Maintenance procedures on DSM pumping projects to improve sustainability

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Dissertation submitted in fulfilment of the requirements for the degree *Magister* in Mechanical Engineering at the Potchefstroom Campus of the North-West University

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May 2015

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Abstract

Title:	Maintenance procedures on DSM pumping projects to improve sustainability
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Degree:	Magister in Mechanical Engineering

Effective dewatering and refrigeration are crucial in mining. Cascading dewatering systems, which are common in deep gold mines, are very energy intensive. These systems present several opportunities for energy cost savings initiatives. Due to rising costs in the gold-mining industry and the stagnant gold price, these initiatives need to be sustained. Maintenance is therefore required on several sections to ensure sustainability.

The literature study in this dissertation investigates the major sections affected by maintenance. Detailed investigations highlight problems that affect project performance negatively. These investigations, together with the literature study, were used to create a maintenance procedure. The focus of the maintenance procedure is on identifying problems and presenting recommended solutions.

The new maintenance procedure is divided into four sections: data loss, mechanical, control and instrumentation, and control parameters. Data loss can be rectified by retrieving data and addressing the cause of the issue. Mechanical problems are fixed by following equipment-specific procedures. Control and instrumentation is divided into software, communication and instrumentation subsections. Each of these categories present several steps to deliver feasible solutions. The control parameters section consists of subsections relating to constraints, preferences and feedback. The new maintenance procedure ensures that the system is effectively controlled within all constraints – thereby sustaining energy cost savings measures. All the procedures use continued feedback to ensure project sustainability and client satisfaction.

The impact of the new maintenance procedure was tested using three case studies. The results proved that structured maintenance helps to maintain sustainable energy cost savings. The combined target impact for the three case studies was an average evening peak load shift of **8.39 MW**. The combined average impact achieved during the selected twelve months was **10.16 MW**, which resulted in an approximate cost saving of **R8.05 million**. The significant savings sustained confirm the importance of the new maintenance procedure.

Acknowledgements

Firstly, I want to thank God for the opportunity and knowledge to complete this dissertation. Without God nothing is possible.

Secondly, I would like to thank the following people:

- TEMM International (Pty) Ltd and HVAC International (Pty) Ltd for the opportunity, financial assistance and support to complete this study.
- Prof. EH Mathews, Prof. M Kleingeld, Dr JF van Rensburg and Dr W Booysen for their constant guidance and support.
- My parents, Ampie and Elize Grobbelaar, for their constant support and their belief in me from the beginning.
- To all my colleagues and persons not mentioned above, just know I appreciate all the support I have received.

All the information used in this dissertation references and acknowledges published work. If any work was not referenced, please inform me so that the problem can be rectified.

List of abbreviations

BAC	Bulk Air Cooler
DSM	Demand Side Management
ECS	Energy Conservation Scheme
EPRI	Electric Power Research Institute
ESCO	Energy Service Company
FP	Fridge Plant
GDP	Gross Domestic Product
IED	Intelligent Electronic Devices
IP	Internet Protocol
IT	Information Technology
MOV	Motor-operated Valve
NERSA	National Energy Regulator of South Africa
PHM	Prognostic Health Management
PLC	Programmable Logic Controller
POET	Performance, Operation, Equipment and Technology
PRV	Pressure-Reducing Valve
RCM	Reliability-centred Maintenance
RTU	Remote Terminal Units
SCADA	Supervisory Control and Data Acquisition
TOU	Time-of-use
TQEI	Total Quality through Employee Involvement
UPS	Uninterruptible Power Supply

List of symbols

kPa	Kilopascal
kW	Kilowatt
kWh	Kilowatt-hour
Ml	Megalitre
MVA	Megavolt ampere
MW	Megawatt
MWh	Megawatt-hour

Definitions

Bearing	A mechanical device that reduces friction where one part turns or slides over another part.
Cavitation	When the pressure of a liquid that is being pumped falls below the vapour pressure.
Condition-based maintenance	Condition-based maintenance is when sensors constantly measure the status of the equipment. Failures are reduced due to diagnostics and intervention.
Corrective maintenance	Corrective maintenance is done to identify and correct the causes of a failed system.
Demand side management	Demand side management is the planning, implementation and monitoring of those utility activities designed to influence consumer use of electricity in ways that will produce desired changes in the utility's load shape, for example, changes in the pattern and magnitude of a utility's load.
DSM intervention	Demand is reduced at certain times, or all times of a day on either the consumer or demand side.
Maintenance	Activities that are done on an item to keep it in a specific state.
Motor-operated valve	Process of using an actuator on a valve is called a motor-operated valve.
Prognostic distance	Prognostic distance is the time interval that the company has to take action for the future failure.
Prognostic health management	Prognostic health management is when a future failure and the time until the failure will occur are predicted. Maintenance and repairs can then be done to ensure that the failure is prevented.

Planned maintenance	Planned maintenance that is done to extend the life span of equipment and to avoid any downtime for equipment that is broken.
Reliability-centred maintenance	Equipment efficiency is improved and operating costs reduced through reliability-centred maintenance, which is the combination and optimisation of predictive and preventive maintenance.
SCADA	IT technology that consists of supervision, controlling and data acquisition.
Standage	The period when there is no load on the pump.
Sustainability	Development that meets the needs of the present generations without compromising the ability of future generations to meet their own needs.
Total productive maintenance	Total productive maintenance includes preventive maintenance and total quality through employee involvement.

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Mining shaft[1]

(Figures that have no academic contribution to this dissertation will be referenced as footnotes and not in the bibliography.)

[1] Rootradical Photography, "Headframes: Two Headframes over an Underground Mining Shaft in Maasmechelen, Belgium," Rootradical, 2010. [Online]. Available: http://rootradical.com/wordpress/2010-04-14/headframes/. [Accessed 06 June 2014].

1.1. Electricity supply and usage in South Africa

1.1.1 Background and funding

During 2008, South Africa experienced an electricity shortfall that resulted in severe blackouts. According to the National Energy Regulator of South Africa (NERSA), the blackouts induced an approximate loss of R50 billion to the economy. Eskom decided to build new power stations to address the electricity shortfall. The lack of research in electricity, and energy in general, has been partially responsible for the dire state that Eskom is currently in [1].

During the winter of 2013, Eskom had the highest energy constraint which resulted in a 1.09% shortage on supply. Eskom has been able to meet the demand for electrical energy but during the last five years the gap between demand and supply has grown smaller. The result was that Eskom could not switch off generating units for maintenance purposes in 2013. This decreased the technical performance of the power stations [2].

Eskom requested a 35% tariff increase per annum for three years (January 2010). The tariff increase was requested to fund the new power generation plant and delivery infrastructure. One effect of economic growth is increased consumption of energy and materials. Sustainable growth is where the economy grows but the energy consumption per gross domestic product (GDP) remains low [3].

NERSA approved a tariff increase of 8% on 19 November 2013. The tariff increase came into effect on 1 April 2014 and will be effective for five years [4]. The revenue approved by NERSA on 28 February 2013 was R863 billion, which resulted in an average increase of 8% in electricity tariffs. This decision resulted in a shortfall of R225 billion. Due to this shortfall, the funding allocated to Eskom's Demand Side Management (DSM) programme has been reduced from R1.2 billion in September 2012 to R700 million in September 2013 [2].

The effect of less funding being allocated to DSM projects is that fewer projects are assigned to energy service companies (ESCOs). Thus, alternative methods must be investigated to ensure that electrical energy savings are achieved and sustained.

1.1.2 Electricity supply, usage and tariffs

Eskom supplies approximately 95% of the electricity used in South Africa. Eskom also supplies approximately 45% of the electricity used in the rest of Africa. Electricity distribution from Eskom reaches close to every sector in South Africa [5].

The mining sector in South Africa uses approximately 20% of the energy supplied by Eskom. Approximately 14% of the energy supplied to the mining sector is used on water pumping of the mine reticulation system. This means that approximately 3% of the energy supplied by Eskom is used for pumping in the mining industry. A detailed layout of electricity usage in the mining sector is illustrated in Figure 1 [6].

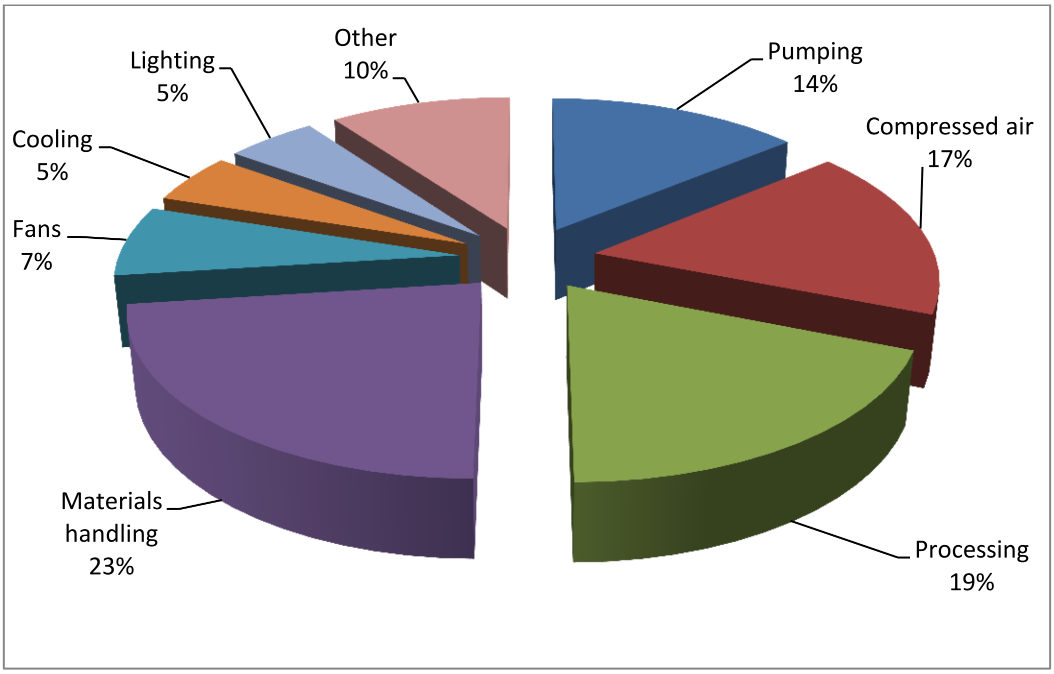


Figure 1: Electricity usage in the mining sector

Eskom introduced time-of-use (TOU) tariffs because of the high electrical energy usage by the industrial and mining sectors. TOU charges the consumer for the amount of electrical energy used depending on the time of day. Different tariffs apply to different times of the day. Consumers who use more than 1 MVA are subjected to different tariff structures including the Megaflex tariff. There are three Megaflex time categories, namely, peak, off-peak and standard times as seen in Figure 2. Electricity costs are dependent on the time of day as well as the season (summer and winter) [7].

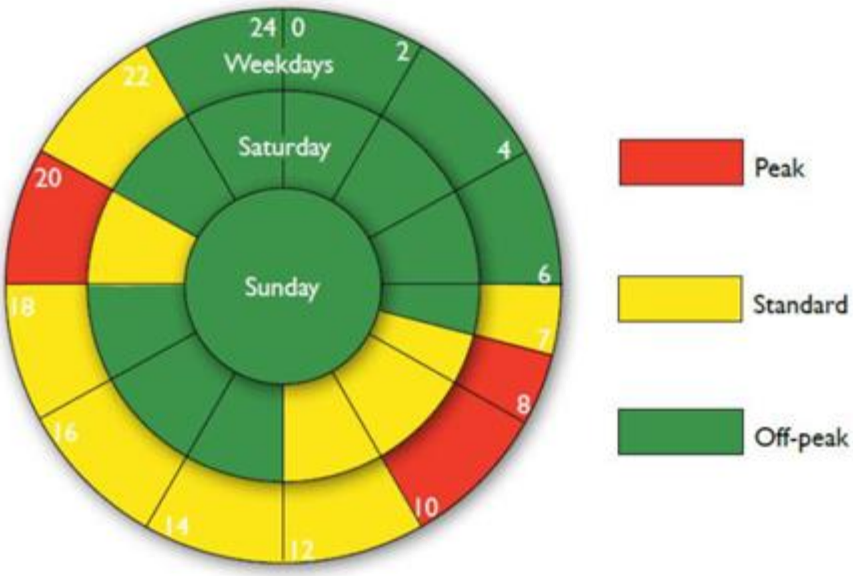


Figure 2: Megaflex – Variable pricing chart

As stated by the Department of Energy, 54% of energy consumed in 2010 was used by industry and mining. Sustainable economic growth of a country is reliant on a sufficient supply of electricity. Currently, there are no viable methods for storing large amounts of electrical energy, thus during peak demand all the required energy has to be generated. Supply growth has to meet demand growth to avoid blackouts. Energy shortages force industries to be less productive and could lead to them producing fewer products. As a result more products have to be imported. The effect of power shortages could lead to companies having to generate their own electrical energy. The drastic electricity price increase for South Africa could encourage industries to be more proactive and reduce their energy demand [8].

One of the strategies implemented in the mining industry to reduce electricity costs is DSM.

1.2. DSM projects

1.2.1 Introduction

DSM has been established in the early 1980s by the Electric Power Research Institute (EPRI). DSM has been defined as “the planning, implementation and monitoring of those utility activities designed to influence consumer use of electricity in ways that will produce desired changes in the utility's load shape, i.e., changes in the pattern and magnitude of a utility's load" [9].

In 1998, South African authorities realised that the fixed generation capacity and the increasing demand in South Africa will result in an eventual shortage in electricity. DSM was, therefore, initiated to mitigate these changes through increasing energy efficiency, load shifting and peak clipping [10].

Before implementation of a DSM project can start, it must be evaluated to see if the project makes economic sense. What this means is that the project cost and potential electrical energy savings have to be investigated. Planning must be done of how the electrical energy savings will be obtained. In some cases, the environmental benefits also have to be investigated [9, 11].

After the investigation is completed, implementation can begin. Once the strategy has been implemented, the system has to be monitored to ensure that electrical energy savings are sustained [9].

1.2.2 Peak clipping and energy efficiency

Peak clipping and energy efficiency are both energy efficiency strategies. A peak clipping strategy is only realised during Eskom peak periods. An energy efficiency strategy is when the consumer reduces its energy consumption over a time span of 24 hours [10]. The reduced energy demand will benefit both the consumer and supplier. Electricity cost will be lower for the consumer; demand will be lower for the supplier.

Peak clipping is reduced energy usage during Eskom peak periods. The result of a project with a peak clipping of 2 MW during Eskom evening peak period is illustrated in Figure 4. The electrical energy reduction with this peak clipping is 4 MWh over two hours.

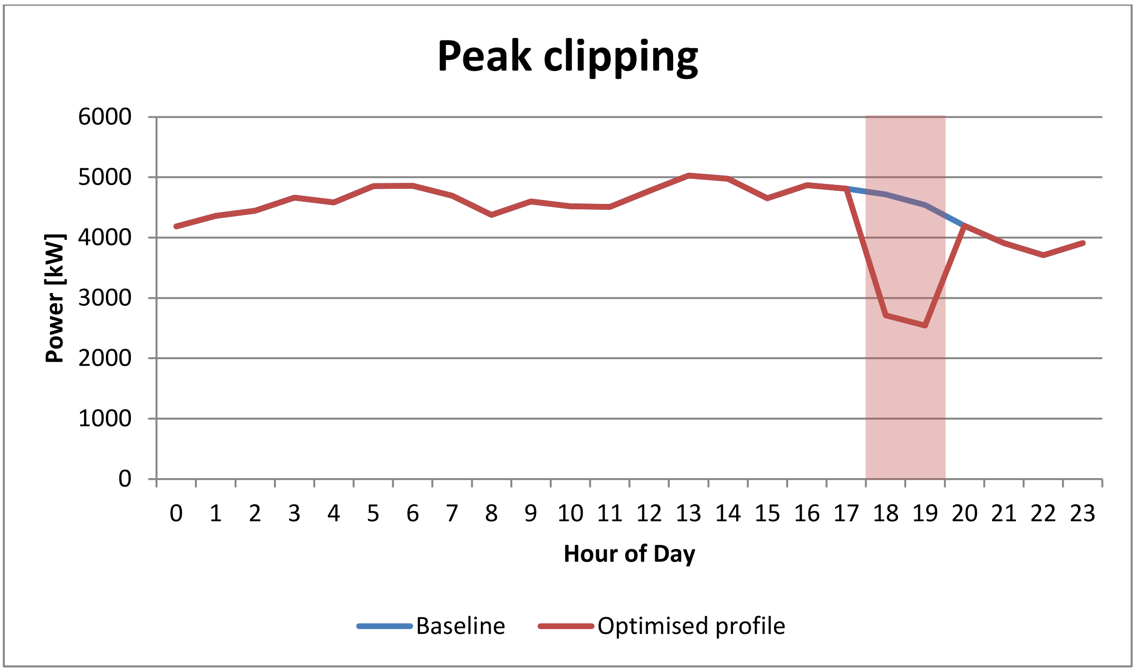


Figure 3: Peak clipping

An energy efficiency project with an average energy efficiency increase of 0.5 MW every hour is illustrated in Figure 4. The effect of this energy efficiency initiative will have an electrical energy reduction of 12 MWh over 24 hours.

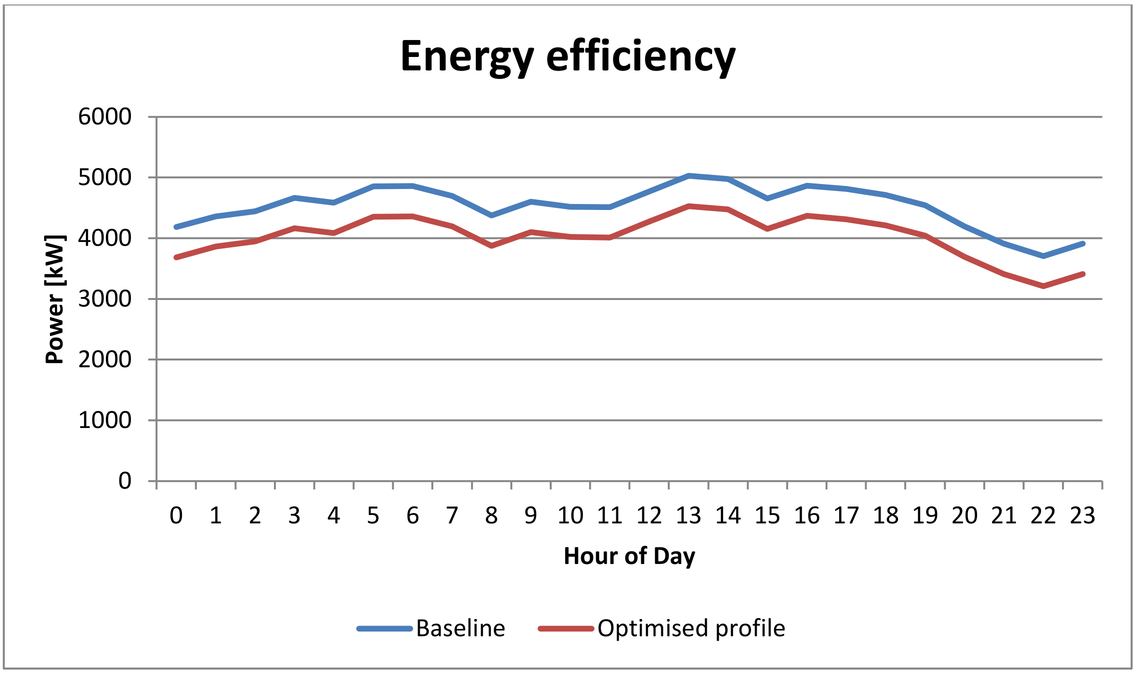


Figure 4: Energy efficiency

1.2.3 Load shifting

The introduction of TOU by Eskom forced large energy users to reduce the amount of energy used during Eskom peak hours. A decrease in consumption was observed since the introduction of TOU but there was potential for more energy to be saved. This resulted in the introduction of load shifting as DSM projects. Load shifting is not a process of using less energy but rather a reduction of energy usage during peak times by shifting load to off-peak or standard times [12].

Load shifting on a mine dewatering pumping system to reduce the load during peak times is a good example of a widely occurring DSM project [13]. Load shifting is the most common DSM strategy used on pumping systems. To ensure load shifting on pumping systems, there has to be sufficient infrastructure, such as dams with the required capacity.

A load shifting project with a morning load shift of 1 MW and an evening load shift of 1.5 MW can be seen in Figure 5. The electrical energy being shifted towards the off-peak and standard times is 6 MWh.

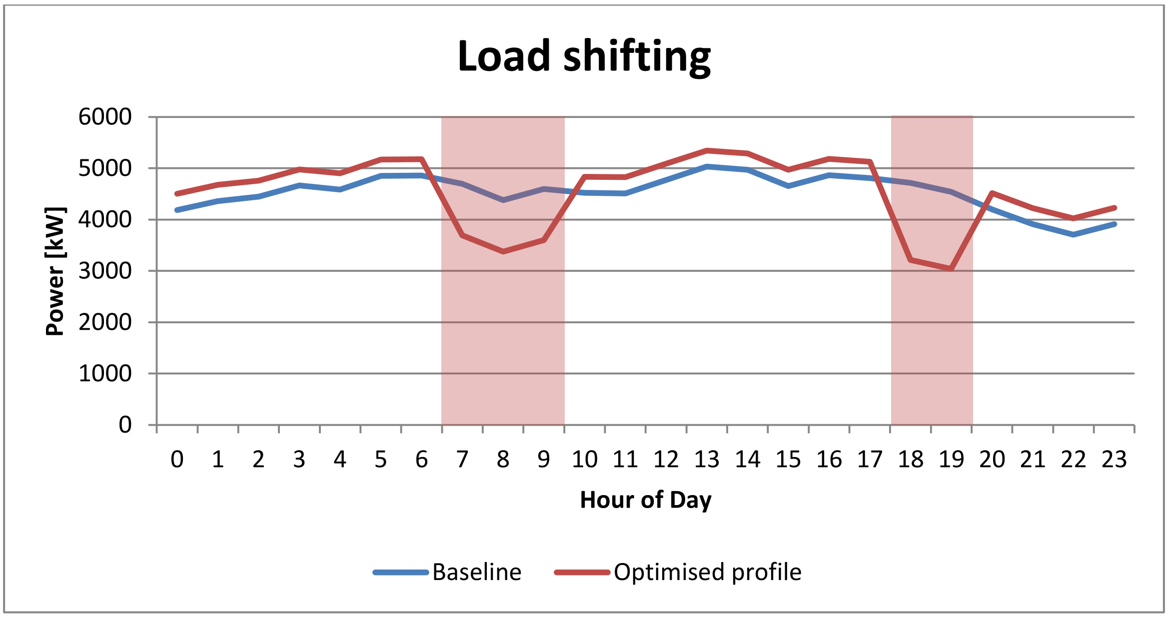


Figure 5: Load shifting

DSM projects must be sustained to ensure that electrical energy and cost savings achieved by the consumer are not lost. Sustainability is also required by the supplier to ensure that no additional load is put on the energy demand.

1.3. Need for sustainable energy savings

1.3.1 Defining sustainability

Sustainability is recognised as one of most important issues currently facing the world. Industries are focusing on being sustainable, remaining profitable and having social responsibilities, while there are growing environmental challenges and decreasing amounts of natural resources. Sustainability or sustainable development has been described as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [14].

The core of most energy policies and strategies currently are: climate change, energy security and sustainability [15]. Sustainability is industry-specific since every industry has its own challenges [14]. The challenges the mining industry currently face, and the need for sustainability are described below.

1.3.2 Why sustainable energy saving is important to the mining industry

South Africa is one of the world’s largest producers of gold, producing 21% of the world output, according to the Chamber of Mines. Furthermore, South Africa has the largest known gold reserve in the world. Because of the number of natural resources, a large quantity of the country’s labour force and economy is dependent on this sector. South Africa can be defined as a ‘mineral-based economy’ because it meets both requirements. In 2012, 48% of exports were natural resources and the contribution to the GDP was 8.8% [16, 17].

Gold mining contributes substantially to government revenue because of high taxation on the mining industry. Gold mines are taxed depending on the mine’s earnings. Earnings are calculated by multiplying the grade of gold (ounces of gold per ton mined), the tons of ore mined and the gold price [18].

Over the past few years, the economic viability of the industry has decreased due to rising costs, degrading ore grades and stagnating gold price. Retrenchments and downscaling in the gold-mining industry were due to lower profitability and increased accident risks [16, 19].

1.3.3 Effects of decreasing profitability in the mining industry

Gold mines have been taxed more than other companies and have been an important contributor to government revenue. Due to gold mining not being as profitable as before, the revenue contributions to government have decreased [18].

It is not always attractive for other countries to invest in the South African gold-mining sector. This is because of carbon tax, increased electricity tariffs and the Energy Conservation Scheme (ECS). Some gold mines could close due to the implementation of ECS and the instability of the gold price. Also, during the last few years the price of electricity has increased more than the price of gold [20, 21].

Due to rising costs and the stagnant gold price, some mines had to downscale. The effects of mine downscaling are [19]:

- Loss of jobs
- Increase in illegal mining
- Increase in environmental hazards
- Rise in poverty and unemployment levels
- Closure of businesses
- Expansion of township settlements into former mining areas
- Negative impact on local government
- Housing market that is below average
- Certain areas being redlined by banks
- Links decreasing between training institutions and mining houses
- Continual changes in the ownership of mines making negotiations between role-players difficult

The availability, abundance and underpricing of coal in the past had the effect that mines were energy intensive and that they did not place an importance on electricity efficiency. Compared with world standards, South Africa also had low electricity prices and energy efficiency. The energy use per unit of GDP in South Africa is amongst the highest in the world. The electricity price has increased to encourage industries to be more energy efficient. This is also to fully cover the operating and capital costs for the distribution of electricity [8].

Apart from electricity shortages, the production of electricity using fossil fuels furthermore has a negative impact on the environment. More than 60% of the greenhouse gases emitted in South Africa come from the sector responsible for electricity generation. This is because the electricity generation sector mainly uses coal-fired power stations. To reduce greenhouse gases, electricity usage has to be decreased [22].

To help reduce expenses to the mining industry, maintenance of DSM projects are required. Maintenance must be done on the DSM projects to ensure that savings that are achieved are sustained. For this reason maintenance by the ESCO is a very important aspect of a mine.

1.3.4 ESCO maintenance for sustainability

After a DSM project is implemented by an ESCO, a project performance assessment is done to ensure that the project achieves the required savings. After the performance assessment is completed, the savings have to be sustained by the client for five years [6].

Some projects fail to sustain the savings after performance assessment is completed. Some of the reasons for failure are [23]:

- No personnel are allocated to maintain the project
- Personnel do not have the required experience or training
- Personnel do not want the responsibility of maintaining the project
- Project performance is not continuously monitored
- New operational changes are not incorporated into the project
- Performance is not regarded as high priority

The solution to the problems mentioned above is to ensure that the ESCO is involved in maintaining the project after performance assessment [6]. Maintenance by the ESCO covers the following aspects [23]:

- Ensuring the control system is up to date
- Ensuring communication and control system is maintained
- Monitoring the project performance and savings
- Monitoring project hardware
- Providing support to the client if required
- Providing regular feedback

Maintenance on existing DSM projects and reimplementation of underperforming projects are necessary to ensure sustainability of savings [23]. This will ensure continued benefit to all parties involved. This dissertation will now further investigate maintenance procedures.

1.4. Existing maintenance procedures

1.4.1 Defining maintenance and types of maintenance

Maintenance is described as activities done on an item to keep it in a specific state [24]. The two main types of maintenance are:

- Preventive maintenance: Maintenance that is done to extend the life span of equipment and to avoid any downtime [25].
- Corrective maintenance: Maintenance that is done to identify and correct the causes of failure [26].

Corrective and preventive maintenance are combined to increase the system's reliability and availability [27]. Maintenance is an important factor for mine pumping systems. The most effective method of preventive maintenance is continuous monitoring. Continuous monitoring has the following advantages [28]:

- Insures efficient operation
- Helps to prevent pump failures
- Reduces the downtime of a pump
- Reduces repair cost
- Operates as an early warning system
- Increases the availability of the pump

Maintenance affects the operational cost and reliability of a system. Reliability is defined by safety and environmental impacts of the system. A method used to regulate maintenance is reliability-centred maintenance (RCM). RCM prioritises the items needed for system reliability and schedules maintenance accordingly. RCM makes use of predictive maintenance which is condition-based maintenance [29].

Maintenance has to be done on mechanical hardware, instrumentation and the control system. Mechanical hardware maintenance is when maintenance is done on the mechanical parts of a system such as pumps, pipes, and so forth. Instrumentation maintenance is done on the control instrumentation such as programmable logic controllers (PLCs), supervisory control and acquisition (SCADA) system, personal computers, cables, and so forth. Maintenance done on the control system includes changes made to the control parameters of the system. This includes changes made to the layout of the system which then must be updated accordingly on the control system.

Maintenance on large systems is important since a breakdown can result in a total system shutdown resulting in substantial financial losses. For this reason maintenance and fault monitoring must be in place to avoid breakdowns [28].

1.4.2 Problems on pumps and factors influencing pump operation

There are two main categories of pump operating problem, namely, hydraulic and mechanical. Since the problems are interdependent, more than one issue have to be inspected to see if the problem is hydraulic or mechanical [24].

The critical hydraulic and mechanical components in a centrifugal pump that have to be monitored to prevent damage and to identify any problems are [28]:

- Bearings
- Seals
- Impellers

Apart from the hydraulic and mechanical problems on a pump, there are also other factors that affect the operation of a system. Some of these factors are human, electric and control factors. The components included in these factors are:

- Electric motors
- PLCs
- SCADA system
- Communication components (such as cables)
- Humans

Automating a system helps with the monitoring of system components. Most of the components can be monitored and the human factor effect is minimised since the system is controlled through PLCs and computers.

