stations are video monitored and the pump statuses are monitored and controlled from the surface control room.

**Tau Lekoa:** Water is used to cool the underground mining conditions and operations. This water is cooled via a surface fridge plant. From the fridge plant the water flows to the hydropower pumps on 900 and 1734 levels. From there the high pressure water is used on the various underground levels. The water flows from the various levels to a surge dam and then into three settlers. From the settlers the water is pumped to the clear water pumping system and again back to the surface dam. At present 1734 level pump station pumps 14 MI of water to 900 level and from there 6 MI of water is pumped to surface per day.
6.5.3 Mines in the Harmony Gold Group

Elandsrand: At present this mine pumps a daily average of between 21 – 26 MI water from the bottom pump station, at approximately 3 300 m below surface, to surface. The mine has 20 electrical pumps on four pump stations on 100, 75, 52 and 29 levels. The current installed capacity for water pumping is 30 MW. The mine has the ability to monitor and control pumps from the surface control room.

Target: There are three main pumping stations at Target. Water is pumped with three 0.5 MW pumps from the pumping station on 67 level to the pumping station on 53 level. From the there the water is pumped with two 1.0 MW and one 0.64 MW pumps to 30 level, from where the water is pumped with two 1.1 MW and one 1.3 MW pumps to the surface. The combined installed electricity on the pumps is 7.6 MW. The pumps can be started from surface, but because there are no operators in the control room responsible for the pumping system, it is started by pump attendants on the various levels.

Evander Operations: Here there are 5 shafts still active in mining operations. The infrastructure on the shafts is old and pumps can not be controlled from surface. Therefore new infrastructure has to be implemented before an automatic management system can be implemented. Two of the shafts, number 7 and 8 are high possibilities for DSM projects. They pump between 7 – 12 MI of water from a depth of 2 300 m.

Cook shafts: The Cook shafts are from the oldest gold mine shafts in the country. There are three shafts still in operation, but they are reaching the end of their mine life. On their pumping systems they do have potential for peak load reduction, but because of their short mine life duration it is not feasible to implement a high technology DSM tool at this stage.

Orkney shafts: There are 5 shafts in this region with an average depth of approximately 2000m. Because of the reduced mining activities they have reduced the amount of water pumped through the clear water pumping system to a daily average of more or less 1 – 5 MI per shaft. There is peak load reduction potential available, but not as much as some of the other mines mentioned. It will be wise to first realise DSM results on the mines with higher potential.

Other Welkom / Virginia Operations: There are at least a dozen other mines in the Welkom / Virginia region within the Harmony group where DSM potential on the pumping systems exists. The
potential is not as high as Bambanani or Elandsrand mines, but there is still DSM results to be realised. Some of the shafts are: Joel, Unisel, Brand, Kudu, St Helena, Njala etc.

6.5.4 Gold mines in other mining houses

The mines with high peak load reduction potential in the other mine groups are listed per group. They are:

**Gold Fields:** Beatrix shafts, Oryx, Kloof Operations, Driefontein Operations.

**Placer Dome Group:** South Deep (south), North shaft, Twin Shafts.

**Durban Roodepoort Deep:** Blyvooruitzigt, Buffelsfontein, Hartbeesfontein.

6.5.5 Summary

The simulation and optimisation models for most of these mines were built according to the preliminary user specifications. The optimised profiles, compared to the historic baselines of the pumping systems can be seen in Appendix E. Table 8 below is a summary of most of the gold mines in South Africa where DSM potential exists on the clear water pumping system. In the table the category in which the mine falls is indicated as well as the peak load reduction potential according to the simulation and optimisation models.

It is seen that by far the most mines are categorised as Type 3 mines. This means that most of the mines have none, little, or very old instrumentation equipment on their underground pumps. Some of these mines are not even equipped with a surface control room from where the pump and dam statuses could be monitored. But there exists huge potential for peak load reduction as well as electricity cost savings. The new procedure was also developed for this type of mines to achieve maximum, sustainable DSM results.
6.6 THE POSSIBLE NATIONAL AND ENVIRONMENTAL IMPACT

The following assumptions were made for the determination of the national peak load reduction potential on clear water pumping systems in South African mines:

- The list of gold mines in Table 8 is fairly comprehensive, but it can be said with certainty that there will still be other gold mines in South Africa that have peak load reduction potential. It is assumed that the table lists only 75% of such gold mines.
- Gold mining constitutes 18% of the industrial electricity energy consumption in South Africa, or two-thirds of the mining electrical energy consumption [32] [47]. The rest of the mining...
industry combined consumes only one-third of the mining electrical energy consumption. Therefore the peak load reduction potential in gold mines contributes two-thirds of the total mine industry potential. The other third is contributed by other forms of mining i.e. platinum, coal, diamonds, etc.

Therefore the national peak load reduction potential for pumping systems on mines in South Africa is estimated to be as follows:

<p>| | | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>113 MW</td>
<td>Gold mines listed in Table above = 75%</td>
<td>Two-thirds</td>
</tr>
<tr>
<td>37 MW</td>
<td>Other gold mines not listed = 25%</td>
<td></td>
</tr>
<tr>
<td>75 MW</td>
<td>One-third contributed by other forms of mining</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>225 MW</td>
<td></td>
</tr>
</tbody>
</table>

In a previous study on the national load shift potential on VCP systems on mines in South Africa it was estimated that a total of 550 MW was available [74]. This calculation was based on the average load shift potential of four case study mines and the assumption that this average can be achieved on every second mine in South Africa. When taking into consideration that the 225 MW estimated in this thesis is only for pumping systems, it seems to be a fairly good estimation.

In Chapter 1 it was seen that pumping systems on mines contribute about 2 300 MW of the peak load in South Africa [17] [18]. It is therefore apparent that peak load reductions on pumping systems could reduce this figure by almost 10%.

In Appendix E a calculation is given that arrives at a ball park figure of R 150 000 savings annually for 1 MW in peak load reduction. Applying this factor to the 225 MW estimated above, the savings that can be achieved by mines by merely scheduling the clear water pumps by means of REMS, is approximately R 34 million per year.

Electricity supply utilities, like Eskom, and other users of electricity will soon have to internalise the external costs of pollution and gas emissions and this will have to be reflected in the price of electricity. Most of the external costs cannot be quantified precisely but have environmental and social costs attached to it. The environmental implications of using 1 kWh of power are as follow [75]:

- 1.21 litres of water used;
- 0.49 kg coal burnt;
- 130 g ash produced.
Peak load reduction in the form of load shift on mines does not reduce the amount of electricity used over a certain period of time and therefore does not directly offer opportunities to improve the environmental impact. The environmental impact is directly related to the reduction in the amount of energy used (EE).

However if peak load reduction can prevent Eskom from building a new power station to supply in the national electricity profile it can have an enormous indirect impact on the environment. If this load shift is constant and sustainable it serves as “virtual power station” in Eskom’s peak times. If the new procedure is implemented at its full potential in South Africa, it can be seen as a power station that supplies 225 MW electric power at the peak period of the day when Eskom needs it most. This “virtual power station” is the most environmental friendly power station ever to be built.

With the electricity cost savings through this new procedure, more money can be spent by the mine industry on research into more environmentally friendly energy sources. Therefore it remains advantageous for the mining industry, Eskom and the country to utilise the new procedure developed.
Through successful and innovative engineering research and development, a new approach was developed to enable the successful implementation of REMS on all the variations of clear water pumping systems in South African mines. Through specific case studies, the tool was modified to perfection. However, there still exists scope to extend it to other mine and industrial processes.
7.1 CONCLUSION

The primary objective of this study was to develop a tool that could achieve maximum DSM (load shift) results in a reliable and sustainable manner in all deep, hard rock mines in South Africa. This objective has been met by demonstrating that REMS, (as developed over the duration of this study), was able to be implemented in all three types of mines. These are:

- **Type 1**: Mines with intricate pumping systems,
- **Type 2**: Pumping systems that include a 3CPFS,
- **Type 3**: Pumping systems with no control infrastructure and/or no 24-hour manned control room.

The following successful and innovative approaches have been developed and implemented over the course of this study. Together these approaches formed a new approach that ensured successful implementation and sustainable peak load reduction. This approach is now applicable to any clear water pumping system on a South African mine.

The first stage was to develop DSM technology with the ability to be implemented on-site. This had the advantage of real-time system data input. Therefore, real-time simulation and optimisation could be done, which resulted in an optimised control schedule relevant for that specific scenario on the mine.

The second stage was to empower the DSM technology with the ability to automatically control the mine pumping system at the optimum operating point. DSM performance was no longer dependant on the reliability of human operators. Humans were not necessary to verify whether the optimised schedule was realistic before they chose to implement it. Because the system received real-time data as inputs, the optimised schedule was realistic and because it had the ability of controlling the pumps, the realistic, optimised schedule could be implemented automatically.

The third stage was to develop a controller inside the DSM technology that had the ability to control any clear water pumping system in a South African mine. After initial studies it was established that mine pumping systems could be divided into any one of three different types. Through various sub-controllers the REMS controller was extended to handle all three types and therefore, any pumping system in South Africa.
The fourth stage was to give the DSM technology “stand alone” functionality. There are mines with no control rooms or no operators responsible for the pumping systems. Therefore, new and additional systems had to be put into place within REMS before it could take over the responsibility associated with the clear water pump process. It was important for the DSM technology to signal any violations of user constraints to mine personnel on site, as well as to the off site control room.

In this project, this approach was implemented for the first time on all three types of mines in South Africa. It was evident that the DSM results were consistently above expectation. This study has therefore conclusively demonstrated that REMS can be successfully implemented on the clear water pumping system of any South African mine.

