CONTROL OF AN UNDERGROUND ROCK WINDER SYSTEM TO REDUCE ELECTRICITY COSTS ON RSA GOLD MINES

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ABSTRACT

Title: Control of an underground rock winder system to reduce electricity costs on RSA gold mines

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This dissertation discusses and presents the necessary steps to identify, simulate and control an underground rock winder system. This is done to reduce the electricity bill on a mine without influencing production. These elements were developed for the gold mining industry in South Africa, as it consumes a big part of the South African electricity supply.

The backbone of this research was based on the time-of-use electricity pricing structure, and the Eskom Demand Side Management (DSM) program. An Energy Savings Company (ESCO) usually performs such an energy analysis on mining appliances, and this thesis can guide the ESCO in completing the project with success.

The tools developed were Real-time Energy Management System (REMS) Winder and REMS Winder Simulator. These integrated tools aim to predict and control load management on rock winders.

This system was successfully implemented on Kopanang gold mine in South Africa. The average load shift obtained in the first month after project completion (June 2006) was 3.5MW, which resulted in a monthly savings of R38,000. A pilot study was further conducted on three other major rock winder systems in the Western-Deep area. From this study it was found that a maximum evening load shift of 9.5MW and a saving of R1.3 million could be realised.

This research showed that with the necessary historical data and accurate simulations, a load shifting project can be successfully implemented on a mine's rock winder system. This new system can be implemented on both platinum and gold mines.

SAMEVATTING

Titel: Die beheer van 'n ondergrondse klip-hyser sisteem met die doel om die elektriese koste te verminder

Outeur: Jan Corné Vosloo

Promotor: Prof. M. Kleingeld

Graad: Magister in Ingenieuerswese (Elektries)

Hierdie thesis beskryf die nodige stappe wat gevolg moet word om 'n spesifieke klip-hyser systeem te identifiseer, simuleer en te beheer sodat die elektriesiteit rekening verminder word. Hierdie elemente was ontwikkel vir die goudmyn industrie, aagesien dit 'n groot effek op die Suid-Afrikaanse elektriese kragverbruik het.

Hierdie navorsing is gebaseer op die tyd-van-verbruik elektrisiteit koste struktuur asook die Eskom DSM (Demand-Side Management) program. 'n ESCO (Energy Savings Company) doen gewoonlik die energie analise op groot myn toerusting om 'n DSM projek te identifiseer. Hierdie thesis lei die ESCO om die projek suksesvol te voltooi.

Die sisteme wat ontwikkel is, is Real-time Energy Management (REMS) Winder en REMS Winder Simulator. Hierdie twee sisteme is geintegreer om die elektriese las beheer op klip-hysers toe te pas.

Die sisteem was suksesvol geimplementeer op- Kopanang goudmyn in Suid-Afrika. 'n Gemidelde lasskuif van 3.5MW is gedurende die eerste maand (Junie 2006) behaal, wat die myn ongeveer R38,000 vir die maand gespaar het. 'n Voorlopige studie was ook verder op drie ander myne in die Western-Deep area gedoen. Die uiteinde van die studie het getoon dat 'n maksimum aand lasskuif van 9.5MW behaal kan word. Hierdie lasskuif sal 'n besparing van R1.3 miljoen per jaar vir die myne saam teweeg bring.

Die navorsing het getoon dat met die regte hitoriese data en akkurate simulasies kan 'n lasskuifprojek suksesvol geimplementeer word op 'n klip-hyser sisteem. Hierdie spesifieke sisteem kan op byde platimum en goudmyne geimplementeer.

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- Within my references I aim to thank all contributors and sources for their information. If the reader feels that any person or source has been omitted, please inform me so that this could be rectified.

- I also wish to thank my family, Vossie Vosloo, Elma Vosloo and Martin Vosloo. They raised me, supported me, taught me, and loved me. To them I dedicate this thesis.

- Finally, and most importantly, I would like to thank the almighty God, for it is under his grace that we live, learn and flourish.

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ABBREVIATIONS

BMR	:	Blair Multi-rope
Btu	:	British thermal units
CAM	:	Compressed Air Management
DSM	:	Demand Side Management
EE	:	Electrical Energy
EIA	:	Energy Information Administration
g/ton	:	grams per ton
GM	:	General Manager
GRG2	:	Generalised Reduced Gradient
KE	:	Kinetic Energy
kg	:	kilograms
kVA	:	kilovolt Ampere
kW	:	kilowatt
kWh	:	kilowatt-hour
M&V	:	Measurements and Verification
MD	:	Maximum Demand
MJ	:	Mega Joule
min	:	minute
MVA	:	Megavolt Ampere
PE	:	Potential Energy
PLC	:	Programmable Logic Controller
RTP	:	Real-time Pricing
REMS	:	Real-time Energy Management System
RSA	:	Republic of South Africa
SCADA	:	Supervisory Control and Data Acquisition

t	:	ton
VAT	:	Value Added Tax

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1.1 Preamble

South Africa's electrical energy demand is rapidly catching up with the maximum electricity supply capacity. New ways to increase the electrical capacity are currently being developed, but these so-called new generation electrical generators will only arrive after the demand surpasses the supply [1]. The only way to prevent South Africa and its neighbouring countries from having an electrical blackout will be to stop the increase in demand (which will result in a negative impact on the economy) [2], or to restructure the daily power demand profile. The second option is more feasible for the Southern African people and its economy.

1.2 Background on world wide energy demand

The world is running out of its traditional energy resources [3]. Still economies expand and populations grow. In addition, everyday new inventions see the light to simplify the human's daily lifestyle. These new discoveries end up using more amounts of energy [2].

The total worldwide energy demand has increased from 207 quadrillion British thermal units (Btu) to 412 quadrillion Btu between 1970 and 2002 [4]. This realises a 50% increase in energy demand in 32 years. It is projected that it will only take 20 years for the world energy consumption to increase by a further 50% [4]. Figure 1 shows the historical and projected world energy consumption.

Of the worldwide total energy consumption, electrical energy contributes up to 30% of this figure [5]. This percentage is however expected to rise due to the increasing oil prices and limited oil availability of the past few years [6].

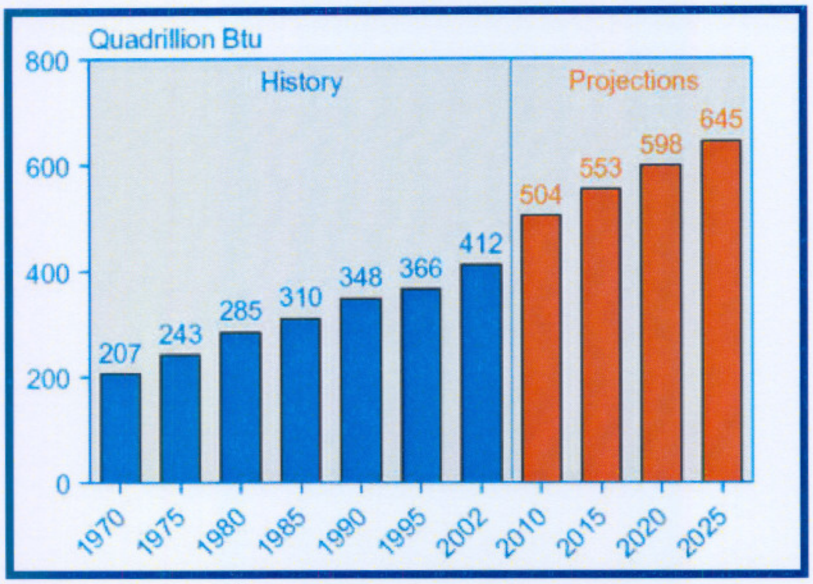

Figure 1: EIA's (Energy Information Administration) world marketed historical and projected energy consumption

1.3 The South African electricity situation

Coal is South Africa's primary energy resource and contributes up to 70% of the energy generation requirements [7]. South Africa also generates electricity from natural gasses, hydro-power, nuclear power, solar power and wind to make up approximately 37,000MW of generating capacity [8]. Figure 2 is a breakdown of South Africa's primary energy resources for the year 2002 [8].

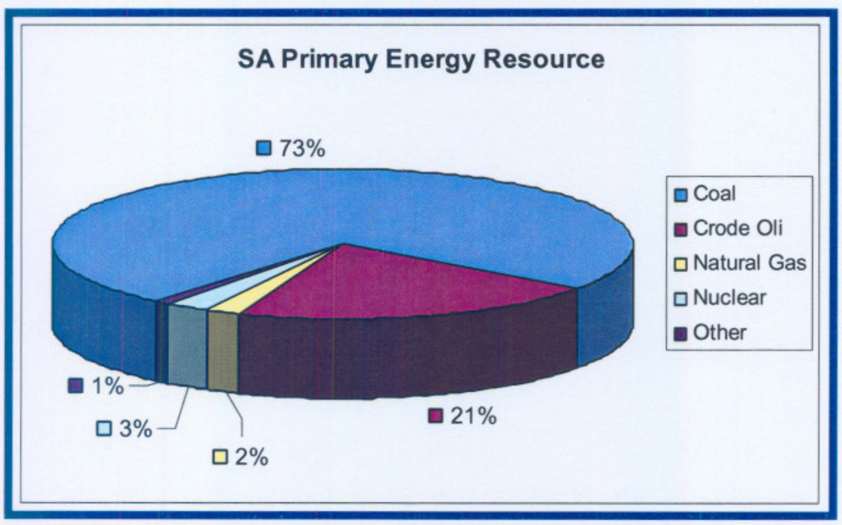

Figure 2: South Africa's primary energy resources

According to figures released by South Africa Info [9] in 2005, the annual economic growth rate averaged 3.5% from September 1999 through to June 2005. This figure states the fact that the South African economy is growing rapidly. South Africa's economy is also very energy intensive [10]. The reason for this is because the biggest part of its economy is primarily based on extraction and processing of minerals [11].

From the above facts it is safe to conclude that South Africa's energy, and with more focus, its electricity demand is rapidly increasing. Speaking at a seminar on the world energy situation, presented in Johannesburg in January 2004, Eskom GM strategist Andrew Etzinger said that South African electricity demand is expected to grow by 1,200MW per year due to the expected economic growth over the next 20 years [12].

With this electrical demand increase, it is estimated that the country's existing power generation capacity will be insufficient to meet the rising national maximum demand by 2007 as shown in Figure 3 [13]. Note how the rapid increase in demand has narrowed the gap between total electricity demand and the available supply.

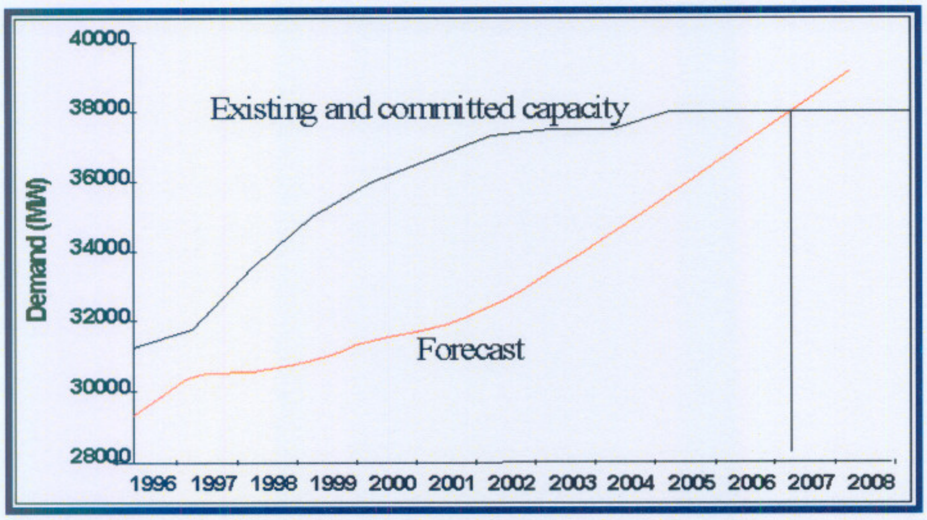

Figure 3: Maximum capacity vs. forecasted demand

The main electricity supplier in South-Africa, Eskom (which produce 60% of the electricity in Africa [14]), investigated the massive increase in electricity demand [15]. The outcome of this investigation found that the power demand profile followed certain trends.

The investigation confirmed that the electricity demand increased significantly during the **winter months**. The months of June, July and August are the three months with the highest peak demand and electricity usage. Eskom classified these months as winter months. Figure 4 illustrates the difference in demand during winter periods and non-winter periods. Note the sudden increase in demand during the winter section. This sudden increase is induced mainly by municipalities with the running of heating appliances like geysers that consume most of the household's electricity demand [16].

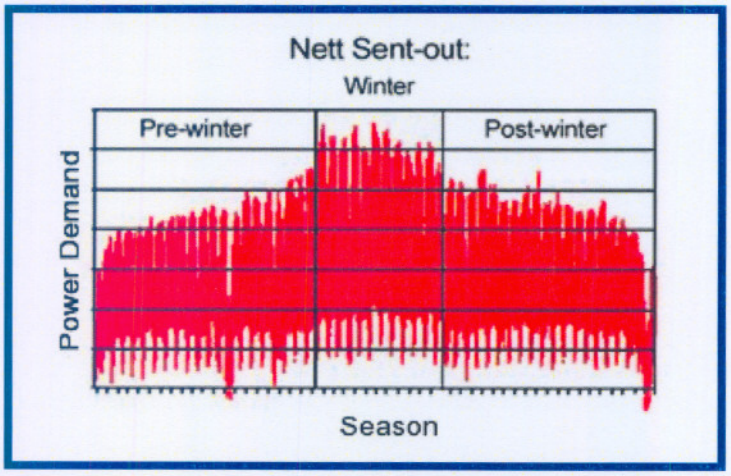

Figure 4: Seasonal electricity demand

The **different days of a week** also play an important role in the electricity demand curve. During weekdays the demand increases significantly compared to Saturdays and Sundays. Public holidays also fall into the weekend category because of the relatively low demand. Figure 5 illustrates the demand during a typical week. This figure also shows that the specific **time in a day** is another factor to reckon with.

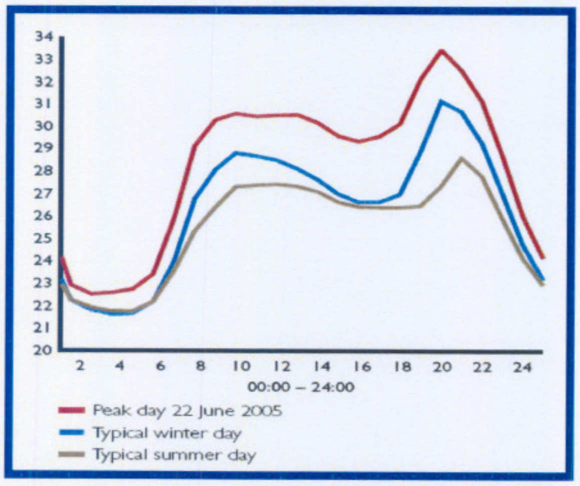

Figure 5: Electricity demand vs. hour of the week [17]

During a typical day the electrical demand increases between 07h00 – 10h00 and 18h00 – 20h00. It can also be seen from the figure that the maximum demand during the evening peaks is much larger than the morning peaks, but on the other hand, the morning peak times last much longer.

1.4 Variable pricing structures and an introduction to DSM

As stated in the previous sections, South-Africa's primary electrical power utility, Eskom, is busy running out of electricity generating capacity. The only way to delay the demand from surpassing the supply capacity is to change or flatten the power profile.

To persuade the client to alter their power usage profile, Eskom introduced the time-of-use pricing structure tariffs. In this structure Eskom increased the electricity costs during the high peak periods and lowered the costs during the low peak periods. These structures encourage Eskom's clients to look at its power profile and encourage an energy-concerned community.

Eskom provides a number of tariff structures, each focus on specific customer needs. These tariff structures are primary grouped into three different non-municipal classes, namely: urban tariffs, residential tariffs and rural tariffs [19]. The mining and industrial sectors are placed into the urban tariff structure. Listed below are the two types of Eskom urban tariffs most commonly used by the industrial and mining sectors:

Night Save: Tariff for urban, industrial and mining customers with a Notified Maximum Demand from 25kVA. This tariff consists of two different time pricing periods namely peak and off-peak.

Mega Flex: Time-of-usage tariff for urban, industrial and mining customers with a Notified Maximum Demand from 1MVA. This tariff consists of three different time pricing periods namely peak, standard and off-peak [19].

The majority of gold mines uses the Mega Flex tariff. This tariff caters for industries and mines that operate on a 24 hour non-stop process. The different time intervals for the three pricing periods are indicated in Figure 6.

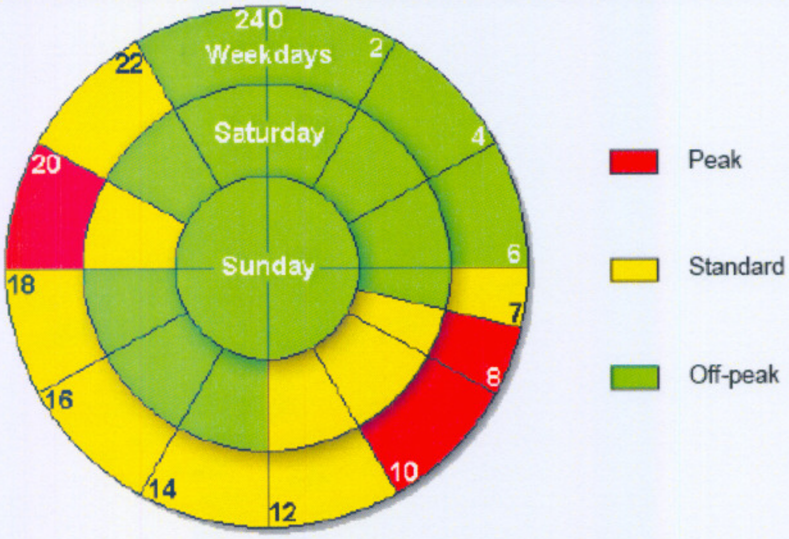

Figure 6: Mega Flex - Variable pricing structures chart

In the above figure it can be clearly seen that peak times, coloured in red, are between 07h00 - 10h00 and 06h00 - 08h00. The off-peak times, coloured in green, is between 22h00 and 06h00. In the off-peak times electricity costs are much cheaper than in the standard or peak times as indicated in the table below [19].

Table 1: Mega Flex – Energy usage tariffs

High-demand season (June - August)		Low-demand season (September - May)
52.22c + VAT = 59.53c/kWh	Peak	14.82c + VAT = 16.89c/kWh
13.81c + VAT = 15.74c/kWh	Standard	9.20c + VAT = 10.49c/kWh
7.51c + VAT = 8.56c/kWh	Off-Peak	6.52c + VAT = 7.43c/kWh

Note how the pricing structure differs between the winter and the summer tariffs. In winter the peak electricity costs increase by almost four times.

The tariff structures forced many of the high electricity consumers to change their electricity usage habits, but the response was not enough to reduce the insight demand. Eskom therefore had to implement a more drastic and reliable program to provide a mechanism to help the energy consumer react to these tariff structures [15].

In 1992 Eskom launched a Demand Side Management (DSM) programme in accordance with regulations drawn up by the Department of Minerals and Energy and the National Energy Regulator of South Africa. This program was first implemented in the early 1980's in the United States of America and later in Europe with great success [18]. It motivates energy users to rather use electrical energy during the daily off-peak or standard times than in the evening peak times. This is done by fully funding the energy users of any infrastructure that might be needed to reduce the evening peak demand. Off all the programs Eskom has implemented during the last few years, DSM seems to be the most successful [15]. The DSM program consists of a number of parties, namely:

- Client (Electricity user)
- Eskom DSM
- Energy Service Company (ESCO)
- Measuring and Verification (M&V)

An ESCO is a company that develops, installs and finances projects designed to improve the daily energy profile of a specific electricity user (client). What makes the DSM program so successful is the fact that it is the ESCO's responsibility to make sure that the Eskom client reduces its electrical usage during the evening peak time [20].

The DSM process gets started after the ESCO has done the necessary research on the specific client where there is potential to reduce the electricity demand during the evening peak time. A few of the rules the project has to adhere to is:

- The project duration has to be 3, 5 or 10 years
- Projects need to be larger than 500 kW
- "Open" submission: reveal all details, costs
- Grouping of projects allowed
- ESCO acts as project manager and custodian of funds

After the ESCO has submitted a project proposal, and Eskom DSM has agreed upon any funding, an agreement between the two parties is signed. In this contract the evening load shift target is stipulated. If for some reason the ESCO fails to reduce the evening peak demand with the contracted value, it will be liable to pay penalties (which were stated in the contract before hand).

After the ESCO and Eskom DSM have signed the contract, the ESCO must make sure that a contract between Eskom DSM and the client is signed in which the client states its co-operation to the Eskom DSM project.

If the necessary infrastructure is installed and the project is completed, the project is evaluated by an M&V team. This M&V team verifies the results for the duration of the project and gives feedback on the performance of the project.

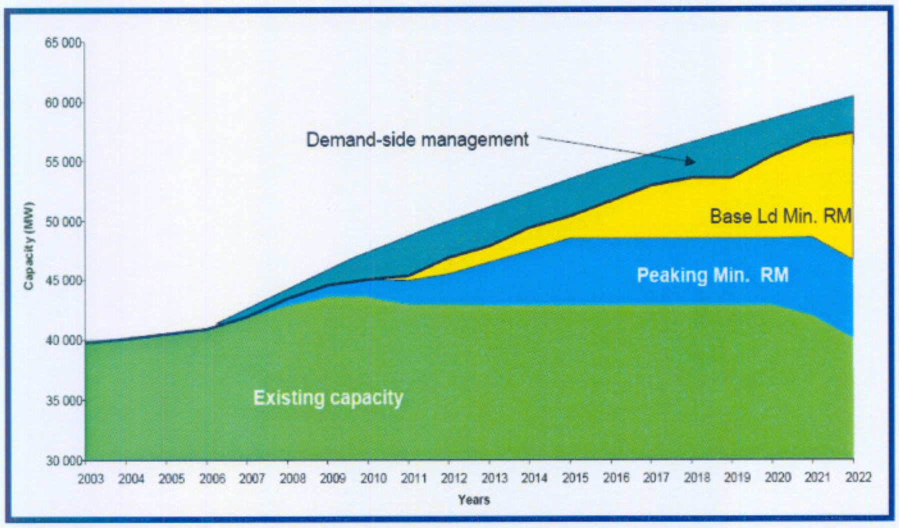

Figure 7: Electricity capacity development plan [22]

Due to the important role DSM plays in the reduction of South Africa's electricity demand, it can be said that the DSM program virtually increase South Africa's electricity capacity. Currently the Eskom's target for DSM is 1.37GW by the year 2015 [21]. This target is likely to change dynamically over time in response to the actual requirement for DSM in South Africa. The involvement of DSM in contributing to the availability of additional electrical capacity can be seen in Figure 7.

Peak Clipping (Figure 8) or the reduction of the system peak electrical usages or loads, is perhaps the most common form of load management. Peak clipping is generally considered to be the reduction of peak load, for example: direct utility control of customer's appliances [24]. This process is often seen as the efficient use of electricity, hence the name efficiency. While this is most often regarded as a means to reduce peaking capacity or electrical purchases, it can also be used to reduce operating cost and dependence on critical fuels.

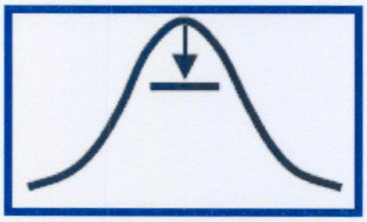

Figure 8: Peak clipping [25]

Valley Filling (Figure 9) is also a widely practiced form of load management. Valley filling entails boosting off-peak loads, which may be particularly desirable to a utility for those times of the year or day where the cost is less than the average price of electricity. Adding priced off-peak load under these circumstances decreases the average electricity cost to customers.

Figure 9: Valley filling [25]

Load Shifting (Figure 10) is the last traditional form of load management. This involves shifting load from peak to off-peak periods, through such applications as water-, heating- and cool storage [24]. Note that the power used during a certain period stays the same. This means that the amount of work done before and after the load shifting is equal; it's only the profile that changes.

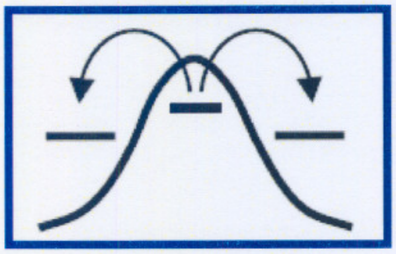

Figure 10: Load shifting [25]

1.5 South Africa's mining situation

Mining in South Africa consumes 17.6% of all electricity generated [26], as shown in Figure 11. It can also be seen from the figure that municipalities and townships are the biggest culprits when it comes to evening and morning peak demand. To change the power profile of thousand of households will have the same effect as changing the power profile of a typical mine. Thus, it makes much more sense changing the power profile of the bigger electrical users in terms of the demand vs. appliance relation, than smaller electricity users.

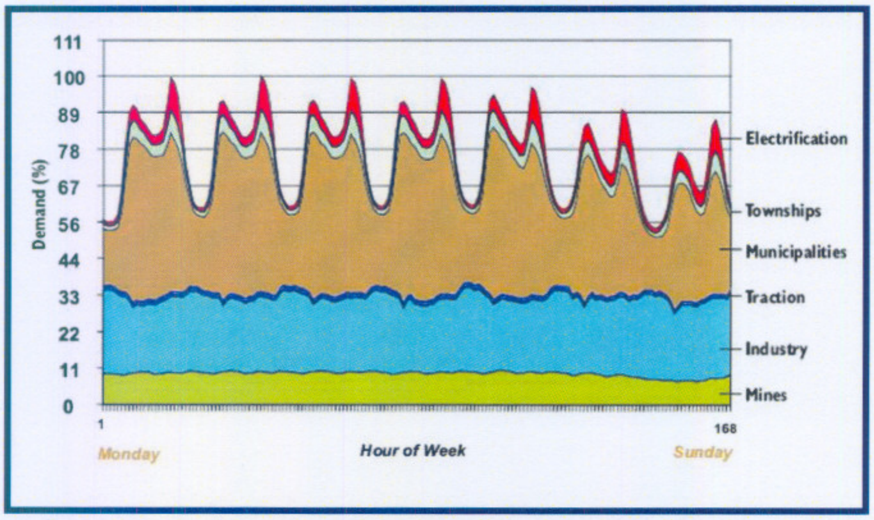

Figure 11: Total electricity demand (%) vs. typical hour of the week

On average, 67% of the energy supplied to mines is electricity. If this is converted into cost, South African mines spend approximately 5 billion rand per annum on electricity [27].

Gold has been an important driver throughout South Africa's modern economy. The country's gold reserves constitute a third of the known total world's gold reserves [29]. Within South Africa, the gold mines are also the single greatest users of electricity across all mining sectors. The amount of electricity used for gold mining is nearly as much as the electricity used by all the other mining sectors combined.

The reason for this is the declining gold ore grades which forced gold production to drop steadily, from 1,000 tons in the 1970s to 395 tons in 2001 [30]. These low gold-ore grades influenced the mining in such a way that the energy required to mine a unit of gold, increased fourfold in this period. This phenomenon is due to the fact that mines are going deeper and have to process more ore for each ton of gold produced. However, some of the mines don't have the capital or gold reefs to increase their production [30]. In some of the cases these mines are forced to close down, which could lead to environmental devastation [31]. It will therefore be beneficial for both the energy supplier and the mine to use energy sensibly and reduce operating costs.

Compressors use up to 21.3% of the total energy consumed on a typical gold mine. Compressed air is mainly used for drilling, however new ways to use hydro power could change this statistic. Other great energy users of an underground gold mining system includes the underground pumping system (17.7%), the mine hoisting system (14.2%) and the cooling and ventilating system [27]. The underground water- and hoisting system may in some cases, depending mostly on the depth of a gold mine, even use more energy than the compressed air system.