Automating a system helps with problem detection and prevention. Automation makes use of a PLC. PLCs are monitored and controlled using a SCADA system [30]. PLCs replaced relay panels which is an older technology [31].

System automation can be achieved through modern information database systems but human factor still plays a large role when it comes to installation and maintenance. Human factor is also responsible for monitoring the system and ensuring a safe working environment. Human factor includes human characteristics and behaviour which, if used correctly, can improve a human-machine system. A human error is a decision that affects the system’s effectiveness and performance negatively [32].

1.5. Review of previous studies on DSM maintenance

Groenewald et al. did a study in 2013 of the effect of maintenance on DSM projects. The study followed the performance of a project over several years. Solutions to encountered problems were discussed and the effect that the solutions had on the electrical energy savings were illustrated. The study showed that savings deteriorated over time if maintenance is not sustained. The problems encountered related back to the control philosophy and human factors [6].

The initial cause of savings deterioration was not investigated, as the reasons were unknown. A list of problems of deteriorating savings was specified but many important factors were not mentioned. The main factors mentioned were human factors and mines not having maintenance contracts. Problems encountered with mechanical hardware and instrumentation were not mentioned. The paper looked at maintenance from the ESCO’s perspective but maintenance on the mechanical hardware and instrumentation were not mentioned or investigated.

It was stated in Groenewald’s paper that the electrical energy savings deteriorated, but the deterioration was not illustrated. This furthermore had the effect that the increase in electrical energy savings could not be seen. The effect of reimplementation of a DSM project was not clearly illustrated by electrical energy savings gained.

1.6. Review of previous studies on sustainability of DSM projects

Pelzer et al. conducted a study in 2011 on the sustainability of DSM projects. It was stated that electrical energy savings will decrease if maintenance is not done on a project. Factors influencing the sustainability of a project are:

- Hardware failure of the control system
- Changes made to the communication network
- Changes made to the process being controlled
- Changes to the business and operational environment
- Conflicting priorities

Two case studies were compared with each other, namely, a case study with a maintenance contract and a case study without a maintenance contract. The cost savings of the two case studies were compared, and it was stated that money was lost due to a lack of maintenance. It was also mentioned that the maintenance of the DSM control system should be outsourced [13].

According to the study, maintenance was done on one case study. But no mention is made of the maintenance tasks that were done. The effects of various factors were not taken into consideration when the study was done. The factors included mechanical failure and data loss. The maintenance required for a maintenance contract was stated but very unclear. It was mentioned that maintenance was required on all the hardware and software components. This covered a large amount of equipment, which should have been specified more clearly. The human factor that was mentioned was the effect of the mine manager but the operators also had an influence on the sustainability of the DSM project.

1.7. Problem statement

Due to Eskom tariff increases as well as consumption penalties, the production costs for mines are drastically increasing. This will force some mines to reduce production and could even force mines to close down. This will affect the South African economy negatively since the country is very dependent on the export of minerals for foreign exchange [33].

The contribution of mining can be seen throughout South Africa on both a local and national economic level, and also has significant effects on the surrounding environment [34]. But, mining is not as profitable as it was in the past, thus expenses have to be cut where possible. DSM projects help mines to cut down on expenses but if DSM projects are not sustained, mines lose considerable profitability. Thus, DSM projects have to be maintained to ensure that mines stay profitable and keep on contributing to local and national economy.

Projects that have already been implemented must be sustained. Pumping projects were selected because a great amount of the energy supplied to the mine is used on the pumping systems, which has significant potential for DSM and savings to be obtained. To ensure the sustainability of DSM projects, a maintenance procedure will be developed. The purpose of the maintenance procedure is to ensure that energy savings are sustained as well as cost savings. The focus of the maintenance procedure will be on control and instrumentation, and control parameters since there is no a lot of procedures available.

1.8. Overview of dissertation

Chapter 1 – Electrical energy usage and need for sustainable energy savings

Chapter 1 provides the background to this dissertation. It summarises electricity in South Africa and the effect of mining on the local and national economy. Furthermore, it describes sustainability as well as maintenance. The problem statement and a review of previous studies are also given.

Chapter 2 – Mine dewatering pumping systems

Chapter 2 functions as the literature study of the dissertation. Pumping systems, DSM pumping systems, maintenance on the entire system and sustainability of DSM projects are discussed in this chapter.

Chapter 3 – Development of a maintenance procedure for mine dewatering pumps

Chapter 3 contains the maintenance procedure for this dissertation. Maintenance issues investigated are discussed and used to develop the maintenance procedure.

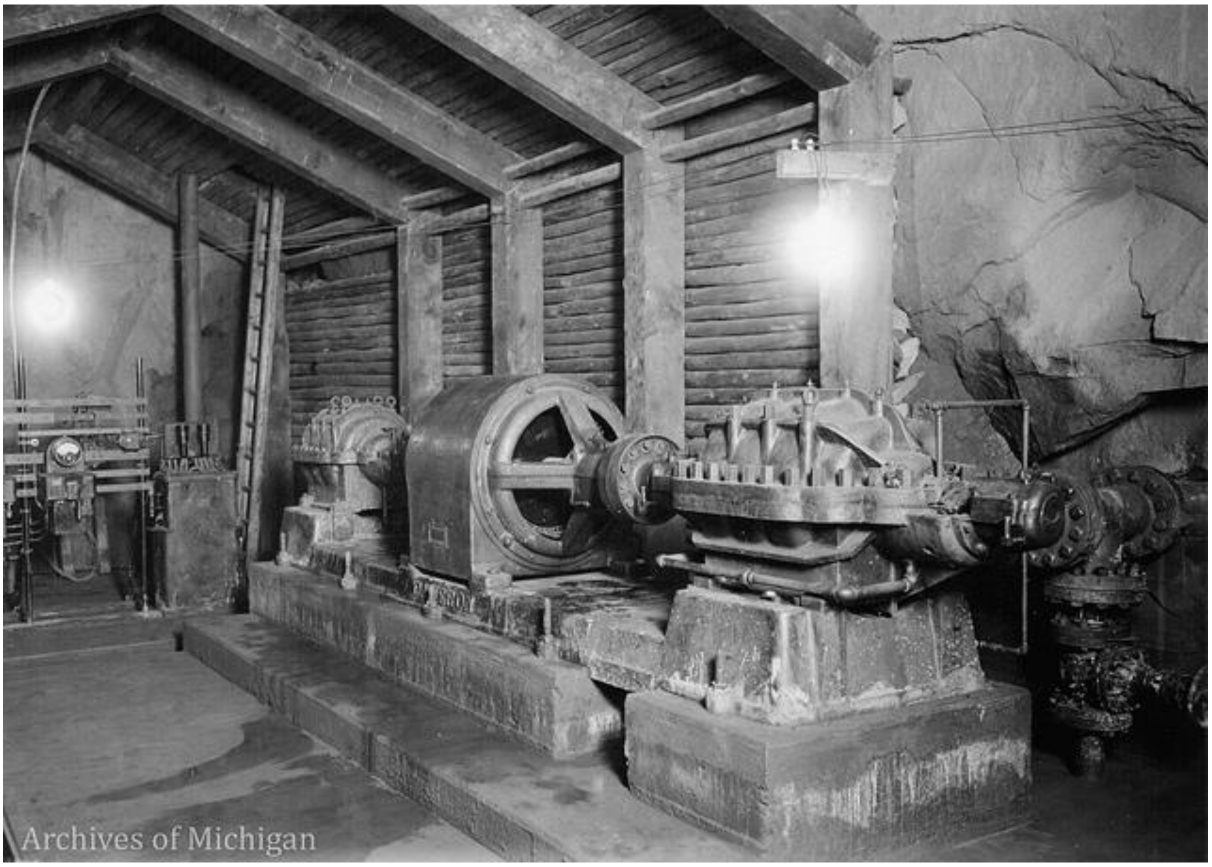
Chapter 4 – Implementation of maintenance procedures

Chapter 4 contains the case studies for the dissertation. The effect of constant maintenance on projects is illustrated. The maintenance procedure created in Chapter 3 is implemented on the mines used in the case studies.

Chapter 5 – Conclusion and recommendations

Chapter 5 discusses the outcomes of this dissertation as well as further recommendations.

Mine dewatering pumping systems



Mine dewatering pump[2]

[2] Cleveland-Cliffs Iron Company, "Plate No. 193: Cameron Centrifugal Pump on 4th Level - from Holmes Mine, Mechanical Department," Mining Agents Annual Report, Ishpeming, Cleveland Cliffs Iron Company, p.704, 1919.

2.1. Introduction

As discussed in the previous chapter, mining consumes considerable amounts of electricity and it is one of the biggest users of electricity [35]. A substantial portion of the energy consumed by mines is used in the form of pumping systems. For this reason there is significant savings potential. Effective maintenance is required to ensure that the savings are sustained. In this chapter mine pumping systems, DSM pumping systems, maintenance on pumping systems and sustainability of DSM projects are discussed.

2.2. Water reticulation systems

2.2.1. Overview of water reticulation systems

One of the biggest consumers of electricity in deep-level mining is water reticulation systems. This type of system consumes up to 42% of the total energy used by a mine. A water reticulation system consists of an underground water supply, refrigeration plants and an underground dewatering system. Energy use increases as the depth of the mine and water volumes increase [33]. A simplified layout of the process is illustrated in Figure 6.

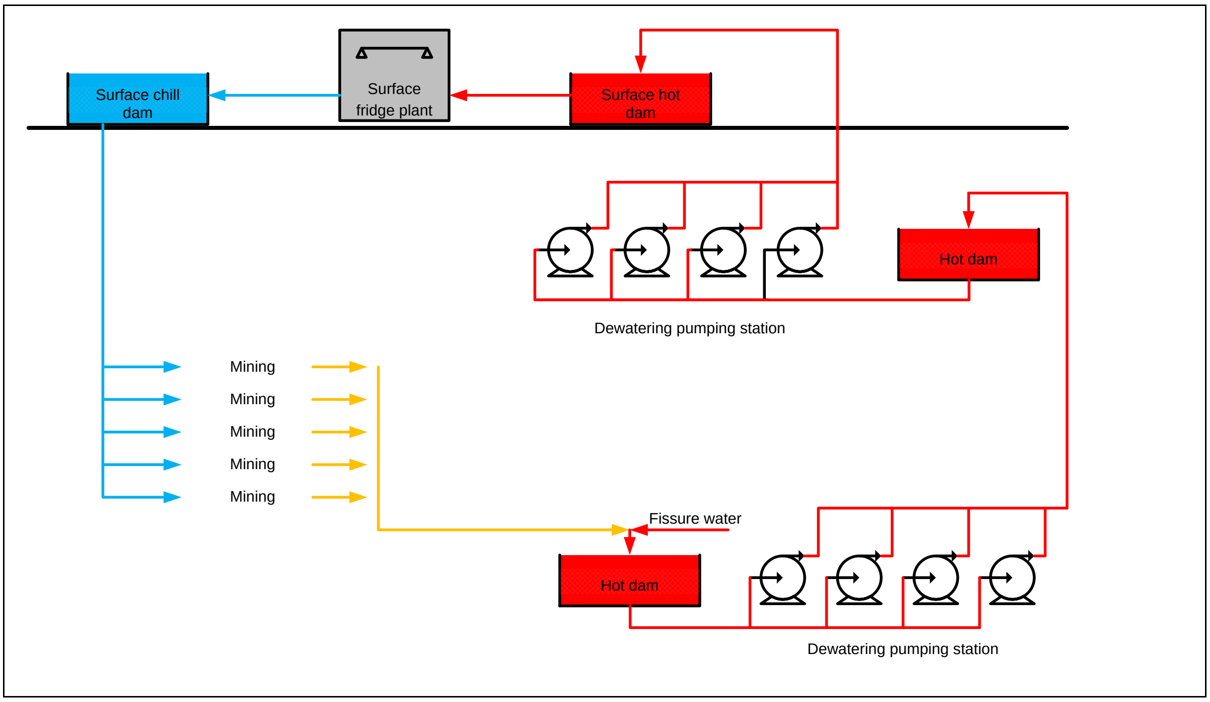


Figure 6: Simplified illustration of water reticulation system

Gold mines in South Africa require large quantities of water. The water is mainly used for mining operations such as dust suppression after blasting, rock drilling and cooling. There are various ways of supplying water underground, but the depth of the mine must be taken into consideration [36].

Mine water supply

Most of the gold mines in South Africa are at deep depths that can reach up to 4 000 m below surface. As water pressure increases approximately 1 000 kPa per 100 m of head, the water pressure has to be reduced to ensure safe operation. Pressure can be reduced by using [36]:

- A dam cascade system to reduce the head
- Pressure-reducing valves (PRVs) to dissipate the pressure/energy
- A hydraulic turbine to absorb the pressure/energy
- A turbine pump to absorb the energy and displace water
- A three chamber pump system (3CPS) to displace water

The most common method for reducing pressure used at South African gold mines is a cascading dam system. In a cascading dam system, water is gravity-fed from surface via the various dams on the respective levels to the shaft bottom. Water flows from a dam on a higher level to a dam on a lower level due to overflow. The process is repeated until the water reaches the shaft bottom. Water is supplied to the working areas through the head difference between the dams. The system is illustrated in Figure 7 [36].

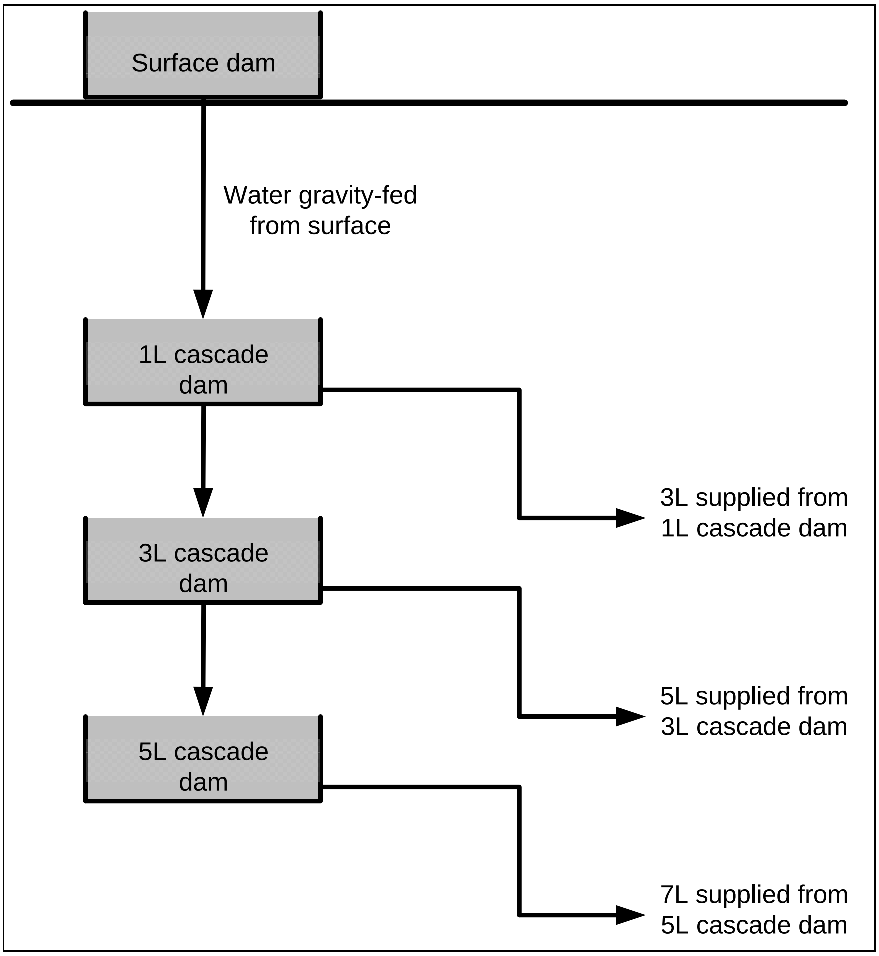


Figure 7: Cascading dam water supply system

PRVs operate in a shaft column supply system. Water is taken on each level. PRVs are installed on each level to reduce pressure and to reduce danger [37].

Mine cooling systems

The cooling system supplies chilled water to maintain underground working temperatures at an adequate level of comfort. Deep mines in South Africa have rock temperatures of up to 60 ^{o}C, but the temperature in the underground working areas must not exceed 27.5 ^{o}C. To maintain the required temperature, cooling of air is required. The cooling system consists of the following components [38]:

- Hot, chilled and cold water storage dams
- Precooling towers
- Refrigeration machines
- Condenser cooling towers
- Bulk air coolers (BAC)

A cooling system uses refrigeration plants (located on surface or underground) to cool water to between 3–5 ^{o}C. The cooled water is then pumped through heat exchangers, such as a BAC, to cool the air. Cold water is also used to cool mining equipment. After use, the water is then collected in settlers that separate the water from any debris that may have been collected in the process. After the water is cleaned, it is pumped to hot dams and eventually to the surface by dewatering pumps. The water is then cooled again and reused [33].

Settlers and clear water dams

The first step in dewatering a mine is accumulating fissure, service and cooling water. Before water can be removed from underground, the dust and rock particles must be separated from the water. Separation is done by settlers which are used in a variety of industries [39].

Solid particles in suspension are stacked together to form larger particles by adding flocculant [40]. Flocculant is a chemical that is added to the water as it enters the settler [40]. The larger particles move to the bottom of the settler as sediment due to gravitational forces [41]. The sediment is extracted from the bottom of the settler into mud dams from where it is pumped to surface for mineral extraction. The water is collected in columns from where it flows into clear water dams. The water collected is also referred to as clear water.

Clear water dams have large storage capacity to ensure that water can be stored before it has to be pumped to surface. According to mine personnel, a cylindrical clear water dam can have an approximate capacity of 3.5 Ml with a height of 12 m. The high height of the dam is used to provide head pressure for the suction side of the dewatering pumps. The clear water dams must be built in the strongest available strata, away from cracks, fissures, and mine workings to prevent any damage [42].

Mines in South Africa generally have more than one clear water dam. This is a requirement for when a dam must be cleaned, and to ensure sufficient storage capacity to maintain mine workings. Dams must be cleaned since some of the particles escape the settlers and accumulate in the clear water dams. The particles in the clear water dams can damage the pumps and decrease the volume of dams.

Mine dewatering systems

A mine dewatering system is responsible for maintaining adequate water levels for the cooling processes and for preventing the mine from flooding [33]. Methods used for the dewatering of mines are 3CPS, turbine pumps and centrifugal pumps. Dewatering systems pump fissure and service water from the shafts to the surface. Service water is water that has been used in mining operations, for example, water used for [35, 38]:

- Cooling of mining machinery such as rock drills
- Rock sweeping operations
- Suppression of dust
- Additional underground cooling requirements such as cooling cars and spot coolers

2.2.2. Dewatering methods

As mentioned in the section above, there are three methods for dewatering of mines – 3CPS, turbine pumps and centrifugal pumps. These methods will be discussed below.

3CPS

There are methods that utilise the potential energy in the reticulation system to improve the overall efficiency of the system. These operations include the use of a 3CPS. The 3CPS process is illustrated in Figure 8.

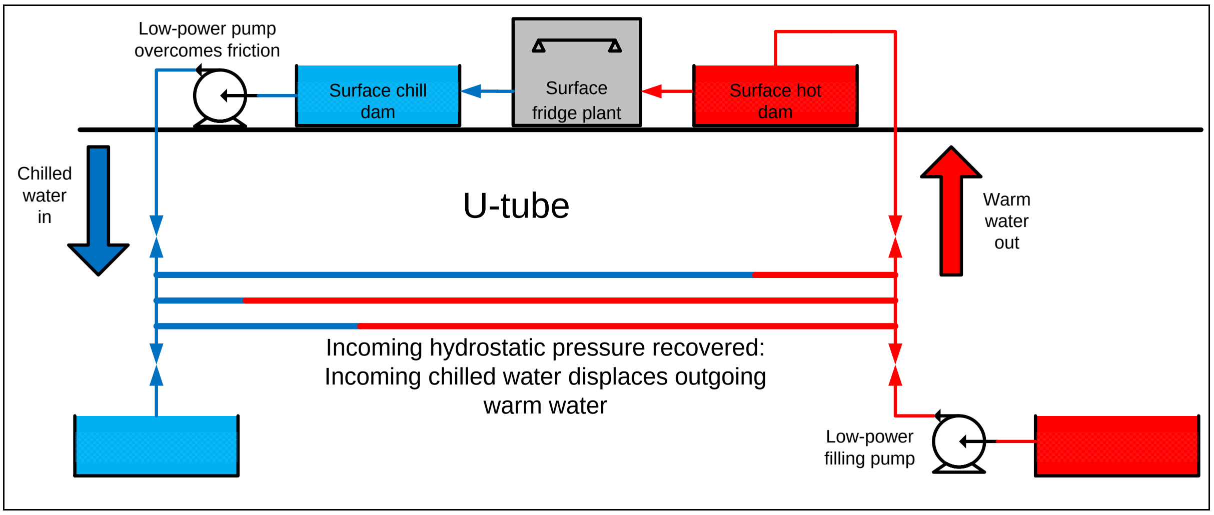


Figure 8: 3CPS

A 3CPS is also referred to as a three chamber pipe feeder system (3CPFS). The system is seen as a closed loop system [43]. The 3CPS uses energy from the chilled water going down the mine under high pressure to displace the warm water that must be ‘pumped’. A 3CPS has a higher energy efficiency than conventional pumping systems. Friction in the system is overcome by using a small booster pump. The system operates in the form of a U-tube. The chambers are filled with water by a small filling pump [44].

Actuated valves are installed on both ends of the 3CPS. The valves are controlled by a PLC that regulates the in- and outflow of water, thus ensuring a steady flow. However, a 3CPS cannot completely replace dewatering pumps because [44]:

- Pumps must operate if the 3CPS is not operational
- The 3CPS only works when cold water enters the system
- When cold water is sent down but warm water must not be pumped out
- Water from outside the system, such as fissure water, must be pumped out

The biggest issue experienced with a 3CPS is the maintenance of valves that control the flow into, and out of the 3CPS. Huge stresses are exerted on the valves while opening and closing. Failure of the valves could cause extended downtime of the system which can be very expensive [43].

Another method of improving the efficiency of the system is using a turbine pump.

Turbine pumps

Turbine pumps are used for pressure reduction as well as energy recovery. One type of turbine pump used in the mining industry is a hydroelectric turbine pump. Hydroelectric turbines operate by converting potential energy from water into mechanical energy. This is achieved by the water rotating a propeller runner or paddle wheel. The mechanical energy from the rotating part then turns an electrical generator which causes it to produce electrical energy [36, 45].

The two main categories of hydroelectric turbine are [45]:

- Impulse turbines: One or more water jets are tangentially directed into paddles of a runner that is turning in the air.
- Reaction turbines: Reaction turbines are driven by the pressure difference on the pressure side and discharge side. The turbine is also completely immersed in the water.

Hydroelectric turbines can be either vertically or horizontally oriented. The most common turbine is the reaction turbine and the shaft is vertically oriented [45].

Turbine pumps are used in the mining industry for dewatering purposes. The pump in a turbine pump differs from a hydroelectric turbine because a turbine does not drive a generator but rather drives a pump. The power required for the pump to operate is supplied by the turbine, thus saving energy [46]. The method that is largely implemented for dewatering of mines is using centrifugal pumps.

Centrifugal pumps

Pumps are divided into two major categories, namely, dynamic and displacement pumps. A pump is considered dynamic when the pump continuously adds energy to the fluid to increase the fluid velocity. A dynamic pump is subdivided into centrifugal and special effect pumps. Displacement pumps periodically add energy (through force) to movable boundaries of volumes containing fluid. Displacement pumps are subdivided into reciprocating and rotary pumps [24].

The main type of pump used worldwide is the centrifugal pump [47]. A multistage centrifugal pump has more than one impeller [48]. Centrifugal pumps are widely used because they are able to handle high flow rates, provide delivery that is smooth and non-pulsating, regulate flow rate without getting damaged, have few moving parts and are easily disassembled for maintenance [49].

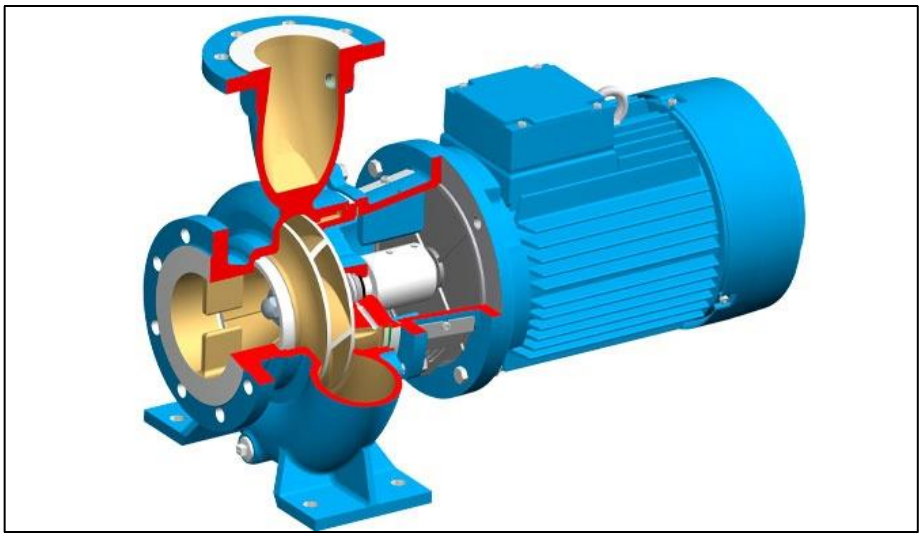


Figure 9: Centrifugal pump[3]

[3] SPX Corporation, "CombiBloc Centrifugal Pump," Johnson Pump, 2014. [Online]. Available: http://www.spx.com/en/johnson-pump/pd-mp-centrifugal-pump-combibloc/. [Accessed 6 June 2014].

A multistage centrifugal pump operates by adding head at each stage of the impellers. Water exits the discharge end of the first impeller (stage) and enters the suction side of the second impeller (stage). Each impeller adds head to the water, and after all the stages are completed, the sum of each stage gives the total head supplied. Friction forces must be taken into consideration. A head of at least 5–10% must be added to the static head so that the total pressure head can be calculated [48].

2.2.3. System design

The term 'system' for a pump network can be defined as the piping network from the outlet of the pump to the pumping destination, which is usually a dam or reservoir. The term 'capacity' is defined as the maximum operational output flow rate of the pump or the cluster of pumps. The capacity of the installed pump, or cluster of pumps, will differ from the specifications received from the supplier since the characteristics of the entire system will have an influence on the pump capacity [47].

Before the layout of the pump station can be determined, the pump that is going to be used must be selected. There is a large number of pumps suppliers. When choosing a supplier, the following factors must be taken into consideration [50]:

- Cost
- Delivery period
- Previous experience with the supplier (positive, negative or none)
- Availability of spares
- Arrangements of service intervals

Pump selection

The correct pump has to be selected – it improves efficiency, which in turn reduces electrical costs and decreases maintenance periods. The two main specifications that have to be investigated when choosing a centrifugal pump are specific speed and suction-specific speed. A pump's impeller specific speed is a non-dimensional parameter that represents the geometrical shape of the impeller. The specific speed of the impeller is a function of the following [51]:

- Capacity (per impeller eye)
- Head that the impeller is able to deliver
- Impeller rotation speed

Impellers with a low specific speed will be able to deliver a high head with a small capacity. This means that the impeller will be thinner but will have a larger diameter [51].

Suction-specific speed is the suction capability of the centrifugal impeller. It defines the relationship between the capacity of the impeller eye – the net positive suction head required, both at the best efficiency point and the rotating speed. The suction-specific speed is required for the correct net positive suction head available requirements of the pump [51].

Centrifugal pump performance curve

When a centrifugal pump has to be selected for a specific application, the correct standard to use is an accurate centrifugal pump performance curve. The performance curve makes use of total head and flow rate required to select the correct pump with the highest efficiency for the application. An example of a centrifugal pump performance curve can be seen in Figure 10 [49].

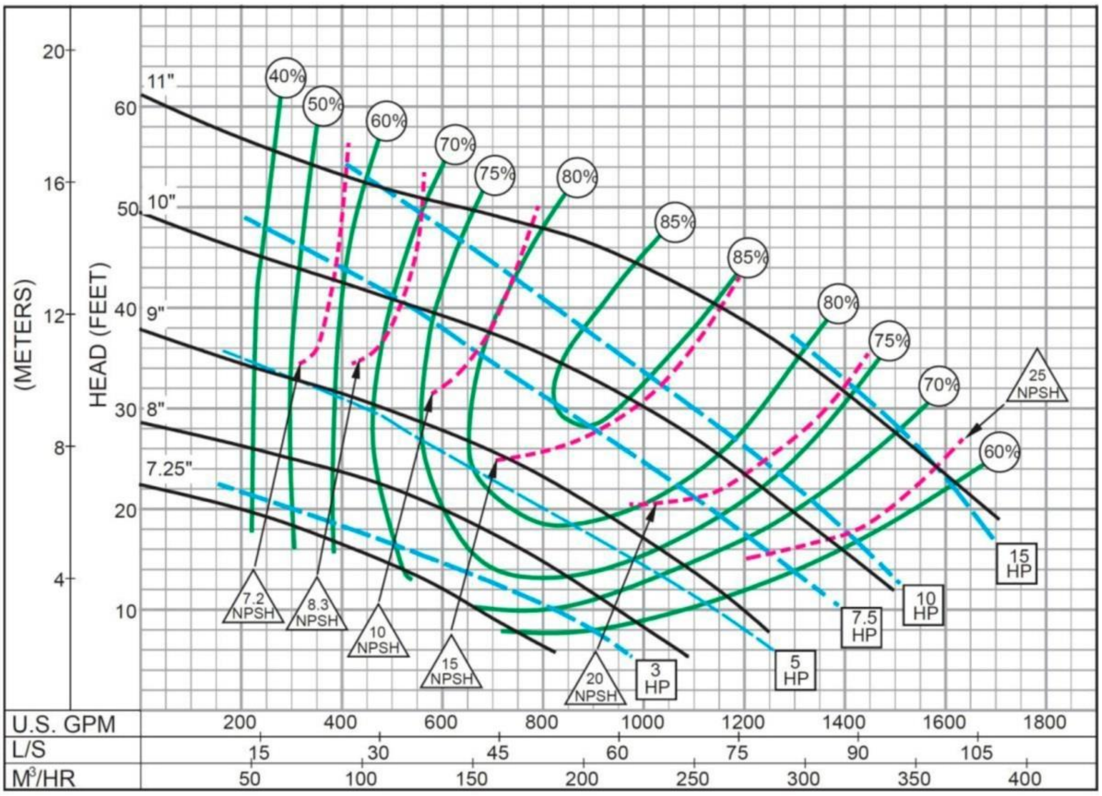


Figure 10: Example of centrifugal pump performance curve[4]

[4] Engineered Software, Inc., "Pump Curve Accuracy," Engineered Software, Inc., 29 January 2013. [Online]. Available: http://kb.eng-software.com/questions/405/Pump+Curve+Accuracy. [Accessed 4 July 2014].