Through a comprehensive study of the possible gold mines where the new approach could be implemented, an informed estimate of the national impact could be made. It was seen that the new approach has the potential to reduce Eskom’s peak by 225 MW. This results in an almost 10% reduction of the 2 300 MW electricity consumed, by pumping systems in the mine industry, during Eskom’s peak times.

This peak load reduction will have an electricity cost saving effect of almost R 34 million on the mine industry as well as a significant indirect effect on the environment.

7.2 CONTRIBUTIONS OF THIS STUDY

Operational contributions

It was shown in Chapter 2, that if maximum DSM results were to be realised the DSM technology would have to be independent of human operators. The only way to make an optimised control system of the pumps independent of human operators was to change the operation to an on-site system to gather real-time pumping system data and perform the simulation and optimisation processes in real-time, as the dynamic mine system changes.

The other operational contribution made, was to empower the control system with reliable automatic control access of the pumping system. The Optimised Schedule was then calculated at a central point on surface by the control system, sent through the communication network of the mine.
to the various pumping stations on the levels below surface and was then executed through PLCs and electrical switchgear.

With these two new contributions, REMS was able to automatically control the pumping system at the optimum operational point, for a specific mine situation and within system constraints. Control room operators on the mine were no longer necessary to execute the optimised control schedule, or to make sure the Optimised Schedule would fit into the constraints of the mine situation for that specific scenario. Although they were still necessary, they were not part of the hourly, daily working operation of the optimised control system and therefore DSM performance results were not dependant on their performance any more.

When calculating the optimised pump schedule, the simulation and optimisation processes did not have to make assumptions of the conditions of the pumping system. With the enhancement of implementing REMS on-site, it had the advantage of automatically gathering real-time system information of the conditions, availability and statuses of the pumping system components. Therefore, the Optimised Schedule could be automatically executed, without a control room operator verifying the realism of it. Because of the real-time information input, the optimised schedule was also relevant for the specific mine scenario and would still realise the maximum possible DSM results available.

These two contributions were implemented at the four mines as discussed in this thesis. The results were above expectations. At Tshepong mine, REMS has been running for 12 months in auto control mode, achieving 103% of the predicted peak load reduction. At Bambanani mine, REMS has been controlling the clear water pumps for the last 9 months. After the first three months of growing pains, the system was in auto control mode for 86% of the time, achieving 106% of the expected peak load reduction. At Masimong 4 and Harmony 3 shafts, REMS has been auto controlling the pumps for the last 4 and 3 months and has also achieved higher than expected results.

It can therefore be concluded that these two operational contributions have made a huge difference to the whole DSM programme in that the full DSM potential of a system can now be achieved on a sustainable basis.
Technical contributions

Several technical contributions have been made to REMS that enabled the successful implementation of DSM initiatives on any type of clear water pumping system on deep level mine. It is important that the DSM technology should be generic and powerful in order to have the ability to be implemented on any mine pumping system. It was demonstrated in this thesis that the REMS controller now had the ability to successfully control a mine under any of the three possible types of situations. Hence it will be able to handle any clear water pumping system on any South African mine.

For this purpose the REMS controller was extended by various types of additional controllers. These were necessary to handle the three different setups of clear water pumping systems. Firstly, some of these are simple, and consist of only two pump stations with storage dams. Others, however, are more complex and intricate, consisting of at least four pump stations, including underground refrigeration plants as well as dumping valves from various levels. Thirdly, there are pumping systems that included 3CPFS, which required a special controller.

Apart from the main REMS controller, the following additional controllers were included into REMS to empower it with the ability to be implemented on all three types of mines:

Valve Controllers were necessary on mines where dumping valves existed between two levels with storage dams. In the case of Bambanani mine, the storage dam on the lower level supplied water to an underground refrigeration plant. The dumping valve was used in those cases when pumps could not supply enough water to the very important refrigeration dam. The dumping valve would then be opened to gravity feed the refrigeration dam with water from the upper dam.

To enable REMS to control the complete clear water pumping system correctly, these dumping valves had to be included into the controller and this required an additional valve controller.

"Minimum / Maximum Pump" Controllers were added to REMS to be able to handle dams with unusual maximum and minimum level constraints. In such cases the dam constraints were very close to each other, for example the lowest level of the dam at 80% and the highest level 100%. Without the min/max pump controller, REMS would start and stop the pumps to and from that dam very frequently, resulting in pump cycling.
The min/max pump controller enabled the person implementing REMS to mathematically calculate the optimum amount of pumps over the longest period of time, and still comply with the dam level constraints. Various real-time data from the pumping system can be used as inputs to the calculation where the output is the minimum and maximum number of pumps to run. This way of controlling the specific pumps reduces cycling.

"Total amount of water" Controllers were added to REMS to control the amount of water in the clear water pumping system. This was necessary at mines where ground water seepage increased the water in the system and a certain amount had to be pumped out to surface dams on an irregular basis. It is impossible for a human operator to determine the total amount of water in a complex mine system.

Because the water balance is very important for good DSM results, it was decided to add a controller to REMS to correctly determine the total amount of water in the hot and cold water system. When it is found that too much water is in the system, all the pumps have to react and pump the water to the correct levels. The additional controller then automatically gets rid of the surplus water at the most convenient time.

"3CPFS" Controllers had to be added to REMS to accommodate those types of mines that included a 3CPFS in the clear water pumping system. It was seen that there are not many mines that fall into this category and it was thought that it will not be possible to control the complete pumping system. But after an investigation it was seen that there are similarities between the control philosophy of a normal pump station and a pump station which included a 3CPFS.

A mathematical simulation model was developed for the 3CPFS which could be added to the other simulation models to form an integrated dynamic simulation model of the whole clear water pumping system. This was then optimised and included to the REMS controller to realise the minimum electricity costs of the whole pumping system. This resulted in maximum peak load reduction on the electrical pumps.

User functionality contributions

Operational changes also had to be made to achieve the maximum peak load reduction on a sustainable basis. The DSM technology had the technical ability to successfully handle any clear water pumping system. However, to ensure long lasting results, user functionality contributions had to be added to make the technology attractive to the operators on the mine to use.
Improvements to REMS functionality as a result of user suggestions:

- User security settings: this gave certain users specific control privileges and other users could only operate, but not adjust, the system.
- Pump sets with own start / stop and other constraints. This was used where certain pumps in the total pumping system formed part of a set, e.g. pumps pumping into different columns, or pumps connected to certain electrical panels.
- REMS control configuration settings display on the viewer panel to enable control room operators to see at what dam levels pumps will be stopped or started by REMS.
- Indication of total running hours of the pumps to provide pump foremen with maintenance information.
- The ability to lock out pumps when maintenance was being done. This enabled control room operators to still keep REMS in auto control mode while certain pumps are locked out of the system for maintenance reasons.
- A REMS historic action list; to see when a pump was stopped or started by REMS or manually.
- An alarm system with SMS functionality; to report any violation of a user constraint to mine personnel on site, as well as off site.

7.3 FINAL GENERIC REMS IMPLEMENTATION PROCEDURE

Subsequent to the completion of all the Case Studies, a generic implementation procedure has been developed for REMS DSM projects, that will cater for all the different types of mines and projects. This is shown in Table 9.

The man-days shown in Table 9 give average values; these will vary according to the type of project that is being encountered. In Appendix C this table is expanded into more detail.
<table>
<thead>
<tr>
<th>NO.</th>
<th>MAIN STEPS OF REMS IMPLEMENTATION PROCEDURE</th>
<th>MAN DAYS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DEVELOP BASELINE</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Before the load shift feasibility study can be done the baseline of the mine equipment must be determined. It is necessary to obtain the baseline before the optimised mine profile is generated by the Potential Analyser. This is done because the baseline is compared with the optimised profile to calculate the load shift potential. In order to obtain the correct baseline the electrical trends must be verified with flow rates and temperature readings.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>DSM FEASIBILITY STUDY</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>To determine the DSM feasibility study information on the following must be gathered. How the system works, where DSM potential exists, how much DSM potential exists and how new control can be implemented. This information must now be gathered and verified to ensure production, safety, health and maintenance standards when applying DSM on the mine. This must be perfect in order to gain the confidence of the client.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>INFRASTRUCTURE INVESTIGATION</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>After the DSM potential is determined, it must be investigated how new control can be implemented to the mine equipment. REMS is dependant on remote control from one central point on the mine. An investigation study is necessary to determine the infrastructure that is to be added to the existing mine infrastructure.</td>
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<tr>
<td>4</td>
<td>COMPONENT SPECIFIC SIMULATION MODEL</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>Mathematical models for each component at the mine will be investigated and configured. These models will be used in a proprietary integrated simulation model to simulate the mine.</td>
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<tr>
<td>5</td>
<td>DEVELOP INTEGRATED SIMULATION MODEL</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>Integrate the models in step 4 with the new interface, adapt existing and develop new components needed for this simulation. Preliminary research has been done, but needs to be checked and updated with this specific DSM project in mind. This ensures the confidence of the client which is needed to allow us to do DSM on the mine.</td>
<td></td>
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<tr>
<td>6</td>
<td>VERIFY INTEGRATED SIMULATION MODEL</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>The simulation model obtained in step 5 must be verified to ensure that accurate results of the mine are generated. Preliminary research information can now be extended to detailed verification to prove the process to the client.</td>
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<tr>
<td>7</td>
<td>DSM OPTIMISER</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>With the results obtained from the simulation and verification processes, the integrated simulation model will now be optimised to find the lowest operating electricity cost point. To ensure safety of production for the client the experience gained in the preliminary research will now be extended to the satisfaction of the client. We must prove to the client that the optimised schedules will not affect any production, safety, health and maintenance standards.</td>
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<tr>
<td>8</td>
<td>IMPLEMENT AND CONTROL INFRASTRUCTURE MODEL</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>REMS must communicate with the client’s SCADA system. The sustainability of this DSM action is dependant on perfect integration of REMS and SCADA. The current SCADA system on the mine will be investigated to determine whether it complies with the required standards of REMS.</td>
<td></td>
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<tr>
<td>9</td>
<td>DEVELOP COMMUNICATION PROTOCOL BETWEEN MINE SCADA SYSTEM AND REMS</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>A TCP/IP supportive interfaces needs to be developed to enable communication between REMS and SCADA. To ensure sustainability it must be ensured that all interfaces aregeneric. This is an important software task.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>CONFIGURE REMS</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>The completed REMS model must be configured to integrate with the current processes of the mine. Current operational procedures can not be changed. In this step this issue will be addressed by modifications to the existing REMS to adapt to the strategies used on the mine.</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>DEVELOP AND CONFIGURE REMS SUPPORT AND MONITOR SYSTEM</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>The support and monitoring system will assist in the gathering, storing, analysing and distribution of important system data. It also gives feedback of the REMS working operation, which can be used when alterations must be made. This support and monitor system will be implemented at the remote site where the monitor room is situated. The support and monitoring of REMS ensures sustainability of the DSM actions.</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>COMMISSION REMS</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Finally REMS will be commissioned to do automatic real-time energy management on the mine.</td>
<td></td>
</tr>
</tbody>
</table>