South Africa has a huge potential for DSM in the gold mining sector due to the fact that it is the leading gold producer in the world [32] and relies on its electricity as an energy source. Underground mining water pump station automation and optimisation is a field in which great DSM successes have been accomplished [33].

Load shift can be realised by using the maximum dam capacities as a means of storing incoming water flows during peak times. During the off-peak and peak times the maximum number of pumps is running to ensure that the underground dams are at their lowest levels before peak times. During the peak times the minimum number of pumps run to ensure that the minimum energy is used in the most expensive part of day. The mine as well as the energy supplier benefit from this project, as the mine pays minimum costs for underground pumping and the energy supplier's capacity for the peak times increases [22].

Lighting is another part that benefits from the DSM program [34]. It is a great consumer of electricity in the South African industry. With the introduction of the new technological and improved lux florescent lights currently available on the market, light replacements seem to be an easy way to increase power efficiencies.

In this chapter, the influence which residential geysers have on the peak demands periods were highlighted. The most common geysers range from 2kW up to 4kW. DSM on geysers is realised by controlling switches, which turns the geyser either on or off, via radio or ripple signals [35]. During the peak demand periods a combination of geysers is switched off, while others are kept on. After a period of time the combination of geysers operating might change and with this technique the load is reduced with a minimal influence on the water temperature.

1.6 Contributions of this study

The contributions of this study are as follows:

- Determine the possibility of control on a mine rock winder system
- Calculate the DSM potential of a mine rock winder system
- Implement DSM strategies to show the feasibility and sustainability of the project
- Use this study to evaluate the effect this study can make on a number of South African rock winder systems

1.7 Environmental impact

Electrical energy efficiency has a positive impact on the environment. There is a one to one correlation between the amount of energy generated and the amount of carbon dioxide emissions [36]. That is, for every kilowatt-hour of electrical energy saved, carbon dioxide emissions decreased by one kilogram [37].

Apart from carbon dioxide emissions, coal generating power stations have environmental impacts on:

- Air pollution: The burning of coal leads to air pollution, acid rain and global warming
- Water usage: Excessive quantities of water are used and extracted from the natural surroundings
- Waste generation: Power stations generate ash and sludge
- Fuel supply: Coal mining uses a vast amount of fuel to extract coal

It is therefore beneficial to limit the current environmental pollution and prevent the building of additional coal power stations.

1.8 Scope of work

South African economy growth is currently booming. Linear to the increase in economy, the electrical demand is also increasing. Eskom, South Africa's main supplier of energy, finds itself in a dilemma to supply the country of electricity, especially during the peak consumption time periods.

Gold mines are some of South Africa's biggest electricity users and are in a financial crisis [15]. Therefore, the need to minimise operational cost is highly welcomed so that the overall profit can be increased. Cost savings on most of the electrical appliances like underground pump stations, fridge plants, compressed air and winders can be realised on gold mines.

In this study the author will focus on the optimisation and automation of an underground winder system on Kopanang mine. By doing so the energy cost for this specific mine was optimised and therefore reduced.

1.9 Overview of this dissertation

In this chapter the world wide, and more specific, the South African energy demand situation was discussed. The influence the mining sector has on the electrical grid was highlighted, and the Eskom DSM programme was discussed in detail.

Chapter 2 introduces rock winders. This chapter focuses on the rock winder theories which include the electricity usage and how the winder fits into whole production line.

Chapter 3 focuses on determining the DSM potential of an underground rock winder system. In this chapter a few guidelines were given to identify a DSM project on rock winders.

Chapter 4 describes the winder software used to optimise the rock winder operational costs. A simulation program was written to represent a specific rock winder system. Necessary tests and simulations are done to determine the maximum DSM potential.

In Chapter 5 a case study was done on AngloGold Ashanti's Kopanang mine. A simulation was built to see how the production will be affected. The software was installed on the mine, and the projected energy profile (from the simulation) and savings were compared to the end-results.

Chapter 6 is a conclusion of the results and ends with several suggestions for further work into the subject.

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CHAPTER 2: ROCK WINDER SYSTEM AND ITS ELECTRICAL IMPACT

South Deep Twin shaft rock winder motor

Twin shaft near Carltonville in Gauteng hosts the deepest vertical single shaft drop (at 2,995m) in the world. Rock winder skips with a 31t capacity travel at 18 m/s through the shaft to maintain a production rate of 500t/h.

This chapter provides a background study into the operation, electrical energy consumption and modelling of underground rock winder systems. This discussion will provide a basis for further investigations into the subject of DSM on rock winder systems. At the end of this chapter the relation between the rock winder system and production is highlighted.

2.1 Introduction

It is a well-known fact that the deepest gold mines are in South Africa. South African mines hoist about 350,000 people every day, and about 10 million tons of ore every month [38].

As stated in Chapter 1, the underground rock winder system consumes up to 14% of the total energy consumption on a typical gold mine. This figure is known to rise on mines where the mining hoist depth increases. In this chapter the underground winder system and its effect on production and electricity usage is discussed.

2.2 Background on South African winder systems

South Africa hosts the deepest mines in the world [39]. The reason for this is that South Africa is one of the biggest gold production countries in the world and the deepest mines are usually gold mines [40]. Economic deposits of gold-bearing ore are known to exist at depths of up to 5,000m underground in a number of South Africa regions like the Goldfields and in the Western Deep area [41]. However, due to the depth of reef in particular areas, methods of extracting deeper reefs by using sub-vertical shaft (multiple shafts) systems are not economically viable.

The South African mining industry is busy investigating new possibilities, with enhanced technology, to use single shaft lifts that could hoist people and ore up to 3,500m. Some of these projects like Placerdome's Twin shaft have the capabilities of transporting down to 2,900m underground in a single shaft [42]. The next big step is to implement a single lift hoisting system that could probably hoist a depth of around 5,000m [43].

Due to the fact that the efficiency of a mine is determined by the performance of the shaft winder system, the winder system can be seen as one of the most important systems in a deep mine [44]. Not only are the mining depths a challenge for mechanical structuring, but the electrical usage is also unique. To understand where the winding system fits, one must go through the basic production operation:

The basic purpose of a mine winder system is to transport anything (which ranges from rock, waste, people and machinery) between the earth's surface and the different mining levels underground. The rock winders of gold mines focus on the transportation of reef (gold ore) and waste (rock containing no gold) that need to be brought to surface. The rock winder is thus part of the ore transportation system that transports rock from underground to the gold plants, where the gold is processed.

The following components need to be defined to understand the winding process:

- **Conveyance (Skip)** – The container in which the rock or people are placed. This container is attached to the end of the cable. The cable is winded and re-winded to move the skip up and down in the shaft
- **Winder motors** – Motors that drive the whole winding operation
- **Winder pulley** – Pulley that guides the cable down the shaft
- **Skip loading box** – A box that loads the skips with either reef or waste

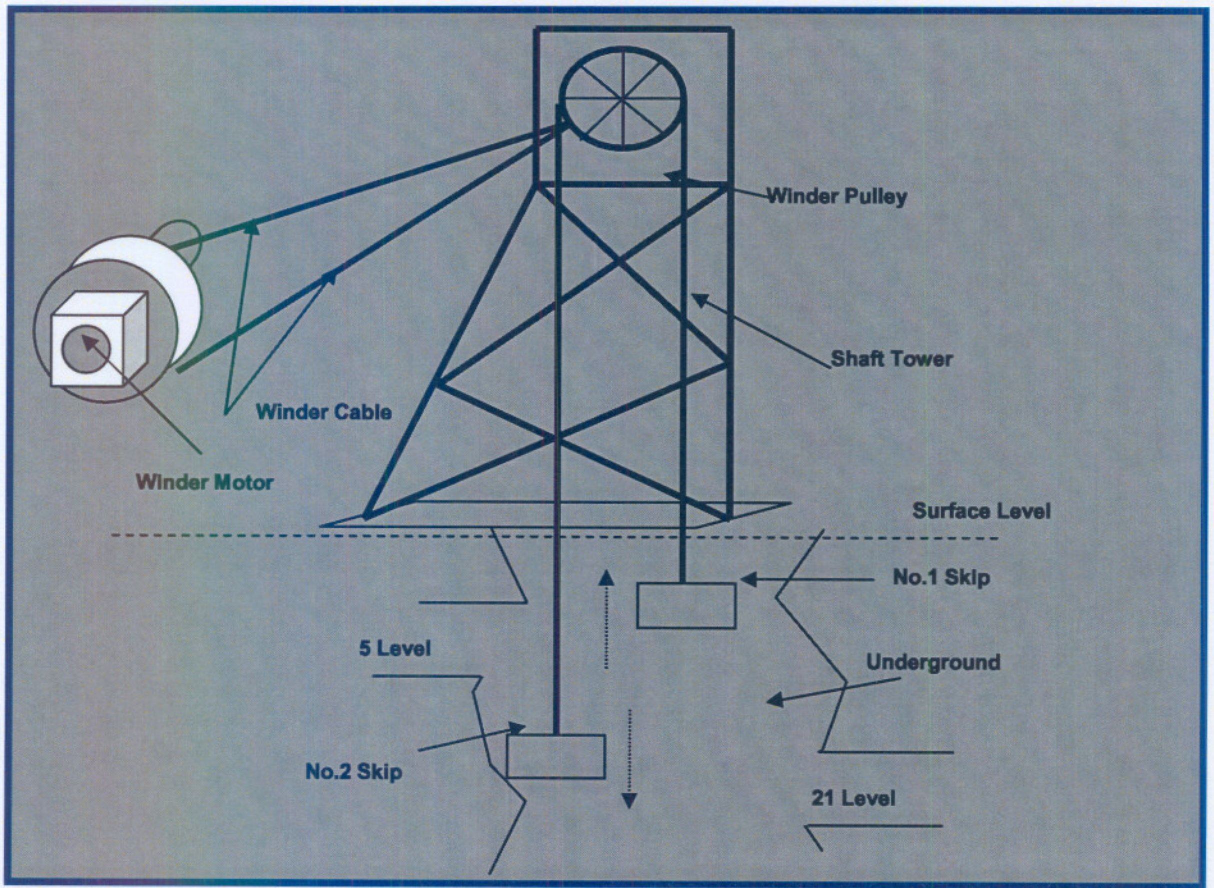

Figure 12: Typical layout of a hoisting system

The ore transportation starts after the underground rock has been blasted and broken into smaller pieces. This is done so that the transportation process can operate much easier. After the blast, the rock is lifted onto the underground mining train (Figure 13).

Figure 13: Underground train

The train then tips the rock into the underground hoppers. The hopper's functionality is to feed the rock to the ore passes where the rock is temporarily stored before it is crushed into smaller pieces and loaded onto a conveyer belt. Figure 14 shows where the different ore transportation components are located and Figure 15 shows where the ore is loaded onto the conveyer.

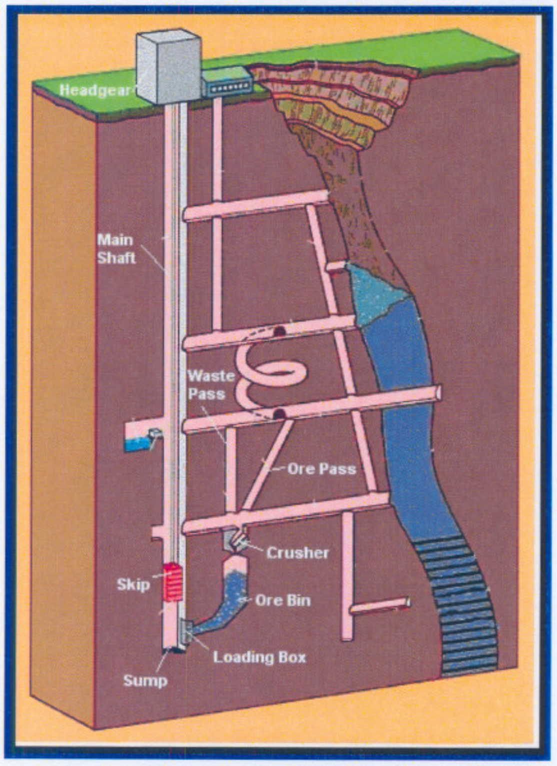

Figure 14: Typical underground mining layout

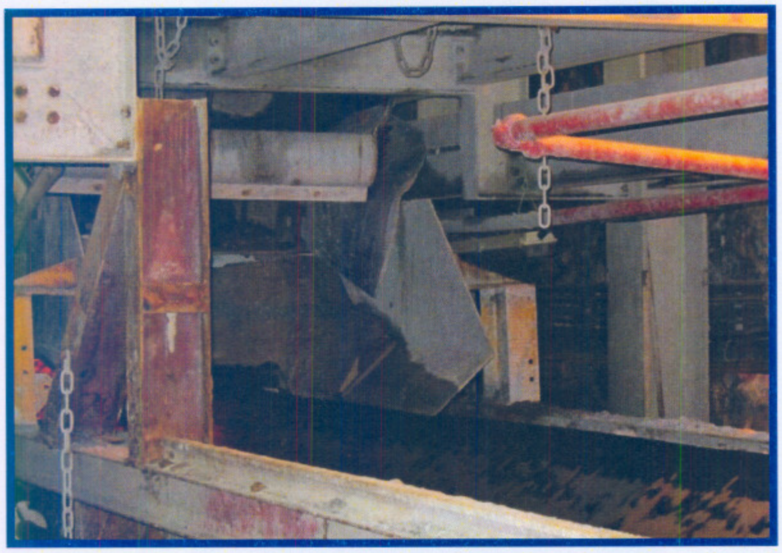

Figure 15: Ore pass feeds onto the conveyer belt

After the ore is loaded onto the conveyer, it is crucial for the reef and waste not to be mixed, as it will influence the gold process in the gold plant.

After the rock has been loaded onto the conveyer, it is stored in a loading box or underground silo, from where it needs to be transported to the surface. The rock is placed in a skip which is attached to the winder cable and this cable is winded around a winder motor, hence the name winder.

An automated process that operates on the weight of the rock winder controls the rock winders. When the skip is fully loaded the winder will automatically hoist the skip, and empty it onto the surface conveyer belt which transports the reef to the surface silo. This is where the reef is stored before it is taken to the gold plant. If the skip is loaded with waste, it is thrown onto a different conveyer which dumps the waste onto a waste pile.

2.3 Winder systems types

2.3.1 Preamble

There are mainly three winder systems used in deep gold mines in South Africa, namely [40]:

- Double drum winder
- Blair multi-rope winder
- Koepe (friction winder)

In this section these winder systems will be examined due to their popularity.

2.3.2 Double drum winder systems

The drum rock winder is the most commonly used winder system in deep South African gold mines [40]. Ropes are winded in opposite directions onto two drums on a single winder system (Figure 11). This connection forces the two conveyances or counter weights to balance each other. The conveyances or counter weights can be positioned relative to the different shaft levels by clutching one or both of the drums to the shaft while keeping the hoist balanced.

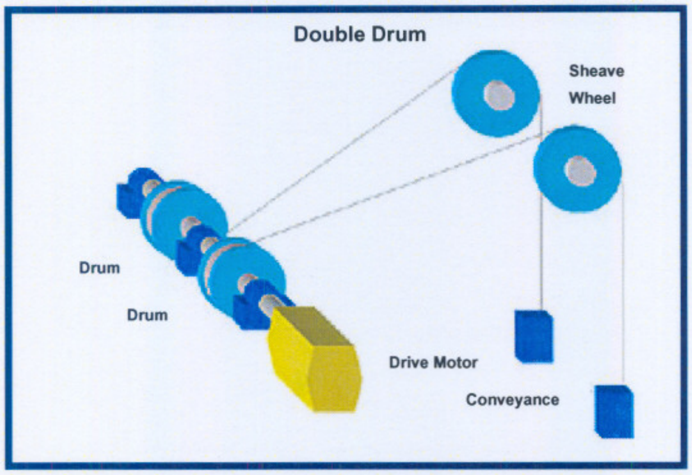

Figure 11: Double drum winder system [45]

2.3.3 Blair multi-rope (BMR) winder systems [40]

The BMR hoist is used almost exclusively in the South African deep mines. It was introduced by Robert Blair, a South African, in 1957. This system was invented so that a drum winder can be extended to two or more ropes. This capability ensures that the BMR winder can hoist heavier conveyances at deeper shafts, and thus try and illuminate the multiple shaft concepts.

The BMR (two-rope) system was developed with a two-compartment drum, which consists of a rope per compartment. Each rope of a compartment is attached to a single conveyance, so that there are two ropes per conveyance as seen in Figure 16. Where the rope is connected to the conveyance there is a balanced wheel to allow moderate rope length changes during winding.

The BMR winder system's physical characteristics make it one of the most popular winder systems. The drum volume is also smaller than its equivalent counterparts. This makes the winder much easier to take underground for sub-shaft installations where necessary. Another advantage is with two ropes to handle the load, each rope can be smaller.

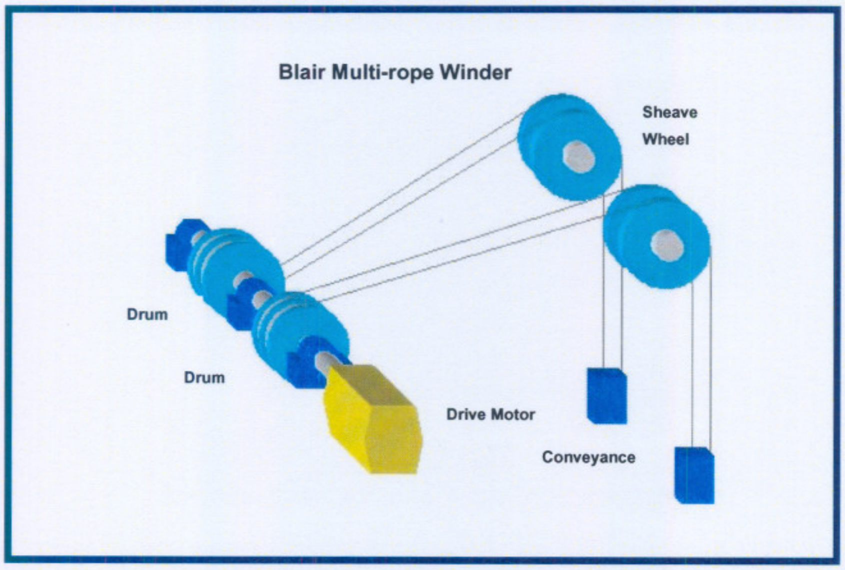

Figure 16: BMR winder system [46]

2.3.4 Koepe winder systems

The Koepe or friction winder is a system where one or multiple ropes are winded over a drum and connects one conveyance to either another counterweight or conveyance. In either case, the ropes are looped at the bottom of the shaft and connected to the bottom of the counterweight or conveyances as seen in Figure 17.

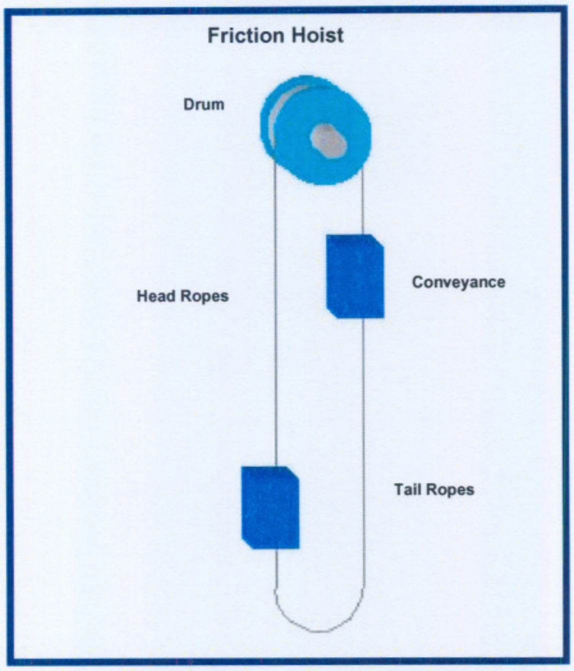

Figure 17: Koepe winder system [47]

The use of the tail rope reduces the unbalanced load and this reduces, in its own right, the peak horsepower required to put the conveyance or counterweight into motion. If the Koepe system is compared to the drum winder system for the same application, the tail rope reduces the initial power rating by about 30% [48]. However, the average power consumption for each hoist is the same for all theoretical calculations.

The initial power reduction effect from the Koepe winder system can be noticed if Figure 18 and Figure 19 are compared. Figure 18 represents the Koepe winder system of Tau Tona mine and Figure 19 the BMR winder system of South Deep mine. These winder systems hoist the same skip mass at approximately the same height, which means that the same amount of power for each cycle is used.

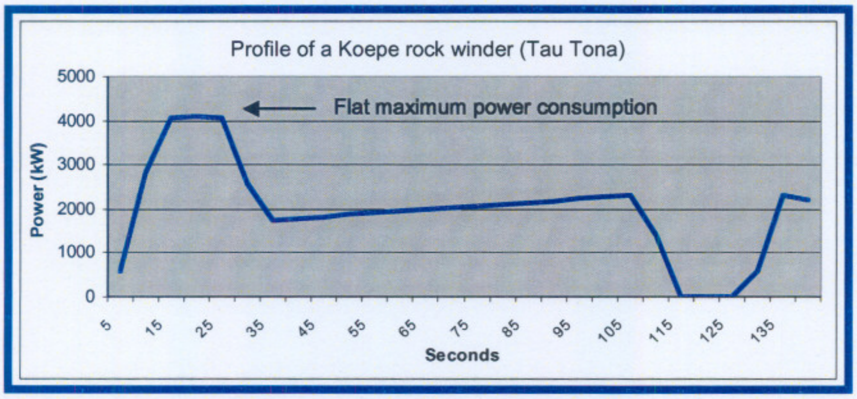

Figure 18: Power profile of a Koepe rock winder cycle at Tau Tona mine

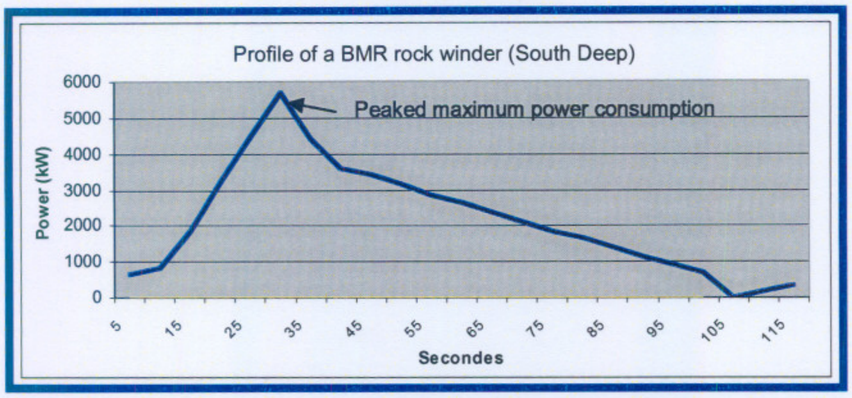

Figure 19: Power profile of a BMR rock winder cycle at South Deep mine

Note how the winder motor's initial power consumption is more flat for the Koepe system. The peak maximum power consumption for the BMR winder system has negative effects on the electrical grid due to its spike. On some winder systems infrastructure is installed to reduce the negative effects this peak has on the surrounding electricity users. Tail ropes have been installed in a few double drum winder systems with the same effect, but this feature has not been accepted by the mining industry.

Due to the fact that the Koepe winder system requires more ropes than the drum system to function, this practice enables it to lift heavier conveyances than the largest drum systems. However, due to the additional ropes on the friction hoist, the maintenance on the system is more expensive and some of the winder experts see this disadvantage as impractical for high hoists.

2.4 Energy consumption of winders

The conveyances of the double-, friction- and Blair multi-rope winder systems are linked to each other by means of the cables and the winder motor shaft. Due to this structure the conveyances balance out each other's gravitational force. The balance effect has a direct impact on the winder systems' energy consumption. With the balance winding property, we get that the conveyance at the one end of the cable moves up and at the same time the other conveyance at the other end of the cable moves down the shaft. In some of the cases the conveyance is replaced by a counter weight (see Figure 20).

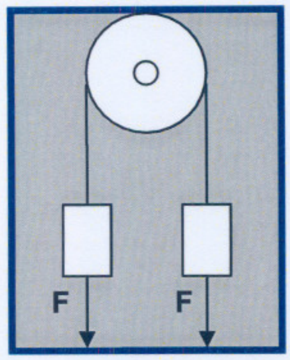

Figure 20: Balanced weight on skips

If none of the conveyances are loaded, the winder motor in simplistic theory only has to overcome the motion of inertia to move the conveyances up and down [49]. This is one of the reasons why the winder motor consumes the most energy when starting the skips motion.

The power usage during a single cycle for a winder motor (Figure 21) can be divided into six key points namely:

- Start (i)
- Peak Power Consumption (ii)
- Start of constant speed (iii)
- End of constant speed (iv)
- Start of electricity regeneration (v)
- End of cycle (vi)

During the start phase (i – ii) the power reaches a peak. This is the timeframe in which the winder motor starts up and the conveyance is put into motion. Not only does the winder motor need to overcome the gravity force of the loaded conveyance, but the motor has to generate enough power to overcome the moment of inertia.

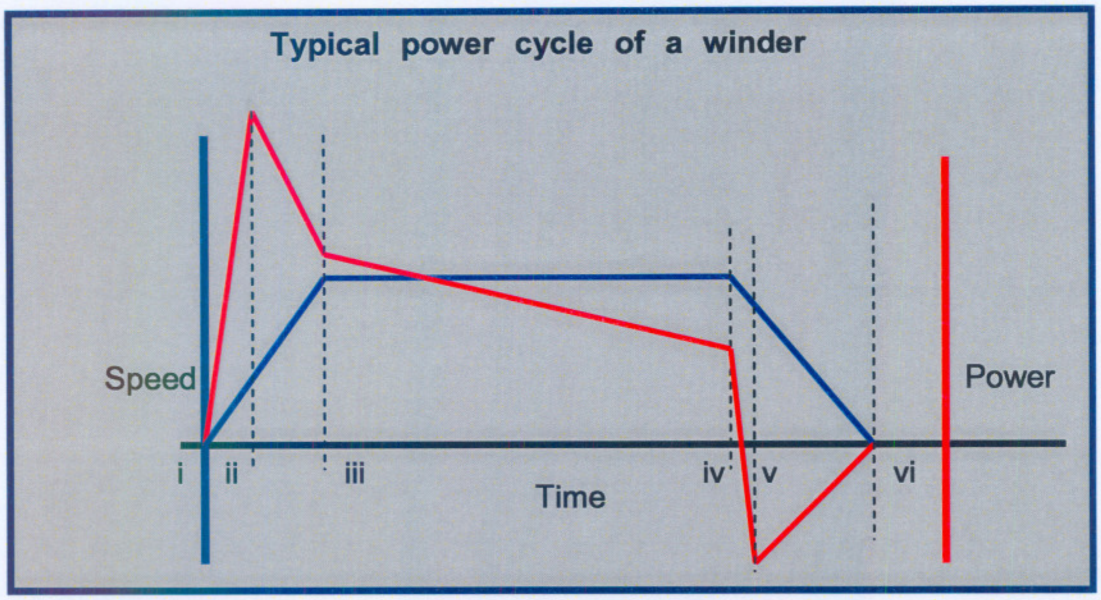

Figure 21: Power vs. speed of a winder cycle profile

After the winder reaches its maximum speed (ii), the power decreases to a point where only the friction and gravity forces need to be overcome. It can be seen from the above figure that the power decreases drastically (iii). After this timeframe the loaded conveyance is hoisted at a constant speed (iii – iv).

Near the end of the conveyance's destination the speed of the winder motor starts to decrease (iv). In this time period (iv – vi) all of the kinetic energy of the conveyance (which is not consumed by either the winder brake, gravity or friction) is regenerated back into the electrical network. This is done by transforming the winder motor into a generator. Not all of the winders have the necessary infrastructure to be able to regenerate this energy. In smaller winder systems it is not always feasible, due to the high cost in maintenance and infrastructure.