Performance, operation, equipment and technology

A centrifugal pump can easily become inefficient if it is not properly designed, installed, operated and maintained. A centrifugal pump is ideal for efficiency improvements such as DSM. System efficiency components are summarised into four categories, namely, performance, operation, equipment and technology (POET) [47].

Performance efficiency of an energy efficiency system is determined by factors such as production, cost, environmental impacts and technical indicators. Operational efficiency is determined by the coordination of time, human and physical system components. Equipment efficiency is the energy output of the specific equipment with respect to the specified output specification. Technology efficiency is defined as the feasibility, life cycle cost and the life span of the specified equipment. Operation efficiency is subdivided into three categories, namely, physical, time and human coordination. Physical coordination in pumping systems is the matching and the sizing of components such as capacity, water flow rate, head, and so forth. Time coordination is control of the real-time power consumption for TOU tariffs and water demand. Human coordination is the influence of experience and human skills on the system [47].

Adding multiple pumps into a single discharge column adds flow rate to the water. When the number of pumps increases, the friction force and total pressure also increase. The result is that the pump efficiency decreases since the discharge pressure is higher. For this reason, the maximum number of pumps operated must be investigated for each individual site. Some mines rather use more than one discharge column to avoid this effect [48].

When designing a pumping system, the aims and desired duties have to be taken into consideration. The main pumping duties are the delivery rate, head required and the type of mine water that has to be pumped. The main aims of pump system design are [52]:

- Effective dewatering
- High operational efficiency
- Low maintenance
- Low overall cost

Factors influencing pump system design

The pumping system should be able to operate with mine water inflow fluctuations, breakdowns (both mechanical and electrical), power cuts and seasonal inflow fluctuations. Factors that influence the design of a pumping system are [52]:

- Mine water inflow quantities:
  - Hydrogeology of the rock surrounding the mining excavations
  - Mine geometry
  - Aquifer characteristics
  - Ground water level
  - Mining depths
  - Structural discontinuities that will formulate flow channels of water to the mine workings
- The amount of water that can enter a mine which is affected by:
  - Surface hydrology
  - Size and shape of source of water
  - Recharge area
  - Hydraulic characteristics of the intervening strata between the source of water and mine workings
- Different sources of water:
  - Surface accumulations such as lakes, rivers, seas or oceans
  - Aquifers (open or confined)
  - Bed separation cavities
  - Solution cavities
  - Old mine workings
- Different types of inflow:
  - Long period of constant rate of inflow
  - Occasional large inflows from a finite source of underground water
  - Drainage of large solution cavities in karst aquifers
  - Water inflow through erosive protective layer
- Seasonal variation in ground water inflow
- Mine water quality
- Mine layout and developments:
  - Estimated quantities of water inflow from various mining districts
  - Decision regarding the requirements of a centralised pumping plant or small pumping plants at each district directly pumping to the surface

- Number and location of main and subsidiary pumps and their standage (the period that there is no load on the pump)
- Estimated head requirements for various pumps
- Length, size and inclinations of various delivery ranges

Pump system layout

Once a pumping set has been selected, and the pipes that are going to be used have been sized, then planning of the system layout can begin. Piping has to be selected. There are two types of piping, namely, shaft piping and chamber piping. Shaft piping delivers water to the chamber down the shaft. Chamber piping is divided into two sections: suction pipes and delivery pipes. Suction pipes are used from the head to the level; delivery pipes are used from the head to the discharge point [50].

When designing a pumping system, the static component has to be taken into consideration. The static component is defined as the static head that must be overcome by the pumping system due to the friction component. There is not much that can be done to reduce the static component, but the energy required and power used to overcome the static component can be reduced. The suggested actions to take are the following [53]:

- Design a life cycle and determine annual cost for the system before any design decision is made.
- Compare at least two different pipe sizes for the lowest life cycle cost if a system has a large friction head.
- Look for ways to reduce the friction factor if the friction factor in the system is high. For example, fit plastic- or epoxy-coated steel pipes that can reduce the friction factor by more than 40% and in return reduce the operating cost of the pumps.

The power required to overcome the friction factor depends on the following factors [53]:

- Flow rate
- Pipe size (diameter)
- Total length of pipe
- Type of fluid being pumped (properties like viscosity and so forth)
- Characteristics of the pipe (type of material, roughness of pipe and so forth.)

2.3. Pumping system control

2.3.1. Introduction

There is a large number of deep underground mines in South Africa, thus making the potential for DSM very high. Load shifting can be done on underground pumping systems without influencing the operations at mines [12].

Load management on dewatering systems reduces the energy load during Eskom peak periods. Mines save money since the tariffs in peak periods are more expensive than the tariffs during standard or off-peak periods. Eskom also benefits since load is reduced during the peak period.

In the past, pumping systems were controlled by pump operators located at the pumping stations. When the downstream dam was able to handle the inflow of water and the upstream dam had storage capacity, water would be pumped from the upstream dam to the downstream dam. By automating the pumping system, the control of the entire system can be centralised and all constraints can be taken into consideration. This in effect makes load shifting on a pumping system easier [35].

Automation of pumping system

One advantage of having a completely automated system is that faults can be detected before any damage is done to the pump. The pump is monitored as it operates, and if any fault occurs the operator is informed. Maintenance can be done and the faulty part can be identified quickly, and be fixed or replaced without having to investigate the problem first. This decreases the time that the pump is not working, thus improving productivity [28].

The objective of automating a pumping system is to pump as much water to the surface as possible outside Eskom peak periods, thus ensuring that the underground dams are at a minimum during Eskom peak periods. The pumps will remain switched off until the maximum preferred dam level is reached. Dam levels are measured throughout the entire process to ensure that the mine shafts are not flooded. Operations that should be avoided on a dewatering pumping cycle include [35]:

- Cycling of pumps
- Operating the dewatering pump when the dam is at its minimum level, since the possibility arises of pumping mud

Load shifting can be implemented on manually controlled pumping projects, but a manual system is less sustainable and not as efficient as an automated system. Manually controlled pumping stations do require less infrastructure than automated systems, but rely on human supervision to function. Automated systems only require human intervention for monitoring and maintenance purposes. Manual control has several disadvantages which include ineffective monitoring of pump conditions (vibration, temperature and so forth), lack of accurate data collection, and load shifting not being effectively utilised [54].

Automated systems are more expensive to implement than manual systems since more infrastructure is required. Automated systems also cost more to maintain since the control system must also be maintained. For an automated system to function properly, information from the following components are required [54]:

- Dam levels, sizes, capacities, flows in and out of the dam and the maximum and minimum dam levels
- Sizes of pumps, flows, number of available pumps and pump efficiencies

Automation of systems is necessary to ensure that high efficiency and high quality work can be done. Simple production tasks have been automated to ensure that the process remains safe and profitable. The purpose of automation is to continuously monitor system parameters such as flows, levels, temperatures and so forth. The parameter values received are used to control the system – by starting or stopping the pumps, opening or closing valves, and so forth. For the system parameters to be obtained, the correct instrumentation is required to ensure that the information is accurate and available in real time [55].

2.3.2. Instrumentation and communication

Valves

Valves are widely used in water distribution networks. Valves are used to control the fluid flow rate and/or pressure of a system. There are different types of valve depending on the use and complexity. The butterfly valve and the globe valve are common types of valve. Instrumentation that is usually used in conjunction with valves are [37]:

- Flow meters
- Pressure transmitters
- Actuators
- PLCs

Butterfly valves

Butterfly valves are used when the pressure drop required is relatively low. The operation of a butterfly valve is similar to that of a ball valve. A flat disc (circular plate) is positioned in the middle of the pipe. On the outside of the valve is an actuator. A shaft is connected to the actuator and runs through the disc. When the actuator turns, the plate either opens (turns parallel to the actuator) or closes (turns perpendicular to the actuator). The difference between the ball valve and butterfly valve is that with a butterfly valve the disc is always present with the flow. For this reason a pressure drop can always be noticed [56]. The butterfly valve is illustrated in Figure 11.

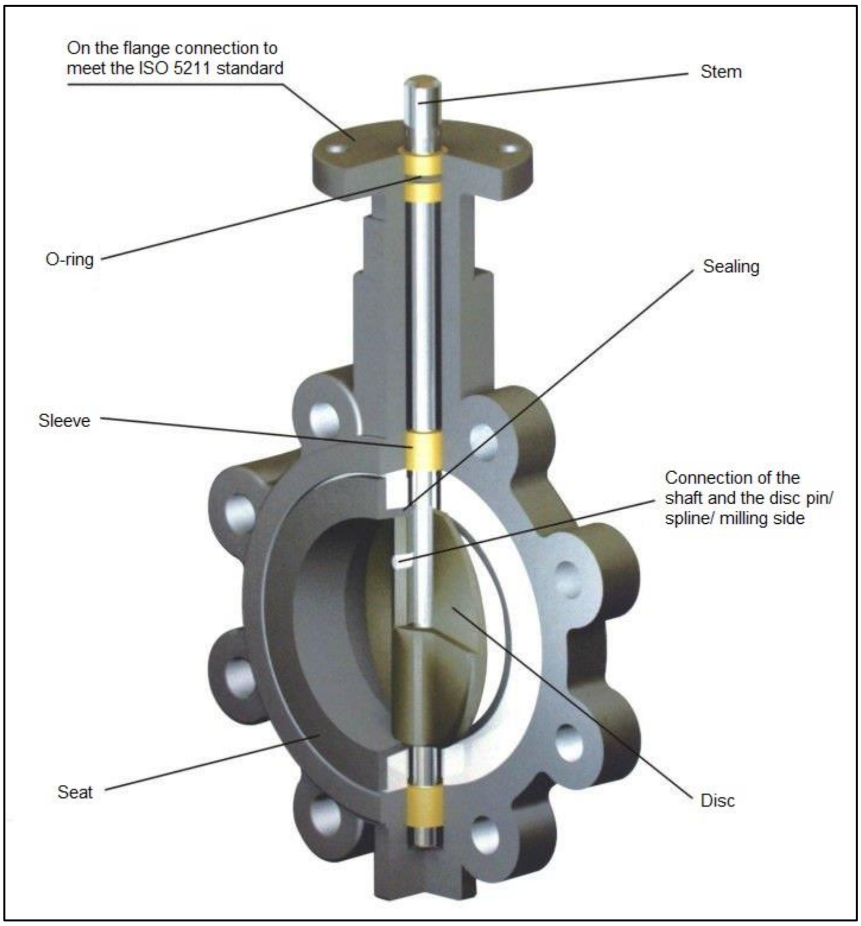


Figure 11: Butterfly valve[5]

[5] Alibaba Group, "Lug Type Butterfly Valve," Tian Jin Kay Darth Wei Valve Co., Ltd., 2014. [Online]. Available: http://tjkdsw.en.alibaba.com/product/663600729-214269636/Lug_type_butterfly_valve.html. [Accessed 23 August 2014].

Globe valves

A globe valve is used to stop, start and regulate flow. The plunger in the valve can completely close the pathway of the fluid or the plunger can be completely removed from the pathway. The plunger in the valve moves perpendicular from the seat. The space between the plunger and the seat gradually decreases as the valve is closed. This allows for good throttling control of the fluid. A globe valve has less seat leakage than a butterfly valve has because of the right angles of contact between the plunger and the seat. One disadvantage of a globe valve is the head loss that is experienced due to the right angles of fluid flows in the valve. Other disadvantages are that globe valves require large installation space and are heavier than other valves with the same flow rating [57]. The globe valve is illustrated in Figure 12.

Figure 12: Globe valve[6]

General valve problems

Since water in mines is under high pressure and flow, problems may occur with valve control. Turbulent flow may be accelerated due to obstruction caused by valve discs or plugs. Damage may be caused to parts that are under engineered in the valve; they can also cause unwanted noise [58].

[6] The Wier Group PLC, "BDK Globe Valve for Chlorine Service," Wier, 2008. [Online]. Available: http://www.weirpowerindustrial.com/products/isolation_valves/gate__globe_valves/bdk%E2%84%A2_globe_valve_for_chlorine.aspx. [Accessed 23 August 2014].

Flow characteristics

If a valve has linear flow characteristics, then the flow rate is directly proportional to the plug travel. This is required if accurate flow control is needed for a wide variety of flow rates. Constant percentage flow increase with equal increments of plug travel is found with equal-percentage flow cages. This states that flow is low at near-seat plug travel and high when the plug is at near-open. Quick-opening flow cages allow for nearly full flow at 40–50% of plug travel [59]. Globe valves cages are illustrated in Figure 13.

Figure 13: Globe valve cages[7]

Actuators

The process of using an actuator on a valve is called a motor-operated valve (MOV). The MOV components consist of an actuator, a motor and a valve. A motor is bolted onto the housing of the actuator. The motor drives the actuator. A gear train is driven by a pinion gear that is attached via a motor shaft. The gear train is splined onto the opposite end of a worm shaft to drive a worm. As the worm shaft revolves, the worm assembly moves axially. This is the process of controlling the output torque of the operator. The drive assembly is rotated by a worm gear that is driven by the worm. A valve stem is lowered or raised by a stem nut that operates as the drive sleeve rotates. The worm gear is stopped from rotating if the valve is seated or obstructed. When this happens, a spring pack is compressed because the worm slides axially along a splined shaft. The torque switch is operated by the axial movement. This causes the motor to be de-energised [60].

The most widely used actuator in the mining industry is the pneumatic actuator. Pneumatic actuators use air cylinders to create movement through pressure. These actuators operate on the same principle as discussed above, and are able to produce radial or axial

[7] C. Sys, "Control Valves," [Online]. Available: http://benvalle.com/Valves.html. [Accessed 23 August 2014].

movement. Pneumatic actuators are widely used because they are lightweight and they have a simple design. A further reason for their use is the abundance of compressed air [37].

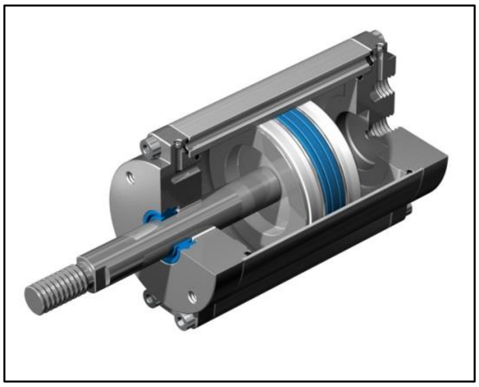


Figure 14: Pneumatic actuator[8]

Pressure transmitters and flow meters

Valves are used to maintain certain system conditions. These conditions include specified pressures and flows. To ensure that these conditions are met, measuring equipment must give measurement feedback to the valve controller. These measurements are used to determine if the valve position must be adjusted to ensure that the desired condition is met.

Figure 15: Electromagnetic flow meter[9]

[8] Stoneleigh Engineering Services, "Pneumatic Actuator," Stoneleigh Engineering Services, 2012. [Online]. Available: http://www.stoneleigh-eng.com/pneumatic_actuators.html. [Accessed 24 August 2014].

[9] South Fork Instruments, "HMFB Series of Electromagnetic Flow Meters," South Fork Instruments, 2009. [Online]. Available: http://www.southforkinst.com/electromagnetic_flow_meters.html. [Accessed 24 August 2014].

One of the most accurate flow meters on the market is the electromagnetic flow meter. It has an accuracy error of approximately 0.05% [61]. The electromagnetic flow meter measures the electromagnetic force that is generated when fluid passes through a magnetic field [62]. This measurement is proportional to the fluid velocity and can be used to calculate flow.

A PLC is responsible for controlling all the signals received from instruments such as flow meters and actuators. Digital input, analogue input and output signals are used by the PLC to send set points, receive measurements and return instructions to the instruments [55, 63].

2.3.3. Programmable logic controllers

A system consists of three parts: the operating computer, the PLC and the instruments to be monitored or controlled. The operating computer is a server or a SCADA that contains the software that will process the data and configure the hardware. The PLC sends signals to the hardware and/or to the operating computer. The PLC usually consists of the following components [55]:

- Processor
- Memory
- Power supply
- Input/output interface
- Communication interface
- Programmable device

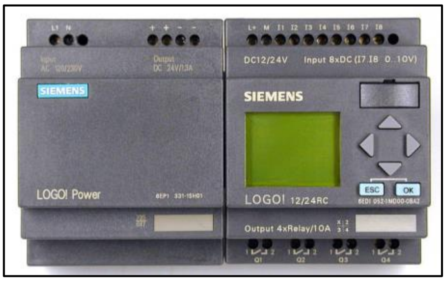


Figure 16: Siemens PLC[10]

PLCs control machines and processes using analogue input/output or digital modules. It is used to store instructions for control functions. Control functions can include [55]:

- Logic

[10] Applied Technology High School, "PLC Fundamentals," Siemens, 6 February 2013. [Online]. Available: http://www.quia.com/pages/saimasaleem/ate326. [Accessed 6 June 2014].

- Sequencing
- Timing
- Counting
- Arithmetic

Before a DSM project can be implemented on a pumping system, it is recommended that the system be automated. When a system is automated, control of the pump is done through a PLC. The PLC checks the critical parameters of the pump and motor before and during operation [35].

Various instruments are used to measure critical parameters. The PLC checks that all the critical parameters are met and that the pump and motor are in a safe working condition. Data from the entire pumping system is displayed through a SCADA. Data is sent in real time from the PLCs underground to the SCADA [35].

2.3.4. SCADA and control systems

Using a SCADA system has positive results on maintenance and process development. A SCADA is used to minimise human intervention on a system to reduce human errors. The SCADA monitors the system and the PLC stores the instructions. The SCADA operates by collecting data from PLCs, intelligent electronic devices (IEDs) and remote terminal units (RTUs), and transferring the data back so that the necessary instructions can be carried out. The information is displayed on screens that are usually located in a control room. A SCADA consists of three sections [64]:

- Master station
- Remote terminals (RTU, PLC and IED)
- Connection between the master station and remote terminals

A SCADA system is a technology that consists of supervision, control and data acquisition. SCADA systems are able to monitor and control the whole system or only parts of it. It uses the information gathered to produce alarms, generate reports, generate graphs or deliver other required outputs necessary for the operation and maintenance of the system [65]. Figure 17 illustrates an example of the different components involved in a SCADA and PLC.

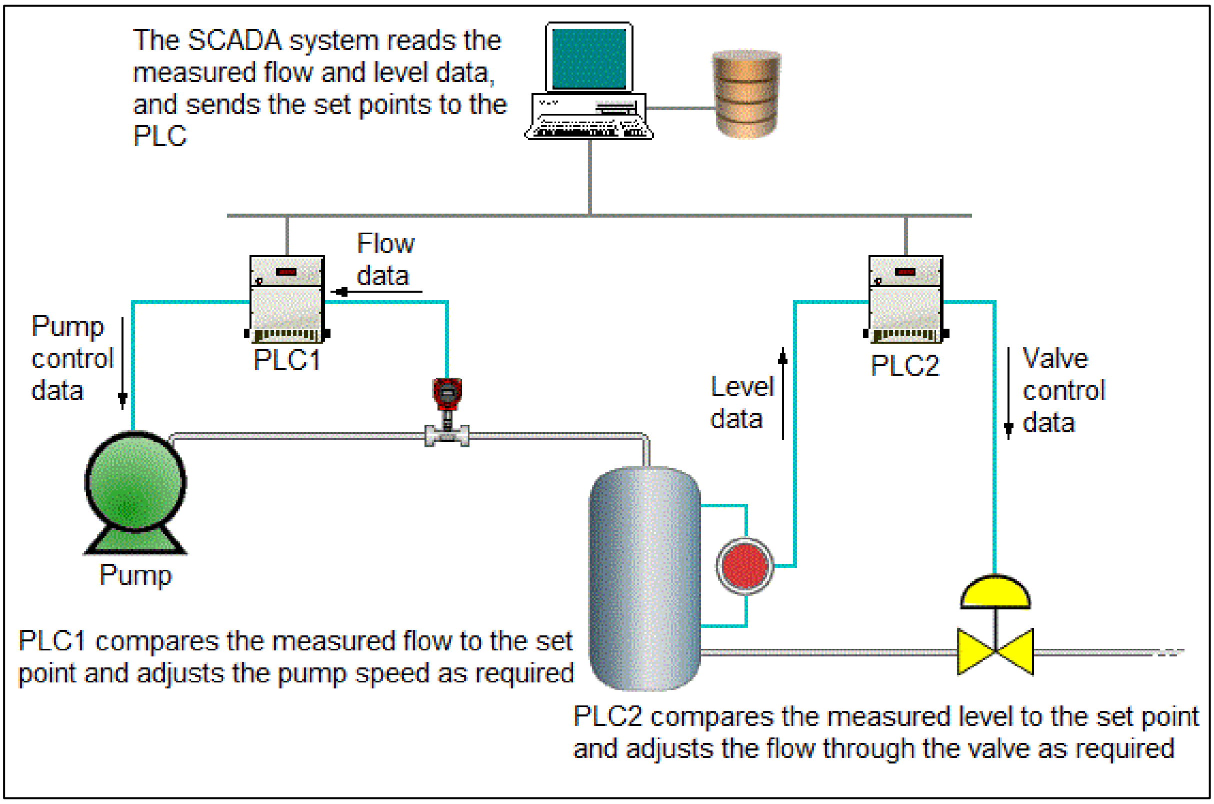


Figure 17: Example of SCADA and PLC control[11]

The benefits of using a SCADA system include [65]:

- Improved efficiency and effectiveness of operation:
  - Detects and prevents failures in the system
  - Detects failures early which allows problems to be fixed quickly
  - Optimises the system operation, reducing energy costs
  - Reduces maintenance so that the system can operate longer without having to wait for maintenance
- Improved efficiency and effectiveness of maintenance:
  - Reduces cost of corrective and preventive maintenance
  - Detects faults in the system that can then be fixed
  - Detects faults in the system as to prevent serious damage
- Reliable simulations:

[11] TechnologyUK, "Supervisory Control and Data Acquisition (SCADA)," TechnologyUK, 2014. [Online]. Available: http://www.technologyuk.net/telecommunications/industrial_networks/scada.shtml. [Accessed 6 June 2014].

  - Through the information gathered, reliable simulations can be done for when system changes must be made, thus reducing unnecessary cost
- Improved system reliability:
  - Because all the information received is in real time, extreme situations can be controlled faster and more effectively

2.3.5. Operational scheduling on pumps

An important task of operational scheduling of a pump station is reducing operational cost. Operational cost could be reduced with operational scheduling through no extra cost on equipment such as pumps and related infrastructure. There are two types of operational cost, namely, energy cost and maintenance cost [66].

Maintenance cost, which is the wear and tear of machines, is difficult to measure. Maintenance cost increases as the number of times that the machines are switched on and off increases. Maintenance cost is directly proportional to the number of pump switches. Pump switching refers to a pump that is switched on after not operating [66].

The main cost related to operational scheduling is the energy cost, which is the energy consumed and the type of energy pricing tariff applicable. Energy consumed is proportional to the time that the pump operated and the pump power used. With the implementation of TOU, the energy cost has a large effect on the operational cost of a pump [66].

2.4. Components affecting sustainability of DSM projects

2.4.1. Introduction

Because of increasing input costs for mining, it is important for DSM savings to be maximised and sustained. Man-made systems require maintenance for the system to keep on functioning correctly. This is especially important for DSM projects where systems interface with several others. Operational changes will require the system to be updated accordingly [13].

Current maintenance procedures

Systems operation is affected by uncertainties such as machine failures and repairs. If a machine experiences too many failures, it is very expensive to repair and it will be more feasible to replace the machine. For this reason, preventive maintenance must be done to increase operating time. Preventive maintenance thereby makes the system more reliable. System capability is improved if preventive and corrective maintenance are controlled and planned. Planning is required since incidents do not occur at regular intervals [67, 68].

A maintenance procedure must be correctly set up to minimise repair costs and machine downtime. If maintenance is done correctly, the availability of the system improves. Availability is defined by maintainability and reliability. Conducting proper maintenance increases profitability in two ways, namely, decreasing the running costs of the system and increasing the capability thereof. The maintenance procedures that are most widely used are [69]:

- Corrective maintenance: Maintenance is done to restore the failed product back to operating status.
- Preventive maintenance: Maintenance is done at certain time intervals to reduce failures in the system.
- Predictive maintenance and condition-based maintenance: Sensors constantly measure the status of the equipment. Failures are reduced due to diagnostics and intervention.
- Total productive maintenance: Maintenance that includes preventive maintenance and total quality through employee involvement (TQEI).
- Reliability-centred maintenance (RCM): Equipment efficiency is improved and operating costs are reduced through the combination and optimisation of predictive and preventive maintenance.

RCM prioritises items that require maintenance to reduce maintenance costs [70]. RCM operates through [29]:

- Maintaining the functions
- Identifying the items (failure modes) that causes function to not be maintained
- Prioritising the failure modes
- Choosing a task to return the function to original state

Another maintenance method is prognostic health management (PHM). PHM is when a future failure and the time until the failure will occur are predicted. Maintenance and repairs can then be done to ensure that the failure is prevented. PHM makes use of prognostic distance, which is the time interval that the company has to take action before the predicted future failure. Prognostic distance improves maintenance since spare parts can be ordered before the failure occurs, thus reducing the machine downtime [71].

2.4.2. Mechanical components

Fault detection on pumps

A very common method for fault detection and diagnostics in centrifugal pumps is vibration signals. Fault detection in a centrifugal pump is done by comparing the running signals with the signals when the pump was running at normal conditions. Problems that can be detected by vibration analysis are [28]:

- Unbalance, looseness and misalignment of shaft
- Bearing problems
- Impeller problems
- Gear problems
- Blade problems

Components that are known to fail because of excessive vibration are [28]:

- Mechanical seals
- Bearings
- Impellers
- Shafts
- Couplings
- Wear rings
- Bushings

Centrifugal pumps

The main type of pump used worldwide is the centrifugal pump [47]. The four main types of maintenance that have to be done on centrifugal pumps are [72]:

- Replacement of mechanical seals and the maintenance of seal peripherals
- Replacement of rolling element bearings

- Adjustment of impeller clearance and impeller replacement
- Replacement of the pump-driver and coupling care

Typical critical parameters that have to be monitored for centrifugal motors and pumps include [28]:

- Shaft displacement
- Bearing temperatures
- Vibration of motor

The monitoring of the critical parameters helps with the detection of the main problems associated with centrifugal pumps, which are [28]:

- Defective bearings
- Defective seals
- Defective impellers
- Cavitation

The effects of problems associated with centrifugal pumps are [28]:

- Abnormal noise
- Leakage
- High vibration

Causes of pump problems

Causes of problems associated with pumps can be any of the following [73]:

- Incorrectly defined pump maintenance program (frequency and scope). Operating conditions must be taken into consideration.
- Analysis of critical components, meaning that maintenance is done on non-critical components and thus the pump is stopped unnecessarily.
- If the maintenance is not adapted according to the load of the machine. As the load of the machines changes, the maintenance on the machines has to change accordingly.
- Personnel responsible for the operation and maintenance of pumps do not have sufficient training, experience and/or access to the correct tools.
- Malpractices that affect the operation and maintenance of the pumps.

Bearings

There are four types of bearing, namely, plain bearings, ball bearings, roller bearings and thrust bearings. A bearing is a mechanical device that reduces friction where one part turns or slides over another. A bearing is a very important part of a machine and must have good carrying capacity and reliability. Bearings used in a pump are responsible for [74]:

- Supporting the hydraulic load (on the impeller)
- Supporting the mass (impeller and shaft)
- Supporting the loads of the drive system
- Maintaining the axial movement and lateral deflection within acceptable limits

Figure 18: Tapered roller bearing[12]

Pumping systems mostly make use of roller bearings. Bearings mostly fail because of fatigue which is caused by high cyclic stresses between the raceways and the roller elements. Thus, bearings have to be inspected to ensure that the pump operates at optimal efficiency [74].

A good design and regular bearing maintenance improve component life. It also reduces operating costs by avoiding major failures and by reducing power costs. If the bearing is damaged and not maintained then it causes vibration at high frequencies and increases energy consumption. Bearing faults result in [74]:

[12] Direct Industry, "Tapered Roller Bearing," Schaeffler, 2014. [Online]. Available: http://www.directindustry.com/prod/schaeffler-technologies-gmbh-co-kg/tapered-roller-bearings-169-789383.html. [Accessed 6 June 2014].

- An 85% increase in vibration level
- A 14% increase in power consumption
- An 18% decrease in pump efficiency

If the efficiency of the pump decreases, then the power to the water decreases and/or the power consumed by the pump increases, affecting the distribution of the water as well as the management system [74].

Cavitation on pumps and valves

Cavitation occurs when the pressure of the liquid that is being pumped falls below the vapour pressure. When this happens bubbles form inside the liquid. If the pressure increases, the bubbles collapse and produce an implosion. If the cavitation occurs close to the wall and has a high velocity, the wall gets corroded and there is chemical attack that causes damage [51].

