Automated control of mine dewatering pumps

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Abstract

Title: Automated control of mine dewatering pumps

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Keywords: Automation, mine dewatering pumps, control, clear water pumping, DSM

Deep gold mines use a vast amount of water for various purposes. After use, the water is pumped back to the surface. This process is energy intensive. The control is traditionally done with manual interventions. The purpose of this study is to investigate the effects of automated control on mine dewatering pumps.

Automating mine dewatering pumps may hold a great number of benefits for the client. The benefits include electricity cost savings through load shifting, as well as preventative maintenance and pump protection procedures. By automating pumps, the client will benefit from operating more cost effectively and realising electricity cost savings. The equipment needed for pump automation and the procedures involved in the process are discussed as part of this study.

A DSM project was implemented in the form of a pump automation project. All safety and quality procedures were followed and training was provided where needed to ensure that personnel understand their duties and responsibilities. This ensures the sustainability of the project after completion.

The performance of the project was tested in manual mode, manual scheduled control, manual scheduled surface control and auto control. Manual intervention achieved the highest electricity cost saving of R8.25 million (11.4 MW load shift saving). To achieve this saving the system was exhausted to a point where columns and infrastructure started failing. Auto intervention achieved an electricity cost saving of R5.57 million (7.7 MW load shift savings).

The auto intervention achieved a lower electricity cost savings compared to the manual intervention. However, taking all factors into account, such as the damage to infrastructure after a period of manual control, the auto intervention proved the best balance for controlling mine dewatering pumps to achieve savings on the cost of electricity and system sustainability for optimal control. Automated systems can avoid system overload and protect the infrastructure from exhaustion.

Opsomming

Titel: Outomatiese beheer van mynontwateringspompe

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Studieleier: Dr J.F. van Rensburg

Sleutelwoorde: Outomatisering, mynontwateringspompe, beheer, helder waterpomp, DSM

Diep goudmyne gebruik groot hoeveelhede water vir verskeie doeleindes. Na gebruik word die water teruggepomp na die oppervlak. Hierdie proses is baie energie-intensief. Die proses word gewoonlik deur intervensies met die hand beheer. Die doel van hierdie studie is om die effek van outomatiese beheer van mynontwateringspompe te ondersoek.

Outomatiese mynontwateringspompe kan vele voordele vir die kliënt inhou. Hierdie voordele sluit in kostebesparings op elektrisiteit deur beurtkrag, voorkomende onderhoud en pompbeskermingsprosedures. Met outomatiese pompe sal die kliënt voordeel trek uit die meer koste-effektiewe beheer en so spaar op elektrisiteitskostes. Die toerusting wat nodig is vir pompoutomatisering en die prosedures wat daarby betrokke is word in hierdie studie bespreek.

’n AKB-projek is geïmplementeer in die vorm van ’n pomp-outomatiseringsprojek. Alle veiligheids- en kwaliteitsprosedures is gevolg. Opleiding is verskaf waar nodig om te verseker dat personeel hulle pligte en verantwoordelikhede verstaan. Dit verseker die volhoubaarheid van die projek na voltooiing.

Die werksuitsette van die projek is getoets met die handmetode, geskeduleerde handbeheer, geskeduleerde handoppervlakbeheer en outomatiese beheer. Handbeheer het die grootste elektrisiteitsbesparing tot gevolg gehad, naamlik R8.25 miljoen (11.4 MW energiebesparing). Om hierdie besparing te bereik is die stelsel uitgeput tot die punt waar standpype en infrastruktuur begin onklaar raak het. Outomatiese beheer het ‘n elektrisiteitsbesparing van R5.57 miljoen tot gevolg gehad (7.7 MW energiebesparing).

Die outomatiese intervensie het minder elektrisiteit bespaar in vergelyking met die handintervensie. Wanneer alle faktore egter in ag geneem word, soos die skade aan infrastruktuur na ’n periode van handbeheer, bied die outomatiese intervensie die beste balans vir die beheer van mynontwateringspompe wanneer dit kom by die besparing van elektrisiteit en die volhoubaarheid van die stelsel vir optimale beheer. Outomatiese stelsels kan stelsel-oorlading voorkom en die infrastruktuur beskerm van uitputting.

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Abbreviations

CPI	Consumer Price Index
C_v	Valve flow coefficient
DE	Drive end
DS	Downstream
DSM	Demand Side Management
ESCo	Energy Services Company
HMI	Human Machine Interface
kW	Kilowatt
kWh	Kilowatt-hour
MC	Manual control
MSC	Manual scheduled control
MSSC	Manual scheduled surface control
MW	Megawatt
NDE	Non drive end
PGM	Platinum Group Metals
PLC	Programmable Logic Controller
REMS	Real-time energy management system
SCADA	Supervisory Control and Data Acquisition
TOU	Time of Use
UPS	Uninterrupted Power Supply
US	Upstream

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Chapter 1. INTRODUCTION AND BACKGROUND

[1]

An electricity shortage in South Africa has forced Eskom to encourage industries to make more efficient use of electricity. To resolve the electricity shortage issue, Eskom is building more power stations. Another long-term solution is the implementation of DSM (Demand Side Management) projects. Load shift dewatering pump automation projects can be implemented to realise electricity cost savings and help Eskom lower the demand in peak periods.

(Pictures with no academic contribution will be referenced as a footnote)

[1] Picture courtesy of https://c1.staticflickr.com/9/8459/7889012216_3ea3dc8310_z.jpg

1.1 INTRODUCTION

South Africa has various energy-intensive industries and these industries keep growing. Electricity demand has escalated to a point where the national grid is failing to produce enough electricity for its consumers [1]. Eskom has a total generating capacity of 43000 MW, but this is not adequate to supply South Africa with electricity without load shedding [2].

In an effort to resolve the electricity issue, Eskom is building two coal power stations, called Medupi and Kusile. Medupi will be completed in 2015 and the completion of Kusile is planned for 2018 [3]. The new power stations will take some strain off the grid as the generating capacity will increase by 4764 MW in 2015, increasing the national generating capacity by more than 10% [2]. By 2018 the generating capacity will again be increased by 4800 MW with the completion of Kusile [3].

Eskom has asked major industries and the residential division to lower their electricity consumption as another initiative to take some strain off the grid. Eskom in return has made resources available to fund these industries to lower their consumption [4].

Eskom's national grid is under threat even more in winter as people use electricity for heating, geysers and pool pumps [1]. To discourage the unsparing use of electricity, Eskom has increased the price of electricity during the winter months. The winter electricity usage is illustrated in Figure 1.

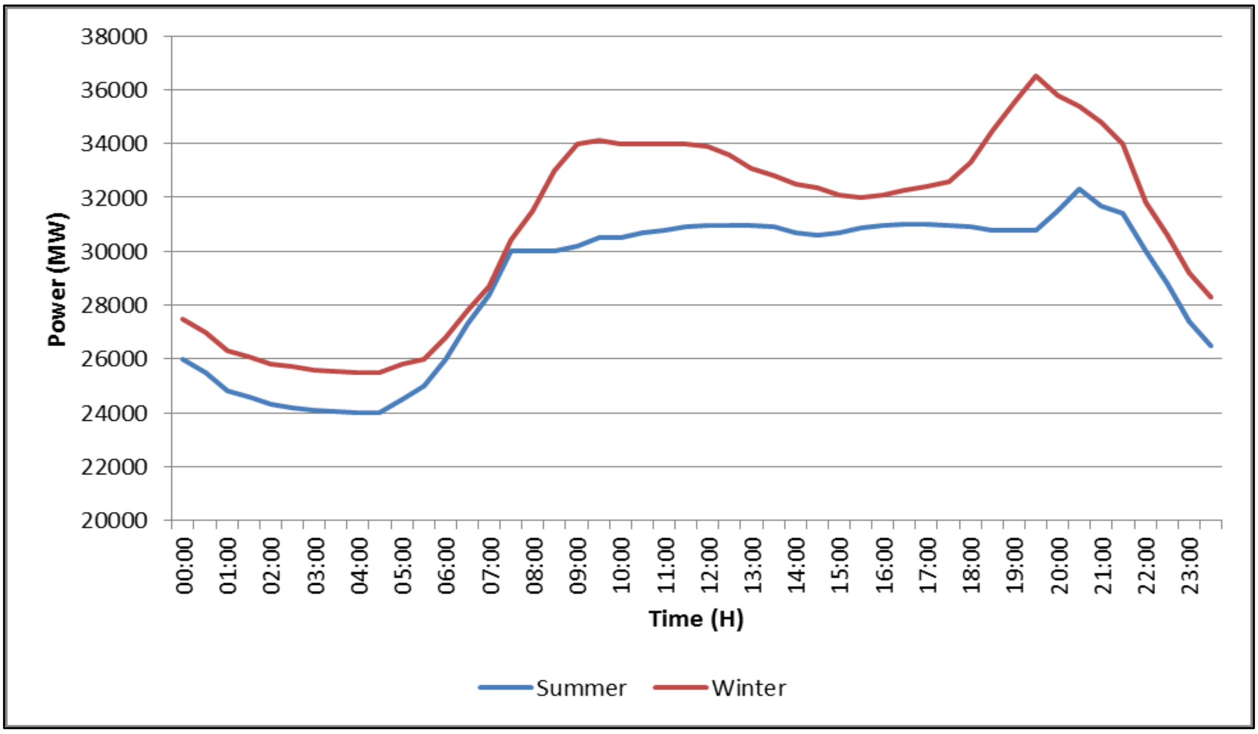


Figure 1: Typical day load profiles for summer and winter [1]

Eskom's electricity prices keep rising each year at an alarming rate. Major electricity price tariff increases with an average of 17.9% were approved from 2009 to 2014 as illustrated in Figure 2 and Figure 3 [5], [6], [7]. The figures display the tariff increase for the Megaflex local authority. The tariff set chosen was for the transmission zone of <300 km and a voltage of 500 V and 66 kV, because the mine used for the case study included in this dissertation falls in this electricity range. Figure 2 illustrates the electricity price increase per year from 2009 to 2014.

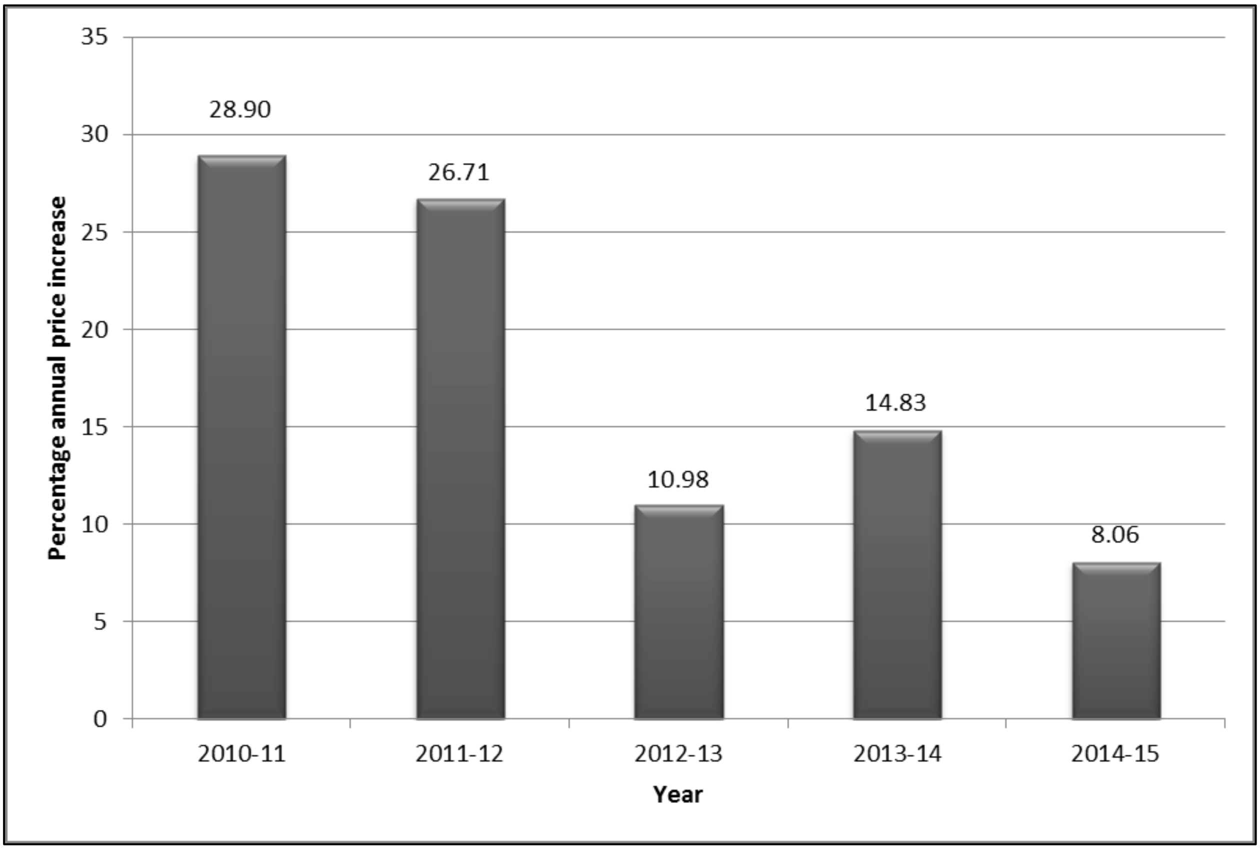


Figure 2: Electricity price increase percentage per year

As illustrated in Figure 3, the cost of electricity in winter months is higher compared to summer months. Opportunities can be identified to use electricity during less expensive periods to realise electricity cost savings. The largest potential to realise electricity cost savings should be allocated to winter months.

With the introduction of Time-of-use (TOU) schedules, industries have been encouraged to adjust the time of day electricity is consumed [8]. The TOU schedule is divided into three categories that include peak periods, off-peak periods and standard periods. Peak periods are the most expensive and off-peak periods the least expensive time to consume electricity.

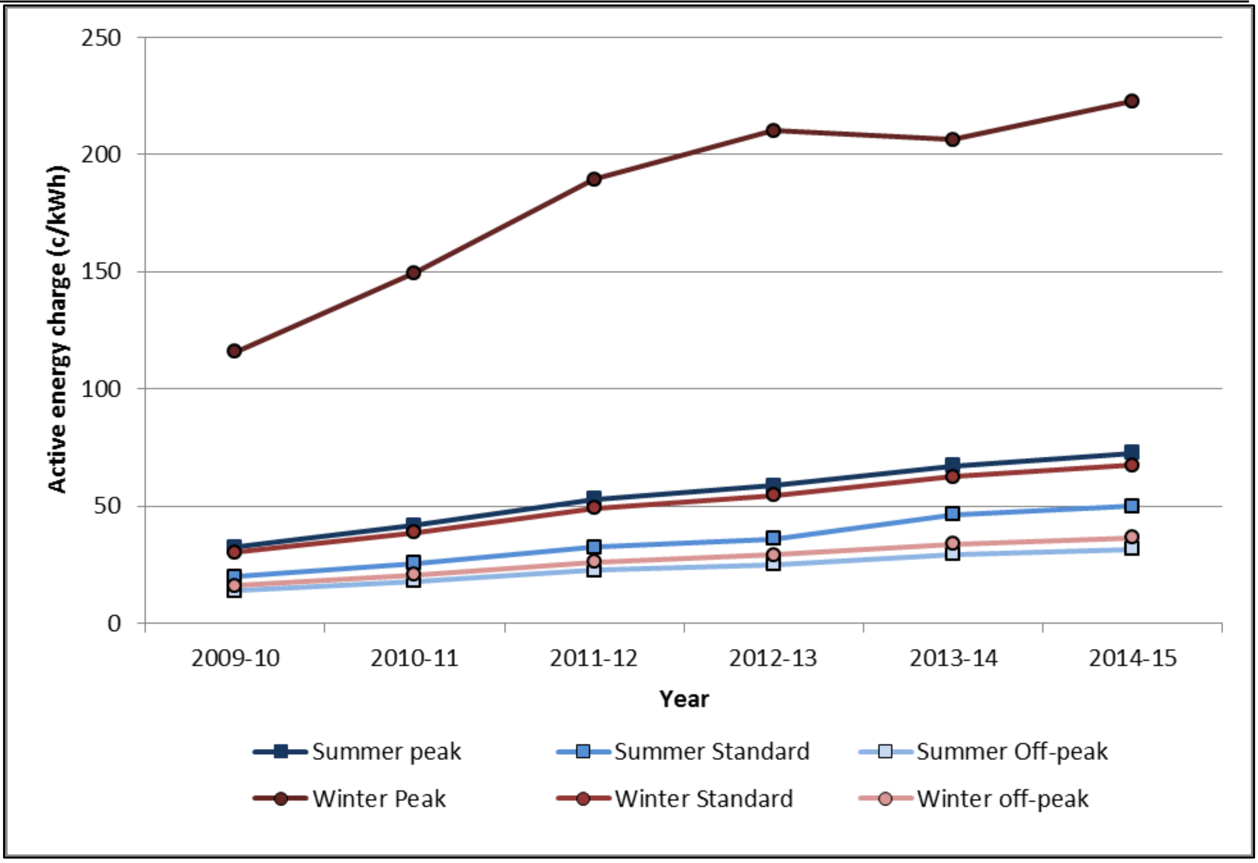


Figure 3: Active energy charge per year from 2009 to 2014

Eskom peak periods for weekdays are in the morning from 7:00 to 10:00 and in the evening from 18:00 to 20:00. The peak, standard and off-peak periods for weekdays, Saturdays and Sundays are illustrated in the TOU schedules as shown in Figure 4.

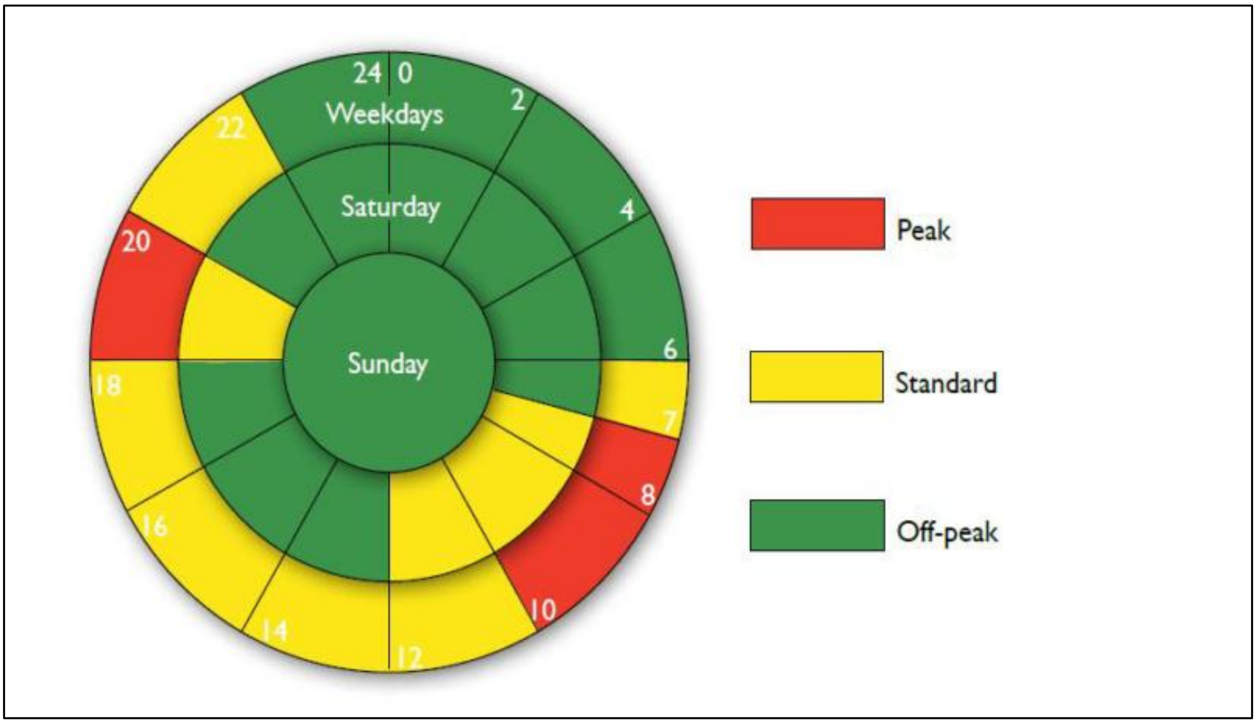


Figure 4: ESKOM TOU schedules

1.2 AUTOMATED CONTROL OF LOAD SHIFT DEMAND SIDE MANAGEMENT PROJECTS

Demand Side Management (DSM) is the implementation of projects to control the way electricity is consumed by different consumers. DSM projects are implemented mainly because of an electricity shortage throughout the world.

With the use of Eskom funding, DSM projects are implemented to support major industries to lower their electricity consumption, helping Eskom restore the national grid [4]. DSM projects can be implemented to lower electricity consumption or to use electricity in time periods where the national grid is under less pressure.

The DSM initiatives most frequently used in mines are peak clipping, load shifting and energy efficiency. This dissertation presents a case study that illustrates how a mine's dewatering pumps can be automated for load shifting.

Load shifting entails the use of electricity in standard and off-peak periods rather than in peak periods [9], [10]. By implementing load shifting projects, electricity cost savings can be realised as electricity is used in less expensive periods of the day.

Pump automation projects contribute greatly to the success of DSM projects. The load shift control intervention on pumping systems can either be manual or automatic. If a pump is not automated, an underground operator has to control the pump manually. When automation is complete, the pump can be controlled by a server in the control room or operated independently with minimal user input.

Some of the most important instruments for the implementation of load shifting on a dewatering pumping system are the dam level sensors. The dam level sensors enable data to be sent from underground to indicate the dam level percentage. The pump system control is dependent on the dam levels and automatic control will not be possible without dam level indications.

Manual control can be conducted without dam level sensors. However, exceptional communication and reliable communication instrumentation is required between the underground operator and the control room operator. Manual control without dam level sensors increases the risk of mine flooding.

The desired method is to fully automate the pumping system to remotely control pumps for load shifting [11]. Automation can help the client monitor the pumping system to ensure system sustainability and optimal operation.

1.3 NEED FOR THE STUDY

Mines use water for various purposes. After the water has been used, it is stored in underground hot water holding dams and then pumped back to the surface for cooling. Mines have been using manual control interventions since deep mining commenced many years ago. Manual control has benefits such as human intervention during operations and low infrastructure costs [11].

Some problems with manual control interventions include:

- Delayed discharge valve opening, causing pump damage or failure,
- High maintenance costs,
- Possibility of mine flooding when communication to and from underground fails,
- Incident reporting inefficiency,
- Inadequate monitoring of vibrations and temperatures,
- Delayed maintenance due to fault finding inefficiency.

It is clear that automated systems could help mines realise cost savings with efficient fault finding instrumentation, issue reporting efficiency, effective maintenance, as well as electricity cost savings by performing load shifting.

Although the Consumer Price Index has remained unchanged from 2012 to 2013 (5,7 %), the price of electricity has increased by a considerably larger percentage [12]. Due to the energy-intensive operation of mine dewatering, 14% of a mine’s electricity consumption can be allocated to dewatering [13].

Electricity prices are increasing drastically compared to other mining operations, as illustrated in Figure 5. A need has emerged for a reduction in electricity bills by all industrial and residential users.

The challenge taken on in this dissertation is to implement a DSM project in the form of a pump automation project for load shifting. Load shifting will assist the client with realising electricity cost savings. Automated systems have benefits such as increased system monitoring for optimal operation.

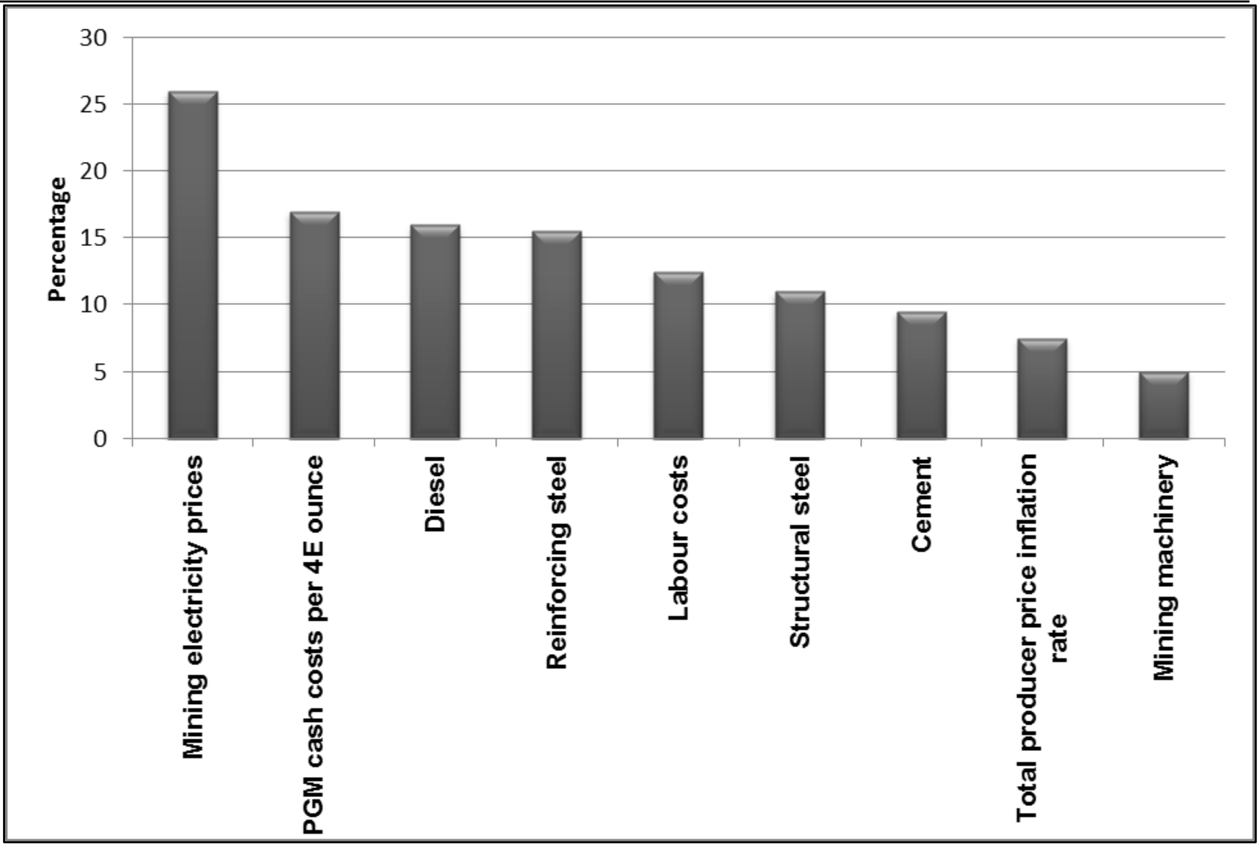


Figure 5: Mining sector cost inflation, from 2007 to 2012[14]

1.4 DISSERTATION LAYOUT

Chapter 1

Mines use large amounts of electricity to operate. Electricity cost savings can be realised by implementing DSM projects to lower electricity consumption or to use electricity during less expensive time periods. A DSM project in the form of a pump automation project is implemented as part of this study to realise electricity cost savings.

Chapter 2

The benefits of pump automation, such as computerised systems, predictable future savings, prolonged pump life cycle, realising electricity cost savings, predictive maintenance intervals and condition monitoring, are briefly discussed. The instrumentation needed for pump automation is mentioned and discussed.

Chapter 3

The pump automation process involves the implementation of a DSM pump automation project to perform load shifting. Dewatering pump automation involves a number of procedures that include identification, investigation, project approval, implementation, commissioning and maintenance. All of these phases are discussed in detail.

Four different control interventions are used to control the pumps. The interventions include manual control (MC), manual scheduled control (MSC), manual scheduled surface control (MSSC) and automatic control. The control interventions are discussed individually in this chapter.

Chapter 4

Results for the different control interventions are compared. A simulation is done and the results are compared to the control interventions. The comparison of the control interventions provides insight into which method of control is the most successful and provides the best sustainability for optimal operation.

Chapter 5

A conclusion is drawn from the results of the different interventions. The future recommendations discussed include maintenance, pump efficiency determination and savings achieved without taking electricity cost savings into account.

Chapter 2. AUTOMATING MINE DEWATERING PUMPS

Chapter 2 discusses the factors that influence an automation project's success. These include energy costs, training, operational expenditure initiatives, reduced human intervention, maintenance, safety, quality assurance and mine strikes. The instrumentation required for automation is specified and the use of simulation models and its benefits are indicated.

2.1 INTRODUCTION

Chapter 2 discusses the factors that influence an automation project's success, the instrumentation needed and the use of simulation models. Gold mines pump water in a cascading manner from one pumping level to another pumping level's dams until it reaches the surface dams [15]. Figure 6 offers an illustration of a typical gold mine shaft pumping system that can be automated.

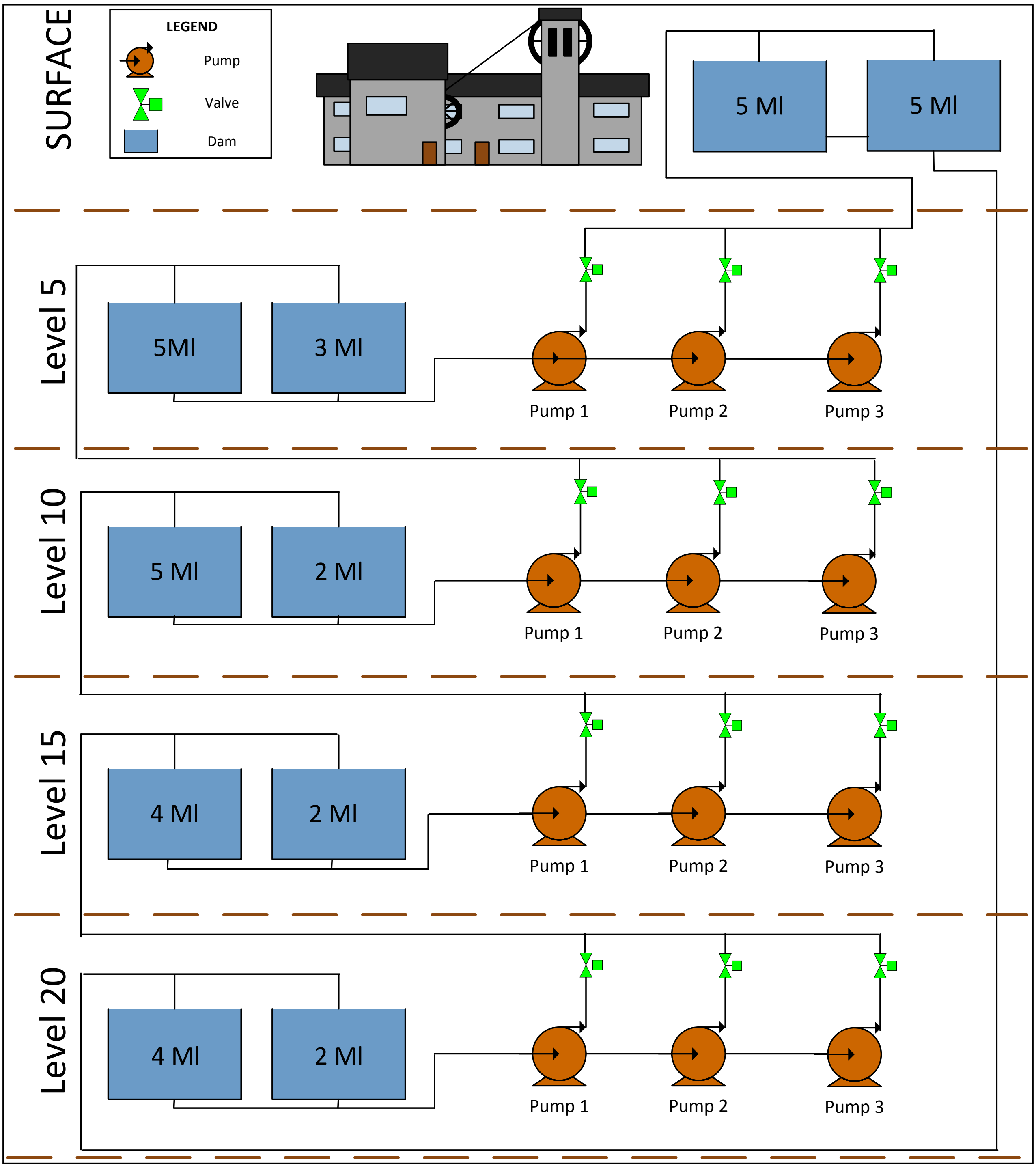


Figure 6: Typical gold mine dewatering system layout

Control room operators are mine personnel situated on the surface in the control room. The operators work shifts to cover a 24-hour day to ensure that an operator is always present. Control room operator duties include monitoring and reporting of:

- Fire detection systems,
- Compressed air management,
- Dewatering pump control,
- Injuries,
- Any unusual mining activity or incidents.

Before automation a pump is controlled manually by the underground pump operator. Pumps are controlled by means of a local control panel situated at the pump. The operation method drastically changes when the pumping system is automated. Once the pumping system is automated, the control can be done from the surface control room or independently by a program installed on a server situated in the control room.

2.1.1 BENEFITS OF AUTOMATION

Mining operations benefit from automation as the system can adapt to numerous situations to assure that production is minimally effected and electricity cost savings are achieved. Automation requires the participation of all relevant parties to realise the maximum benefits. These parties include engineers, operators (control room and underground), technicians, riggers and fitters, electricians, foremen, managers, design engineers, automation engineers and contractors [16].

Automation holds a number of benefits that include:

- Computerised systems that react consistently,
- Future savings can be calculated and used for mine expenditure determination,
- Prolonged pump life cycle by predictive, improving and preventative maintenance through data availability,
- Realising electricity cost savings by shifting the electrical load to less expensive periods,
- Predictive maintenance intervals can be determined by facilitating condition monitoring.

Automated systems use instrumentation to enable the client to actively monitor a system. The system layout and configuration will determine the instrumentation needed for automation. Typically, mine dewatering pumps will have temperature transmitters, vibration transmitters, pressure transmitters, flow meters, actuators, balance disk flow switches and PLC's installed when automated.

Safety trip conditions can then be programmed into the PLC of a pump to trip the pump when any unwanted conditions occur. Using trip conditions ensures that each pump is protected from running when damaged to avoid further damage or complete failure [17]. Replacing faulty equipment before pump failure occurs can save the mine millions of Rands. When a component fails it could cause damage to other components in working condition and this can cost the mine even more money.

Automated systems imply reduced human intervention. An automated system maximises savings by improving reliability [18]. Human intervention causes inconsistent behaviour, which is unwanted. The automated system’s monitoring personnel will have more responsibility, and in some cases earn a better income [19].

Automated systems help the mine to employ fewer employees. Personnel only need to monitor the pumps as the programmed server will control them [20]. Labour costs can then be lowered, which will see the mine realise labour cost savings [21]. With instrumentation being the core of pump automation, opportunities are created for technicians.

2.1.2 PUMP CONFIGURATION IMPORTANCE

The configuration of the pumps on each level is very important. Discharging water from more than one pump into the same column simultaneously can decrease the efficiency of the pumping set. When the maximum flow inside a column is reached, the efficiency of the pumping system deteriorates drastically when starting more pumps [8].

The best method is to operate pumps in different columns to avoid pumping flow loss due to incorrect pump configuration. Figure 7 shows the configuration of pumps discharging water into a mutual column and the effect that a parallel flow configuration will have on the head pumping ability, as well as on the water flow rate [22].