It is important to note that not all of the winder systems have the same power profiles. These profiles differ according to the type of winder, height of the hoist, winder motor, shaft friction, motor efficiency and conveyance mass. There is a number of ways to calculate the estimated average power consumption during a winder cycle. The most accurate way is to install a power logger on the electrical feeder of the winder system. This method can however be time consuming and power loggers are expensive to come by. A qualified electrician is also needed to connect the logger. Different ways to calculate the energy consumption had to be determined, and was developed in this study.

During the initial winder system installation the winder is put through a few tests to see if it performs according to its design. After this test the mine is issued with a winder specification report. This report states the winder's maximum load capacity, maximum speed, cycle time and amount of energy consumed during a specific trip. If the report can be come by, these results can be can be used as guideline.

However, another way to calculate the average power consumption during a typical cycle is to use Sigurd Grimestad's hypothesis. According to Sigurd [48] the power consumption (external work) for a mine rock winder is 1 kWh/ton for each 367m of hoisting distance at 100% efficiency (no mechanical or electrical losses). In practise the efficiency is about 80%.

Another way to determine the ideal average power per cycle is to apply the rules of physics. The kinetic energy (*KE*) needed to transport an object to specific height (*h*), is equal to the potential energy (*PE*) of the same object at its destination (friction less system) [50].

Before this discussion is carried on further, the following assumptions should be considered to simplify the energy calculations for the winder system [50]:

- The extra friction induced by the cage is constant for each specific winder
- The conveyance for each specific conveyance, which is constant for each winder cycle, is measured in ton
- South African deep mines always use balanced winder systems and the influence of the weight of the conveyances can thus be neglected
- The influence of the winder rope can be neglected in a balanced winder system

The physical parameters of a mine winding system include:

- Vertical height of the winding system (*n*)
- The conveyance, or the mass that is being transported (*m*)
- The efficiency of the specific mine winding system (*eff*)

Consider a mass (*m*) that needs to be transported to a height (*h*) by a rock winder system. The mass is usually the sum of the people's weight in the conveyances which are being transported. For a rock winder it is the weight of the rock.

The gravitational potential energy law state that [50]:

$$PE = m \times g \times h \; joule \tag{2-1}$$

To convert the units from mechanical energy PE (Nm) to electrical energy (kWh) the conversion of *1Nm = 2.78e-7kWh* is used. Thus, the electrical energy needed to hoist a mass (*m*) a vertical height (*h*), losses included, is:

$$EE = \frac{m \times h \times 2.7344 \times 10^{-6}}{eff} kWh \tag{2-2}$$

2.5 Rock winder system model

In the previous section the energy consumption of a typical winder system was discussed briefly. In this section a rock winder detailed model is formulated to assist in investigating the effect the rock winder has on the production as well as on the electricity demand grid.

The efficiency of a winder system is given by the ratio of the input power *Pin* to the output power *Pout.*

$$Pin = \frac{Pout}{eff} \tag{2-3}$$

For multiple winding systems of all types, the input power is the ratio of the sum of the output power (to hoist the conveyance and the power needed to overcome the winder friction) to its efficiency. According to mining model specialist, Prof. Johann Delport [50], the output power *Pout* is directly proportional to the sum of the mass of the rock (*m*), gravitational acceleration (*g*) and the height (*h*) to get:

$$Pin = \sum_{x2=1}^{m2} \cdots \sum_{y2=1}^{n2} \frac{(m_{payload:x2y2} + m_{friction:x2y2}) \times g \times h_{x2y2}}{eff_{x2y2}} \quad (2\text{-}4)$$

Where:

$m2$ = number of winding types

$m_{payload:x2y2}$ = flow of conveyance of cage y2 of type x2 (tons/s)

$m_{friction:x2y2}$ = additional mass flow to compensate for cage friction of cage y2 of type x2 (tons/s)

h_{x2y2} = vertical height of mine winding system y2 of type x2 (m)

eff_{x2y2} = efficiency of mine winding system y2 of type x2

The model can be converted by changing the flow of rock to the vertical speed of the winding. The end-user group energy conversion model for the mine winding system in the case for a mine winding system is thus given as:

$$Pin = \sum_{x2=1}^{m2} \cdots \sum_{y2=1}^{n2} \frac{(ton_{payload} / cage_{x2y2} + tons_{friction} / cage_{x2y2}) \times g \times h_{x2y2}}{eff_{x2y2} \times \left[\frac{h_{x2y2}}{v_{x2y2}} + T_{unload} \right]} \quad (2\text{-}5)$$

Where:

$tons_{payload} / cage_{x2y2}$ = conveyance per mine winding system y2 of type x2 (ton)

$tons_{friction} / cage_{x2y2}$ = friction load per mine winding system y2 of type x2 (ton)

v_{x2y2} = vertical speed of mine winding system y2 of type x2

T_{unload} = time to unload mine winding system

From the above model it is clear that the electrical power consumed by the rock winder system (*Pin*) is related to the amount of rock extracted ($ton_{payload}$), and therefore has a direct effect on the production of the mine. This model represents a rock winder system consisting of one or multiple rock winders. In the next chapters these formulas and methodology will be used to calculate similar models for a reduced cost operation.

2.6 Effect on production

On a typical mine the success is usually measured according to two elements, namely:

- Production target (in ton)
- The average grade of the ore hoisted (in gold grams per ton)

The first element usually gives feedback on the operational success of the mine, while the second element's success is determined by nature.

A mine's daily production target is the amount of reef transferred from underground to the surface silo, during a 24-hour period. To understand the production of a mine, one must study the daily production cycle:

The mine usually has 3 shifts that range from:

- 22h00 – 06h00
- 06h00 – 14h00
- 14h00 – 22h00

In these shifts the mining process usually starts where miners drill holes into the rock to insert the explosives on different mining levels. Mining personnel are then evacuated from the blasting levels and the explosives detonated. After the blast the mining personnel return to the levels and load the blasted rock onto the underground trains, where the rock is then transported to the loading box. Due to the fact that blasting finishes at around 14h00, hoisting cycles can be expected to increase at 17h00. The daily mining operation cycle starts at 22h00 and ends at 21h59 the following day.

If the daily production target is not met, the gold plant might be at risk of losing production. The winder system is a direct link from the underground mining operations to the gold process plant. If the winder system doesn't hoist reef to fill the surface silos, the gold plant wouldn't have any ore to process. This will cost the mine and gold plant dearly. Figure 22 indicates the close link between the winder system and the gold process plant. Note that after the ore is transported to surface, it is directly taken to the ore storage or ore silos.

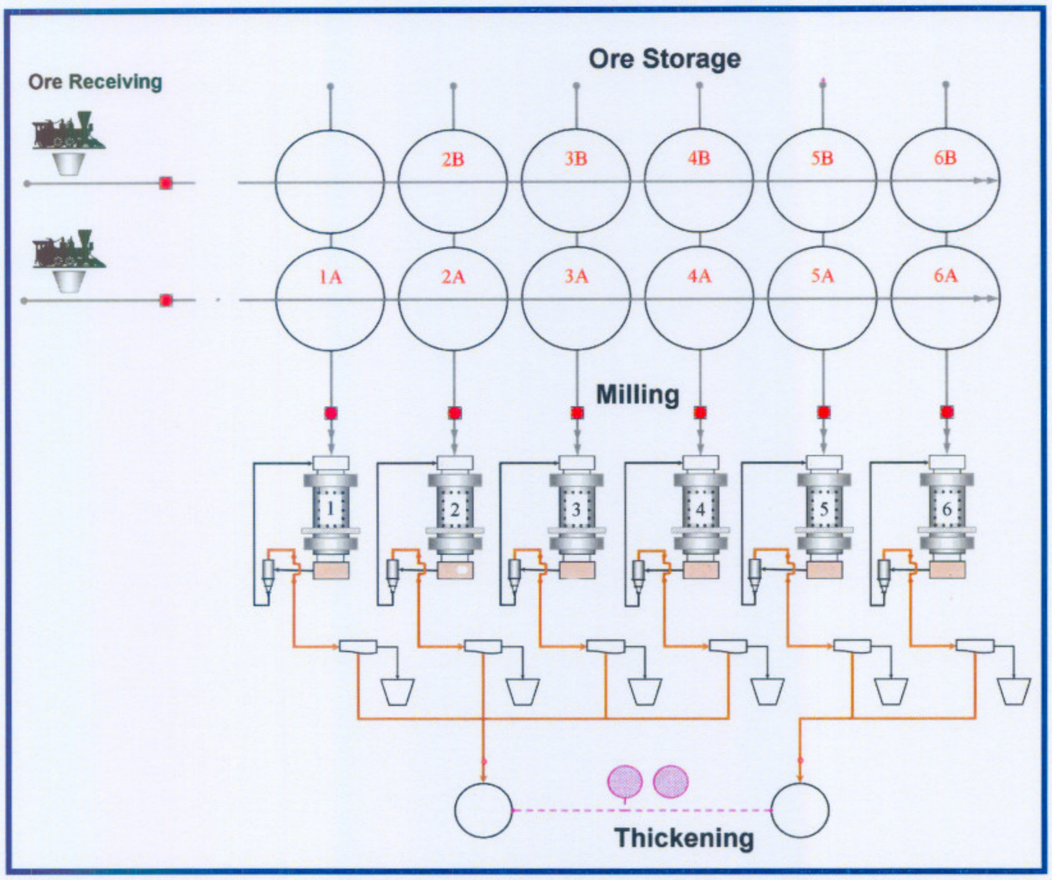

Figure 22: Gold plant process layout

2.7 Need for a real-time load shifting system

Chapter 1 stated the fact that it is becoming increasingly necessary for big electrical users to apply the principle of energy reduction during peak demand periods. This principle does not necessarily mean that the total energy consumption is reduced, but rather suggests that the electrical energy used during the peak demand period should be kept to a minimum.

Due to the substantial savings in electricity costs that can be achieved in the mining sector and the funding that has been made available by Eskom for this purpose, a number of ESCOS have been formed and systems to save electricity have been developed. However, there still remains a need to develop a real time energy management system that consists of the following properties:

- The automated scheduling of the electrical components of winder systems
- Optimised scheduling that responds to real-time live data
- The automated control of electrical equipment in accordance with such calculated schedules

In this thesis the first known published attempt to implement optimised scheduling of rock winders in South Africa or even worldwide is discussed.

2.8 Conclusion

In this chapter the winder system's basic operation, its electrical impact and effect on production were discussed. All these elements needed to be addressed to determine the electrical impact and risks involved on the winder system. The need for a real-time load shifting system on winders was also mentioned. Before the operational costs can be optimised, one must understand where the winder system fits and how it influences the basic operation of a mine. The methodology for creating operational models was also studied, with intentions of designing one in the next chapter.

In this thesis the first known published attempt to implement optimised scheduling of rock winders in South Africa or even worldwide is discussed.

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CHAPTER 3: RESEARCH THE DSM POTENTIAL OF AN UNDERGROUND ROCK WINDER SYSTEM

Wind power in Guangdong

"Energy derived from green sources is not specifically delivered to the customers who choose it, but to the power grid, which displaces power that would have otherwise been produced from traditional (fossil fuel) generating sources." Source: Stan Wise, Georgia PSC Commissioner.

In this chapter the knowledge gathered in the previous chapters is used to determine the DSM potential of an underground rock winder system. Due to the high risks involved for both ESCO and gold mine, this chapter discusses the necessary steps and modelling that should be taken to determine an accurate DSM potential.

3.1 Introduction

From the previous chapters the South African demand problem, as well as the energy consumption and theory behind the underground rock winder were highlighted. Determining the potential of an underground rock winder is essential. It could save a lot of time as well as millions in costs if properly designed. If the DSM project is implemented and the simulation model is inaccurate, or if the incorrect data is captured, the outcome could result in significant financial losses.

Thus, before the DSM potential is determined it is the ESCO's responsibility to make sure that the data is:

- Reliable
- Enough to represent the system under **normal operational conditions**
- Accurate

If all these elements are adhered to, the calculated load shift potential of the rock winder, as well as its electrical and production impact will be accurate.

3.2 Investigation and electrical audit

3.2.1 Preamble

In this section the investigation into the electricity usage of a rock winder system is broken up into three steps. These steps will guide the ESCO in determining the DSM potential of an underground rock winder system in the most efficient way. These steps are namely:

- Initial rock winder investigation
- Winder operation schedule
- Winding cycle power profile metering

Before the investigation is started, a few deep mines are identified for possible DSM or cost optimisation projects. After the completion of the first step, the particular rock winding systems will be prioritised. The reason for prioritising the rock winder systems is to identify the systems that have the biggest influence on the electrical demand and highest operating cost. It is of no use putting recourses and time into a system with limited DSM opportunity, when a system with a much larger consumption still uses maximum energy during the Eskom problem demand periods and thus pay a higher operating cost.

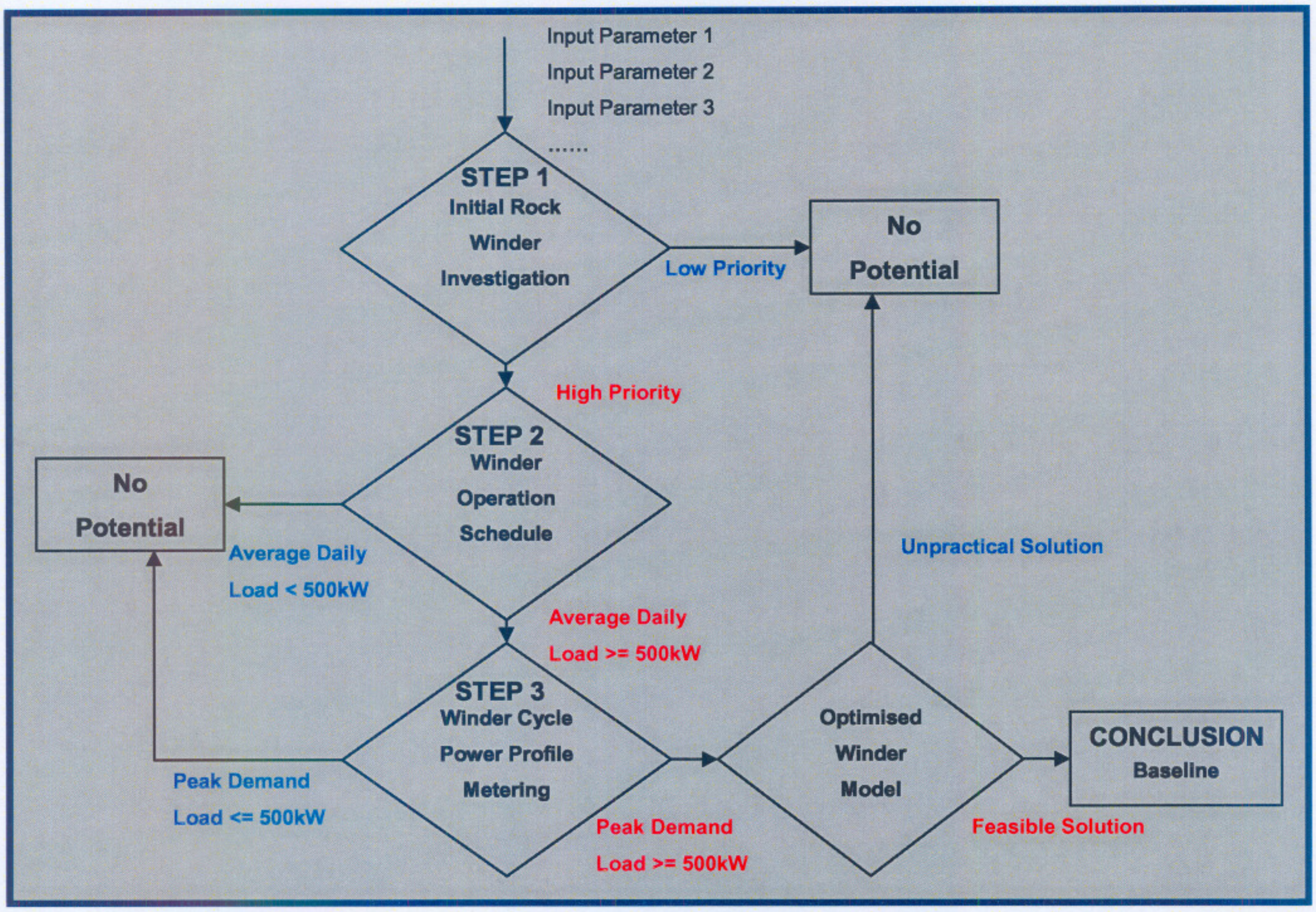


Figure 23: Flow chart of winder potential investigation

Due to the diversity of the different rock winder systems, it is usually difficult to prioritise them. The parameters (which are also the input parameters in Step 1) that have an influence on the electrical demand and operating cost of a rock winder are:

- Type of rock winder
- Winder motor size

- Depth of a specific hoist
- Conveyance capacity (mass that's being hoisted per cycle)
- Operating times
- Production characteristics

The DSM potential investigation will now be discussed in detail. Refer to Figure 23 after each step to put the respective steps into perspective.

3.2.2 Step 1: Initial rock winder investigation

The first step in investigating the electrical usage of a rock winder system is to calculate the average daily energy consumption of the specific system. This calculation (Equation 2-2) as discussed in Chapter 2, is used to get a generic view of the electricity consumption. After the calculation is done and the project seems feasible, an in-depth investigation can be launched.

The energy used to hoist a daily production target with mass (*m*) a height (*h*) is:

$$EE = \frac{m \times h \times 2.7344 \times 10^{-6}}{eff} kWh \qquad (2\text{-}2)$$

This formula is used to calculate the estimated daily energy usage of a rock winder system, and not to calculate the daily power profile. Table 2 shows the energy needed to make the daily target production on a number of mines. The data was collected from mining personnel at the various mines. In this case the efficiency (*eff*) was 100% for each mine. This value was used due to the fact that the mines are only prioritised, and spending time calculating the efficiency of the rock winders will have little impact on the priority.

Priority	Mine	Rock winder	Hoist distance (m)	Target production per day (t)	Skip size (t)	Potential energy (gigajoule) usage	Energy usage (kWh/day)	Mine Rock Winder System Energy Usage (kWh/day)
1	Mponeng	East	2500	4500	16	1102.50	30625.00	29726.67
		West	2500	4500	16	1102.50	30625.00	
		Underground	1140	9000	18	1005.48	27930.00	
2	Great Noligwa	Main	1585	8400	25	1304.74	36242.75	28576.02
		Sub vertical	914	8400	14	752.73	20909.28	
3	Tau Lekoa	NO3	1734	5667	18	963.00	26750.13	20061.42
		NO4	1734	2833	7.5	481.42	13372.71	
4	Kloof 4#	Main	2000	3100	15	607.60	16877.78	10970.56
		Sub vertical	600	3100	12	182.28	5063.33	
5	Kloof 7#	Main	1800	3100	20	546.84	15190.00	10126.67
		Sub vertical	600	3100	20	182.28	5063.33	
6	Cook 3	RW	1343	2600	20	342.20	9505.46	9505.46
7	Cook 1	RW	1000	2000	10	196.00	5444.44	5444.44
8	Cook 2	RW	900	1200	10	105.84	2940.00	2940.00

Table 2: Estimated daily rock winder power consumption

From this table it can be seen that Mponeng mine needs to consume 29,726kWh/day, to make the daily production target of 9,000t. The combination of a high daily production target and deep shaft depth make the Mponeng rock winder system's power consumption much higher. From this table it is easy to prioritise the different rock winder systems according to the daily energy consumption.

3.2.3 Step 2: Winder operation schedule

After Step 1 is completed and the rock winder systems prioritised and identified to be audited, the next step is to determine the operational schedule. The operational schedule gives an indication of when the rock winders operate. To determine if a specific rock winder operates at minimum cost, a daily operating profile is required. This profile represents the average number of times a rock winder cycles during a specific hour, within a 24-hour period.

An effective and accurate way to retrieve this particular information is to either read the number of winding cycles from a tachometer [52], or to get the amount of cycles from a Hoisting report – see Appendix A. The mine is obligated, according to law, to log the speed-against-time profile for each winder. Most of the mines therefore install a tachometer to log the velocity of the skips. Each tachograph (velocity graph of winders) represents a specific day. From these sheets the number of cycles during an hour can be calculated by counting the number of speed peaks.

The rock winder only hoists skips from surface to the rock loading box and vice-versa. This means that the winder speed vs. time graph for each cycle would be similar, due to same amount of rock being hoisted. Figure 24 below is a part of a tacho-sheet and indicates the typical cycle period.

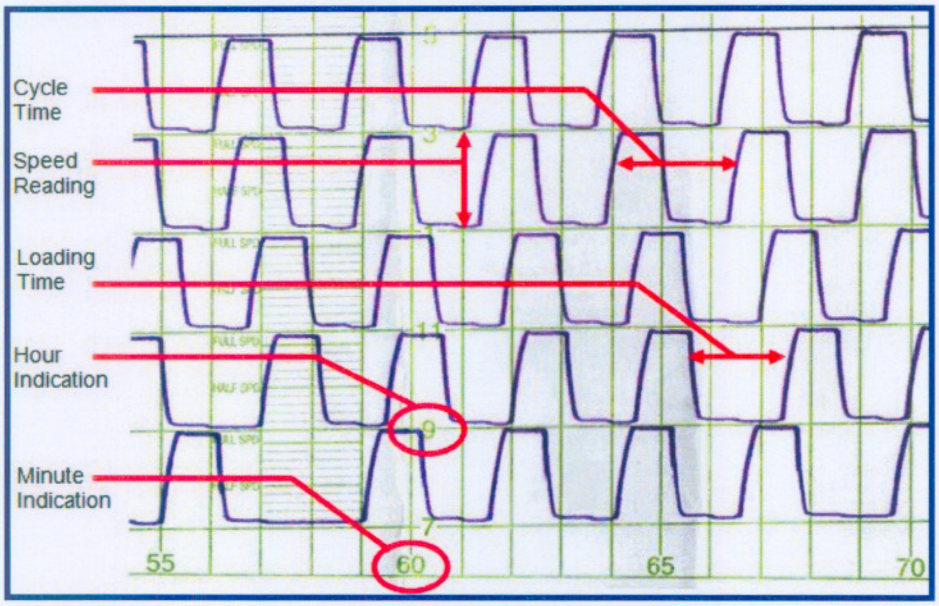


Figure 24: Example of a rock winder tachograph

From Figure 24 it is clear how many cycles occurred during a specific hour. Usually 3 months of tachographs are used to create an accurate average 24-hour cycle profile that should represent the system under normal operating conditions. Figure 25 shows a typical cycle profile where nothing is done to optimise the winder's operational cost. Especially during the evening peak times (after blasting times at 18h00) it seems that the rock winder operation is running at maximum capacity (running non-stop).

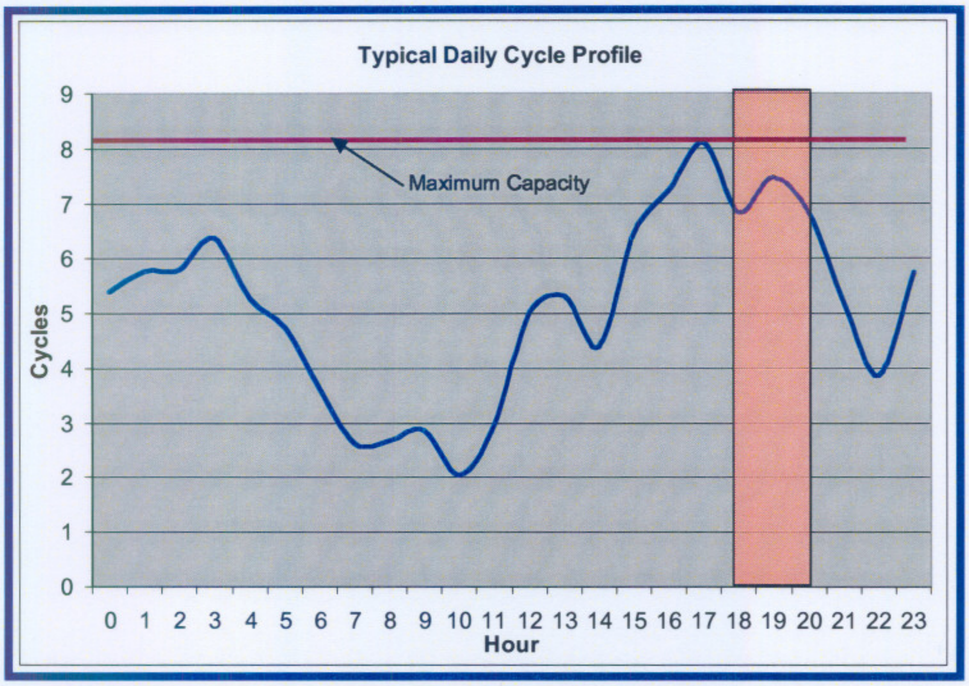


Figure 25: Typical daily cycle profile

The above figure can however be converted to an estimated average daily power profile, as in Figure 26. To get this estimation, Equation 2-2 was modified. Unlike Step 1, the mass (*m*) of the equation was replaced by the capacity of the skip (*t*). This is done so that the minimum energy needed to hoist a single skip cycle can be represented. This result is then multiplied by the number of cycles in a specific hour to get:

$$EE = m(skip) \times h(hoist) \times 2.7344 \times 10^{-6} \times \frac{Cycles}{hour} kWh \qquad (3\text{-}1)$$

If the rock winder system is made up of more than one winder, this step can be repeated for the remaining winders and added together to create an average daily minimum power profile of a rock winder system.

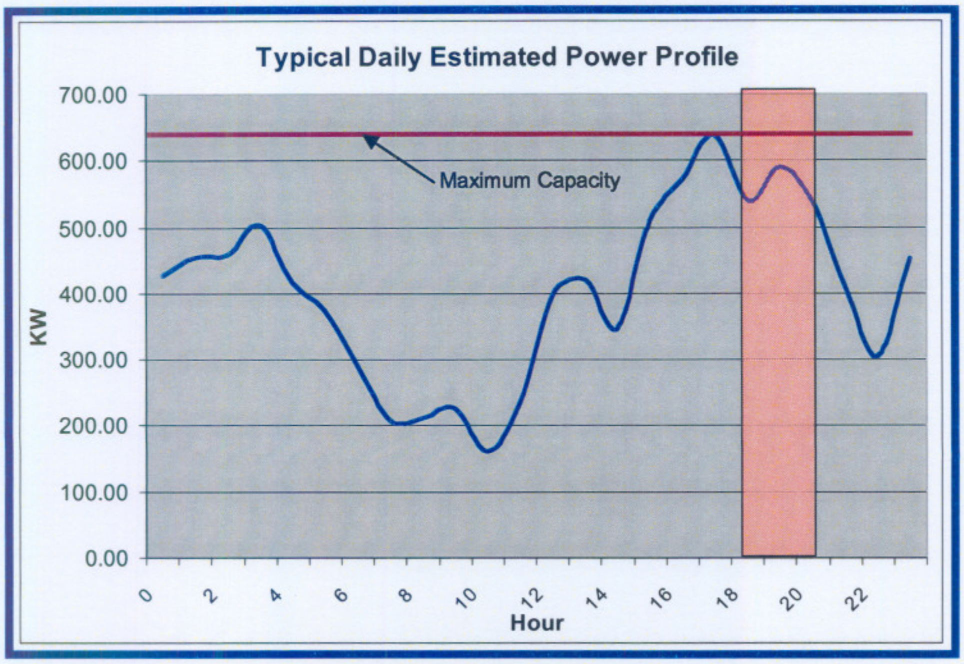


Figure 26: Estimated power profile

At the end of this step the electrical energy used in the evening peak demand period is calculated. This is done so that the winding systems that do not consume enough energy (during the evening peak period) to make a big enough impact on the electrical grid, is terminated from the selection.

The minimum energy that needs to be consumed during the evening peak electrical period for the specific winder system to advance to Step 3, is 1,000kWh. The reason for using this specific amount of energy is due to the fact that Eskom DSM only submits projects with 500kW and more load shift potential. Table 2 was updated with the evening energy usage and the projects that didn't make the 1,000kWh cut-off were terminated (coloured in grey).