This phenomenon occurs in centrifugal pumps at the impeller inlet and under certain conditions along the impeller vane because of the reduction in local pressure and the increase of the fluid velocity. The phenomenon can be controlled in centrifugal pumps by controlling the formation of bubbles at the impeller inlet by avoiding the suction pressure falling below the liquid vapour pressure. Cavitation in pumps can cause substantial damage and increase the maintenance that is required [51].

Problems associated with cavitation are the following [28]:

- Decrease in hydraulic performance
- Pump damage through pitting
- Erosion of impeller
- Structural vibration

Cavitation is one of the biggest problems experienced with valves. Cavitation in valves occurs when the local pressure is lower than the saturated vapour pressure. All of this happens at ambient temperatures. Cavitation bubbles form and collapse causing damage to the valve walls. Cavitation in valves causes the following [75]:

- Structural vibration
- Unwanted noise
- Localised stresses in the pipe walls and valve body

Cavitation is a function of upstream and downstream pressure. Cavitation can be detected since the phenomenon starts at a certain valve opening. It can thus be prevented when the valve opening is identified. Cavitation is also a function of rough surfaces and can, therefore, be reduced by using smoother surfaces [75].

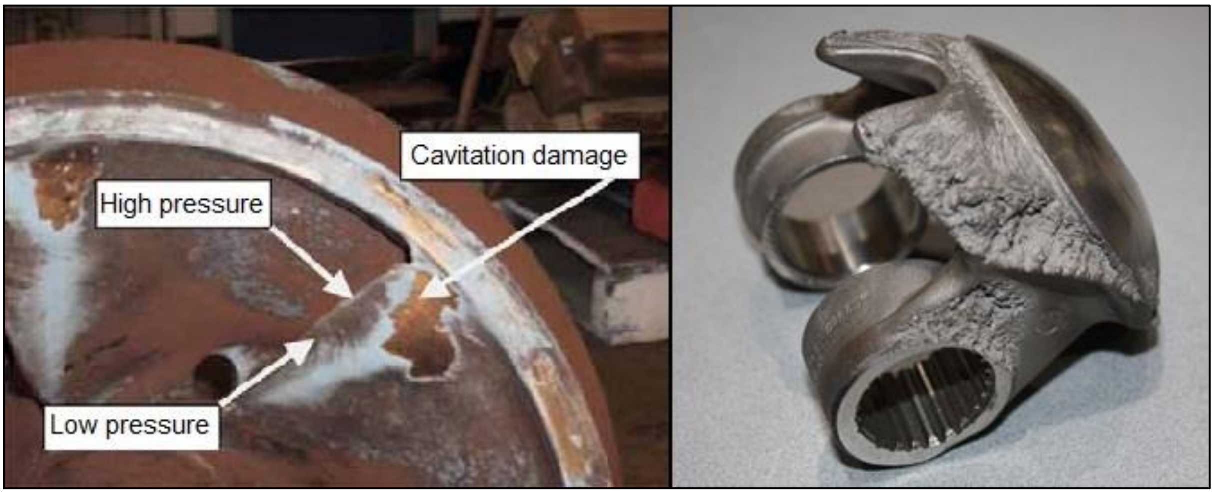


Figure 19: Cavitation damage to pump impeller and valve trim[13]

Water hammer

Water hammer is the process by which pressure fluctuations are created because of fluid inertia when the valve suddenly closes [76]. This phenomenon causes a pressure shockwave within the fluid. Some of the effects of water hammer are [77]:

- Valve failure
- Pipe leaks
- Damage to flow passage components

Water hammer can cause column separation that could have negative effects on the pumping station [78]. Column separation is when the column that transports the liquid is broken due to high pressure waves [79].

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[13] G. Machado, Belzona, Inc., "Polymeric Solution for Pumps Suffering from Cavitation," Cahaba Media Group, 2014. [Online]. Available: http://www.pump-zone.com/topics/pumps/centrifugal-pumps/polymeric-solution-pumps-suffering-cavitation. [Accessed 6 June 2014].

S. Hocurscak, K. Rayhill and Neles & Mapag, "Curb Control Valve Cavitation," Chemical Processing, 17 July 2013. [Online]. Available: http://www.chemicalprocessing.com/articles/2013/curb-control-valve-cavitation/. [Accessed 23 August 2014].

Figure 20: Pipe damage caused by water hammer[14]

Human factor on maintenance of pumps

Centrifugal pumps are widely used for different applications. A significant number of problems is, therefore, experienced on centrifugal pumps. These problems have to be diagnosed by a human expert, since when done by a non-expert, diagnosing the problem can be costly and time consuming [24].

The main errors in maintenance procedures can be contributed to [32]:

- Improper training
- Use of outdated maintenance manuals
- Lack of proper experience
- Poor design factors:
    - Issues involving equipment
    - Maintenance
    - Work layout
- Difficulties faced by workers:
    - Improper work tools
    - Fatigue
    - Overstressed workers
- Environmental factors:
    - Humidity
    - Lighting
    - Temperature

[14] Cheng Fluid Systems, "Water Hammer," Cheng Fluid Systems, 2013. [Online]. Available: http://www.chengfluid.com/flow_problems/water_hammer. [Accessed 24 August 2014].

The work environment can be improved by [32]:

- Hiring workers with the necessary experience for the environment
- Providing better training
- Ensuring emotional stability

2.4.3. Control and instrumentation

Pumping systems are located in harsh environments that cause damage to the cabling infrastructure. Since data communication plays a very important role in automated systems, maintenance has to be done on the cabling infrastructure to ensure that system data is received. Wireless technology has been introduced to many parts of current automated systems in other industries, but in mining this is not possible since wireless networks cannot operate at the deep mining depths [55].

Maintenance, which has to be done to ensure all components can communicate with each other, includes [55]:

- Trenching for new wires to be laid
- Repairing wires
- Replacing stolen wires

Site maintenance and fault detection of machines can be done via the Internet. Companies with several sites can access the sites remotely to analyse the information gathered. Time and money are saved since companies do not have to travel to sites to do fault diagnosis. Performance of the control system and the processes can be monitored and malfunction of machines can be detected. Performance can be monitored continuously to ensure that the system remains productive. For remote access to function effectively, there is a back end that is located locally and a front end that is located remotely. Apart from monitoring, data can also be transferred over the Internet [80].

2.4.4. Control parameters

For load shifting to be sustainable, the pumping system has to be simulated, optimised and controlled [12]. The characteristics of each individual site are different. Thus, the way each site will be controlled is unique. The system can be simulated before it is implemented to determine if the system is going to function correctly at a particular site [54]. A simplified system layout is illustrated in Figure 21.

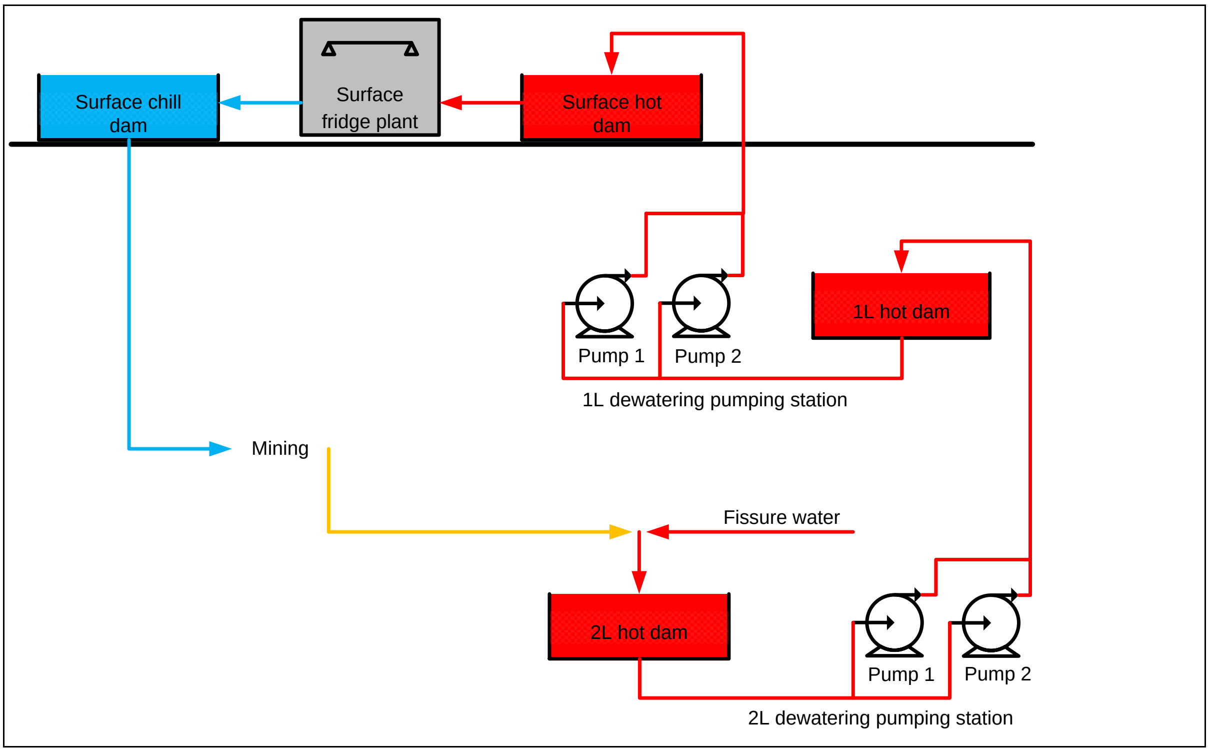

Figure 21: System control layout

The system illustrated in Figure 21 has to be controlled according to certain parameters. The parameters for the illustrated system are presented in Table 1.

Table 1: System parameters

<table>
<tr><th colspan="7">Parameter (dams)</th></tr>
<tr><td>Surface chill dam</td><td colspan="2">Minimum level</td><td colspan="2">Maximum level</td><td colspan="2">Desired level</td></tr>
<tr><td>Surface hot dam</td><td colspan="2">Minimum level</td><td colspan="2">Maximum level</td><td colspan="2">Desired level</td></tr>
<tr><td>1L hot dam</td><td colspan="2">Minimum level</td><td colspan="2">Maximum level</td><td colspan="2">Desired level</td></tr>
<tr><td>2L hot dam</td><td colspan="2">Minimum level</td><td colspan="2">Maximum level</td><td colspan="2">Desired level</td></tr>
<tr><th colspan="7">Parameter (pumps)</th></tr>
<tr><th colspan="7">1L dewatering pumping station</th></tr>
<tr><td>Pump 1</td><td>Availability</td><td>Capacity</td><td>Flow rate</td><td>Priority</td><td>kW</td><td>Running hours</td></tr>
<tr><td>Pump 2</td><td>Availability</td><td>Capacity</td><td>Flow rate</td><td>Priority</td><td>kW</td><td>Running hours</td></tr>
<tr><th colspan="7">2L dewatering pumping station</th></tr>
<tr><td>Pump 1</td><td>Availability</td><td>Capacity</td><td>Flow rate</td><td>Priority</td><td>kW</td><td>Running hours</td></tr>
<tr><td>Pump 2</td><td>Availability</td><td>Capacity</td><td>Flow rate</td><td>Priority</td><td>kW</td><td>Running hours</td></tr>
</table>

Parameter (flows)			
Inflow			
Surface chill dam	Minimum flow	Maximum flow	Desired flow
Surface hot dam	Minimum flow	Maximum flow	Desired flow
1L hot dam	Minimum flow	Maximum flow	Desired flow
2L hot dam	Minimum flow	Maximum flow	Desired flow
Outflow			
Surface chill dam	Minimum flow	Maximum flow	Desired flow
Surface hot dam	Minimum flow	Maximum flow	Desired flow
1L hot dam	Minimum flow	Maximum flow	Desired flow
2L hot dam	Minimum flow	Maximum flow	Desired flow

Each specific component has certain criteria that has to be fulfilled for the system to be controlled according to the desired parameters. The system must be controlled to achieve:

- Safety
- Energy efficiency
- Cost efficiency

The system must be controlled safely to ensure that no damage is done to infrastructure and that no harm comes to the personnel working on the system. Energy efficiency is desired to ensure that the least amount of energy is used to obtain the desired results. This is also necessary for effective load shifting to be done on the system. Cost efficiency is desired to ensure that the least amount of capital is used to obtain the desired results. This is done by prioritising pumps and ensuring that effective maintenance is done.

The control philosophy has to update along with changes made to the production process [81]. There are several reasons why projects that was once performing well and achieving the required savings, cease to perform. Some of the reasons why savings are being lost are [13]:

- Control room hardware failure: Hardware gets damaged because of the harsh conditions in the mine. Broken equipment does not get replaced or repaired because DSM projects do not have high priority.
- Communication network changes: If changes are made to the SCADA and PLC, but the control of the system is not upgraded, then the system will not function. This is even the case when small changes are made, for example, when a tag is renamed but not updated on the control of the system, the system will not function correctly.

- Infrastructure changes: When changes are made to the infrastructure of the system they have to be updated on the control of the system. For example, if a pump is replaced with a bigger pump or a dam is enlarged, then the necessary changes must be applied. If this is not done then the system will not control as it supposed to.
- Operating or business condition changes: This is when changes are made to mine operations. This can be shift times changing or Eskom extending peak times. The necessary changes must be applied to the control system to accommodate the changes made on the operation or business side.
- Priority conflicts: The main purpose of the mine is to extract the maximum amount of product possible. This can affect the DSM project since DSM can be neglected to increase the production of the mine.

If DSM projects are maintained and sustained then savings are achieved easily, ensuring a good return on investment. Maintenance of a DSM project should include [13]:

- Maintaining hardware and software
- Monitoring system performance
- Providing feedback to relevant parties
- Providing regular updates to include changes in infrastructure and operations

2.5. Conclusion

Mine pumping systems use a large amount of energy, there is therefore potential for load shifting to be performed. Work is not complete after a DSM project has been implemented on the pumping system. Savings have to be sustained to ensure that future savings are not lost. For this reason maintenance is very important.

Pumping system maintenance involves hardware, software and a control system. To reduce downtime and operational cost, the correct maintenance procedure has to be chosen to ensure that the system operates effectively. The software has to be maintained. The best method is to have a maintenance contract with the ESCO that was responsible for the project implementation. The control system must be kept up to date with any changes in the operational procedure. This can be changes to the physical system or changes to the operation itself. Procedures in the gold mining industry were only selected since broadening the investigation will make the investigation too extensive.

Development of a maintenance procedure for mine dewatering pumps

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3.1. Introduction

Chapter 2 illustrated that there are currently a few maintenance procedures available for mechanical hardware, but that there are not enough maintenance procedures available for control and instrumentation, and control parameters.

The objective of this chapter is to investigate case studies from industry to identify key issues for the deterioration of energy cost savings measures. This chapter focuses on developing a maintenance procedure for hardware, control and instrumentation, and changes to operational parameters to achieve the desired results.

3.2. Analysis of existing projects

3.2.1. Introduction

As discussed in Chapter 2, the deterioration of energy cost savings can be grouped into three categories: hardware, control and instrumentation, as well as changes to control parameters. These problems and their effects on energy cost savings will be investigated. The results from the investigations will be used to draw up a maintenance procedure that can be used to mitigate these problems.

Confidentiality agreements protect the names of the mines where the case studies took place. Sensitive mine information is not included in this dissertation. Please contact the author with any questions.

3.2.2. Data collection and calculations

The data for each mine was retrieved with a data processing program. The data includes pump statuses, dam levels, flows and so forth. The data retrieved from the mines was compared with the relevant project baselines. The project baselines used were the 24-hour energy usage profiles with which energy cost savings were compared to. Data from July 2013 to June 2014 was used for the investigation to calculate the average daily impact and cost savings.

The information retrieved was then used to plot graphs of the target daily impact [MW], average daily impact [MW] and cost savings [R]. The missed cost savings were calculated using the project baselines. Details on the savings calculator and the equations used are presented in Appendix A.

The mines that were investigated were all invoiced based on Eskom's Megaflex tariff. The energy cost savings for the winter months (June to August) were much higher than for the other months because the TOU tariff structure for the winter months is much higher. The increased tariff structure during the winter months can be seen in the investigations that follow.

3.2.3. Investigation 1 – The impact of data loss

Data loss has a big impact on the management of a project. If data loss occurs, information about the project performance is lost. The inability to proactively manage a project based on its performance can have a significant effect on its cost savings potential. Although data loss is noticed when it occurs, it does not affect mining operations.

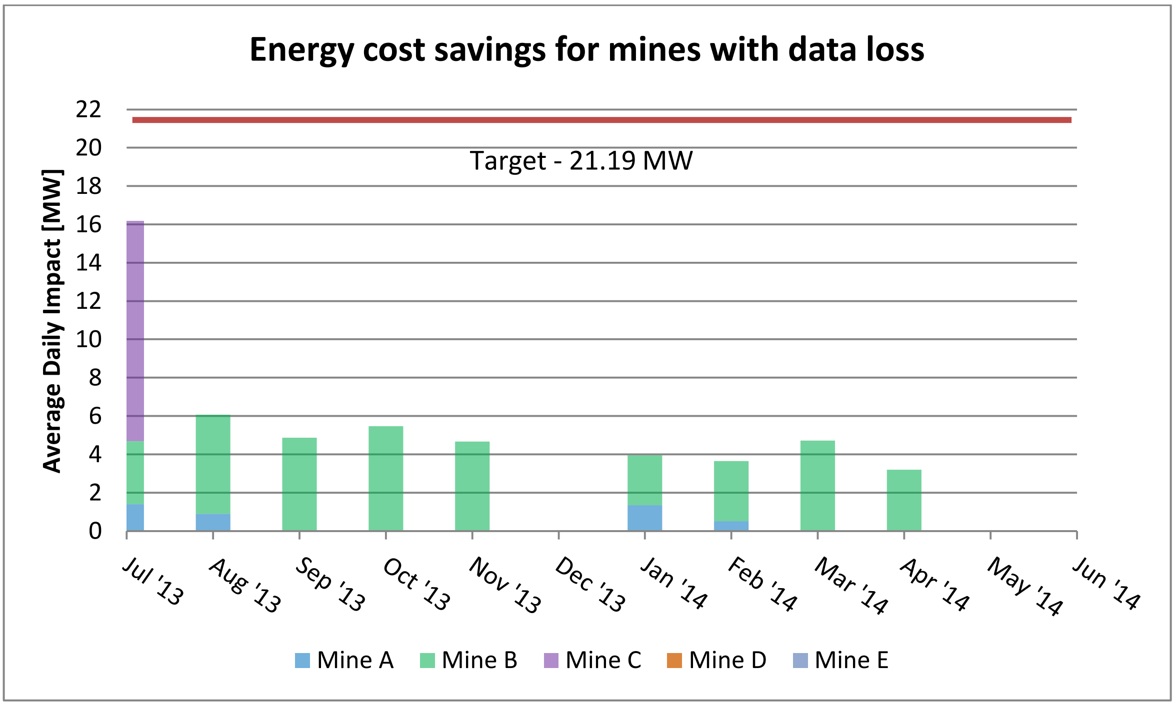


Figure 22: Energy cost savings – Data loss

Figure 22 shows the combined energy cost savings of five mines (Mine A, Mine B, Mine C, Mine D and Mine E). The combined targeted load shift to be achieved by the mines was 21.19 MW. Because of data loss that occurred, the savings achieved were not recorded.

When data loss occurs, the energy cost savings achieved are unknown, thus the effect of load shifting cannot be managed. Apart from energy cost savings not being realised, operation of pumps are not recorded. Potential problems can therefore occur unnoticed. Figure 23 illustrates the percentage savings achieved versus the savings missed due to data loss.

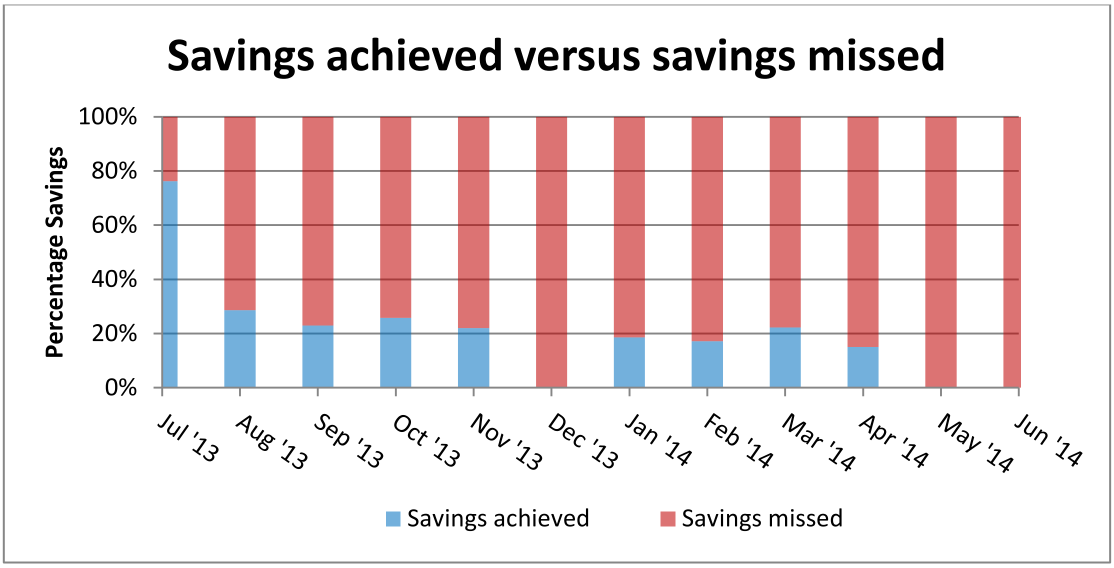


Figure 23: Savings achieved versus savings missed

The estimated cost savings not recorded due to data loss are significant. The total estimated cost saving lost for the 12 months for the five mines is approximately R12.7 million. Table 16 in Appendix B displays the missed energy cost savings.

According to the investigation, data loss should be rectified as soon as it occurs to prevent missed savings. The effect of load shifting and the operation of pumps are not recorded with missed savings.

3.2.4. Investigation 2 – The impact of mechanical failure

Mine F is a gold mine located in the Gauteng province of South Africa. Due to a lack of maintenance during the two month period from July to August 2013, the efficiencies of the dewatering pumps decreased. The effect was that the pumps did not have the capacity to pump the required water volumes from the dams. This eventually resulted in one of the levels flooding causing significant infrastructure damage. The energy cost savings for the mine are illustrated in Figure 24.

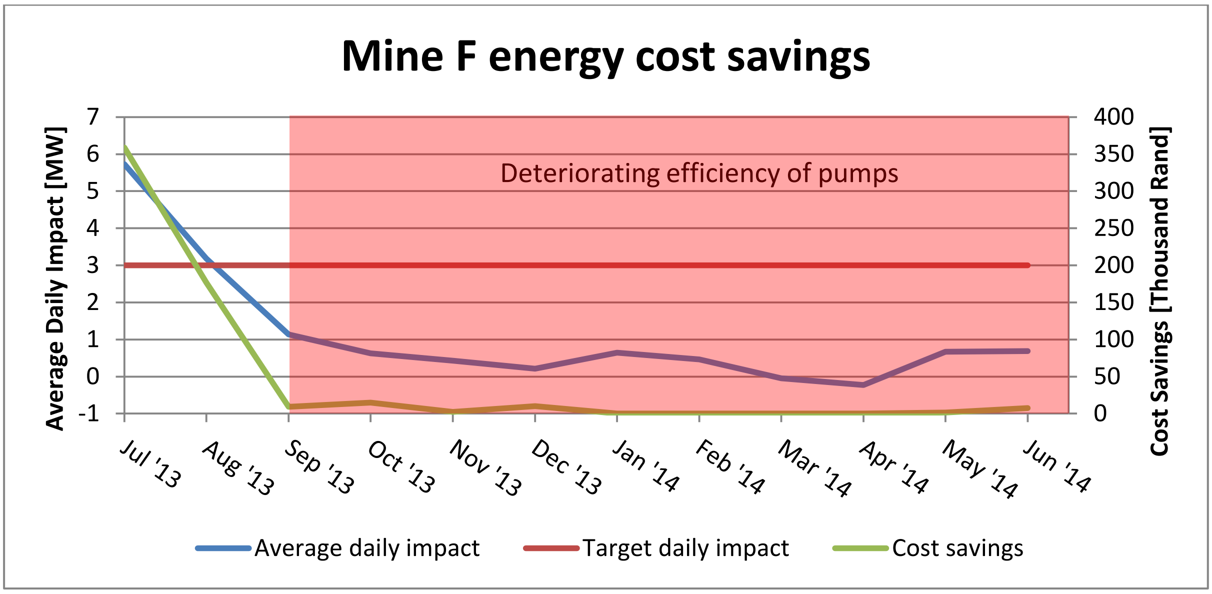


Figure 24: Mine F – Energy cost savings

The decreasing pump efficiencies had a significant effect on the energy cost savings for Mine F. Figure 24 shows a rapid deterioration from July 2013 to September 2013. From there the situation stagnated, resulting in significant losses. The estimated energy cost saving missed due to the ineffective pumps was approximately R2.1 million. Table 17 in Appendix B shows the estimated energy cost savings missed.

3.2.5. Investigation 3 – Control and instrumentation

Mine G is a gold mine located in the Free State province of South Africa. The energy cost savings decreased during December 2013 due to a lack of monitoring. During this time, personnel responsible for monitoring the energy cost savings were on leave. Mine G furthermore experienced communication loss during April 2014. The effects of the two events are illustrated in Figure 25. The dip and subsequent rise in savings during and after these periods clearly illustrate the impact.

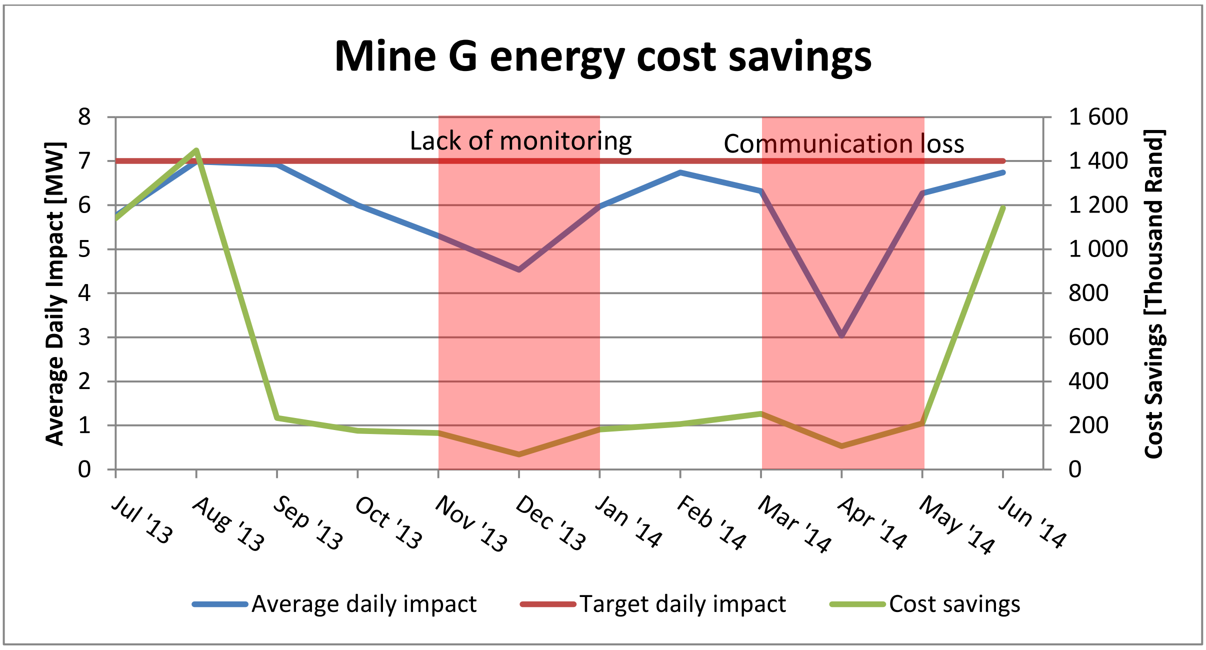


Figure 25: Mine G – Energy cost savings

Mine H is a gold mine in the Free State province of South Africa. Mine H experienced similar problems as Mine F with the control system and the communications during November 2013. The problems were rectified but then surfaced again between April 2014 and May 2014. The effect of the communication and control system is illustrated in Figure 26.

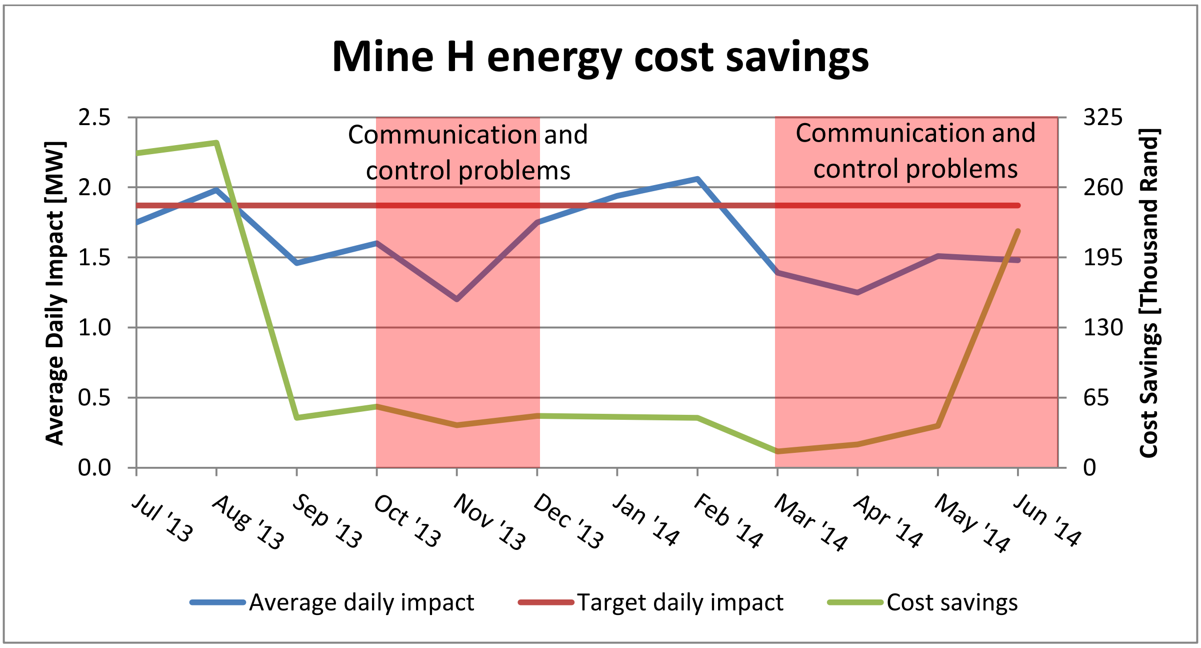


Figure 26: Mine H – Energy cost savings

The communication problems experienced at Mine G and Mine H had a significant effect on the energy cost savings impact of the project. The estimated loss in energy cost savings for Mine G and Mine H amounted to R7.8 million and R700,000 respectively. Table 18 and Table 19 in Appendix B display the missed savings.