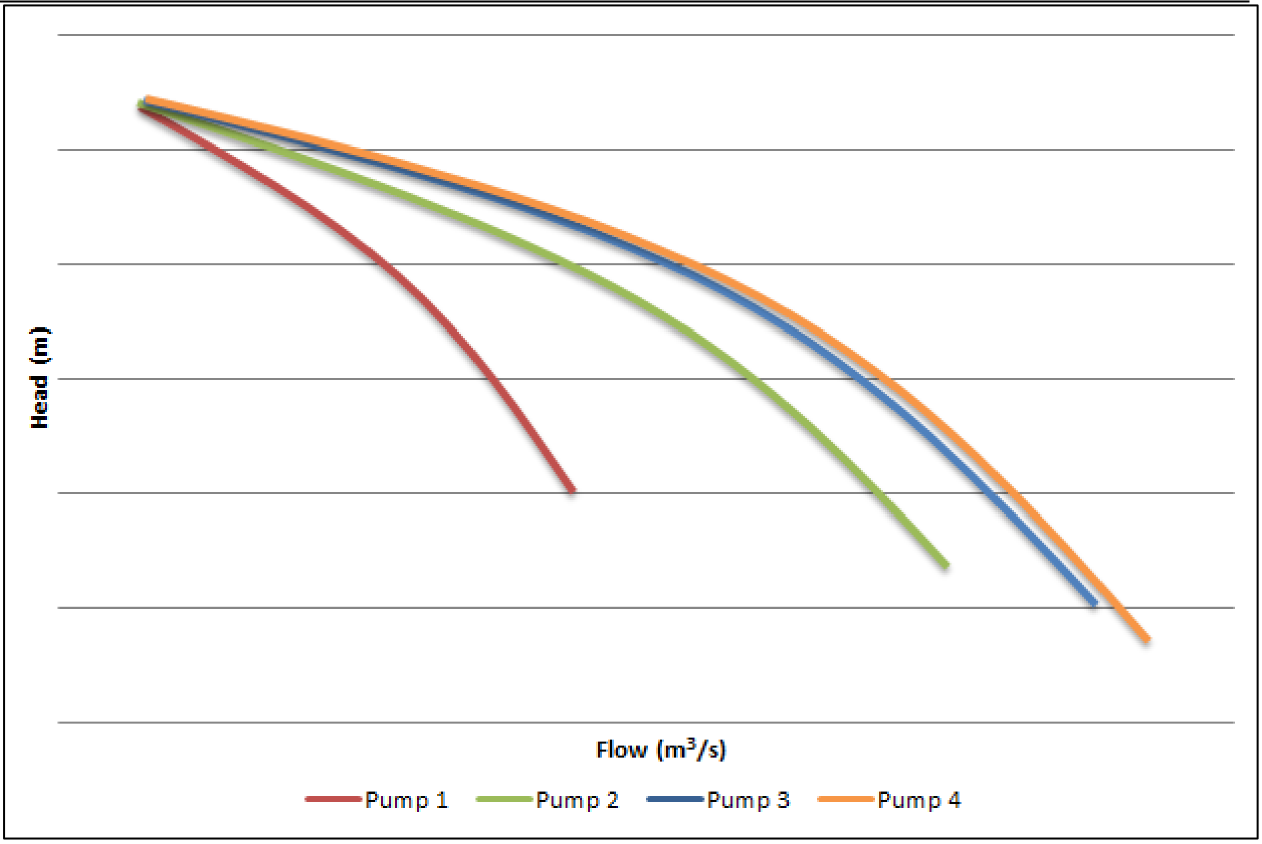


Figure 7: Parallel flow configuration behaviour

2.1.3 CALCULATING PROPOSED ELECTRICITY SAVINGS

A baseline is the power profile of the client and indicates the operation of the dewatering pump system before project implementation. The baseline is a critical aspect to quantify the savings achieved. Comparing the baseline to the electricity usage after implementation provides insight into the savings achieved by the project [23].

When referring to the baseline, the amount of electricity used before the implementation over an average 24-hour period is compared to the energy consumption after implementation [23]. The baseline is scaled after the comparison is done to ensure that the impact is energy neutral. The scaled baseline is calculated each day and then used to quantify the savings achieved for the day.

Scaled baseline calculation

Scaling factor calculation

$$ScF = \frac{\sum_0^{23} A[h]}{\sum_0^{23} B[h]} \qquad \text{(Eq. 1)}$$

Where:

ScF = Scaling factor.

A = Actual average hourly power usage over a 24-hour profile.

B = Baseline average hourly power usage over a 24-hour profile.

Scaled baseline

$$SB[h] = B[h] \times ScF \quad \text{(Eq. 2)}$$

Where h ranges from 0 to 23(0= 00:00-1:00 and 23= 23:00 and 00:00).

SB = Scaled baseline hourly power usage over 24-hour profile.

B = Baseline average hourly power usage over a 24-hour profile.

ScF = Scaling factor.

Power saving calculation

Load shifted:

$$LS\,[h] = \frac{\sum_k^n B[h] \times ScF}{n-(k-1)} \quad \text{(Eq. 3)}$$

Where:

LS = load shifted (kWh).

k = first hour taken into calculation.

n = last hour taken into calculation.

h = baseline average hourly power usage over a 24-hour profile.

Morning peak:

$$LS\,[7,8,9] = \frac{\sum_7^9 B[h] \times ScF}{3} - \frac{\sum_7^9 A[h]}{3} \quad \text{(Eq. 4)}$$

Evening peak:

$$LS\,[18,19] = \frac{\sum_{18}^{19} B[h] \times ScF}{2} - \frac{\sum_{18}^{19} A[h]}{2} \quad \text{(Eq. 5)}$$

2.2 SIMULATION MODELS

Before projects are implemented, investigations are done to determine the possible savings achievable by the DSM project. Investigations follow a number of steps. One of the most important aspects of a DSM project's investigations is the use of simulation models. Simulation models can predict a project's unknown risks, possible savings and overall performance [24], [25].

Data is obtained from the client and baseline calculations are prepared. A simulation model is then set up to determine what the maximum electricity savings will be. Pump flows, maximum dam levels, dam capacities, maximum pumps per station and typical constraints are needed to accurately calculate the maximum electricity savings [26]. Accurate simulation results of 90% upwards can be achieved when the mine enables access to all the necessary data.

The results can give an indication of the possible electricity savings achievable, as illustrated in Figure 8 [26]. Future opportunities for possible DSM projects can be determined with accuracy. The simulation results can give an indication of the resources needed for a successful load shift. Some projects might need more financial input to achieve the same electricity savings than other projects.

A typical gold mine dewatering pump load shift profile with baseline and scaled baseline is illustrated in Figure 8. The peak periods are indicated on the graph with a transparent red background. The reduction in electricity usage during the peak periods and the comeback load in standard and off-peak periods can be clearly seen from Figure 8.-

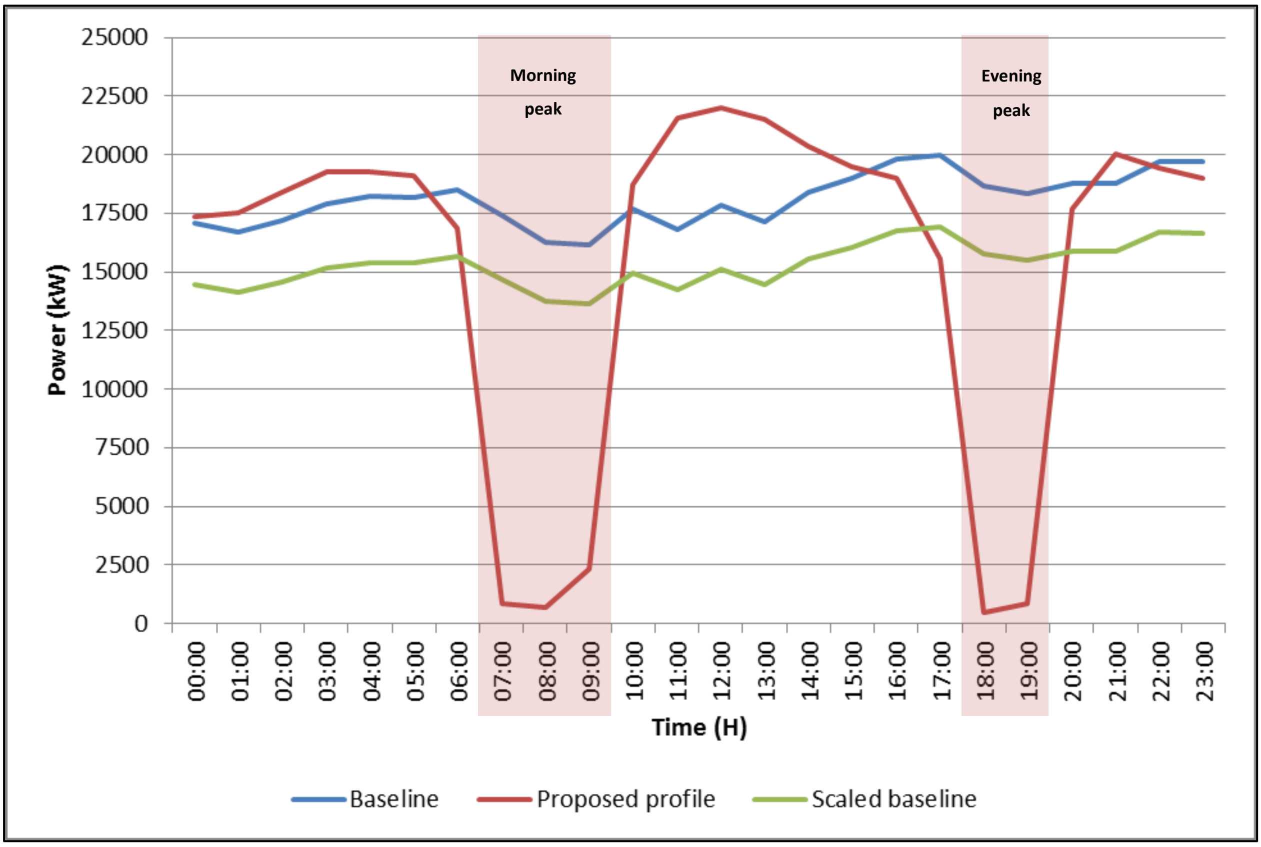


Figure 8: Baseline, proposed profile and scaled baseline

There is always a possibility of project underperformance after implementation. Comparing the project simulation results with actual results can give insight into the project. Project performance can be optimised and investigated by simulations to identify problem areas and can enable the client to realise maximum benefits.

Various simulation models have been developed by companies to simulate load shifting on mine dewatering pumps, as well as load shifting in other sectors of the mine. The simulation model used in this dissertation is Real-time Energy Management System (REMS).

REMS can be used as a simulation model or a real-time energy management programme to control mine dewatering pumps automatically using real-time data with minimal user input. By using the REMS simulation package one can accurately simulate the possible outcomes and then implement the simulation in the mine. Implementation will abandon the simulation of time and use real-time data from underground PLCs.

2.3 FACTORS INFLUENCING AUTOMATION PROJECT SUCCESS

Numerous factors may influence the success of an automation project. These factors should be assessed and documented before a pumping station is automated. The main points of discussion and research includes energy costs, training, cost reducing initiatives, reduced human intervention, maintenance, safety, quality, mine strikes, water hammering, the number of pumps and permitted dam level usage.

2.3.1 ENERGY COSTS

Energy consumption of a pump is dependent on various factors, including [27]:

- Load profile,
- Motor and pump efficiencies,
- Pipe and valve configurations and specifications.

The efficiency (η) of a pump can be calculated by using equation 7 [16]:

$$\eta = \frac{\rho g Q H}{P_m} \quad \text{(Eq. 6)}$$

Where:

η = Efficiency of pump as a decimal (Decimal)

ρ = Density of water (kg/m^3)

g = Acceleration of gravity (m/s^2)

Q = Flow rate (m/s^3)

H = Energy head added to flow (m)

P_m = Input power (W)

For the pumping unit (motor and pump), the overall efficiency can be calculated as [16]:

$$Overall\ efficiency = pump\ efficiency \times motor\ efficiency \quad \text{(Eq. 7)}$$

2.3.2 TRAINING

Information sessions and continuous training have to be provided to all personnel involved with the automation project. All personnel have to be informed and trained, enabling the personnel to resolve problems and repair equipment whenever required [28].

Most mines have enough personnel, but the workforce is still unskilled and inexperienced and has to be trained to complete a task or installation. The mind-set used to interpret any problem or situation is reliant on the training received [28]. Without training the mine could experience delays that would in effect cost them a notable amount of money. Programs used for automated control should have a simple Graphical User Interface (GUI) to ensure ease of access and minimal training [29], [30].

Training can be conducted by using presentations and practical demonstrations. The responsibilities of all personnel must be clearly stated during the training sessions. The mine can increase work efficiency and realise long-term benefits if it provides the training best suited to the resolution of issues. After training has been conducted, all personnel know their responsibilities and are able to address and resolve issues.

Experience in resolving issues is important and can only result from years of doing so. The mine can benefit greatly by employing skilled and experienced problem solving personnel in each field to train young and inexperienced employees. The future success of the mines depends on the effectiveness of the training provided and skills transferred from experienced personnel to young unskilled personnel [31]. During this study training was conducted with the departments shown in Table 1.

Table 1: Departments trained

Department	Responsibility	Description
Engineering	Universal	Training was conducted with the engineers to ensure an overall understanding of the project.
Maintenance	Maintenance	Engineers have to perform maintenance as indicated by automated system and attend to breakdowns as needed.
Operations	Surface control and reporting	Reporting of issues such as underground communication failure, column failures, pump failures, power failures and all communications from the surface.
	Pump stations control	Underground pump operators have to be present at pumping stations underground to report possible issues and breakdowns that occur.
Mechanical	Mechanical	Fitters are need for mechanical installations in underground surroundings. Fitters can be contacted when maintenance is required on a pump.
Electrical	Electrical	An electrician will receive training to resolve any electrical issues.
Technical	Instrumentation	It is the technician's responsibility to resolve any issues related to instrumentation. Technicians are an important part of ensuring the sustainability of the pump automation project.

2.3.3 OPERATIONAL EXPENDITURE INITIATIVES

As electricity prices increase annually, concerns regarding the operational expense of the mines are rising. The logical solution is to remove items from the budget, starting with the least important sectors. The client can operate without automating systems and therefore system automation is taken out of the budget, or some major components of automation are abandoned.

However, it is more profitable to rather reduce the budget for other sectors, as DSM projects can help the mine realise electricity cost savings. As illustrated in Figure 9 all the projects displayed in the figure achieved better load shift targets than the proposed targets. It is evident that a DSM project can help the mine by reducing its electricity cost, thereby creating the opportunity for other budget adjustments.

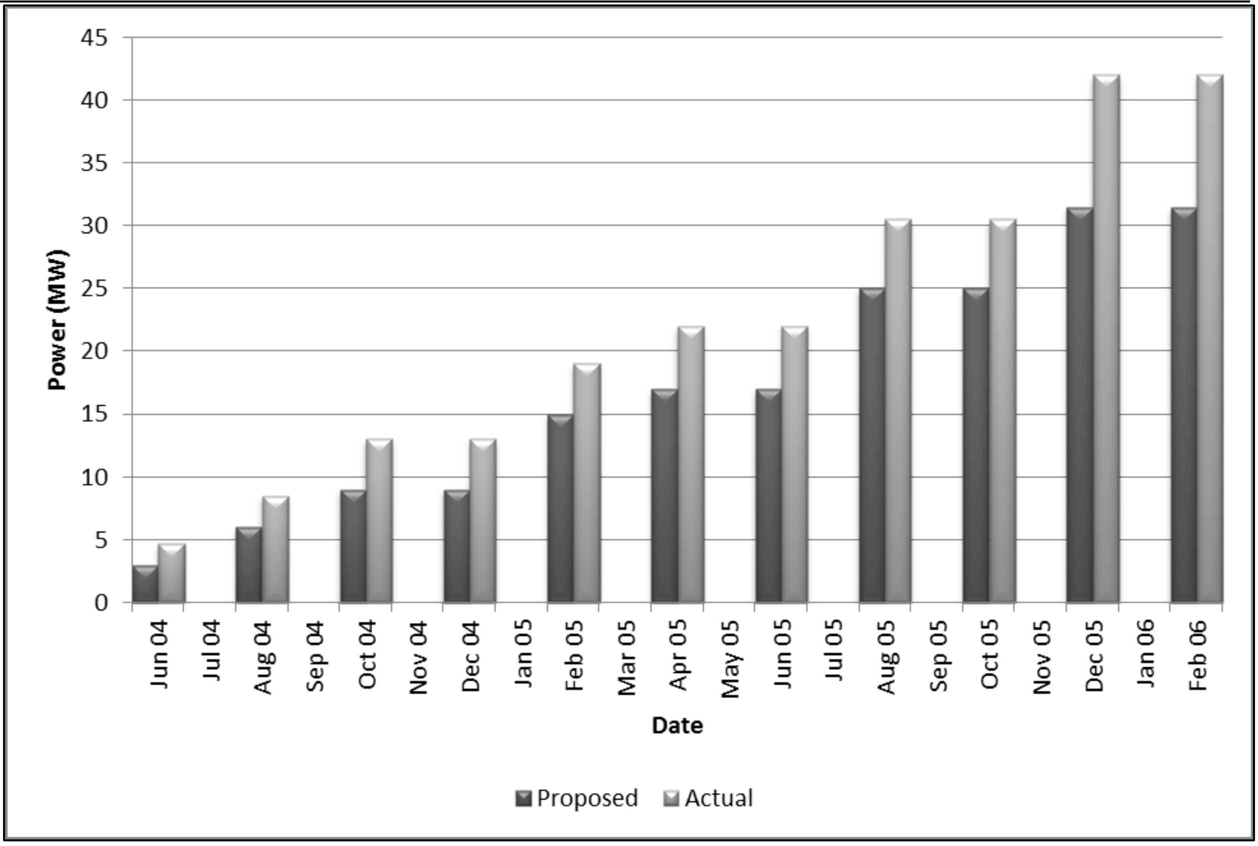


Figure 9: Cumulative load shift target and actual load shift achieved[32]

Automating a mine pumping system requires large capital expenditure. Usually the budget of a mine does not allow for complete automation. The reduction of the funds for automation means that only the basic instrumentation is installed, negatively influencing the benefits of automation [17].

Maintenance and operating cost are the first sectors that can function with reduced funding. These undesirable budget cuts cause neglected maintenance and in return cause breakdowns that influence production. When production is influenced the mine is negatively affected financially [28].

2.3.4 REDUCED HUMAN INTERVENTION

Reducing human intervention on a mine's dewatering operations can be advantageous or disadvantageous. When people are continuously relied upon for a specific outcome there is always a chance of human error, which in the mining industry can prove fatal [28]. Automation can therefore reduce the risks of human error. Another advantage of automation is reduced labour costs. As labour costs rise, the mines will operate more cost efficiently with automated systems [21].

The main disadvantage of reducing human intervention is the possibility of involuntary termination of employment. Although programmed control systems are able to operate automatically with minimal user input, there is still a need for operators to monitor the system. Control room operators monitor the control systems for possible risks when alarms incorporated into the system warns them of an issue that has to be addressed [33].

2.3.5 MAINTENANCE

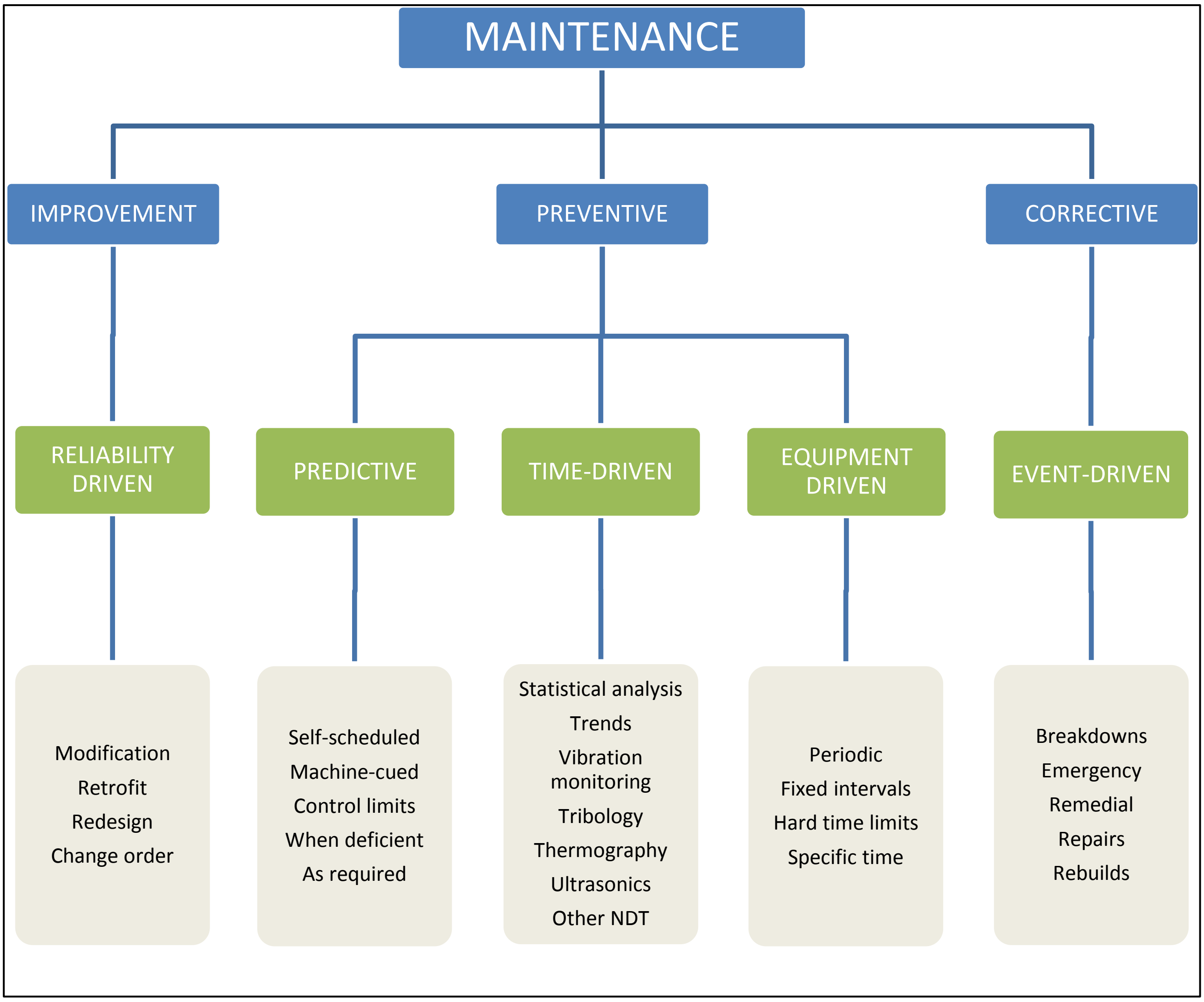
In some mines in South Africa maintenance on automated systems are neglected. Poor maintenance practices can cause problems with the pumping system [34]. The main reason for the problem is the robust environment of mines. Equipment and tools do not last as long in these brutal conditions.

An acceptable automated design has to be implemented, taking into account maintenance, operating costs and the environment [35]. The only sustainable solution is to install equipment that is designed to operate in these conditions, increasing the cost of the project considerably. The advantage of installing heavy duty equipment is that maintenance costs will then be reduced [36]. It must be noted that even when the correct equipment for the environment is installed, there is still a need for maintenance.

Critical spare parts should always be kept on site to reduce downtime if a component fails [16]. It is important for the client to identify these components and to plan in advance when these items are required. This will ensure that production, safety and sustainability are minimally affected.

Table 2 indicates the type of maintenance procedures available. By implementing these procedures effectively, the cost of maintenance can be calculated and maintenance cost savings can be realised. Corrective maintenance can be avoided by setting up a maintenance structure where improvement maintenance and preventative maintenance is the main focus. When maintenance is performed effectively, production will be influenced minimally.

Table 2: Maintenance structure[37]



2.3.6 SAFETY

Every mine has its own safety regulations and procedures. The contractor implementing the automation installation must follow these safety regulations and procedures to avoid damage, injury or in extreme cases, fatalities [38].

After automation, pumps are started automatically. If procedures such as lockout procedures are not followed with precision, damage to equipment or injury to mine personnel can occur. Lockout procedures involve locking out a pump to ensure that the pump does not start while maintenance is underway.

Risk assessments are prepared and signed off by the client to reduce and mitigate a possible risk. The extent to which training is provided can also reduce the possibility of any unwanted safety concerns. Noncompliance can lead to safety problems. Legal action could be taken against the mine or a person of interest.

Cooling and ventilation in a mine is one of the most important aspects, as no mine can operate without these. Major safety concerns also arise from cooling as health risks come into play [38]. When engaging in any activity in the mine, the safety and health regulations should not be affected and should be adhered to at all times [39].

2.3.7 QUALITY ASSURANCE

A contractor is usually employed to install the equipment for pump automation. The quality is determined by the client's standards and the contractor's experience regarding pump automation. After completion all equipment is commissioned and tested to ensure quality standards are adhered to. The client does not accept and sign off work that does not meet the minimum quality standards.

The quality of a component is defined by the manufacturer's quality standards. The desired project results are influenced by each component's quality [40]. When installing a poor quality component, a weak point is created. High quality robust equipment is desired for the extreme underground conditions.

2.3.8 FLUID HAMMERING

Fluid hammering costs mines a significant amount of money each year [41]. Fluid hammering is caused by power failures, pump switch-off or start-up, column separation, valve instability (rapid closing or opening) and pump blockage [42]. The worst form of hammering occurs when the flow through a pipe is stopped instantaneously [41]. Shock waves in the pipe cause unusual stress. In some cases pipes fail, causing damage to infrastructure. Water hammering is also a safety concern to the mine.

Fluid hammering also occurs in sections where pipes have slopes. Failure can occur at these slopes when the pressure exceeds the manageable pressure inside the pipe [43]. Water hammering can occur before or after a valve. The most common water hammering that occurs in the mining environment is valve-induced water hammering, as illustrated in Figure 10 [44], [45].

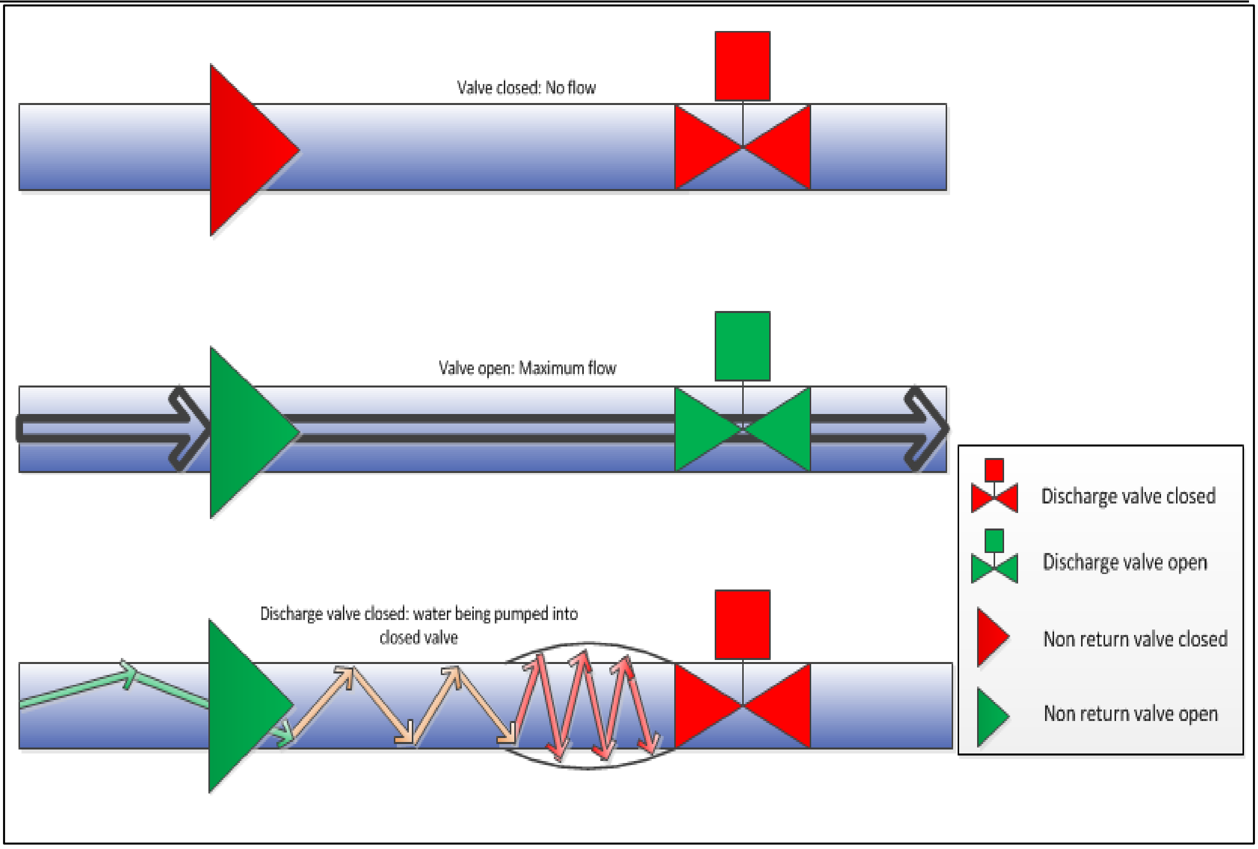


Figure 10: Valve induced water hammering

2.3.9 MINE STRIKES

In South Africa the economy is greatly dependent on the success of mines [46]. Strikes have a negative effect on the economy. Mine strikes occur when wage negotiations by mining companies and worker unions fail to produce an agreement. Figure 11 illustrates the working hours lost in South Africa during strikes.

The hours lost do not only affect the mines' production, but can also delay projects for weeks, and in some cases months. This affects the electricity cost savings that could have been achieved if the project was not delayed.

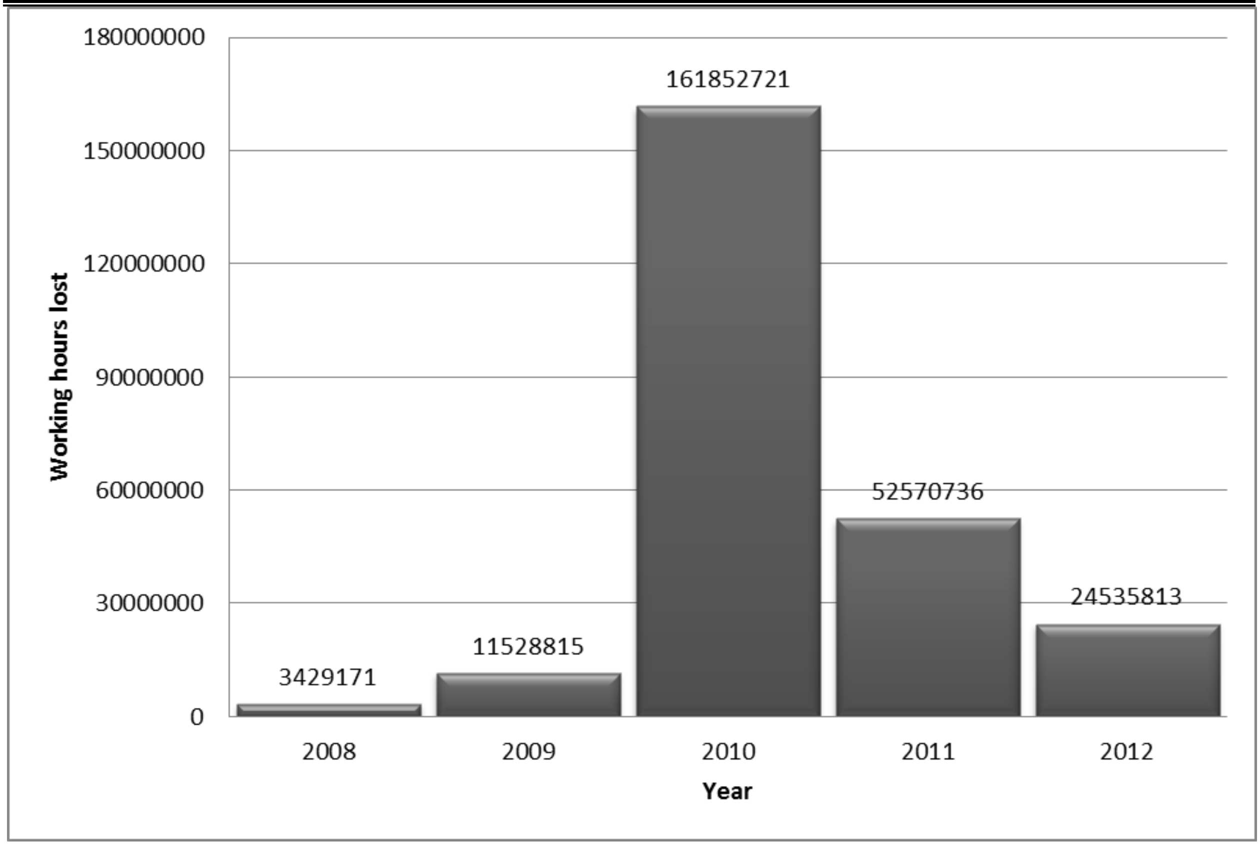


Figure 11: Working hours lost due to strikes in South Africa from 2008 to 2012[47].

2.4 INSTRUMENTATION NEEDED FOR AUTOMATION OF DEWATERING PUMPS

Chilled water is used for drilling, dust suppression and cooling operations such as those used in cooling cars and spot coolers [48]. After chilled water has been used, it is channelled from the various levels into underground settlers. From the settlers the hot water is transferred to the underground holding dams. The water is then pumped to the surface in a cascading configuration.

The following is required to determine the volume of water that can be pumped to the surface [24]:

- Dam capacities;
- Allowed dam levels;
- Pumps available and healthy condition;
- Capacity of pumps;
- Columns available;
- Columns permitted flow rates;
- Underground water consumption.

Pump automation can become very complex and may require considerable instrumentation for automated control. The basic instrumentation includes temperature transmitters, vibration transmitters, flow meters, PLCs, servers, pressure transmitters, valves and dam level indicators. The location of these instruments on each pump is illustrated in Figure 13.

Programmable Logic Controller

A PLC is a computational device used to control industrial machines or systems [49]. The PLC of a pump, as illustrated in Figure 12 and Figure 13, is used for communication and control between the surface and underground [26]. The communication protocols used by the mine is shown in Appendix A.

Safety trip conditions can be programmed into PLCs to avoid possible pump or component damage when unwanted conditions occur [26]. The costs of implementing PLCs are very high, ranging from R250 000 to R800 000, as software development and commissioning is required [50]. Other equipment PLCs need to operate successfully and uninterrupted include:

- PLC enclosure,
- Uninterrupted power supply (UPS) and power supply,
- Human machine interface (HMI),
- Circuit breakers,
- Input output (I/O) section – analog and digital,
- Centralised processing unit (CPU).