From Table 3 it can be seen that only three of the eight initial projects will advance to the next step.

Table 3: Estimated average energy used during (18h00 and 20h00)

Priority	Mine	Mine Rock Winder System Energy Usage (kWh/day)	Estimated Average Energy used during (18h00 -20h00)
1	Great Noligwa	28576.02	2857.60
2	Mponeng	29726.67	2724.94
3	Tau Lekoa	20061.42	1588.20
4	Cook 3	9505.46	863.41
5	Kloof 4#	10970.56	822.79
6	Kloof 7#	10126.67	759.50
7	Cook 1	5444.44	598.89
8	Cook 2	2940.00	196.00

3.2.4 Step 3: Winder cycle power profile metering

After Step 2 is completed and the winder systems that could make a significant difference in the evening peak electricity demand period have been identified, resources and time can be invested into the cycle power metering.

This metering will include the power consumed to overcome not only the losses of the winder motor, but also the friction induced by the skip and cable. From the power cycle metering profile, the effect of electricity regeneration will also be indicated. After the metering is done, the assumption is made, as it was in Step 2, that for every winding cycle the exact same power profile occurs. This assumption is valid due to the fact that each skip is weighed while it is being filled to ensure that the same amount of rock is hoisted for each cycle.

Figure 27 is an example of a typical power profile for continuous winder cycles. These cycles are measured and integrated to form an average cycle power profile, which will represent the energy used during a typical skip hoist. Note how similar the cycles are. This proves the fact that the same amount of rock mass is hoisted with each cycle.

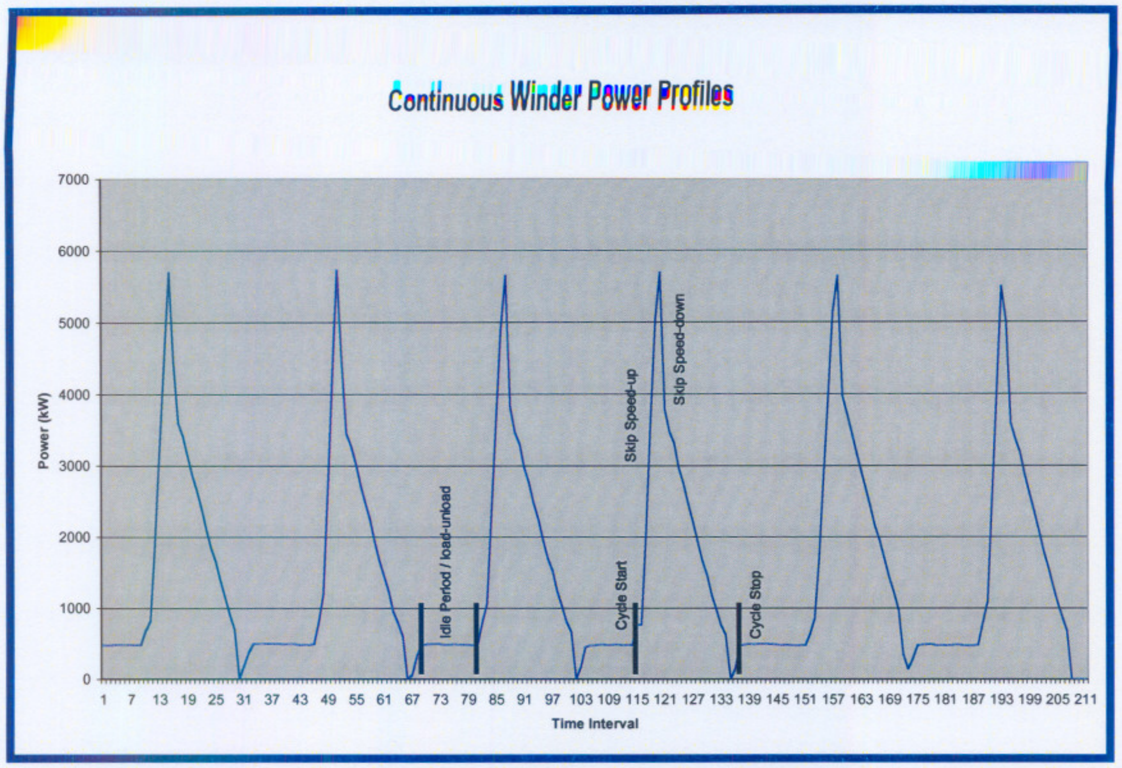


Figure 27: Continuous winder cycles

Figure 28 is an example of a typical rock winder power profile. In this case the rock winder didn't have the necessary infrastructure to regenerate power back into the electrical grid (the power never becomes negative).

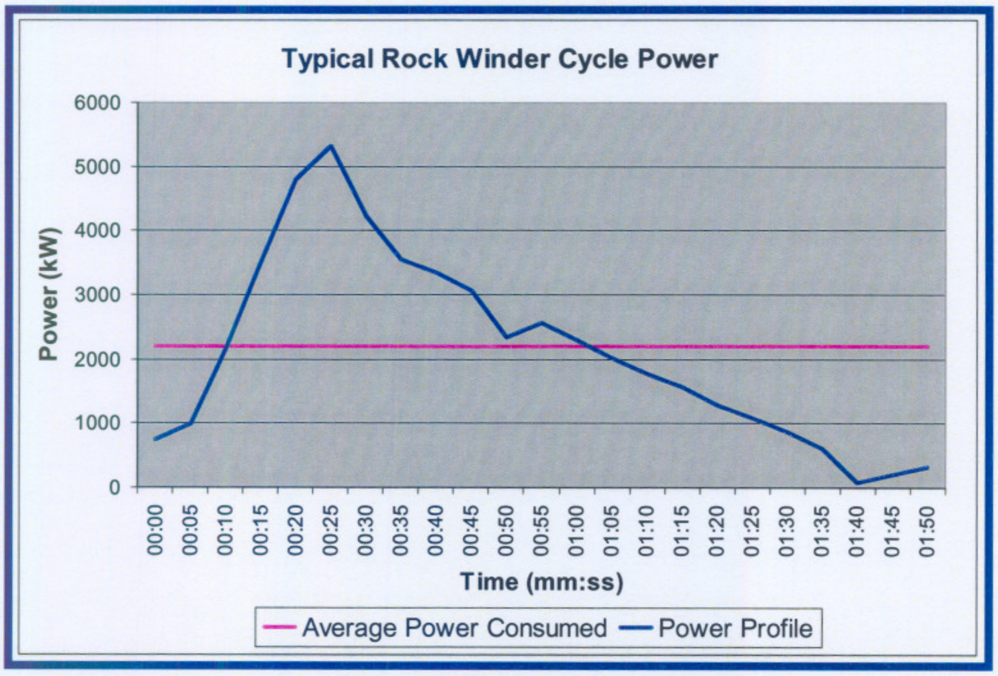


Figure 28: Typical rock winder cycle power profile

To calculate the power consumed during a hoist cycle, the constant average power consumption during a hoist is calculated (shown in Figure 28). The area below this constant line is the same as the area below the power profile, which indicates that the same amount of energy is consumed. Next, the time it takes for the skip to move from the bottom of the shaft (where it is loaded) to travel to its destination (where the skip is unloaded) is measured. These two parameters are then multiplied so that:

$$EE\ per\ cycle = Pin_{cycle}\ (kW) \times Ct(hour) \tag{3-2}$$

Where: Pin_{cycle} = Average power consumed during cycle and,
Ct = Cycle time.

The result from this equation can then be multiplied with the number of cycles during each hour, to get:

$$EE(h) = EE\ per\ cycle \times \frac{n_h}{hour} \tag{3-3}$$

Where n = total cycles during a specific hour and,
$EE(h)$ = average energy usage during a specific hour (h)

From this equation a much more accurate daily power profile than Step 2 can be constructed. This profile is also known as the baseline, which represents the daily power profile before the cost optimisation is done.

Table 4 shows the average energy that could be shifted form the evening load. The values were taken from the baselines. Note the increase in baseline value, if compared to the estimated energy value. The reason for this is that the baseline energy includes friction, cable and skip losses.

Table 4: Maximum electrical load that could be shifted from the evening peak

Priority	Mine	Estimated Average Energy used during (18h00 -20h00)	Average Energy used during (18h00-20h00)	Efficiency of Rock Winder System
1	Great Noligwa	2857.60	3429.122194	83.33%
2	Mponeng	2724.94	3596.926954	75.76%
3	Tau Lekoa	1588.20	1953.480604	81.30%

Note the efficiencies of the rock winder systems in the above table. The efficiencies vary from 75% to 83%. Mponeng has the lowest efficiency. An explanation for this could be that its winder system is made up of three rock winders and the other two mines only have two.

3.3 Optimisation cost model

After the baseline is constructed and the amount of energy consumed by the rock winder system is calculated, an optimisation model needs to be configured to calculate the DSM potential without influencing production. Figure 29 illustrates where the main input parameters fit into the model so that it could be configured. The parameters that follow are necessary to configure an optimised model that could represent a rock winder system:

Surface Rock Silo Capacity (t) - SSL
Underground Rock Silo Capacity (t) - USL
Skip Capacity (t) - SC
Flow Rate from Hoppers (t / hour) - fh
Hoisting Flow Rate (Cycles / hour) - fc
Flow Rate from Gold Plant (t / hour) - fgp
Hour of the day (h) - h
Mega Flex Electricity Tariff (R/kWh) - t
Energy (kWh) / cycle - Pc
Cost per hour - Ch

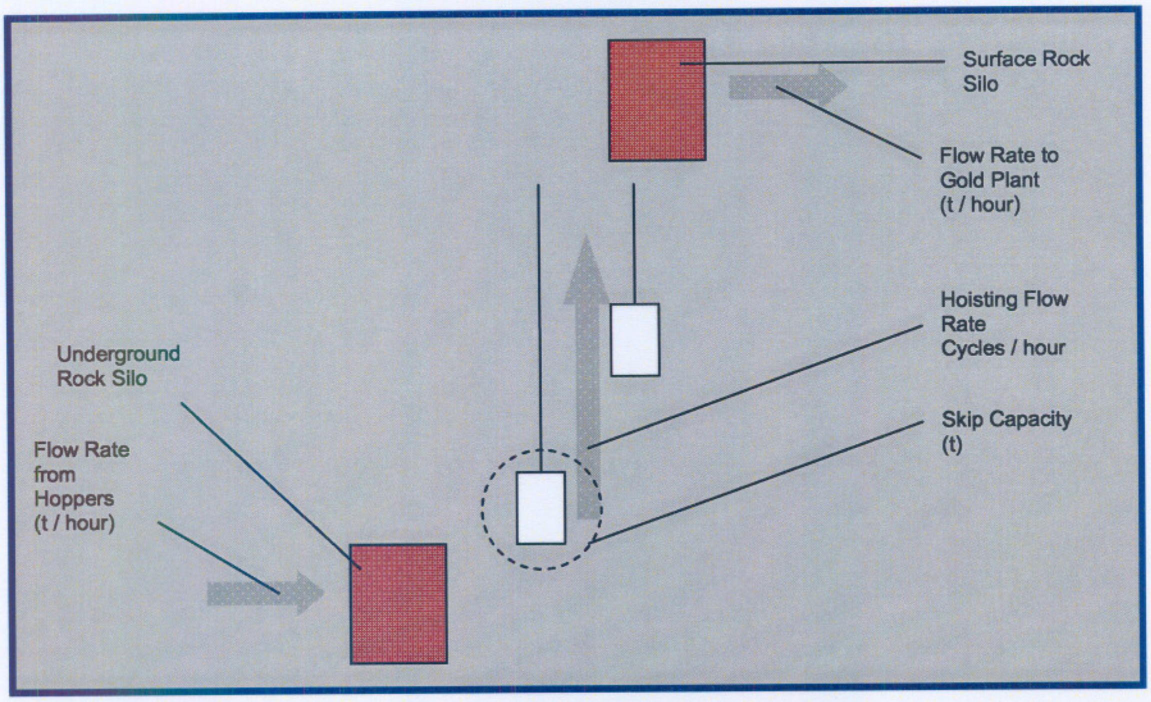


Figure 29: Optimised cost model

The model is solved with the Generalised Reduced Gradient (GRG2) nonlinear optimisation code developed by Leon Lasdon, University of Texas at Austin, and Allan Waren, Cleveland State University [53]. This code is used in the Microsoft® Excel application, called Solver. The Solver is part of a suite of commands that uses a process of changing the values in cells to see how those changes affect the outcome of formulas on the worksheet. With Solver, the optimal value for a formula can be calculated in one cell. In this simulation the optimal value is the minimum operational costs.

Solver works with a group of cells that are related to the formula in the target cell. Solver adjusts the values in the changing cells you specify, to produce the result you specify from the target cell formula. In this case the changeable variable is the hoisting flow rates (fc) during a specific hour.

The rock flow formulas are given by:

$$USL_h = USL_{h-1} + fh_h - SC \times fc_h \tag{3-4}$$

$$SSL_h = SSL_{h-1} + SC \times fc_h - fgp_h \tag{3-5}$$

Where h represents an element in an array for each hour.

The cost for each hour is given as:

For h=0; $$Ch_h = Pc \times fc_h \times t_h \qquad (3\text{-}6)$$

To start the optimisation, the assumption is made that there is no rock in the underground silo at the start of the first hour, so that:

$$USL_0 = fh_0 - SC \times fc_0 \qquad (3\text{-}7)$$

For the surface silo the assumption is made that the silo has X amount of rock stored before the first hour so that:

$$SSL_0 = X + SC \times fc_h - fpg_0 \qquad (3\text{-}8)$$

And the cost in the first hour:

$$Ch_0 = Pc \times fc_0 \times t_0 \qquad (3\text{-}9)$$

To minimise the operational cost of the rock winder of a specific mine, Equations 3-4, 3-5 and 3-6 should be calculated for h = 0, 1, 2...23 under the following constraints:

- Maximum Underground Silo Capacity >= USL_h >= 0;
- Maximum Surface Silo Capacity >= SSL_h >= 0;
- Hoisting flow rate in a specific hour (h): fc_h >=0;
- Hoisting flow rate in a specific hour (fc_h) = 0 where h is the hour in which the mine does shaft exams;
- Minimum Underground Silo Capacity <= USL_h <= Maximum Underground Silo Capacity;
- Minimum Surface Silo Capacity <= SSL_h <= Maximum Underground Silo Capacity;

So that the minimum daily operational cost will be:

$$Ctotal_{min} = Ch_0 + Ch_1 + ... + Ch_{23} \qquad (3\text{-}10)$$

This optimisation needs to be done for all the different rock winders on a mine. The different winder power for each hour ($Pc_h fc_h$) should be added together to form a minimised cost power profile on the complete mine rock winder system. The model was used in the Microsoft® Excel package.

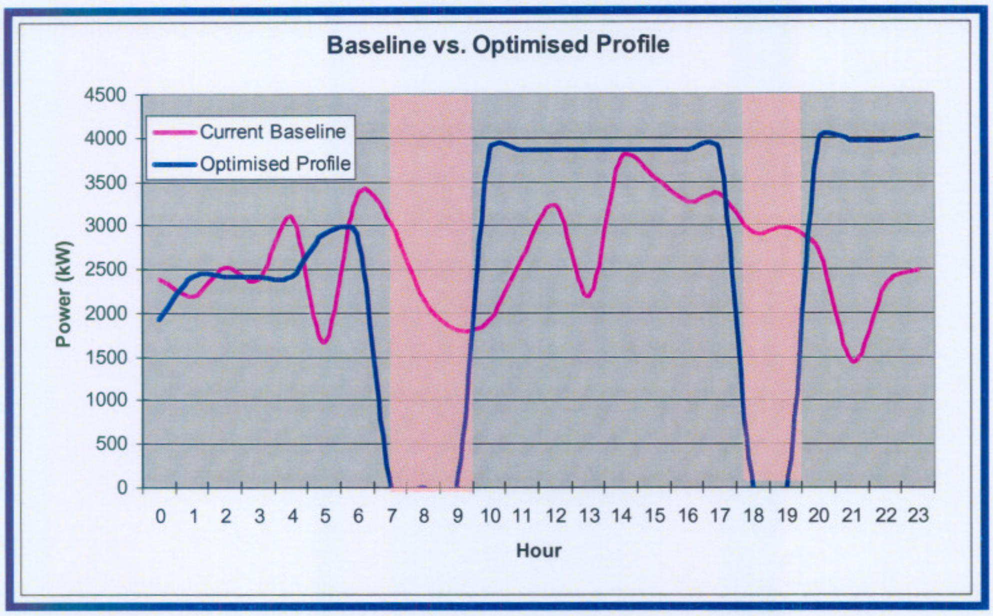


Figure 30: Baseline vs. optimised profile

Figure 30 shows a typical rock winder optimisation power profile. The average energy used during the day is the same for both the baseline and the optimised profile. This indicates that the amount of rock hoisted during the day is the same for the two profiles. The optimisation model will be used to calculate the operating schedule in terms of cycle per hour for the most cost effective rock hoisting operation. This model can also simulate silo level trends.

3.4 Conclusion

In this chapter, three steps were discussed to calculate the baseline for any rock winder system. It is essential that the information and data collected at a mine are correct and represent the history of the rock winder operation. After the baseline was calculated, an optimised profile was configured to calculate the minimum operational cost of the specific rock winder system by adhering to specified constraints. Due to the linearity of the tariff structures with the peak demand periods, this simulation also shifts the maximum load from these electrical demand periods.

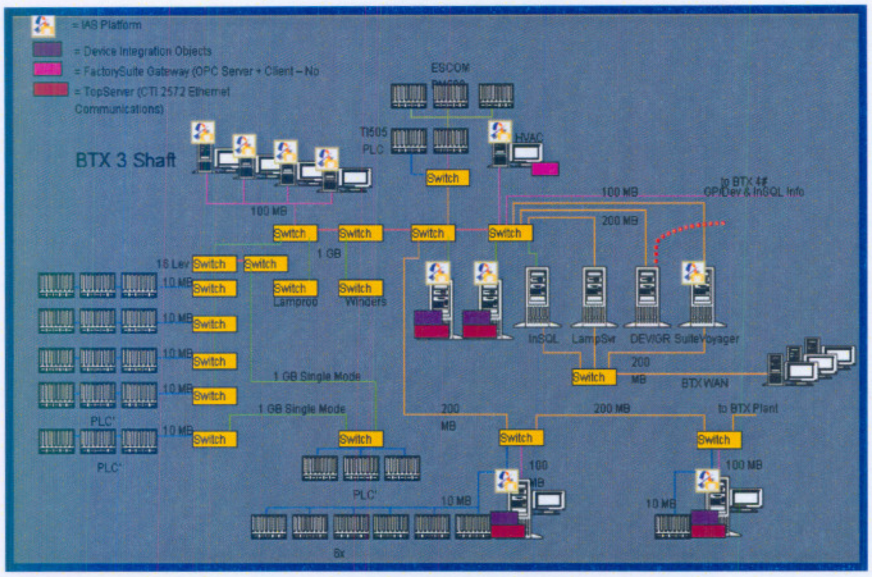
In the next chapter the software and simulation techniques will be discussed to control a rock winder system real-time. The optimised model will be used to test the specific software.

References

[52] "Accident / Illness Investigations Procedures", U.S. Department of Labour, Mine Safety and Health Administration, 200 Constitution Ave., NW Washington, DC 20210 November 2000.

[53] Fylstra, P, Lasdon, L, Watson, J, Waren, A "Design and Use of the Microsoft Excel Solver", Vol 28, No.5, Sep-Oct 1998.

CHAPTER 4: NEED FOR A REAL-TIME CONTROLLER AND SIMULATION SYSTEM OF A ROCK WINDER



Beatrix 1, 2 and 3 shafts SCADA and IT networking layout

Beatrix 1, 2 and 3 shafts located south of Virginia are three separate mines that cover an estimated area of more than 25 square kilometres. These shafts mainly operate and function on their own - except for the control room each of them share. This ability is made possible by an integrated SCADA system. Surface and underground appliances of 1 and 2 shafts can be controlled via 3 shaft's control room.

A new DSM tool was developed. This tool realised new approaches that ensured maximum and sustainable DSM results on rock winders. In this chapter REMS Winder is discussed, and later on it is incorporated with the REMS Winder Simulator. The results obtained from the simulator outputs are compared to the optimised winder model discussed in Chapter 3.

4.1 Introduction

In this chapter the real-time Winder Controller's software philosophy is discussed. From Chapter 2 the mine winder system was shown to be one of the most important transportation links in the gold extraction process. Due to this importance, the software implemented should be designed and tested under all conditions before it is implemented.

The mine winder system consists of variables that could change dynamically. The most important variable is the amount of rock being hoisted each day. The change in the rock hoist target has a direct impact on the energy usage of the winder system. This means that if the rock from underground increases, more skips need to be hoisted and therefore the energy usage and cost will increase as well.

Due to this scenario, a fixed hoisting schedule for each day is not possible. Thus, it is important to simulate the entire winding system, and by using the simulation model determining an optimal control strategy at any point in time.

The software designed to control and enforce load shifting on a mine rock winder system is called REMS Winder. REMS Winder is a component of the REMS Platform, designed by HVAC International. This software is a fully automated, on-site, Real-Time Energy Management System (REMS) that controls electricity-intensive mining appliances via the mining SCADA (Supervisory Control And Data Acquisition) system. This system was originally designed to shift the maximum evening load on Kopanang mine's underground pumping system, but was later modified to control mining fridge plants, compressors and now rock winder systems.

Figure 31 shows the REMS system, with all its components. REMS Platform is the core program onto which different sub-programs operate. These programs can vary from REMS CAM (Compress Air Management), REMS for pumps and REMS Winder. REMS Platform also has an extra feature that controls the maximum demand (REMS MD) of all the biggest electrical appliances on the mine.

The communication between REMS and the PLC (Programmable Logic Controller) doesn't happen directly. The rock winder status and silo levels are gathered by the winder PLC. The winder PLC then transfers the data back to the SCADA, where it is then sent to the REMS Winder system. According to the gathered data, production target and time of day, the REMS Winder Controller, which is incorporated in REMS Winder, calculates an operating schedule. The schedule represents the most cost effective rock flow (skips hoist/hour) during that specific time of day. If REMS Winder schedules the rock winder to run, it uses the same route as described to send a command to the PLC. After the PLC gets the command it goes through its programmed routine to switch the rock winder either on or off.

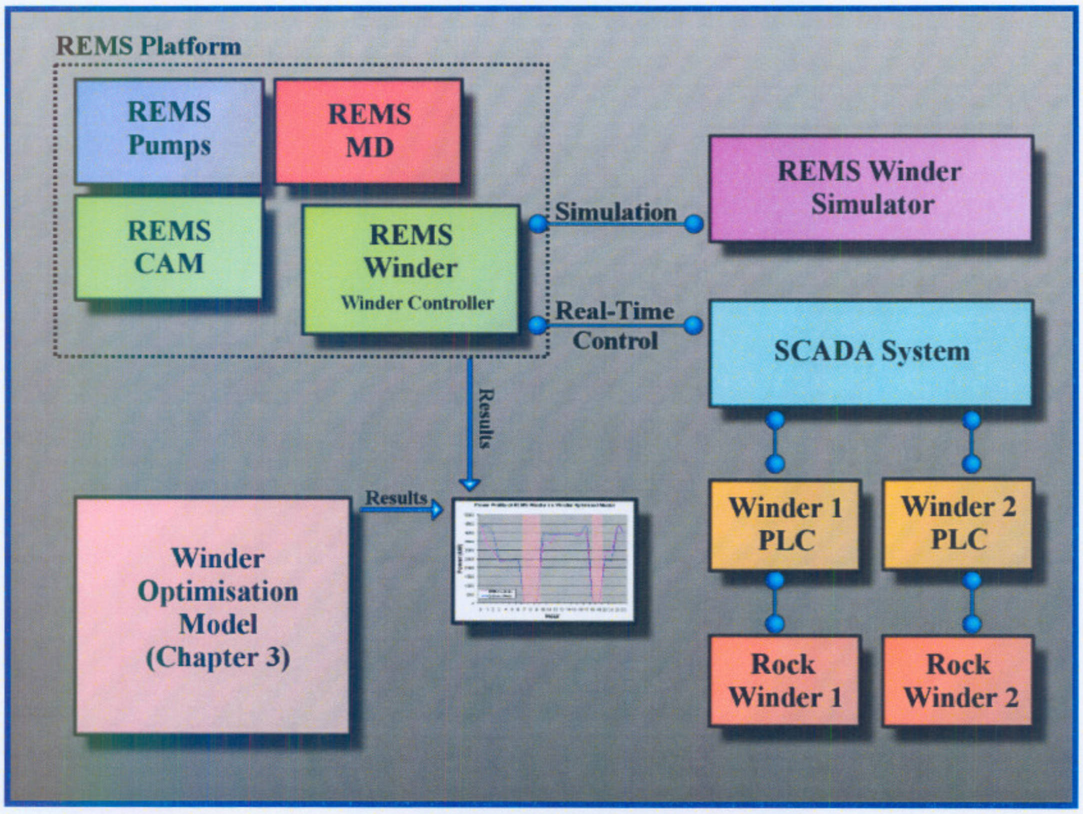


Figure 31: REMS system layout

Due to the fact that a SCADA system differs from mine to mine and isn't easy to come by, a simulation system (REMS Winder Simulator) was written (is discussed in Appendix B). This simulator simulates a SCADA system, so that the necessary tests can be preformed before the system is implemented on a real mining winder system. The results obtained from the simulations are then compared to the winder optimised model (described in

Chapter 3) to indicate if the Winder Controller is configured for the most cost-effective operation.

4.2 Integrated control and software module for a rock Winder Controller

The Winder Controller is part of the REMS Platform and is used to control the rock winders in a deep mine in order to shift load out of daily times of peak electricity usage. This controller was programmed with the help of Mr. Hanro Bosman, an engineer in the energy management field.

The Winder Controller consists of two sections: the surface controller and the underground controller. The surface controller is responsible for controlling the reef level of the surface silo, while the underground controller is responsible for the reef level of the underground silo (which includes loading boxes and stockpiles). Both of these silos have to be controlled so that the surface silo, feeding the gold plant, doesn't get overloaded or runs empty. It is also of no use hoisting skips if there is no rock in the underground silo.

The control method used by the Winder Controller to control the rock winder is called the maximum and minimum level control. The surface controller checks the boundaries of the surface silo. The controller should always be configured to control the surface silo at its maximum level during the off-peak and standard daily electricity periods (Figure 32). A winder will be stopped as soon as the surface silo reaches its specified maximum level. Should the silo level still be rising and the winder operates in parallel with another winder, the second winder will be stopped at the maximum level plus the stop offset level. The first winder will be started when the silo reaches its specified minimum level. Subsequent winders will be started when the silo's level reaches its minimum minus the start offset.

The underground controller checks the boundaries of the underground silo. The controller should always be configured to control the underground silo at its minimum level during the off-peak and standard daily electricity periods. A winder will be started as soon as the underground silo reaches its specified maximum level. Should the silo level still be rising and the winder operates in parallel with another winder, the second winder will be started at the maximum level plus the start offset level (see Figure 32). The first winder will be stopped when the silo reaches its specified minimum level. Subsequent winders will be stopped when the silo's level reaches its minimum level minus the stop offset (see Figure 32).