Table 9: Main steps of REMS implementation procedure.
7.4 RECOMMENDATION FOR FURTHER RESEARCH

Throughout this thesis, it was established that REMS can be successfully implemented on any type of clear water pumping system in a South African mine. Through the implementation of the system on various mines, it was improved and adapted to perfection. Therefore, not much can be done to further improve the system.

However, one thing that can be improved on REMS is the fact that not all of the predicted cost savings were achieved at some of the case study mines. The cost savings directly relates to the morning and evening load shift results. Due to the fact that more attention was given to achieve evening load shift results, the morning peak load shift achieved was not 100% and resulted in lower actual cost savings achieved.

In future REMS can also be extended to other processes. The clear water pumping system is only one electricity intensive process on a mine. There are many other industrial and mining processes where load shift could be successfully implemented. The primary requirement for such processes must be sufficient surge capacities so that equipment can be switched off during peak times.

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

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

In future REMS can be extended to also simulate, optimise and automatically control these processes on mines and industrial sites in South Africa.
REFERENCES


References


[50] “Preliminary Energy Outlook for South Africa”, Energy Research Institute, Department of Mechanical Engineering, University of Cape Town, Private Bag, Rondebosch 7701, October 2001, p 10, Figure 7.


[71] Nortje, T., Manager, Industrial Projects, Eskom DSM, Personal Communication, Mobile: +27(0)82 331 3789, 24 November 2005.


Before a DSM project can commence the historic trend of electricity consumption for the specific process must be determined. This is done by calculating an average daily profile from various months. Preferably summer months and winter months as the electricity consumption on mine processes can vary according to seasons. The daily average trend is called the baseline and is compared with the achieved results as the load management performance and cost savings are calculated. Graphs of the baselines for the different pump stations are shown in Appendix A. They are combined to form the baseline of the complete clear water pumping system.
BAMBARANI BASELINE CALCULATIONS

40 Level pumps (1200 kW)

Figure A1: Daily average number of pumps on 40 Level pump station.

73 Level pumps (1200 kW)

Figure A2: Daily average number of pumps on 43 Level pump station.

91 Level pumps (800 kW)

Figure A3: Daily average number of pumps on 91 Level pump station.

105 B Level pumps (1800 kW)

Figure A4: Daily average number of pumps on 105 B Level pump station.

Appendix A: Baseline Calculations
105 A Level pumps (800 kW)

Figure A5: Daily average number of pumps on 105 A Level pump station.

Calculation of Baseline for Bambanani

Figure A6: Combined baseline for complete clear water pumping system.
HARMONY 3 SHAFT BASELINE CALCULATIONS

Figure A7: Daily average number of pumps on 4/3 Level pump station.

Figure A8: Daily average number of pumps on 14B Level pump station.

Figure A9: Combined baseline for complete clear water pumping system.
MASIMONG 4 SHAFT BASELINE CALCULATIONS

1200 Level pumps (1500 kW)

2180 Level pumps (1250 kW)

Figure A10: Daily average number of pumps on 1200 Level pump station.

Figure A11: Daily average number of pumps on 2180 Level pump station.

Calculation of Baseline for Masimong 4 shaft

Figure A12: Combined baseline for complete clear water pumping system.
Before a REMS can be implemented on a mine approval must be obtained from mine management. To obtain this, the complete Scope of Work of the project is documented and presented to the mine. In this Appendix a combined Scope of Work for Bambanani, Masimong 4 shaft and Harmony 3 shaft is demonstrated.
LOAD SHIFT THROUGH IMPLEMENTATION OF A REAL TIME ENERGY MANAGEMENT SYSTEM (REMS) ON THE CLEAR WATER PUMP SYSTEMS AT THE HARMONY FREE STATE OPERATIONS

HVAC INTERNATIONAL (PTY) LTD

AND

HARMONY GOLD

JANUARY 2004
OPTIMISATION OF THE CLEAR WATER SYSTEM AT THE
HARMONY FREE STATE OPERATIONS TO ACHIEVE MAXIMUM
LOAD SHIFT AT MINIMUM ELECTRICITY COST

BAMBANANI MINE OPTIMISATION OF THE CLEAR WATER PUMP SYSTEM

SYSTEM LAYOUT

At Bambanani water is used to cool the underground mining conditions and operations. This water
is cooled via two underground fridge plants. From the fridge plants the water flows to the mining
operations and then back to the settlers. From the settlers the water is pumped via the clear water
pump system and again back to the two fridge plants. The water completes this cycle continually
throughout the day. A minimum amount of water is pumped to the surface.

At present Bambanani mine pumps from 105 level an average of 650 l/s clear water throughout the
day. The water from 105 level is pumped to 92 level and 73 level hot water dams. 91 level and 73
level hot water dams feed 75 level dam that supplies 75 level fridge plant with sufficient water.
From the 73 level dam water is pumped via the 73 level pump station to 40 level hot water dam. 40
level hot water dam feeds 58 level dam to supply 58 level fridge plant with sufficient water. From
40 level hot water dam water is also pumped to the surface via 40 level pump station. The current
total installed capacity to pump this water is
28 MW. This can be seen in *Figure 47*.
PRICING STRUCTURE

Eskom provides alternative pricing structures for large consumers of electricity. The six main tariffs available to them are NightSave, MegaFlex, MiniFlex, RuraFlex, Real-time Pricing (RTP) and Wholesale Electricity Pricing (WEP). RTP and WEP are still in the testing phase with various pilot sites being used. Many mines are not fully aware of these alternatives and the possible benefits to them with regard to DSM opportunities. The more advanced tariffs are advantageous for industries that are capable of shifting load for a certain period of time.
Bambanani mine is currently on the MegaFlex tariff. MegaFlex is more suitable for large consumers that need a supply of 1 MVA and above. The TOU period can be seen in Figure 48. This is ideal for large consumers capable of shifting load for long periods (4 to 5 hours per day). The only negative is that this tariff is very rigid with little room for innovative scheduling. Optimisation will be used to find the optimum operating schedule of the underground pumping system.

DATA AVAILABILITY

Bambanani mine has a comprehensive Supervisory Control and Data Acquisition (SCADA) system. All underground dam levels and the operation of pumps are logged.

CONCLUSION

The management is keen on any savings and open to suggestions. The infrastructure is in place to easily automate the systems under investigation. As a result of the SCADA system being in place most of the operational condition data are easily available. The pumping system has large dams that can be used for storage. This is a pre-requisite for load shifting.
OPTIMISATION OF THE UNDERGROUND CLEAR WATER PUMPING SYSTEM

There are two types of constraints applicable on this system. These are the available number of pumps and minimum and maximum dam levels. On level 105 there are 10 electrical pumps. On level 91 there are 9 electrical pumps. There are 7 electrical pumps on level 73 and on level 40 there are another three electrical pumps installed.

The clear water dam levels and other warm water dam levels must be kept between 40% and 90% at all times as per client constraints. To keep the water balance intact the clear water pump system must supply the dams that feed the fridge plants with sufficient water.

OPTIMISATION PROCEDURE

The calculated load shift is based on the following profiles for the year 2003.

- Settler flow
- Daily amount of water pumped
- Equipment constraints
- Underground dam capacities

The 5.8 MW load shift profile is obtained by pumping the same amount of water, as was previously done, but shifting pumping load from the evening peak.

Production and operating constraints that were taken into account are the following:

- Maximum number of pumps active daily
- Minimum and maximum dam levels and dam capacities
- Underground water usage
- Safety constraints
- Maintenance constraints
- Allowable on/off switch periods for all elements
RESULTS

Table 10 gives the results that were obtained from the optimisation model. The hourly amount of electricity used on the pumping system is given. Table 10 also supplies the average measured electricity consumed by the pumping system for 2003. By comparing the figures of the measured electricity used with the simulated electricity used during the second peak period (between 18:00 and 20:00), the load shift potential can be determined. This is illustrated in Table 10.

<table>
<thead>
<tr>
<th>Hour of day</th>
<th>Measured electricity consumption (kW)</th>
<th>Simulated electricity consumption (kW)</th>
</tr>
</thead>
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<td>00:00</td>
<td>11,147</td>
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</tbody>
</table>

Table 10: Average hourly electricity used on the clear water pumping system.

The average daily pump load profile, before the REMS intervention and our recommended optimised profile are shown in Table 10. Note that it was previously not possible for this very energy conscious mine to react to on the high price signal.
It is impossible, to stay within constraints, e.g. dam levels, amount of pumps available, etc. if a full optimisation of the complete system is not done as we suggested with REMS. The result is a missed load shift opportunities especially during the evening peak.