3.2.6. Investigation 4 – Changes to control parameters

Mine I is a gold mine in the Gauteng province of South Africa. Mine I experienced deteriorating performance from November 2013 to January 2014 due to work on the dewatering pumps. During January 2014 the operational constraints were changed. The new constraints required more pumps to be operational at all times which had a detrimental effect on the project. During February 2014, the problem was rectified and the energy cost savings returned. The performance of Mine I is illustrated in Figure 27.

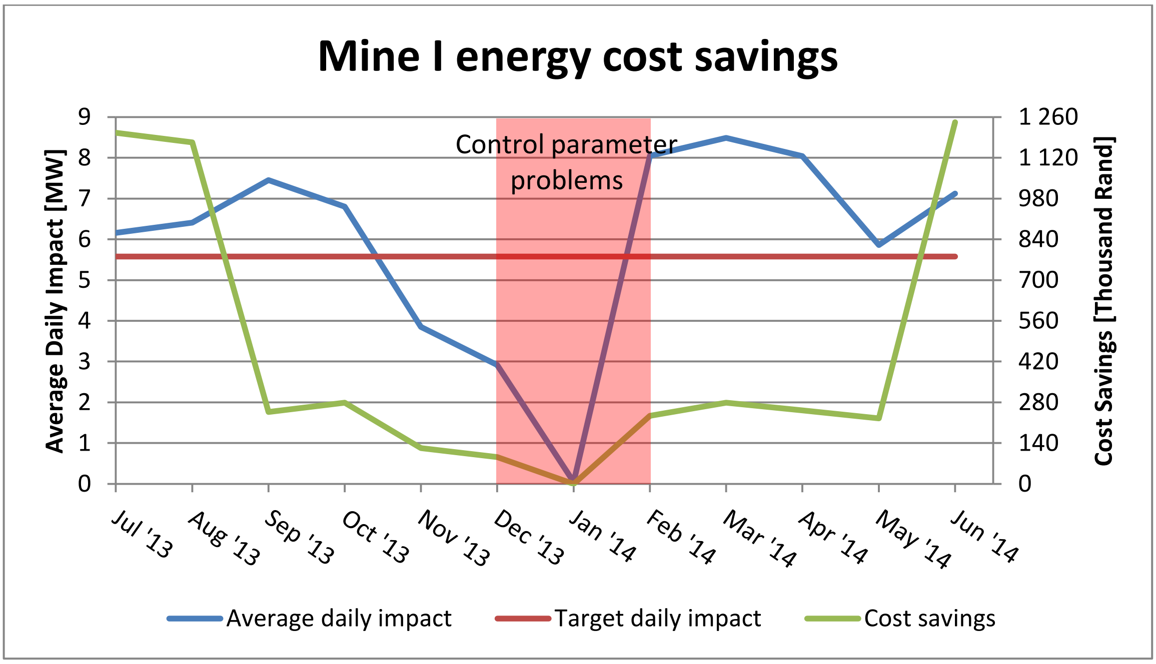


Figure 27: Mine I – Energy cost savings

The estimated energy cost savings that were missed for Mine I amounted to R700,000. Table 20 in Appendix B displays the energy cost savings missed.

3.2.7. Conclusion

The deterioration in project performance was investigated and the cost implications were calculated. The cost implication for data loss was approximately R12.7 million. The cost implications for mechanical failure, control and instrumentation, and control parameters were approximately R11.3 million in total. Thus, these problems have a significant effect on cost savings.

Although data loss is noticed when it occurs, it does not affect mining operations. As a result, the mine does not prioritise rectifying the problem. On the other hand, mechanical hardware failures negatively influence mining operations, thus they are immediately attended to. There is a lack of procedures available to attend to control and instrumentation, and control parameter maintenance. Therefore, more emphasis will be placed on investigating these problems.

Since the problems investigated had significant effects on the project performance, a maintenance procedure will be created to identify the problem and provide a solution.

3.3. Development of a maintenance procedure

3.3.1. Introduction

The results gathered from the investigations are used to create a holistic maintenance procedure. The procedure is structured based on the major problems identified in the previous sections. A high level overview of the procedure is illustrated in Figure 28. Each major component will be discussed in more detail in the sections that follow. Maintenance done during normal operation must continue to make sure that the unplanned maintenance is held to a minimum. This maintenance is referred to as preventative maintenance. If the savings is achieved and no problems are experienced then no unplanned maintenance is required.

The sub procedures are not shown in Figure 28 since the diagram will become cluttered. The effect of an alarm system is not shown in this study since the procedures can function without it.

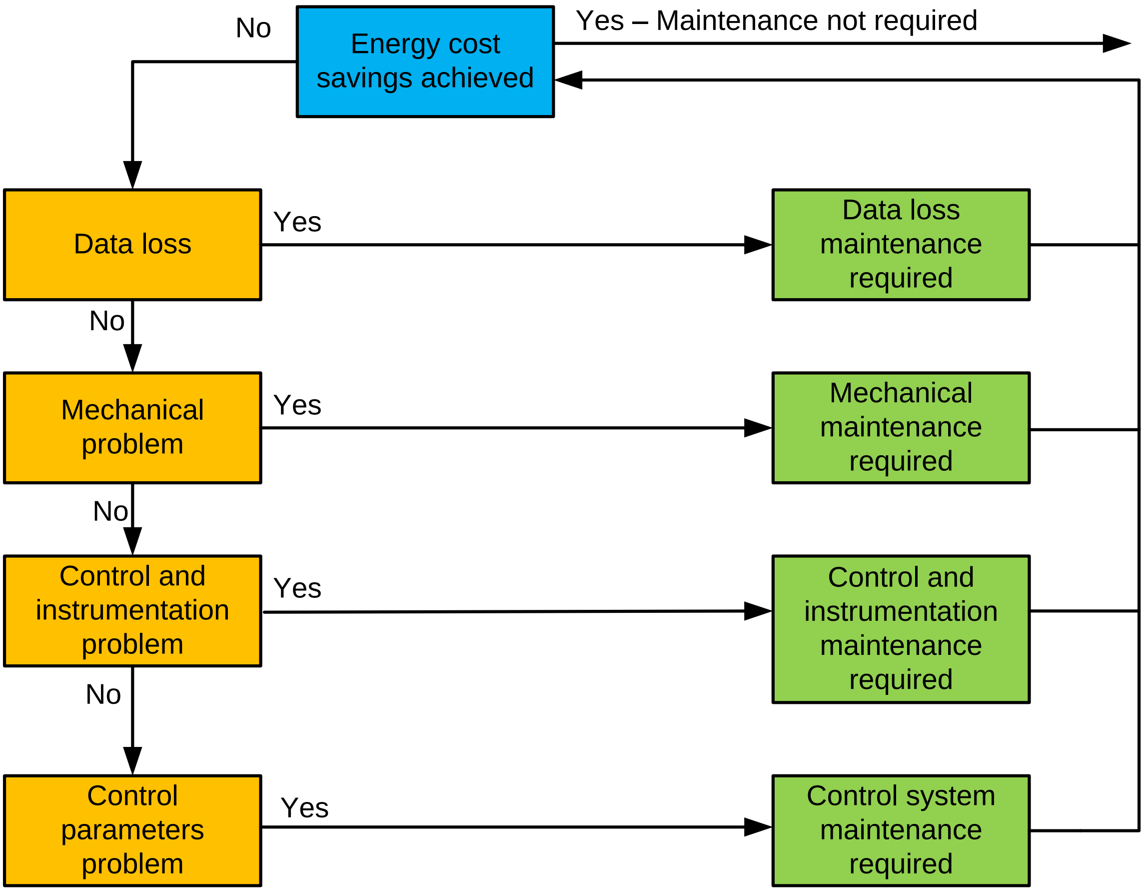


Figure 28: Maintenance procedure flow chart

3.3.2. Procedure 1 – Addressing data loss

The complexity of industrial networks and communication systems present many potential problems that can result in data loss. The first procedure in Figure 28 should be followed when data loss occurs. In the event of data loss the data must be retrieved and manually processed. The data can be collected from various points in the system – including the SCADA, control servers or log sheets. If data is available on log sheets, then the data first has to be entered manually into the computer and processed.

Data loss is usually noticed when it happens because no reports are generated that display the progress for the day. The reports generated are an automated process which establishes that reports are generated automatically daily. Data must be processed to ensure that no potential energy cost savings are lost and to be informed if there are any problems with the system. The procedure is illustrated in Figure 29.

Once data has been processed, the cause of data loss must be addressed. The most common cause of data loss is a problem with control and instrumentation. The rest of the maintenance procedures must be followed to solve the problem.

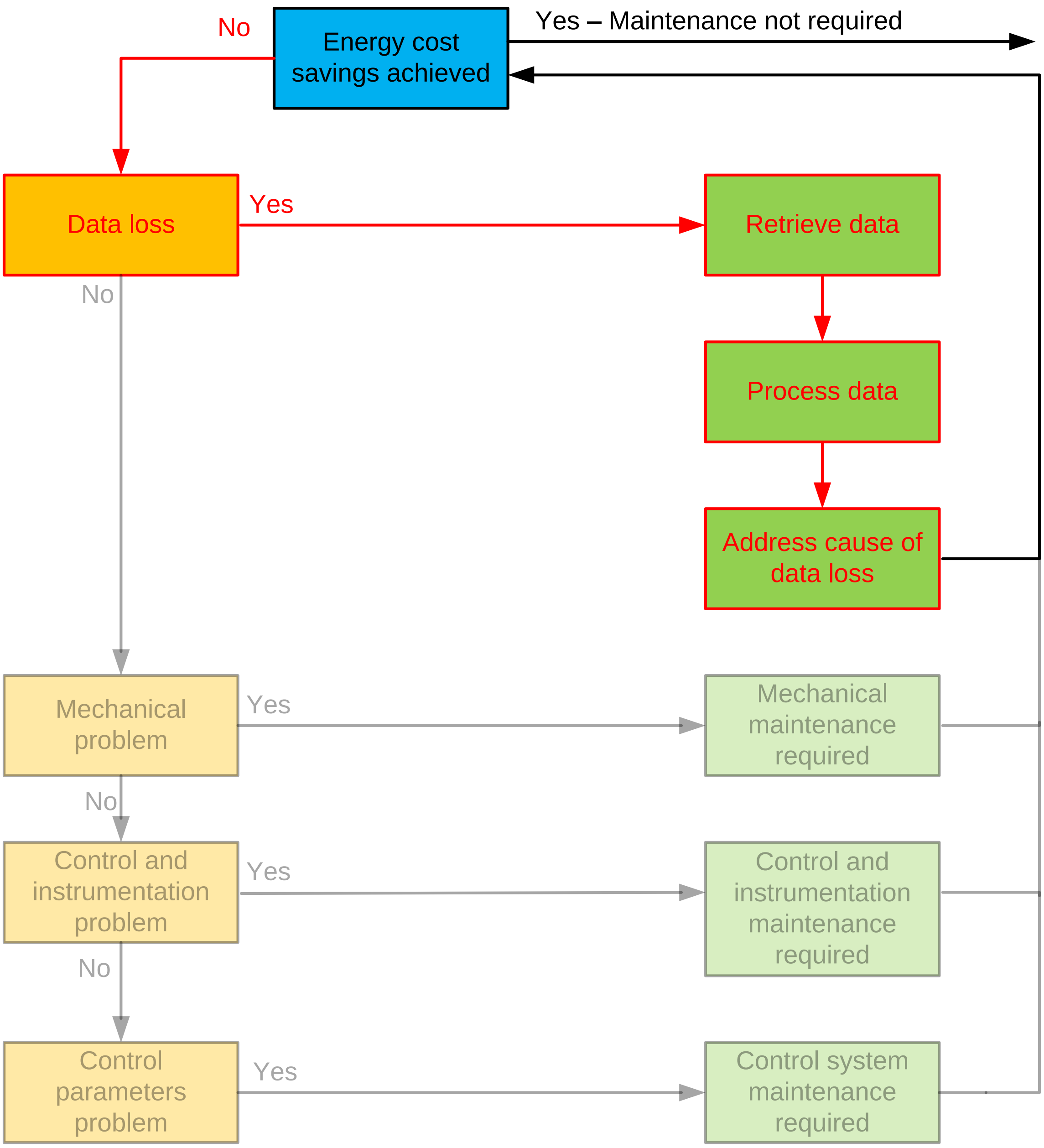


Figure 29: Procedure 1 – Data loss

3.3.3. Procedure 2 – Mechanical failure maintenance

The second procedure is addressing mechanical hardware maintenance. If data is available, then it is possible to monitor project performance. The literature review demonstrated that the most common type of maintenance required is maintenance on the various mechanical components. Although the literature review only stated a few examples of maintenance available for mechanical parts, there are maintenance procedures available for most of the mechanical parts of a pumping system. Once the failed mechanical part has been identified, the supplier/contractor must be informed so that the correct maintenance procedure can be followed. This must be done since every component has a specific maintenance procedure. The procedure is illustrated in Figure 30.

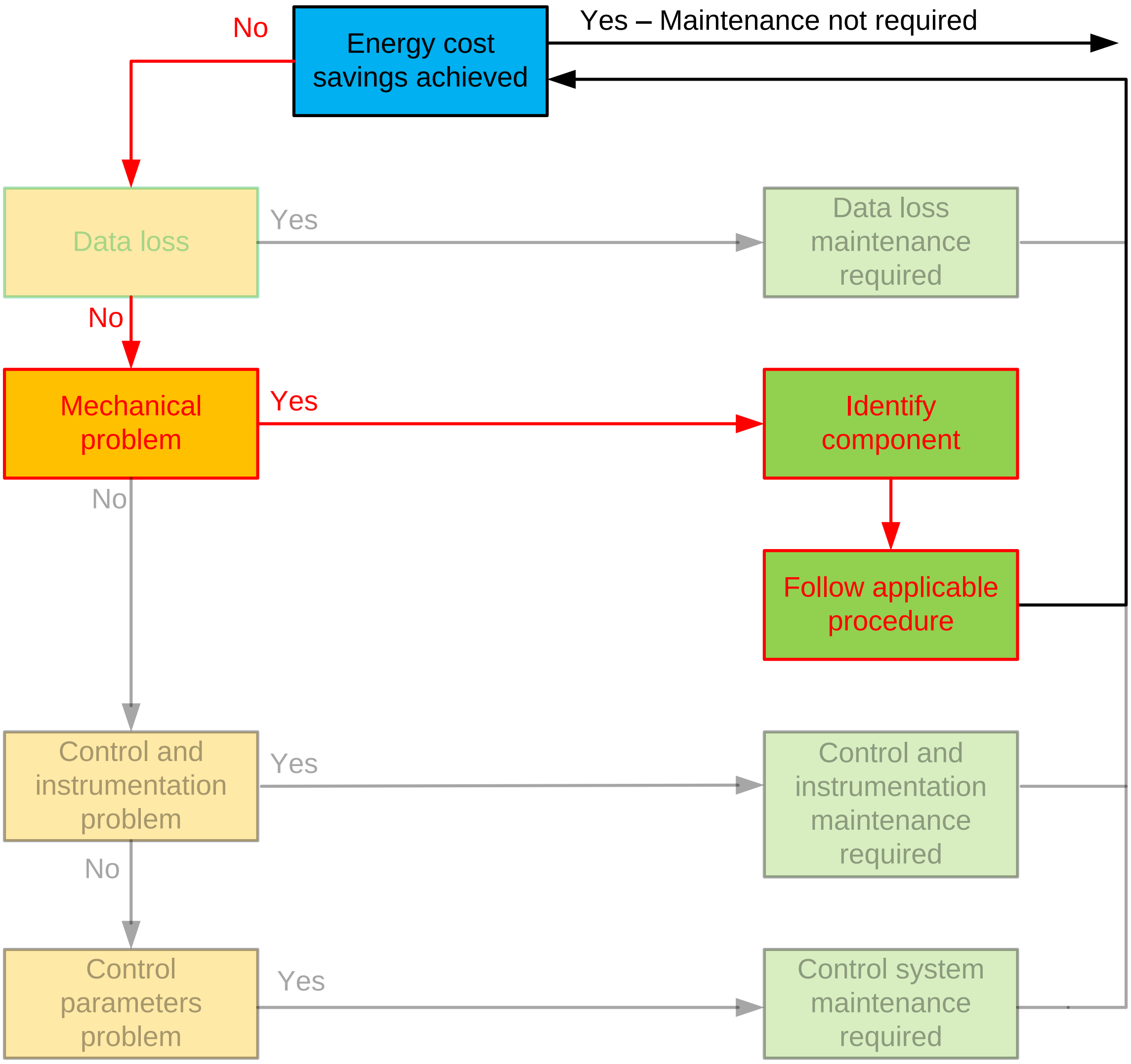


Figure 30: Procedure 2 – Mechanical maintenance

Mechanical hardware maintenance is performed by either the mine or by the supplier. Mechanical failure has a significant effect on critical processes. The issue is, therefore, addressed almost immediately.

3.3.4. Procedure 3 – Control and instrumentation maintenance

The third procedure is for when maintenance is required on the control and instrumentation of the system. If there is no data loss and all the mechanical hardware are working then control and instrumentation must be investigated. The procedure is illustrated in Figure 31.

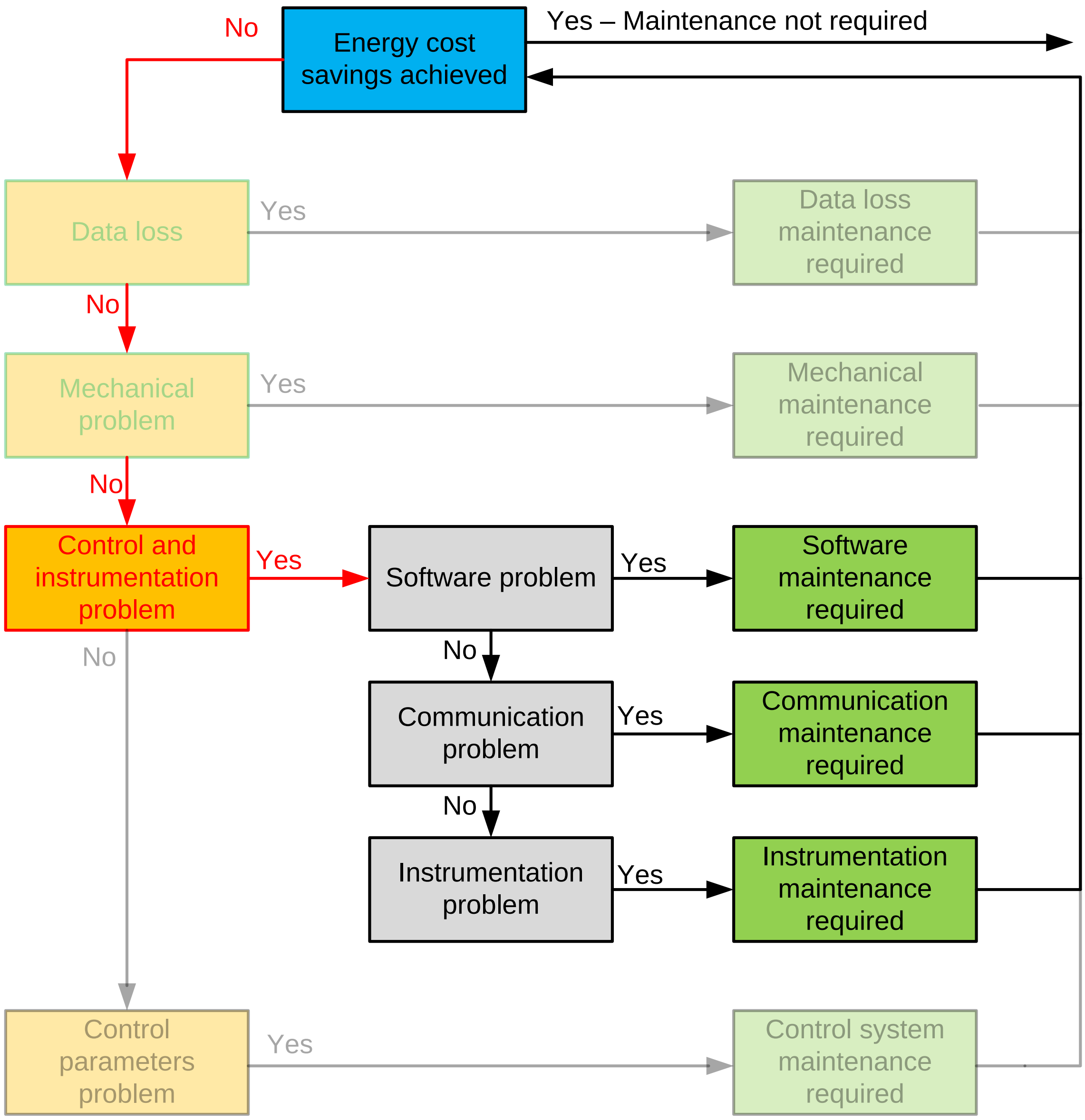


Figure 31: Procedure 3 – Control and instrumentation maintenance

Maintenance on control and instrumentation can be divided into three categories, namely, software, communication and instrumentation. Maintenance done on the control and instrumentation is mostly done by the ESCO, since the ESCO is responsible for monitoring daily electrical energy savings. The ESCO is also responsible for controlling the system.

Procedure 3.1 – Software problem

The first step of control and instrumentation maintenance takes place when there are problems with the control system software. This step is illustrated in Figure 32. The software included in the control system are:

- Control software: Software that controls the system operations containing the platform and tags for the project.
- Data communication software: Software that sends data from the site computer to the ESCO's computers. The ESCO's computers are responsible for generating reports that display project performance. Data displayed includes power usage, pump statuses, dam levels, and so forth.
- Connection software: Software used to remotely connect to the server on-site for monitoring the project, making changes to the server or doing required maintenance.
- Efficiency monitoring software: Software that monitors the efficiencies of certain items, for example, the efficiencies of pumps operating on a level. Information gathered is used to prioritise the pumps and calculate running costs. Using this information, the pump that is most efficient and has the cheapest running cost can be operated.

All the software must be correctly set up when the servers are implemented on-site. This includes the settings for the control, data communication, connection and efficiency monitoring software. If the software is not correctly set up, then it first has to be rectified before any control can be done. The network connection must also be set up correctly so that values can be received from the mine's computer.

The first fault detection step is rebooting the computer. There could be instances where a program crashed; the problem is solved when the system is restarted. If rebooting does not solve the problem then the following steps must be followed:

1. Restart the program.

2. Upgrade the program. The problem could be an outdated software program that does not work with newer versions of other software. There could also be a software issue ('bug') that had been rectified in an updated version of the software.
3. Inform the IT department if these changes do not solve the problem so that the problem can be investigated further.
4. Make changes according to feedback received if the IT department has found the problem.

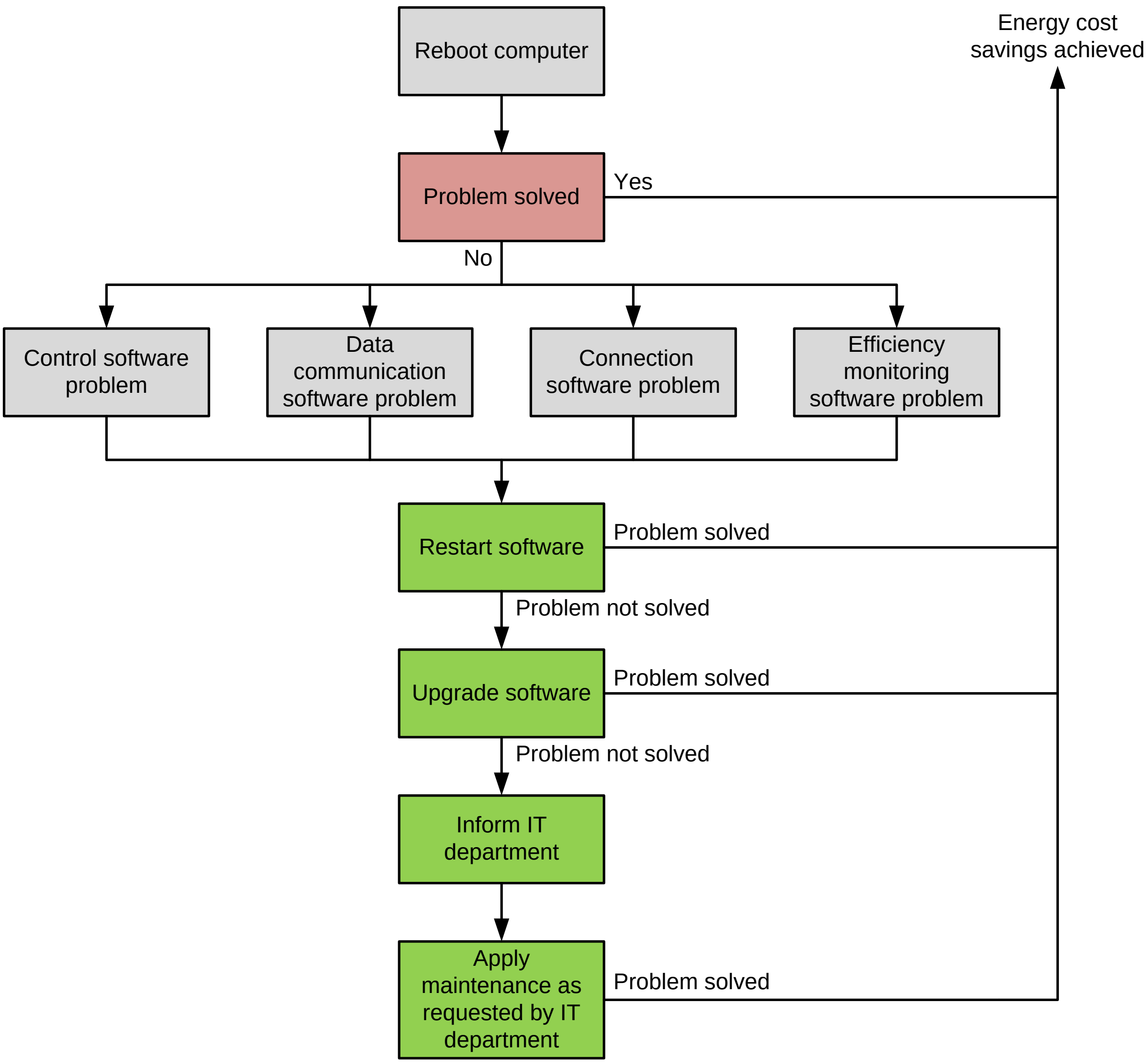


Figure 32: Procedure 3.1 – Software problem

Procedure 3.2 – Communication problem

The second step of control and instrumentation maintenance takes place when problems are encountered with communication. This step is illustrated in Figure 33.