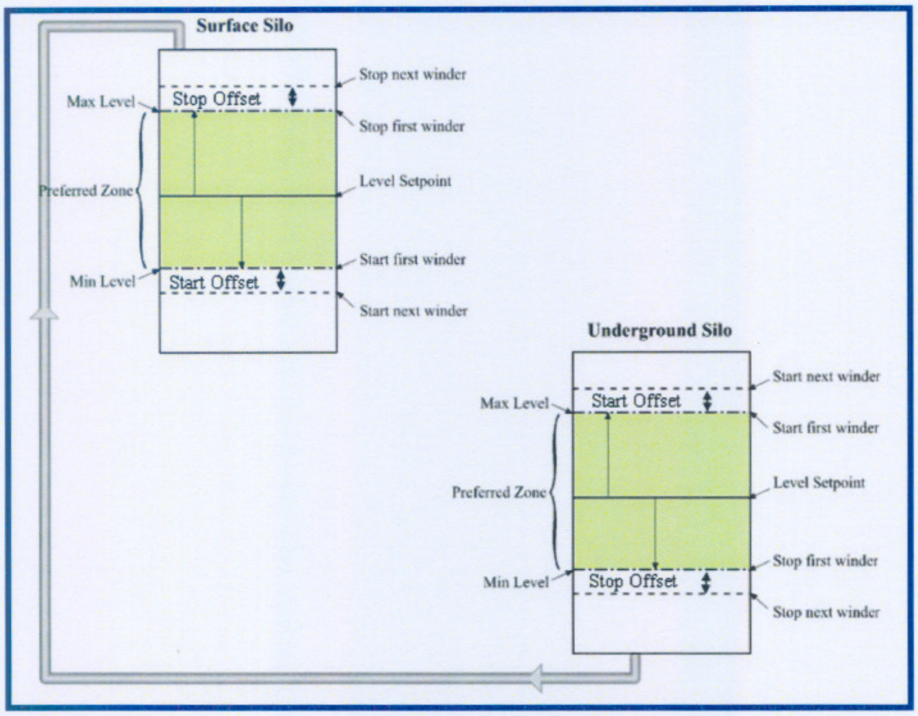


Figure 32: Schematic of Winder Controller's control philosophy

Under the condition that the surface silo has priority, the controller's schedule is calculated using the surface silo's levels. The underground silo's levels will only be used during calculations if the surface silo's levels are inside the preferred operating zone as illustrated in Figure 32. The same conditions apply if the underground silo has priority.

In some instances, the mine does not have an underground silo level measuring system. In these cases, the amount of underground ore is not available on the SCADA system and the controller will therefore control the winders only according to the level of the surface silo.

The advantage of the maximum and minimum level controller is that the operating schedule calculation is already optimised for minimum winding during peak electricity times. The negative side however, is that the controller can't easily be configured for planned maintenances like weekly shaft exams. It is important to remember that too much winder cycling in peak and standard electricity period times could increase the Maximum Demand (MD) and should be regulated in the controller.

4.3 Simulation software

Due to the fact that the rock Winder Controller and software model are new interventions, the software needs to be tested. This is done by creating a simulation module so that real time rock winder operations can be simulated. Not only can this simulation module be used to test the control software, but it can also be used to simulate and optimise baseline profiles.

When developing a simulation model for mine operations, each element which has an influence on the operation should be simulated in detail. It is impossible to simulate the complete winder system in its practical operation, but the developer should try its utmost best to include all the parameters. Each element should be built according to a mathematical model which accurately represents the specific element. It is important to ensure that the mathematical model reacts exactly the same way as the real element would react in its practical operation.

A number of these mathematical models are integrated to form a complete simulation model. Each model represents a different component of the complete winder system, and these components fit into the other models so that a complete winder system is represented.

Different winder systems operate on different ways. In fact, each winder system has a distinct layout. To simulate a rock winder system the following elements should be set as inputs:

- Amount of rock (reef and waste) mined underground
- Reef transported to gold plant
- Time and day of shaft exam
- Skip size
- Surface silo capacity
- Underground silo capacity
- Cycle time (loading time + travel time)
- Scheduled maintenance

The input data should include an average of a typical weekday of a rock winder operation. However, if enough data can be captured, each day in a typical month could be simulated that will give a much more accurate representation of the real rock winder operation.

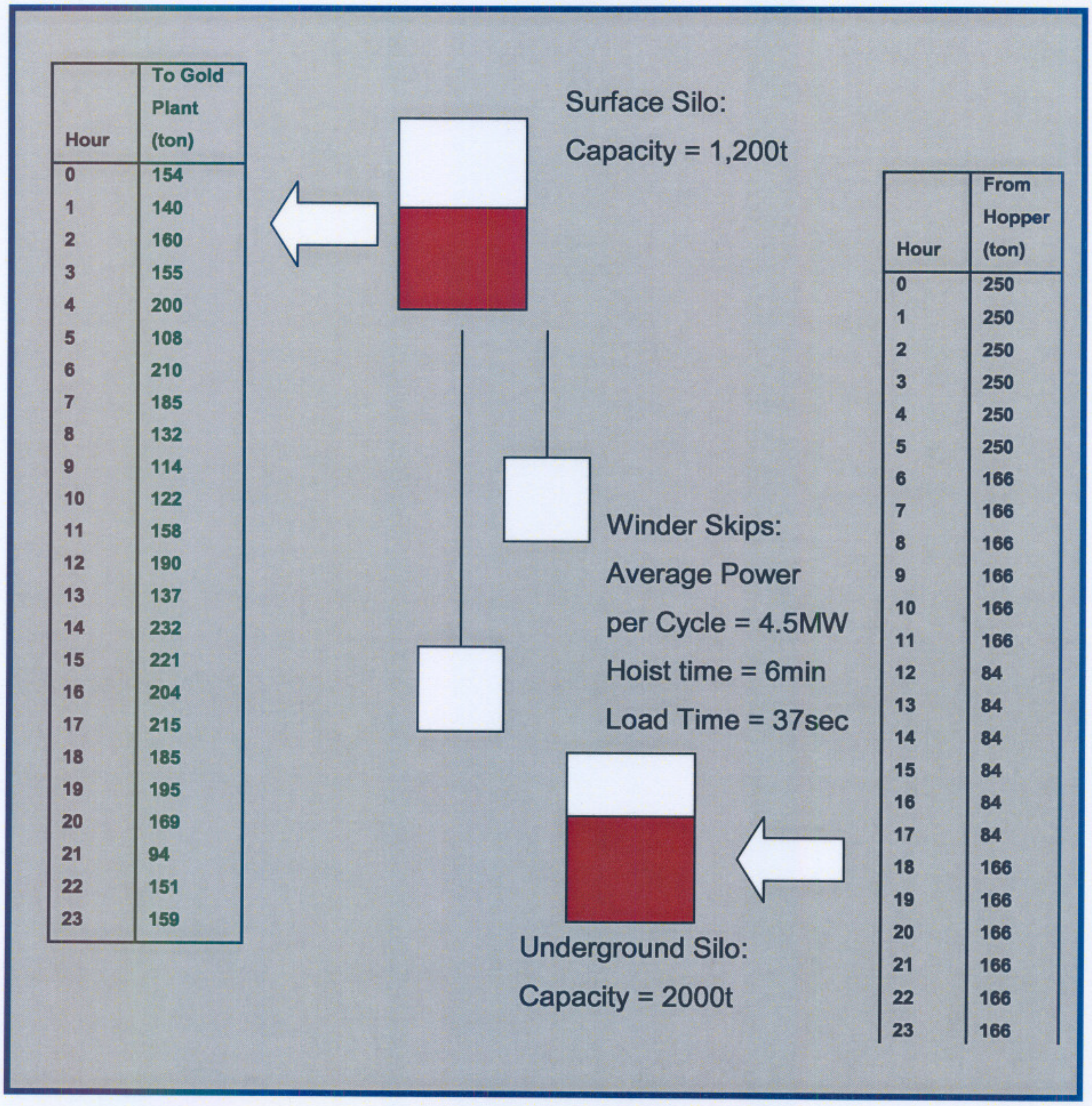
To optimise the cost of the rock winder system, the controller should be configured in such a way that the minimum cycles take place during the electrical peak periods. This implicates that before the start of peak times the underground rock silos (reef and waste) should be at its minimum. On the other hand, the surface silo should be at its maximum level so that the gold plant doesn't have to reduce operations due to the fact that the surface silo is empty.

One of the most valuable aspects of a simulation is to predict what will happen in future. In the REMS Winder simulator the change in silo levels can be predicted after a certain time interval. This is done by setting the inputs equal to the real rock winder status at a specific time of a day. The simulation can run faster than real time which means that the simulation results can be obtained in a short period of time.

4.4 Simulator configuration and software testing

In this section the REMS controller is tested and results shown. This test was done before the system is implemented on an actual rock winder system:

- To evaluate if a winder system is configured for minimum operating cost, by comparing the results to the winder model described in Chapter 3
- To test the newly developed system and demonstrate its robustness, stability and most of all proof that the controller responds according to its design



Hour	To Gold Plant (ton)
0	154
1	140
2	160
3	155
4	200
5	108
6	210
7	185
8	132
9	114
10	122
11	158
12	190
13	137
14	232
15	221
16	204
17	215
18	185
19	195
20	169
21	94
22	151
23	159

Hour	From Hopper (ton)
0	250
1	250
2	250
3	250
4	250
5	250
6	166
7	166
8	166
9	166
10	166
11	166
12	84
13	84
14	84
15	84
16	84
17	84
18	166
19	166
20	166
21	166
22	166
23	166

Figure 33: Input parameters of the REMS Winder test

The REMS Winder software was tested on this simulator for its beta phase. Different kinds of winder systems were built in the REMS simulator and the results compared with the model simulator discussed in the previous chapter. In one of the tests a real winder system's parameters were used. Figure 33 contains these input parameters.

These parameters were set for both the REMS Winder simulation as well as in the optimised winder model. The REMS maximum/minimum level controller was used in the Winder Controller with the following configurations:

- Max Level (0-5, 22-24 hour) 95%
- Max Level (6, 10-17,20-21 hour) 80%
- Max Level (7-9, 18-19 hour) 50%
- Min Level (0-6, 10-17, 20-24 hour) 70%
- Min Level (7-9, 18-19 hour) 40%

These maximum and minimum values were programmed in such a way that the winder extracts the maximum number of reef during the standard and off-peak Eskom electricity tariff times. The reason for using the Maximum and Minimum level controller is because this specific mine winder system shuts down from 7h00 to 10h00, for the daily shaft exam. This falls directly into the morning electricity peak demand, in which the controller will shut the operation. The following figure (Figure 34) shows the energy comparison between the Winder Model and the REMS Winder simulator.

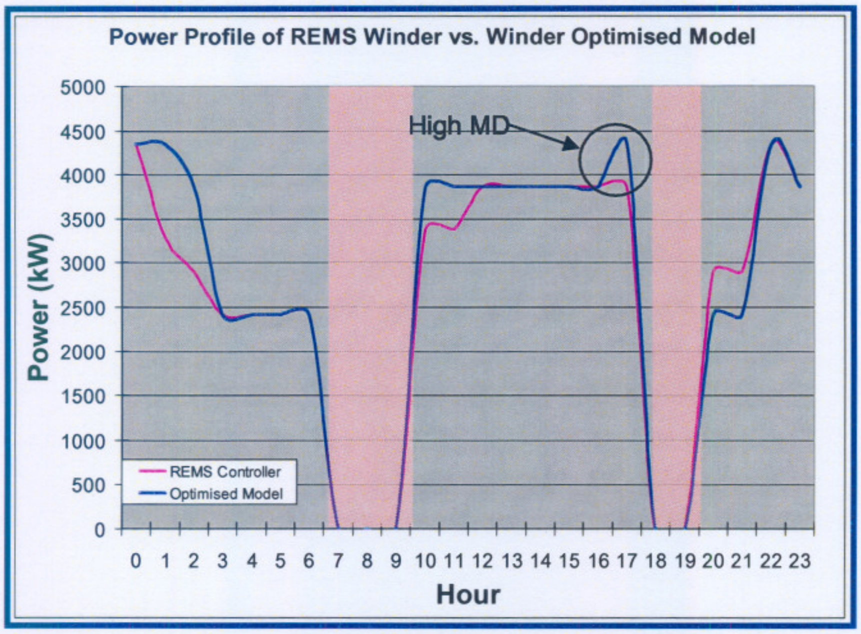


Figure 34: Daily power profile of the Winder Model vs. REMS Winder Simulator

From Figure 34 the results show that both the simulator as well as the optimised model stopped the rock winder between the peak periods. The graphs reacted in a similar way and the maximum energy used in a specific hour for both the winder model and winder simulator were 4,400kWh. However a difference came in at 17h00, when the Optimised Model ran the winder at maximum capacity. REMS Winder didn't react in the same way due to an added feature in REMS to minimise the MD during standard and peak times. One can however see that REMS used more energy after the evening peak to make up for the losses. From the calculations the daily energy usages of both these graphs were nearly 32,000kWh.

The following figure (Figure 35) indicates the surface silo level for both the winder simulator and model.

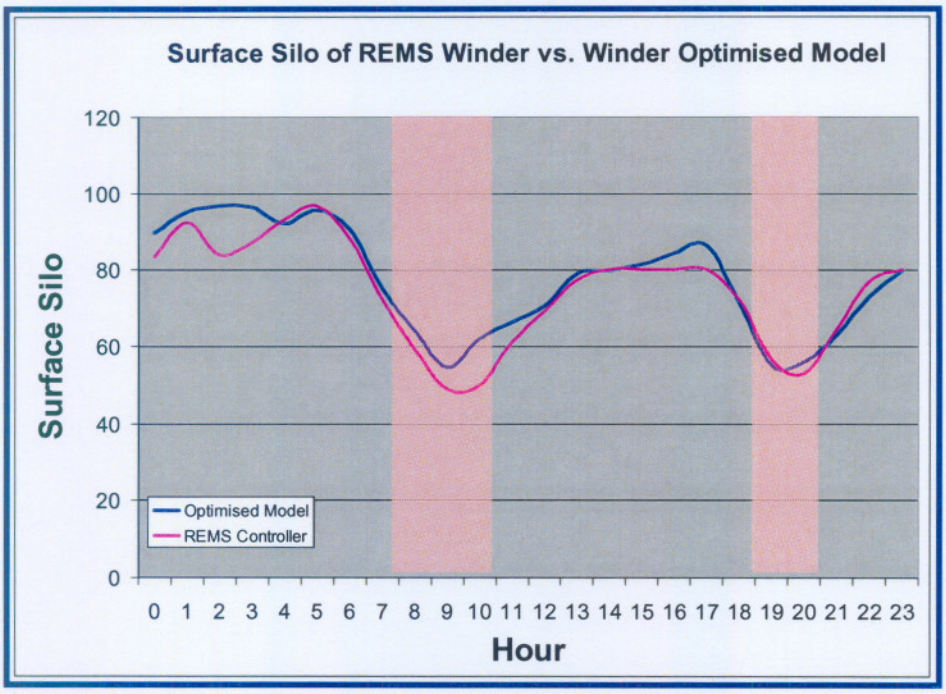


Figure 35: Surface silo level of the Optimised Model vs. REMS Winder Simulator

From the above figure a decrease in silo level can be clearly seen during the peak periods. During these times the rock winder also idles, which means that the only flow rate is out of the surface silo. The dam levels of both the cases began at around 87% and ended at approximately 80%. This means that the amount of rock that is hoisted in the simulated day is the same for the different cases. Figure 36 shows the target hoisting profile for the optimised model as well as the Winder Controller. The two profiles follow the same trend, as expected. Both these profiles reached the 100% production target mark.

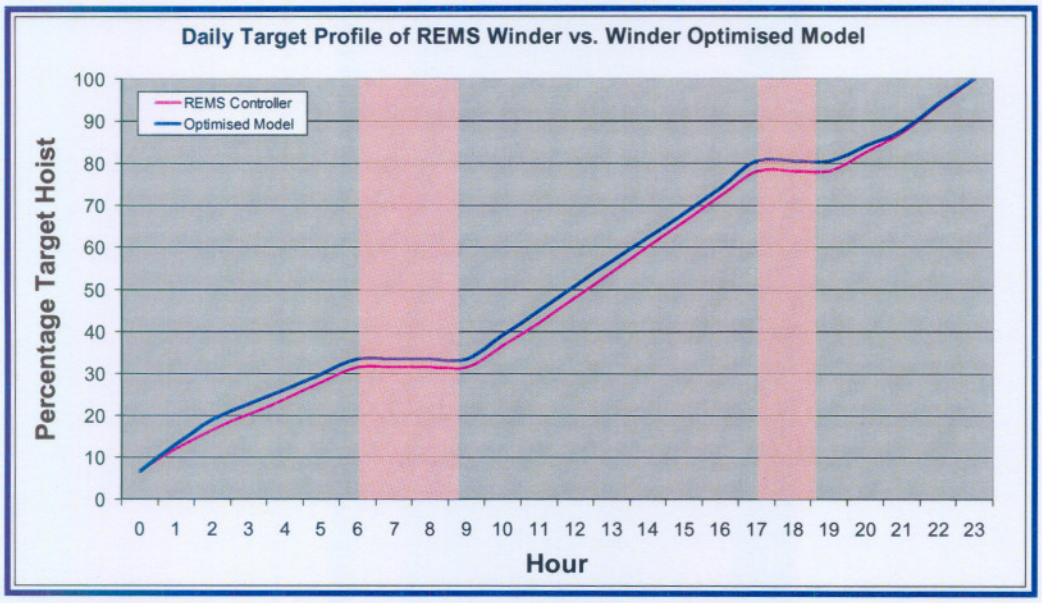


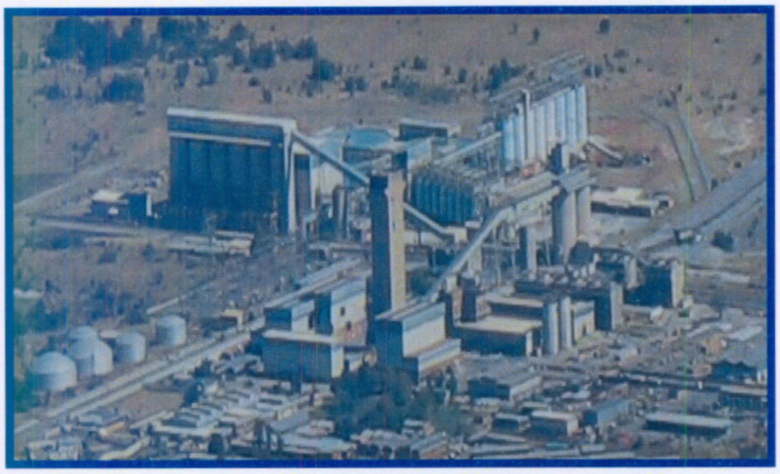
Figure 36: Daily target profile of REMS Winder vs. Optimised Model

4.5 Conclusions

In this chapter the REMS Winder control philosophy was explained in detail. To test the software a simulator was built and the results verified with the winder optimised model discussed in Chapter 3. The same mining parameters were used so that the results could be compared. The power profiles and production characteristics reacted in the same way for both of these cases.

From these tests enough confidence was gathered to implement the system on a mining rock winder system. In the next chapter the implementation of the REMS system on a case study mine, including the results and savings will be discussed.

CHAPTER 5: IMPLEMENTATION AND RESULTS OF THE REMS WINDER SYSTEM ON A RSA MINE (CASE STUDY)



Kopanang mine & No.9 Gold plant

Kopanang is a Sotho word meaning "gathering together, building bridges"'. The mine has won the Dick Fisher Global Safety Award in 2005 – a first for a South African mine. This was also the first time the award was given to an underground mine.

The purpose of this study was to reduce the operational costs of an underground rock winder system. This chapter is a case study to verify the procedures, simulations and software developed in the previous chapters. Kopanang mine was identified as a candidate mine for this survey. REMS Winder was installed and fully operational before the month of July 2006.

5.1 Introduction

Kopanang mine is one of four mines which make up the AngloGold Ashanti's Vaal River operations. Great Noligwa, Tau Lekoa and Moab Khotsong are the other three mines. These mines are situated near the towns of Klerksdorp and Orkney in the North-West Province and the Free State.

The Vaal River complex has four gold plants, one uranium plant and one sulphuric acid plant, and is able to treat between 180,000 and 420,000 tones of ore per month [54]. Although the Vaal River operations produce uranium oxide as a by-product, the value is not significant relative to the value of the gold produced.

During the 2005 financial year Kopanang mining plant milled 21 million tons of ore, with an average gold recovery of 8.38g/ton [54]. During this specific year Kopanang has produced 482,000 ounces of gold. The total costs of operation to extract a kilogram of gold ranged in the region of R56,427 per kilogram or $277 per ounce at an exchange rate of R5.77 for $1.

Ore extraction at Kopanang mine is as important as at any other gold mine. The mine predominantly feeds one of the two process lines at the Vaal River No 9 gold plant. The other process line is fed exclusively by ore from Tau Lekoa mine. Both of these lines are augmented by low-grade ore from the nearby waste dumps.

Figure 37: Aerial photograph of the Vaal River No 9 gold plant [Google earth]

Kopanang mine has two Blair Multi-Rope rock winders that cover a depth of 2,350m between surface and underground. The rock winder also consumes about 10% of the electricity supplied to the mine; see Figure 38 [55].

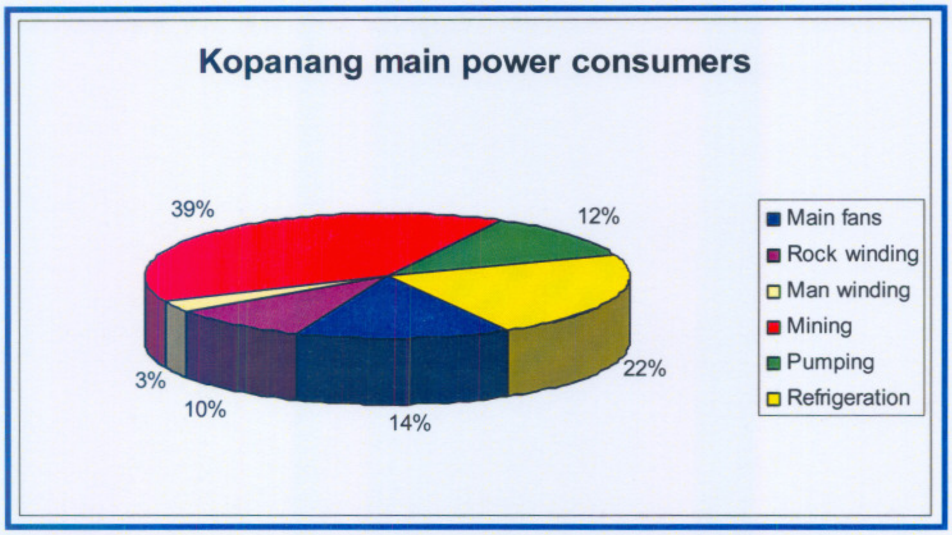


Figure 38: Kopanang electricity distribution

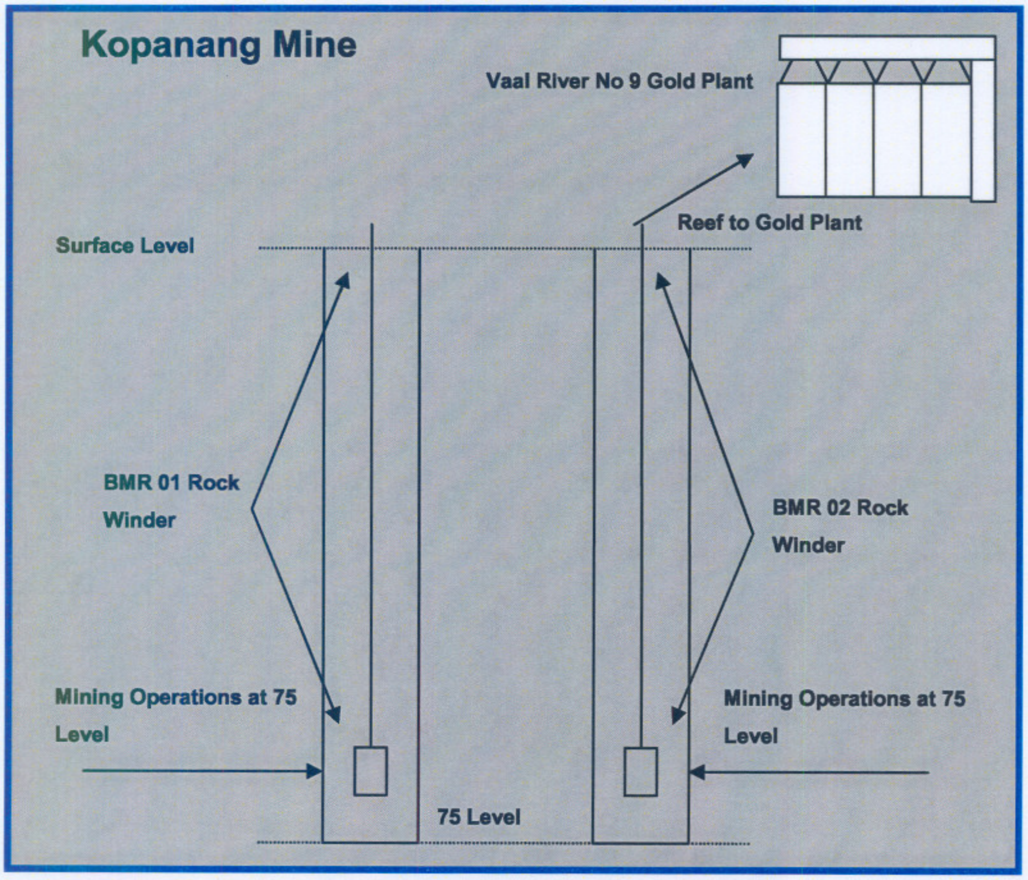


Figure 39: Kopanang winder system layout

The two rock winders called BMR1 and BMR2 operate in parallel and transport either ore or waste from Level 72 (where the loading boxes are situated) to surface. From the surface the ore is transported via conveyer to the Vaal River No 9 plant and the waste transported to the waste pile. Figure 39 shows the basic layout of the ore transportation process.

5.2 Determine the baseline of Kopanang rock winder system

5.2.1 Preamble

To launch the study an initial load shift potential on Kopanang's rock winder system had to be determined. In doing so the following information was gathered:

- Vertical transportation height = 2,350m
- BMR1 skip size = 20t
- BMR2 skip size = 17t
- Target waste hoist per day = 3,500t
- Target reef hoist per day = 6,200t
- Surface silo capacity = 6,000t
- Target daily rock hoist = 9,700t

The above information will be used to determine the estimated operational cost and the influence Kopanang rock winder system has on the electricity grid. After this, the steps discussed in Chapter 3 will be used to determine the DSM and cost optimisation potential.

5.2.2 Step 1 - Initial rock winder investigation

According to Equation 2-2, the minimum energy needed to hoist the daily target of rock:

$$
\begin{aligned}
EE &= m \times h \times 2.7344 \times 10^{-6}\, kWh \\
&= 9700t \times 2350m \times 2.7344 \times 10^{-6}\, kWh \\
&= 62330 kWh\ per\, day
\end{aligned}
$$

This result indicates that the rock winders need to consume 62,330kWh energy during the day to hoist the target of 9,700t of rock. Due to the fact that the losses are not incorporated into the minimum energy, an extra 15 - 20% can be added. With the system losses brought into account, the estimated energy needed to hoist the daily target is an estimated 72,000kWh.

Equation 5-1 transforms the daily energy used to hoist the daily production target into the average constant power needed to make the target rock hoist.

$$\begin{aligned} Pin &= \frac{Daily\ Energy(kWh)}{24h} \\ &= \frac{72000}{24} \approx 3000kW \end{aligned} \qquad (5\text{-}1)$$

From this calculation it can be assumed that a constant power average of 3,000kW, during a typical day is consumed to make the production target. This indicates that the rock winder system at Kopanang mine is likely to use more power during the evening demand peak than the DSM minimum load shift target of 500kW. This means that the process can continue to Step 2.