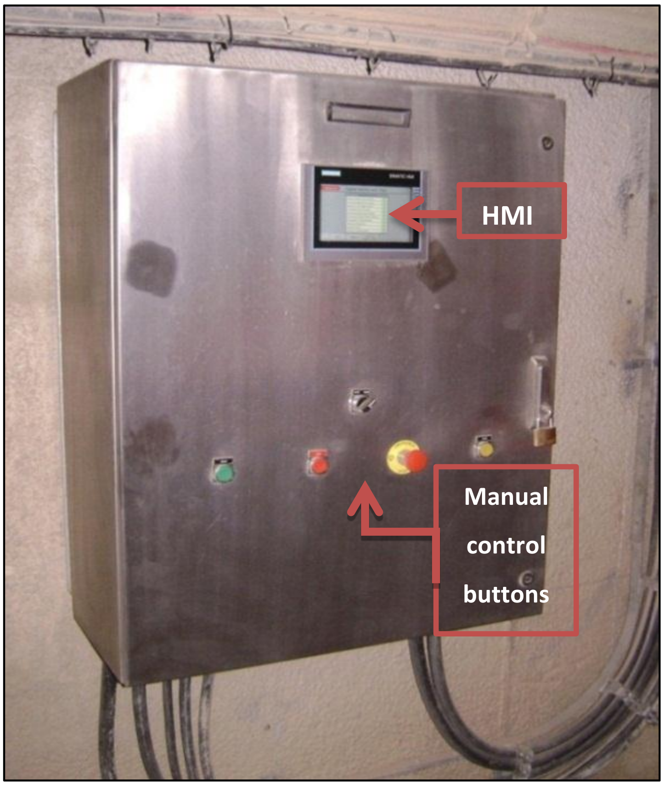


Figure 12: PLC enclosure with HMI

Number	Description
1	Motor NDE bearing temperature
2	Motor shaft displacement
3	Motor winding temperature
4	Motor winding temperature
5	Motor winding temperature
6	Motor air temperature
7	Motor DE bearing temperature
8	Motor vibration transmitter
9	Pump DE bearing temperature
10	Pump DE vibration transmitter
11	Balance disk switch
12	Pump NDE bearing temperature
13	Suction pressure
14	Discharge pressure
15	Balance disk flow
16	Valve position feedback
17	Balance flow temperature
18	Suction temperature
19	Discharge temperature

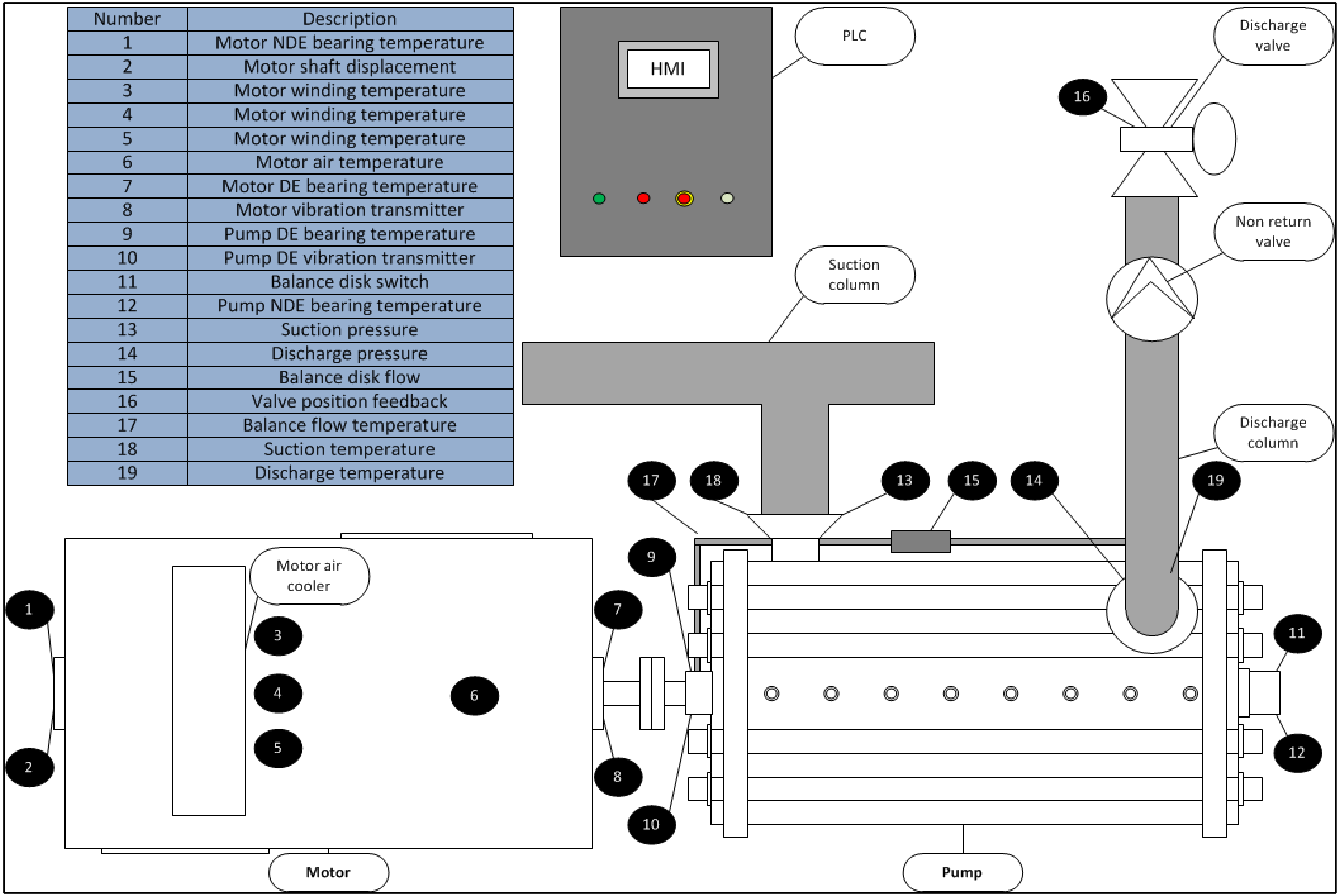


Figure 13: Typical instrumentation for multistage pump automation

The functions of the PLC include:

- Monitoring dam levels, column pressures, flow rates, temperatures and vibrations,
- Sending pump condition signal indications so that the pump is able to start,
- Communication with HMI panel,
- Communication with SCADA,
- Tripping a pump when unwanted conditions occur.

Cabling and wiring

In the mining industry, high quality cables with good conductive properties are needed to withstand the extreme environmental conditions [51]. Armoured cables are used to provide protection against the hazardous environment. Compared to unarmoured cables, armoured cables cost considerably more. Gold mines typically reach depths of 3.9 km. Cables can therefore become quite long, which also increases the cost.

The underground PLCs are connected to the surface SCADA for communication by use of a fibre optic network cable [26]. The PLC is connected to the instrumentation by means of a copper cable. Cable racking is required to ensure that the cables are kept out of dangerous areas where possible damage could occur. A typical cable used for mining purposes is shown in Figure 14.

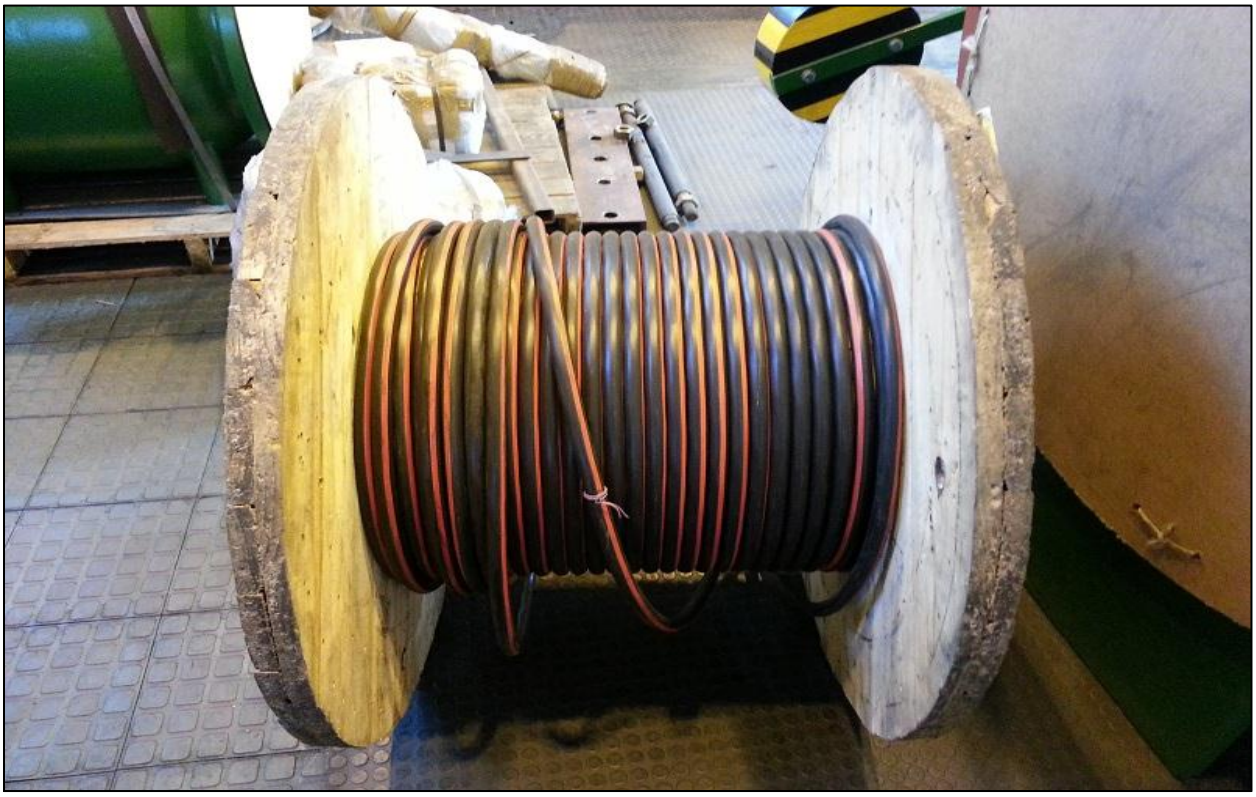


Figure 14: Cabling used in mines

Vibration transmitter

Due to the mechanical operation of a pump, vibrations are inevitable [52]. Vibration meters measure the vibrations caused by bearing wear. Vibration meters are used to send signals to the PLCs to trip pumps when vibrations exceed the maximum permitted level [17].

Vibration transmitters can be installed on the DE and the NDE of the motor or pump to measure the bearing vibrations. These meters are installed on pumps and motors when an automation project is implemented [8]. A typical vibration transmitter installed on the DE of the pump is illustrated in Figure 15.

Figure 15: Vibration transmitter installed on the DE of the pump

Temperature probes

Temperature probes are used to monitor the condition of a pump and to possibly activate a trip condition to avoid damage to a pump [17]. They can give insight into the current condition of certain units of the pump. Temperature probes can be installed on the drive end, as well as the non-drive end of the motor or pump to continuously measure the bearing temperatures [8]. A typical temperature probe installed on a multistage pump is illustrated in Figure 16.

Different temperature probe applications on mine multistage pumps include:

- Motor winding temperature (blue phase),
- Motor winding temperature (white phase),
- Motor winding temperature (red phase),
- Motor air temperature,
- Motor DE bearing temperature,
- Motor NDE bearing temperature,
- Pump DE bearing temperature,
- Pump NDE bearing temperature,
- Balance flow temperature,
- Pump suction temperature,
- Pump discharge temperature.

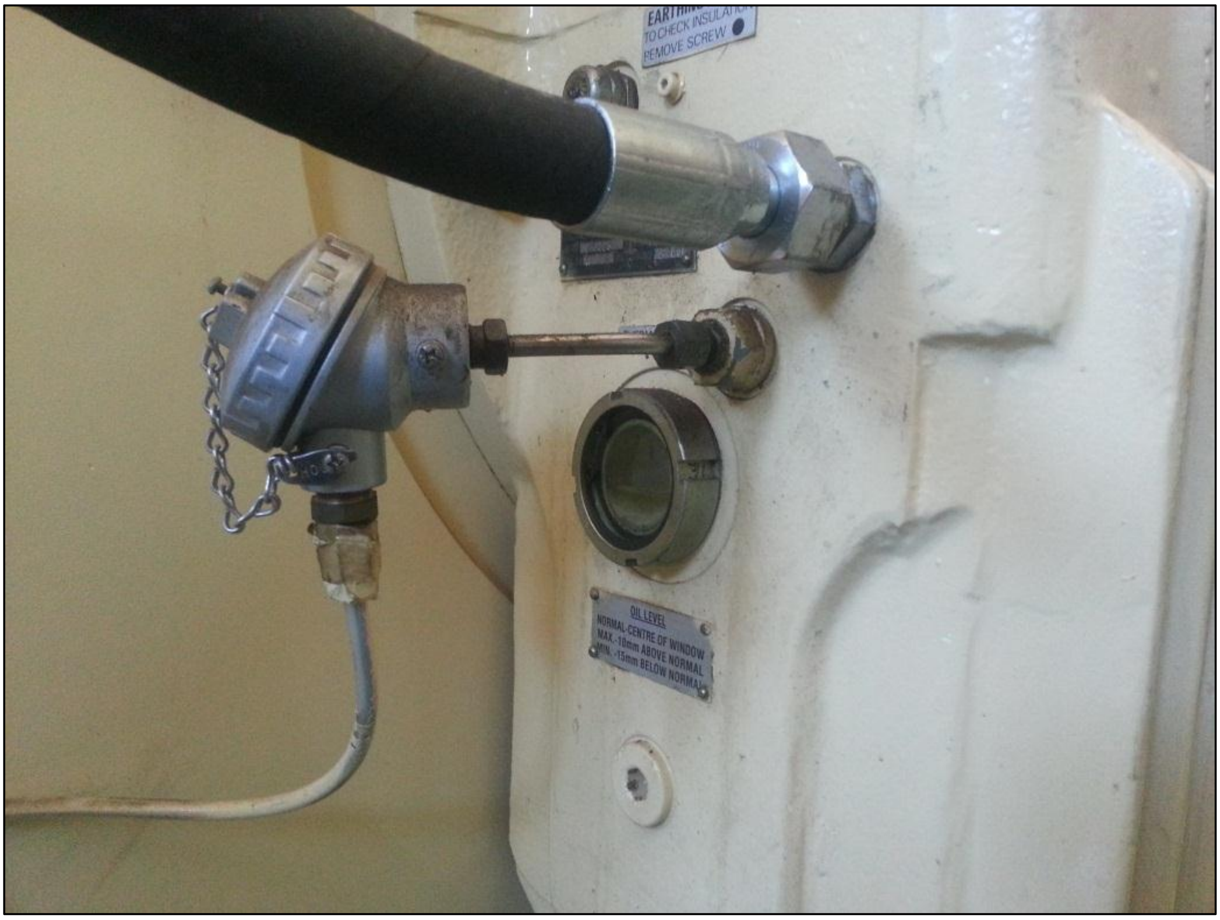


Figure 16: Temperature probe installed at the DE of motor

Shaft displacement meters

Shaft displacement meters are necessary to monitor the vibrations, position and profile of the motor or pumps shaft [53]. When the displacement is more than the specified value, the pump will not be able to run at optimum efficiency [26]. Trip conditions can occur when critical shaft displacement conditions are reached.

Balance disk

A balance disk is a disk located inside a typical multistage pump. When operational, the pump impellers cause stresses and thrust inside the pump [48]. The balance disk wear switch is used to measure the axial thrust inside a pump caused by internal wear [54]. The balance disk wear switch detects wear due to long term pump use and will trip the pump if necessary to avoid complete failure [26].

The balance disk flow switch will adjust the flow according to the efficiency of the pump. When the pump's efficiency deteriorates past the minimum certified efficiency, the pump will trip [26]. A typical balance disk wear switch is illustrated in Figure 17.

Figure 17: Balance disk wear switch

Pressure sensors

Industrial operations are highly dependent on pressure sensors for control and safety [55]. It is important to specify the best sensor for each application. In applications where high sensitivity sensors are required, the correct sensor should be installed, as safety measures are sometimes dependent on the sensor [55]. Pressure sensors can be installed to monitor pressure on various applications.

The discharge pressure is the pressure measured at the discharge or outlet of the pump. Trip conditions can be set up to prevent pumping into an empty column [26] [56]. It is important to monitor the discharge pressure to avoid damage to a pump or column. Suction pressure is measured at the inlet of the pump. The suction pressure is dependent on the head of the dam from which the pump gets water. Trip conditions can be enabled to avoid pumps operating on empty dams [26].

Column pressure transmitters measure the pressure at the discharge of the pump in the discharge column. The pressure can indicate if the pump is running and when issues occur. Column failures can be avoided if safety trip conditions are programmed into the PLC to trip a pump when the pressure in the column becomes too high [26]. A typical pressure transmitter installed on the discharge column is shown in Figure 18.

Figure 18: Discharge pressure transmitter

Discharge valves

It is important to select the correct valve and size for each application so that the required flow is delivered. The most commonly found valves in pump automation projects are ball valves and gate valves. The Bernoulli equation is used to select the correct valve [57]. The flow coefficient (Cv) is used to select valves. The following equation is used to calculate the flow coefficient [58]:

$$Cv = Q\sqrt{\frac{G}{\Delta P}} \qquad \text{(Eq. 8)}$$

Where

Cv = Valve flow factor

Q = Flow volume (m^3/s)

ΔP = Pressure difference (P_1-P_2) in bar

G = Specific gravity of fluid

Manufacturers have a standardised table with valve Cv's that indicates the correct valve for the specific application. Using the Cv for valve selections is relatively easy, depending on the manufacturer's indications [57].

Discharge valves are valves located at the discharge of the pump. Discharge valves communicate with the PLC via the connected actuator. The valves are set to close gradually to reduce water hammering. A gate valve that is used as a discharge valve is illustrated in Figure 19.

Actuators

Actuators control valve position. The actuator will communicate with the PLC to determine when to open and close the discharge valve. The sizing of valves and actuators is critical. If the valve actuator is not sized correctly, the valve plug may be drawn into the valve seat [41]. A typical mine discharge valve and actuator is displayed in Figure 19.

Valve position feedback is sent to the PLC. If the valve does not function according to the prescribed control, a trip condition occurs and the valve is forced closed. This will ensure that the pump does not pump water into a closed valve, causing pump damage or failure [26].

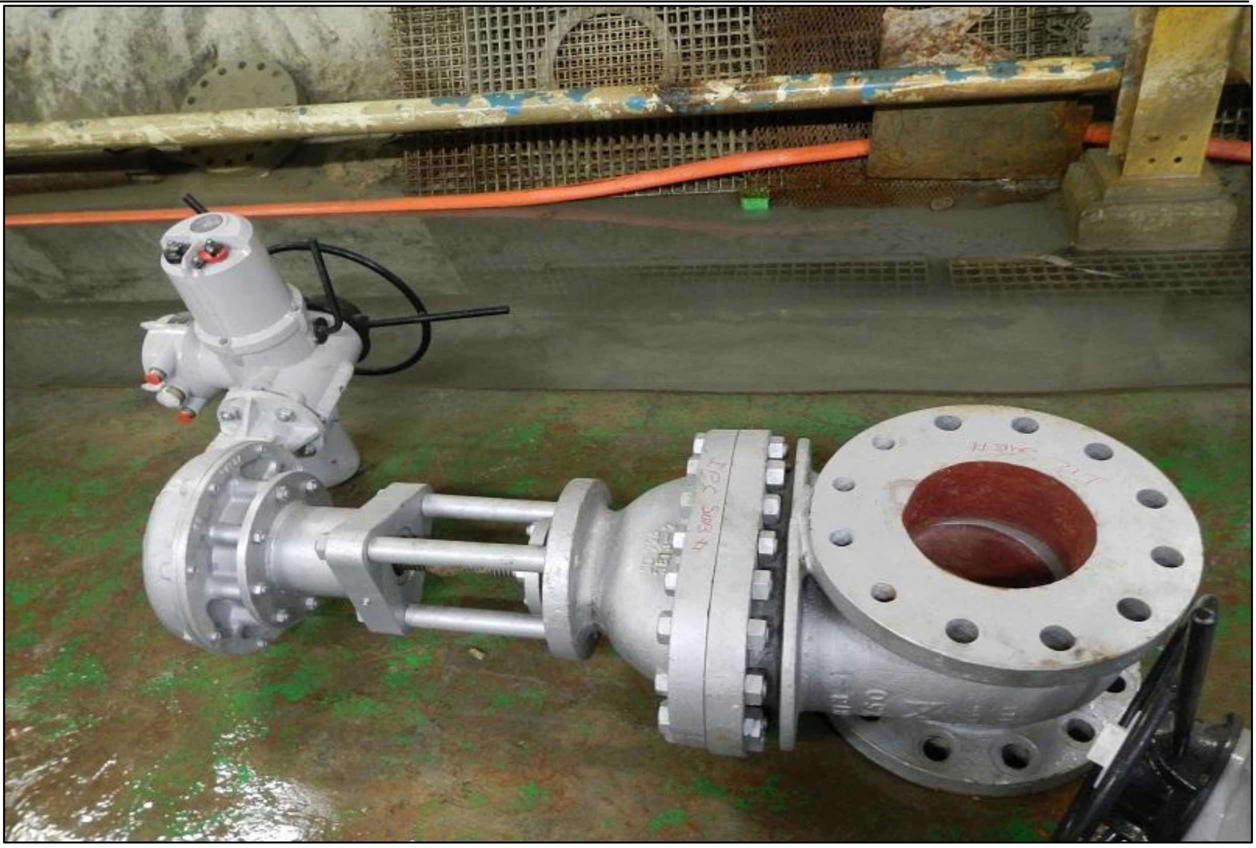


Figure 19: Discharge gate valve and actuator

Non-return valves

Non-return valves are located on the pump discharge column. They are used to prevent reverse flow and to assist with maintenance [59]. The correct valve configuration is very important to ensure that the pump configuration is minimally effected. A typical non-return valve installed on the discharge column of the pump is illustrated in Figure 20.

Figure 20: Typical non-return valve

Supervisory control and data acquisition (SCADA)

The SCADA is a program installed on a server located in the control room. It is used to indicate schedules, log data and control pumps automatically with the help of a control room operator or software [60] [61]. The SCADA is the backbone of the whole control system of the mine and sends instructions from the control room to the PLCs [62]. A typical gold mine SCADA GUI is illustrated in Figure 21.

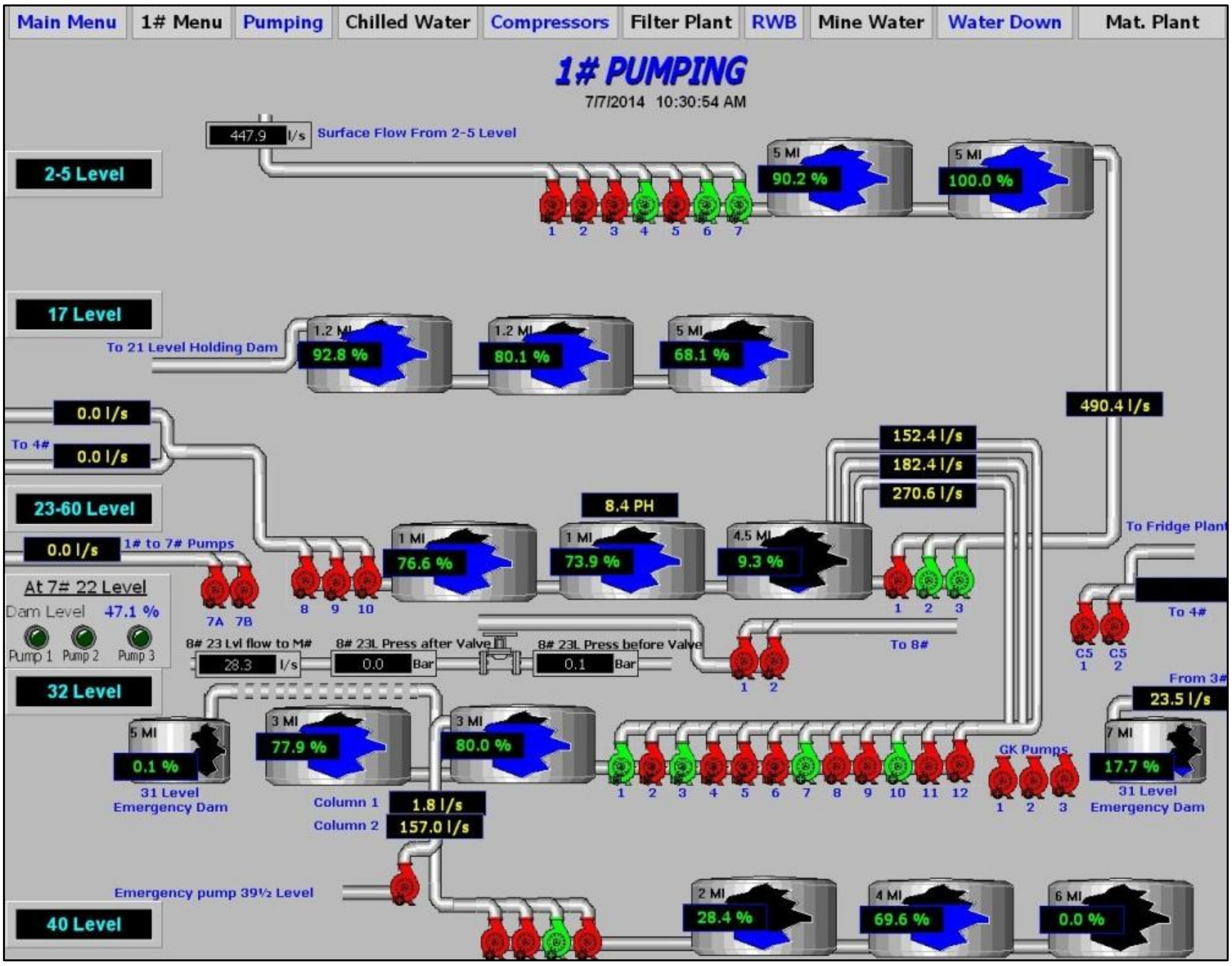


Figure 21: Typical gold mine SCADA

Dam level sensors

With automated control, the scheduled control of the pumps is mainly dependent on dam levels to alter the control schedules. Taking this into consideration, it is very important to have accurate and reliable dam level indications. One of the most effective items used for dam level indication is pressure transmitters [53].

Ultrasonic dam level indicators are instruments that are installed above the dam. A signal is sent out to the water. The time it takes for the signal to return can be scaled and this gives an indication of what the dam level is. These indicators have to be calibrated to show the correct dam level indication.

Pressure transmitters as shown in Figure 22 are submerged into the water and kept at an unchanged level at all times. The water will induce pressure on the meter, depending on the volume of the water in the dam. By using a scaling method the pressure is converted to an accurate dam level indication on the SCADA.

Figure 22: Submersible pressure transmitters[63]

Flow sensors

Flow sensors measure the flow inside a pipe or column. The delivery flow rate of the pump can be determined by installing a flow sensor in the discharge column of the pump [64]. Measuring the flow can provide insight into the condition of the pump. Safety trip conditions can be programmed into the PLC to trip the pump when no-flow conditions occur, preventing pump damage or failure.

Different flow sensor applications include:

- Cooling water flow sensor,
- Discharge column flow sensor,
- Balance disk flow sensor.

2.5 SUMMARY

Dewatering pumps use large amounts of electricity to pump out as much as 15 Ml to 60 Ml water per day per mine shaft. The implementation of DSM projects is a way of realising electricity cost savings. One method is to implement DSM projects to automate a mine's dewatering pumps and to perform a load shift. Load shifting will then enable the client to realise electricity cost savings

Simulation models can be used for project identification, the prediction of electricity cost savings and projected performance. After implementation of the automation project, the project can be optimised by using simulation models. Although simulation models can predict the outcome of a project, actual events after implementation could differ due to diverse mine activities.

The basic equipment needed to automate a mine's dewatering pump system is communication instrumentation, PLCs, flow meters, pressure transmitters, temperature transmitters, vibration transmitters, a SCADA-system and dam level sensors [60].

When taking budget cuts into consideration, some of the critical equipment may be abandoned. However, any project is directly affected by the decision to abandon some of the equipment. In an effort to compensate for the lowered budget, some projects use old instrumentation already installed on pumps. Problems often occur when the new instrumentation is not compatible with old or existing instruments.

The project performance is influenced by various factors, including the budget, safety and quality procedures, mine strikes, maintenance and human intervention. These factors all contribute to the success of the project.

Chapter 3. AUTOMATED CONTROL OF MINE DEWATERING PUMPS

Chapter 3 examines dewatering pump automation, the process from manual to auto and the performance assessment period. The installations and procedures involved in the automation project are discussed. Risks are identified and a control philosophy is compiled to help Gold Mine A understand how the control should be implemented.

3.1 INTRODUCTION

Investigations were completed and a DSM project in the form of a pump automation project was implemented to automate control of dewatering pumps at Gold Mine A. Gold Mine A is situated near Westonaria. Load shifting was implemented to realise electricity cost savings. The possible setbacks experienced when implementing an automation project are discussed in this chapter. Possible solutions for issues were implemented and are reviewed.

Dewatering pump automation involves a number of processes, including identification, investigation, project approval, implementation, commissioning and maintenance. The precision with which these procedures are implemented determines the success. Figure 23 illustrates the dewatering pump layout of the mine with basic automation infrastructure.

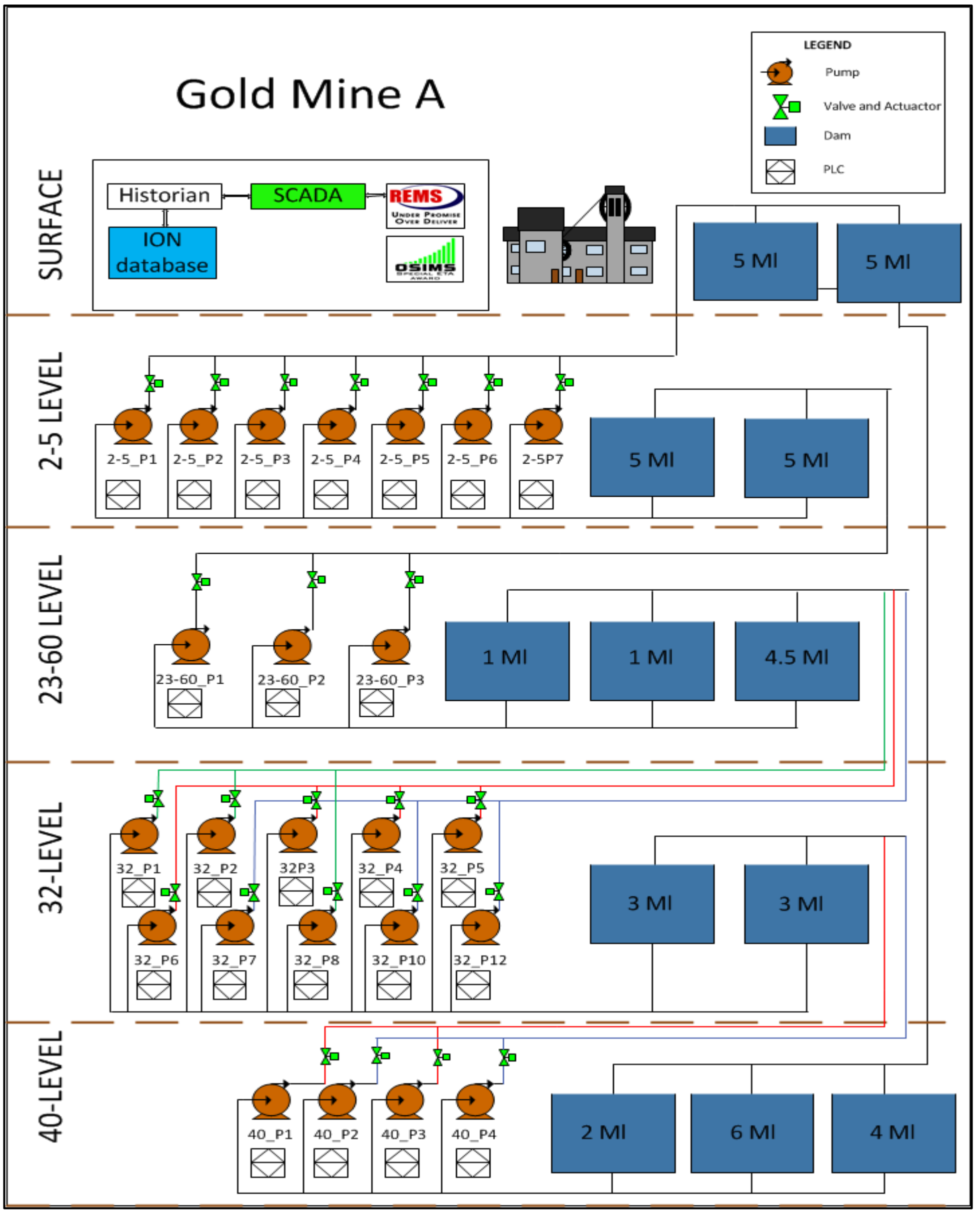


Figure 23: Gold mine A dewatering pump system layout

Gold Mine A has 24 pumps on four levels that will be automated. The number of installed pumps on each level is dependent on the dam capacities and the head pressure the pump has to overcome to pump water the level above. The installed capacities of the pumps at each pumping station are displayed in Table 3.

Table 3: Installed pump capacities

Pump station	Installed capacity of each pump	Number of pumps
2-5 level	1800 kW	7
23-60 level	3600 kW	3
32 – level	1500 kW	10
40 – level	1350 kW	4

Baseline

The baseline illustrates the power consumption profile of Gold Mine A before implementation of the project. The baseline is very important to quantify electricity cost savings, as explained in Chapter 2. A quick calculation can be made without simulation models to identify if a pump automation project has savings potential.

The baseline was obtained from underground log sheets that indicate when each pump was in operation. As seen in Figure 24, an optimised profile was created by simulating a total pump shut-off in the peak periods and adding a comeback load to off-peak and standard periods. The quick calculation illustrated a load shift savings potential of 17.5 MW.

The savings potential illustrated in Figure 24 is the maximum load that can be shifted and therefore the maximum load shift potential possible when no limiting factors are taken into consideration. Other factors such as dam capacities, column availabilities, pump availabilities, dam water inflows and dam water outflows have to be investigated and incorporated into simulation models. This will indicate if the maximum savings potential of 17.5 MW is possible.

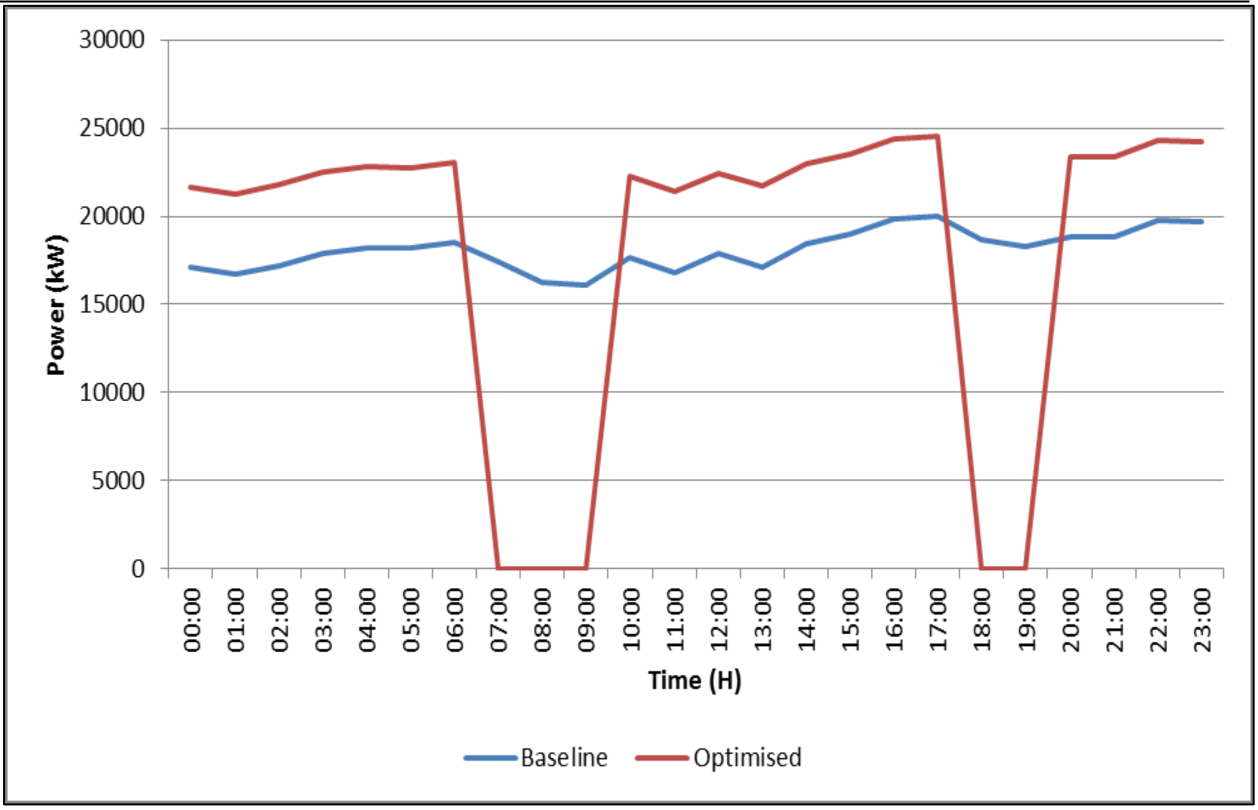


Figure 24: Baseline and optimised dewatering pumping power usage profile

3.2 DEWATERING PUMP AUTOMATION PROCESS

This section discusses the simulations, installations, procedures, commissioning and risk assessment compiled to automate Gold Mine A's dewatering pumps.

3.2.1 SIMULATIONS

Data was obtained from Gold Mine A for incorporation into a simulation model. The data used in the pump automation simulation program included:

- Pump availabilities,
- Pump efficiencies,
- Pump flow rates,
- Pump maintenance intervals,
- Dam capacities,
- Dam availabilities,
- Maximum allowable dam levels,
- Minimum allowable dam levels,
- Dam inflows.

REMS was used to simulate the project performance, load shifting possibility and electricity cost savings achievable. The REMS simulation layout is illustrated in Figure 25.