The full potential of the new on-site REMS technology can be realised when the current profile is compared to the recommended optimised profile. By comparing the current load profile with our recommended optimised profile it can be seen that there exist more than 5.8 MW load shift potential between 18:00 and 20:00.

![Average daily load profiles for Bambanani mine](image)

*Figure 49: Average daily load profile for Bambanani clear water pumps.*

The area under each load profile represents the average daily energy use on the pumps. The amount of energy used for each profile is the same. As the peak time energy is more expensive, a load shift results in an energy cost saving.

As a result of the 5.8 MW load shift, a ballpark figure for the energy cost savings is R100 000/MW/year. This means that REMS will lead to an extra cost saving of R 580 000 per year for Bambanani mine.
MASIMONG4 GOLD MINE OPTIMISATION OF THE CLEAR WATER PUMP SYSTEM

SYSTEM LAYOUT

At Masimong 4 water is used to cool the underground mining conditions and operations. This water is cooled via a surface fridge plant. From the fridge plant the water flows to the mining operations and then back to the settlers. From the settlers the water is pumped via the clear water pump system back to the surface to be cooled again. This water cycle continues throughout the day.

At present Masimong 4 mine pumps from 2180 level an average of 162 l/s water throughout the day. From level 2180 water is pumped to the hot water dam on level 1200. This water is then pumped via the 1200 level pump station to the surface dam. The current installed capacity to pump this water is 11 MW. This can be seen in Figure 50.

![Figure 50: Simulation model of the pumping and cooling processes at Masimong4 gold mine.](image-url)
OPTIMISATION OF THE UNDERGROUND CLEAR WATER PUMPING SYSTEM

There are two types of constraints applicable on this system. These are the available number of pumps and minimum and maximum dam levels on each level. On level 2180 there are 4 electrical pumps. The level 2180 hot water dam must be kept between 30% and 100% as per client constraints.

On level 1200 there are also 4 electrical pumps. The hot water dam level on level 1200 must be kept between 30% and 100% as per client constraints. To keep the water balance intact the clear water pump system must supply the surface hot dam with sufficient water.

RESULTS

Table 11 gives the results that were obtained from the optimisation model. The hourly amount of electricity used on the pumping system is given. Table 11 also supplies the average measured electricity consumed by the pumping system for 2003. By comparing the figures of the measured electricity used with the simulated electricity used during the second peak period (between 18:00 and 20:00), the load shift potential can be determined. This is illustrated in Table 11.
The average daily pump load profile, before the REMS intervention and our recommended optimised profile are shown in Table 11. Note that it was previously only possible for this very energy conscious mine to react partly on the high price signal.

It is impossible, to stay within constraints, e.g. dam levels, amount of pumps available, etc. if a full optimisation of the complete system is not done as we suggested with REMS. The result is a missed load shift opportunities especially during the evening peak.

The full potential of the new on-site REMS technology can be realised when the current profile is compared to the recommended optimised profile. By comparing the current load profile with our recommended optimised profile it can be seen that there exist more than 3.9 MW load shift potential between 18:00 and 20:00.

---

**Table 11: Average hourly electricity used on the clear water pumping system.**

<table>
<thead>
<tr>
<th>Hour of day</th>
<th>Measured electricity consumption on pumps (MW)</th>
<th>Simulated electricity consumption on pumps (MW)</th>
</tr>
</thead>
<tbody>
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</table>
The area under each load profile represents the average daily energy use on the pumps. The amount of energy used for each profile is the same. As the peak time energy is more expensive, a load shift results in an energy cost savings.

As a result of the 3.9 MW load shift, a ballpark figure for the energy cost savings is R 100 000/MW/year. This means that REMS will lead to an extra cost saving of R 390 000 for Masimong 4 mine.
HARMONY3 GOLD MINE OPTIMISATION OF THE CLEAR WATER PUMP SYSTEM

SYSTEM LAYOUT

At Harmony3 water is used to cool the underground mining conditions and operations of various neighbour mines. The mine is currently used as a pumping station. It pumps the water from Merriespruit 1 and Merriespruit 3 to the surface. The Masimong 4 and 5 operations are dependant on the pumping operations of Harmony3 since the underground water table between these mine is connected. When Harmony3 stops pumping, Masimong4, Masimong5, Merriespruit1 and Merriespruit3 will flood. This mine pumps a daily average of 19 Ml water.

At present Harmony3 mine pumps from 14B level an average of 162 l/s water throughout the day. From level 14B water is pumped to the hot water dam on level 4/3. This water is then pumped via the 4/3 level pump station to the surface dam. The current installed capacity to pump this water is 11 MW. This can be seen in Figure 52.

Figure 52: Simulation model of the pumping and cooling processes at Harmony3 gold mine.
OPTIMISATION OF THE UNDERGROUND CLEAR WATER PUMPING SYSTEM

There are two types of constraints applicable on this system. These are the available number of pumps and minimum and maximum dam levels on each level. On level 14B there are 9 electrical pumps. The level 14B hot water dam must be kept between 30% and 100% at all times as per client constraints.

On level 4/3 there are also 6 electrical pumps. The hot water dam level on level 4/3 must be kept between 30% and 100% as per client constraints. To keep the water balance intact the clear water pump system must supply the surface hot dam with sufficient water.

RESULTS

Table 12 gives the results that were obtained from the optimisation model. The hourly amount of electricity used on the pumping system is given. Table 12 also supplies the average measured electricity consumed by the pumping system for 2003. By comparing the figures of the measured electricity used with the simulated electricity used during the second peak period (between 18:00 and 20:00), the load shift potential can be determined. This is illustrated in Table 12.
The average daily pump load profile, before the REMS intervention and our recommended optimised profile are shown in *Table 12*. Note that it was previously only possible for this very energy conscious mine to react partly on the high price signal.

It is impossible, to stay within constraints, e.g. dam levels, amount of pumps available, etc. if a full optimisation of the complete system is not done as we suggested with REMS. The result is a missed load shift opportunities especially during the evening peak.

The full potential of the new on-site REMS technology can be realised when the current profile is compared to the recommended optimised profile. By comparing the current load profile with our recommended optimised profile it can be seen that there exist more than 3.8 MW load shift potential between 18:00 and 20:00.

*Table 12: Average hourly electricity used on the clear water pumping system.*

<table>
<thead>
<tr>
<th>Hour of day</th>
<th>Measured electricity consumption on pumps (MW)</th>
<th>Simulated electricity consumption on pumps (MW)</th>
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The area under each load profile represents the average daily energy use on the pumps. The amount of energy used for each profile is the same. As the peak time energy is more expensive, a load shift results in an energy cost savings.

As a result of the 3.8 MW load shift, a ballpark figure for the energy cost savings is R 100 000/MW/year. This means that REMS will lead to an extra cost saving of R 380 000 for Harmony3 mine.
After REMS was implemented on the various types of clear water pumping systems, a generic implementation procedure has been developed for REMS DSM projects, that will cater for all the different types of mines and projects. The detailed, generic implementation procedure together with man-days is shown this Appendix. The man-days are average values and will vary according to the type of project that is being encountered.
# DETAILED IMPLEMENTATION PROCEDURE OF REMS

**NO.** | **STEPS AND DESCRIPTION** | **MAN DAYS**
---|---|---
1 | **DEVELOP BASELINE**
   Before the load shift feasibility study can be done the baseline of the mine equipment must be determined. It is necessary to obtain the baseline before the optimised mine profile is generated by the Potential Analyser. This is done because the baseline is compared with the optimised profile to calculate the load shift potential. In order to obtain the correct baseline the electrical trends must be verified with flow rates and temperature readings. | 28
1.1 | Identify data required that is not available on the mine. To apply DSM to the mine certain data from the mine processes may be needed that is not currently being measured. These shortcomings must be identified in this step. | 3
1.2 | Identify the appropriate measuring equipment to measure data required from 1.1. To measure the data required in step 1.1, new measuring equipment is needed at certain stages in the mine processes. The measuring equipment must be identified. | 3
1.3 | Install measuring equipment. The new measuring equipment is now installed at the various stages in the mine processes. | 4
1.4 | Electrical trends. Collect the electrical trends for the mine for the past 3 months (12 months if available). Gather all this information to form an archive of the electricity usage of the mine. This data will later be used to compare with the optimised profile to determine the DSM potential. | 4
1.5 | Collect calibration data. Calibration data for the baseline such as equipment efficiencies in the mine must be gathered. All these must be used to ensure that the baseline is correct calibrated. | 4
1.6 | Collect verification data. To verify the data for the baseline such as flow rates and temperatures of all the different processes in the mine must be gathered. This information will also be used when a mathematical simulation model is designed, representing the mine. | 4
1.7 | Verify baseline. Verify the baseline with the data collected in 1.7 and 1.8 to ensure the correct baseline. If there are any differentiations the process must be repeated or it must be discussed with mine personnel. | 4
1.8 | Meet with managers of mine to discuss the baseline. The findings of the baseline must be discussed with the mine managers. Make sure they are satisfied that the current situation on the mine is reflected in the baseline. This is a very important step because the baseline will be used in the load shift and cost savings calculations for the duration of the project. If there are any differences concerning baseline the necessary steps must be repeated. | 2
2 | **DSM FEASIBILITY STUDY**
   To determine the DSM feasibility study information on the following must be gathered. How the system works, where DSM potential exists, how much DSM potential exists and how new control can be implemented. This information must now be gathered and verified to ensure production, safety, health and maintenance standards when applying DSM on the mine. This must be perfect in order to gain the confidence of the client. | 38
2.1 | System layout. The system layout of the whole mine should be obtained. This step is very important to get an overall idea of the strategies used in the mine and must be arranged with the mine managers. This means that the complete process must be fully understood. | 6
2.2 | Collect design data and control strategies. Design data for the mine and control strategies for the different control processes must be collected to ensure that an authentic simulation model can be designed. This is a laborious task. | 4
2.3 | Configure REMS Potential Analyser. After the system layout is obtained and the design data and control strategies are gathered the REMS Potential Analyser can be configured according to the specific mine. It is important to build the Analyser correct to represent the specific mine. | 10
2.4 | Obtain a preliminary optimised profile. Once the Analyser is built a preliminary optimised profile according to load shift is obtained. Because it goes through several interactions until correct it must be repeated several times. This optimised profile will be compared to the baseline to determine the DSM potential. | 2
2.5 | Compare optimised profile with baseline. To determine the DSM potential the previous behaviour (baseline) of the mine must be compared with the optimised profile generated by the Analyser. The difference of the two is the load shift potential that exists. | 8