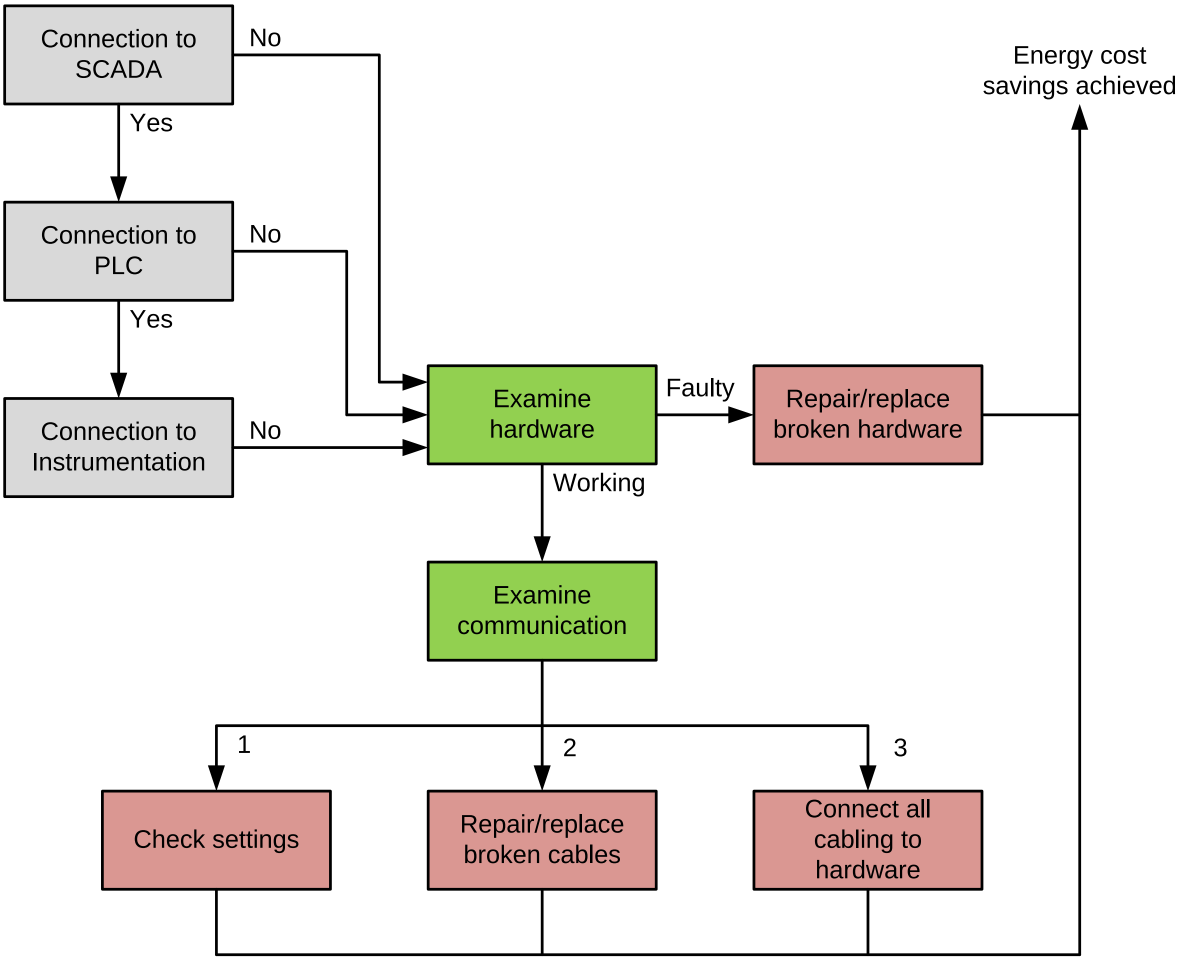


Figure 33: Procedure 3.2 – Communication problem

The communication problem can be between the following components:

- Between the site server, which includes the uninterruptible power supply (UPS) and the modem, and the SCADA
- Between the SCADA and the PLC
- Between the PLC and the instrumentation

Communication problems can also be encountered with instrumentation installed on mechanical equipment such as:

- Flow meters
- Power meters

- Dam level sensors
- Temperature probes
- Pressure transmitters

The first step when investigating a communication problem is to determine between which hardware components the communication problem is occurring. Once this has been established, the maintenance procedure can be used. The steps are:

1. Examine hardware: Inspect hardware to see if it is working. As communication takes places between two hardware components, both components must be inspected, for example, the SCADA and the PLC. If there are problems with the hardware then it must be repaired or replaced.
2. Examine communication: Check if there is communication between the hardware components. If there is no communication, no data will be received and control of the system will be impossible. If there are communication problems between hardware components, then the following must be done:
    - Check that all of the Internet protocols (IPs) and settings are correct
    - Check for damage to cabling (cables, wires, and so forth)
    - Check that all the cabling is connected to the hardware

Procedure 3.3 – Instrumentation problem

The third step of control and instrumentation maintenance takes place when a problem is encountered with the instrumentation. This step is illustrated in Figure 34. Instrumentation is divided into two categories, namely:

- Control instrumentation: Instrumentation that controls equipment according to certain set points. For example, an actuator that controls a valve according to the required flow by the pump.
- Data instrumentation: Instrumentation that measures the desired parameters:
    - Flow meter that measures flow in pipe.
    - Temperature probe that measures temperature of pump motor.

The steps to follow when instrumentation problems are encountered include:

1. Do general maintenance: This includes tasks to keep the instrumentation in working order, for example, cleaning the nozzles of a pneumatic valve to ensure that there are no blockages.

2. Calibrate equipment: The equipment must be calibrated to ensure that it is measuring correctly. This is also done to ensure that there is no damage to the measuring equipment.
3. Contact supplier/contractor to repair or replace: If the problems cannot be rectified by the first two steps then the supplier/contractor of the equipment must be contacted. The instrument can then either be repaired, or replaced if it is badly damaged or too expensive to repair.

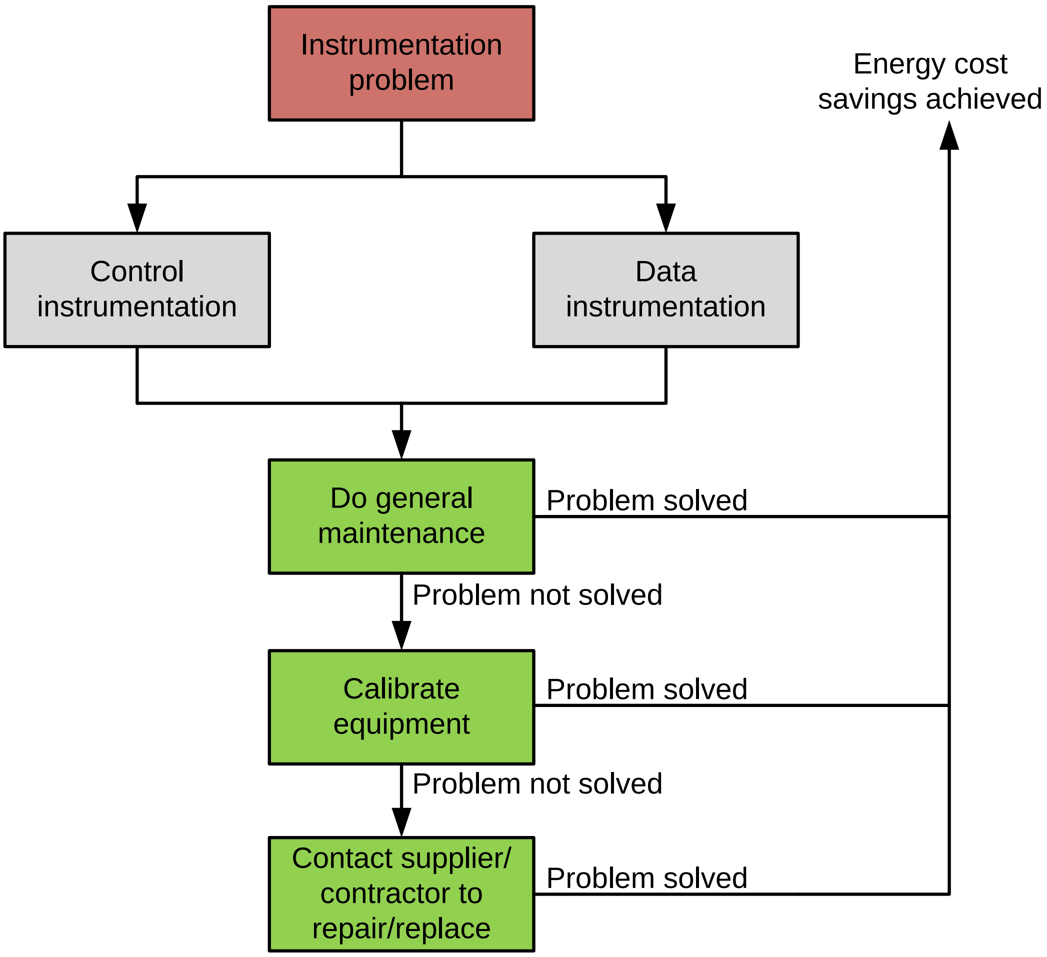


Figure 34: Procedure 3.3 – Instrumentation problem

3.3.5. Procedure 4 – Control parameter maintenance

The fourth procedure takes place when maintenance must be done on control parameters. Maintenance is required on control parameters if all the mechanical hardware, and control and instrumentation are operating. Control parameter maintenance is divided into three categories, namely, constraints, preferences and feedback. The procedure is illustrated in Figure 35.

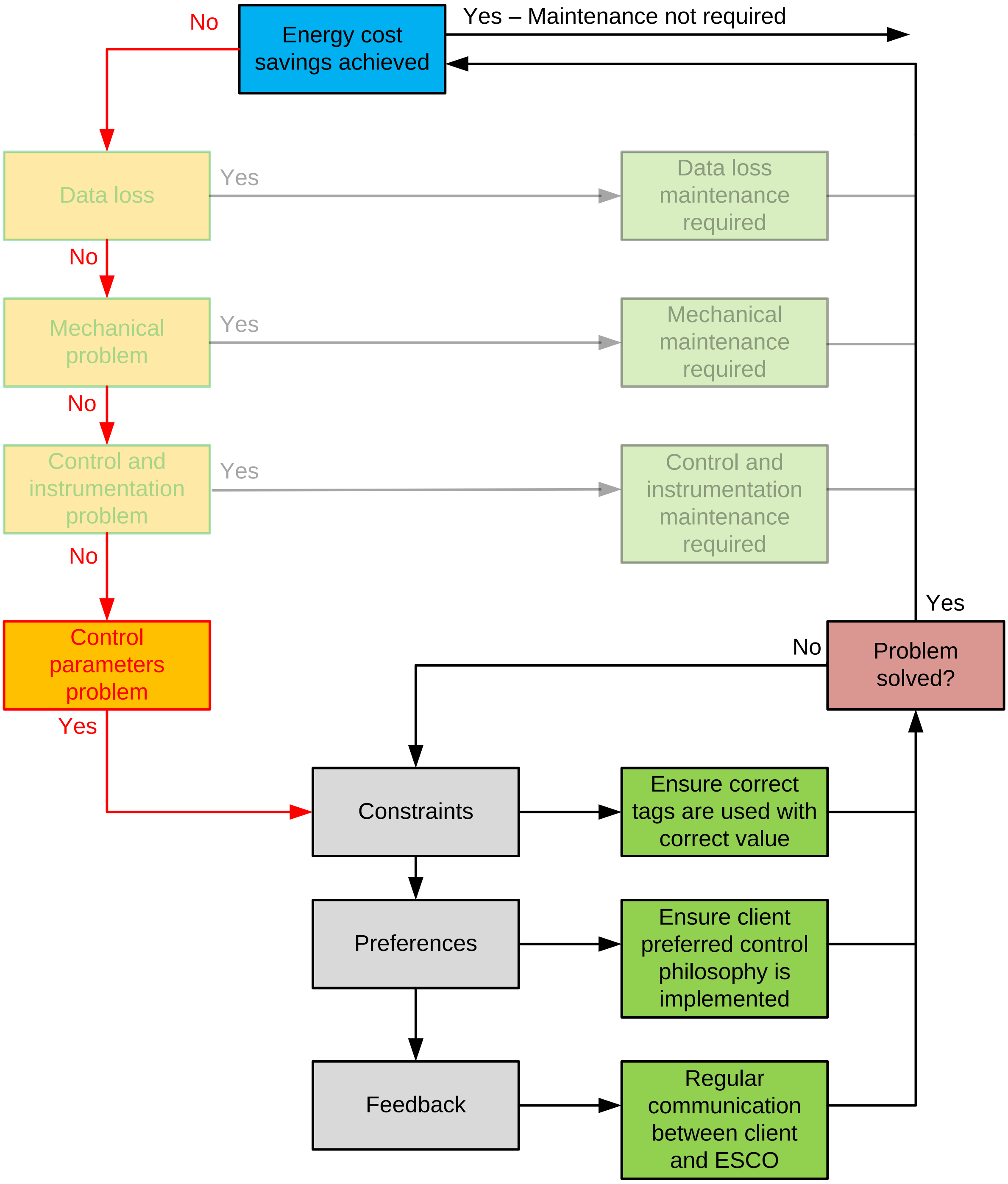


Figure 35: Procedure 4 – Control parameter maintenance

Procedure 4 consists of three steps:

1. Constraints: The first step is to ensure that the project constraints are implemented. The constraints include the layout of the system with all the relevant information incorporated into it. The information consists of the following:
    - Number of pumps available
    - Dam sizes and levels
    - Capacities and sizes of pumps
2. Preferences: The client has certain criteria that the system must fulfil, for example, a pump has to monitor a dam level before switching on or off. Certain pumps have additional criteria, for example, monitoring the status of other equipment, such as a 3CPS, to decide when it must operate.
3. Feedback: Constant feedback is required between the client and the ESCO to ensure that any system changes are incorporated into the control. This includes changes such as pump failure and dams being cleaned, thus not being available.

3.4. Conclusion

Investigations were conducted to determine the causes of degrading project performance. The main reasons were mechanical failures, control and instrumentation, and control parameters. The effect of data loss is that information regarding project performance is also lost. The investigations were used to create a maintenance procedure to enable the identification of problems and present recommended solutions to the issues. This procedure can be implemented on any mine pumping system. The procedure will be tested in the next chapter.

Implementation of maintenance procedures

Deep-level mining shaft[15]

[15]Mining-technology.com, "Assmang Manganese Mines, Northern Cape Province, South Africa," Kable, 2014. [Online]. Available: http://www.mining-technology.com/projects/assmang/assmang6.html. [Accessed 14 July 2014].

4.1. Introduction

Three case studies will be shown in this chapter. The case studies illustrate the results obtained when the new maintenance procedure was implemented. The results show that constant maintenance helps to maintain the electrical energy savings of a project and helps to maintain the costs savings achieved. The case studies were done at three gold mines in South Africa and will be referred to as Case Study A, Case Study B and Case Study C.

Confidentiality agreements protect the names of the mines where the case studies took place. Sensitive mine information is not included in this dissertation. Please contact the author with any questions.

A structural maintenance approach was developed in Chapter 3. The impact of the approach was verified by implementing the approach as case studies on industrial mines. The frequency of maintenance was measured using data obtained from maintenance engineers' logbooks. The impact of the maintenance approach was determined by monitoring the project performance/cost savings. MW target savings were used as an indicator due to the changing electricity tariffs.

The maintenance procedure created in Chapter 3 was used to determine the maintenance required. Numerous procedures were available for maintenance on mechanical hardware. Mechanical failures were fixed by the mine since it affected mine operations. Since data loss was noticed almost immediately, it was rectified as it occurred. The mine did not regard the control and instrumentation, and control parameters as high priority since they did not affect mine operations and, thus, had to be maintained by an external party. The applied maintenance procedures are illustrated for each case study under application of maintenance procedure.

4.2. Case Study A

4.2.1. Overview

Case Study A took place at a gold mine situated near Virginia in the Free State province of South Africa. The mine has five ore-producing levels, namely: 1750L, 1780L, 1810L, 1940L and 2010L. Chilled water, which is used for cooling at the surface fridge plants, is sent underground for cooling and mining purposes. After it is used, it is channelled together with fissure water to shaft bottom, which is approximately 2 200 m below the surface.

There are two dewatering pumping stations, one located on 2180L and one located on 1200L. The pumping station on 2180L is approximately 2 180 m below surface and has one 1.5 MW and three 1.25 MW multistage centrifugal pumps. Water is pumped from 2180L to 1200L. There are four 1.5 MW multistage centrifugal pumps on 1200L that pumps water to the surface precooling dam. The water is then used again at the surface fridge plants.

Case Study A is a load shifting project with targeted electrical energy savings of 2.29 MW. The project was implemented in 2005 and has a maintenance contract with the ESCO to ensure that the savings are sustained. A simplified layout of the mine's water reticulation system is illustrated in Figure 36.

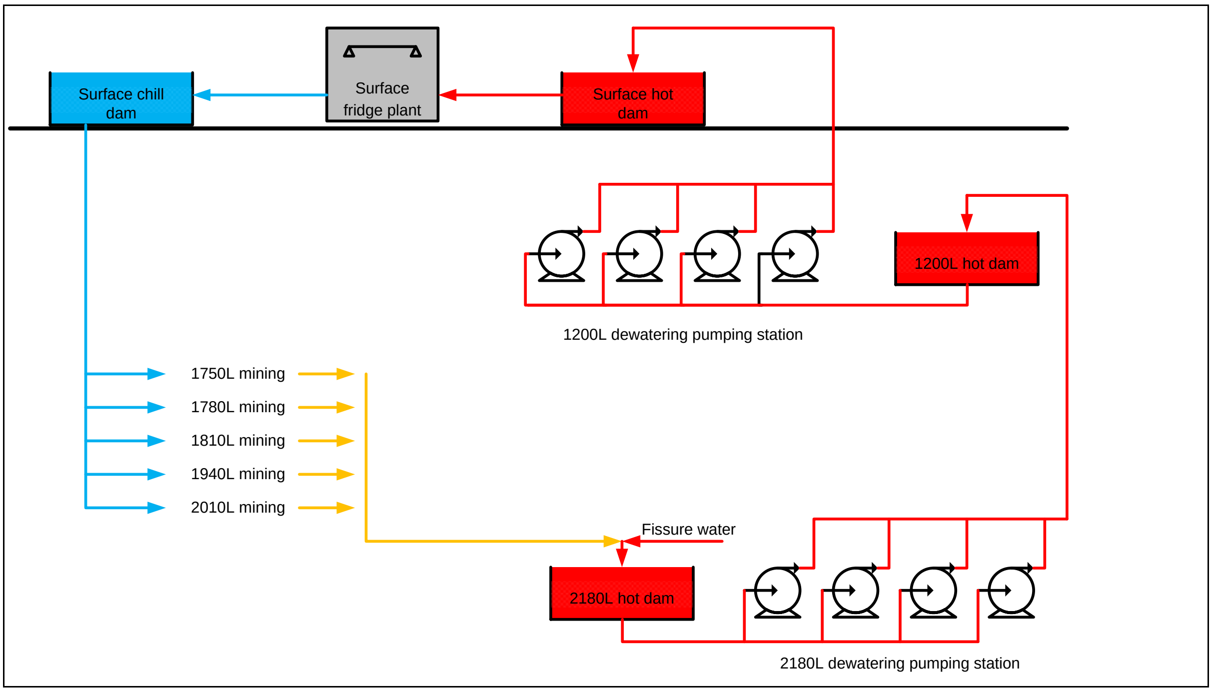


Figure 36: Case Study A – Simplified layout

4.2.2. Application of maintenance procedure

The completed maintenance tasks, together with their correlating dates, are presented in Table 2. The selected maintenance procedure is displayed in red.

Table 2: Case Study A – Maintenance tasks completed

	Maintenance procedure				
Date	**Pr 1**	**Pr 2**	**Pr 3**	**Pr 4**	**Action taken**
03/07/2013					Reboot computer
11/07/2013					Update data communication software
22/08/2013					Have meeting about fridge plants (FP)
03/09/2013					Retrieve FP information for new investigation
01/10/2013					Retrieve FP constraints for investigation
02/10/2013					Implement FP constraints into control software
05/11/2013					Implement FP constraints into control software
19/11/2013					Update control software
10/12/2013					Maintain efficiency monitoring software
09/01/2014					Give general feedback regarding performance
14/01/2014					Give general feedback regarding performance
16/01/2014					Give feedback about control parameter constraints
05/02/2014					Give general feedback regarding performance
05/03/2014					Efficiency monitoring software maintenance
12/03/2014					Efficiency monitoring software maintenance
13/03/2014					Update data communication software
17/03/2014					Maintain efficiency monitoring software
18/03/2014					Maintain efficiency monitoring software
02/04/2014					Implement constraints into control software
07/04/2014					Implement constraints into control software
15/04/2014					Retrieve efficiency monitoring software constraints
16/04/2014					Implement efficiency monitoring software constraints
24/04/2014					Maintain efficiency monitoring software
24/04/2014					Update data communication software
14/05/2014					Update control and instrumentation hardware
15/05/2014					Maintain mechanical pump (flow)
21/05/2014					Set up control and instrumentation hardware
22/05/2014					Set up control and instrumentation hardware
28/05/2014					Do general mechanical pump check up
05/06/2014					Maintain control software
18/06/2014					Update control philosophy preferences
25/06/2014					Update data communication software
26/06/2014					Retrieve control software platform for backup

The actions identified for each problem shows that each procedure was implemented successfully. The number of maintenance site visits and the selected procedures are illustrated in Figure 37.

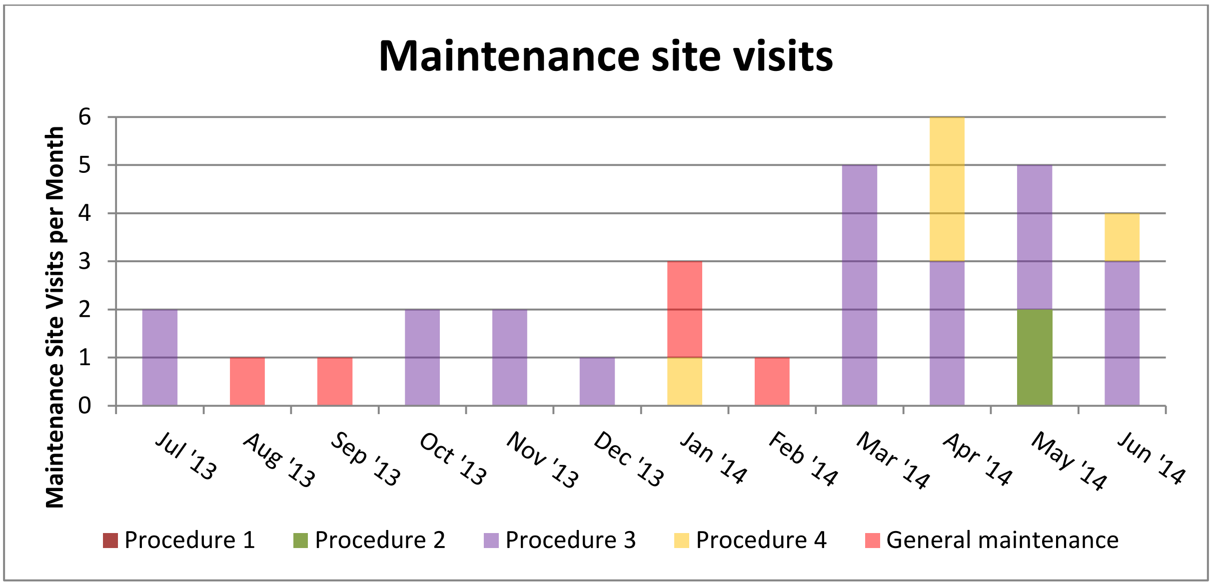


Figure 37: Case Study A – Maintenance site visits

The majority of maintenance issues related to control and instrumentation. An increase in events during the period from March 2014 to June 2014 was due to problems encountered with the efficiency monitoring software.

4.2.3. Savings achieved

The electricity energy savings and cost savings for Case Study A are illustrated in Figure 38.

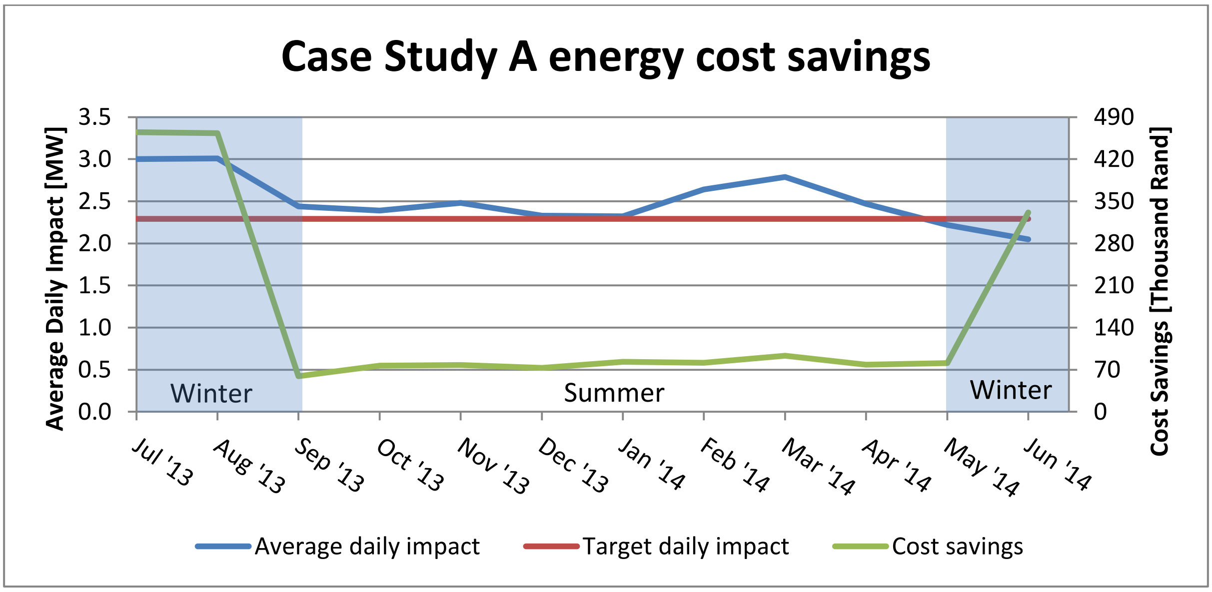


Figure 38: Case Study A – Energy cost savings

The electrical energy savings remain fairly constant due to maintenance being done. Maintenance is done when a problem is encountered to ensure that all operations are working correctly. The decrease in savings from March 2014 was mitigated by additional maintenance.

Table 21 in Appendix C displays the values for the electrical energy and cost savings. The cumulative performance of the project is illustrated in Figure 39. The cumulative impact remains more than the cumulative target throughout the 12 months that were recorded.

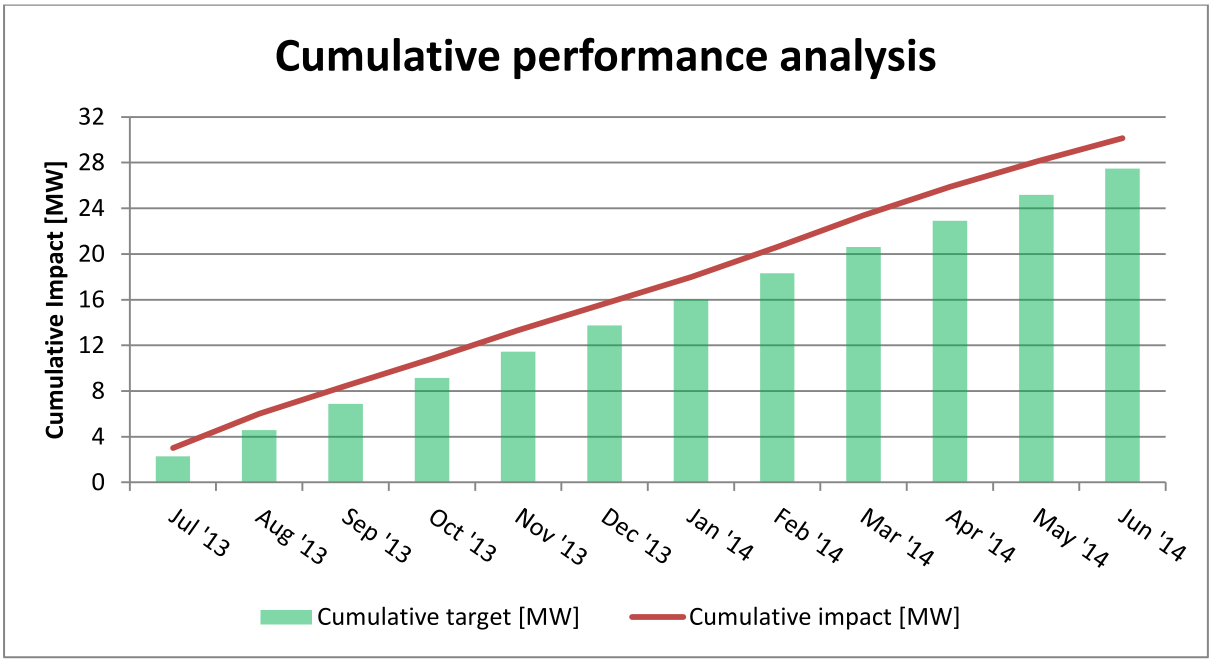


Figure 39: Case Study A – Cumulative performance analysis

4.2.4. Issues experienced

Case Study A underperformed during the months of May and June 2014. The reason for the underperformance was because the dam on 2180L was being cleaned. This was done because of mud accumulating in the dam, thus decreasing the size and efficiency of the dam. During the time that the dam was being cleaned, the operation of the dewatering pumping system was switched to manual control. This had the effect that the control program could not control the pumps and that they were controlled manually by the pump operators. The schedule and status of the pumps on 2180L for 18 June 2014 are illustrated in Figure 40. Status describes the amount of pumps operating.

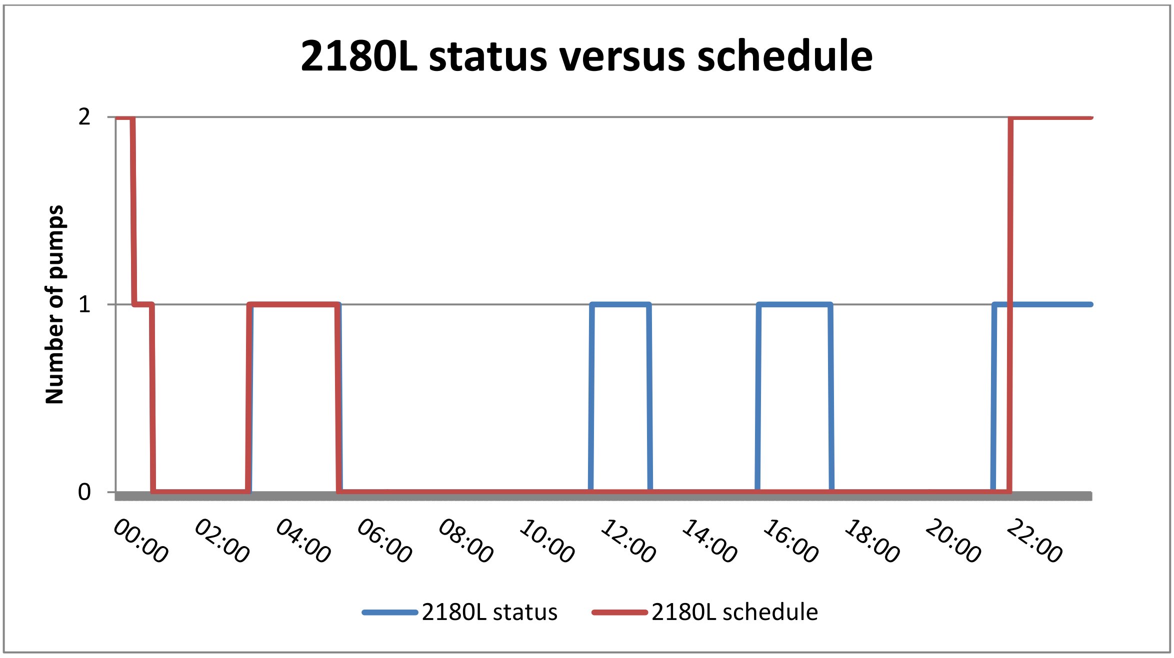


Figure 40: Case Study A – 2180L status versus schedule

The schedule and status of the pumps on 1200L for 18 June 2014 are illustrated in Figure 41.