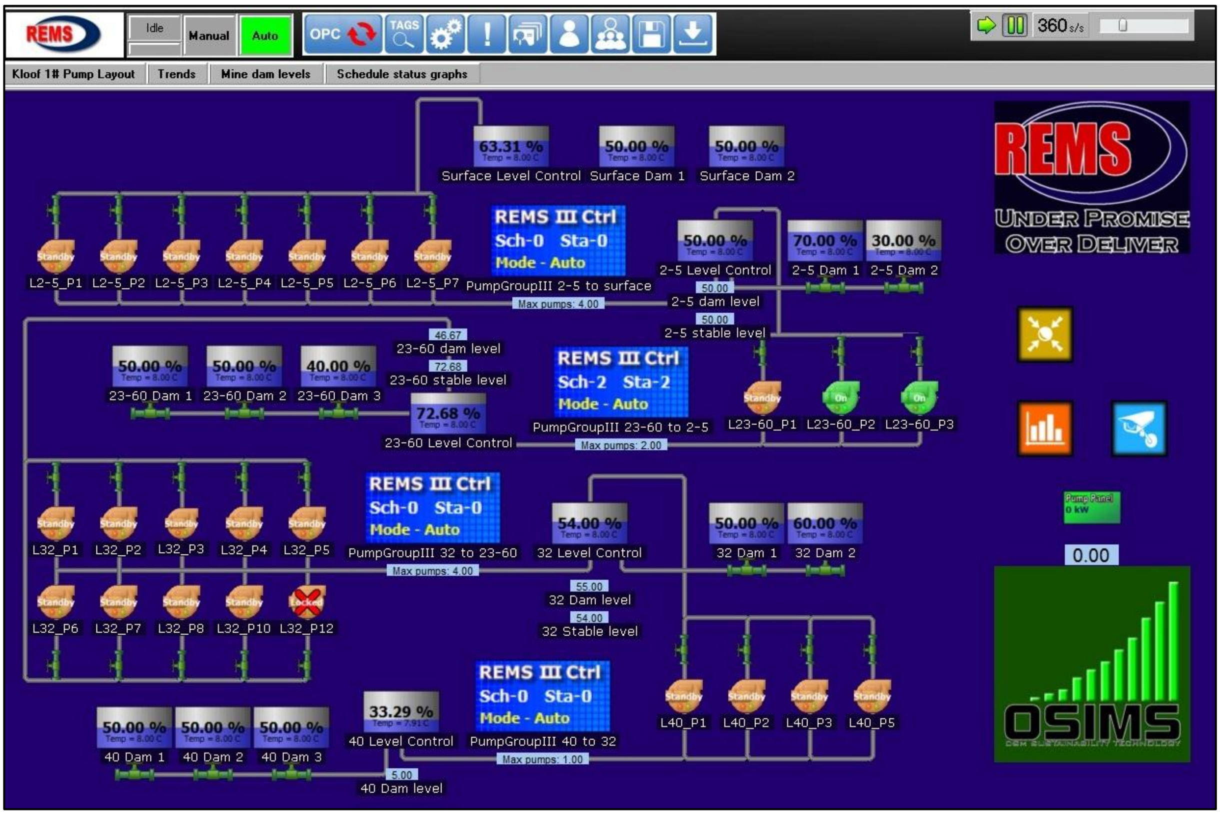


Figure 25: REMS simulation program to predict possible electricity cost savings

3.2.2 INSTALLATIONS, PROCEDURES AND COMMISSIONING

The project's predicted opportunities include electricity cost savings and improved monitoring of the pumping system. After investigations were complete and the project opportunities had been predicted by means of simulations, contractors were contacted to give quotations for installations and instrumentation required.

When quotes were compared the following was taken into account:

- Company age as an indication of experience,
- Company experience with relevance to pump automation projects,
- Quote total cost,
- Reviewing quality of previous work done,
- Reviewing contractor-specific site experience.

Due to a limited budget and the high cost of automation hardware, installations and engineering, some of the automation instrumentation could not be installed. The automation instrumentation was ranked from most important to least important to determine what instrumentation could be removed from the quotes.

After a contractor was appointed, the installations commenced and the instrumentation and hardware were installed on all the pumping levels. The instrumentation installed on each pump and motor is illustrated in Figure 26. Red balloon numbers indicate that the instrument was not installed and is excluded from the scope.

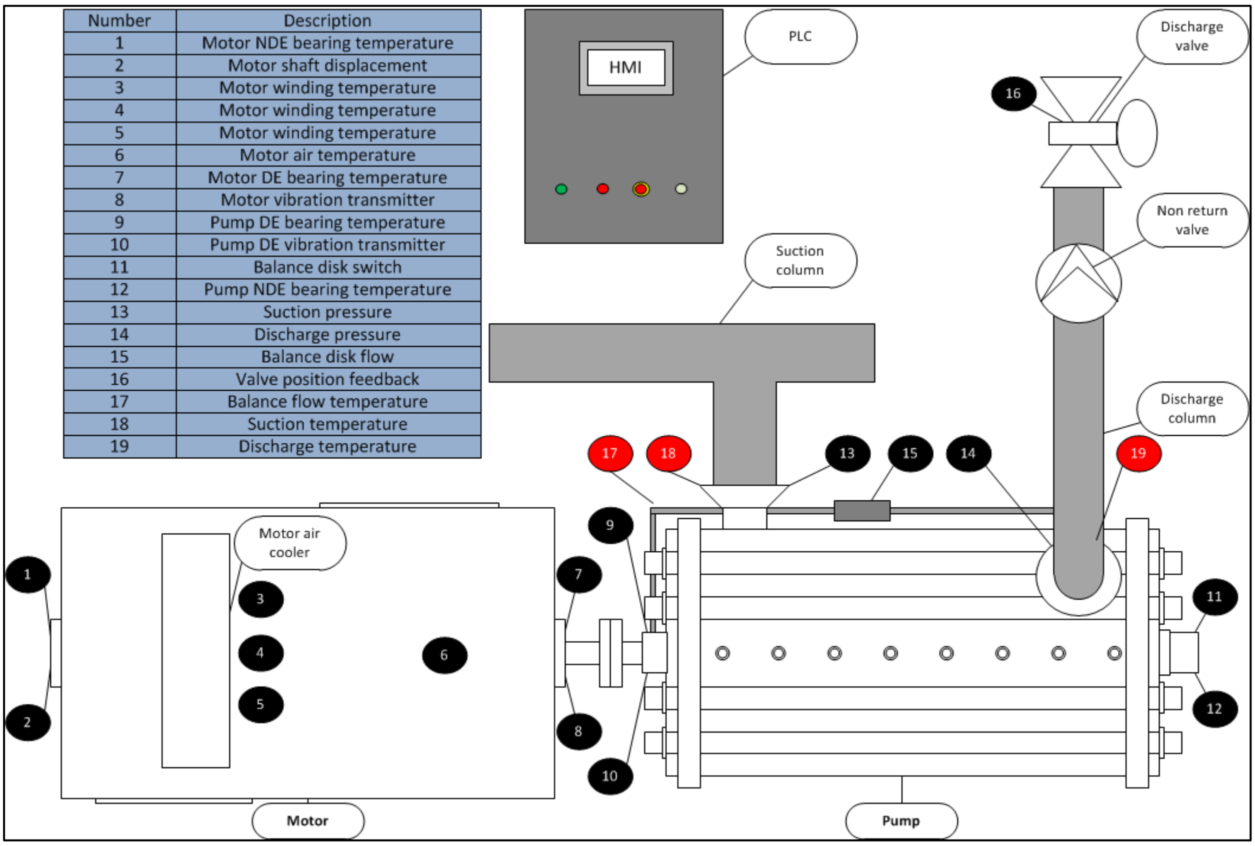


Figure 26: Instrumentation and hardware installed on each pump of Gold Mine A

Communication and control

Communication is one of the most important components of automated control. When communication channels are broken, automated control is abandoned. The basic flow diagram for communication is illustrated in Figure 27.

The SCADA was installed in the control room. The SCADA is the connection between the surface and underground. Any commands sent to the pumps go directly from the SCADA to PLCs or from the underground PLCs to the SCADA. A fibre-optic cable like the one shown in Figure 27 was installed and commissioned to establish a connection.

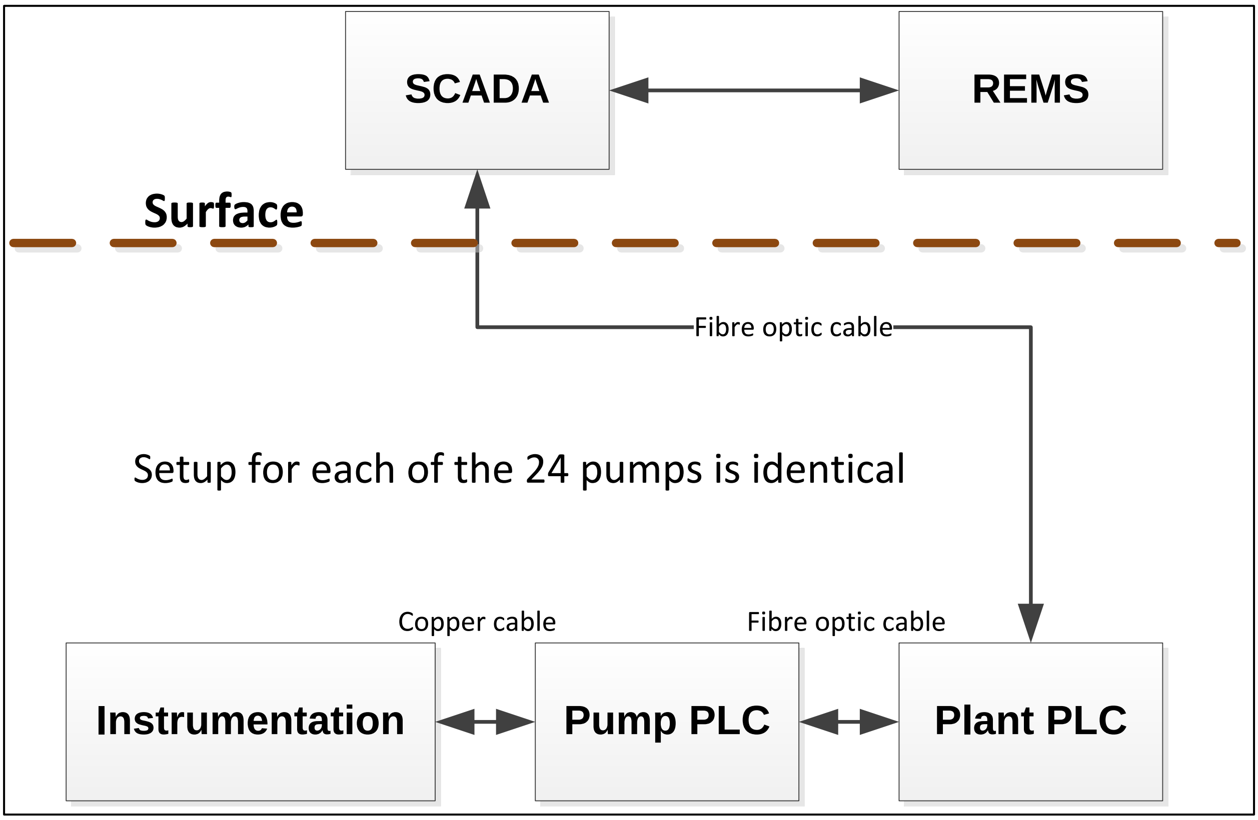


Figure 27: Basic communication flow diagram

In an effort to keep the SCADA GUI as simple as possible, colours were linked to the status and condition of a pump as illustrated in Table 4. The four possible conditions include pump healthy and available, pump running, pump unhealthy and communication error to pump. A healthy pump indicates the pump has no active alarms or faulty equipment.

Table 4: Pump colour indication definition

Icon	Colour	Pump condition
	Grey	Pump healthy and available (Stopped)
	Green	Pump running
	Red	Pump unhealthy (pump not in working order)
	Purple	Communication error to pump

The overview layout of the SCADA is illustrated in Figure 28. The main screen of the SCADA indicates the following:

- Pumps,
- Pump statuses,
- Pump chambers,
- Pump trip and alarm signals,
- Dams,
- Dam percentage levels,
- Water flow directions.

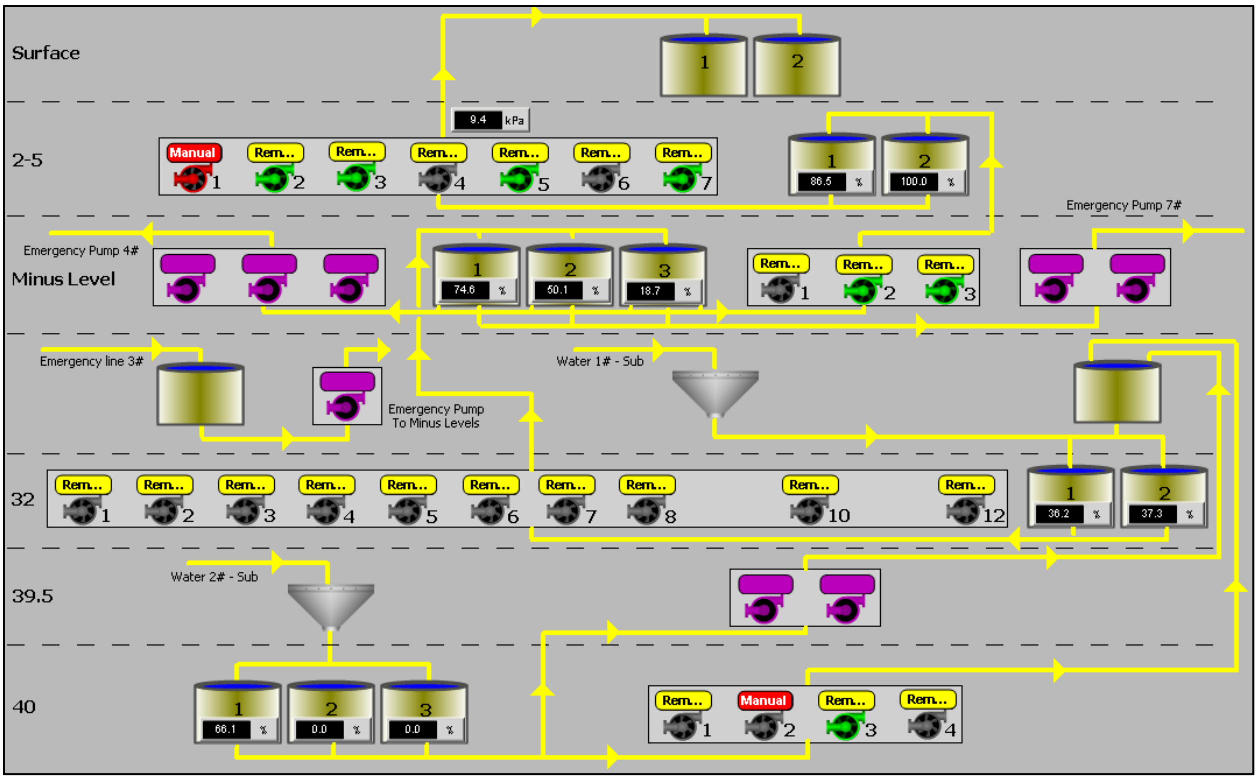


Figure 28: SCADA pumping system layout

Pumps are controlled by a number of different procedures that involve the SCADA and PLC. When the SCADA signals a pump to start or stop, the signal is sent underground to the relevant pump PLC where the necessary steps are taken to control the pump safely and efficiently. Pumps can be reset by the control room operator after a trip event to enable continued control of the pump.

Starting the pump entails ready-to-start conditions and a safety check sequence before start-up. A ready-to-start loop is implemented to ensure that all the safety procedures are adhered to.

The sequence will process all the safety trip conditions before making the pump available for start-up. If any of the safety trip conditions are active the pump will not be available for start-up. The start-up sequence diagram is illustrated in >>>Table 5.

>>>Table 5: Safety check sequence before start-up

No.	Start-up safety	Description
1	Common trip?	Common trips include conditions such as balance disk flow too low, discharge valve torque failure and high shaft displacement signals.
2	Common alarm?	Common alarms are activated when temperatures or vibrations are higher than permitted levels. Common alarms will indicate the cause of alarm when unwanted conditions occur.
3	Plant auxiliaries healthy?	The plant auxiliary phase in the sequence prevents pumps from starting when dams are too low. This avoids pump damage due to operation without water.
4	Discharge valve closed?	The discharge valve must be closed before a pump is started on the SCADA. If the discharge valve is not closed, the pump will not be able to start, as a trip condition will be satisfied. A time interval of 180 seconds was allocated to the valve reaching a fully opening position. In the event where the fully open signal is not received by the PLC within the 180 seconds, the pump will be tripped by the PLC.
5	Restart prevention active?	The restart prevention will prevent a pump from starting up directly after the pump has tripped. The prevention signal will give a true feedback signal after a pump trip, making the pump unavailable for three minutes.

Stopping the pump entails a controlled stop sequence. Once a stop signal is received by the PLC, either from the control room or manual underground control, the stop sequence will be activated. The stop sequence will close the discharge valve gradually until it reaches a position of between six and twelve per cent open, depending on the PLC's configuration. The sequence then sends a pump switch-off signal to stop the pump. As a safety precaution the pump can be stopped by means of the underground PLC control panel, or from surface irrespective of the mode of the pump (manual or automatic).

Pump trip conditions

Each pump, when selected on the SCADA, will display its own ready-to-start signals, trip condition indications, alarms and start-up sequences. When a pump needs repair work, the mine will be able to acquire data from the SCADA to enable them to view and find the faulty pump and problem area on the pump. The cause of the breakdown can be established by monitoring the instrument data sent from underground to the SCADA. The display menu for an individual pump when opened on the SCADA is illustrated in Figure 29.

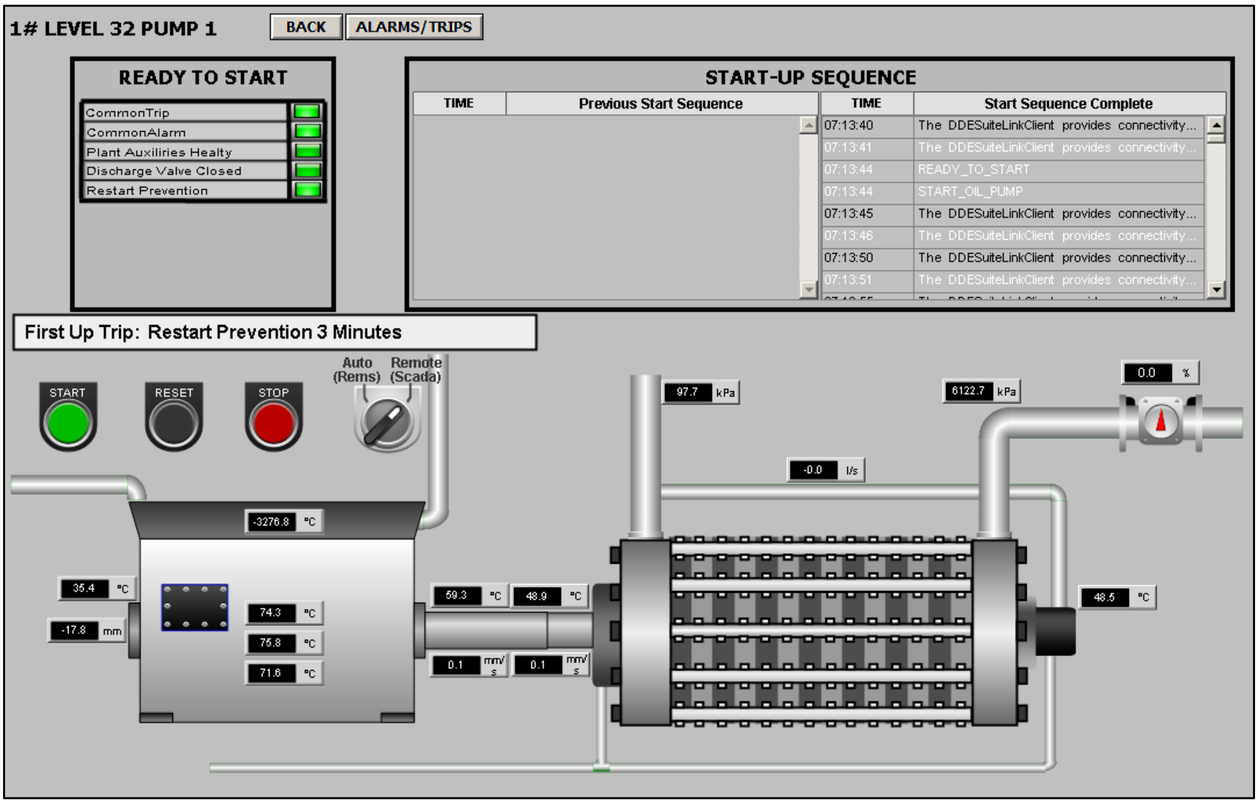


Figure 29: SCADA pump layout

Pump trip conditions are used for the safety of a pump. Safety trip conditions to trip a pump when unwanted conditions occur are illustrated in Figure 30. A pump will not be able to start if any of the trip conditions illustrated in Figure 30 are satisfied.

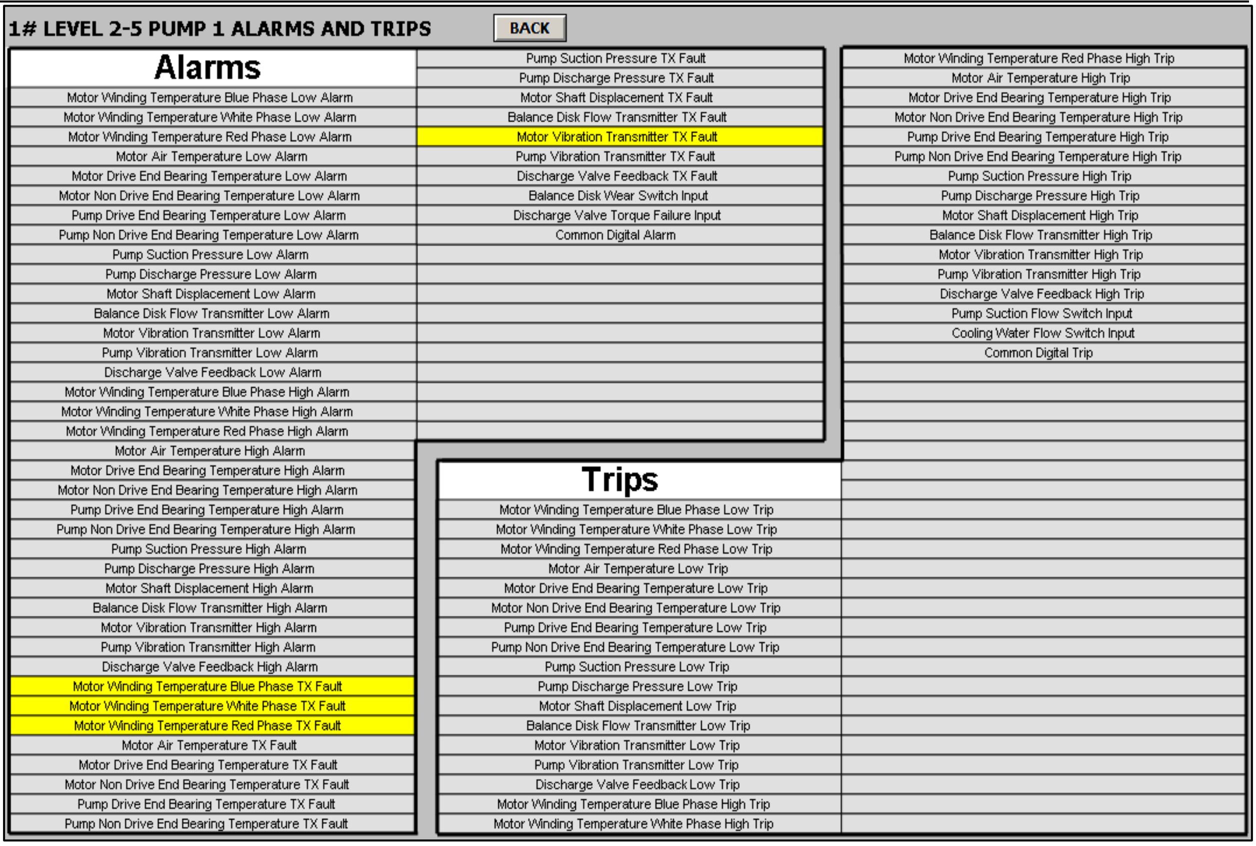


Figure 30: Pump alarms and trip conditions example

Training

The quality of the training provided is a key component to the sustainability of the project. After project completion a contractor will hand over the project to the mine or engage in a maintenance agreement. When maintenance agreements are not engaged into, the project efficiency can deteriorate drastically, depending on the success of the training provided.

The training documents used to train the control room operators are illustrated in Appendix A. Training as discussed in Chapter 2 was conducted with the engineering, technical, operations, electrical and mechanical departments.

Safety procedures

The contractor adhered to the safety regulations and procedures at all times. Safety procedures included:

- Pump lockout testing of each pump conducted to ensure a pump will not be able to start when the lockout procedure is applied to a pump.
- Risk assessment documents contain all possible risks. The risk assessment must be done thoroughly. Failure to predict a risk could have major consequences.
- A control philosophy document was compiled to explain the control procedures followed.
- When starting or stopping a pump from the SCADA, a tick box appears on the SCADA asking the controller if he/she understands the risk of controlling the pump. If the box is not marked, the pump will not be able to start, stop or reset.

Unexpected setbacks

Unexpected setbacks occur due to various reasons, such as maintenance issues, breakdowns delaying installation progress, unexpected delays causing more delays, existing equipment compatibility issues and mine sabotage.

Maintenance

Minimal maintenance was done at Gold Mine A. Issues emerged when critical processes and installations could not commence due to breakdowns. In most circumstances breakdowns could have been prevented by preventative maintenance, as discussed in Chapter 2. Preventative maintenance can be calculated into the budget and long-term savings can be realised. Production efficiency will also benefit the mine when preventative maintenance is implemented. Maintenance can be implemented at non-critical times.

Pump automation can facilitate maintenance as the possible area of maintenance required can easily be identified. However, the problem persists when improvement maintenance on the automation equipment is also abandoned. When the instruments required for identification of pump maintenance is abandoned, the mine will not be able to identify any problem to efficiently repair broken parts.

Breakdowns delaying installation progress

Planned installations can be delayed by various factors. Although the installations are done by contracting companies, some input from the client or mine is still required. Input from the mine is especially needed when underground installations are conducted. The mine has details about the environment or configuration of equipment that might help the contractor with performing a specific task.

Factors preventing planned installations included:

- Winder breakdowns,
- Ventilation issues,
- Shaft damage,
- Power failures,
- Pump failures,
- Valve failures,
- Column failures,
- Communication failures,
- Cable damage,
- Strikes,
- Electrical incomer issues.

Unexpected delays causing more delays

Medical inductions are conducted to enable a person to go underground to do installations. Any person proceeding underground for installations had to undergo a medical induction before underground installations could commence. These tests were completed to ensure no unwanted medical conditions were apparent when travelling underground, assuring the safety of any person going underground.

Medical inductions took four weeks to complete. Once completed, medical induction passes expire after a year. After expiry another medical induction test has be conducted before underground installation can commence.

The mine engaged in a wage strike, delaying the underground installations. After eight weeks the strike was over and installations could commence. However, the contracting company's medical inductions were no longer valid and new inductions had to be conducted before installations could commence, delaying the underground installations even further.

Existing equipment compatibility

Expensive equipment has to be installed for automation of pumps. The project funds restricted the installation of all new instrumentation. Old instrumentation installed before implementing the current automation project was used wherever possible. Problems emerged when the existing mine instrumentation was incompatible with newly installed PLC's. Some of the old instrumentation was damaged and had to be replaced. New orders were placed for the non-operational equipment, delaying the project.

Mine sabotage

As discussed in Chapter 2, pump automation can in some cases cause involuntary labour retrenchments. To ensure job security, mine personnel sometimes try to sabotage the instruments to negatively influence the success of the project. To prevent sabotage on the automated pumping system, Gold Mine A could install cameras underground.

Installing cameras underground can assist in reducing mine sabotage and cameras can capture the events before the failure of a component. The installation of cameras was recommended to the mine, but currently no cameras are installed.

Commissioning

In order for the mine to sign off on installations done by the contractor, commissioning and sign-off procedures were implemented. The system was commissioned to ensure that all aspects of the communication and hardware have been interlinked as required for the system to function successfully. Commissioning ensures that the parts are installed according to the safety and quality standards of the mine.

3.2.3 RISK ASSESSMENT

The calculation of risks is done using Table 6, Table 7, Table 26 and Equation 10. The likelihood or frequency of occurrence of a particular incident is allocated to a level ranging from one to five. Another level, also ranging from one to five, is allocated to the severity of the incident, as shown in Table 6 [65].

Table 6: Risk assessment severity table

Level	Consequence severity	Likelihood or Frequency
5	Catastrophic	Very Likely
4	Major	Likely
3	Moderate	Occasional
2	Minor	Unlikely
1	Insignificant	Rare

A matrix table is used with values ranging between 1 and 25. The table consists of levels of risks indicated with different colours. Green indicates that the risk is safe and all methods have been implemented to ensure that the risk is unlikely to occur. The green zone ranges from 1 to 5. Yellow indicates that the risk is a problem and some solutions should be explored to ensure that the risk is addressed. The yellow zone ranges between 6 and 14. Red indicates a high risk region and other controls have to be implemented to decrease the risk without further delay. The red zone ranges between 15 and 25.

Table 7: Risk assessing table

	Catastrophic	Major	Moderate	Minor	Insignificant
Very Likely	25	20	15	10	5
Likely	20	16	12	8	4
Occasional	15	12	9	6	3
Unlikely	10	8	6	4	2
Rare	5	4	3	2	1

The number allocated to the likelihood or frequency of the incident is multiplied with the consequence severity. Equation 10 is used to calculate the risk.

$$RATN = S \times P \qquad \text{(Eq. 9)}$$

Where:

$RATN$ = Risk assessment table number.

S = Level allocated to consequence severity.

P = Level allocated to frequency or likelihood of risk occurrence.

Example: An ESKOM power failure occurs. The Consequence of severity is Minor (Level 2) and the likelihood or frequency is Occasional (Level 3). Using the equation results in a RATN of 6, making the risk a yellow code risk. The risk can be lowered by adding safety measures such as installing uninterrupted power supplies or generators.

A risk assessment has been compiled to identify the possible risks present with pump automation at Gold Mine A. The risk assessment is shown in Appendix B.

3.2.4 CONTROL PHILOSOPHY

A control philosophy is required to assist the mine in understanding the approach used to control the pumps. The control overview, objects needed for control, communication, scheduling procedures, interaction with neighbouring shafts and alarm conditions will be discussed briefly.

The aim of the project is to optimise the pump schedule to create a situation where load is shifted out of the Eskom evening peak periods, resulting in a load shift and electricity cost saving. Pumps can be controlled remotely, enabling pumps to be stopped and started from the surface control room through the REMS system.

Pump information is available on the SCADA obtained from the underground PLC's. The machine PLC sends the data to the plant PLC. The plant PLC captures and processes data. The data captured includes dam levels, column pressures, column flows, vibrations, temperatures and trip interlock signals, which are sent by means of a fibre optic communication channel to the surface SCADA.

The programmed REMS server communicates with the SCADA situated in the control room. The SCADA in the control room is also used as a communication medium to and from the REMS server. The REMS communicates to the SCADA using an OPC connection. By means of monitoring the SCADA, the control room operators are able to monitor underground activity to identify actions to be taken.

Due to the cascading configuration of dewatering system operation, the REMS control has to monitor all the pump chambers simultaneously. The system control is compiled by a pump chamber assigned with a specific controller. This enables the REMS to use multiple controllers to dictate the effect a full or empty dam will have on an upstream or downstream pump chamber. The cascade control for Gold Mine A is shown in Figure 31.

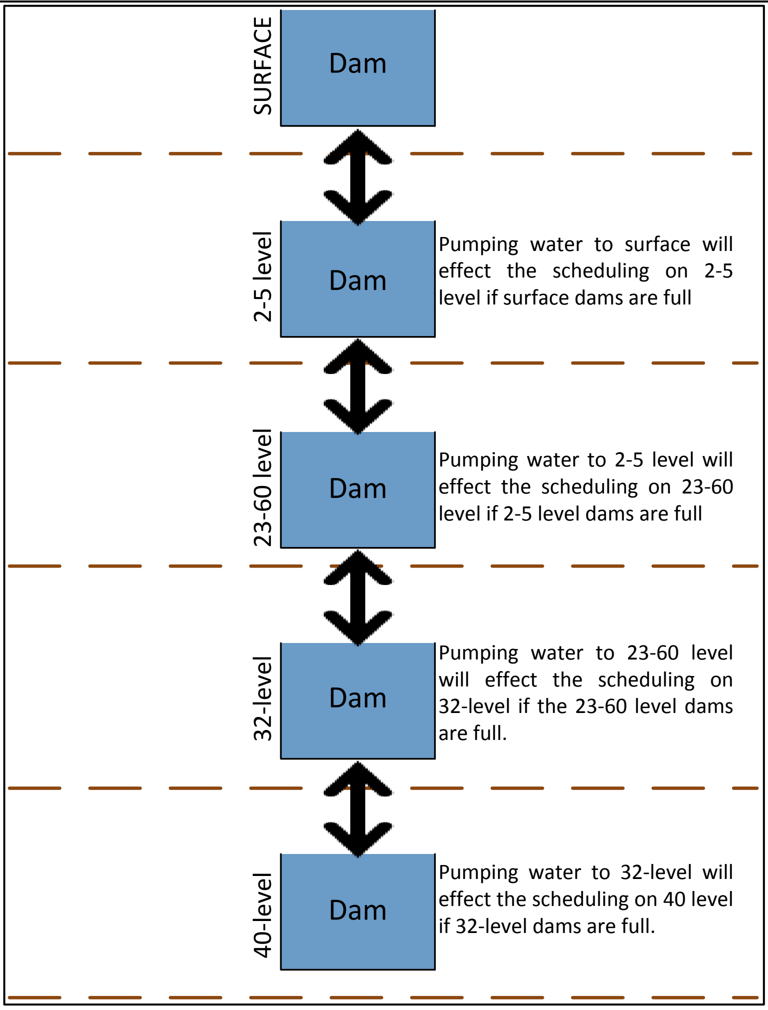


Figure 31: Cascading control configuration

REMS control overview

The REMS platform controls the dewatering system from a centralised point. The REMS monitors the dam levels, current pumps running and period of the day to determine the necessary dynamic action.

The underground PLCs act as the interlocking device to ensure the whole operation is done safely and according to mining standards. Alarm conditions are flagged on the SCADA and REMS servers to alert the control room operator of any issues with the control or system. A SMS function to notify personnel of any alarm condition can be incorporated on request.

The REMS platform is the human interface, displaying changes in the dewatering system in real time. Controllers, data loggers and numerous profiles are incorporated into the system for effective control. The Gold Mine A REMS platform is shown in Figure 32. The layout is a duplication of the actual pumping system underground layout.

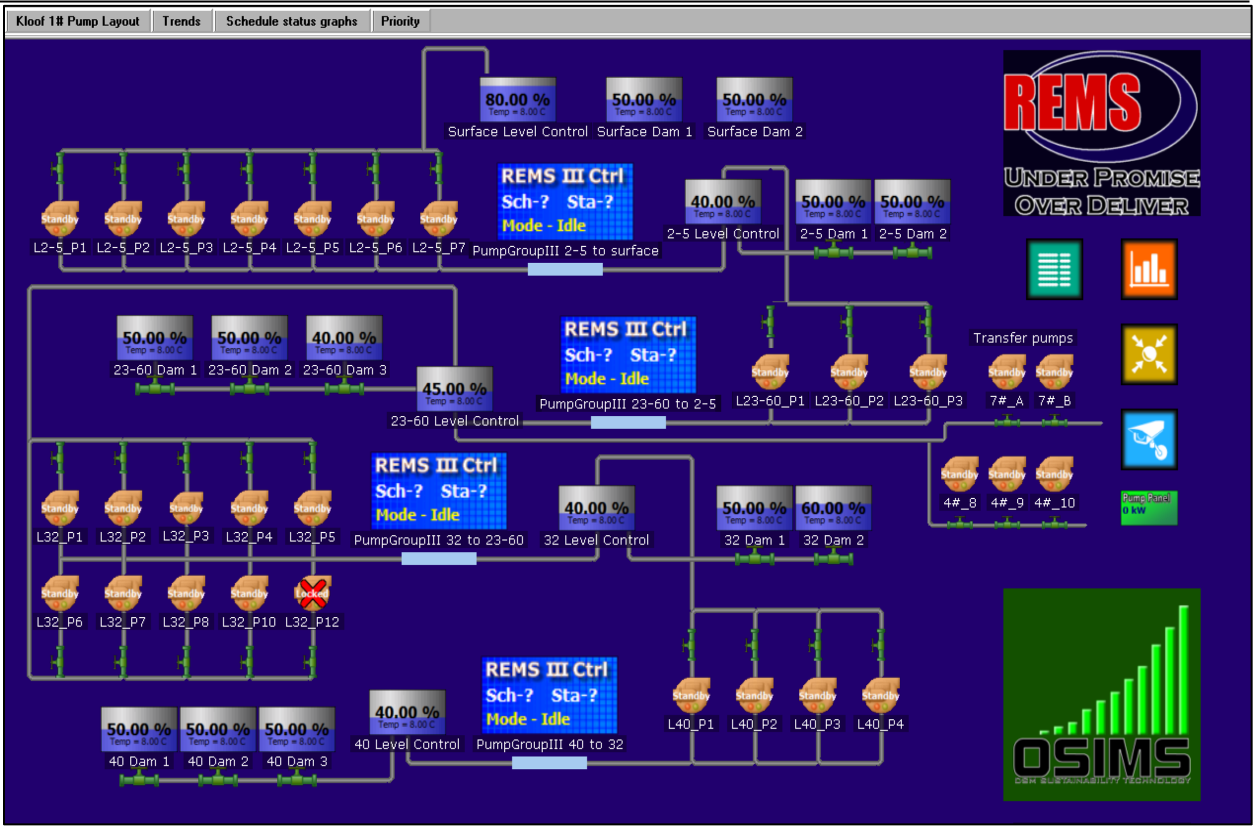


Figure 32: Platform overview

System control overview

The REMS control bases changes made to the pumping schedule on various inputs received via the process tags and REMS system internal tags. The control ensures that dams are at a minimum level before the peak periods [66]. This will ensure that pumps can be switched off for the longest period possible and in return realise electricity cost savings. The basic system flow chart for altering the pump schedule is shown in Figure 33.