---

Appendix C: Detailed implementation procedure of REMS 161
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.6</td>
<td>Complete load shift feasibility study report. All DSM potential findings are documented in a Scope of Work.</td>
</tr>
<tr>
<td>2.7</td>
<td>Discuss load shift feasibility report with mine managers. The Scope of Work for the mine from 2.6 must now be discussed with the mine managers. The document states the DSM potential that exists and how it will be realised with the REMS technology.</td>
</tr>
<tr>
<td>2.8</td>
<td>Get permission from mine managers to continue with DSM project. The mine managers must agree on the findings in the Scope of Work and must give permission for the DSM project to continue. The different section managers of the mine infrastructure must be informed that the project is progressing. This is necessary to get co-operation from them in later stages.</td>
</tr>
<tr>
<td>3</td>
<td>INFRASTRUCTURE INVESTIGATION After the DSM potential is determined, it must be investigated how new control can be implemented to the mine equipment. REMS is dependent on remote control from one central point on the mine. An investigation study is necessary to determine the infrastructure that is to be added to the existing mine infrastructure.</td>
</tr>
<tr>
<td>3.1</td>
<td>Discuss REMS control philosophy with mine personnel. Meet with specific personnel responsible for instrumentation projects. Discuss with them the control philosophy and interaction of REMS with the various mine equipment.</td>
</tr>
<tr>
<td>3.2</td>
<td>Identify additional infrastructure. It is necessary to identify the additional infrastructure that is needed for REMS to control the mine equipment from one central point. Normally this will include a SCADA system, programmable logic controllers (plcs), a communication network and transducers.</td>
</tr>
<tr>
<td>3.3</td>
<td>Discuss implementation of additional infrastructure with mine managers. List and document the additional infrastructure necessary. Discuss the implementation procedure of it with mine managers.</td>
</tr>
<tr>
<td>3.4</td>
<td>Develop infrastructure implementation model. Together with the mine personnel, develop an infrastructure implementation model. Supply the model with different implementation phases and start / end dates. Also, determine the responsibilities that technical mine personnel must supply with each implementation phase.</td>
</tr>
<tr>
<td>3.5</td>
<td>Quotations from subcontractors. Get quotations from different subcontractors to supply and commission the additional infrastructure. Usually the mine has got preferred subcontractors.</td>
</tr>
<tr>
<td>3.6</td>
<td>Compare and choose a subcontractor. Together with the mine managers compare the different quotation and choose subcontractors to supply and commission the additional infrastructure.</td>
</tr>
<tr>
<td>4</td>
<td>COMPONENT SPECIFIC SIMULATION MODEL Mathematical models for each component at the mine will be investigated and configured. These models will be used in a proprietary integrated simulation model to simulate the mine.</td>
</tr>
<tr>
<td>4.1</td>
<td>Identify mine components with the most DSM potential to be modelled and simulated.</td>
</tr>
<tr>
<td>4.2</td>
<td>Identify simulation components which need to be adapted according to the existing models. Examples of typical components that may need to be adapted are motors, pumps, chillers and cooling towers.</td>
</tr>
<tr>
<td>4.3</td>
<td>Use information from manufacturer's catalogues to adapt mathematical models where needed.</td>
</tr>
<tr>
<td>4.4</td>
<td>Transform the adapted mathematical models into components that comply to the requirements of the existing simulation software. The existing software for integrated simulation is component based. The mathematical models must therefore be transformed to comply with the same requirements (i.e. types of input and output) of other existing components.</td>
</tr>
<tr>
<td>4.5</td>
<td>Program the adapted simulation components to incorporate the mine components.</td>
</tr>
<tr>
<td>4.6</td>
<td>Identify new simulation components not yet developed.</td>
</tr>
<tr>
<td>4.7</td>
<td>Use information from manufacturer's catalogues to develop the new mathematical models.</td>
</tr>
<tr>
<td>4.8</td>
<td>Transform the new mathematical models into components that comply to the requirements of the existing simulation software.</td>
</tr>
<tr>
<td>4.9</td>
<td>Program the new simulation components to incorporate the mine components.</td>
</tr>
<tr>
<td>4.10</td>
<td>Develop new user interface to include Eskom tariffs and DSM actions for all components (i.e. existing, adapted and new).</td>
</tr>
<tr>
<td>5</td>
<td>DEVELOP INTEGRATED SIMULATION MODEL Integrate the models in step 4 with the new interface, adapt existing and develop new components needed for this simulation. Preliminary research has been done, but needs to be checked and updated with this specific DSM project in mind. This ensures the confidence of the client which is needed to allow us to do DSM on the mine.</td>
</tr>
</tbody>
</table>

Appendix C: Detailed implementation procedure of REMS
| 5.1 | Obtain layout of system to be simulated.  
Study the layout of the system obtained in 2.1. This system layout must be studied with the DSM potential in mind for the mine. Each component and the whole mine must be studied with this in mind. | 8 |
| 5.2 | Apply boundary data for the mathematical models.  
For each component of which a mathematical model is built, the boundary values must be obtained from the system layout. These values must be built into the mathematical models to ensure the completeness of the models. | 5 |
| 5.3 | Integrate all the mathematical models into one simulation model.  
After the boundary data is built into the mathematical models all the models must be taken and put into one simulation model. This model represents the whole mine and is used to simulate on. | 10 |
| 5.4 | Prepare verification data for simulation. | 4 |
| 5.5 | Obtain the relevant information for each measured component on the mine.  
Information to be obtained is performance parameters, scheduling and control strategies. | 4 |
| 5.6 | Enter input data into software simulation.  
After all the relevant information is gathered from the mine, these values must be entered into the simulation model obtained in step 3.3. | 3 |
| 5.7 | Conduct simulations for each adapted or new simulation component. | 10 |
| 5.8 | Enter simulated data into data structure.  
The results obtained from the simulation model are entered into a database and will be used to compare with. This step is important because the correctness of the results, and input values can be verified. | 6 |
| 6 | VERIFY INTEGRATED SIMULATION MODEL.  
The simulation model obtained in step 5 must be verified to ensure that accurate results of the mine are generated. Preliminary research information can now be extended to detailed verification to prove the process to the client. | 56 |
| 6.1 | Plan measurements to be taken for verification of integrated simulation model.  
The measuring points and position of the data loggers must firstly be decided upon. Measurements typically taken include water flow rates, temperatures and electricity consumption of DSM potential components at the identified points. | 8 |
| 6.2 | Obtain mine data to verify simulation model. | 6 |
| 6.3 | Compare this data for verification purposes. | 6 |
| 6.4 | Conduct real-time comparison of measured and simulated data.  
To compare the data, the average, as well as maximum difference between the real-time simulated and measured values is firstly calculated. The percentage that the simulation values are within a certain accuracy limit is then also determined. | 20 |
| 6.5 | Verify new integrated simulation model.  
Implement corrections and revise models where required. | 8 |
| 6.6 | This can be an iterative process. Where the component models are insufficiently accurate, measurements will again be conducted and compared to the simulated results of the updated models. | 8 |
| 7 | DSM OPTIMISER.  
With the results obtained from the simulation and verification processes, the integrated simulation model will now be optimised to find the lowest operating electricity cost point. This is the final step concerning the mathematical simulation model. During the preliminary research a rough and first optimised simulation model for the specific mine was obtained. To ensure safety of production for the client the experience gained in the preliminary research will now be extended to the satisfaction of the client. We must prove to the client that the optimised schedules will not affect any production, safety, health and maintenance standards. | 46 |
| 7.1 | Specify mine operational constraints.  
After the mathematical simulation model is verified to be the same as the real mine process, the mine constraints needs to be specified. Constrains can be the levels of dams at certain periods, availability of pumps and the daily maintenance issues. | 10 |
| 7.2 | Apply mine operational constraints to the optimised simulation model.  
The constrains specified in 7.1 must be applied to the simulation model. This application is very important to ensure the authenticity of the model. | 10 |
| 7.3 | Specify variables for the model.  
The variables where most DSM potential exists needs to be specified. | 6 |
| 7.4 | State the objective function for the optimisation model.  
After the variables are specified the objective function can be stated. The objective function is the function where the cost is minimised and the electricity load shifted out of Eskom's peak times is maximised. | 6 |
### IMPLEMENT AND CONTROL INFRASTRUCTURE MODEL

#### 7.5
Obtain the optimised model. From the objective function stated in 7.4 the optimised model can be obtained. Finally an optimised model can be compiled that will use electricity tariffs to minimise the cost and maximise the load shift of the mine.

#### 7.6
Create the optimised operating schedule from the output of the optimisation model.

#### 8
Our REMS must communicate with the client's SCADA system. The sustainability of this DSM action is dependent on perfect integration of REMS and SCADA. The current SCADA system on the mine will be investigated to determine whether it complies with the required standards of REMS.

#### 8.1
Discuss implementation of REMS with personnel on mine. Determine which SCADA system is in place at the mine and how REMS can be integrated with current system.

