RESEARCH INTO REAL-TIME ENERGY MANAGEMENT ON OLD GOLD MINES

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ABSTRACT

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

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

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

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

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

This dissertation presents a study of certain aspects of real-time energy management on old gold mines, by focusing on electrical load shifting on underground water pumping systems. Old gold mines use old, proven and energy-intensive methods that were not

designed to conserve energy. This study also researches the challenges associated with the implementation of energy management strategies on old gold mines.

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

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

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

SAMEVATTING

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

Outeur: N.L. de Lange

Promotor: Dr. M.F. Geyser

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

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

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

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

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

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

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

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

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

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LIST OF ABBREVIATIONS

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

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

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

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

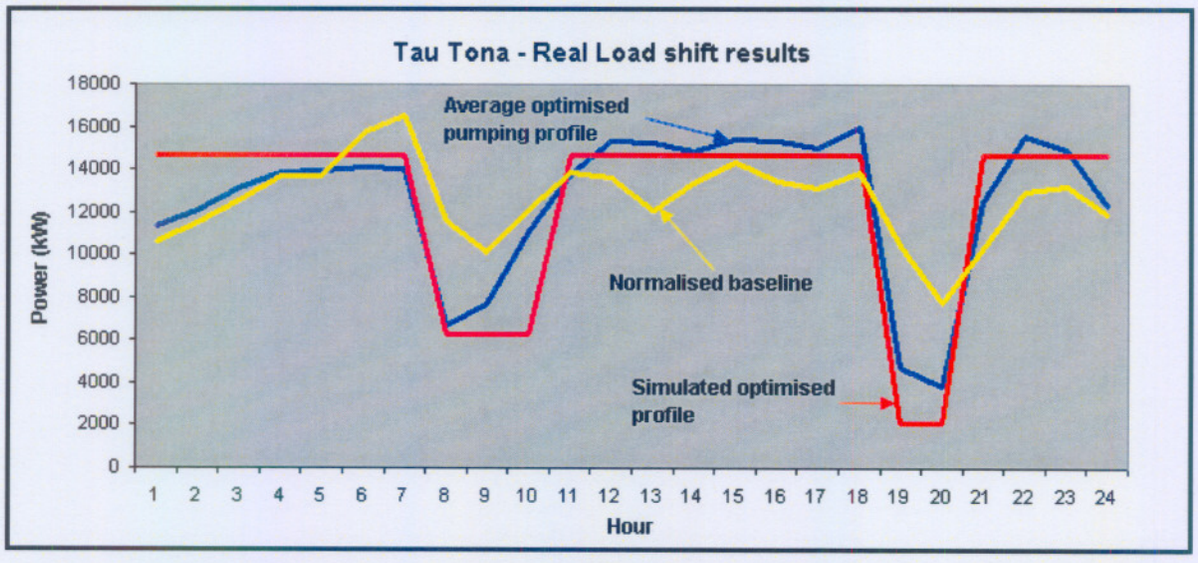


Figure 4-3: Load shift profile that was realised at Tau Tona mine

The average optimised profile in the figure is very similar to the simulated optimised profile. This shows that the potential that was calculated in *chapter 3* can be realised if more preparation work is done before peak periods, and less pumping is done during peak

periods. If the average optimised profile is compared with the normalised baseline profile, the true influence of the load-shifting strategy can be observed.