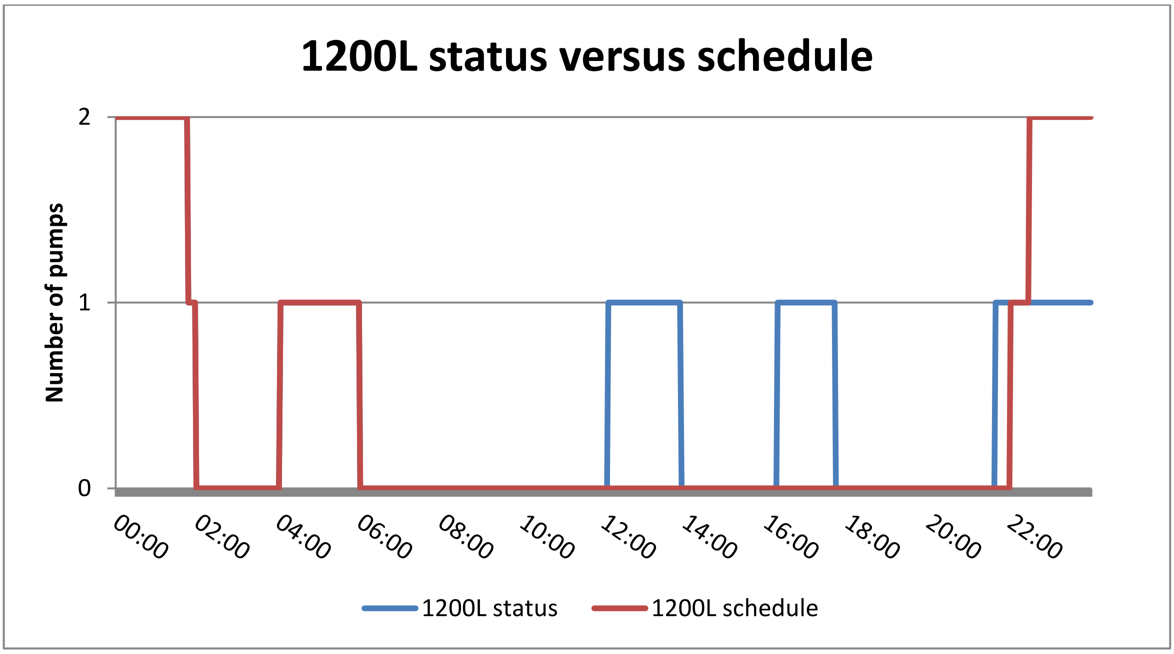


Figure 41: Case Study A – 1200L status versus schedule

It is clear that the status and schedule do not correlate with each other. This clearly affected the savings since the targeted savings were not achieved. After work on the dam was completed, the savings returned to normal. The electrical energy savings (average weekday impact) for Case Study A from April to July 2014 are shown in Table 3. It illustrates that the energy cost savings returned to above the targeted impact after work was completed on the dam.

Table 3: Case Study A – Underperformance

Case Study A energy cost savings			
Month	**Average daily impact [MW]**	**Target daily impact [MW]**	**Cost savings [R]**
Apr 2014	2.47	2.29	78 000
May 2014	2.22	2.29	81 000
Jun 2014	2.05	2.29	332 000
Jul 2014	2.32	2.29	417 000

4.3. Case Study B

4.3.1. Overview

Case Study B was done at a gold mine situated near Odendaalsrus in the Free State province of South Africa. The mine has ten ore-producing levels, namely, 52L, 55L, 57L, 60L, 63L, 66L, 69L, 71L, 73L and 75L. The mine has a 3CPS that is used for dewatering. The shaft bottom at the mine used for Case Study B is almost 2 400 m below surface.

Case Study B has two dewatering pumping stations that are automatically controlled using a control program. The one pumping station is located on 45L and the other pumping station is located on 66L. The pumping station on 66L has seven 1.5 MW multistage centrifugal pumps. Water is pumped from 66L to 45L. The pumping station on 45L consists of three 2.5 MW multistage centrifugal pumps. There is also a 3CPS system that is used to pump water from 45L to surface. Water is pumped from 45L to the surface precooling dam. Water is then cooled at the surface fridge plants and sent back underground.

Case Study B is a load shifting project with a contractual targeted electrical energy saving of 3.10 MW. The project was initially implemented in 2005 and has had a maintenance contract with the ESCO since implementation was completed. The simplified layout of the mine is illustrated in Figure 42.

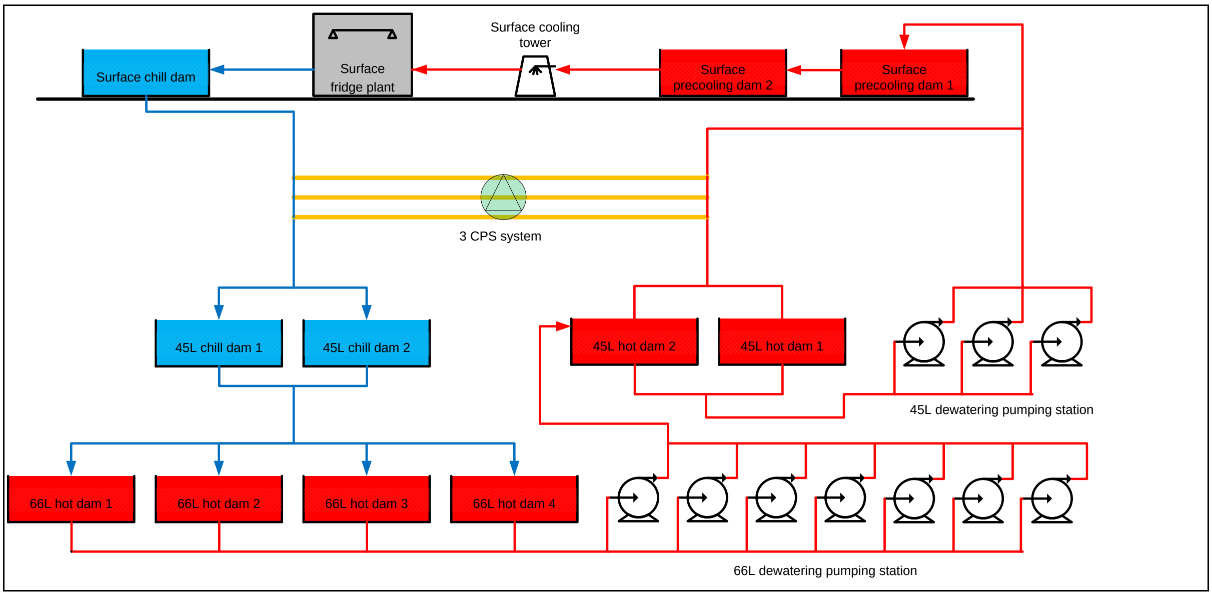


Figure 42: Case Study B – Simplified layout

4.3.2. Application of maintenance procedure

The completed maintenance tasks, together with their correlating dates, are presented in Table 4. The selected maintenance procedure is displayed in red.

Table 4: Case Study B – Maintenance tasks completed

	Maintenance procedure				
Date	**Pr 1**	**Pr 2**	**Pr 3**	**Pr 4**	**Action taken**
02/07/2013					Implement control philosophy preferences
03/07/2013					Implement control philosophy preferences
09/07/2013					Implement control philosophy preferences
10/07/2013					Implement control philosophy preferences
15/07/2013					Implement control philosophy preferences
25/07/2013					Implement control philosophy preferences
30/07/2013					Implement control philosophy preferences
01/08/2013					Implement control philosophy preferences
06/08/2013					Implement control philosophy preferences
07/08/2013					Implement control philosophy preferences
12/08/2013					Implement control philosophy preferences
13/08/2013					Deliver control and instrumentation hardware
14/08/2013					Implement control philosophy preferences
22/08/2013					Implement control philosophy preferences
28/08/2013					Implement control philosophy preferences
29/08/2013					Implement control philosophy preferences

Date	Maintenance procedure				Action taken
	Pr 1	Pr 2	Pr 3	Pr 4	
03/09/2013					Implement control philosophy preferences
04/09/2013					Implement control philosophy preferences
12/09/2013					Implement control philosophy preferences
17/09/2013					Implement control philosophy preferences
30/10/2013					Set up control and instrumentation hardware
31/10/2013					Set up control and instrumentation hardware
14/01/2014					Give general feedback regarding performance
11/02/2014					Maintain control software
24/02/2014					Maintain control software
25/02/2014					Maintain control software
26/02/2014					Maintain data communication software
04/03/2014					Maintain efficiency monitoring software
11/03/2014					Retrieve efficiency monitoring software constraints
12/03/2014					Implement efficiency monitoring software constraints
01/04/2014					Implement control program constraints
02/04/2014					Maintain network connection; reboot server
07/04/2014					Maintain connection software
16/04/2014					Give general feedback regarding performance
17/04/2014					Maintain data communication software
20/05/2014					Deliver control and instrumentation hardware
29/05/2014					Give general feedback regarding performance

The actions identified for each problem shows that each procedure was implemented successfully. The number of maintenance site visits and the selected procedures is illustrated in Figure 43.

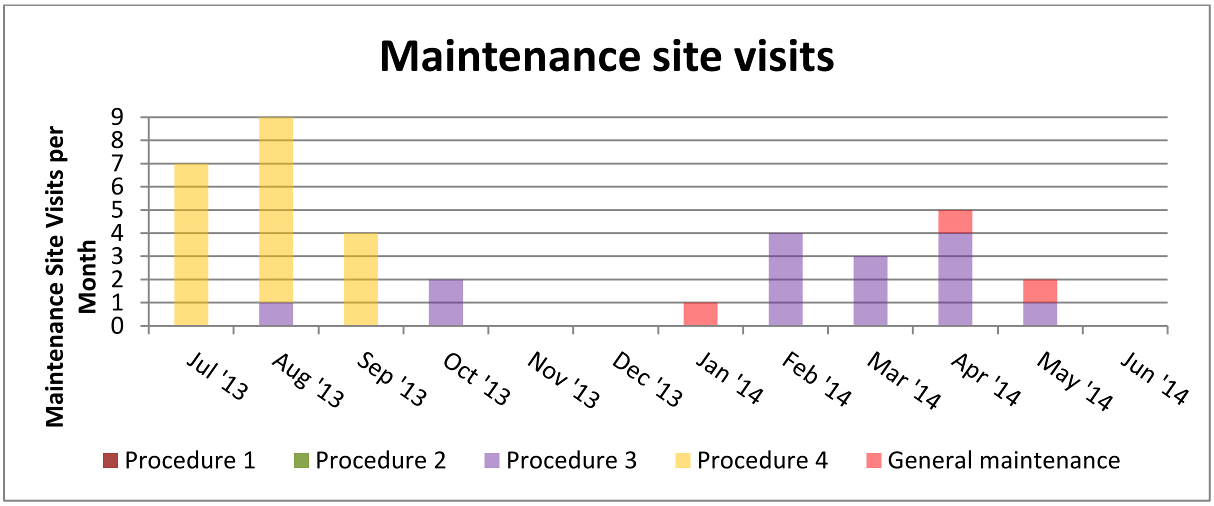


Figure 43: Case Study B – Maintenance site visits

The majority of maintenance issues related to control parameters that had to be updated. An increase in events during the period from July to September 2013 was due to an outdated control philosophy. Once the control philosophy was updated, maintenance site visits decreased until no maintenance was done during November and December 2013.

4.3.3. Savings achieved

The electrical energy savings and cost savings for Case Study B are illustrated in Figure 44. The savings remained fairly constant throughout. The decrease in savings during December 2013 was due to no maintenance being done on the case study. Maintenance was done from January 2014 and the savings returned to above the target daily impact.

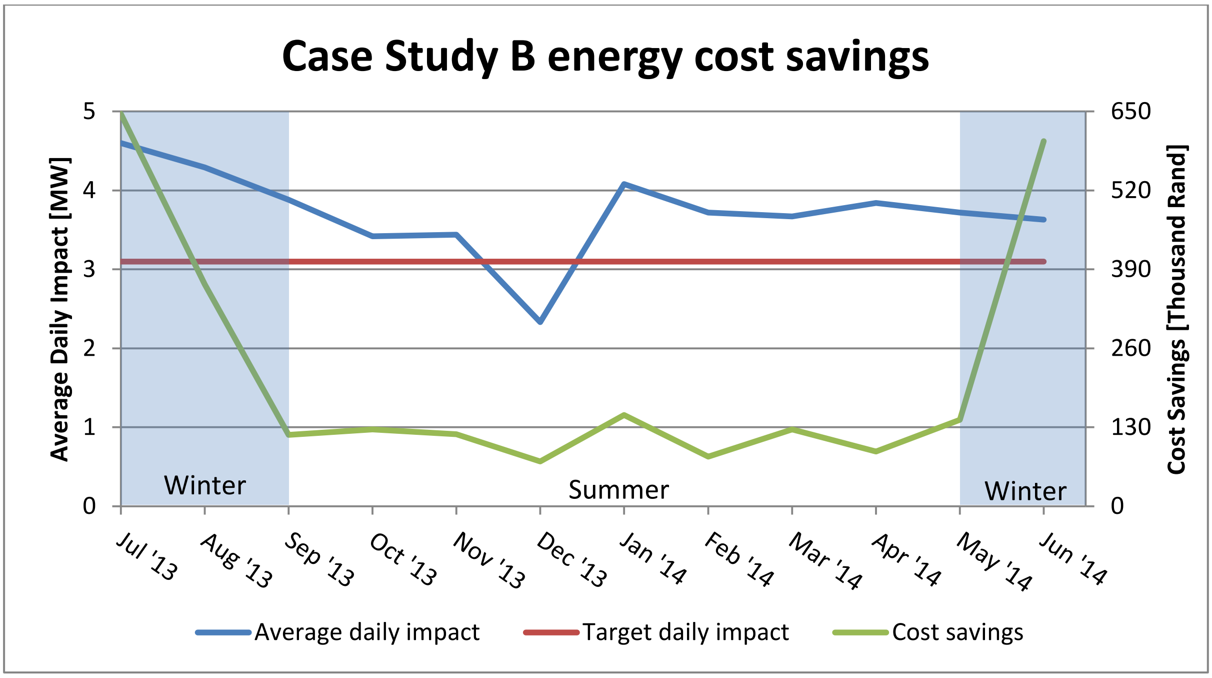


Figure 44: Case Study B – Energy cost savings

Table 22 in Appendix C displays the electrical energy and cost saving values for Case Study B. The cumulative performance of the mine is illustrated in Figure 45. Throughout the 12 months that were recorded the cumulative impact remained more than the cumulative target.

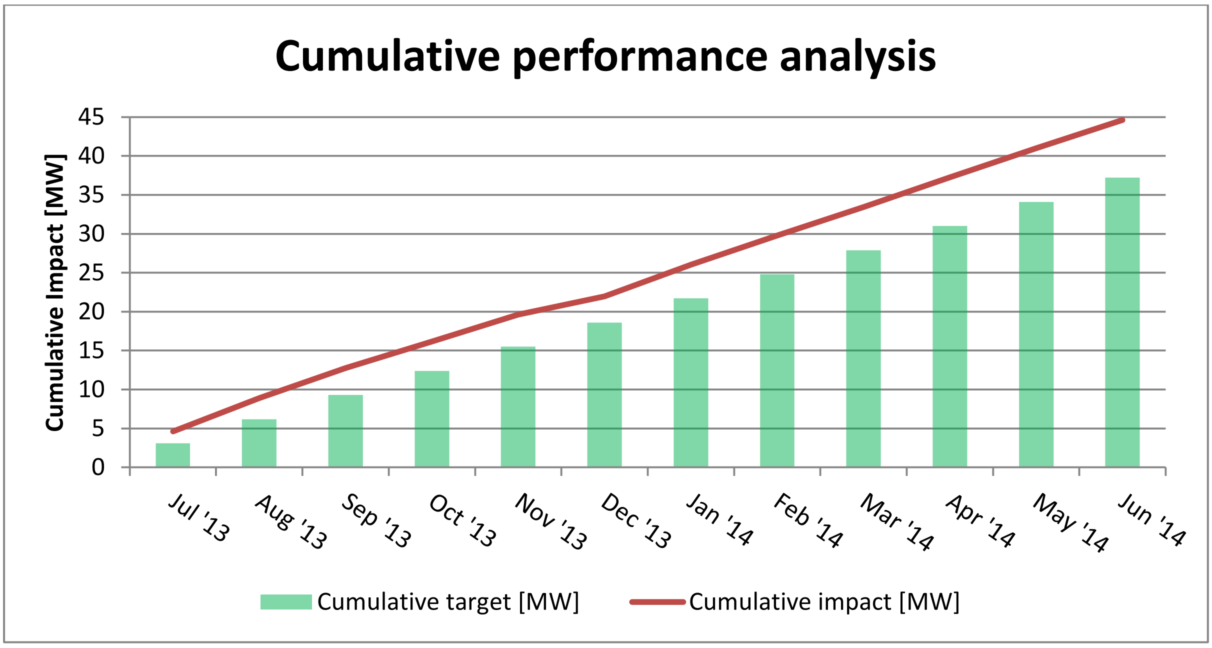


Figure 45: Case Study B – Cumulative performance analysis

4.3.4. Issues experienced

An issue was experienced at Case Study B with the control philosophy. The tag responsible for controlling the pumps on 45L is illustrated in Figure 46.

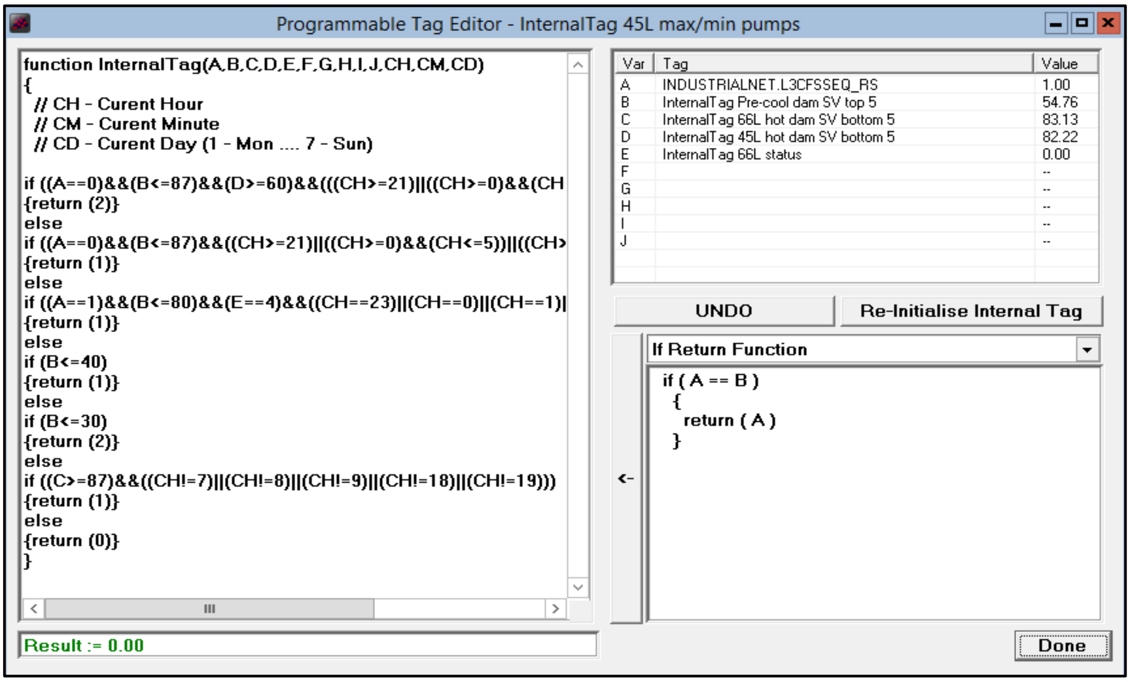


Figure 46: Case Study B – 45L control tag

The control of Case Study B was very complex since the 3CPS had to be taken into consideration. Control of 45L pumps did not only depend on the dam level of 45L and the dam level of the surface pre-cool dam 1, but also on the dam level on 66L and the status of the 3CPS. The whole system was integrated to ensure that no levels were flooded and to ensure that working conditions were safe. Implementation of the control system was very complex and time consuming.

4.4. Case Study C

4.4.1. Overview

Case Study C was done at a gold mine situated near Orkney in the North West province of South Africa. The mine has eight ore-producing levels, namely: 44L, 47L, 50L, 53L, 59L, 62L, 64L and 68L. Mining depths range from 1 350 m to 2 240 m. The simplified layout of the mine is illustrated in Figure 47.

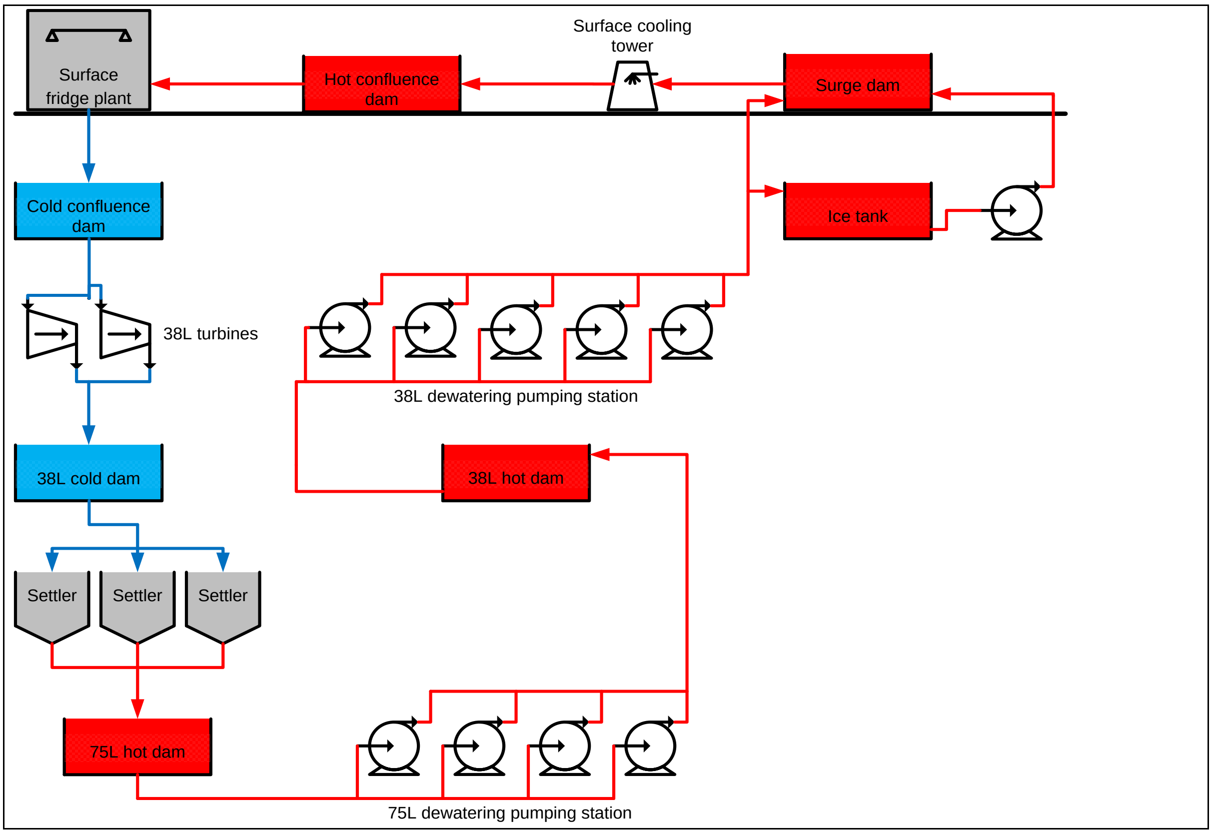


Figure 47: Case Study C – Simplified layout

The mine has two dewatering pumping stations, namely, 38L and 75L. The 75L dewatering pumping station has four 2 MW multistage centrifugal pumps. The water is pumped from 75L hot dam to 38L hot dam. The 38L dewatering pumping station has three 2 MW multistage centrifugal pumps and two turbine pumps. The turbine pumps operate with energy being generated by water flowing through it from the cold confluence dam to the 38L cold dam. The energy generated is used to generate the two pumps connected to it. Water is pumped from 38L hot dam to the surge dam on surface. If the surge dam is at maximum capacity, then the valve that goes to the surge dam is closed and water flows to the ice dam.

Case Study C is a load shifting project with a contractual targeted electrical energy saving of 3.00 MW. The project was initially implemented in 2004 and has had a maintenance contract with the ESCO since the implementation was completed.

4.4.2. Application of maintenance procedure

The completed maintenance tasks, together with their correlating dates, are presented in Table 5. The selected maintenance procedure is displayed in red.

Table 5: Case Study C – Maintenance tasks completed

	Maintenance procedure				
Date	**Pr 1**	**Pr 2**	**Pr 3**	**Pr 4**	**Action taken**
15/07/2013					Update control philosophy preferences
26/09/2013					Give general feedback regarding performance
10/10/2013					Give general feedback regarding performance
29/10/2013					Give general feedback regarding performance
21/11/2013					Update control philosophy preferences
27/11/2013					Update control and instrumentation software
04/12/2013					Collect data for maintenance
09/12/2013					Upgrade control and instrumentation hardware
09/01/2014					Give general feedback regarding performance
15/01/2014					Maintain control software
03/02/2014					Mechanical maintenance (PLC) required
10/03/2014					Maintain control software
01/04/2014					Give general feedback regarding performance
01/04/2014					Collect data and platforms for maintenance
13/05/2014					Give general feedback regarding performance
19/05/2014					Maintain control software
20/05/2014					Maintain control software
21/05/2014					Maintain control software

	Maintenance procedure				
Date	**Pr 1**	**Pr 2**	**Pr 3**	**Pr 4**	**Action taken**
22/05/2014					Maintain control software
23/05/2014					Maintain control software
09/06/2014					Maintain control software
17/06/2014					Give general feedback regarding performance

The actions identified for each problem shows that each procedure was implemented successfully. The number of maintenance site visits and the selected procedure are illustrated in Figure 48.

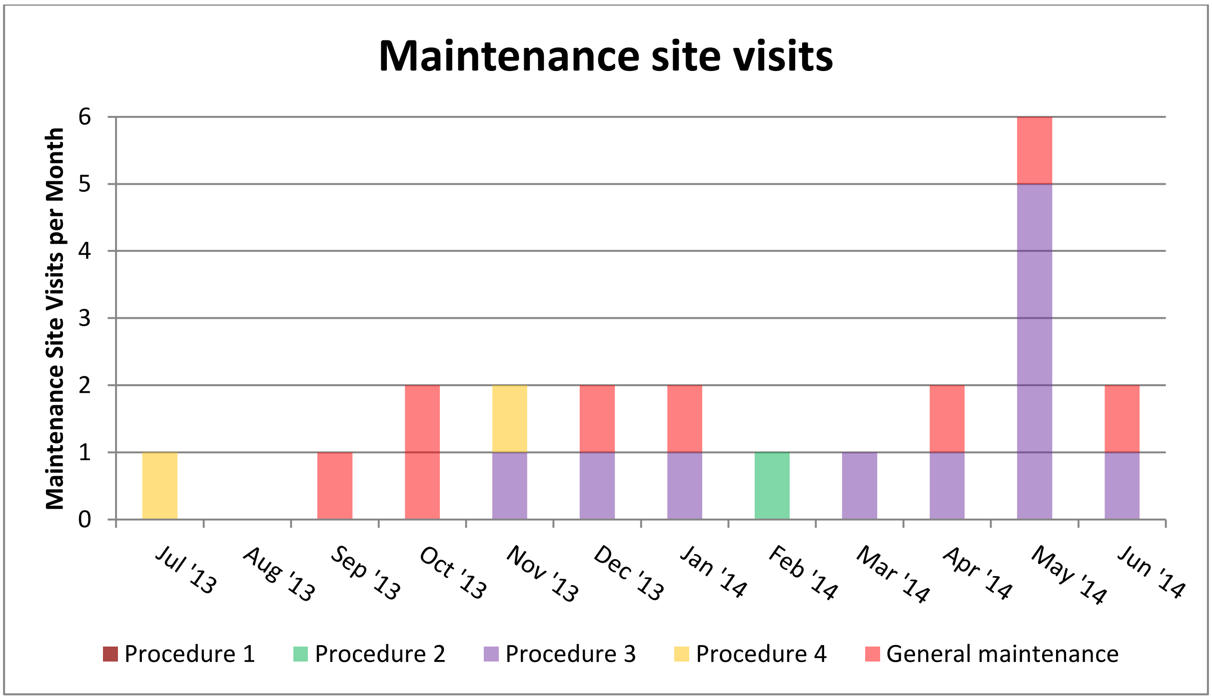


Figure 48: Case Study C – Maintenance site visits

The majority of maintenance issues related to control and instrumentation but there was also a large quantity of general maintenance that was done to ensure that energy cost savings were achieved. An increase in events during the May 2014 period was due to the control software maintenance being attended to.

4.4.3. Savings achieved

The electrical energy and cost savings for Case Study C are illustrated in Figure 49. Since constant maintenance was being done on the project, the savings remained fairly constant throughout the selected 12-month period. The decrease in savings during December 2013 was not due to less energy being used by the mine.