#### 8.2
Investigate current SCADA system. Investigate what measurements are logged on the SCADA system and how this system is used to control the equipment at the mine.

#### 8.3
State shortcomings in SCADA system where modification is required.

#### 8.4
Discuss the shortcomings with technician in charge of SCADA system.

#### 8.5
Modify current system to adapt to new procedures.

#### 8.6
Investigate current hardware. Investigate current installed infrastructure (communication lines, PCs, etc.) between SCADA and equipment to be controlled.

#### 8.7
Modify current hardware system to enable communication. Implement hardware to enable communication between equipment to be controlled and the SCADA system.

### DEVELOP COMMUNICATION PROTOCOL BETWEEN MINE SCADA SYSTEM AND REMS

A TCP/IP supportive interfaces needs to be developed to enable communication between REMS and SCADA. To ensure sustainability it must be ensured that all interfaces are generic. This is an important software task.

#### 9.1
Determine the best communication method. This step is important and must be thoroughly conducted before any changes to the SCADA system. The communication between all the different processes and the control of it must be determined here.

#### 9.2
Program SCADA interface in REMS. After determining the best communication method, a REMS interface must be programmed to collect and send data from and to the SCADA system.

#### 9.3
Test new SCADA and REMS interface. This and the previous step is important to ensure good two way communication between REMS and the SCADA system. Because REMS is controlled from a remote system on site, communication between REMS and SCADA must work 100%.

### CONFIGURE REMS

The completed REMS model must be configured to integrate with the current processes of the mine. We can not change current operational procedures. In this step this issue will be addressed by modifications to the existing REMS to adapt to the strategies used on the mine.

#### 10.1
Configure REMS according to current operating strategies.

#### 10.2
Simulate response of equipment. Simulate with a software simulation program how the new controlled equipment will react when controlled by REMS algorithms.

#### 10.3
Verify the simulation process and modify if necessary. The simulation of the response of the equipment must be verified to compare with the mine equipment.

#### 10.4
Modify the REMS configuration according to results from 10.2 and 10.3. Make the necessary adjustments to REMS according to the results obtained from the previous two steps.

#### 10.5
Finalise REMS configuration.

#### 10.6
Obtain current operating strategies and equipment constraints.

### DEVELOP AND CONFIGURE REMS SUPPORT AND MONITOR SYSTEM

The support and monitoring system will assist in the gathering, storing, analysing and distribution of important system data. It also gives feedback of the REMS working operation which can be used when alterations must be made. This support and monitor system will be implemented at the remote site where the monitor room is situated. The support and monitoring of REMS ensures sustainability of the DSM actions.

---

Appendix C: Detailed Implementation procedure of REMS
11.1 Develop system to transfer daily operating data of REMS.
The operating data needs to be sent daily to the remote monitoring room. This will be send via modem from the mine.

11.2 Develop database structure for important operating data.
A structure at the remote site were all the important operating data will be stored must be developed. Typical operating data that will be stored is real-time operating schedules, availability of mine equipment and feedback reporting of control room operators on the mine.

11.3 Develop structure to analyse data from 1.
After the daily operating data is collected at the remote monitoring room it must be analysed. This information will later be used in weekly and monthly reports about the performance of REMS.

11.4 Develop structure to generate required reports.
Reports consisting of i.a. the cost savings and load shift should be distributed weekly and monthly to the mine. Daily reports consisting of percentage auto / manual control, equipment availability, R/t saving and MW load shift is also send to the mine when the project is in the beginning phase. A structure to generate the required reports should be implemented.

12 COMMISSION REMS
Finally REMS will be commissioned to do automatic real-time energy management on the mine.

12.1 Discuss commission strategy with mine management.
Before the commissioning process starts the strategy must first be discussed with the mine management.

12.2 Implement REMS interface.
The interface that was developed in 7.2 to ensure two way communication between REMS and the SCADA system can now be implemented on the mine.

12.3 Test REMS interface.
After the implementation of the interface between REMS and the SCADA system on the mine, the interface must be tested. This test must be performed to make sure there is clear communication between the mine’s SCADA system and REMS.

12.4 Commission REMS.
After the communication interface exists, the REMS configuration can be installed and commissioned.

12.5 Test newly implemented system.
After commissioning REMS on the mine the system must be tested. These tests can continue to exist for the duration of the project to ensure maximum cost savings.

12.6 Update REMS at planned intervals.
Regularly update and calibrate optimisation model to adapt to changing mine conditions. This step will continue at regular intervals for the duration of REMS on the mine.

Table C1: Detailed, generic implementation procedure of REMS.

Appendix C: Detailed Implementation procedure of REMS
User acceptability is one of the most important issues when sustainable results must be achieved. In order to test the user acceptability of the REMS product, two types of questionnaires were given to the mine after implementation was completed. Management level and operational level questionnaires were given to the specific persons and presented valuable feedback that was used to improve the process. The two types of questionnaire can be seen in this Appendix.
MANAGEMENT LEVEL:
REMS AFTER IMPLEMENTATION QUESTIONNAIRE FOR TSHEPONG MINE

CONTACT DETAIL
Name: ___________________________________________________________
Position at mine: ________________________________________________
Office Tel. no.: _________________________________________________
Email address: _________________________________________________

PRE-IMPLEMENTATION

1. Was the process of gathering mine system data time consuming for you or your personnel?

   Yes __________ No __________ Do not know __________

Comment: _______________________________________________________

2. Were you presented with clear preliminary results about the proposed project?

   Yes __________ No __________ Do not know __________

Comment: _______________________________________________________

3. Did you think at that stage that the DSM results promised were possible to realise on your mine?

   Yes __________ No __________ Do not know __________

Appendix D: User Acceptability questionnaires
4. Was it possible to realise the results on your own?

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>Do not know</th>
</tr>
</thead>
</table>

Comment: ____________________________________________

IMPLEMENTATION PROCEDURE

5. How did you experience the implementation procedure?

<table>
<thead>
<tr>
<th>Good</th>
<th>Not good</th>
<th>Do not know</th>
</tr>
</thead>
</table>

Comment: ____________________________________________

6. Were you satisfied with the technology implemented on your clear water pump system?

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>Do not know</th>
</tr>
</thead>
</table>

Comment: ____________________________________________

7. Were you confident that no mine constraints would be violated in order to realise DSM results?

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>Do not know</th>
</tr>
</thead>
</table>

8. Do you think REMS controls the pumps in a smarter way than your control room operators / pump attendants?

Yes ☐  No ☐

Do not know ☐

Comment: __________________________________________________________

SUSTAINABILITY OF DSM RESULTS

9. Are you satisfied with the DSM results?

Yes ☐  No ☐  Do not know ☐

Comment: __________________________________________________________

10. Do you think the results are sustainable?

Yes ☐  No ☐

Do not know ☐

Comment: __________________________________________________________

11. Are you satisfied with the after-implementation REMS support?

Yes ☐  No ☐  Do not know ☐
Comment: _________________________________________________________

_____________________________________________________________________

ANY OTHER COMMENT:

_____________________________________________________________________

_____________________________________________________________________

_____________________________________________________________________

_____________________________________________________________________

_____________________________________________________________________

_____________________________________________________________________

_____________________________________________________________________
OPERATOR LEVEL:
AFTER IMPLEMENTATION QUESTIONNAIRE FOR TSHEPONG MINE

CONTACT DETAIL

Name: 
Position at mine: 
Office Tel. no.: 
Email address:

INCLUSION OF OPERATOR LEVEL USERS

12. Was the purpose of the new technology explained to you before the project started?

- Yes □
- No □
- Do not know □

Comment: 

13. Did you think it was possible to automatically control the pump system?

- Yes □
- No □
- Do not know □

Comment: 

14. Do you think the new technology (REMS) is necessary to control the pumps to realise DSM results?

- Yes □
- No □
- Do not know □

Comment: 

Appendix D: User Acceptability questionnaires
IMPLEMENTATION PROCEDURE

15. How did you experience the implementation process?

Comment: ________________________________________________________________

16. Was your knowledge about the pump system used when the REMS controllers were configured?

Comment: ________________________________________________________________

OPERATOR LEVEL USER BENEFITS

17. Do you think the pump system is controlled in a smart way?

Comment: ________________________________________________________________

18. Does REMS help you in your daily tasks?

Comment: ________________________________________________________________

Appendix D: User Acceptability questionnaires 172
19. Do you feel the REMS project is a team effort between the mine and REMS engineers?