The REMS schedule determines the number of pumps scheduled to run and pumps presently running. Observing the availability of the pumps within the controlled pump group set, the control will either schedule up or schedule down the number of pumps running. This is continuously monitored and the schedule is changed throughout the day, depending on the dam levels.

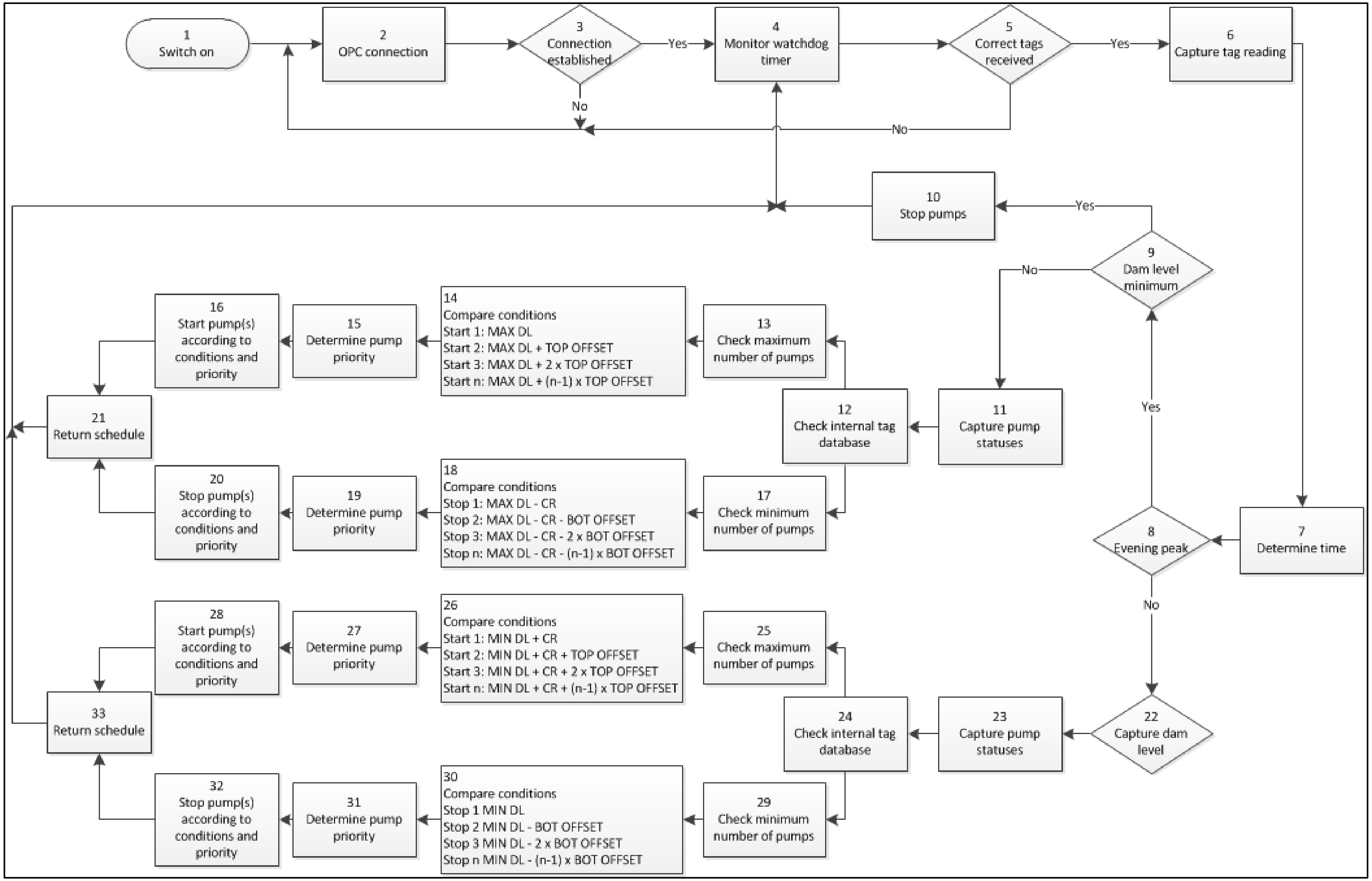


Figure 33: Basic control flow chart (Adapted from [26])

Dam level control

Dam level indications are considered to be some of the most important data for auto control on mine dewatering pumps. The schedule is altered as the dam levels change throughout the day. The pumps are controlled according to the dam levels in Table 8, controlling the pumps between the minimum and maximum dam levels as indicated.

Table 8: Dam level control

	Max level (%)	Min level (%)
2-5 level	**100**	**25**
Dam 1	100	25
Dam 2	100	25
23-60 level	**100**	**25**
Dam 1	100	25
Dam 2	100	25
Dam 3	40	0
32-level	**100**	**25**
Dam 1	100	25
Dam 2	100	25
40-level	**100**	**25**
Dam 1	100	25
Dam 2	100	25
Dam 3	100	25

The upstream dam (US) is the dam on the same level as the pumps from which the water is pumped. The downstream dam (DS) is the dam water is being transferred to by the pumps on the US dam pumping level. The pumps transfer water from the upstream dam into the downstream dam. An example is illustrated in Figure 34 using Table 9.

Table 9: US and DS example

Reference level	US dam	DS dam
Level 10	C	B
Level 5	B	A

By using Figure 34 and Table 9, one can see that the US dam for level 10 is dam B, and the DS dam for level 10 is dam C. The US dam for level 5 is dam B, and the DS dam is dam C. The same configuration will apply if more pumping levels are added.

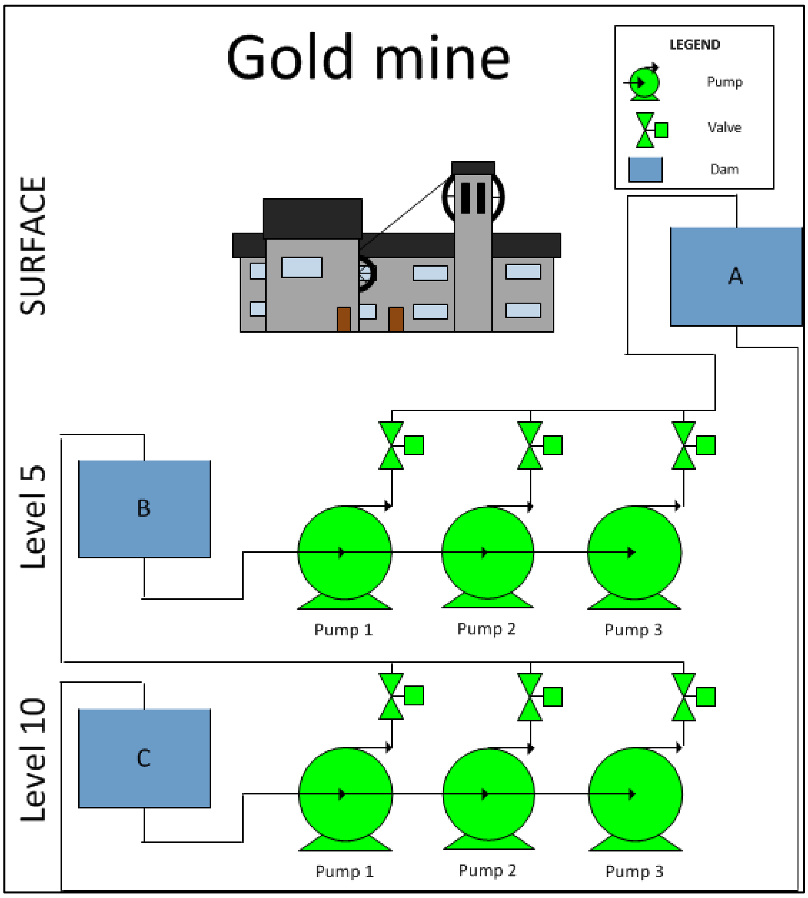


Figure 34: US and DS example

Pump and column configuration

The pumping set configurations are illustrated in Table 10. These configurations are very important and can affect the control. When the configurations are not taken into account, damage to infrastructure such as column failure can occur. In some instances mine power failures can occur when configurations shown in Table 10, Table 11, Table 12 and 32-level extended configuration discussed below are not followed.

Table 10: Pump configuration

<table>
<tr><th>Pump station</th><th>Max</th><th>Column</th><th>Pump</th><th>Pumps per column</th></tr>
<tr><td>2-5 level</td><td>4</td><td>1</td><td>1-7</td><td>4</td></tr>
<tr><td>23-60 level</td><td>2</td><td>1</td><td>1-3</td><td>2</td></tr>
<tr><td rowspan="10">32-level</td><td rowspan="10">6</td><td rowspan="3">1</td><td>1</td><td rowspan="10">2</td></tr>
<tr><td>2</td></tr>
<tr><td>8</td></tr>
<tr><td rowspan="4">2</td><td>3</td></tr>
<tr><td>4</td></tr>
<tr><td>5</td></tr>
<tr><td>6</td></tr>
<tr><td rowspan="3">3</td><td>7</td></tr>
<tr><td>10</td></tr>
<tr><td>12</td></tr>
<tr><td rowspan="4">40-level</td><td rowspan="4">2</td><td rowspan="2">1</td><td>1</td><td rowspan="4">2</td></tr>
<tr><td>2</td></tr>
<tr><td rowspan="2">2</td><td>3</td></tr>
<tr><td>4</td></tr>
</table>

2-5 level extended configuration

Pump two, pump four and pump six are new pumps and have a water flow rate of 180 l/s. Pump one, pump three, pump five and pump seven are older pumps and have a water flow rate of 120 l/s. The column maximum acceptable flow rate is 550 l/s. The flow rate of each pump is shown in Table 11.

Table 11: 2-5 level pumps flow rate

2-5 level pumps	Pump new/old	Flow rate
1	Old	± 120 l/s
2	New	± 180 l/s
3	Old	± 120 l/s
4	New	± 180 l/s
5	Old	± 120 l/s
6	New	± 180 l/s
7	Old	± 120 l/s

If two new pumps (pumps two, pump four or pump six) are operating simultaneously, a maximum of three pumps in total will be permitted to run, and not the usual four pumps. The two possible pump operation scenarios are shown in Table 12.

Table 12: 2-5 level pumping scenarios

	Scheduled scenario			
Configuration	**New pumps**	**Old pumps**	**Maximum pumps**	**Total flow rate**
1	1	3	4	± 540 l/s
2	2	1	3	± 490 l/s

32-level level extended configuration

Before the pump automation project implementation, Gold Mine A had problems with electricity supply on 23-60 level. The mine was forced to switch pump one on 23-60 level to the same incomer as pump four, five and six on 32-level. Pump one on 32-level has an installed capacity of 3600 kW. As a result, the mine will not be able to run pump one on 23-60 level if pump four, pump five or pump six on 32-level is running.

REMS internal tag manager

Special control conditions are programmed into an internal tag. By accessing these tags, all Gold Mine A's special control conditions are accessed and incorporated into the system for effective and efficient control. The tag manager is displayed in Figure 35.

To program special conditions into an internal tag, a programmable tag is used with a script based interface. The tag editor graphical user interface is shown in Figure 36. Pump automation projects differs for each site and control is based on the specific site requirements. Tags are used in conjunction with internal tags to restrict or allow the scenarios listed below. Almost any special request can be programmed into internal tags.

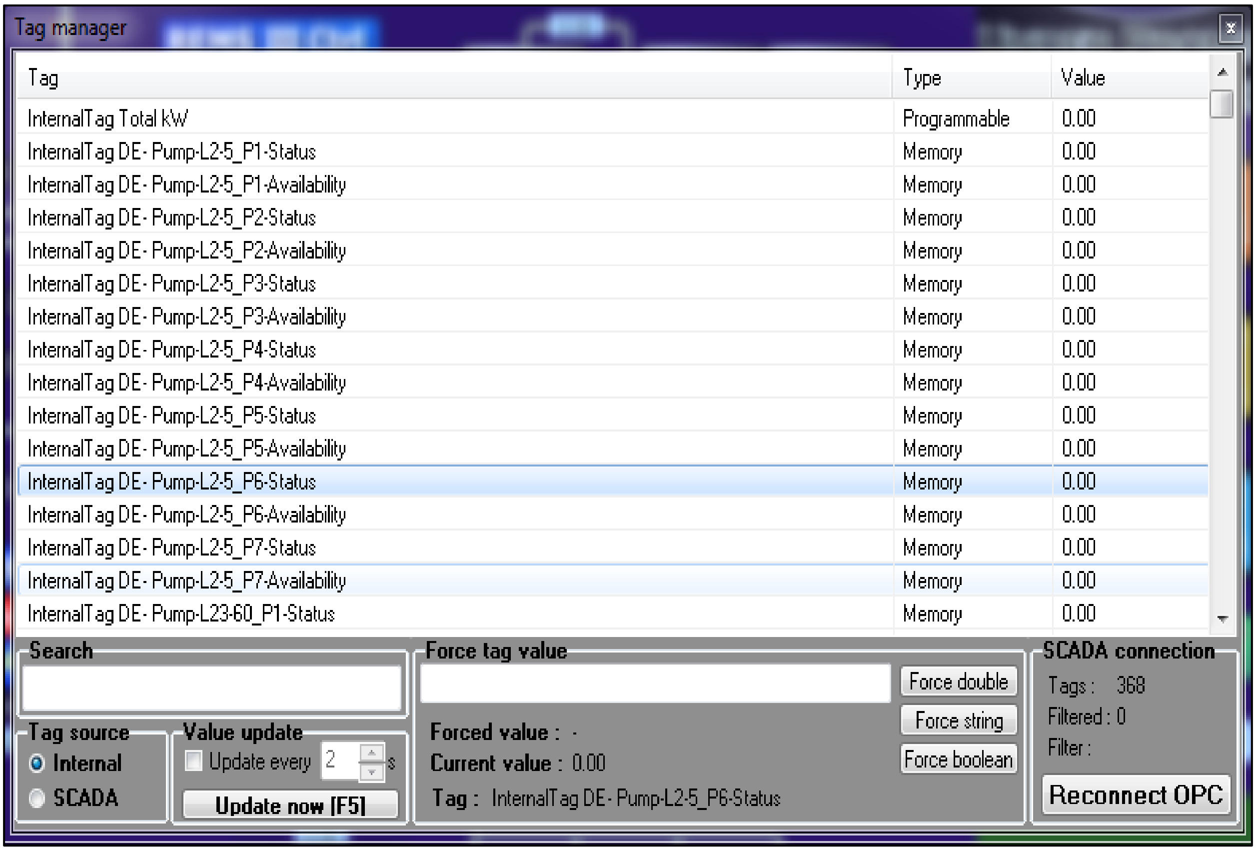


Figure 35: Internal tag manager

Some of the internal tags programmed into the REMS system for Gold Mine A include:

- Restricting the number of pumps pumping into the same column simultaneously,
- Limiting the total number of pumps running simultaneously,
- Specific control or interlocking as specified by the foreman or shaft engineer,
- Prioritising pumps from most efficient to least efficient,
- Adjusting pumping set configurations as discussed in pump and column configurations,
- Calculations of average dam control,
- Dam lockouts to remove dams not available from average dam calculations.

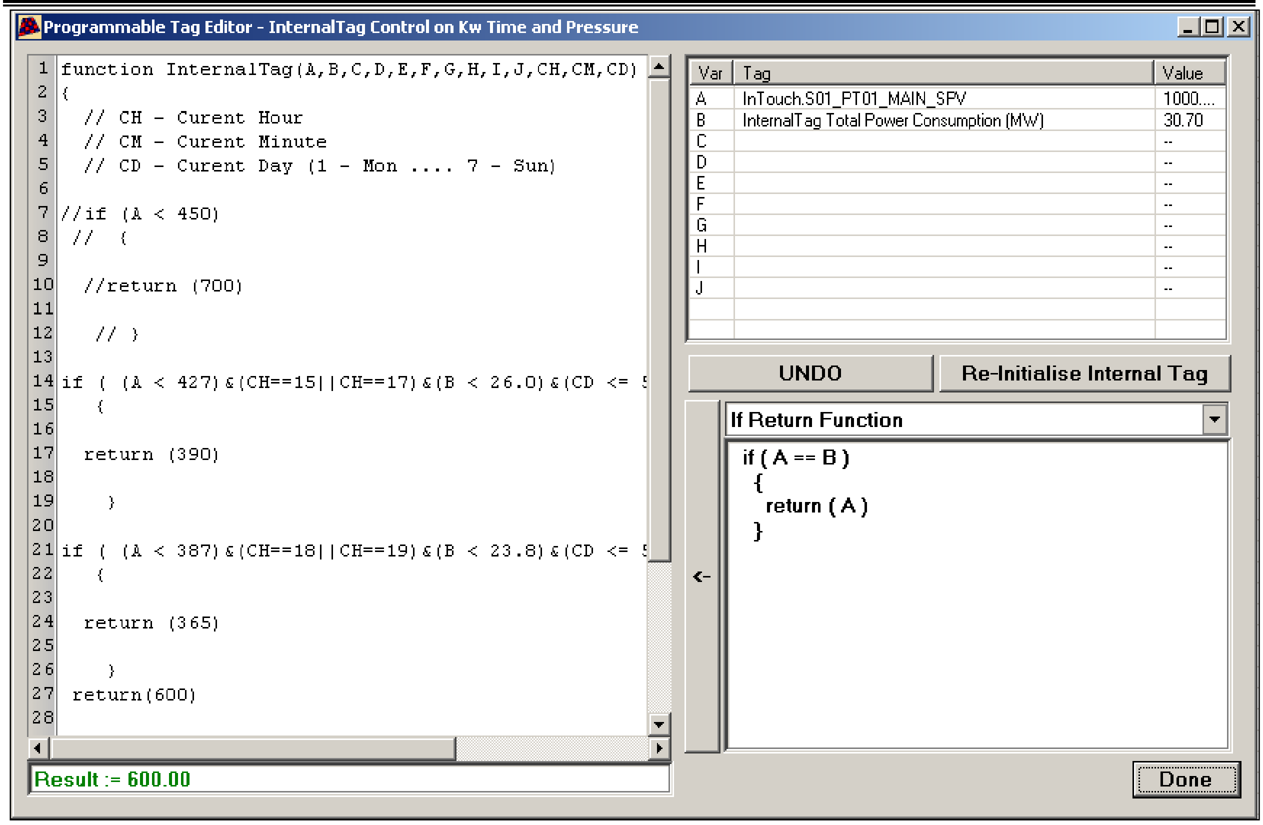


Figure 36: Internal tag editor script interface

REMS control objects

The REMS has different control objects used to control components. The objects are used to indicate the schedule and to control pumps. Control objects used include REMS pump controllers, REMS dam objects, REMS pump objects, OPC monitoring, REMS pump panel, alarms and pump prioritising. These objects all have specific tasks to form part of the overall control done by the REMS system.

REMS III controller

The REMS pumps group controller controls a specified group of pumps on a pumping level. The controller displays the number of scheduled pumps and the status of the applicable pump group. The controller interface is used for basic information input and outputs. The controller is shown in Figure 37.

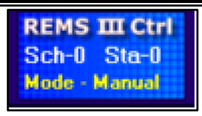


Figure 37: Pump group controller

Tags are monitored by the controller based on certain control parameters, such as a priority organiser to rotate the pumps in the correct order depending on the time of the day and efficiency of the pump. The controller interface is shown in Figure 8.

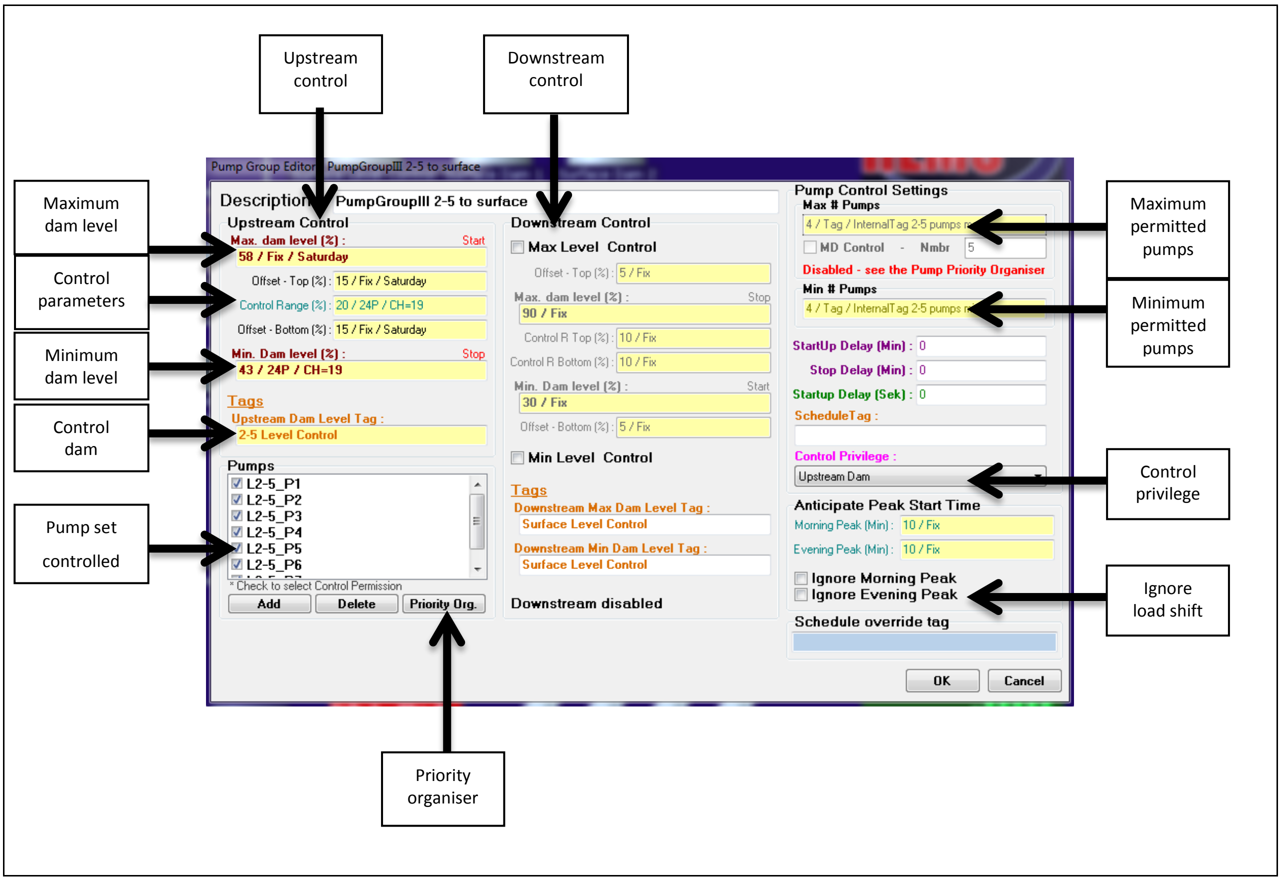


Figure 38: Pumps group controller interface

The controller's main parameters are the dam levels, pump statuses, pump availabilities and pump priorities. The action taken for control can be determined by using the main parameters in conjunction with the time of day and internal tag database. The controller uses the following dam level abbreviations for control:

- MIN DL – Minimum dam level
- MAX DL – Maximum specified dam level
- CR – Control range
- TOP OFFSET – Dam level upper range offset
- BOT OFFSET – Dam level bottom range offset

The control range and offset is programmed into the controller using the controller rules. The controller determines whether the current hour is in the peak period, off-peak period or standard period and alters the pump schedule accordingly.

The controller ensures that the dam levels never exceed the maximum permitted dam level of 100% or fall below the minimum permitted dam level of 25%. The values of each of the dam level items described above are used for control. Each has a specific value based on percentage of the dam level. These values are captured in the controller and the controller then determines the system characteristics and actions to be taken next.

The controller schedules one pump more or schedules one pump less depending on the control range and bottom or top offset. During the evening peak period the control range and offset is changed and the controller determines the schedule based on the maximum dam levels. Pumps are stopped if possible and dam levels are monitored during the Eskom peak period to prevent dams from overflowing. The opposite applies during the Eskom off-peak period and the controller controls according to the minimum dam level to prepare the dams for load shifting during the peak periods.

REMS dam object

The REMS dam object, as seen in Figure 39, displays the dam level and water temperature of a specific dam. Dam objects can be configured to indicate a single dam or an average dam for a pumping set. Average dams are used for control of the relevant pumping set. Average dams are calculated by combining all the available dams on the level. Each level has one average dam that can be used by the REMS pump controller.

Figure 39: REMS dam object

The dam level tag is captured in the dam editor by means of a memory internal tag and used for indication and control in the REMS pump controller. Ultrasonic dam level indicators were installed for dam level indication. The dam level indications fluctuated severely, causing the pumps to start and stop at very short intervals. The dam level fluctuations were filtered out by using a dam level filter window and time period linked to the window. The dam editor is shown in Figure 40.

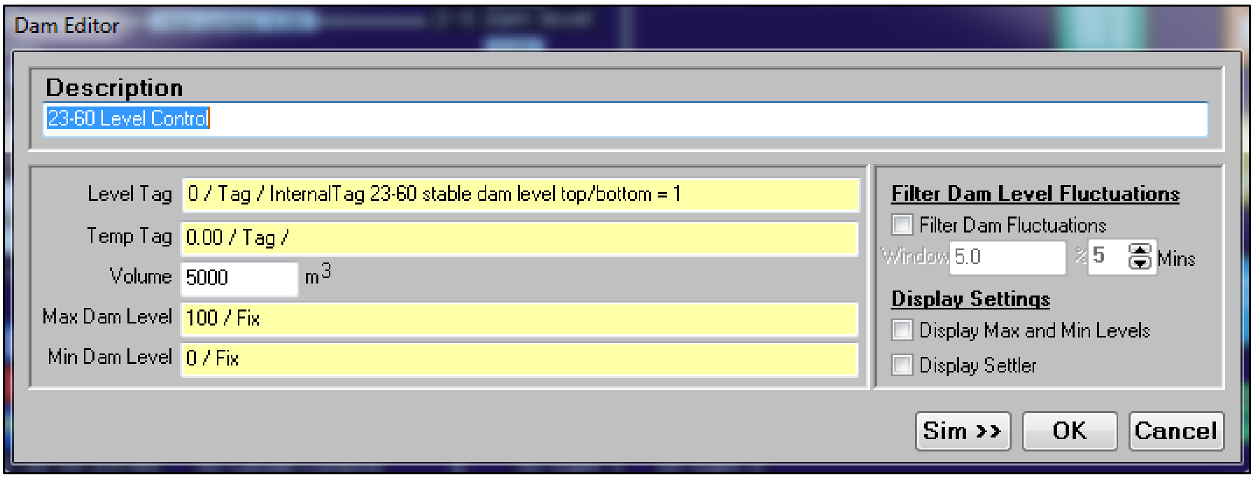


Figure 40: REMS dam object editor

As the dam levels change, the dam level fluctuation filter neglects any dam level value returned with more than 5% difference from the previous value and keeps abandoning the value if outside of 5% for a maximum of five minutes. In a scenario where the value sent by the underground PLC is more than 5% and five minutes have passed, the value immediately sent after the five minute interval is indicated as the current dam level.

Example 1

When the dam level is 100% and the next value sent from the ultrasonic dam level indicator is less than 5% from the 100% on 94%, the value will be kept 100%. When the value from the ultrasonic dam level indicator sent recurs less than 5% of the 100% level for five minutes, the next value sent after a five minute interval will be the new dam level indication, irrespective of being inside or outside the 5% window. In this scenario, if the value indicates 94% (which is outside of the 5% window) for more than five minutes, the new value will then indicate 94%.

Dam lockout

Each level has an average dam used for pump control. The average dam is calculated from the available dams on that specific level. An option to remove dams from the calculation of the average dam has been included. This will ensure the average dam is always accurate by disregarding dams not in use.

Scenarios where dams are removed from calculation of control dam:

- Cleaning mud filled dams,
- Dam column damage,
- Dams used as emergency dams.

The control dam will be calculated from the available dams for control. A valve was added to the platform to enable the removal of the dam from the control dam by closing the valve as illustrated in Figure 41 and Figure 42. The dam valves are not linked underground but are only used for average dam calculations, and this control is done manually.

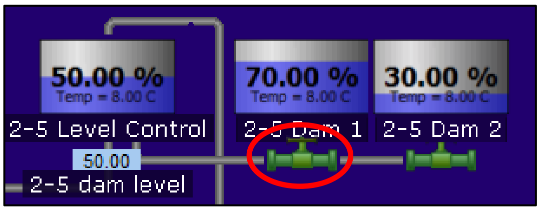


Figure 41: Dam lockout valve

As illustrated in Figure 42, dam 1 after lockout is not used for scheduling. This internal tag used for the control dam enables the mine to keep the system in automatic mode, even when maintenance on the pumping system is required.

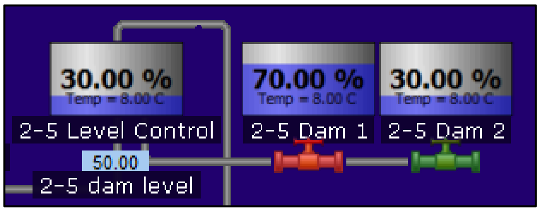


Figure 42: 2-5 level dam 1 locked out

REMS pump object

The REMS pump object displays the status and condition of the pump. The pump is added to the pump group using the REMS pump controller to enable controlling of the pump according to the schedule and specified priority. Pumps can be controlled by the control room operator by using the pump object or independently by the system when switched to auto mode. The pump object is shown in Figure 43.

Figure 43: Pump object

The interface for control options and settings of the pump is indicated in Figure 44. All the important information regarding the pump settings and control can be found and edited in the pump editor. The pump editor is available for each individual pump. A hold delay feature is used to ensure the signal of the pump when started or stopped is pulsed and not kept active, , as indicated in Figure 44. The signal will stay active for the duration of seconds inserted into the Hold delay edit box.

There is a feature available to set a maximum number of pump safety trip condition resets to prevent a pump from being reset more than the specified number of times. This prevents pump damage or running a pump when maintenance is required. The maximum number of resets feature is important to ensure the safety standards were adhered to.

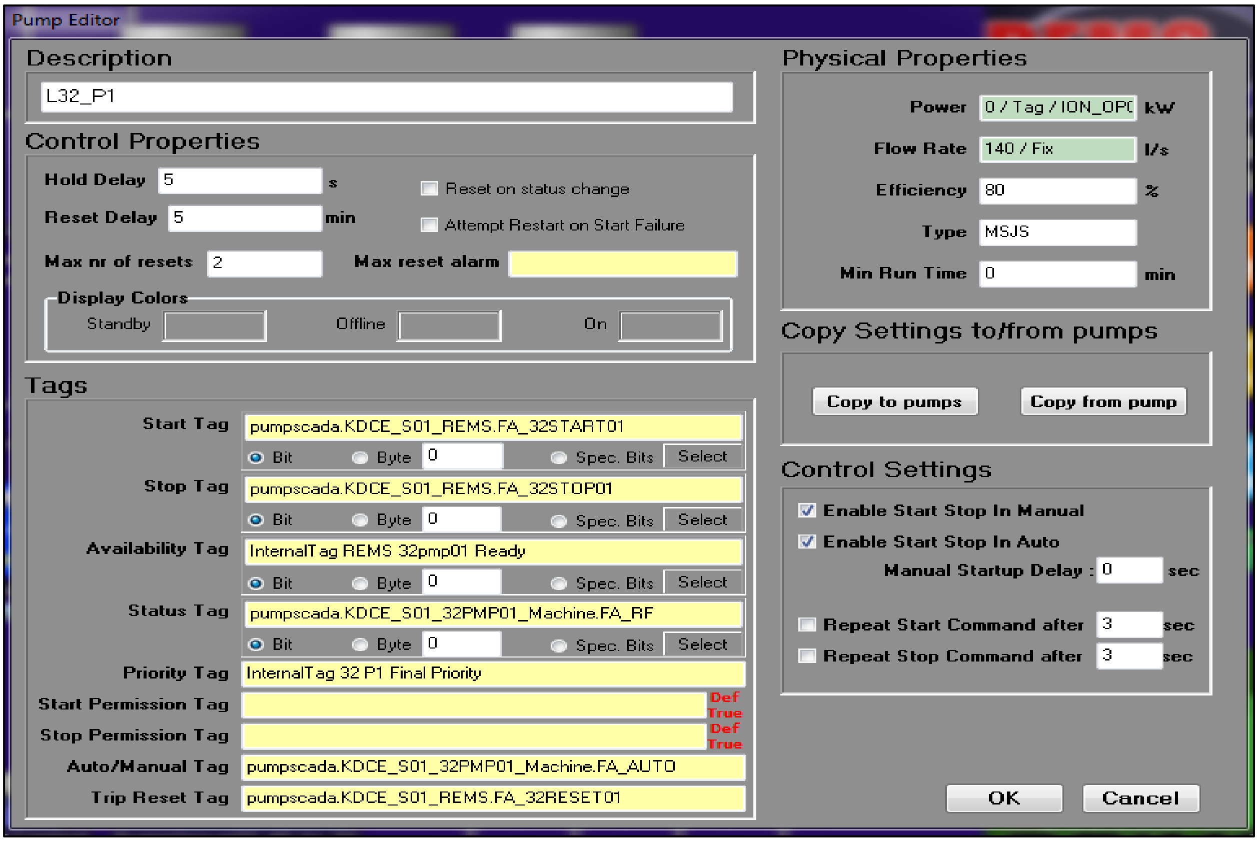


Figure 44: Pump object editor

REMS OPC monitor

The REMS OPC monitor ensures that redundant communication between the REMS and the SCADA is maintained. The REMS watchdog timer has to be monitored by the SCADA to have complete redundancy. A second counter from the SCADA was inserted into the OPC monitor. When the second counter fails to change, the OPC connection will be restarted. The OPC monitor is shown in Figure 45.

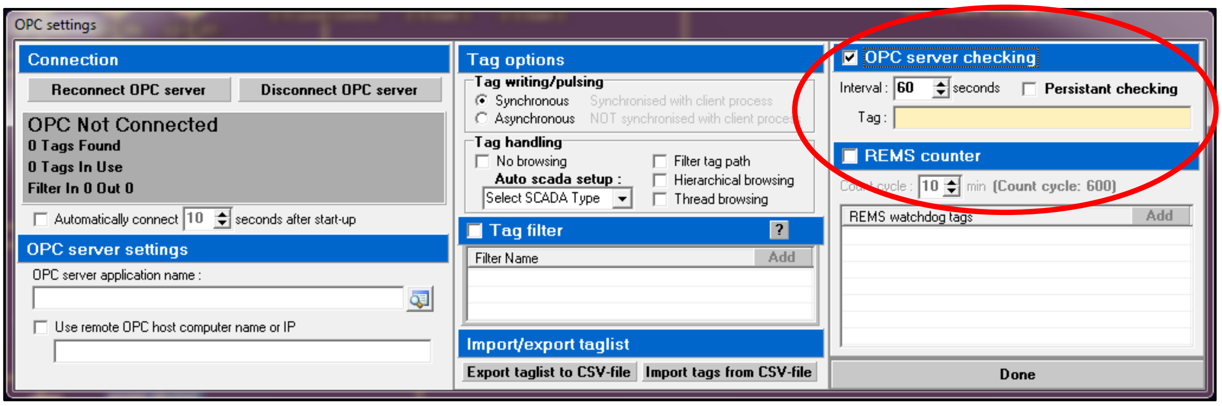


Figure 45: OPC monitor

The OPC monitor checks the SCADA watchdog timer for a constant change in the time interval and displays an indication at the bottom of the REMS screen if the SCADA is operational or disconnected as illustrated in Figure 46.