5.2.3 Step 2 - Winder operation schedule

To get the average daily operational schedule of the rock winder system, a month's tachographs of both the winders were captured. To convert the results into a power profile, the estimated power needed to lift a single skip was multiplied with the average cycles during a specific hour. The estimated average energy consumed (excluding the energy to overcome the losses) for a single cycle by each rock winder is:

From (2-2): $$EE = \frac{m \times h \times 2.7344 \times 10^{-6}}{eff}$$

For BMR1: $$EE_{BMR1} = \frac{20 \times 2350 \times 2.7344 \times 10^{-6}}{100\%} \approx 129kWh$$

and BMR2: $$EE_{BMR2} = \frac{17 \times 2350 \times 2.734 \times 10^{-6}}{100\%} \approx 109kWh$$

Where: m = skip size (t)

h = height of hoist (m)

eff = efficiency of rock winder system (100%)

With the above calculations the estimated power profile of both the rock winders is calculated by using Equation 3-3 where:

For h=0,1,…,24: $EE_{BMR1}(h) = EE_{BMR1} \times \frac{n_h}{hour}$

$$EE_{BMR2}(h) = EE_{BMR2} \times \frac{n_h}{hour}$$

Where: n_k = number of cycles during hour (h).

Figure 40 shows the estimated power profile of the rock winders at Kopanang mine.

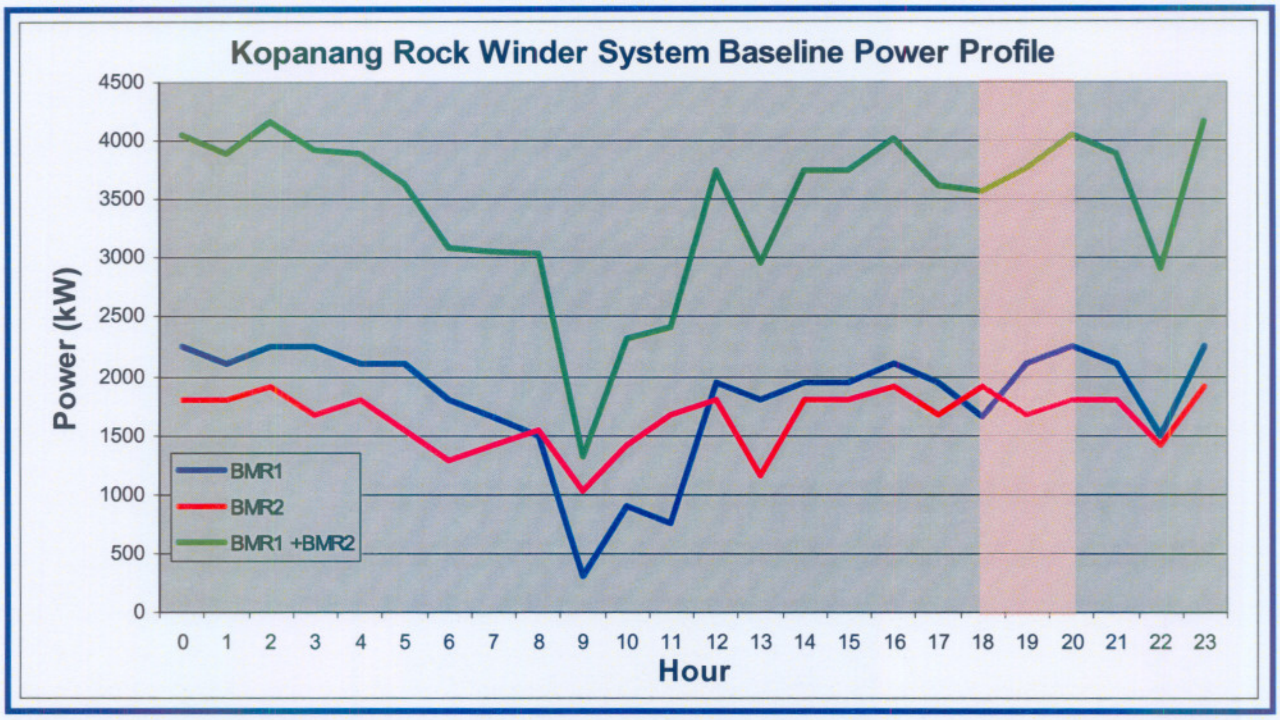


Figure 40: Estimated power profile of the Kopanang rock winder system

Figure 40 clearly illustrates that an estimated 3,667kW could be shifted out of the evening peak period. This evening peak load potential is much higher than the minimum load shift of the 500kW. Thus, this project can continue to Step 3.

5.2.4 Step 3 - Winding cycle power profile metering

Metering was installed to determine the true energy usage of Kopanang's rock winder system. Both rock winders were measured with state of the art power logging devices to measure the exact power consumption (including power to overcome losses) of the rock winders.

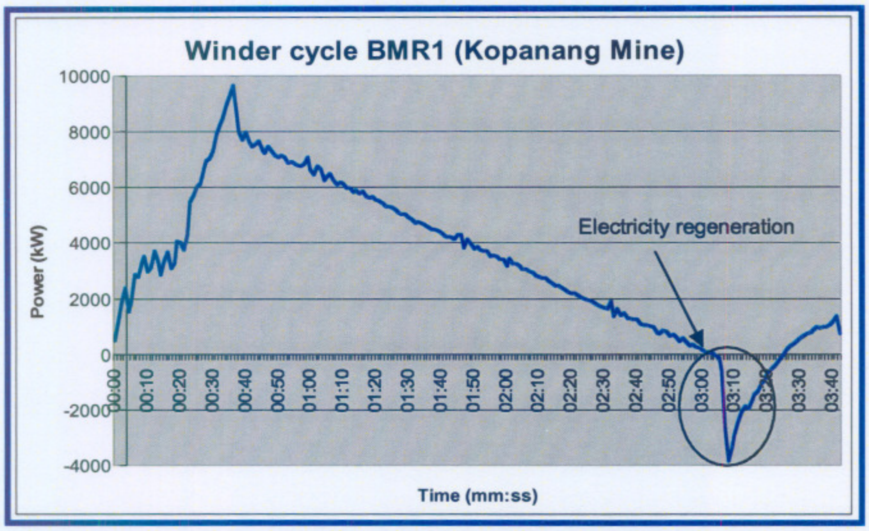


Figure 41: BMR1 winder cycle power profile

From the measurements the following was noted:

- Average time for the skip to move from shaft bottom to surface = 223 seconds
- Average skip loading time = 29 seconds
- Average power during the cycle = 3,257kW
- Average energy consumed during a cycle = 201.75kWh

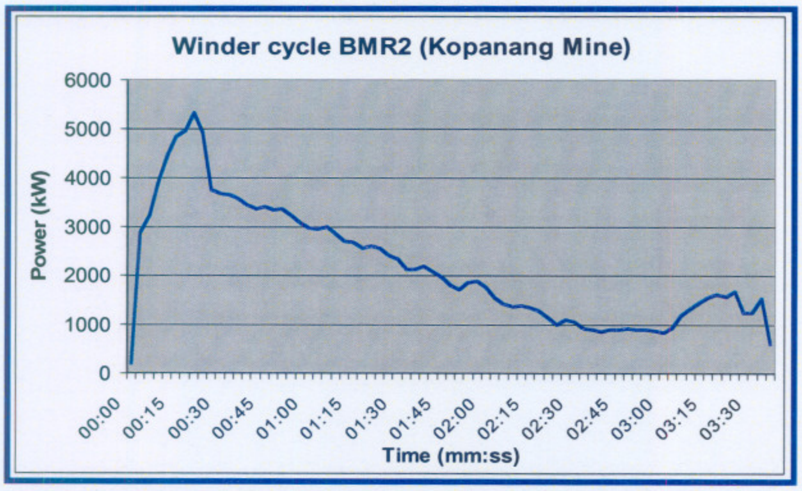


Figure 42: BMR2 winder cycle power profile

Figure 42 is the average power profile of BMR2 rock winder for a single cycle.

From the measurements the following were noted:

- Average time for the skip to move from shaft bottom to surface = 216 seconds
- Average skip loading time = 21 seconds
- Average power during the cycle = 2,181kW
- Thus the average energy consumed during a cycle = 130kWh

Note the difference in the winder cycle profile of BMR1 and BMR2. This is due to the winder systems using different winder motors and skips sizes. There is also a clear indication that BMR1 generates its excess energy back into the electricity grid, unlike BMR2. If the cycle energy of Step 3 is compared with the cycle energy of Step 2 of the various rock winders, a huge difference is noticed. This highlights the importance of measuring a winder cycle and so determines exactly what the losses in the system are.

Table 5: Efficiency of Kopanang rock winder system

Winder	Ideal Energy Consumption (Step2)	Measured Energy Consumption (Step 3)	Efficiency
BMR1	129kWh	201kWh	64.18%
BMR2	109kWh	130kWh	83.85%
BMR1+BMR2	238kWh	331kWh	72%

From Table 5 the ideal energy consumption (calculated in Step 2) of Kopanang rock winder system is compared to the measured energy consumption (measured in Step 3). From this calculation the complete rock winder's efficiency was calculated at 72%. Note that the efficiency of BMR2 is much higher than BMR1. This may look like a lot, but seeing that the rock winder is part of the production process, and the production process the main concern of any mine, great emphasis is placed on the speed of the extraction of rock. Using the measurements taken from the winder cycle power profiles, it can be calculated that BMR1 takes 12.6 seconds to hoist 1ton of rock and BMR2 takes 13.9 seconds. In section 5.3 the impact of this will be put into perspective.

From the above calculations an accurate baseline can be configured by multiplying the average energy consumed during a cycle, with the cycle profile, as shown in Equation 3-3. The following figure shows the results.

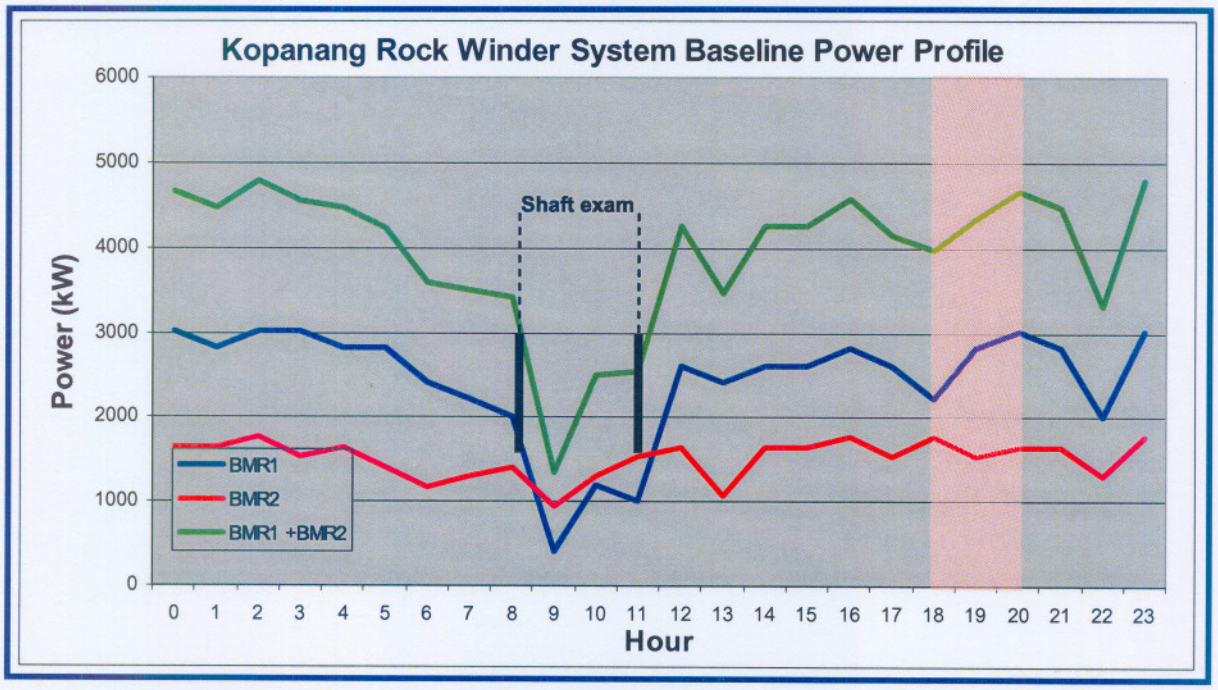


Figure 43: Baseline profile of the Kopanang rock winder system

By studying Figure 43, it can be seen that the load from BMR1 dips between 08h00 and 11h00. This is due to BMR1's scheduled shaft exam. During shaft exam the entire shaft is inspected, and during that time all the rock winders have to cease operation. The baseline values for each hour are shown in Table 6, where 0 is the hour between 00h00 and 01h00.

From Figure 43 and Table 6 it can be seen that the average load used during the evening peak power period of Kopanang winder system is 4,150kW.

Table 6: Baseline values of Kopanang rock winder system

Hour	Total Consumption
0	4660.00
1	4459.00
2	4777.50
3	4542.50
4	4459.00
5	4224.00
6	3587.00
7	3503.50
8	3420.00
9	1342.00
10	2498.50
11	2532.50
12	4258.00
13	3469.50
14	4258.00
15	4258.00
16	4576.50
17	4140.50
18	3973.50
19	4341.50
20	4660.00
21	4459.00
22	3302.50
23	4777.50
Total	94480.00

The average annual electricity cost of operating the rock winder in this manner is R3,300,000. This estimation was calculated by assuming that the same electricity profile was used for each day, during winter and summer tariff periods. If the power used during the evening peak period can be shifted to another time interval, it will have a substantial positive impact on the local electricity network and increase savings for the mine.

In the next section a simulation will be run to determine the maximum load that could be shifted out of the electricity demand periods.

5.3 Simulate the rock winder system of Kopanang mine

5.3.1 Preamble

In this section the potential evening load that could be shifted, as well as the savings generated will be calculated. This is done by using REMS Winder in conjunction with the simulation software.

5.3.2 BMR1 rock winder

Figure 44 represents the optimised REMS Winder profile for BMR1 rock winder under normal daily winding circumstances. This simulation was done in conjunction with the optimised winder model discussed in Chapter 3.

By using the winder cycle profile and the tachographs collected from the mine, Table 7 indicates how the maximum cycles per hour were calculated for the simulation. This table also calculates the estimated operating hours per day to hoist the production target of 5000t. Note that the target rock of 5000t that needs to be hoisted is not the specified target for BMR1 rock winder. However, seeing that this study focuses on the operational costs and DSM, this target was calculated so that the daily operating duration of the rock winders are equal. By doing this, the idle times between the two rock winders as well as the DSM potential can be divided equally.

Table 7: BMR1 maximum cycles per hour

Calculating the maximum cycles per hour Kopanang BMR1	
From cycle power profile:	
Hoisting time (min)	3.7
Skip loading time (min)	0.5
Total time per cycle (min)	4.2
Total cycles per hour	14.3
From Tacho Sheets: Maximum of 15 cycles per hour	
Thus, 14 cycles per hour used for simulation	

Calculating operating hours per day	
Ton hoisted per day	5000
Skips per hour	14
Ton per skip	20
Skips hoists per day for 5000 ton	250
Operating hours per day	17.86
6 hours per day idle	
5 for DSM	
1 hours for stoppages	

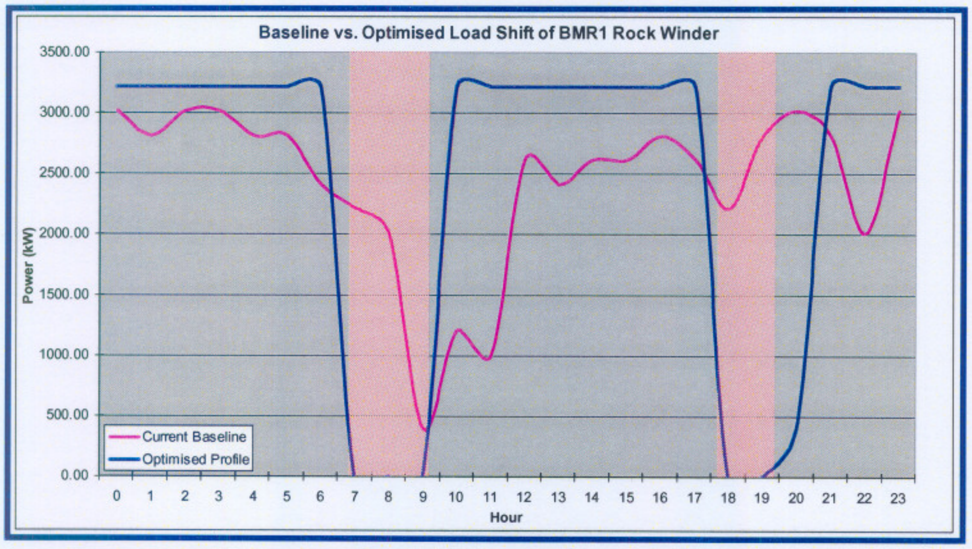


Figure 44: Load reduction profile for BMR1 rock winder

The current baseline plot is shown in Figure 44. REMS Winder will not operate during the evening peak times unless it is absolutely necessary. Rather than using the evening peak times for winding, REMS Winder will operate the winder during the morning peaks. Table 8 contains the values on which these plots are based. Note that the simulation done in REMS Winder, as well as the operating hours, shows that the mine can stop the rock winder for the peak electricity demand periods without influencing the production.

Table 8: Optimised load vs. baseline load of BMR1 rock winder

Hour	KW (Optimised)	kW (Baseline)	Time interval power difference
0	3216.00	3015.00	-301.50
1	3216.00	2814.00	
2	3216.00	3015.00	
3	3216.00	3015.00	
4	3216.00	2814.00	
5	3216.00	2814.00	
6	3216.00	2412.00	-804.00
7	0.00	2211.00	1541.00
8	0.00	2010.00	
9	0.00	402.00	
10	3216.00	1206.00	-979.88
11	3216.00	1005.00	
12	3216.00	2613.00	
13	3216.00	2412.00	
14	3216.00	2613.00	
15	3216.00	2613.00	
16	3216.00	2814.00	
17	3216.00	2613.00	
18	0.00	2211.00	2512.50
19	0.00	2814.00	
20	402.00	3015.00	1105.50
21	3216.00	2814.00	
22	3216.00	2010.00	-703.50
23	3216.00	3015.00	
	58290.00	**58290.00**	

The simulation model was configured in such a way that the peak incoming rock traffic is catered for. The high peak rock hoisting times occur just after the rock has been blasted in the afternoons. It can be seen from the current baseline graph that the hoist traffic rate increases between 12h00 and 19h00. To deal with this increase, REMS Winder will keep the bottom stockpile at minimum before the evening peak electricity times.

One of the most important characteristics of this optimised baseline profile, is that the overall energy consumed during the daily operation must be the same as the current baseline. This means that the daily extracted tonnage of reef and waste will be equal for the baseline and simulation.

The following constraints were met by the REMS Winder simulation:

- The winder can only cycle a maximum of 14 times an hour
- The rock hoist traffic increases just after the blasting times
- Each skip can only load a maximum of 20 tons of waste or reef
- The winders operate without any stoppages or breakdowns. If any occur the winder will be forced to operate during the morning or evening electricity peak period
- Shaft exams occur between 07h00 and 10h00 daily

The optimisation realised a maximum saving of R360,000 per year with an evening and morning peak load reduction of 2.5MW and 1.5MW.

5.3.3 BMR2 rock winder

Table 9 indicates how the maximum cycles during an hour and minimum operating hours were calculated. BMR2 needs to hoist only 4,200t due to BMR1 hoisting 5,000t of rock. Note that the influence of a faster rock winder in terms of ton/seconds is visible if the daily operating hours are set the same for the two rock winders. For the same daily operating hours, BMR1 hoists 800t more than BMR2, and only after this calculation does BMR1 comes to its own right. Figure 45 represents the optimised REMS Winder profile under normal daily winding circumstances for BMR2 rock winder.

The current baseline plot is included in this figure. This simulation was done in conjunction with the optimised winder module discussed in Chapter 3.

Table 9: BMR2 maximum cycles per hour

Calculating the maximum cycles per hour Kopanang BMR2	
From cycle power profile:	
Hoisting time (min)	3.6
Skip loading time (min)	0.4
Total time per cycle (min)	4.0
Total cycles per hour	15.2
From Tacho Sheets: Maximum of 15 cycles per hour	
Thus, 14 cycles per hour used for simulation	

Calculating operating hours per day	
Ton hoisted per day	4200
Skips per hour	14
Ton per skip	17
Skips hoists per day for 4200 ton	247
Operating hours per day	17.65
6 hours per day idle	
5 for DSM	
1 hours for stoppages	

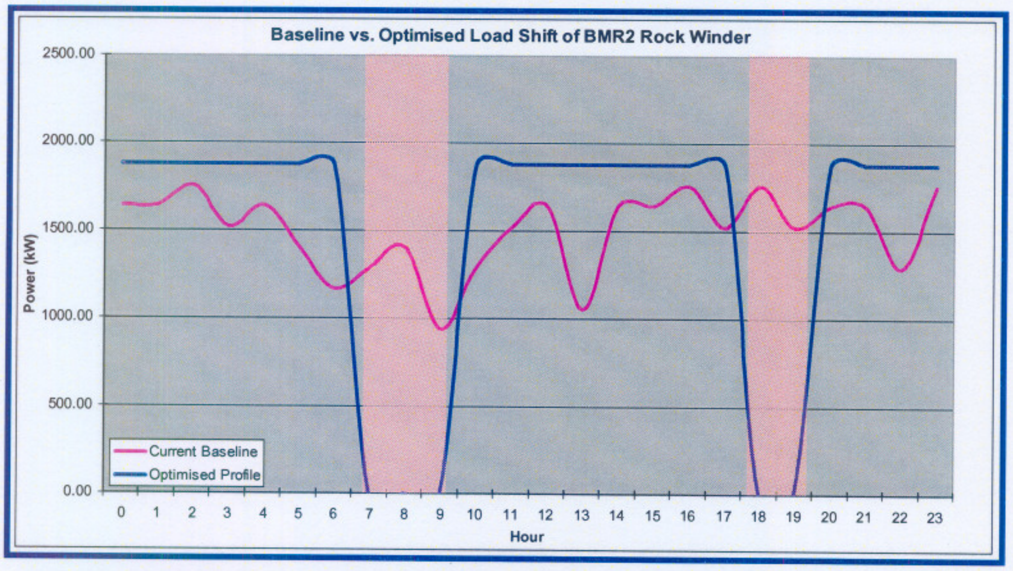


Figure 45: Load reduction profile for BMR2 rock winder

Table 10 contains the values on which these plots are based.

Table 10: Optimised load vs. baseline load of BMR2 rock winder

Hour	KW (Optimized)	kW (Baseline)	Time interval power difference
0	1872.00	1638.00	-273.00
1	1872.00	1638.00	
2	1872.00	1755.00	
3	1872.00	1521.00	
4	1872.00	1638.00	
5	1872.00	1404.00	
6	1872.00	1170.00	-702.00
7	0.00	1287.00	1209.00
8	0.00	1404.00	
9	0.00	936.00	
10	1872.00	1287.00	-365.63
11	1872.00	1521.00	
12	1872.00	1638.00	
13	1872.00	1053.00	
14	1872.00	1638.00	
15	1872.00	1638.00	
16	1872.00	1755.00	
17	1872.00	1521.00	
18	0.00	1755.00	1638.00
19	0.00	1521.00	
20	1872.00	1638.00	-234.00
21	1872.00	1638.00	
22	1872.00	1287.00	-351.00
23	1872.00	1755.00	
	36036.00	**36036.00**	

The following constraints were met by the REMS Winder simulation:

- Each winder can only cycle a maximum of 14 times an hour
- The rock hoist traffic increases just after the blasting times
- Each skip can only load a maximum of 17 ton of waste or reef
- The winders operate without any stoppages or breakdowns. If any occur the winder will be forced to operate during the morning or evening electricity peak period
- Shaft exams occur between 07h00 and 10h00 daily

Maximum savings of R280,000 per year with an evening and morning load reduction of 1.6MW and 1.2MW are estimated with the implementation of REMS Winder.

5.3.4 Combined winder simulation

The maximum potential load, according to the REMS Winder simulation, that could be reduced in the evening and morning peak times of Kopanang's rock winder system, is 4.1MW and 2.7MW. See Figure 46. Table 11 contains the values on which the graph is based.

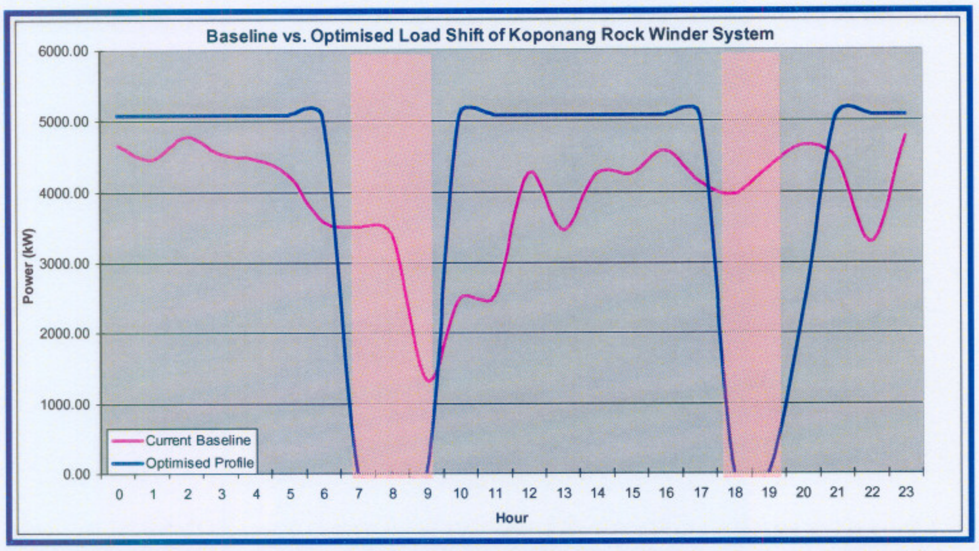


Figure 46: Load reduction profile for Kopanang's rock winder system

By transforming the load shift into cost, the mine will save a maximum of R600,000 on their electricity bill per year. This potential load reduction can only be achieved if no winder breakdowns or stoppages occur. The load reduction will be done on both the rock winders at Kopanang, i.e. BMR1 and BMR2.

Table 11: Optimised load vs. baseline load for Kopanang's rock winders

Hour	KW (Optimized)	kW (Baseline)	Time Interval power difference
0	5088.00	4653.00	-574.50
1	5088.00	4452.00	
2	5088.00	4770.00	
3	5088.00	4536.00	
4	5088.00	4452.00	
5	5088.00	4218.00	
6	5088.00	3582.00	-1506.00
7	0.00	3498.00	2750.00
8	0.00	3414.00	
9	0.00	1338.00	
10	5088.00	2493.00	-1345.50
11	5088.00	2526.00	
12	5088.00	4251.00	
13	5088.00	3465.00	
14	5088.00	4251.00	
15	5088.00	4251.00	
16	5088.00	4569.00	
17	5088.00	4134.00	
18	0.00	3966.00	4150.50

19	0.00	4335.00	
20	2274.00	4653.00	871.50
21	5088.00	4452.00	
22	5088.00	3297.00	-1054.50
23	5088.00	4770.00	
	94326.00	**94326.00**	

5.4 Load shifted and financial results

The figure below is a screen shot of the REMS Winder Software implemented at Kopanang mine. The minimum/maximum level controller was used to control this specific rock winder system.