- Yes
- No
- Do not know

Comment: _____________________________________________________________

_____________________________________________________________________

20. Are you satisfied with the after implementation support?

- Yes
- No
- Do not know

Comment: _____________________________________________________________

_____________________________________________________________________

ANY OTHER COMMENT:

_____________________________________________________________________

_____________________________________________________________________

_____________________________________________________________________

_____________________________________________________________________

_____________________________________________________________________

_____________________________________________________________________

_____________________________________________________________________

Appendix D: User Acceptability questionnaires
APPENDIX E

SIMULATION AND OPTIMISATION RESULTS OF POTENTIAL GOLD MINES WHERE THE NEW PROCEDURE CAN BE APPLIED

A comprehensive study has been done about possible gold mines where the new approach described in this thesis could be implemented. Preliminary simulation and optimisation models of the pumping systems were built to determine the load shift potential. The information was used to determine the national impact of the new approach. For every mine a daily profile with the baseline and optimised profile is shown, together with the load shift and cost savings potential as can be achieved with the REMS technology.
ANGLO GOLD MINES

KOPANANG

Kopanang mine:
Historic vs. Optimised pump profiles

Potential morning peak reduction: 1.8 MW
Potential evening peak reduction: 3.9 MW
Potential annual electricity cost savings: R 480k

GREAT NOLIGWA

Great Noligwa mine:
Historic vs. Optimised pump profiles

Potential morning peak reduction: 1.4 MW
Potential evening peak reduction: 2.7 MW
Potential annual electricity cost savings: R 407k

Appendix E: Simulation and Optimisation results of potential gold mines
TAU LEKOA

Tau Lekoa mine:
Historic vs. Optimised pump profiles

Potential morning peak reduction: 1.4 MW
Potential evening peak reduction: 1.6 MW
Potential annual electricity cost savings: R 355k

MPONENG

Mponeng mine:
Historic vs. Optimised pump profiles

Potential morning peak reduction: 7.5 MW
Potential evening peak reduction: 5.5 MW
Potential annual electricity cost savings: R 1,389k
TAU TONA

Potential morning peak reduction: 3.9 MW
Potential evening peak reduction: 5.4 MW
Potential annual electricity cost savings: R 921k

SAVUKA

Potential morning peak reduction: 1.3 MW
Potential evening peak reduction: 2.4 MW
Potential annual electricity cost savings: R 380k
HARMONY GOLD MINES

ELANDSRAND

Elandsrand mine: Historic vs. Optimised pump profiles

Potential morning peak reduction: 2.9 MW
Potential evening peak reduction: 3.0 MW
Potential annual electricity cost savings: R 600k

TARGET

Target mine: Historic vs. Optimised pump profiles

Potential morning peak reduction: 1.7 MW
Potential evening peak reduction: 1.5 MW
Potential annual electricity cost savings: R 324k
**EVANDER 7 SHAFT**

Evander 7 shaft: Historic vs. Optimised pump profiles

- Potential morning peak reduction: 0.0 MW
- Potential evening peak reduction: 3.9 MW
- Potential annual electricity cost savings: R 346k

**RANDFONTEIN 4 SHAFT**

Randfontein 4 shaft: Historic vs. Optimised pump profiles

- Potential morning peak reduction: 1.1 MW
- Potential evening peak reduction: 6.5 MW
- Potential annual electricity cost savings: R 644k
GOLD FIELDS MINES

BEATRIX 1,2,3 SHAFTS

Potential morning peak reduction: 4.2 MW
Potential evening peak reduction: 6.3 MW
Potential annual electricity cost savings: R 1,184k

BEATRIX 4 SHAFT

Potential morning peak reduction: 5.0 MW
Potential evening peak reduction: 5.1 MW
Potential annual electricity cost savings: R 1,283k
KLOOF 7 SHAFT

Potential morning peak reduction: 3.8 MW
Potential evening peak reduction: 12.6 MW
Potential annual electricity cost savings: R 1,392k

PLACER DOMES MINES

SOUTH DEEP (SOUTH SHAFT)

Potential morning peak reduction: 0.9 MW
Potential evening peak reduction: 6.1 MW
Potential annual electricity cost savings: R 578k

Appendix E. Simulation and Optimisation results of potential gold mines
Previously, type 3 mines, which did not consist of adequate control and instrumentation equipment, had never been considered for DSM projects, since automated load shift required an intensive investment in capital infrastructure. REMS was adapted to control the pumping system with the minimum control infrastructure. This Appendix describes the additional control infrastructure that was implemented at Masimong 4 shaft and Harmony 3 shaft.
MASIMONG 4

Masimong currently has a surface control room, but no SCADA. A new SCADA will have to be supplied and installed.

This Adroit SCADA will be linked to the two pump stations on 1280 level and 2100 level via a new fibre optic network for communication. The network will comprise of an Ethernet switch in the surface control room mounted in a 19" rack cabinet and connected to the SCADA via Ethernet.

The fibre in the shaft will be connected on each level to a switch that in turn will be connected via Ethernet to a Quantum Schneider Ethernet module in each PLC rack. Each PLC rack will consist of a CPU, Ethernet module, analogue and digital input and output modules. A vibration transmitter, flow switch, pressure switch and electric actuator will be installed on each pump and connected to a junction box via single pair cables. The junction box will then be connected via a multicore cable to the PLC for interlock, trip and remote monitoring and controlling.

All LT and HT drives will be interfaced with the PLC to facilitate remote control and monitoring of the pumps from a surface control room. Each PLC will be mounted in an enclosure with a HMI installed in the panel door to facilitate local control and indication. The system will be commissioned and tested on a pump-by-pump basis to ensure minimum interruption of the day-to-day operation of the mine. All fibre optic cable will be spliced and tested prior to commencing with commissioning. All loop drawing for panels and junction boxes will be supplied. A breakdown of the main equipment items is given below:

<table>
<thead>
<tr>
<th>QTY</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>140CPU11303 CPU 512K 1XMB+</td>
</tr>
<tr>
<td>1</td>
<td>140CPS11410 AC P/S 115/230V</td>
</tr>
<tr>
<td>1</td>
<td>140XBP01600 Backplane 16 slot</td>
</tr>
<tr>
<td>4</td>
<td>140DAI55300 AC input 4 x 8 Channel 115V ac</td>
</tr>
<tr>
<td>3</td>
<td>140DRA84000 Relay output 16 x 1 NO</td>
</tr>
<tr>
<td>3</td>
<td>140ACI040 Analogue input module 16 channel</td>
</tr>
</tbody>
</table>

Appendix F: Additional Control and Instrumentation equipment required
1 140NOE77110 Ethernet module
1 XBTF024110 Magelis 10.4" colour operator interface panel
1 XBT-Z9710 cable

**Panel for PLC 1280 level:**

1 Panel consisting of a PLC section 1800 (200) x 1200 x 300 and an electrical section 1800 (200) x 800 x 300 manufactured from 3CR12
1 Wiring of PLC and operator panel including terminals, wire, rail, trunking, wire numbers, 24V Black Max power supply etc
1 Wiring of electrical panel including 12 x 2.2 kW contactors, thermal overload, local stop start, push buttons etc

**Field Instrumentation 1280 level:**

6 SOR 6NN - K45 - R1 - F1A pressure Switches
6 Mc Donnel & Miller Model F57 - 4LJ flow switches
6 Monitran vibration sensors
Model: MTN1185 - CM8 - 20F
Range: 0 - 20mm/sec
7 Polycarbonate junction boxes including terminals, trunking, wire numbers etc
1 Installation of field instrumentation underground, installing cable and termination, junction boxes Etc
1 Termination of electrical equipment
6 DN200 full bore ball valve, A105 carbon steel body, 304SS ball and stem, R-PTFE seta and seals c/w 3:1 ratio gearbox and 110Volt electric actuator ELD2500

**Main PLC 2100 level consisting of the following:**

1 140CPU11303 CPU 512K 1XMB+
1 140CPS11410 AC P/S 115/230V
1 140XBP01600 Backplane 16 slot
4 140DAI55300 AC input 4 x 8 Channel 115V ac
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>140DRA84000 Relay output 16 x 1 NO</td>
</tr>
<tr>
<td>3</td>
<td>140ACI040 Analogue input module 16 channel</td>
</tr>
<tr>
<td>1</td>
<td>140NOE77110 Ethernet module</td>
</tr>
<tr>
<td>1</td>
<td>XBTF024110 Magelis 10.4&quot; colour operator interface panel</td>
</tr>
<tr>
<td>1</td>
<td>XBT – Z9710 cable</td>
</tr>
</tbody>
</table>

**Panel for PLC on 2100 level:**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Panel consisting of a PLC section 1800 (200) x 1200 x 300 and an electrical section 1800 (200) x 800 x 300 manufactured from 3CR12</td>
</tr>
<tr>
<td>1</td>
<td>Wiring of PLC and operator panel including terminals, wire, rail, trunking, wire numbers, 24V Black Max power supply etc</td>
</tr>
<tr>
<td>1</td>
<td>Wiring of electrical panel including 12 x 2.2 kW contactors, thermal overload, local stop start, push buttons etc</td>
</tr>
</tbody>
</table>

**Field Instrumentation 2100 level:**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>SOR 6NN – K45 – R1 – F1A pressure switches</td>
</tr>
<tr>
<td>6</td>
<td>Mc Donnel &amp; Miller Model F57 – 4LJ flow switches</td>
</tr>
<tr>
<td>6</td>
<td>Monitran vibration sensors</td>
</tr>
<tr>
<td></td>
<td>Model: MTN1185 – CM8 – 20F</td>
</tr>
<tr>
<td></td>
<td>Range: 0 – 20mm/sec</td>
</tr>
<tr>
<td>7</td>
<td>Polycarbonate junction boxes including terminals, trunking, wire numbers etc</td>
</tr>
<tr>
<td>1</td>
<td>Installation of field instrumentation underground, installing cable and termination, junction boxes Etc</td>
</tr>
<tr>
<td>1</td>
<td>Termination of electrical equipment</td>
</tr>
<tr>
<td>6</td>
<td>DN200 full bore ball valve, A105 carbon steel body, 304SS ball and stem, R-PTFE seta and seals c/w 3:1 ratio gearbox and 110Volt electric actuator ELD2500</td>
</tr>
</tbody>
</table>

**Network: Fibre optics**
<table>
<thead>
<tr>
<th>2500m</th>
<th>12 Element 12 Fibre Mine Shaft cable</th>
</tr>
</thead>
<tbody>
<tr>
<td>400m</td>
<td>4 Fibre 6 Element Heavy Duty Duct cable</td>
</tr>
<tr>
<td>1</td>
<td>Installation of fibre optic cable in haulage</td>
</tr>
<tr>
<td>1</td>
<td>RS2-4TX/1FX switch</td>
</tr>
<tr>
<td>3</td>
<td>RS2-3TX/2FX switch</td>
</tr>
<tr>
<td>4</td>
<td>FE-C107-ST Fibre to copper converters</td>
</tr>
<tr>
<td>3</td>
<td>3M Splice box</td>
</tr>
<tr>
<td>64</td>
<td>MM pigtails</td>
</tr>
<tr>
<td>64</td>
<td>ST midcouplers</td>
</tr>
<tr>
<td>64</td>
<td>Splice protectors</td>
</tr>
<tr>
<td>10</td>
<td>Grey glands</td>
</tr>
<tr>
<td>88</td>
<td>Fusion splices</td>
</tr>
<tr>
<td>1</td>
<td>Enclosure</td>
</tr>
<tr>
<td>23hrs</td>
<td>Labour</td>
</tr>
<tr>
<td>1</td>
<td>19&quot; Rack wall mount c/w fan and filter</td>
</tr>
</tbody>
</table>