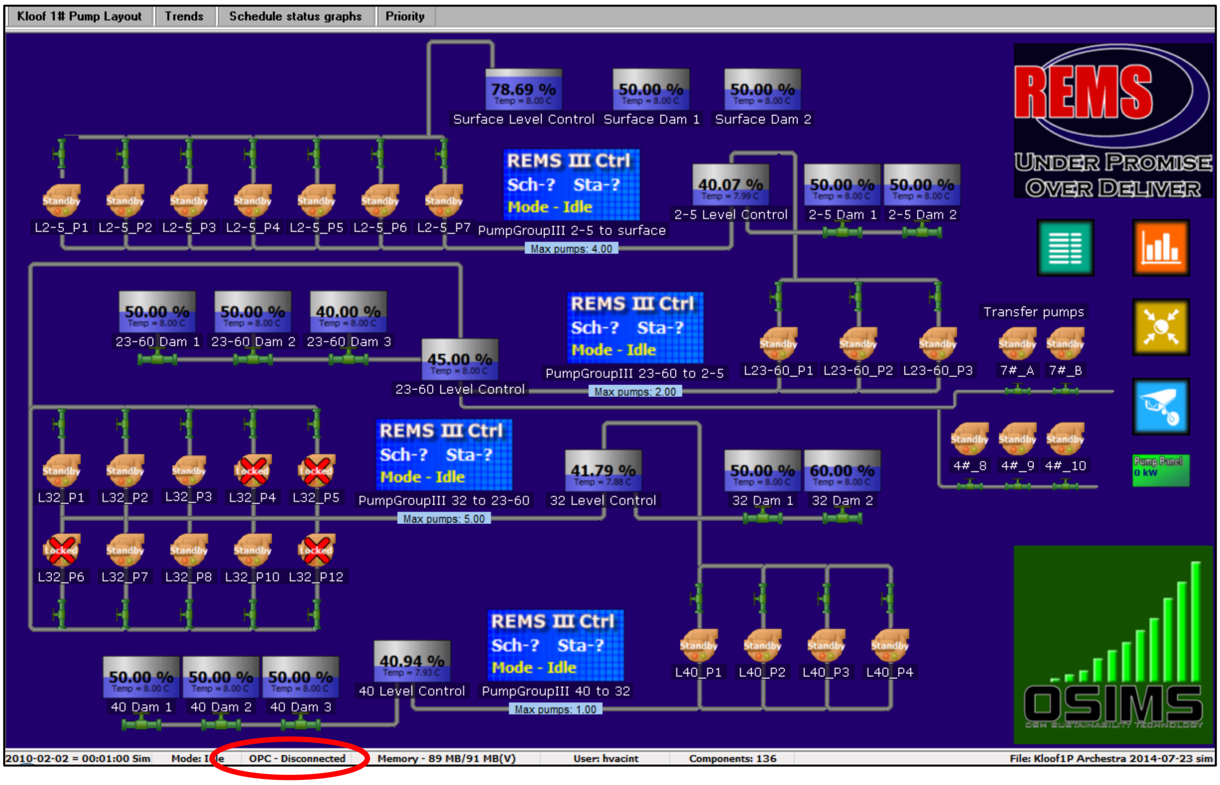


Figure 46: OPC indicator

REMS modes

REMS only controls if the platform is switched in the correct control mode. Depending on the client's needs, the control can be changed between Edit mode, Idle mode, Manual mode or Auto mode.

- **Auto**
  Automatic control enables automatic control by the REMS server. Data is sent to and from the SCADA to control the underground pumps and monitor the dam levels. Automatic control involves minimal user input. The control room operator is only required if problems such as column or pump failures occur.

- **Manual**
  Manual control is used for manual surface control interventions. Pumps, the REMS pump controllers and valves can be controlled in manual mode. No automatic control is enabled and monitoring and control are done by the control room operator. All available data is logged in manual mode.

- **Idle**
  All available data is displayed and logged by REMS software. The system does not display a schedule and is not able to control any component remotely. Idle mode is used for monitoring purposes only.

- **Edit**
  Edit mode is used by trained personnel for development of the site specific layout and configurations. Only certain trained professional personnel are able to access the Edit mode. Changes to the layout and platform can be done while in Edit mode.

REMS pump panel

When pumps start, the motor causes a start-up current spike. Depending on the setup of the mine, motors starting simultaneously can be a hazard as power failures can occur. Pumps are prevented from being started simultaneously with a REMS pump panel as indicated in Figure 47.

A time is allocated to the Start Up Delay block. This ensures that a time period delay in seconds is allocated to each pump before the next pump is started. The Start Up delay time period can be increased or decreased depending on the required need. Pumps not allowed to start simultaneously can be added in the REMS pump panel as illustrated in Figure 47.

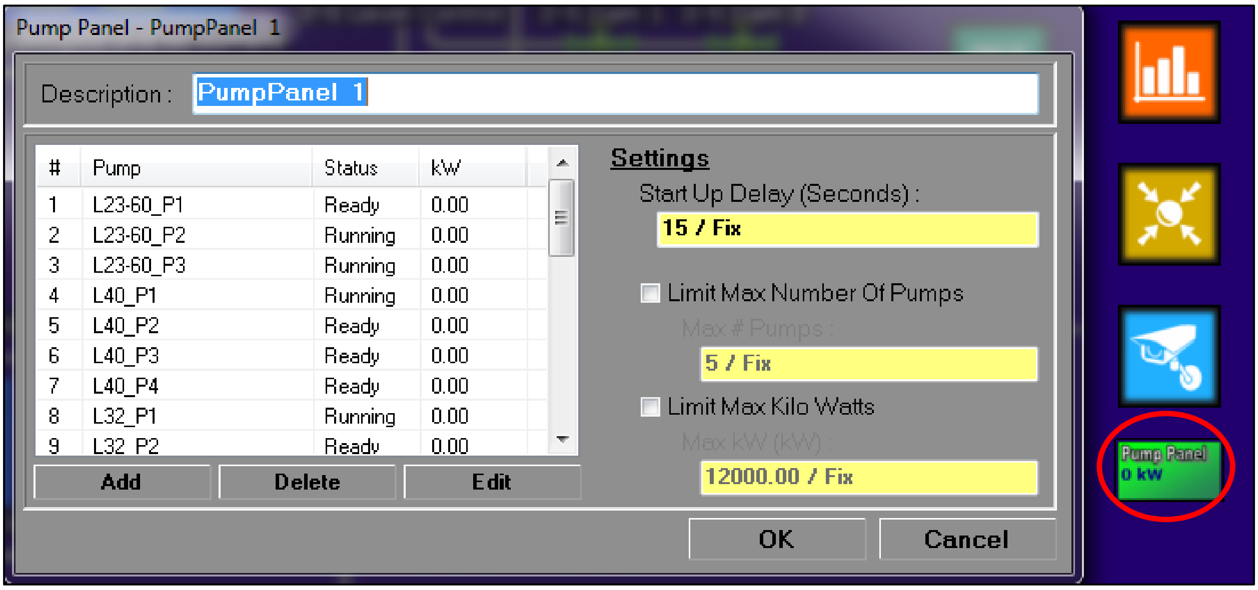


Figure 47: REMS pump panel

REMS alarm conditions

Alarms are incorporated into the system to ensure that the operator is informed when unwanted conditions occur. An alarm is displayed continuously if continued issues occur. The control room operator must acknowledge each alarm for the alarm indication to disappear. The typical alarm conditions include:

- OPC communication issues,
- Network communication issues,
- Fewer pumps available than scheduled,
- Too many pumps running in a conjoint column,
- Dam level high,
- Dam level low,
- Incorrect pump configuration applied,
- Operator not following schedule.

Prioritising pumps

Using efficiency reports, pumps can be prioritised to run the most efficient pumps during the peak periods and standard periods and the less efficient pumps during off-peak periods. Operating the most efficient pumps in peak and standard periods helps reduce the consumption of electricity during peak and standard periods and in return realise electricity cost savings.

A priority page was added to the platform to prioritise the most efficient to least efficient pumps as illustrated in Figure 48. The current setup uses an efficiency report from the mine to manually insert the most efficient pump to least efficient pump.

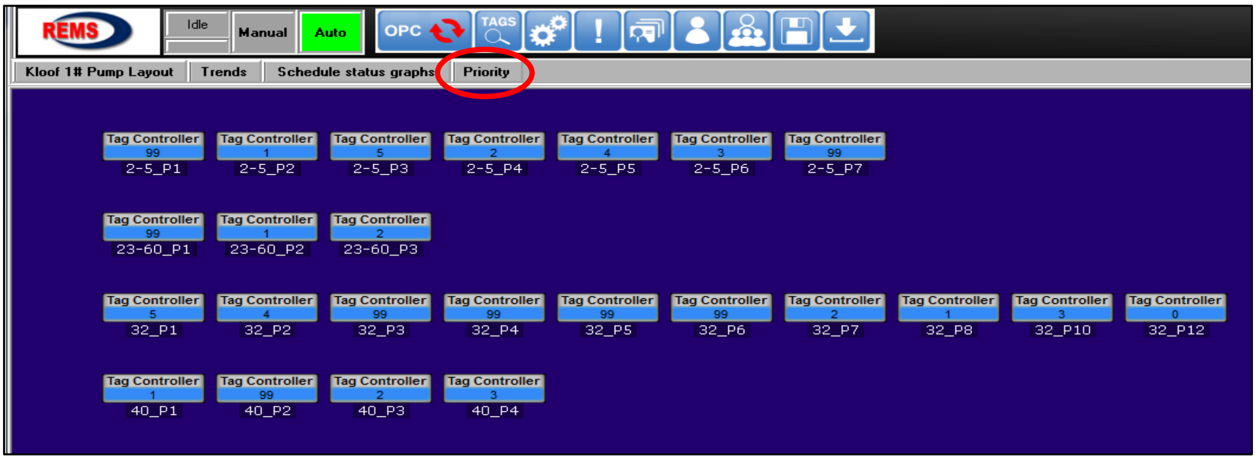


Figure 48: Priority page

For demonstration purposes, 32-level will be used.

Table 13: 32-level efficiency report

Pump	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**10**	**12**
Efficiency (%)	63	67	N/A	N/A	N/A	N/A	70	71	67	N/A
Start priority	5	4	99	99	99	99	2	1	3	99

Figure 49: 32-level priority tabs

After the priorities have been inserted manually, the REMS pump controller prioritises the pumps according to their efficiencies, depending on the time of the day as illustrated in

Figure 50 and Figure 51. The maximum permitted pumps per level can also be included as illustrated in Figure 51.

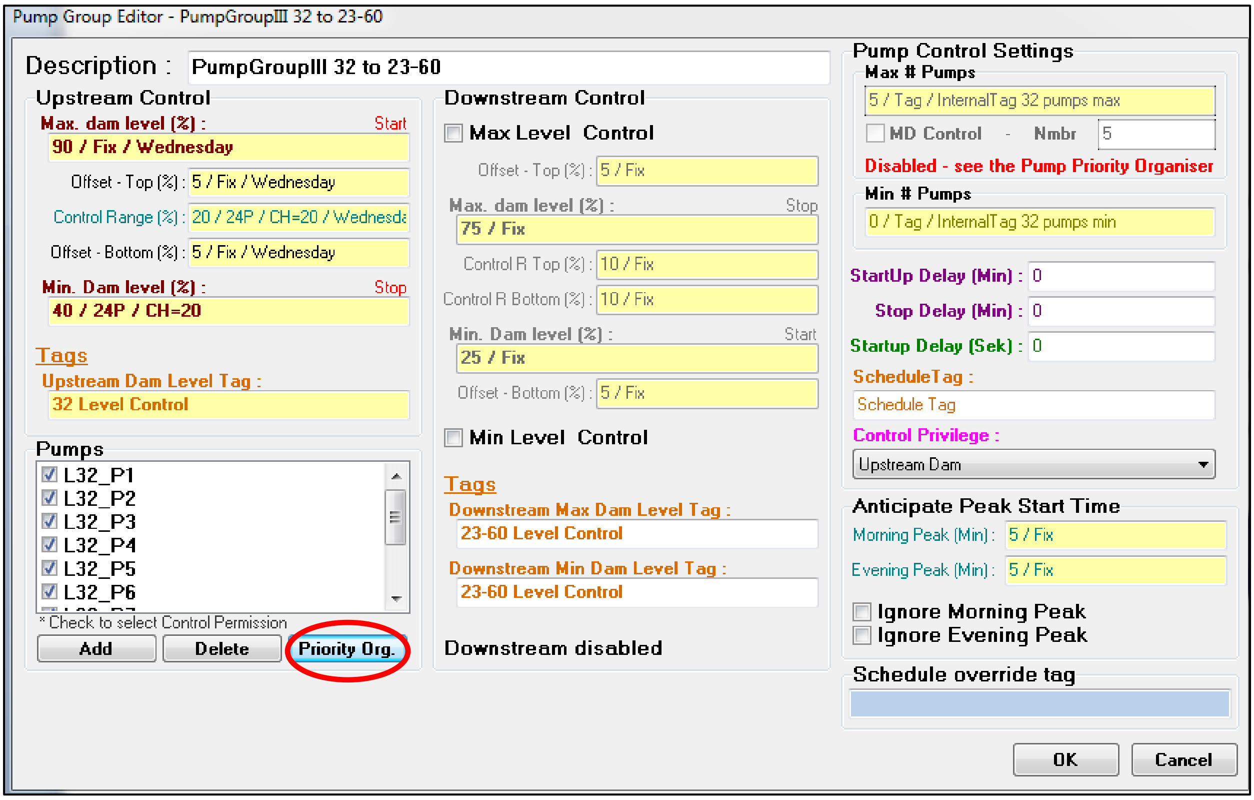


Figure 50: 32- level REMS pump controller

In the scenario shown in Figure 51 where pump two and pump ten have the same priority, but are in different columns, REMS first starts a pump in a column that does not have a pump running already. This configuration is followed because pump set efficiency decreases when pumps are operated in a conjoint column, as discussed in Chapter 2.

Pumps become fatigued when operating for too long periods. In an effort to distribute the running hours and load on the pumps evenly, a less efficient pump will be scheduled to have priority over more efficient pumps in the off-peak periods, as illustrated in Figure 52.

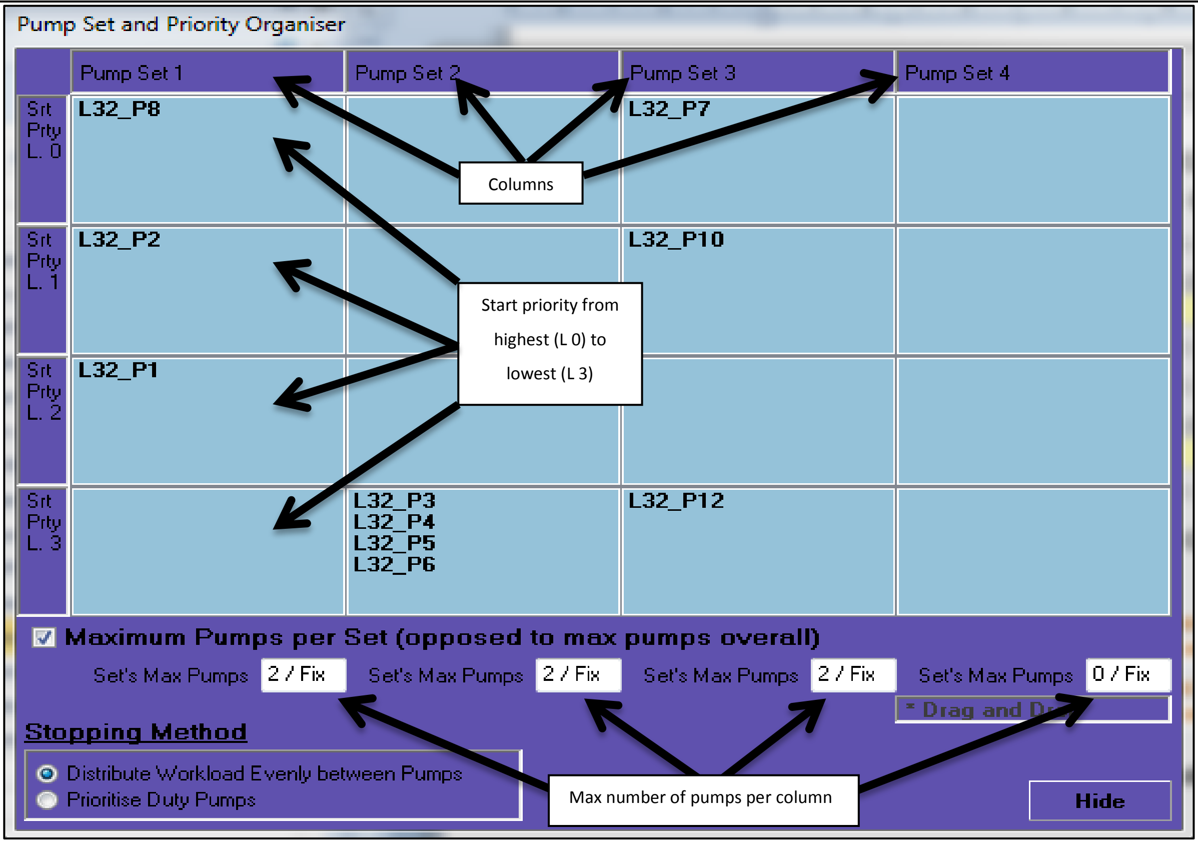


Figure 51: 32-level REMS pump controller priority organiser for peak period

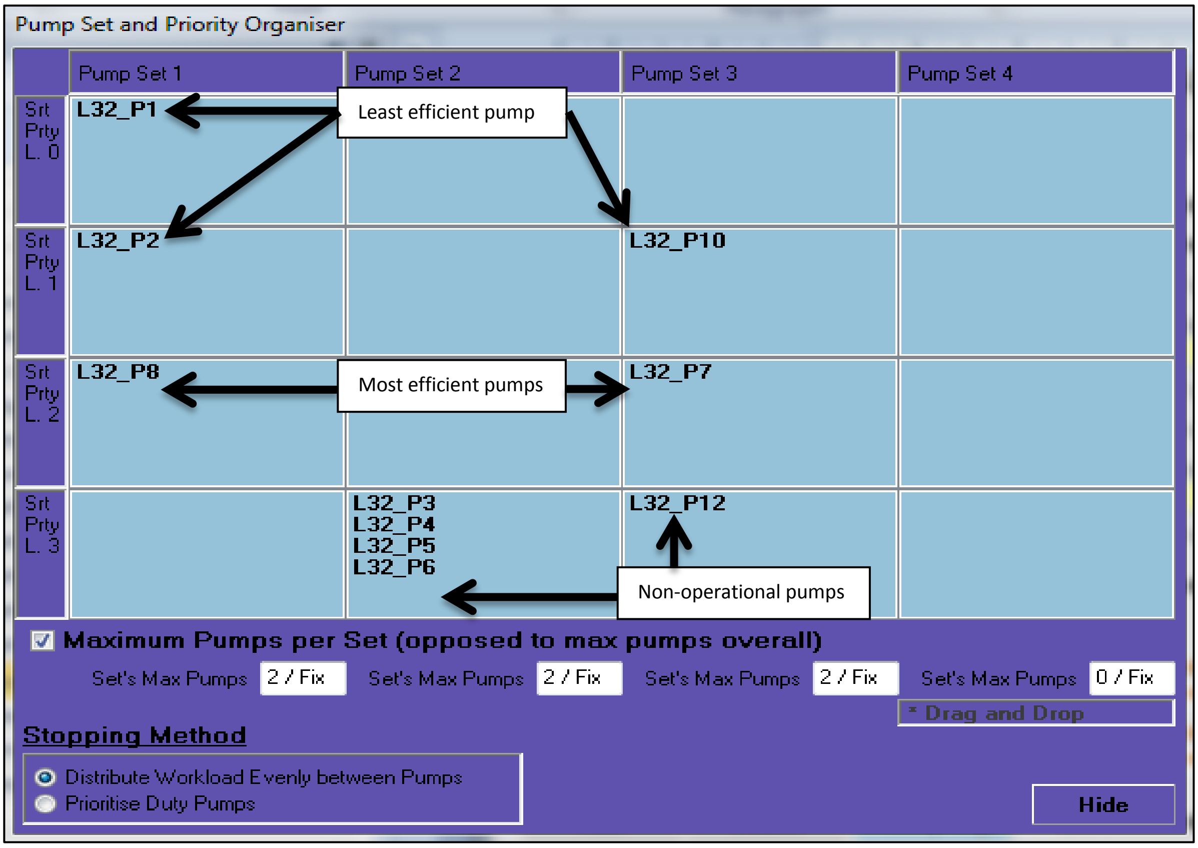


Figure 52: 32-level REMS pump controller priority organiser for off-peak period

REMS logging

Data is logged in two minute intervals for each day. At midnight each day, a new log file is created for the next day. All the log files for the day are archived and can be emailed to any email address upon request and correct configuration. This data is used to determine whether certain changes are needed on the system to operate optimally.

Logging data can simplify investigations when maintenance is required to determine exactly the time period of failure and conditions that occurred before failure. Future failure of components can be investigated with the logged data files and can possibly be avoided by incorporating solutions.

REMS interaction with neighbouring shafts

Gold Mine A does not have a fridge plant to cool down used service water. Hot water is held in the surface dams and filtered through the Gold Mine A's filter plant. The filtered water is transferred to a neighbouring shaft fridge plant where it is cooled down to be re-used as chilled service water. The neighbouring shaft has service water holding dams to store water. The rest of the chilled service water is transferred back to Gold Mine A into the service water underground holding dam.

Pumping to neighbouring shafts can be valuable if the dewatering system at Gold Mine A is unable to manage with the amount of water in the system. The transfer of water has to be prioritised based on the available pumping capacity at the neighbouring shaft. When failures such as column failures occur, transfer pumps can be used to pump water to neighbouring shafts to avoid dams from overflowing.

3.3 MANUAL TO AUTO CONTROL PROCESS

The control of mine dewatering pumps was ensured by using four interventions separately. The interventions include manual control, manual scheduled control, manual scheduled surface control and auto control. Table 14 indicates the input required by Gold Mine A for each intervention. Table 15 indicates each operator's responsibility regarding the control of mine dewatering pumps.

Table 14: Control procedure input required

Procedure	Underground control	Surface control	Scheduling	Automatic control
Manual control (MC)	✓	×	×	×
Manual scheduled control (MSC)	✓	×	✓	×
Manual scheduled surface control (MSSC)	×	✓	✓	×
Auto control	×	✓	✓	✓

Table 15: Operator responsibility

Nr	Procedure	Control room operator	Underground operator
1	Manual control	Monitor and communicate	Actively control
2	Manual scheduled control	Monitor and communicate	Actively control
3	Manual surface control	Communicate and actively control	Monitor
4	Auto control	Monitor	Monitor

3.3.1 MANUAL CONTROL

Manual control is applied by means of human intervention and minimal computerised input. Computerised systems are only used for viewing or monitoring purposes by the operator. The surface control room operator observes the dams and makes a judgement call depending on the dam levels for controlling a pump.

The surface control room operator gives an instruction to the underground pump operator to stop or start a pump. Communication channels should always be maintained as communication is very important with the manual control intervention.

3.3.2 MANUAL SCHEDULED CONTROL

Manual scheduled control requires the mine to run according to a programme that indicates a schedule for pump operation. The procedure involves the control room operator communicating with the underground pump operator. The underground pump operators then stop or start a pump whenever the control room operator requests.

Operators have to follow a start-up procedure formulated for each specific system [53]. The schedule is then used and followed accurately to enable the contractor to make conclusions and update the system if issues arise. This enables the contractor to resolve issues before the system is switched to automatic mode.

3.3.3 MANUAL SCHEDULED SURFACE CONTROL

Manual scheduled surface control is the last step implemented before complete auto control is applied. Manual surface control involves the SCADA and the control room operator for control. The server receiving data from the SCADA indicates how many pumps should operate simultaneous on each level by taking the dam levels into consideration.

Manual scheduled surface control is the intervention where pumps are controlled by the control room operator, requiring minimal input from the underground pump operator. The underground operator’s only duties are to monitor the system and inform the control room operator when issues occur with the pumps station.

3.3.4 AUTO CONTROL

Auto control is the desired control method for automation systems. Auto control abandons all human intervention. The server connected to the SCADA observes dam levels and then control pumps according to these levels. The internal tags are very important for control. The system runs through all the internal tags to ensure the correct decision for control is made.

Minimal input from the control room operator or underground pump operator is required for auto control. The only input required is for the control room operator to ensure the system is operating without any issues. When issues are observed, the control room operator contacts all relevant parties to resolve the issue as soon as possible.

The risk of problems with auto control interventions increases when the control room operators are not aware of problems and fail to address these problems. Training is therefore essential to provide the operators with the knowledge to immediately identify problems when they occur. Auto control will be compared to manual control to identify the best solution.

Auto control is the desired intervention as safety margins are programmed into the system for optimal operation. This ensures that the system is sustainable over very long periods if maintained. For optimal pumping system operation and efficiency, the client needs to adopt and accept the system. This is the ultimate challenge for sustainability of automated systems.

3.3.5 FUTURE MAINTENANCE

After the project has been completed the mine will take over all the responsibilities of the project maintenance and savings. It is very important to observe the system continuously, as only a small sequence of events could cause the project to underperform. The mine will not necessarily appoint personnel to ensure that system maintenance is done and sustainability is ensured. The desired option is to appoint an ESCo for optimal operation and sustainability of the automated system.

3.4 PERFORMANCE ASSESSMENT

Performance assessment is the period used by ESCos, Eskom and the client to determine if a project reached its projected electricity savings target. Traditionally, performance assessment is done after project implementation for an agreed period. The savings are then analysed. If a project has reached its electricity savings target, the client has to reach the target of these savings for five years following sign-off. In the scenario where the ESCo could not reach the savings target, a new target is set for the client to continually reach for five years.

Financial penalties can be imposed on the ESCo or the client depending on when the savings could not be achieved. If the savings are not achieved in the performance assessment period, the ESCo can be held liable for penalties imposed because of project under performance. The client can also be penalised if the savings are not reached continually for the agreed period after the ESCo has proven in the performance assessment period that the savings target is achievable. Automated systems will reduce the risk of penalties.

3.4.1 VERTICAL PUMPING FROM OTHER SHAFTS PREVENTING LOAD SHIFTING

Some factors prevent load shifting. The mines are interlinked and thus the mine can decide to pump water from another shaft to the shaft where an automation project is in progress. The shaft being automated will then have more water to pump to the surface. Load shifting is then influenced as more water in the system could mean that pumps have to be started before the peak period has come to an end. The main reason pumps are started before the end of the peak period is to avoid dams from overflowing.

Implementing multiple pump automation projects on the mine groups is the desired action. A combined savings for the different shafts can then be determined. Maximum electricity cost savings will be realised when automation of all mine shafts' dewatering pumps have been completed. The system can observe other shafts to engage in the best decision for optimal pumping system operation.

3.4.2 OPTIMISATION

The demand of the mine to pump water to the surface can increase at any moment. In a scenario where it has been raining for a few days, the mine will have more water to pump to surface, increasing the demand for pumping.

Optimising the pump system improves the electricity cost savings of the mine. For optimal dewatering pumping system operation, the following factors can be observed and improved:

1. Maximum allowed dam level control,
2. Minimum allowed dam level control,
3. Pump efficiencies - Using more efficient pumps.

3.4.3 COMMUNICATION FAILURES

During project implementation, communication failures were experienced. The communication failures occurred due to various factors that included:

1. Underground power failure,
2. Surface power failure,
3. Fibre optic cable damage,
4. Underground negligence such as switching off PLCs.

3.4.4 ISSUE REPORTING

Projects can take up to four years to complete due to various contributing reasons as discussed in Chapter 3. Many unexpected issues, such as breakdowns, arise while the project is still in progress. To ensure that all the issues are addressed and all responsible parties are aware of these issues, communication is very important. The management has to be informed of project delays and reporting of these issues should take effect as soon as experienced.

Project meetings were held to ensure the issues are discussed and properly reported. The meeting discussed the possible savings, breakdowns and any general issues. Ordinarily, project feedback meetings were held once a week. If, however, any issues arise that require an urgent meeting, the relevant parties were informed and a meeting was held to discuss the issue.

The ideal project meeting includes one person from each relevant department. This ensures that all aspects are discussed thoroughly. One senior person from the mine should be present when a project feedback meeting is held. The senior person present is the chairperson at the meeting and all major decisions are made by the chairperson.

3.5 SUMMARY

Chapter 3 discussed the dewatering pump automation process, the process from manual to auto and the performance assessment period. The four control interventions include manual control, manual scheduled control, manual scheduled surface control and auto control.

The installations and procedures involved in the automation project were discussed. Risks were identified and a control philosophy was compiled to help Gold Mine A understand how the control should be conducted. Safety and quality procedures were adhered to during implementation of the pump automation project.

Manual control involves the underground operator for control and the control room operator for observation, monitoring and reporting of issues. The underground operator is responsible for the dewatering pump control. After automation, auto control intervention can be implemented. The auto control intervention requires minimal user input as the control room operator and underground operator are only required to monitor the system for issues.

A performance assessment period was implemented to indicate if the savings target could be achieved. The performance assessment served as an indication to Eskom, the client and the ESCo if financial penalties would be imposed on the ESCo. If the ESCo could not reach the agreed target within the performance assessment period, the client would have a new target to reach. Financial penalties could be imposed on the client if the current or new target could not be reached for a five year period after the performance assessment.

Chapter 4. RESULTS

The results obtained after the pump automation project implementation is reviewed and discussed in Chapter 4. The simulation results are compared to the actual results of Gold Mine A dewatering. The results include testing of the different interventions to find the best intervention. The best intervention was chosen by balancing the electricity cost savings achieved and system sustainability.

4.1 INTRODUCTION

Chapter 4 shows the results of the difference in control by comparing the savings achieved by manual control, manual scheduled control, manual scheduled surface control and automatic control. The four control interventions are compared to identify the best control intervention for sustainability and savings achieved. The simulation results are shown and verified by actual operation data.

4.2 RESULTS OF SIMULATION

A simulation was conducted using REMS to simulate the events of a pump automation project performing load shift. Data was obtained and processed to find the most accurate simulation possible. Breakdowns could not be simulated. The simulation was a guideline used before implementing the scheduling for control with the REMS server situated in the control room.

The simulation results for a single day can be seen in Figure 53, Figure 54, Figure 55 and Figure 56. Each of the four different levels was illustrated separately to indicate the status of the pumps and dam level for each hour of the day. The blue and red lines indicating the status of the pumps and schedule respectively will have exactly the same profile as the simulation control the pumps according to the schedule.

The x-axis of the top graph illustrates the time of the day in hours and the y-axis illustrates the number of pumps on the level. The red line is an indication of the scheduled profile and the blue line indicates the actual status of the pumps on the corresponding level. The x-axis of the bottom graph illustrates the time of the day and the y-axis illustrates the dam percentages on the level. The yellow line is an indication of the US dam profile and the purple line indicates the DS dam level.

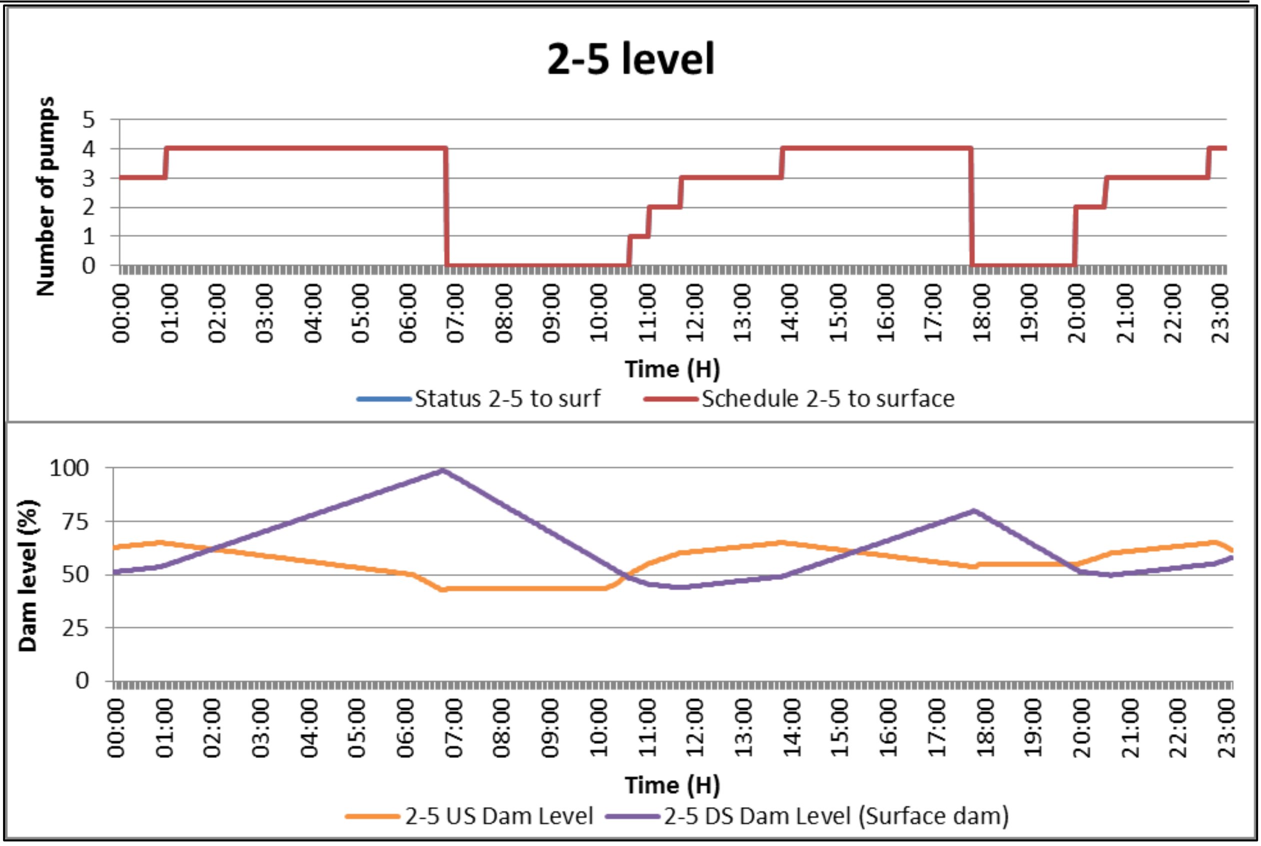


Figure 53: 2-5 level pump running status, scheduled control and dam levels simulation

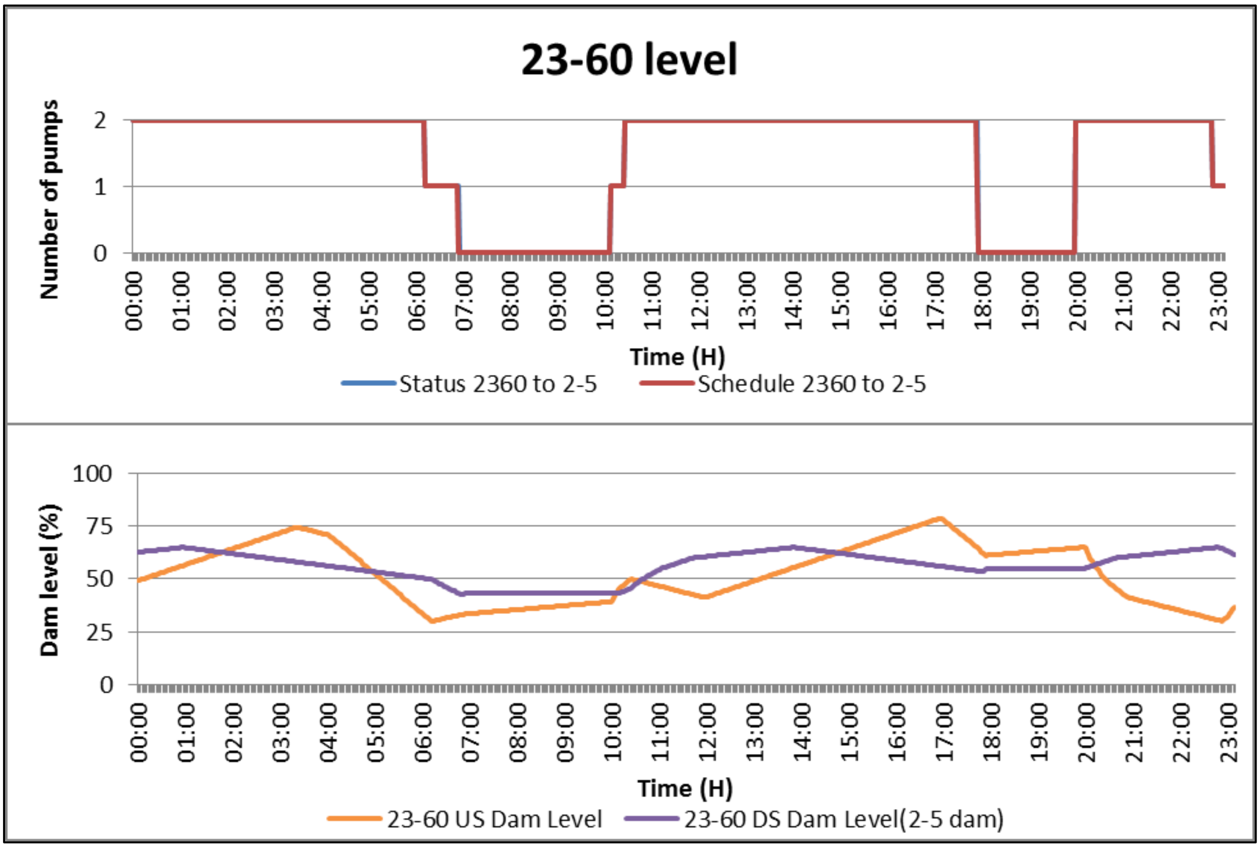


Figure 54: 23-60 level pump running status, scheduled control and dam levels simulation