4.4.2 Electricity cost savings

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

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

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

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

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

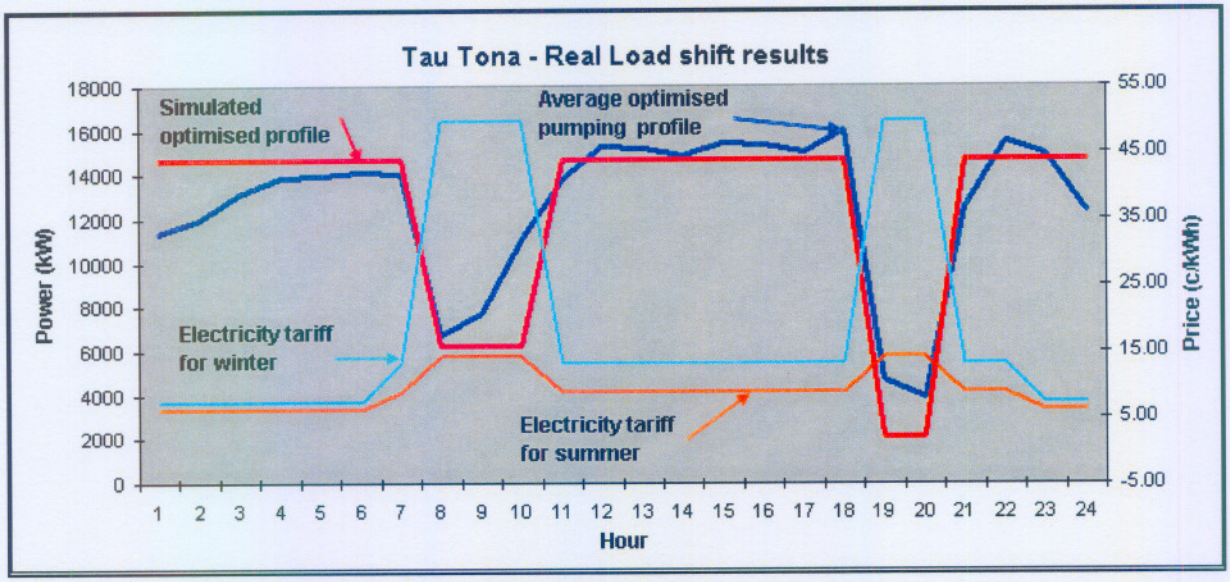


Figure 4-4: Real load shifting results for Tau Tona mine

4.4.3 Change in system control strategy

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

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

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

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

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

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

4.5.1 Real load-shifting results

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

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

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

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

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

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

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

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

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

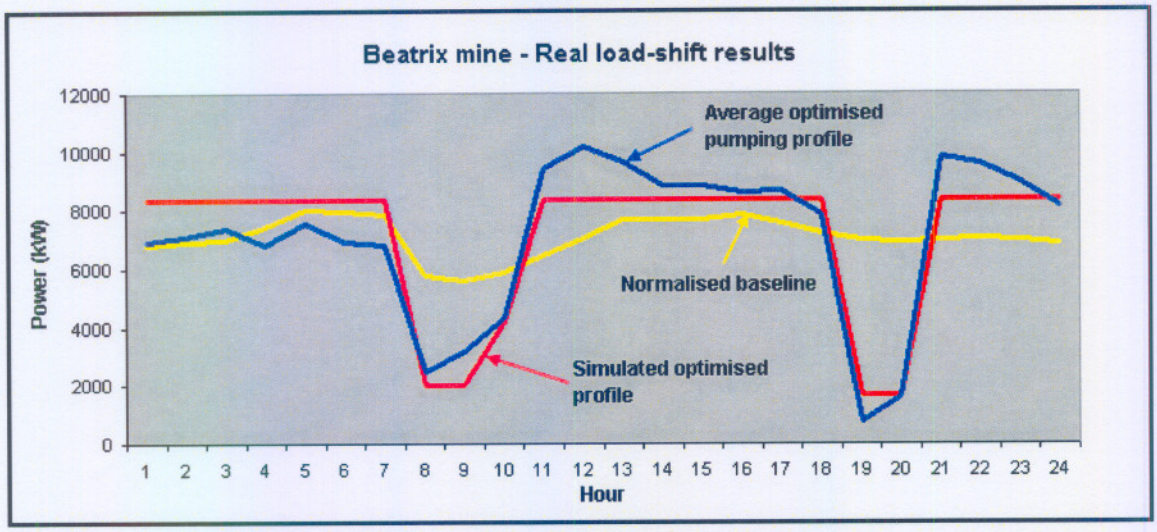


Figure 4-5: Real load shift results at Beatrix mine

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

4.5.2 Electricity cost savings

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

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

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

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

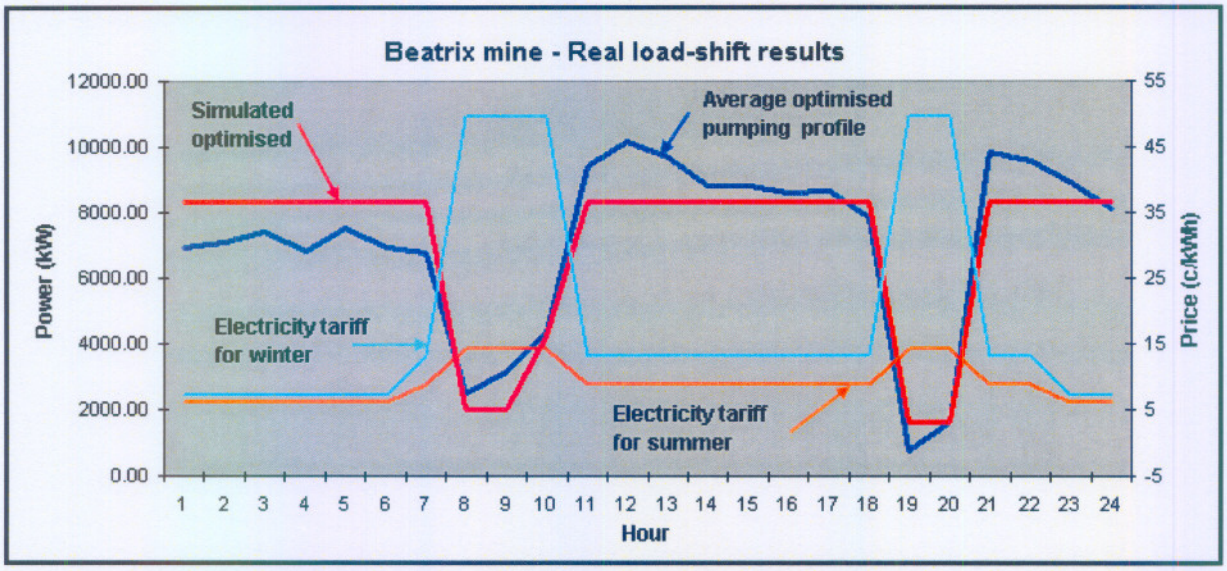


Figure 4-6: Cost saving results for Beatrix system

4.5.3 Change in system control strategy

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