**Network: SCADA**

| 2     | Mecer PC with 17" monitor |
| 1     | Adroit 5.0 Standalone System – 5000 Scanned points not configured with all configuration tools and drivers |

**Network: Software:**

| 2     | Development of HMI data panel |
| 2     | Development of PLC software |
| 1     | Development of SCADA software |
| 1     | Final test and commissioning |

**General**

| 1000  | Metres one pair 0.5mm², screened, dekabon orange instrumentation cable |

---

*Appendix F: Additional Control and Instrumentation equipment required*
1000 Metres two pair 0.5mm², screened, dekabon orange instrumentation cable

1000 Metres sixteen pair 0.5mm², screened, dekabon orange instrumentation cable

<table>
<thead>
<tr>
<th>Reactors</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 1500 kW 6600 Volt Reactor Starter complete with shorting contactors. Timers with taps at 60% 70% and 80% rated for 8 starts per hour for pump start</td>
</tr>
<tr>
<td>8 Design, manufacture and routine test</td>
</tr>
<tr>
<td>8 Delivery of Reactors to Harmony Free State Operations</td>
</tr>
<tr>
<td>8 Implementation of Reactors</td>
</tr>
</tbody>
</table>

HARMONY 3

Harmony 3 also does not have a SCADA system at present.

A newly developed Adroit SCADA system will have to be installed and linked to the two pump stations on 4/3 level and 14B level via a fibre optic network for communication. This network will comprise of an Ethernet switch in the surface control room mounted in a 19'' rack cabinet and connected to the SCADA via Ethernet.

The fibre in the shaft will be connected on each level to a Switch. On 4/3 level the network will be expanded 1500m to the pump station. The switch will then be connected via Ethernet to a Quantum Schneider Ethernet module in each PLC rack. Each PLC rack will consist of a CPU. Ethernet module, analogue and digital input and output modules. A vibration transmitter, flow switch, pressure switch and electric actuator will be installed on each pump and connected to a junction box via single pair cables.

The junction box will then be connected via a multicore cable to the PLC for interlock, trip and remote monitoring and controlling. All LT and HT drives will be interfaced with the PLC to facilitate remote control and monitoring of the pumps from a surface control room. Each PLC will be mounted in an enclosure with a HMI installed in the panel door to facilitate local control and indication.

Appendix F: Additional Control and Instrumentation equipment required
The system will be commissioned and tested on a pump-by-pump basis to ensure minimum interruption of the day-to-day operation of the mine. All fibre optic cable will be spliced and tested prior to commencing with commissioning. All loop drawing for panels and junction boxes will be supplied. Below is a detailed breakdown of the necessary equipment:

### Main PLC 4/3 level consisting of the following:

<table>
<thead>
<tr>
<th>QTY</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>140CPU11303 CPU 512K 1XMB+</td>
</tr>
<tr>
<td>1</td>
<td>140CPS11410 AC P/S 115/230V</td>
</tr>
<tr>
<td>1</td>
<td>140XBP01600 Backplane 16 slot</td>
</tr>
<tr>
<td>4</td>
<td>140DAI55300 AC input 4 x 8 Channel 115V ac</td>
</tr>
<tr>
<td>3</td>
<td>140DRA84000 Relay output 16 x 1 NO</td>
</tr>
<tr>
<td>3</td>
<td>140ACI040 Analogue input module 16 channel</td>
</tr>
<tr>
<td>1</td>
<td>140NOE77110 Ethernet module</td>
</tr>
<tr>
<td>1</td>
<td>XBTF024110 Magelis 10.4&quot; colour operator interface panel</td>
</tr>
</tbody>
</table>

### Panel for PLC on 4/3 level:

1. Panel consisting of a PLC section 1800 (200) x 1200 x 300 and an electrical section 1800 (200) x 800 x 300 manufactured from 3CR12

1. Wiring of PLC and operator panel including terminals, wire, rail, trunking, wire numbers, 24V Black Max power supply etc

1. Wiring of electrical panel including 12 x 2.2 kW contactors, thermal overload, local stop start, push buttons etc

### Field Instrumentation on 4/3 level:

6. SOR 6NN – K45 – R1 – F1A pressure switches

6. McDonnel & Miller Model F57 – 4LJ flow switches

---

*Appendix F: Additional Control and Instrumentation equipment required*
6. Monitran vibration sensors
   Model: MTN1185 – CM8 – 20F
   Range: 0 – 20mm/sec

7. Polycarbonate junction boxes including terminals, trunking, wire numbers etc

1. Installation of field instrumentation underground, installing cable and termination, junction boxes etc

1. Termination of electrical equipment

6. DN200 full bore ball valve, A105 carbon steel body, 304SS ball and stem, R-PTFE seta and seals c/w 3:1 ratio gearbox and 110Volt electric actuator ELD2500

**Main PLC 14B level consisting of the following:**

1. 140CPU11303 CPU 512K 1XMB+
2. 140CPS11410 AC P/S 115/230V
3. 140XBP01600 Backplane 16 slot
7. 140DA155300 AC input 4 x 8 Channel 115V ac
5. 140DRA84000 Relay output 16 x 1 NO
5. 140AC1040 Analogue input module 16 channel
1. 140NOE77110 Ethernet module
2. 140XBP01600 Backplane expander modules
1. 140XCA71706 Backplane expander cable
1. XBT024110 Magelis 10.4” colour operator interface panel
1. XBT – Z9710 cable

**Panel for PLC on 14B level:**

1. Panel consisting of a PLC section 1800 (200) x 1200 x 300 and an electrical section 1800 (200) x 800 x 300 manufactured from 3CR12
1. Wiring of PLC and operator panel including terminals, wire, rail, trunking, wire numbers, 24V Black Max power supply etc
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wiring of electrical panel including 18 x 2.2 kW contactors, thermal overload, local stop start, push buttons etc.</td>
</tr>
<tr>
<td>9</td>
<td><strong>Field Instrumentation on level 14B:</strong></td>
</tr>
<tr>
<td>9</td>
<td>SOR 6NN – K45 – R1 – F1A pressure switches</td>
</tr>
<tr>
<td>9</td>
<td>Mc Donnel &amp; Miller Model F57 – 4LJ flow switches</td>
</tr>
</tbody>
</table>
| 9 | Monitran vibration sensors  
Model: MTN1185 – CM8 – 20F  
Range: 0 – 20mm/sec |
<p>| 10 | Polycarbonate junction boxes including terminals, trunking, wire numbers etc |
| 1 | Installation of field instrumentation underground, installing cable and termination, junction boxes etc |
| 1 | Termination of electrical equipment |
| 9 | DN200 full bore ball valve, A105 carbon steel body, 304SS ball and stem, R-PTFE seta and seals c/w 3:1 ratio gearbox and 110Volt electric actuator ELD2500 |
|   | <strong>Network: Fibre optics</strong> |
| 2200m | 12 Element 12 Fibre Mine Shaft cable |
| 1500m | 4 Fibre 6 Element Heavy Duty Duct cable |
| 1 | Installation of fibre optic cable in haulage |
| 1 | RS2-4TX/1FX switch |
| 3 | RS2-3TX/2FX switch |
| 3 | 3M Splice box |
| 64 | MM pigtails |
| 64 | ST midcouplers |
| 64 | Splice protectors |
| 10 | Grey glands |</p>
<table>
<thead>
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<th>Fusion splices</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Enclosure</td>
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<td>Labour</td>
</tr>
<tr>
<td>1</td>
<td>19&quot; Rack wall mount c/w fan and filter</td>
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</tbody>
</table>

**Network: SCADA**

<table>
<thead>
<tr>
<th></th>
<th>Mecer PC with 17&quot; monitor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Adroit 5.0 Standalone System -- 5000 Scanned points not configured with all configuration tools and drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**Network: Software**

<table>
<thead>
<tr>
<th></th>
<th>Development of HMI data panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Development of PLC software</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Development of SCADA software</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Final test and commissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**General**

<table>
<thead>
<tr>
<th></th>
<th>Loop drawing, schematics etc</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Metres one pair 0.5mm², screened, dekabon Orange instrumentation cable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Metres two pair 0.5mm², screened, dekabon Orange instrumentation cable</th>
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<tbody>
<tr>
<td>1500</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Metres sixteen pair 0.5mm², screened, dekabon Orange instrumentation cable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500</td>
<td></td>
</tr>
</tbody>
</table>
Daily reports are generated once a week to evaluate the operational performance of REMS as well as the control setup. On these daily reports the condition of the pumps can also be monitored. Useful information is sent through to mine personnel responsible for the maintenance of the pumping system. In future the running hours of each pump can be included in these reports. Example daily reports for Masimong 4 shaft, Harmony 3 shaft and Tshepong mine can be seen in this Appendix.
Evening load shift: 4.67 MW
Electricity cost saving: R 1017.10
Daily problems: System in manual mode from 2:00 – 8:00 (am) due to maintenance.
Evening load shift: 4.00 MW
Electricity cost saving: R 998.31
Daily problems: System in manual mode from 8:50 – 9:40 (am) and 17:05 – 17:55 due to maintenance on 4/3 level pump station.
Evening load shift: 3.18 MW
Electricity cost saving: R 450.19
Daily problems: None
Appendix G: Daily Reports