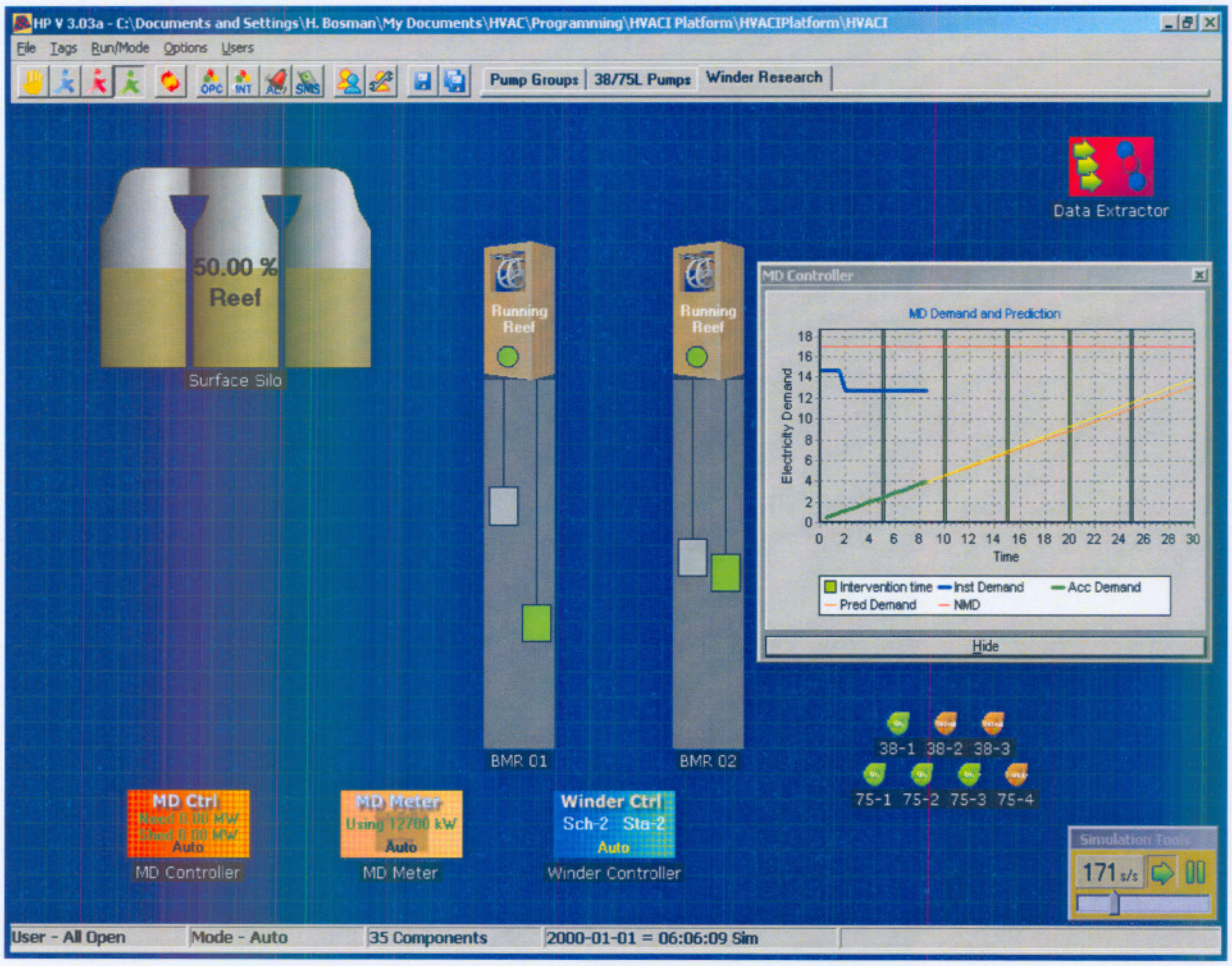


Figure 47: REMS Winder software implemented at Kopanang

The maximum level inputs for the surface silo are shown in Figure 48. These values were calculated by the winder optimised model, and configured into REMS Winder. Note how the values vary according to the different hours and tariffs in a day.

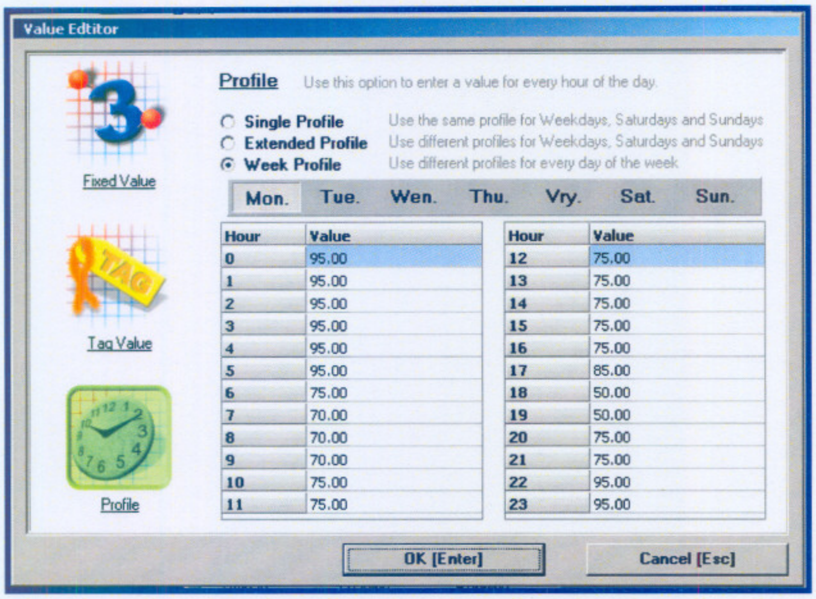


Figure 48: Maximum level inputs

Figure 49: Minimum level inputs

The minimum level inputs for the surface silo are shown in Figure 49. One can see from the values that the silo level will not decrease below 40% between its lowest levels at 18h00 and 19h00.

After the implementation of the REMS Winder system on Kopanang mine the results were compared to those of the simulation results. Because the external production requirements changed, the system did not completely respond to the simulation.

The objective of this study was however to implement a cost-effective energy control system on a mining rock winder system. To achieve this goal there were objectives that had to be adhered to. The biggest and surely the most important objective was to shift the electrical load during the evening and morning peak times. If this criteria was met the operational costs would automatically decrease.

The project was completed before June 2006. Since June the winder system reacted well according to the pricing structure and very good evening load shift results were obtained. The figure below shows the results accumulated since the implementation.

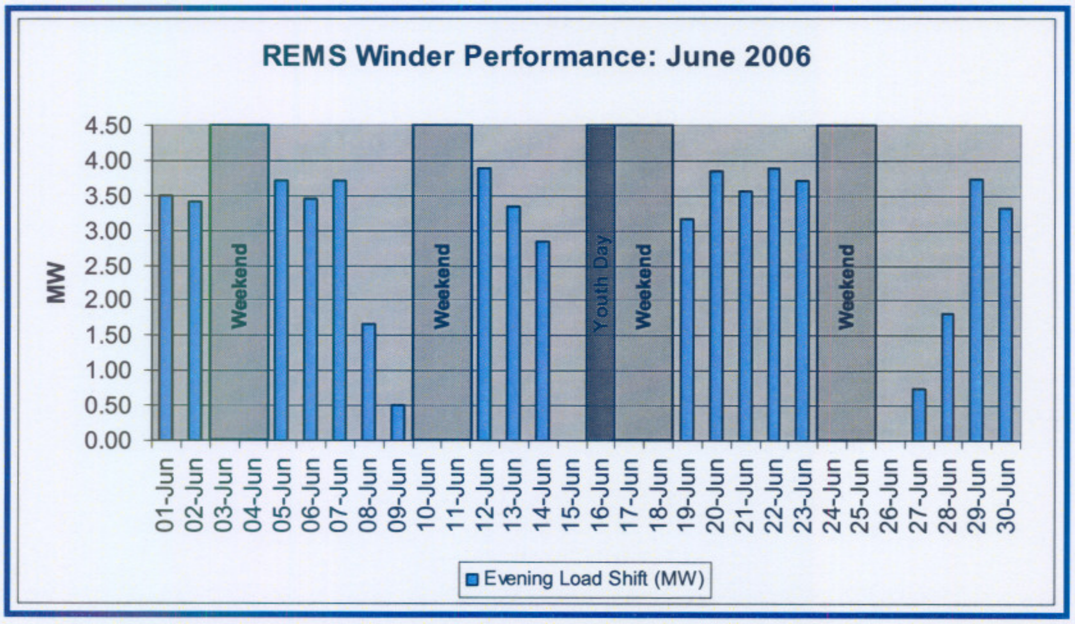


Figure 50: REMS Winder evening peak load shift performance on Kopanang mine

One can see from Figure 50 that the average evening load shifted during weekdays was 3.56MW, these exclude condonable days. The condonable days are the days in which the REMS Winder system was disabled. During this month the mine saved R38,276.03.

5.5 Evaluate the effect on the production

As discussed in Chapter 2, one of the most important aspects in developing a system that operates the rock winder system cost effectively is not to interfere with the production of the mine. A good guideline in evaluating if the production is affected is to monitor the surface silo level of the mine. If any of the rock winders didn't meet the daily target, the surface silo will indicate the shortage in reef hoisted.

The figure below illustrates the average measured weekday level percentage of the surface silo during the first month of the REMS Winder implementation.

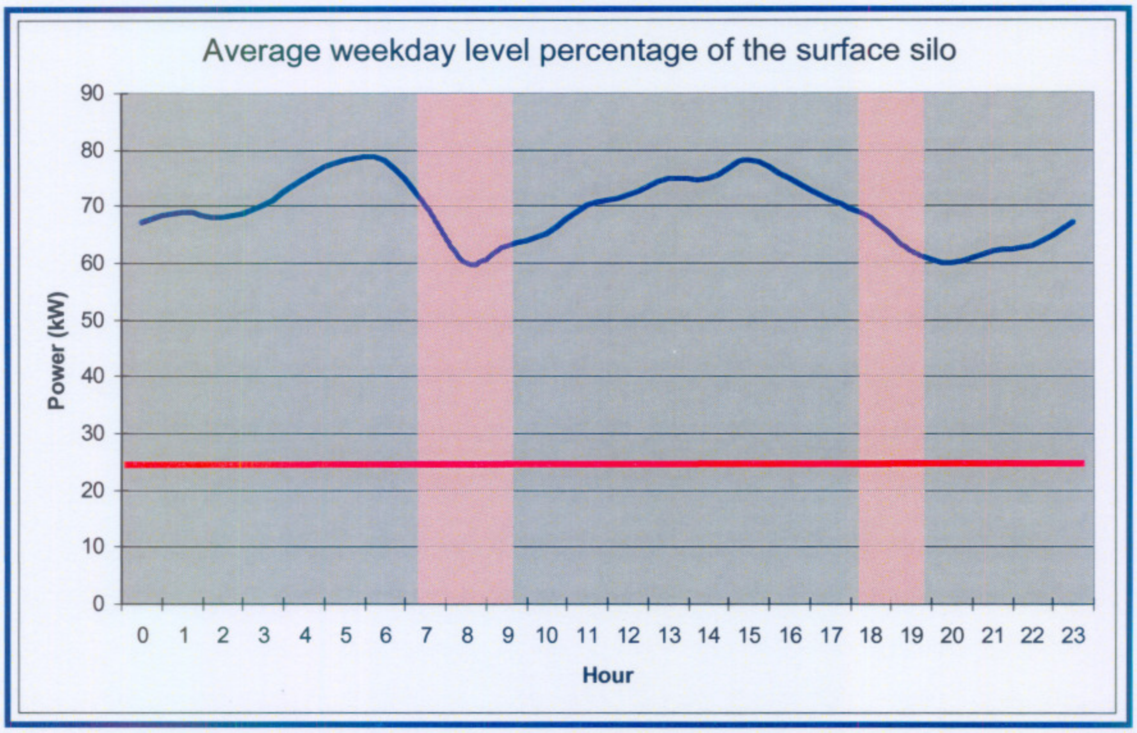


Figure 51: Average surface silo of Kopanang mine

According to the Vaal River No 9 Gold plant, the gold purification process needs to decrease production if the surface silo drops below the 25% mark. From the above figure it is clear that the average silo level didn't drop below the 60% mark. If the winder for some reason is unable to hoist any rock during any time of the day, the silo level is high enough to supply the gold plant for at least 3 more hours before it has to reduce its production. This is a good indication that the REMS Winder system controls the two rock winders according to specifications.

5.6 Conclusion

The full potential of the onsite REMS controller can be realised when the true optimised profile is compared to the simulated optimised profile. The figure below shows the difference between the electricity profile before the REMS Winder implementation and the actual optimised profile after the implementation. Note that these results were obtained from real-time data loggers installed on the electricity sub station feeding the various rock winders on Kopanang mine. The unrealised potential savings of R33,000 is due to a higher winder usage during standard and peak times, instead of during off-peak times. This is illustrated in the following graph.

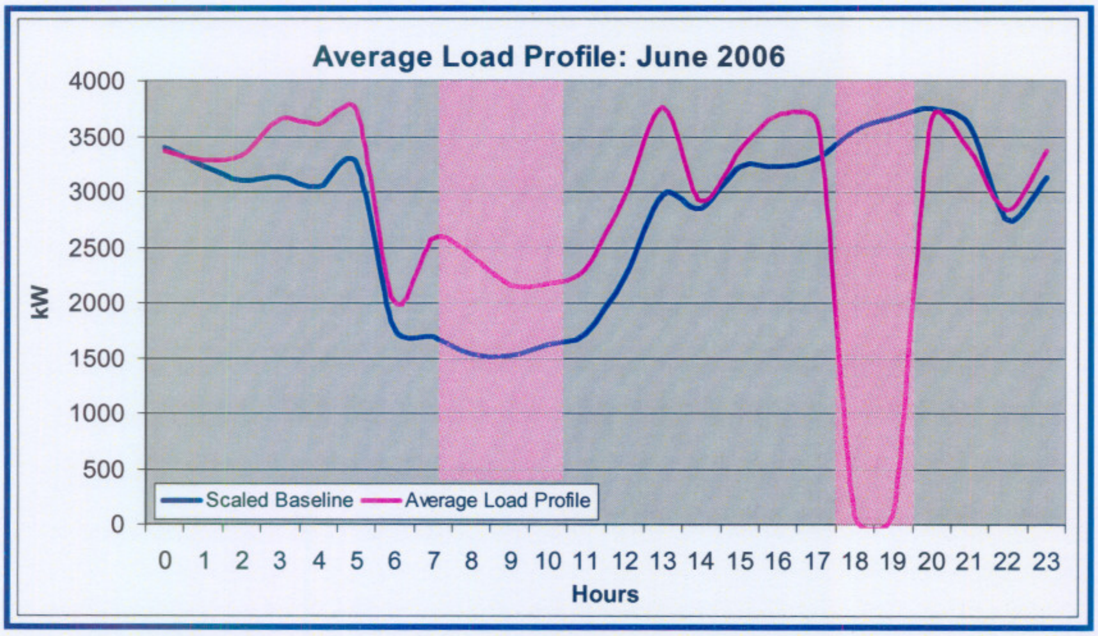


Figure 52: Average power profile of June 2006 vs. baseline before REMS Winder installation

The results obtained from the REMS Winder implementation were very satisfactory as seen from the figure above. The 3.5MW load shifted from the evening peak period has a great influence on the local electrical grid.

Putting the load shift magnitude into perspective, 3.5MW contributes to 0.18% of the City of Cape Town's peak electricity demand [56]. As discussed in chapter one, the evening load shift can also represent a virtual power station. The most direct relation to a virtual power station is the Lesotho Highlands power scheme, which only operates during high peak demand periods. REMS Winder on Kopanang generates almost 5% of the power scheme's maximum capacity, and this without any costs [56].

Table 12: Case study summary

	Evening Load shift (MW)	Savings (R)
Simulated Maximum Savings	4.1	R600, 000
Savings Achieved	3.5	R180,000 projected

It can however be seen from Figure 52 that REMS Winder had to increase the operation during the morning peak electricity period to compensate for reducing the load during the evening peak period. The mine didn't benefit from this effect. However, due to the fact that Eskom has bigger demand problems during the evening peak period, REMS was programmed in this manner. This influenced the saving on the rock winder operation. However, a saving of R180, 000 per year can still be accumulated. This saving was generated without Kopanang mine paying for anything. Eskom only paid for the winder automation system as well as the power loggers on the mine incomer. This cost can not be stated due to various influencing factors like complexity of the system and its interconnection capabilities with the type of mine SCADA system influencing it.

The savings from Table 12 were calculated by normalising the baseline, simulated optimised profile and actual optimised profile. By doing so the profiles are said to be energy neutral. This term means that the profiles use the same amount of energy throughout the day. After the profiles are normalised, the daily tariffs are used to determine the annual costs for the different profiles.

The problem that was encountered was that the control-room operators override the REMS Winder system during the evening peak periods. If the operator sees the winder standing, he thinks that something is wrong with the automated rock Winder Controller and then he operates the winder manually. It will take time for the operators to trust the REMS system and before they will realise what positive impact it has on the electrical demand and cost savings for the mine.

To realise the full potential of REMS Winder and to broaden the effect it could have on the electrical power grid, pilot studies were done on other large rock winder systems in the Western-area region. The pilot study included rock winder systems of:

- Mponeng mine Appendix C
- Tau Tona mine Appendix D
- South Deep mine Appendix E

The procedures discussed in the previous chapters were used to simulate and optimise the mentioned rock winder operations. The findings are shown in Table 13.

Table 13: Simulated possible load shift

Rock Winder system	Savings	Posible evening load shift
Mponeng	R 300,000	2.1MW
Tau Tona	R 400,000	3.0MW
South Deep (South & Twin shafts)	R 600,000	4.4MW
Maximum Impact	**R 1,300,000**	**9.5MW**

From the table it is clear that the REMS Winder system could have a remarkable impact not only for the electricity peak demand, but could save millions in mining operating costs. This pilot study shows that there is a definite future for the REMS Winder system on South-African gold mines.

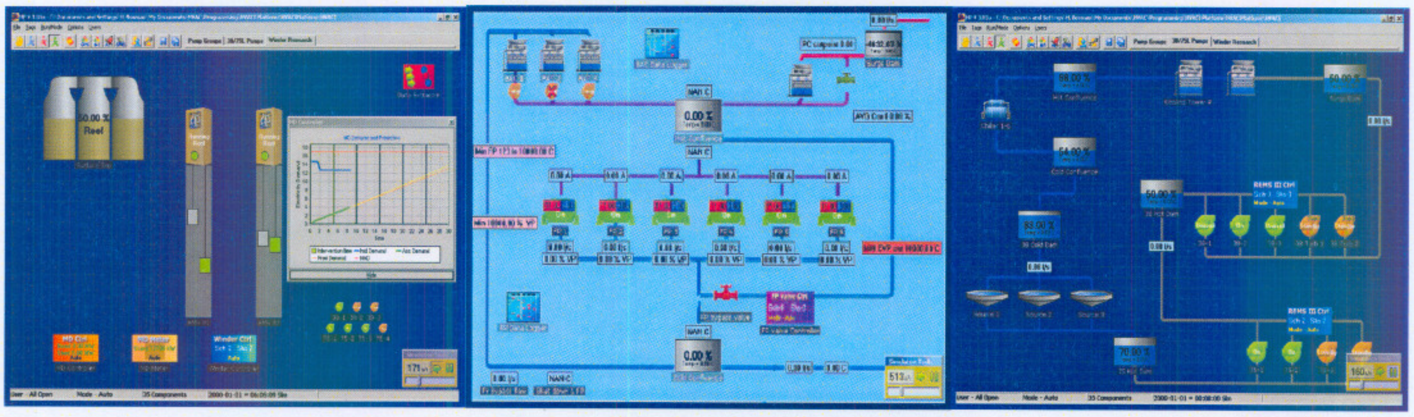
References

[54] "Anglogold Ashanti country report Vaal river", AngloGold Ashanti, 11 Diagonal Street, Johannesburg, South Africa, 2005.

[55] Consultation with R. Mack, Engineering Manager, Kopanang mine, Orkney, Tel (018) 478 992, 2006.

[56] "State of Energy Report for Cape Town 2003", State Energy Report, Cape Town Metropolitan, The Green Building, 9B Bell Crescent Close, Westlake Business Park, Tokai, 7945, Cape Town.

CHAPTER 6: FINAL CONCLUSIONS AND RECOMMENDATIONS



REMS systems installed on Kopanang mine

REMS systems from left – REMS Winder with REMS Maximum Demand, REMS Fridge plant and REMS Pumps. These systems shift an estimated average of 9MW out of the evening peak demand period that realises an annual electricity reduction of more than R2million.

This chapter discusses the limitations that were observed during the study. Possible solutions and recommendations to these limitations are highlighted to ensure that even better automatic control is achieved on this subject in future.

6.1 Final conclusion

The primary objective of this study was to develop a controller that could reduce electricity cost on South African gold mines.

Firstly, the literature survey concluded that a rise in the worldwide energy consumption is expected. In South Africa the electrical energy demand is reaching high magnitudes, and may exceed supply as early as 2007. The mining industry and especially the gold industry consume a large portion of the South African energy, with rock winders being one of the largest energy consumers. However, definite potential exists for load shift on this subject. Studies on this subject are usually done by Energy Service Companies (ESCOs), and the optimal way to establish savings is to implement a Real-Time Energy Management System that controls the rock winder system automatically.

To prioritise and determine if a DSM potential and possible savings can be realised on a rock winder system, a three-step investigation guideline was discussed. After following this guideline the ESCO will have an indication what the maximum DSM potential will be on a specific rock winder system.

After the rock winder's maximum potential is determined, its operation is simulated with REMS Winder. This software controls rock winder systems by adhering to the optimised cost operation model and it has also has an added function that can predict savings in advance.

In the last part of this dissertation a case study was done on the rock winder systems of Kopanang mine. REMS Winder was installed on this mine with great success. This study resulted in the following conclusions:

- The evening load shift on a winder system can be as large as 3.5MW
- An annual electricity saving of up to R180,000 can be achieved with the implementation of REMS Winder.

It can therefore be concluded that this study achieved the main objective as stated in Chapter 1 by optimising the energy cost. Furthermore, pilot studies showed that with minor infrastructure three other rock winder systems could realise another 9.5MW evening load shift, which could results in R1, 300,000 in savings.

6.2 Recommendations

Recommendations have resulted from this study that could have made this project an even bigger success. Not only will these recommendations benefit the electrical demand issue in South Africa, but the mining industry will also reduce electricity and operational costs.

The same study conducted on the winder system of the mine was also conducted on the fridge plant and pumping system of Kopanang mine. There is however plans in place to launch a study on the compressor and gold extraction systems. If the demand of these systems could be reduced, as in the winder system, the total electrical costs and peak demand will decrease by an even bigger margin.

After the implementation of a number of REMS systems on a mine, it was noticed that the mine's electrical energy consumption increased to a higher than usual peak level, after the high demand periods. This increased consumption is the result of multiple appliances switching on, and the mine could be penalised by their energy supplier if the demand is too high. An ideal solution will be to implement a system that could lower and prevent the mine's electrical demand from rising above a certain level. This might be done by monitoring the mine incomers, and delaying the start of certain appliances.

APPENDIX A: Kopanang mine – hoisting report

KOPANANG MINE - HOISTING REPORT

DATE: 10-Nov-05

SHIFT No. 12	ORE PASS LENGTH	REEF NO.1		WASTE NO.2		WASTE NO.3	
TIPS		LENGTH	TONNES	LENGTH	TONNES	LENGTH	TONNES
44 - 47	98.5		0	0	0		
47 - 50	91.6		0	0	0		
50 - 53	102.5		0	0	0		
53 - 56	80		0	30	375		0
56 - 59	85.4		0	85	850		0
59 - 62	85		0	85	2890		0
62 - 64	85.5		0	85	1615		0
64 - 68	91.9		0	0	0		0
68 - 70	97.4		0	0	0	70	1260
70 - 73	83.3		0	0	0	40	3200
73 - 74	43.5		0	0	0	20	240
TOTAL		0	0	0	0	130	4700
U/G SILO			0	5	550	0	0
GRAND TOTAL		0	0	0	550	130	4700
		IN SYSTEM YESTERDAY		0			

SKIPS HOISTED	REEF		WASTE		TOTAL TONS			
SHIFT	BMR NO.1	BMR NO.2	BMR NO.1	BMR NO.2			PROG CALL	96000
							PROG ACTUAL	80165
							VAR.	-15835
MORNING SHIFT	10	77	89			IN SYSTEM	0	TOTAL
AFTERNOON SHIFT	30	111	69			U/G SILO	0	
NIGHT SHIFT	64	46				SURFACE-SILO	2200	
TOTAL SKIPS	104	234	158	0		GENERATED	6175	
TOTAL TONS	2080	4095	3160	0		DAILY-CALL	8000	
GRAND TOTAL TONS	6175		3160		9335	VARIANCE	-15835	
WEIGHTOMETER	PREVIOUS	TODAY	ACTUAL	%		DAILY	-1025	
No 1 Reef		6176	6176	0.02		WASTE-SILO	3600	
No 2 Waste		3521	3521	11.42		WASTE-ACTUAL	29349	
	TOTAL TONS HOISTED - REEF AND WASTE PROGRESSIVE M.T.D.						109514	

WATER COMPARISON					
SHIFT	WASTE TONS	REEF TONS	WATER	Kl/TON	PLAN
1	904	6663	20678	3.1034	1.8
2	189	7344	19360	2.6362	1.8
3	3770	7052	27247	3.8637	1.8
4	1424	6650	23243	3.4952	1.8
5	2402	8330	26111	3.1346	1.8
6	3743	5865	24593	4.1932	1.8
7	867	7673	23694	3.0880	1.8
8	1114	6988		0.0000	1.8
9	5730	4360	35077	8.0452	1.8
10	2315	6694	24621	3.6781	1.8
11	3380	6370	23586	3.7027	1.8
12	3621	6176	22761	3.6838	1.8
13					1.8
14					1.8
15					1.8
16					1.8
17					1.8
18					1.8
19					1.8
20					1.8
21					1.8
22					1.8
23					1.8
24					1.8
25					1.8
26					1.8
27					
Total	29349	80165			

WINDER DELAYS					
DELAYS	BMR NO1	BMR NO2	SIEM S	SIEM N	M/ANNE
MAX DEMAND					
SURFACE SILO FULL					
TIP FULL					
BOX HANG-UP	64				
BOX EMPTY	208	296			
WINDER O.O.O					
LOADING O.O.O					
SCHEDULED	75	75			
SLOW LOADING	5	57			
TAKING SAMPLES					
SHIFT CHANGE OVER					
CHANGE / OVER	40				
UNSCHEDULED		76			
TOTAL	392	504	0	0	0
				TOT MIN	896

MATERIAL CAR REPORT		
MATERIAL CARS UP & DOWN		
	PLAN	ACT
SOUTH		187
NORTH		211
M/ANNE		
TOTAL	0	398
MATERIAL CARS NOT		
LEVEL	UP SOUTH	DOWN NORTH
TOTAL	0	0
CARS AVAILABLE TODAY		73
CARS OUTSTANDING		224
TOTAL		297

MUD PRESS TONS			% Of Total Tons Hoisted
	CYCLE	TONS	
M.T.D	251	1130	1.41
ACT DAILY	26	117	1.89