a) Beatrix 1#

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

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

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

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

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

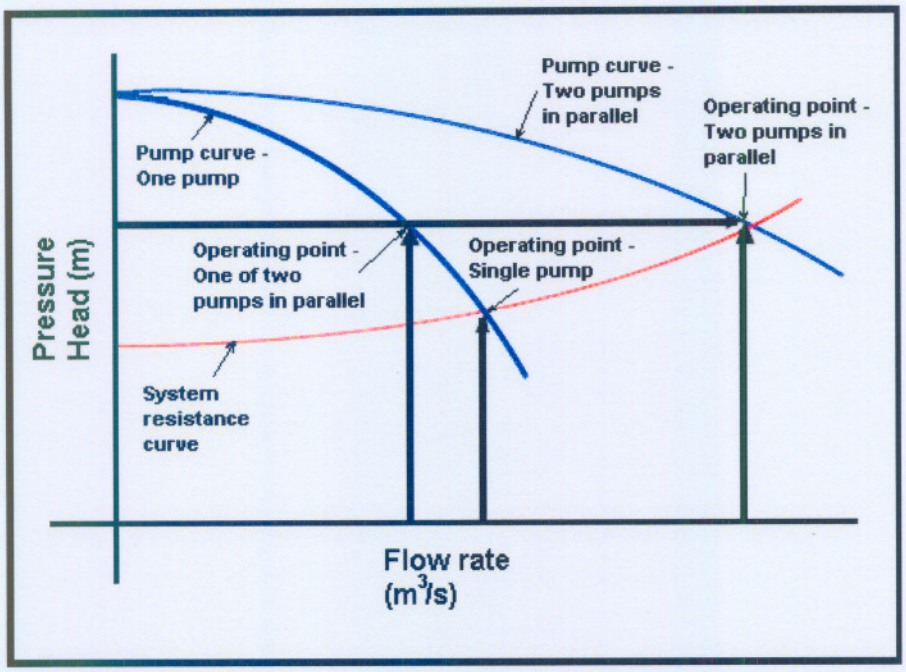


Figure 4-7: Parallel pumping operation

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

b) Beatrix 2#

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

c) Beatrix 3#

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

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

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

4.6 Conclusion

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

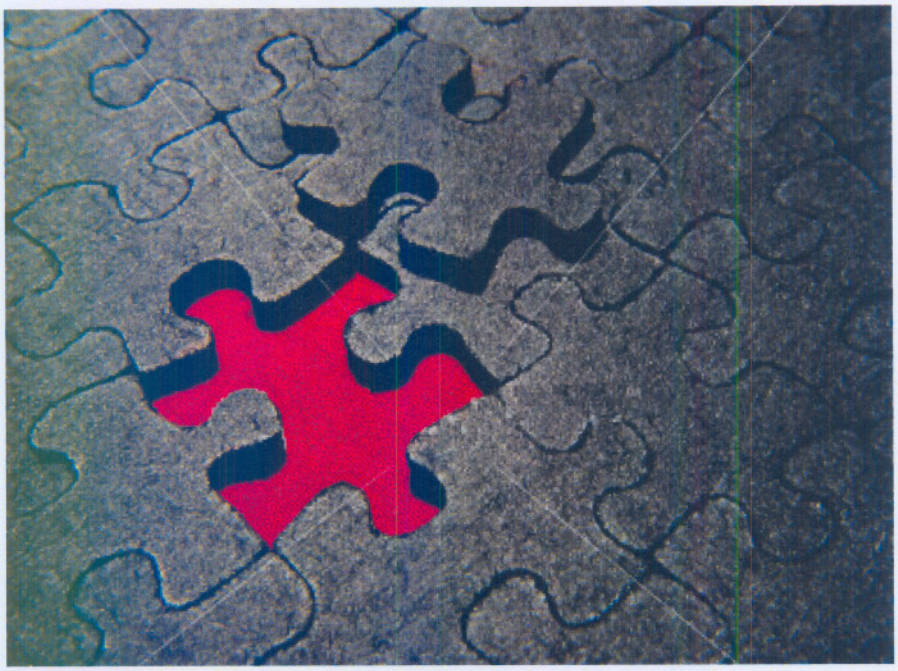
At Harmony 3#, the implemented load-shifting strategy has generated results that is higher than the potential, at a constant rate. The estimated savings have unfortunately not been realised due to many problems with old infrastructure, causing many condonable days. Most of these issues cost major amounts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

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

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

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

5. CLOSURE



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

5.1 Conclusion

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

a) The potential for energy management on old gold mines

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

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

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

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

The research into the potential for load shift at the three old gold mines in *chapter 3* has shown the large potential for energy savings at these mines. Through the Eskom DSM process, strategies were implemented on the mines, without influencing the mining or

production levels in any manner. The results as discussed in *chapter 4* confirmed this potential.

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

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

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

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

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

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

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

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

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

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

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

A conclusion regarding the feasibility of energy management strategies on old gold mines can be made at the hand of the conclusions made in the previous sections. There exists potential for energy management on old gold mines. There exists large potential for the implementation of sustainable energy management strategies on old gold mines if certain

requirements are fulfilled. All of the challenges associated with the implementation of such strategies on old gold mines during this study can be overcome by the above-mentioned requirements.

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

5.2 Recommendations for further studies

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

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

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

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

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

5. cement plants.

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

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