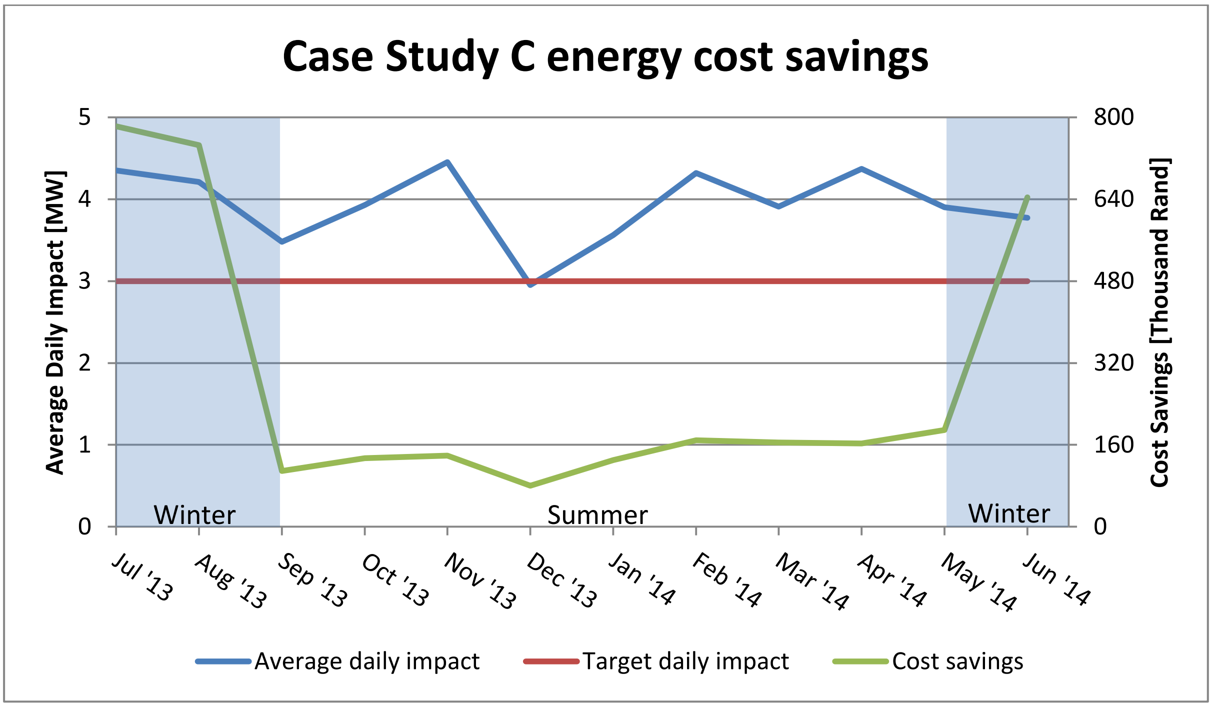


Figure 49: Case Study C – Energy cost savings

Table 23 in Appendix C displays the electrical energy and cost savings values. The cumulative performance of the mine is illustrated in Figure 50. The cumulative impact remained more than the cumulative target, and also kept increasing throughout the 12-month period.

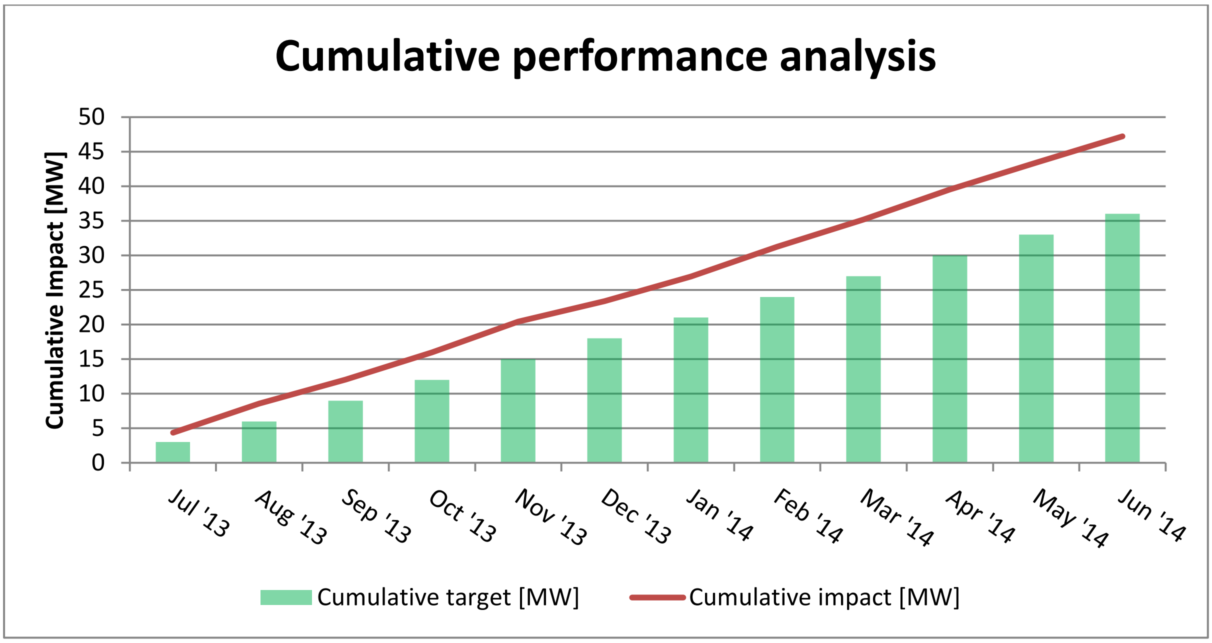


Figure 50: Case Study C – Cumulative performance analysis

4.4.4. Issues experienced

Case Study B and Case Study C underperformed during December 2013. Case Study B underperformed because of a lack of maintenance. Maintenance was being done on Case Study C, but still it underperformed. The reason for the underperformance was a decrease in production and water usage that resulted in a decrease in electricity usage. The energy usage for Case Study B and Case Study C are illustrated in Figure 51 and Figure 52 respectively. The energy usage for Case Study B remained constant but it still did not achieve target while Case Study C had a reduced average daily impact with a reduced energy usage.

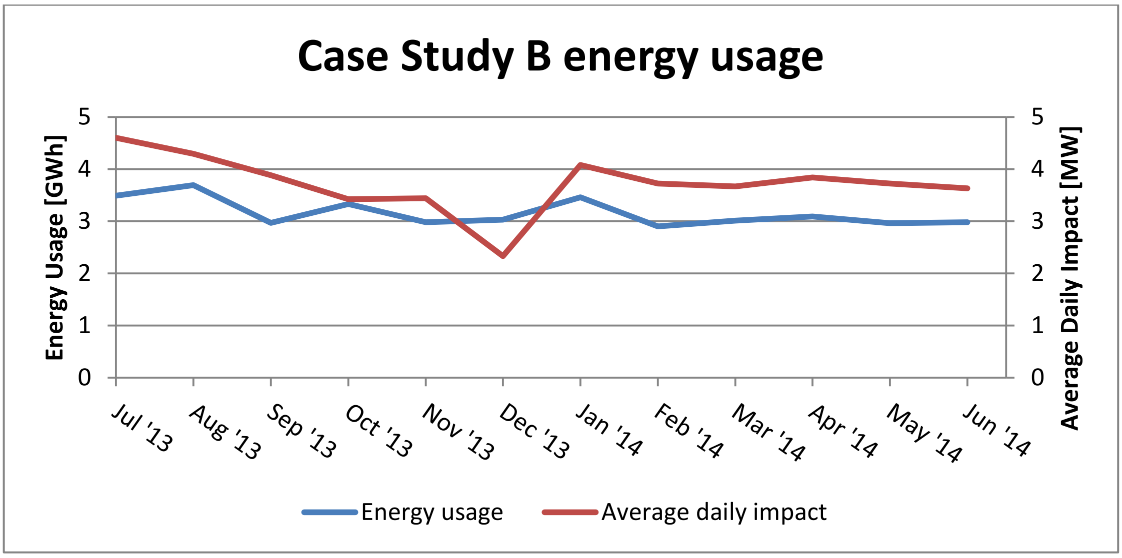


Figure 51: Case Study B – Energy usage

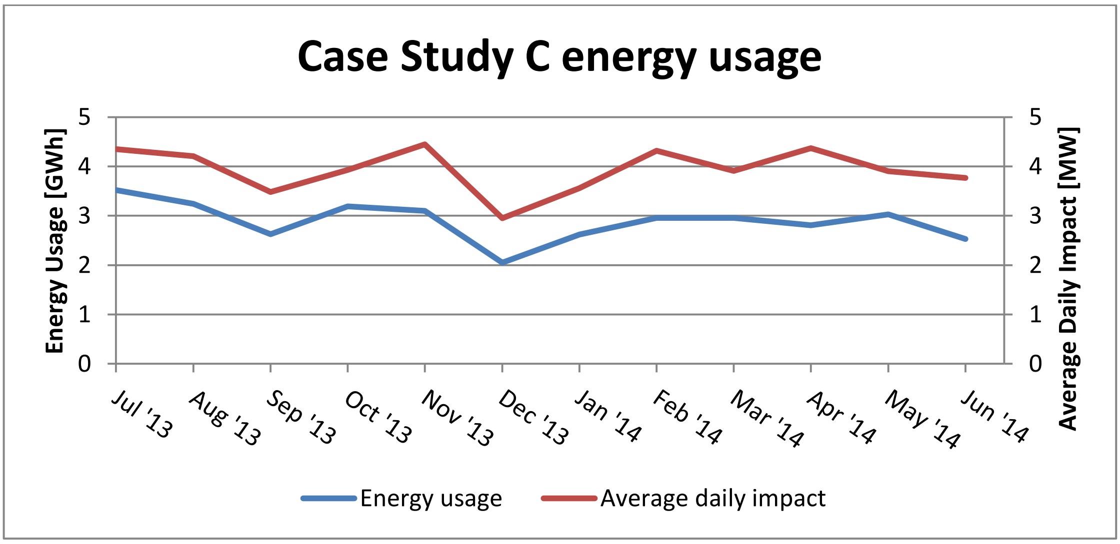


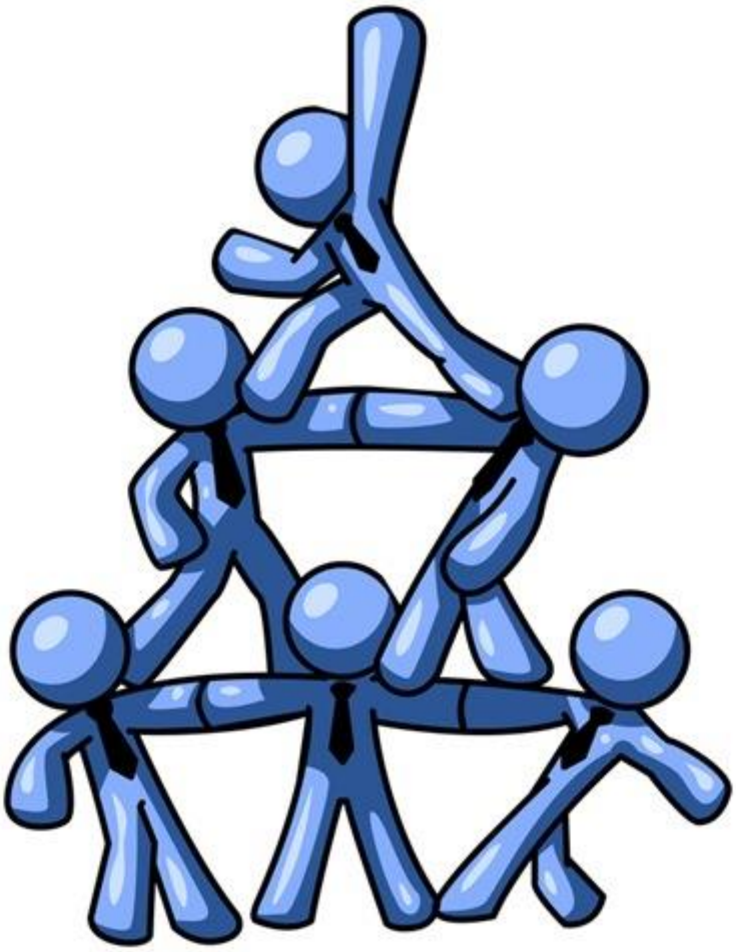
Figure 52: Case Study C – Energy usage

4.5. Conclusion

Three case studies were used to demonstrate that constant maintenance sustains electrical energy cost savings. Constant maintenance ensures that savings remains constant, and if problems occur, maintenance can be done to ensure that the savings are restored.

The maintenance procedure that was created in Chapter 3 was implemented on the maintenance done for the three case studies. Through the case studies in Chapter 4, it was proved that the maintenance procedure works.

Conclusion and recommendations



5.1. Conclusion

Mine pumping systems are very energy intensive, thus they present several opportunities for energy cost savings initiatives. These initiatives must be sustained to ensure profitability of mines. Sustainability on several sections is improved by the use of maintenance.

Research has shown that major sections are affected by maintenance. Problems that affect project performance negatively were identified and the cost implications were calculated. The cost implications due to data loss were approximately **R12.7 million**. A cost implication of **R11.3 million** was as a result of mechanical failures, control and instrumentation, and control parameters. The investigations, together with the research done, were used to create a maintenance procedure. The maintenance procedure was used to identify problems and to present recommended solutions.

The maintenance procedure created is divided into four sections: data loss, mechanical, control and instrumentation, and control parameters. Data loss is rectified through data retrieval and addressing the cause of the problem. Mechanical failures are rectified by following equipment-specific procedures. Control and instrumentation have several steps to deliver feasible solutions to the problem encountered. Control parameters ensure that the system is controlled correctly within all constraints. Client satisfaction and project sustainability are ensured through continued feedback.

The maintenance procedure created was tested by doing three case studies at three South African gold mines (Case Study A, Case Study B and Case Study C). The results obtained from the selected twelve months showed an average peak load shift of **10.16 MW** and a cost saving of **R8.05 million**. This resulted in an average overachievement of **1.77 MW** above the targeted impact of 8.39 MW.

In conclusion, by implementing the developed maintenance procedure and by providing constant maintenance, the sustainability of a system was improved and energy cost savings were achieved.

Maintenance procedures in other industries were not investigated since this will make the study too extensive. Maintenance must be done by an ESCO since mine management does not always place priority on DSM projects. Maintenance is done as it is required or if energy cost savings are not achieved.

5.2. Recommendations for further study

The maintenance procedure created during this dissertation was designed to improve the sustainability of energy cost savings for pumping systems in South African gold mines. The maintenance procedure can be implemented on pumping industries in the world. Further study can be done by creating maintenance procedures for the following system processes:

- Compressed air
- Refrigeration
- Process lines

Maintenance procedures can also be created for other technologies such as peak clipping and energy efficiency initiatives.

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Appendix A – Savings calculators and equations

The first step when using the savings calculator sheet is to insert the baseline of the project with the proposed profile for the project. The profile is shown in Table 6.

Table 6: Savings calculator – Baseline and proposed profile

Hour of day	Baseline	Optimised
1	100 000	12 180
2	100 000	12 175
3	100 000	12 116
4	100 000	12 564
5	100 000	12 338
6	100 000	12 505
7	100 000	12 411
8	100 000	12 606
9	100 000	10 941
10	100 000	9 667
11	100 000	8 608
12	100 000	7 272
13	100 000	12 574
14	100 000	14 223
15	100 000	14 695
16	100 000	14 635
17	100 000	14 319
18	100 000	13 594
19	100 000	98 000
20	100 000	98 000
21	100 000	9 875
22	100 000	10 314
23	100 000	11 245
24	100 000	11 668
Total	**2 400 000**	**458 524**

The Megaflex tariffs differ for peak, standard and off-peak periods. The tariffs also differ from summer to winter. The Eskom charges for 2014 are illustrated in Table 7.

Table 7: Eskom 2014 electricity charges

Period	Winter cent/kWh (excl. VAT)	Summer cent/kWh (excl. VAT)
Peak	201.33	65.68
Standard	60.99	45.20
Off-peak	33.12	28.68

The savings calculator document used the tariff structures to calculate the cost. The tariff structures are different from hour to hour since the tariffs differ between hours. Table 8 shows the tariff structure for summer.

Table 8: Savings calculator – Summer tariff structure

	Summer tariff	Summer tariff	Summer tariff
Hour	Weekday	Saturday	Sunday
1	R32.59	R32.59	R32.59
2	R32.59	R32.59	R32.59
3	R32.59	R32.59	R32.59
4	R32.59	R32.59	R32.59
5	R32.59	R32.59	R32.59
6	R32.59	R32.59	R32.59
7	R51.13	R32.59	R32.59
8	R74.10	R51.13	R32.59
9	R74.10	R51.13	R32.59
10	R74.10	R51.13	R32.59
11	R51.13	R51.13	R32.59
12	R51.13	R51.13	R32.59
13	R51.13	R32.59	R32.59
14	R51.13	R32.59	R32.59
15	R51.13	R32.59	R32.59
16	R51.13	R32.59	R32.59
17	R51.13	R32.59	R32.59
18	R51.13	R32.59	R32.59
19	R74.10	R51.13	R32.59
20	R74.10	R51.13	R32.59
21	R51.13	R32.59	R32.59
22	R51.13	R32.59	R32.59
23	R32.59	R32.59	R32.59
24	R32.59	R32.59	R32.59

Table 9 shows the tariff structure for winter.

Table 9: Savings calculator – Winter tariff structure

	Winter tariff	Winter tariff	Winter tariff
Hour	Weekday	Saturday	Sunday
1	R37.58	R37.58	R37.58
2	R37.58	R37.58	R37.58
3	R37.58	R37.58	R37.58
4	R37.58	R37.58	R37.58
5	R37.58	R37.58	R37.58
6	R37.58	R37.58	R37.58
7	R68.86	R37.58	R37.58
8	R226.30	R68.86	R37.58
9	R226.30	R68.86	R37.58
10	R226.30	R68.86	R37.58
11	R68.86	R68.86	R37.58
12	R68.86	R68.86	R37.58
13	R68.86	R37.58	R37.58
14	R68.86	R37.58	R37.58
15	R68.86	R37.58	R37.58
16	R68.86	R37.58	R37.58
17	R68.86	R37.58	R37.58
18	R68.86	R37.58	R37.58
19	R226.30	R68.86	R37.58
20	R226.30	R68.86	R37.58
21	R68.86	R37.58	R37.58
22	R68.86	R37.58	R37.58
23	R37.58	R37.58	R37.58
24	R37.58	R37.58	R37.58

The baseline is combined with the tariff structure per hour to calculate the cost per day for the project. The summer cost per day for the project is shown in Table 10.

Table 10: Savings calculator – Summer cost per day

	Summer tariff			
	Hour	Summer tariff Weekday	Summer tariff Saturday	Summer tariff Sunday
	1	R28 620.63	R28 620.63	R28 620.63
	2	R28 622.13	R28 622.13	R28 622.13
	3	R28 641.35	R28 641.35	R28 641.35
	4	R28 495.46	R28 495.46	R28 495.46
	5	R28 569.15	R28 569.15	R28 569.15
	6	R28 514.76	R28 514.76	R28 514.76
	7	R44 784.29	R28 545.28	R28 545.28
	8	R64 759.00	R44 684.59	R28 481.73
	9	R65 992.52	R45 535.73	R29 024.24
	10	R66 936.51	R46 187.09	R29 439.42
	11	R46 728.66	R46 728.66	R29 784.61
	12	R47 411.98	R47 411.98	R30 220.15
	13	R44 700.93	R28 492.14	R28 492.14
	14	R43 857.54	R27 954.57	R27 954.57
	15	R43 616.53	R27 800.95	R27 800.95
	16	R43 646.95	R27 820.34	R27 820.34
	17	R43 808.75	R27 923.47	R27 923.47
	18	R44 179.46	R28 159.76	R28 159.76
	19	R1 482.00	R1 022.60	R651.80
	20	R1 482.00	R1 022.60	R651.80
	21	R46 080.86	R29 371.70	R29 371.70
	22	R45 856.49	R29 228.69	R29 228.69
	23	R28 925.20	R28 925.20	R28 925.20
	24	R28 787.56	R28 787.56	R28 787.56
Total		**R924 500.72**	**R717 066.41**	**R632 726.91**

The winter cost per day for the project is shown in Table 11.

Table 11: Savings calculator – Winter cost per day

	Winter tariff			
	Hour	Winter tariff Weekday	Winter tariff Saturday	Winter tariff Sunday
	1	R33 002.87	R33 002.87	R33 002.87
	2	R33 004.59	R33 004.59	R33 004.59
	3	R33 026.76	R33 026.76	R33 026.76
	4	R32 858.53	R32 858.53	R32 858.53
	5	R32 943.51	R32 943.51	R32 943.51
	6	R32 880.78	R32 880.78	R32 880.78
	7	R60 313.83	R32 915.97	R32 915.97
	8	R197 772.77	R60 179.55	R32 842.69
	9	R201 539.91	R61 325.84	R33 468.27
	10	R204 422.82	R62 203.07	R33 947.02
	11	R62 932.44	R62 932.44	R34 345.06
	12	R63 852.71	R63 852.71	R34 847.30
	13	R60 201.57	R32 854.70	R32 854.70
	14	R59 065.72	R32 234.82	R32 234.82
	15	R58 741.14	R32 057.68	R32 057.68
	16	R58 782.11	R32 080.04	R32 080.04
	17	R59 000.01	R32 198.96	R32 198.96
	18	R59 499.26	R32 471.42	R32 471.42
	19	R4 526.00	R1 377.20	R751.60
	20	R4 526.00	R1 377.20	R751.60
	21	R62 060.01	R33 868.94	R33 868.94
	22	R61 757.83	R33 704.02	R33 704.02
	23	R33 354.06	R33 354.06	R33 354.06
	24	R33 195.35	R33 195.35	R33 195.35
Total		**R1 543 260.57**	**R871 901.03**	**R729 606.54**

Using the cost per day, the cost savings for summer and winter days as well as total expected savings were calculated. The summer and winter days were combined since they were also on different tariff structures. The winter months are from June to August. The number of public holidays and weekends were also taken into consideration when the annual savings were calculated.

The summer savings are illustrated in Table 12.

Table 12: Savings calculator – Summer savings

Average daily savings		R853 185.27
Summer savings		R232 919 579.72

Classified as		Saturday	Sunday
Public holiday		5	6

Total summer savings		**R240 301 262.25**

The winter savings are illustrated in Table 13.

Table 13: Savings calculator – Winter savings

Average daily savings		R1 331 115.77
Winter savings		R122 462 651.16

Classified as		Saturday	Sunday
Public holiday		2	0

Total winter savings		**R124 206 451.22**

The annual savings are illustrated in Table 14.

Table 14: Savings calculator – Annual savings

Total savings	**R364 507 713.47**

The cost savings missed for the projects were calculated from the values obtained from the average daily savings for summer and winter. The cost savings missed were calculated using the following equation:

$$Cost\ savings\ missed = Average\ daily\ savings \times Days\ in\ month - Cost\ savings\ achieved$$

The average daily savings were retrieved from the savings calculator document. For June, July and August the winter average daily savings were used. For all the other months the summer average daily savings were used. The days in the month are illustrated in Table 15.

Table 15: Days in the month

Month	Days
January	31
February	28
March	31
April	30
May	31
June	30
July	31
August	31
September	30
October	31
November	30
December	31

The cost savings achieved were obtained from the reports for the different projects and the different months. The average daily impact missed was calculated using the following formula:

$$Average\ daily\ impact\ missed = Target\ daily\ impact - Average\ daily\ impact\ achieved$$

The equations formulated were implemented on the projects. The investigations are given in Chapter 3.

Appendix B – Data for missed energy cost savings opportunities

Table 16 shows the estimated energy cost savings missed due to data loss.

Table 16: Estimated cost savings missed – Data loss

Estimated energy cost savings missed						
Month	Mine A	Mine B	Mine C	Mine D	Mine E	Total
Jul 2013	R705 306	R0	R468 708	R494 686	R268 847	R1 937 547
Aug 2013	R894 893	R0	R986 273	R494 686	R268 847	R2 644 699
Sep 2013	R169 763	R0	R182 241	R162 394	R50 059	R564 458
Oct 2013	R175 422	R0	R188 316	R167 808	R51 728	R583 273
Nov 2013	R169 763	R0	R182 241	R162 394	R50 059	R564 458
Dec 2013	R175 422	R60 152	R188 316	R167 808	R51 728	R643 425
Jan 2014	R169 024	R45 151	R188 316	R167 808	R51 728	R622 026
Feb 2014	R151 938	R0	R170 092	R151 568	R46 722	R520 319
Mar 2014	R175 422	R0	R188 316	R167 808	R51 728	R583 273
Apr 2014	R169 763	R5 416	R182 241	R162 394	R50 059	R569 874
May 2014	R175 422	R60 152	R188 316	R167 808	R51 728	R643 425
Jun 2014	R879 090	R300 582	R954 458	R478 728	R260 174	R2 873 032
Total	**R4 011 229**	**R471 454**	**R4 067 836**	**R2 945 888**	**R1 253 403**	**R12 749 811**

Table 17 shows the estimated energy cost savings missed at Mine F as a result of mechanical failure.

Table 17: Mine F – Estimated energy cost savings missed

Estimated energy cost savings missed		
Month	Energy [MW]	Cost
Sep 2013	1.86	R148 479
Oct 2013	2.37	R153 423
Nov 2013	2.57	R148 485
Dec 2013	2.79	R153 428
Jan 2014	2.36	R153 437
Feb 2014	2.54	R138 589
Mar 2014	3.05	R153 437
Apr 2014	3.23	R148 488
May 2014	2.33	R153 436
Jun 2014	2.31	R765 392
Total	**25.41**	**R2 116 594**

Table 18 shows the estimated energy cost savings missed at Mine G due to control and instrumentation.

Table 18: Mine G – Estimated energy cost savings missed

Estimated energy cost savings missed		
Month	**Energy [MW]**	**Cost**
Jul 2013	1.24	R1 645 848
Aug 2013	0.01	R1 645 540
Sep 2013	0.08	R316 577
Oct 2013	1.00	R327 195
Nov 2013	1.70	R316 646
Dec 2013	2.47	R327 303
Jan 2014	1.03	R327 189
Feb 2014	0.26	R295 484
Mar 2014	0.68	R327 118
Apr 2014	3.96	R316 705
May 2014	0.73	R327 162
Jun 2014	0.26	R1 592 673
Total	**13.42**	**R7 765 439**

Table 19 shows the estimated energy cost savings missed at Mine H due to control and instrumentation.

Table 19: Mine H – Estimated energy cost savings missed

Estimated energy cost savings missed		
Month	**Energy [MW]**	**Cost**
Jul 2013	0.12	R327 964
Sep 2013	0.41	R60 251
Oct 2013	0.27	R62 251
Nov 2013	0.67	R60 258
Dec 2013	0.12	R62 259
Mar 2014	0.48	R62 292
Apr 2014	0.62	R60 276
May 2014	0.36	R62 268
Jun 2014	0.39	R317 447
Total	**3.32**	**R747 301**

Table 20 shows the estimated energy cost savings missed at Mine I as a result of changes to control parameters.

Table 20: Mine I – Estimated energy cost savings missed

Estimated energy cost savings missed		
Month	**Energy [MW]**	**Cost**
Nov 2013	1.73	R228 656
Dec 2013	2.66	R236 313
Nov 2013	5.53	R236 405
Total	**9.92**	**R701 374**

Appendix C – Energy cost savings achieved

Table 21 shows the energy cost savings for Case Study A.

Table 21: Case Study A – Energy cost savings values

Case Study A energy cost savings			
Month	Average daily impact [MW]	Target daily impact [MW]	Cost savings
Jul 2013	3.00	2.29	R465 000
Aug 2013	3.01	2.29	R463 000
Sep 2013	2.44	2.29	R59 000
Oct 2013	2.39	2.29	R77 000
Nov 2013	2.48	2.29	R78 000
Dec 2013	2.33	2.29	R73 000
Jan 2014	2.32	2.29	R83 000
Feb 2014	2.64	2.29	R82 000
Mar 2014	2.79	2.29	R93 000
Apr 2014	2.47	2.29	R78 000
May 2014	2.22	2.29	R81 000
Jun 2014	2.05	2.29	R332 000

Table 22 shows the energy cost savings for Case Study B.

Table 22: Case Study B – Energy cost savings values

Case Study B energy cost savings			
Month	Average daily impact [MW]	Target daily impact [MW]	Cost savings
Jul 2013	4.60	3.10	R646 000
Aug 2013	4.29	3.10	R365 000
Sep 2013	3.88	3.10	R117 000
Oct 2013	3.42	3.10	R127 000
Nov 2013	3.44	3.10	R118 000
Dec 2013	2.33	3.10	R74 000
Jan 2014	4.08	3.10	R150 000
Feb 2014	3.72	3.10	R82 000
Mar 2014	3.67	3.10	R126 000
Apr 2014	3.84	3.10	R90 000
May 2014	3.72	3.10	R142 000
Jun 2014	3.63	3.10	R601 000

Table 23 shows the energy cost savings for Case Study C.

Table 23: Case Study C – Energy cost savings values

Case Study C energy cost savings			
Month	**Average daily impact [MW]**	**Target daily impact [MW]**	**Cost savings**
Jul 2013	4.35	3.00	R782 000
Aug 2013	4.21	3.00	R745 000
Sep 2013	3.48	3.00	R109 000
Oct 2013	3.93	3.00	R134 000
Nov 2013	4.45	3.00	R139 000
Dec 2013	2.95	3.00	R80 000
Jan 2014	3.56	3.00	R130 000
Feb 2014	4.32	3.00	R169 000
Mar 2014	3.91	3.00	R165 000
Apr 2014	4.37	3.00	R163 000
May 2014	3.90	3.00	R189 000
Jun 2014	3.77	3.00	R643 000