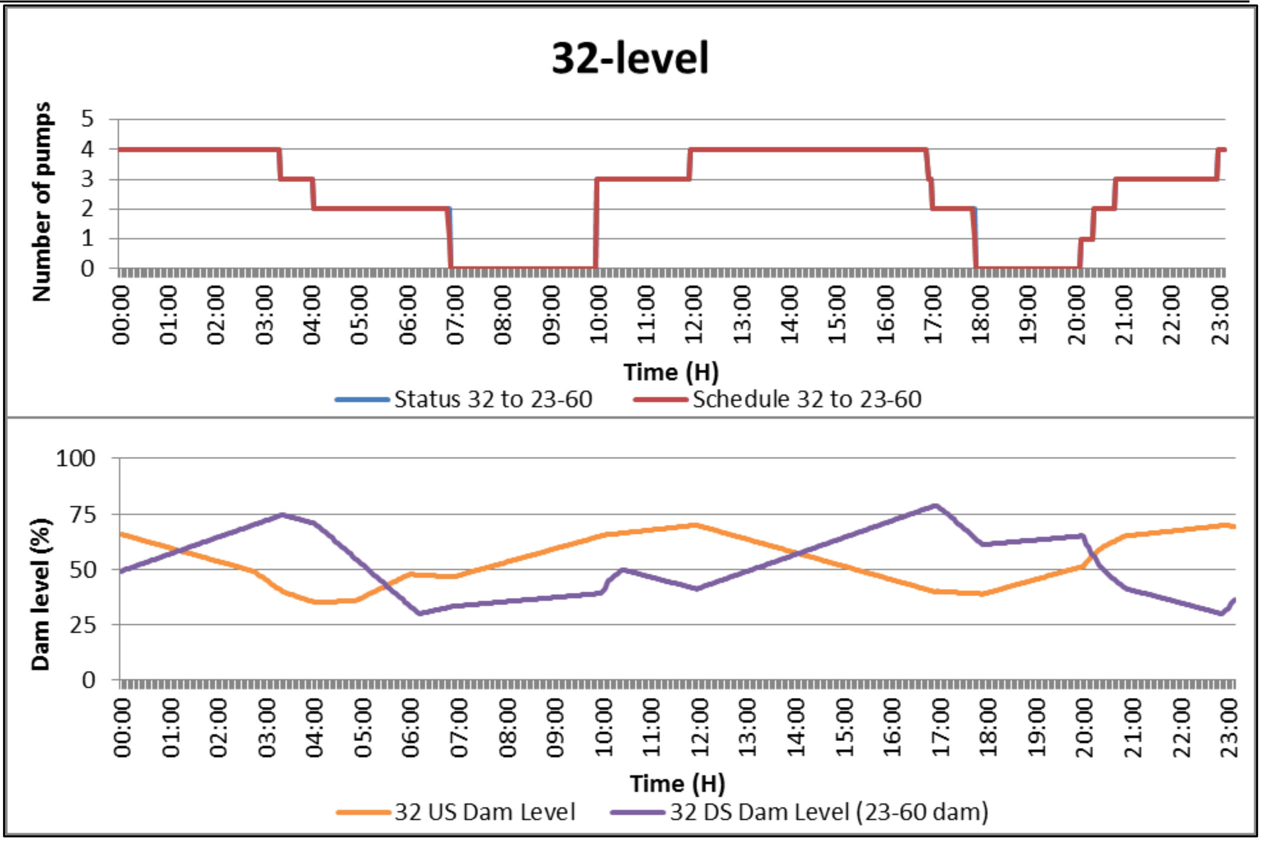


Figure 55: 32-level pump running status, scheduled control and dam levels simulation

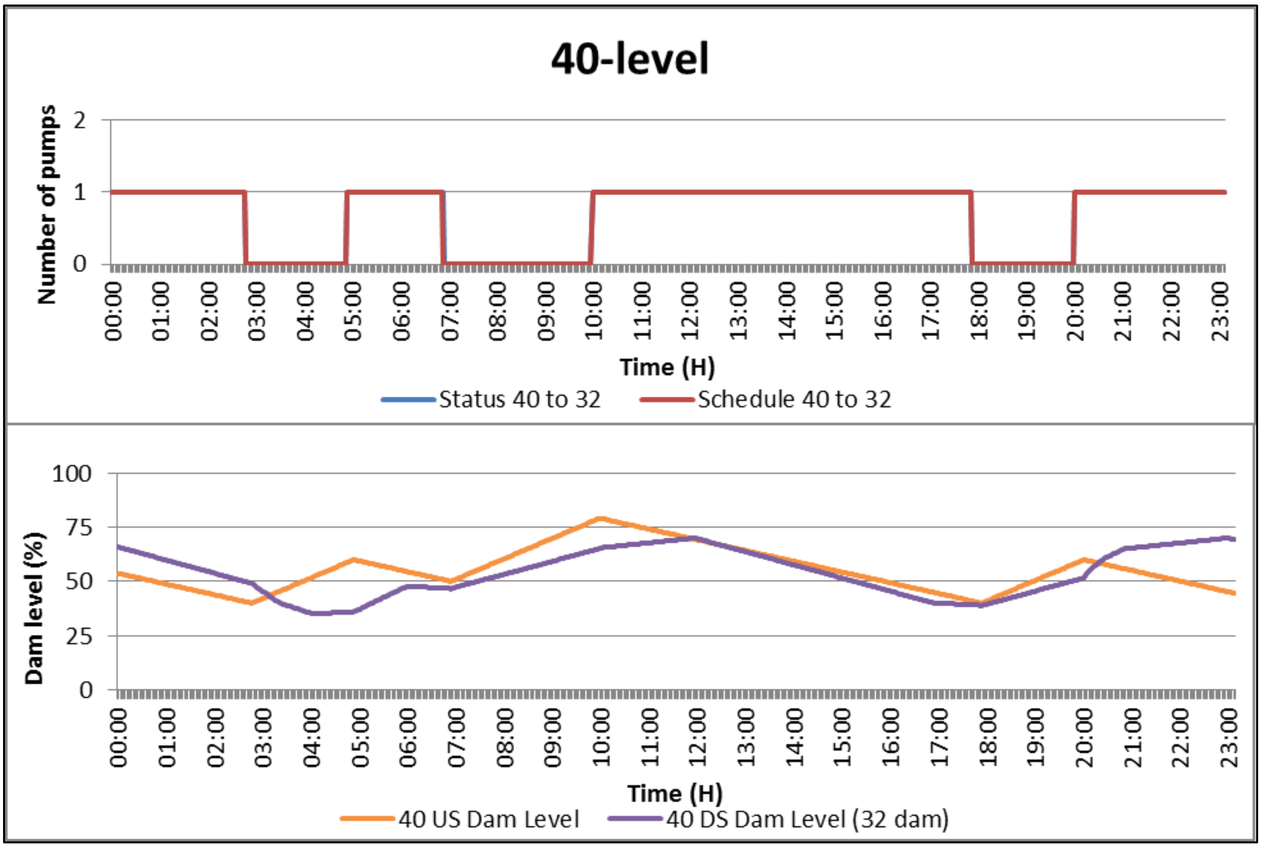


Figure 56: 40-level pump running status, scheduled control and dam levels simulation

By observing the graphs one can be see that a load shift was performed from 07:00 to 10:00 during the morning peak period, as well as from 18:00 to 20:00 during the evening peak. An overall stacked graph of operating pumps per level is illustrated in Figure 57.

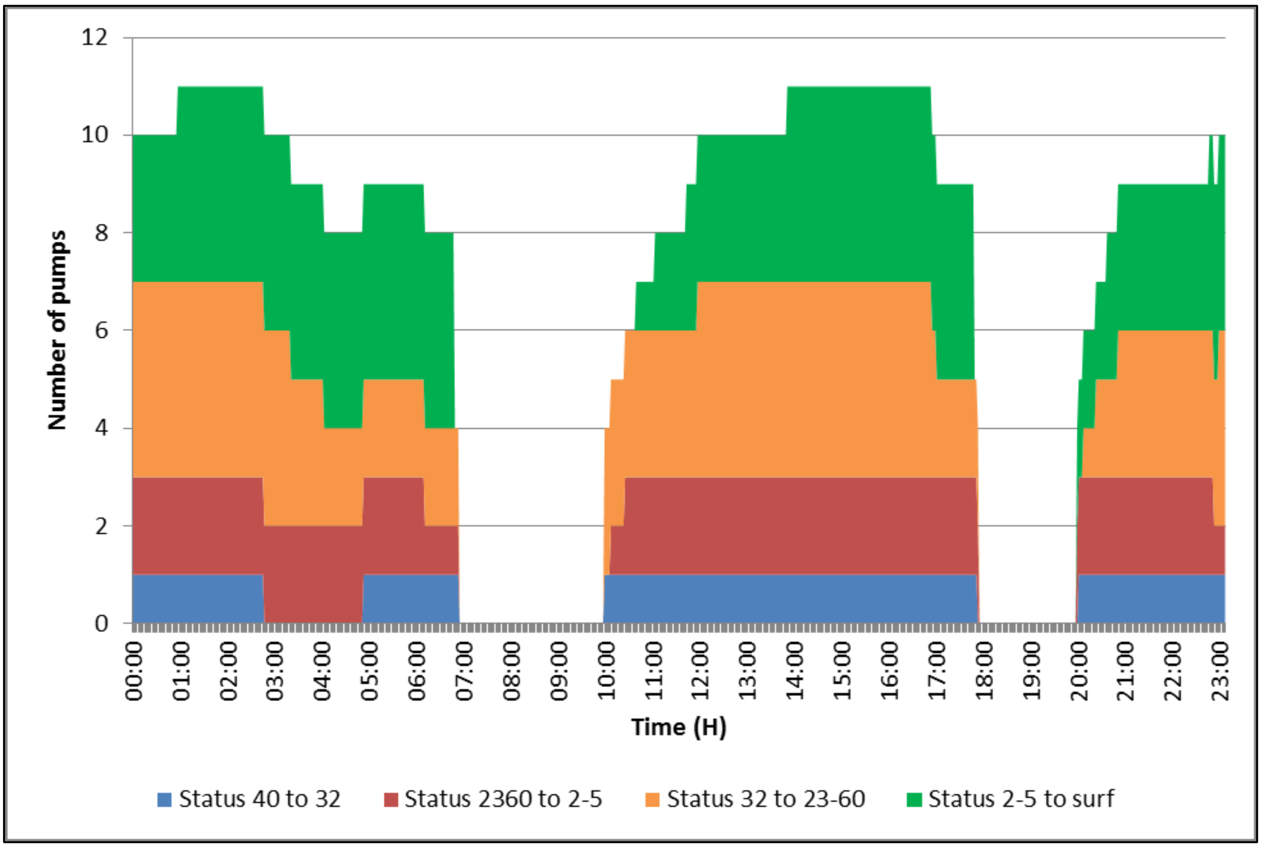


Figure 57: Total running pumps simulation

Simulation verification

A single day's dewatering pump system actual operation profile of Gold Mine A for 29 April 2014 was used to verify the simulation. Comparing the actual operation of the mine to the simulation indicated that the simulation is feasible as illustrated in Figure 58 as the savings achieved differed with 2.1%.

Table 16 compares the simulation results to an actual day's operation of Gold Mine A. The compared results include average weekday saving, average hourly power usage, summer weekday cost savings, winter weekday cost saving and annual cost savings. The difference between the simulation and actual operation profiles is indicated by a percentage.

Figure 58: Simulated power usage profile compared to actual running profile

Table 16: Simulation compared to running profile data

	Simulation	Gold Mine A	Difference
Average weekday saving	14 302 kW	13 999 kW	2.1 %
Average hourly power usage	14 757 kW	14 778 kW	0.001 %
Summer weekday cost saving	R 22 903	R 19 747	-
Winter weekday cost saving	R 121 430	R 114 096	-
Annual cost saving	R11 910 043	R10 861 084	-

The simulation accumulated an average weekday saving of 14 302 kW, with an average hourly power consumption of 14 757 kW. This indicates an annual cost saving of R11 910 043. The simulation was verified by using a single day's running profile of Gold Mine A in April 2013. The average hourly consumption for 29 April 2013 was 14 778 kW and the load shift saving achieved was 13 999 kW.

The overall power usage by the simulation for a single day was 354 175 kWh, while the actual operation profile indicated a total power usage of 354 654 kWh for the day. Comparing the overall usage, a difference of 0% was obtained, indicating that the simulation is accurate.

4.3 IMPLEMENTATION OF CONTROL INTERVENTIONS

As discussed in Chapter 3, four control interventions were implemented. The control interventions included manual control, manual scheduled control, manual scheduled surface control and auto control. Issues with communication on the mine were experienced on various occasions. Data was lost due to these communication issues. The average daily power profile for dewatering pumps was used whenever data for a day was lost.

4.3.1 MANUAL CONTROL

Manual control had minimal control room operator contribution. The only control room operator input was to observe and monitor the system for issues. The control was done by the underground pump operator. Manual control was implemented from February 2013 to October 2013. The performance assessment period was conducted from March 2013 to May 2013 while the system was controlled in manual.

The power profile for the period is illustrated in Figure 59. The blue line indicates the actual operation profile. The red line indicates the baseline and the green line indicates the scaled baseline.

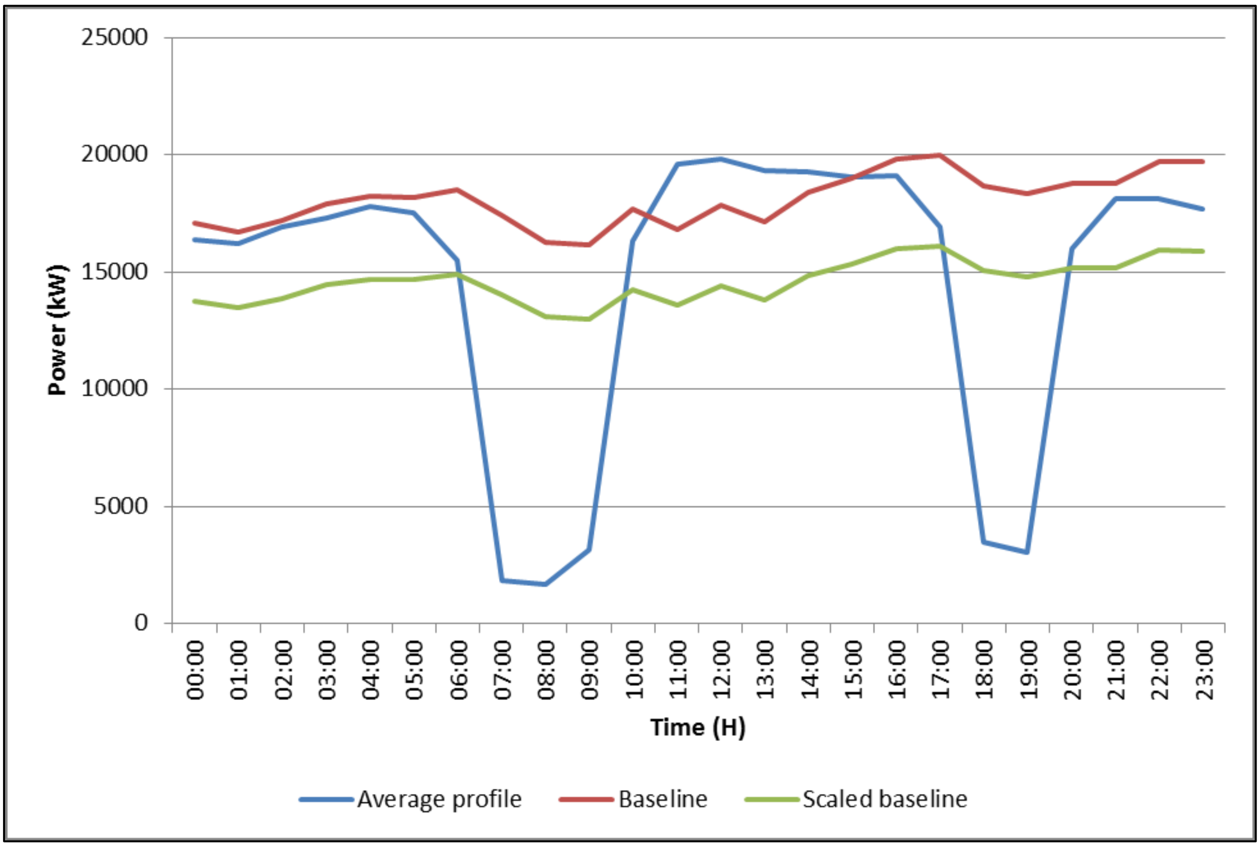


Figure 59: MC power savings profiles

Table 17: MC intervention performance

Saving period	Load shifted (kW)	Cost saving (R)
Weekday morning peak average	11 161	-
Weekday evening peak average	11 647	-
Weekday morning and evening average	11 404	-
Summer months average	11 530	320 190
Winter months average	11 153	1 789 441
	Annual saving	**8 250 035**

As seen in Figure 59 and Table 17, the manual control intervention managed to shift a load of 11.2 MW out of the morning peak period and 11.6 MW out of the evening peak period. The load shift resulted in an average R320 190 electricity cost saving for the summer months and R1.8 million for the winter months. An annual electricity cost saving of R8.3 million is achievable with the manual control intervention.

4.3.2 MANUAL SCHEDULED CONTROL

Manual scheduled control as discussed in Chapter 3 involved the control room operator communicating with the underground operator to stop and start the pumps manually. No surface control was conducted. The control room operator only monitored the pumping system from the surface.

Scheduled control graphs for one day are illustrated in Figure 60, Figure 61, Figure 62 and Figure 63. The graphs are an indication of the precision with which the systems schedule was followed by the control room operator and the underground operator.

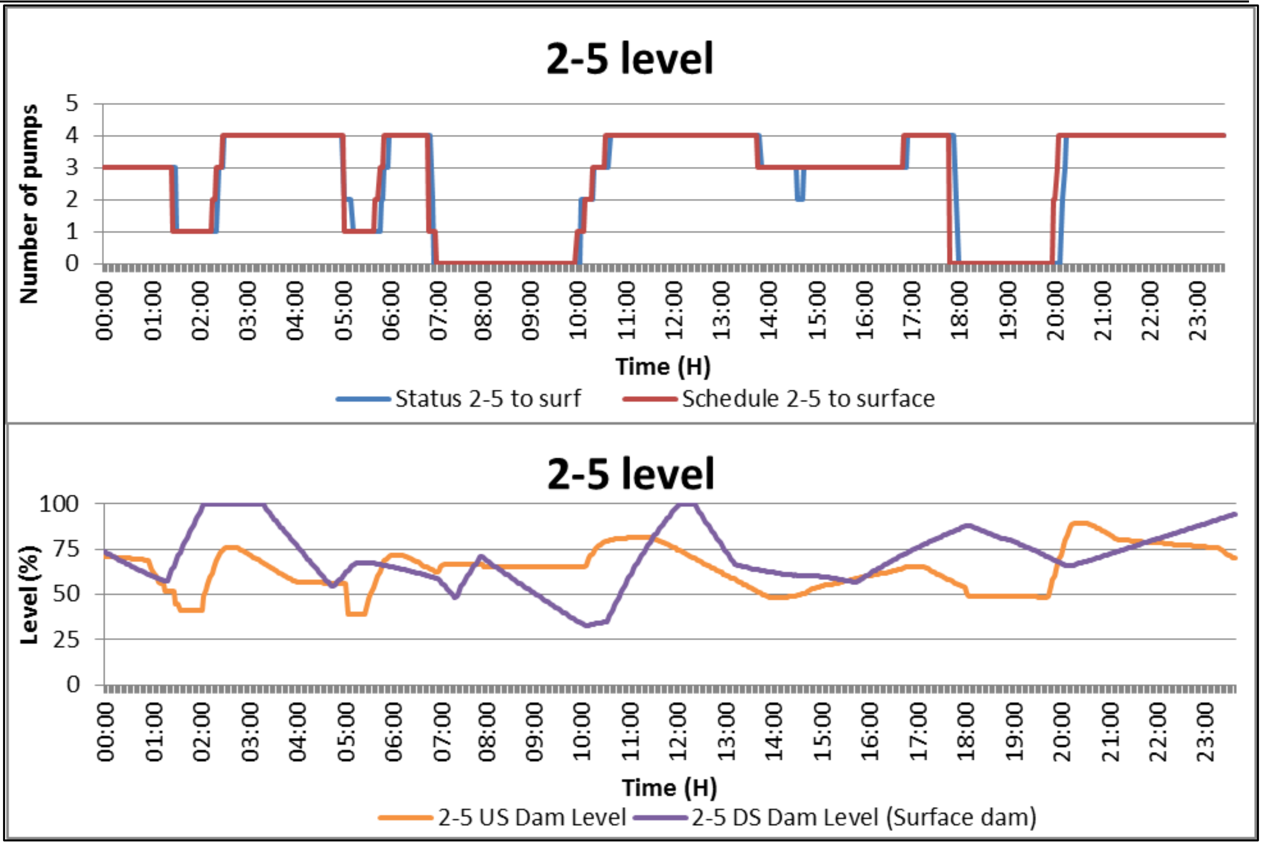


Figure 60: 2-5 level pump running status, scheduled control and dam levels (MSC)

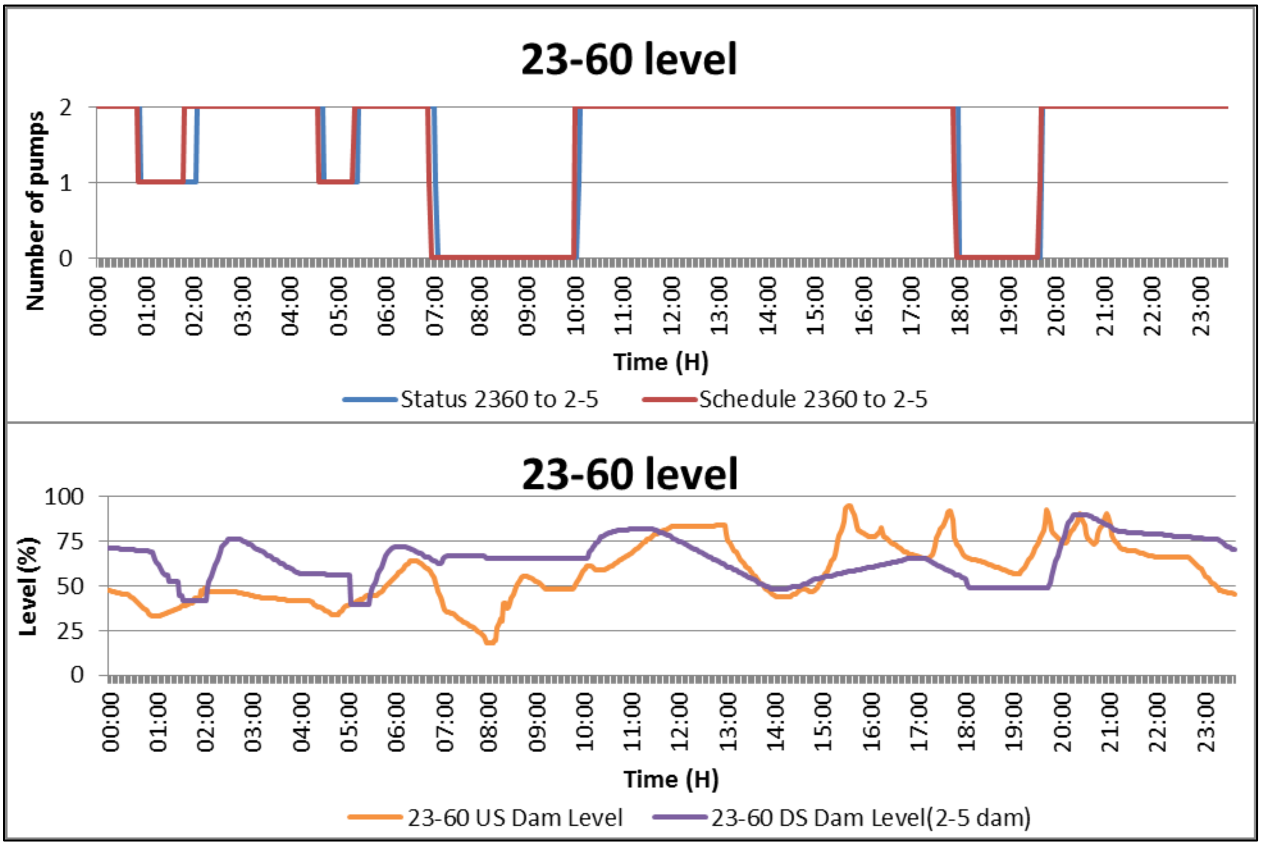


Figure 61: 23-60 level pump running status, scheduled control and dam levels (MSC)

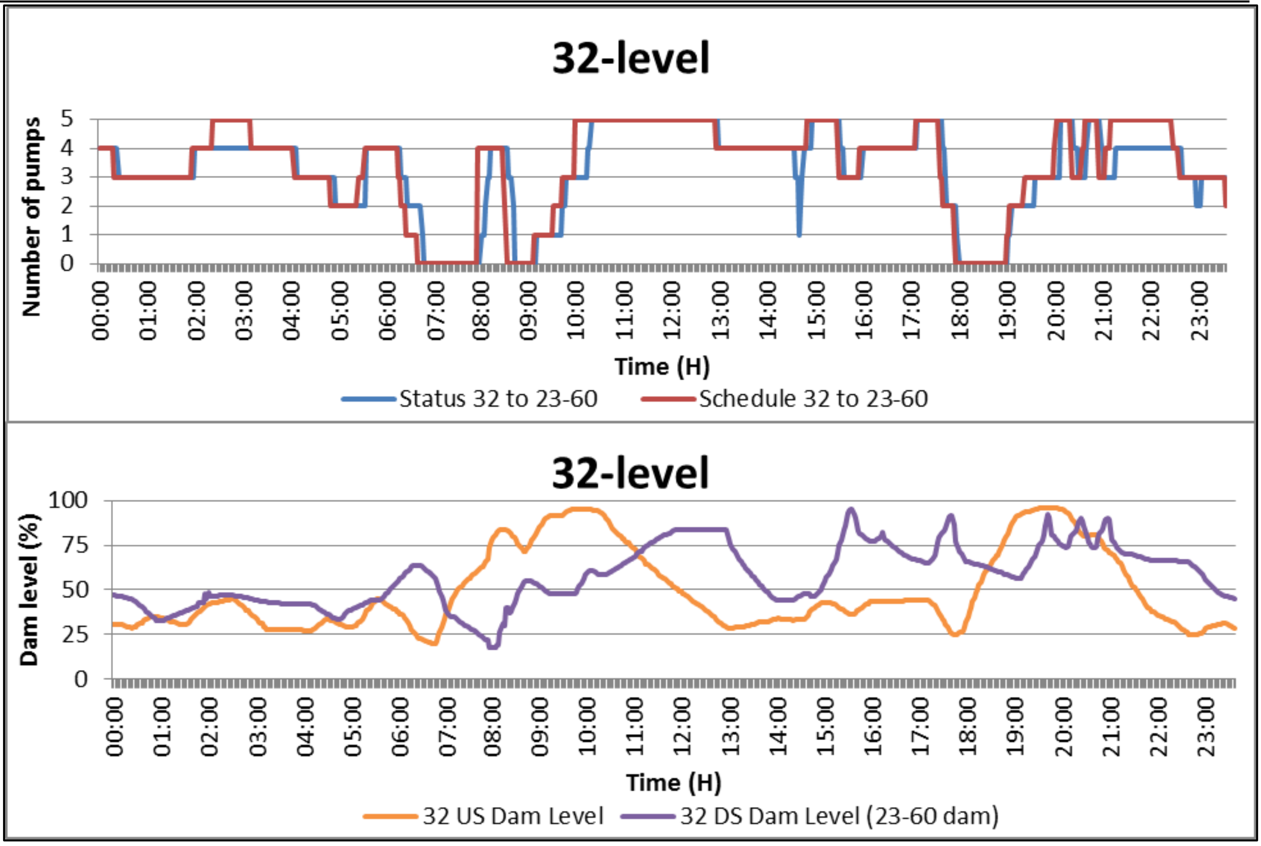


Figure 62: 32-level pump running status, scheduled control and dam levels (MSC)

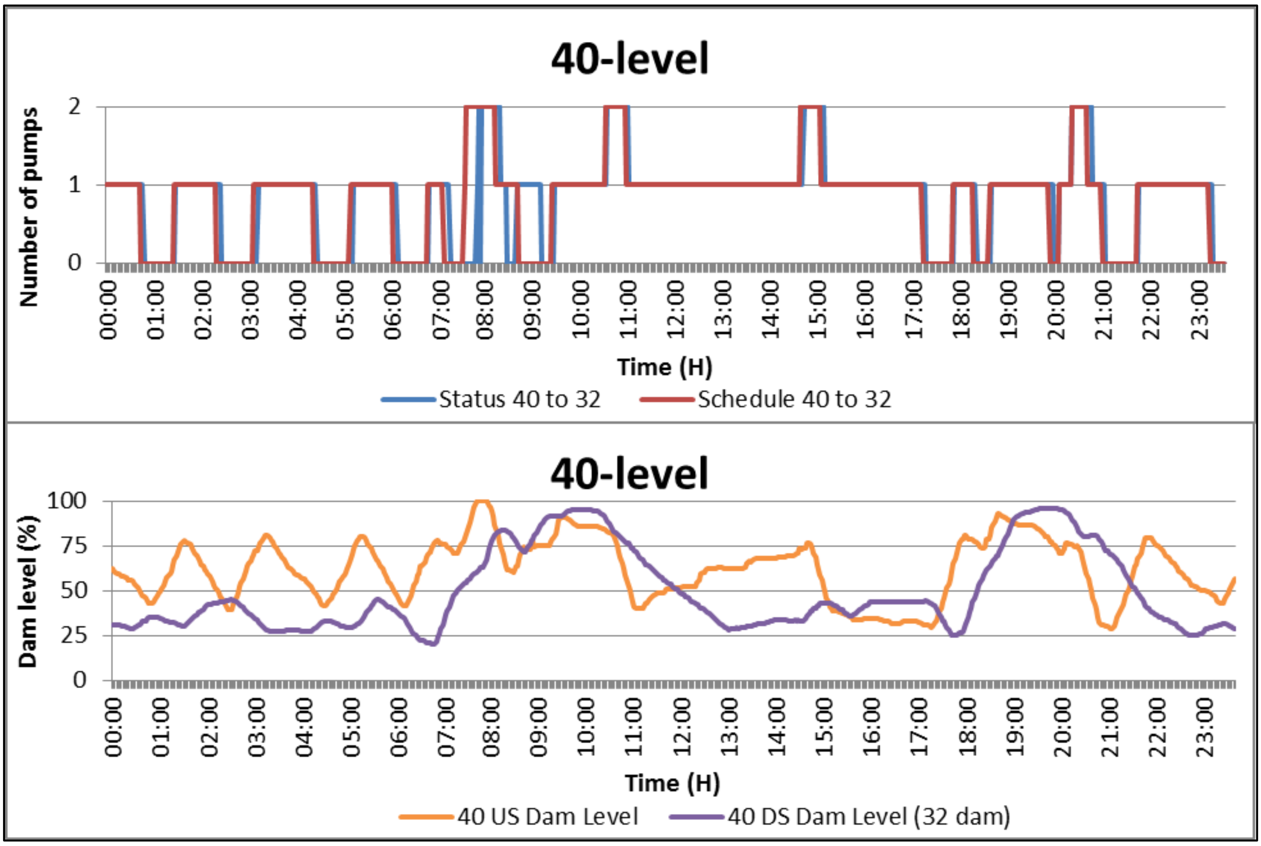


Figure 63: 40-level pump running status, scheduled control and dam levels (MSC)

The schedule was followed accurately with only minor deviations. In some instances issues occurred when the underground pump operator took a long time to start or stop a pump after receiving a signal from the control room operator. Controlling pumps from the surface could eliminate this issue as the delay period will be eliminated.

At the time of testing, Dam 2 on 40-level was being washed by the mine and was therefore offline. This caused the pumps on 40-level to be stopped and started very often as the dam capacity did not allow pumps to operate for long periods. Adjusting the offsets and control ranges in REMS resolved the issue.

Manual scheduled control was implemented from November 2013 to December 2013. Many communication issues were experienced, which resulted in data loss or inaccurate data being logged. The power profile is illustrated in Figure 64. The blue line indicates the actual operation profile. The red line indicates the baseline and the green line indicates the scaled baseline.

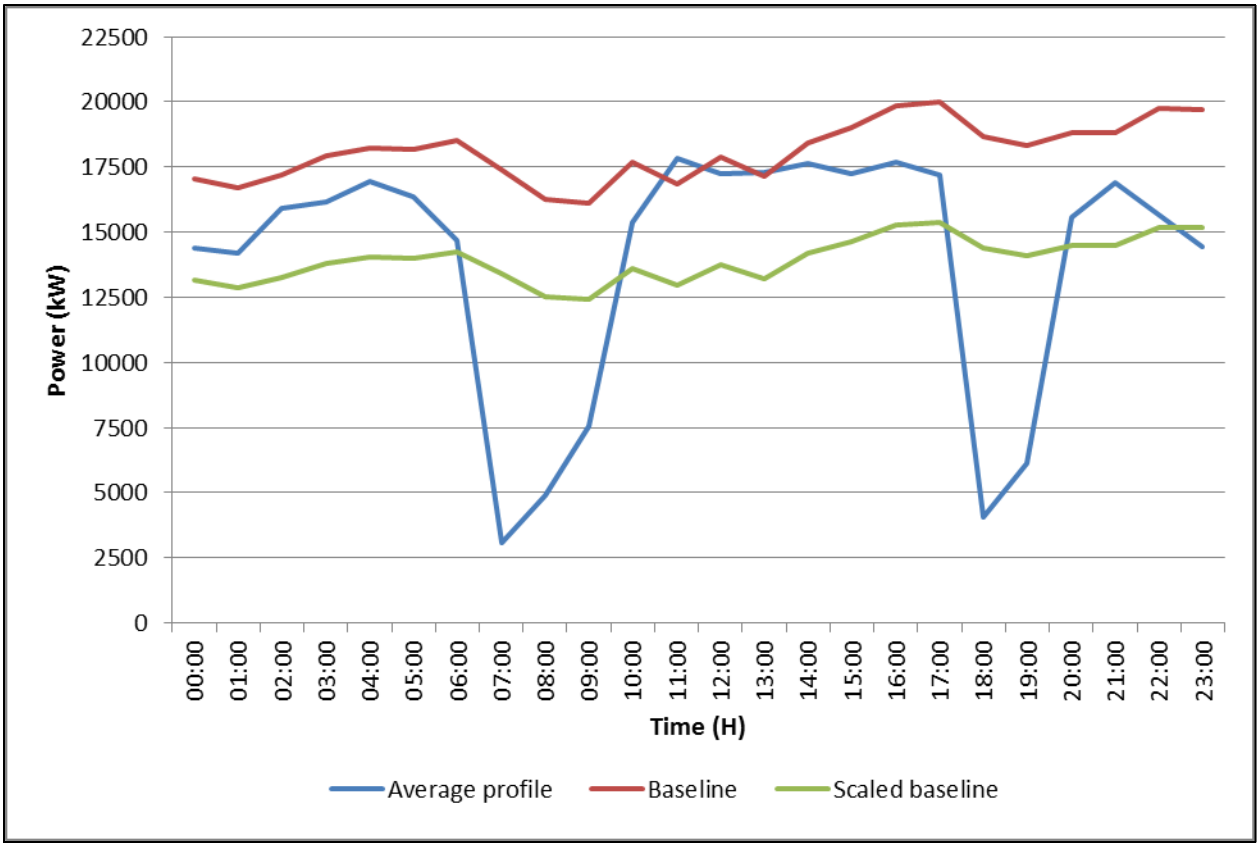


Figure 64: MSC power savings profiles

Table 18: MSC intervention performance

Saving period	Load shifted (kW)	Cost saving (R)
Weekday morning peak average	7 601	-
Weekday evening peak average	9 148	-
Weekday morning and evening average	8 374	-
Summer months average	8 702	221 357
Winter months average	8 702	1 322 844
	Annual saving	**5 960 746**

As seen in Figure 64 and Table 18, the manual scheduled control intervention managed to shift a load of 7.6 MW out of the morning peak period and 9.1 MW out of the evening peak period. The load shift resulted in an average R221 357 electricity cost saving for summer months and R1.3 million for winter months. An annual electricity cost saving of R6 million is achievable with the manual scheduled control intervention.