%

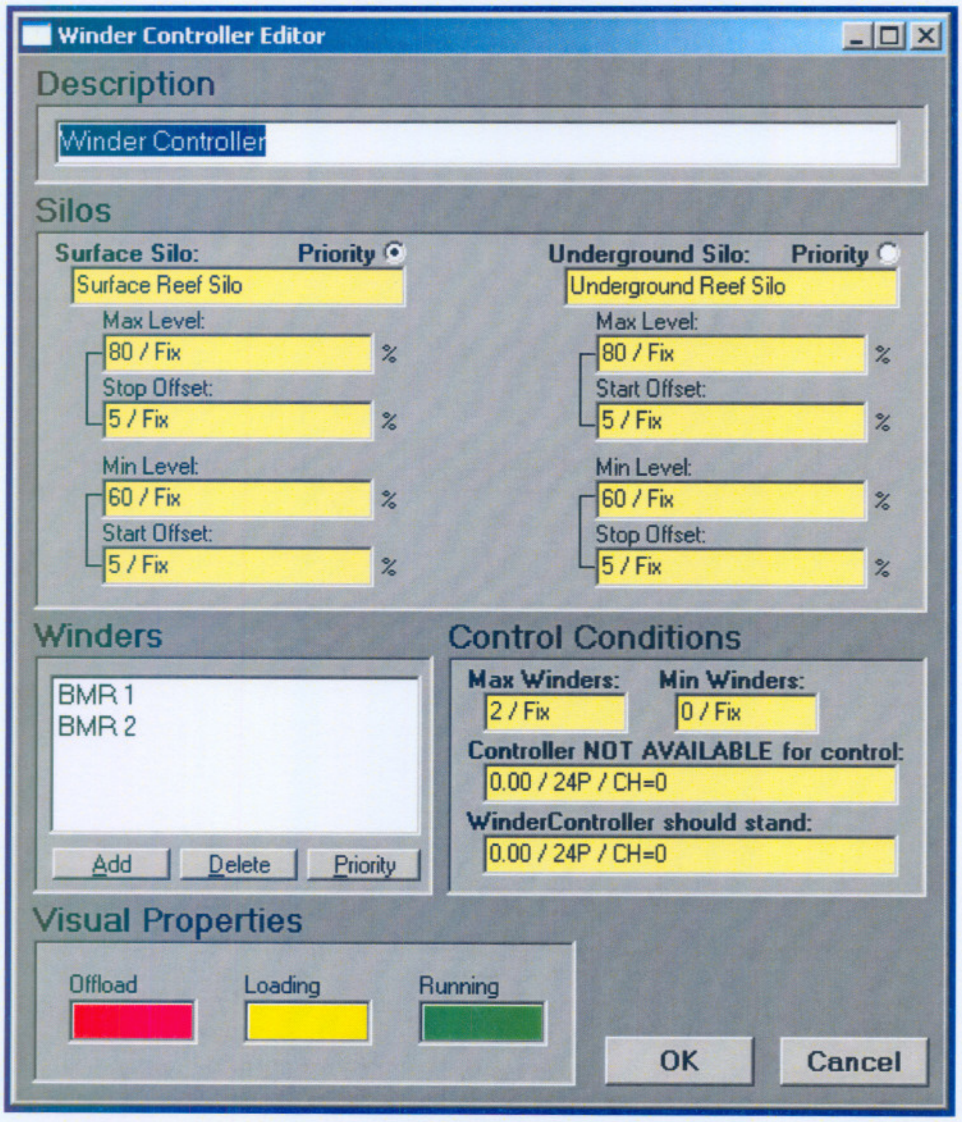
Surface Silo	2200
Mill Bins 4	340
Mill Bins 5	350
Mill Bins 6	320
Total Avail	3210
TREATED 0 →	6890
Waste taken in	820
REEF STOCK PILE AT SURFACE PLANT TIP	
PROGRESSIVE TONS	

70 LEVEL BIG MAMA LOCO TOTAL TONS TRAMMED	REEF No. 1		WASTE No. 2	
SHIFT	TOTAL SPANS	TOTAL TONS	TOTAL SPANS	TOTAL TONS
MORNING SHIFT	7	1386	0	0
AFTERNOON SHIFT	11	2178	0	0
NIGHT SHIFT	3	594	0	0
TOTAL	21	4158	0	0

Flushing Tons	Change over	Day Tons	Prog Tons
No.1	0	0	240
No.2	0	0	962
		0	1202

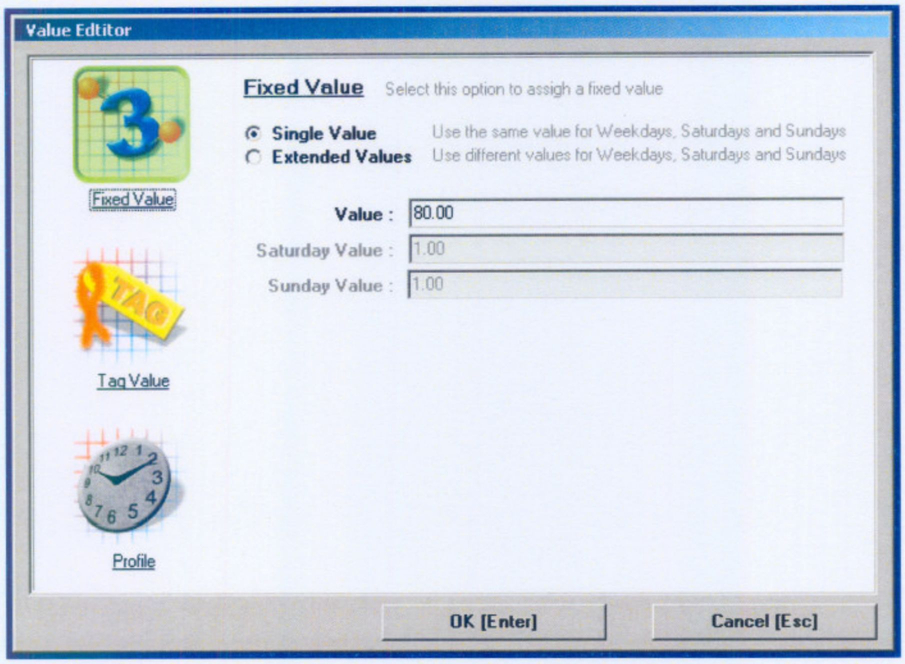
APPENDIX B: REMS WINDER INTERFACE

The Winder Controller is used to control the rock winders in a deep level mine in order to shift load out of daily times of peak electricity usage.



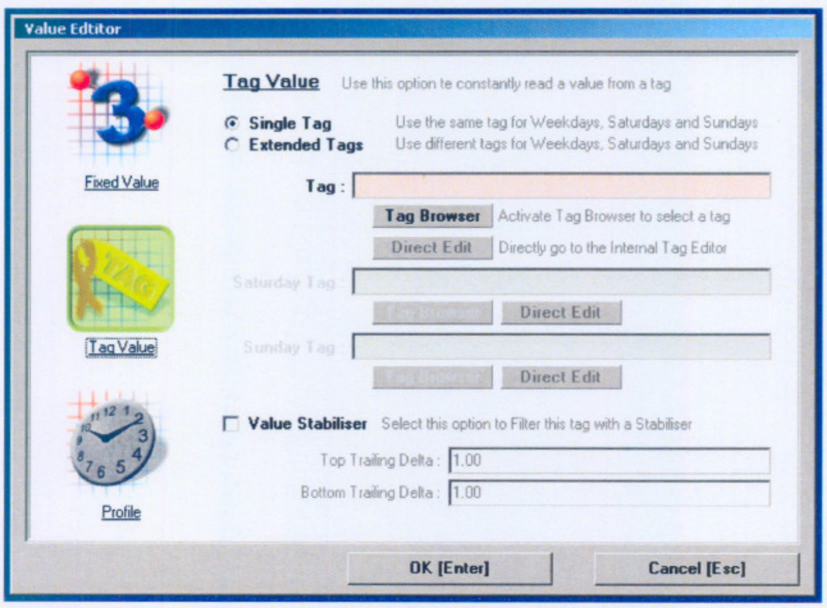
The Winder Controller Editor's settings and functionality is explained in the table below.

Setting	Function
Description	Name used for logging purposes and in the Platform viewer
Silo: Surface Silo	Indicates which silo's levels should be monitored to control the winders
Silo: Surface Silo: Priority	If this radio button is checked, the surface silo's levels would have control priority over the underground silo's levels
Silo: Surface Silo: Max Level	Maximum level of surface silo (see discussion of Controllers)
Silo: Surface Silo: Stop Offset	Stop offset of surface silo (see discussion of Controllers)
Silo: Surface Silo: Min Level	Minimum level of surface silo (see discussion of Controllers)
Silo: Surface Silo: Start Offset	Start offset of surface silo (see discussion of Controllers)
Silo: Underground Silo	Indicates which silo's levels should be monitored to control the winders
Silo: Underground Silo: Priority	If this radio button is checked, the underground silo's levels would have control priority over the surface silo's levels
Silo: Underground Silo: Max Level	Maximum level of underground silo (see discussion of Controllers)
Silo: Underground Silo: Stop Offset	Stop offset of underground silo (see discussion of Controllers)
Silo: Underground Silo: Min Level	Minimum level of underground silo (see discussion of Controllers)
Silo: Underground Silo: Start Offset	Start offset of underground silo (see discussion of Controllers)
Winders	List of the winders to be controlled according to the silo levels
Control Conditions: Max Winders	Maximum number of winders allowed to run under certain conditions (see discussion of Controllers)
Control Conditions: Min Winders	Minimum number of winders allowed to run under certain conditions (see discussion of Controllers)
Control Conditions: Controller not available for control	Specify when the control may not control the winders (see discussion of Controllers)
Control Conditions: Controller should stand	Specify when the winders should preferably stand (see discussion of Controllers)
Visual Properties: Offload	Display colour of winders when it is in offload condition
Visual Properties: Loading	Display colour of winders when it is in loading condition
Visual Properties: Running	Display colour of winders when it is in running condition



The tag value can be a single tag, or an extended tag. The extended tag gives the possibility of having different values for weekdays, Saturdays and Sundays. A tag's value can either be received from the mine's SCADA or from an internal Platform tag as set by the user.

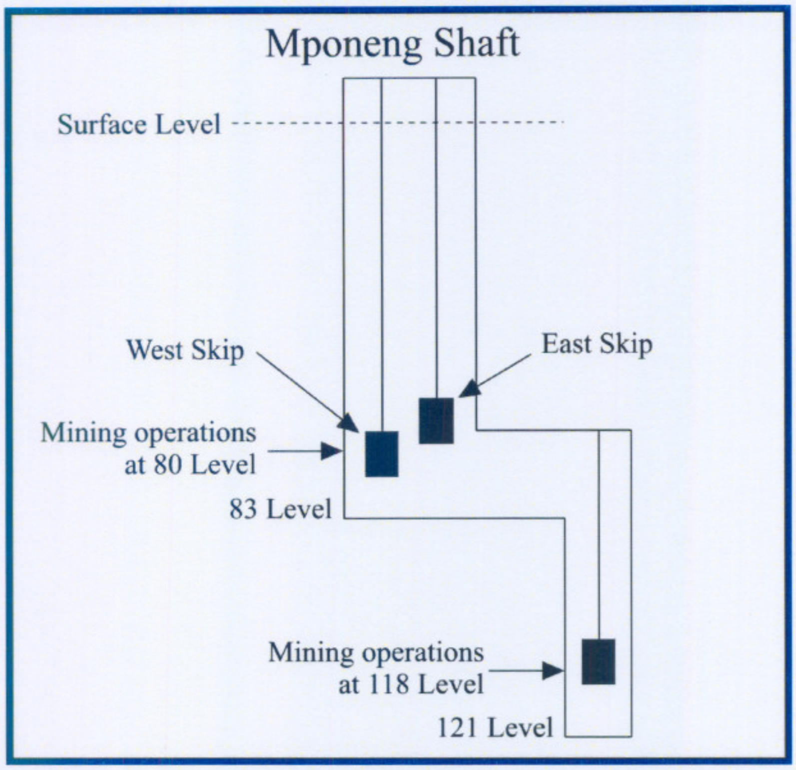
A value stabiliser filter can be applied on the tag value as well. This stabilises the value extracted from the tag to prevent irregularities or spikes from affecting the controller.



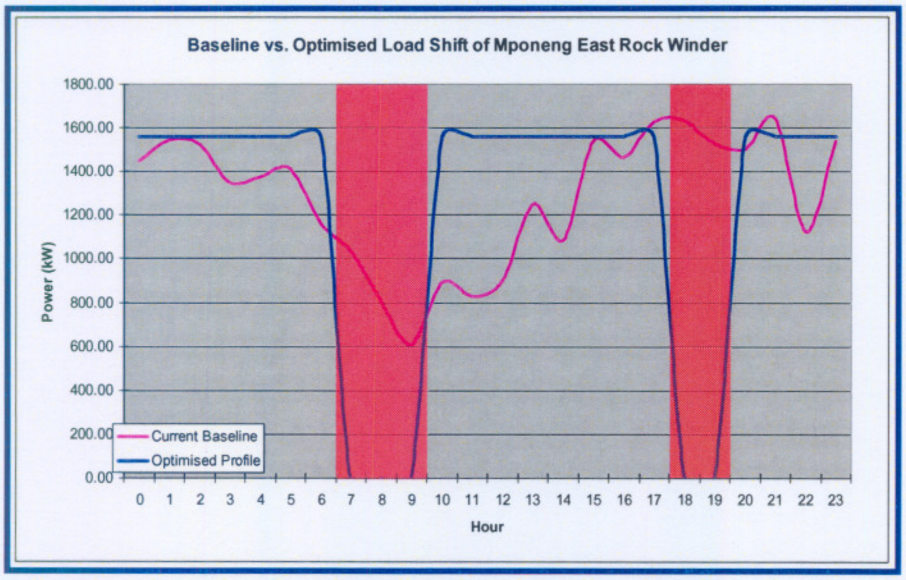
The 24 hour profile enables the user to specify a different value for each hour of the day. This option can be expanded to an extended value for weekdays, Saturdays and Sundays. A weekly profile is available as well, giving the user the option to specify a value for every hour in a week.

APPENDIX C: PILOT STUDY - MPONENG MINE

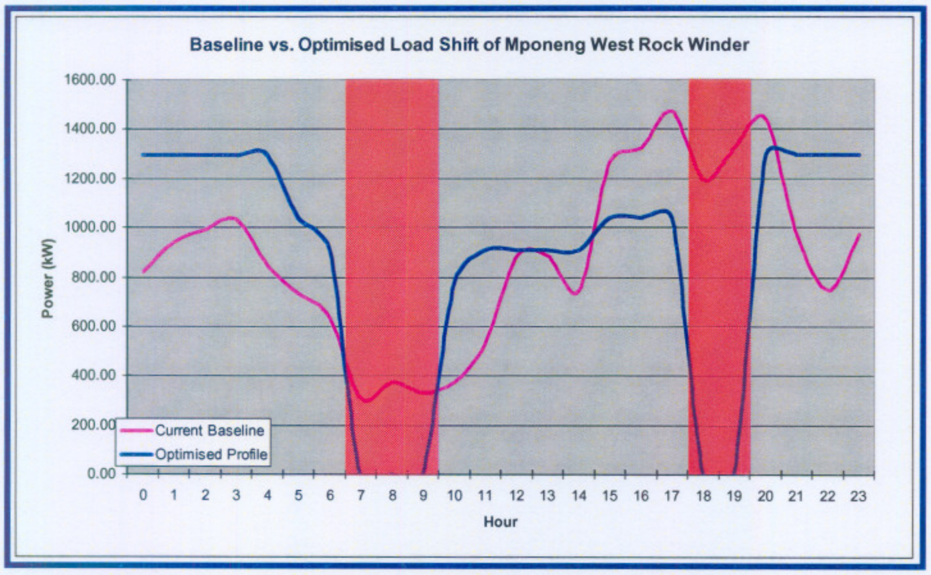
Mponeng shaft layout



Optimised vs. Baseline profile Mponeng BMR East

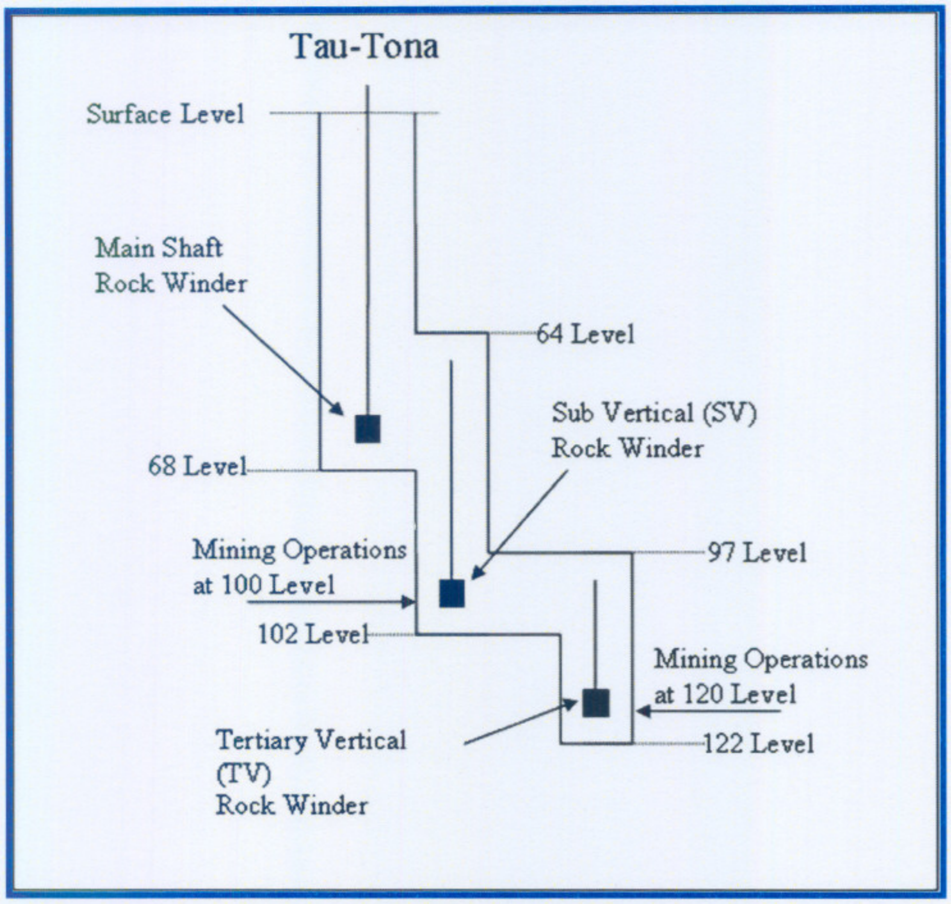


Optimised vs. Baseline profile BMR West

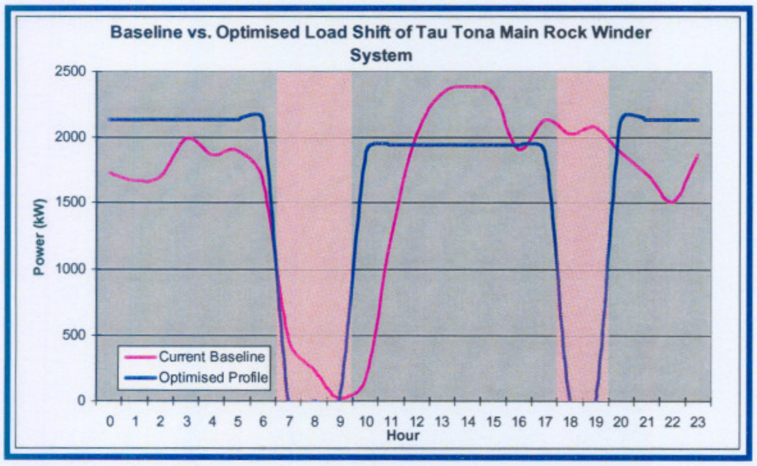


APPENDIX D: PILOT STUDY - TAU TONA MINE

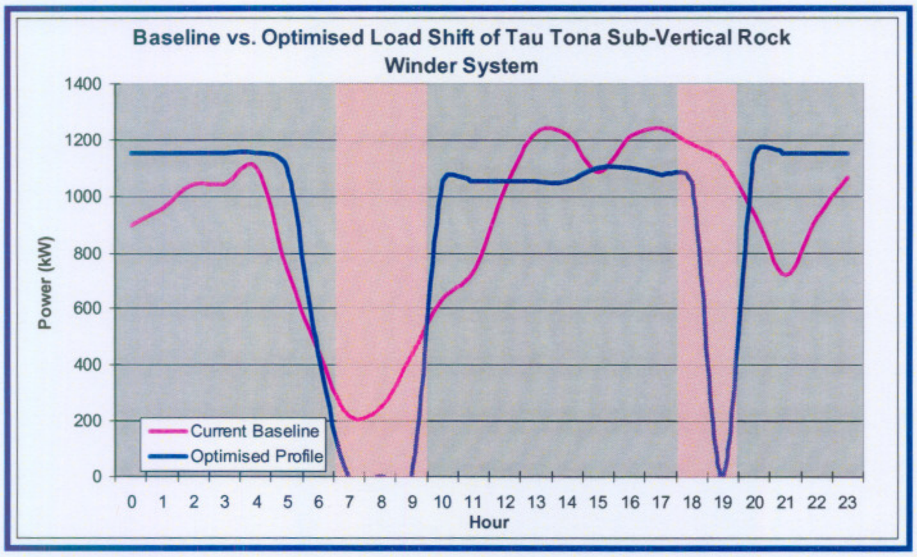
Tau Tona shaft layout



Optimised vs. Baseline profile Tau Tona Main rock winder

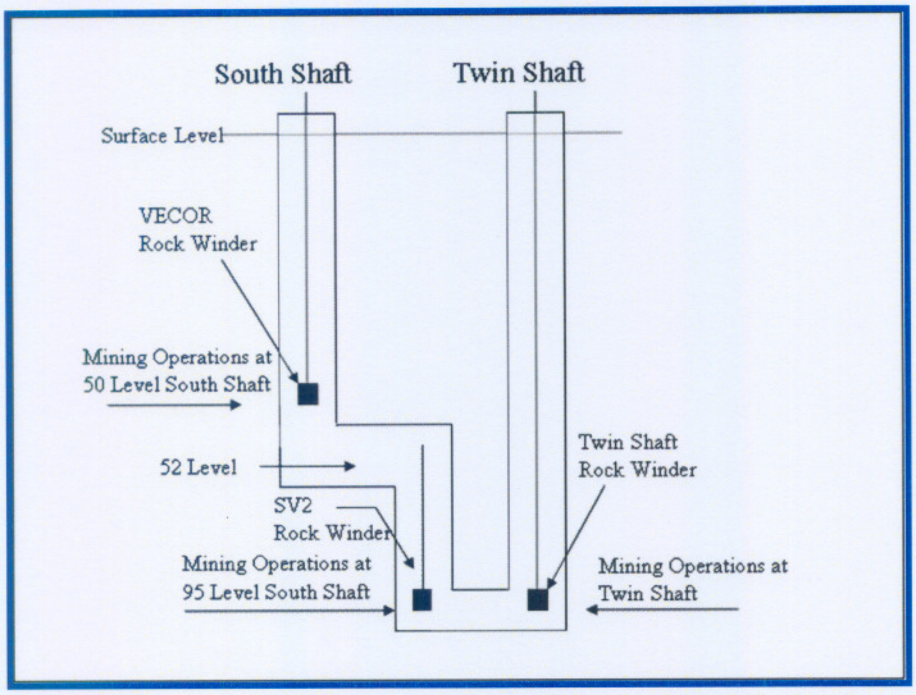


Optimised vs. Baseline profile Tau Tona Sub-vertical (SV) rock winder

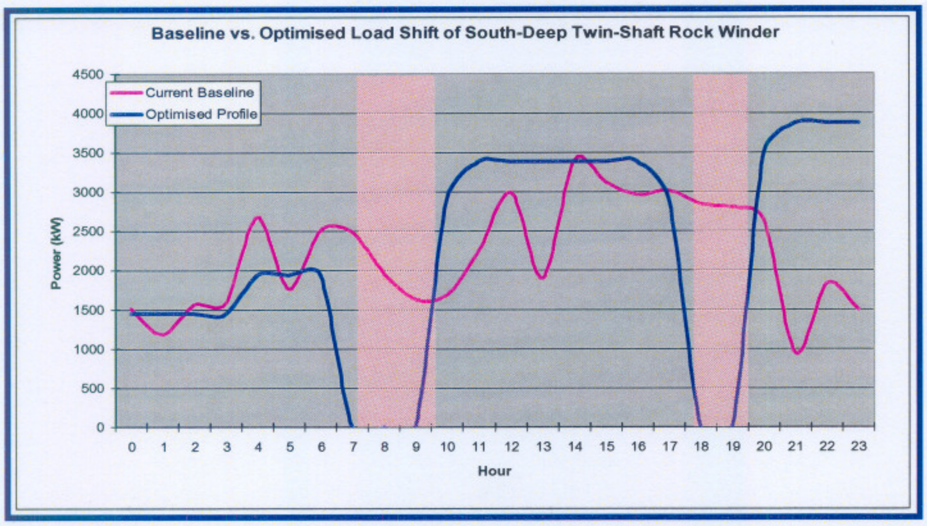


APPENDIX E: PILOT STUDY – SOUTH DEEP MINE

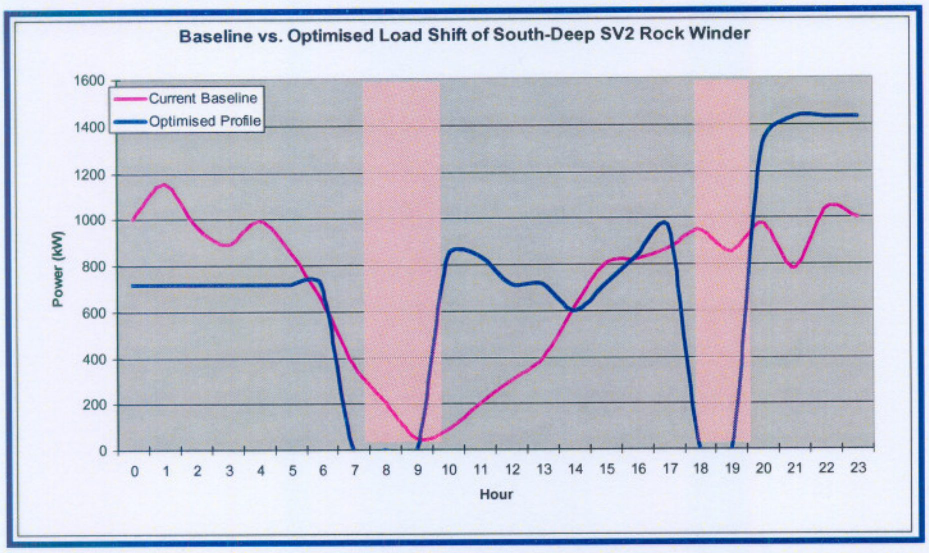
South Deep shaft layout



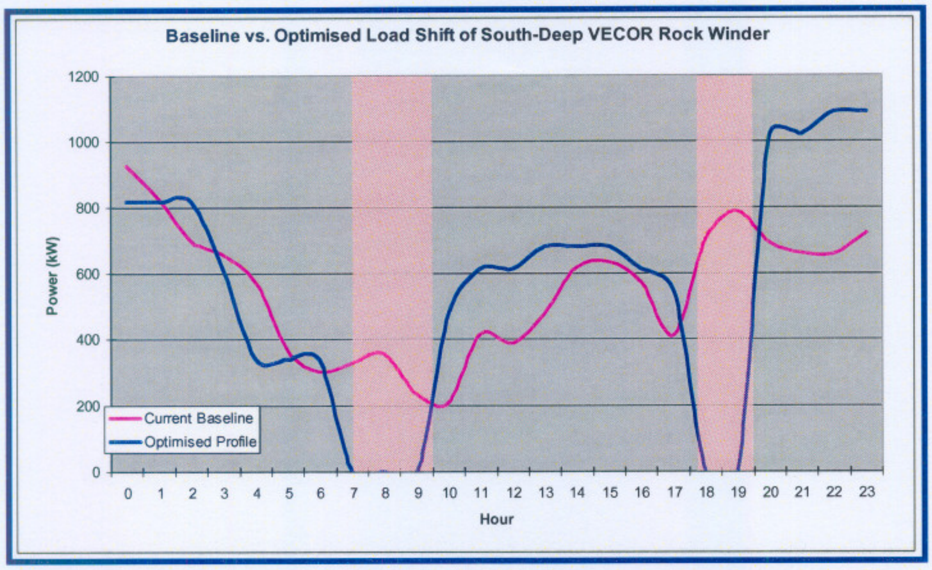
Optimised vs. Baseline profile of South Deep Twin-shaft



Optimised vs. Baseline profile South Deep South-shaft (SV2)



Optimised vs. Baseline profile South Shaft (VECOR)



CHAPTER 1: INTRODUCTION AND BACKGROUND

Lethabo powerstation

Lethabo power station, located near Vereeniging, burns coal with a calorific value of 15 - 16 MJ/kg and an ash content of 42%. It is the only power station in the world running on such low grade coal.

This chapter presents background on the current electricity situation in South Africa. It also introduces the time-of-use tariff structure implemented by Eskom to make the industrial and mining sectors more energy-concerned. The last section concludes with a brief summary of the remaining chapters.