Manual scheduled control savings achieved a lower saving than the manual control intervention because the safety margins were taken into consideration by the programmed server. The programmed server will indicate 100% dam level indication if the dam is 30 minutes from overflowing. With Manual control the operator underground could go to the dam underground and physically see how full the dam is. Even when the system would indicate a 100% dam indication, the operator underground can then override the system and leave the pumps off until the dam is about to overflow.

4.3.3 MANUAL SCHEDULED SURFACE CONTROL

Manual scheduled surface control is control conducted via the surface SCADA. The desired schedule indicated on the SCADA is followed by the operator by manually controlling pumps from the surface. The savings achieved for the month are illustrated below. An assumption is made that the rest of the months in the year could have similar results and an annual saving is determined.

The findings of the control are illustrated using a single day that indicates how well the schedule was followed by the control room operator. The four different levels are illustrated in Figure 65, Figure 66, Figure 67 and Figure 68 below.

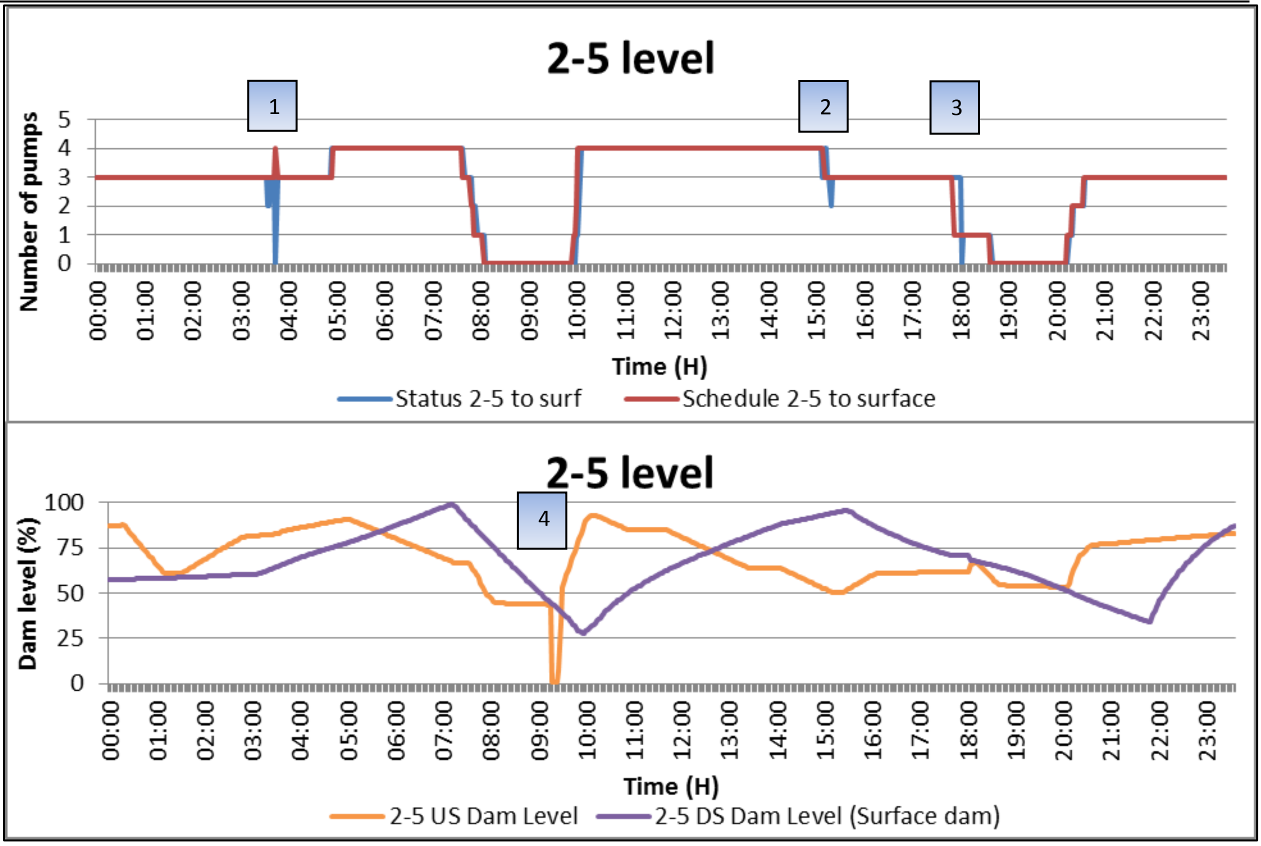


Figure 65: 2-5 level pump running status, scheduled control and dam levels (MSSC)

The deviations on 2-5 level included unusual activity such as power failures, pumps tripping and communication failures were experienced by the mine while manual scheduled surface control was implemented. This is shown and described in Table 19.

Table 19: 2-5 level deviation table

Number	Time	Description
1	03:40	Underground power failure
2	15:10	Pump tripped
3	18:00	Underground power failure
4	09:20	US dam communication failure

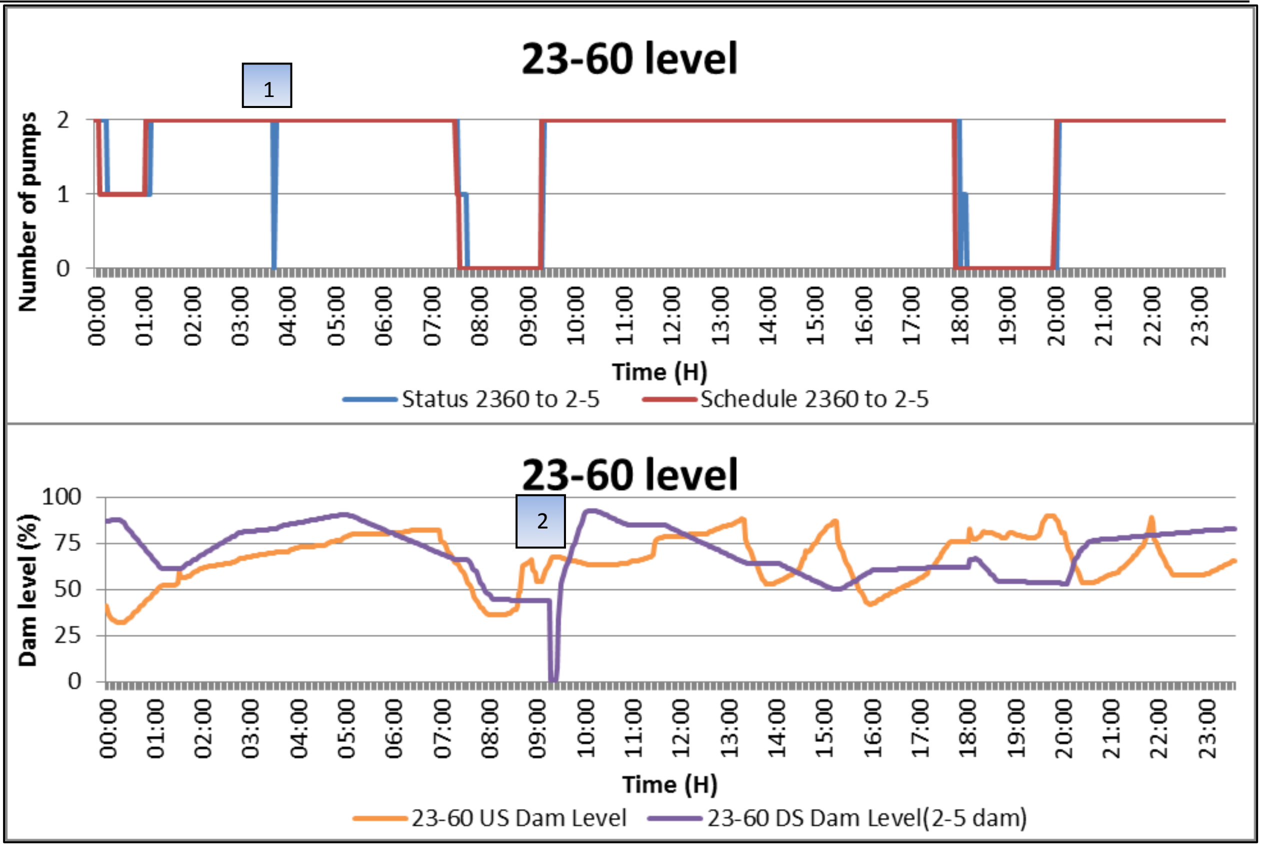


Figure 66: 23-60 level pump running status, scheduled control and dam levels (MSSC)

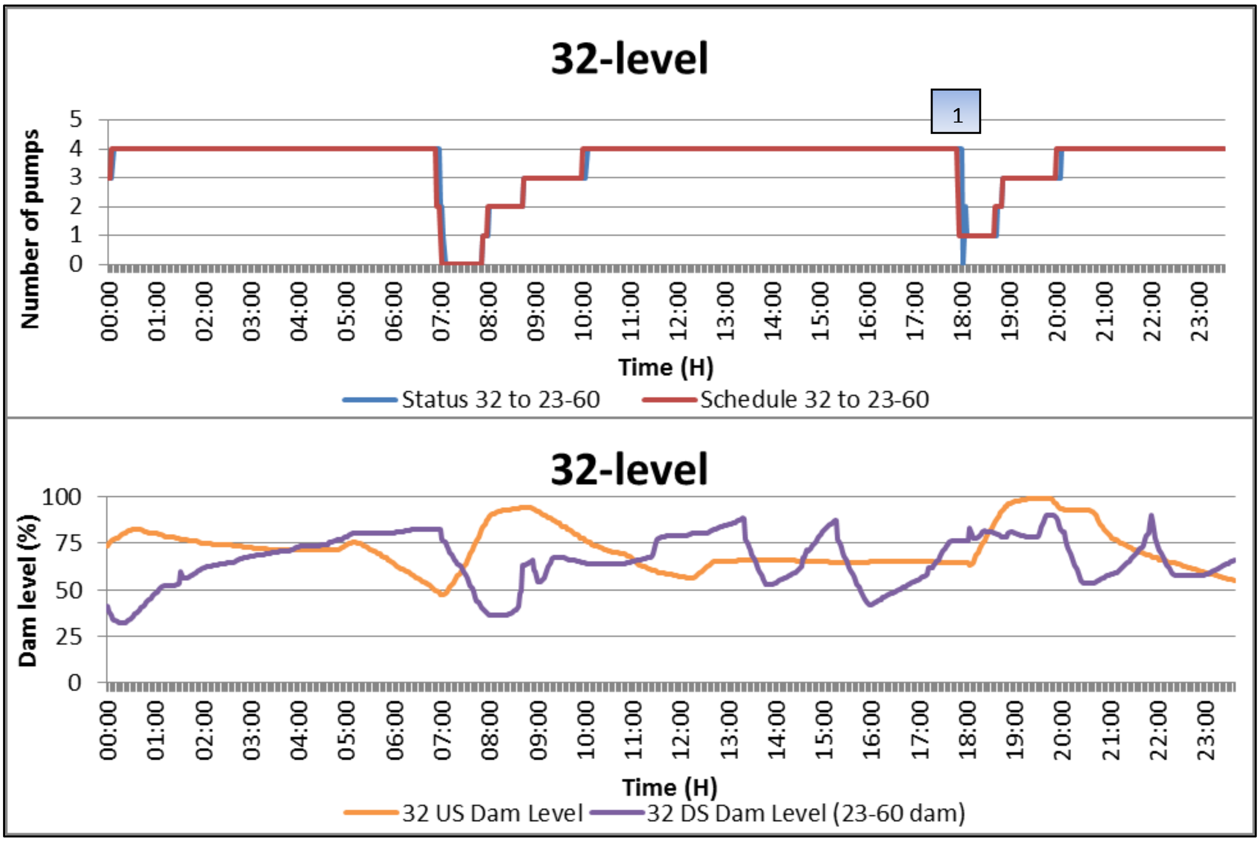


Figure 67: 32-level pump running status, scheduled control and dam levels (MSSC)

The deviations on 23-60 level included unusual activity such as power failures, pumps tripping and communication failures that were experienced by the mine, while manual scheduled surface control was implemented. This is shown and described in Table 20.

Table 20: 23-60 level deviation table

Number	Time	Description
1	03:40	Underground power failure
2	09:20	DS dam communication failure

The deviations on 32-level were unusual activity such as power failures, pumps tripping and communication failures that were experienced by the mine, while manual scheduled surface control was implemented. This is shown and described in Table 21.

Table 21: 32-level deviation table

Number	Time	Description
1	18:00	Underground power failure

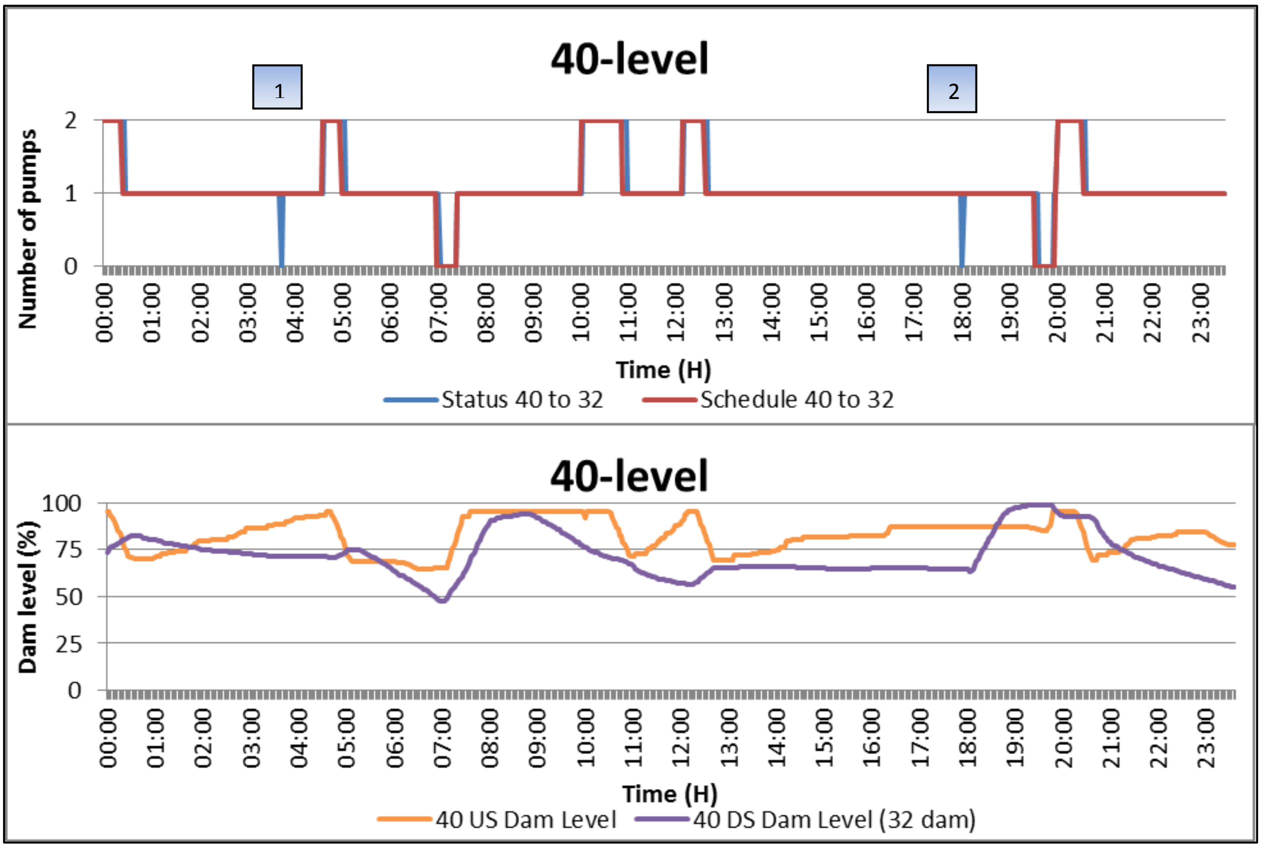


Figure 68: 40-level pump running status, scheduled control and dam levels (MSSC)

The deviations on 40-level included unusual activity such as power failures, pumps tripping and communication failures that were experienced by the mine, while manual scheduled surface control was implemented. This is shown and described in Table 22.

Table 22: 40-level deviation table

Number	Time	Description
1	03:40	Underground power failure
2	18:00	Pump tripped

Manual scheduled surface control was implemented from January 2014 to August 2014. The average power savings profile is illustrated in Figure 69. The blue line indicates the actual operation profile. The red line indicates the baseline and the green line indicates the scaled baseline.

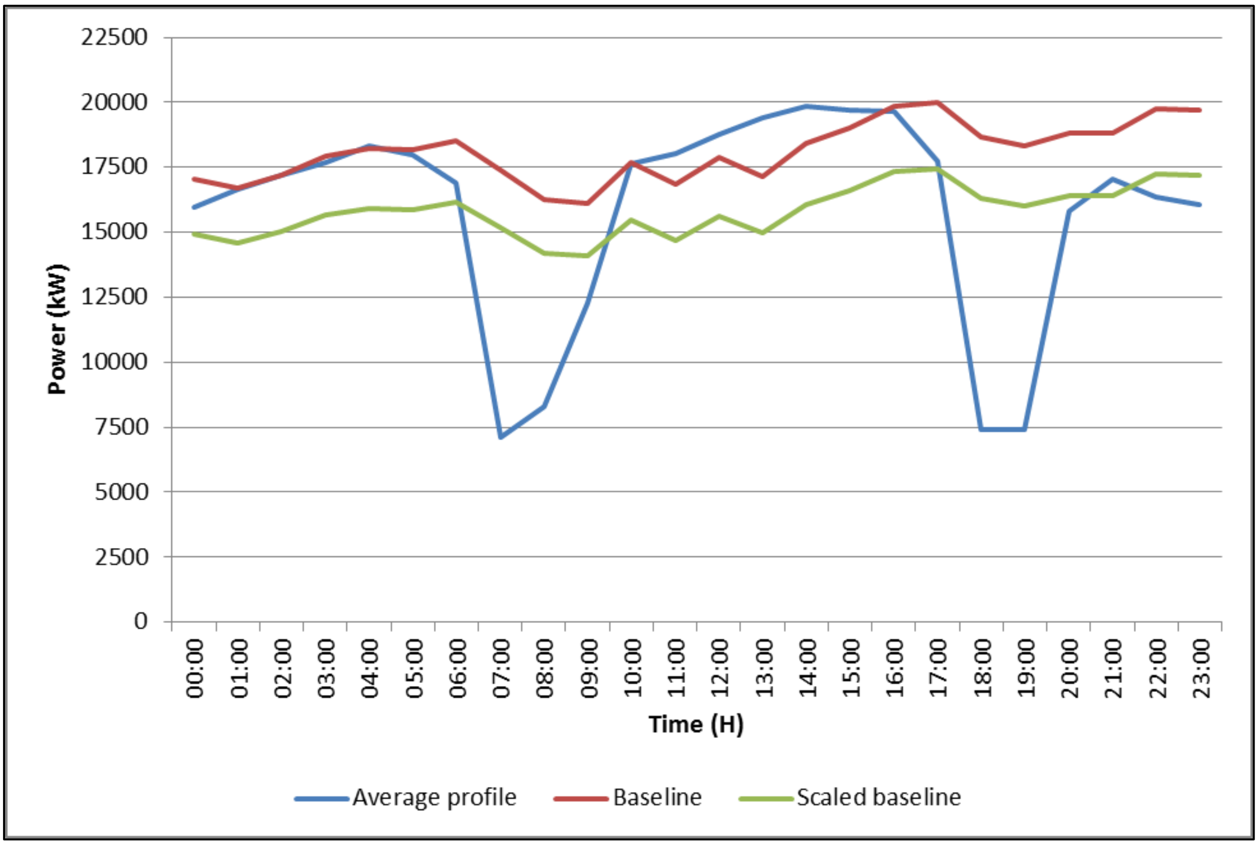


Figure 69: MSSC power savings profiles

Table 23: MSSC intervention performance

Saving period	Load shifted (kW)	Cost saving (R)
Weekday morning peak average	5514	-
Weekday evening peak average	9091	-
Weekday morning and evening average	7302	-
Summer months average	6392	155 639
Winter months average	8820	1 436 236
	Annual saving	**5 709 461**

As seen in Figure 69 and Table 23, the manual scheduled surface control intervention achieved a load shift saving of 5.5 MW in the morning peak period and 9.1 MW in the evening peak period. The load shift resulted in an average R155 639 electricity cost saving for summer months and R1.4 million for winter months. An annual electricity cost saving of R5.7 million is achievable with the manual scheduled surface control intervention.

4.3.4 AUTO CONTROL

Auto mode is the intervention used for complete automatic control. The SCADA does not only indicate the desired schedule, but controls pumps according to the schedules sent out by REMS controllers for each level without any user input. The operator on duty then only monitors the system for major faults and looks out for communication failures.

Upon implementation of the automatic intervention, Gold Mine A realised the column installed on 2-5 level permits a maximum flow rate of 300 l/s. As the previous permitted flow was 550 l/s, the savings achieved was negatively affected by the decreased permitted flow rate. Scheduled control graphs for one day are illustrated in Figure 70, Figure 71, Figure 72, Figure 73.

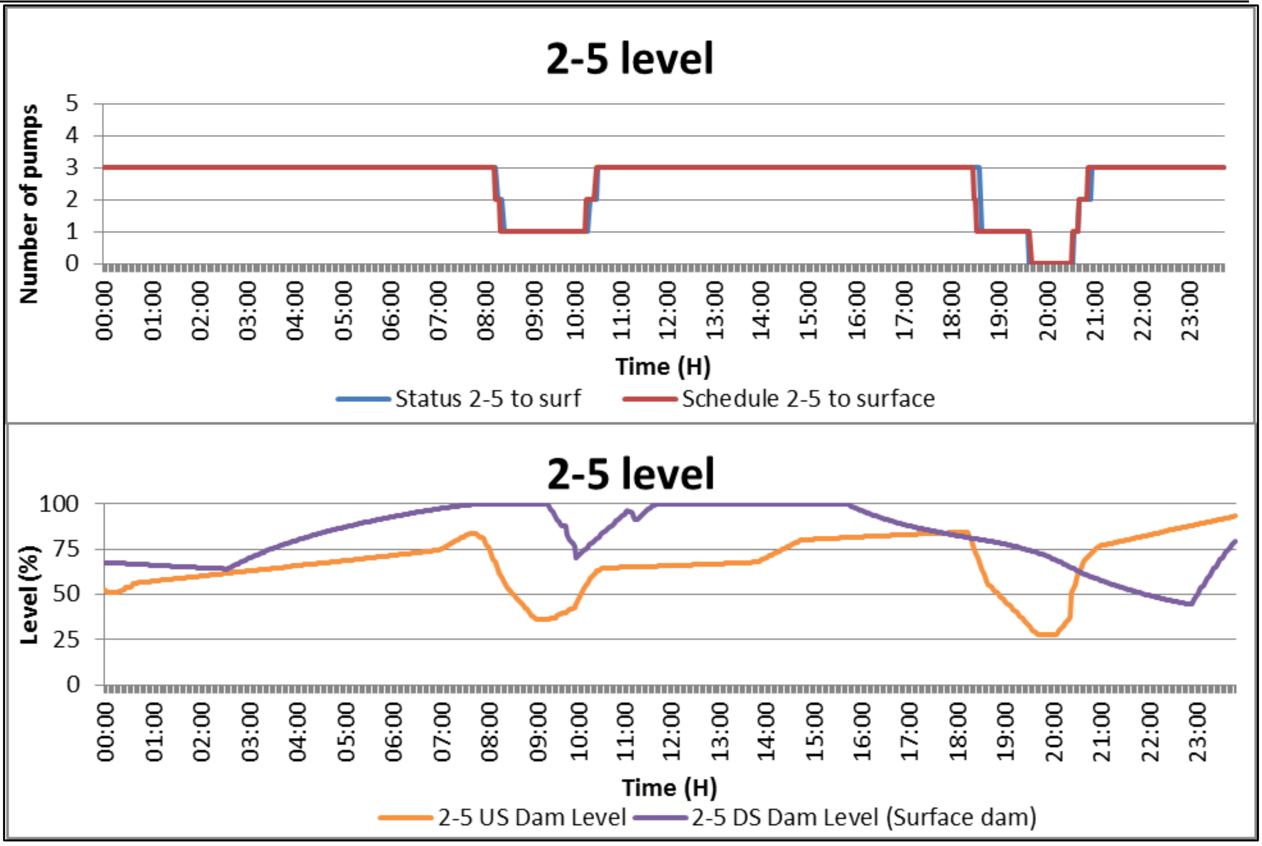


Figure 70: 2-5 level pump running status, scheduled control and dam levels (Auto control)

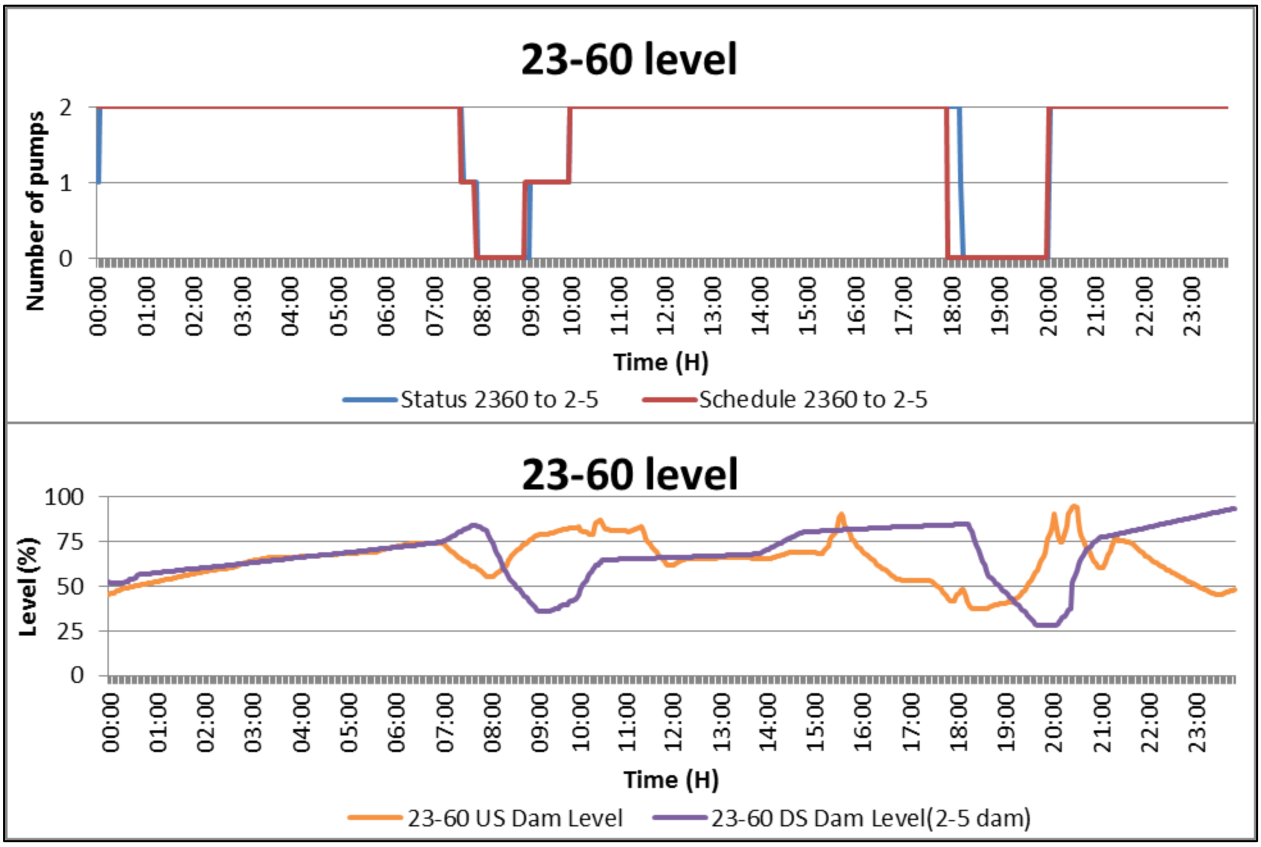


Figure 71: 23-60 level pump running status, scheduled control and dam levels (Auto control)

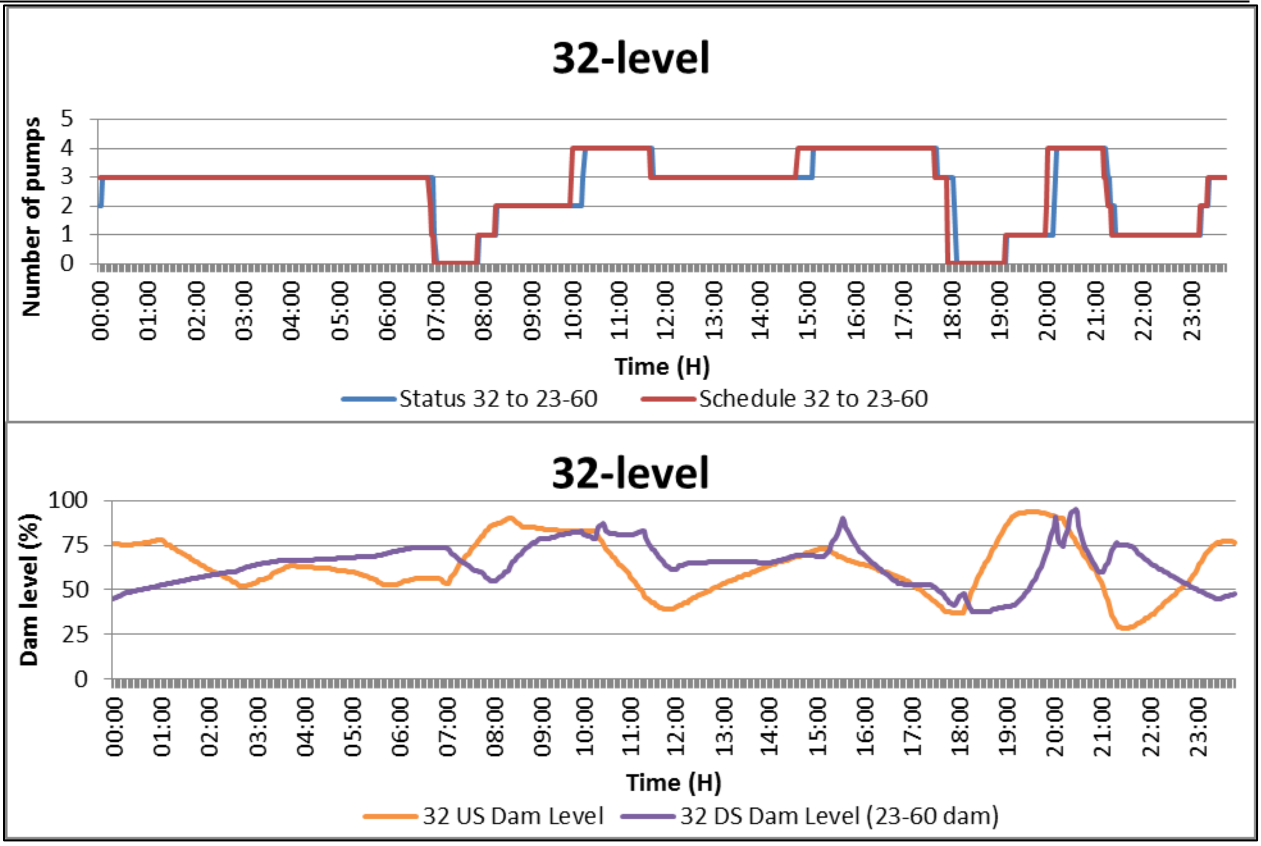


Figure 72: 32-level pump running status, scheduled control and dam levels (Auto control)

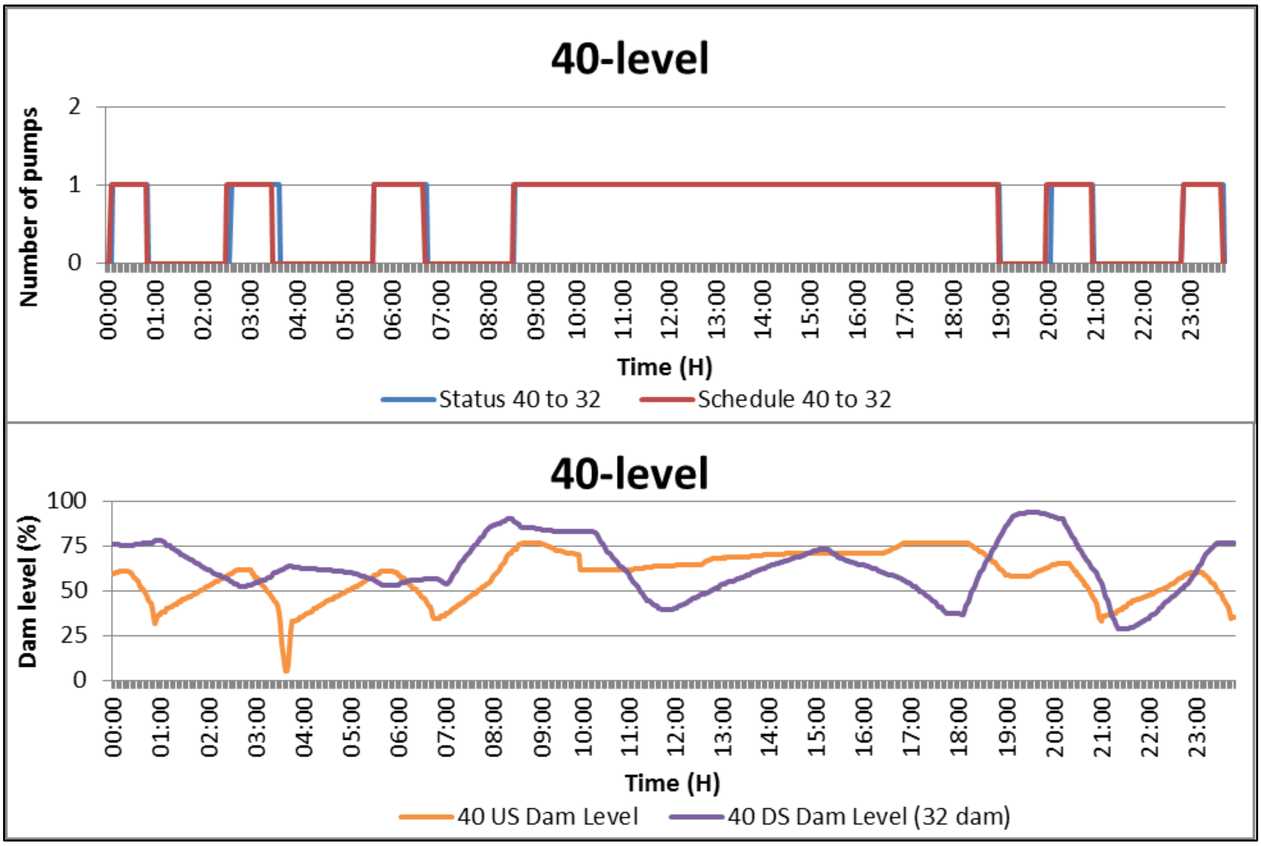


Figure 73: 40-level pump running status, scheduled control and dam levels (Auto control)

Auto control was implemented for two days in September 2014 and one day in October 2014. Initially Gold Mine A did not want to leave the system in auto control due to a lack of trust in the implemented system. However, after continued testing the mine agreed to switch the system to permanent auto control.. The average power savings profile is illustrated in Figure 74 and the performance of the auto control intervention is shown in Table 24.

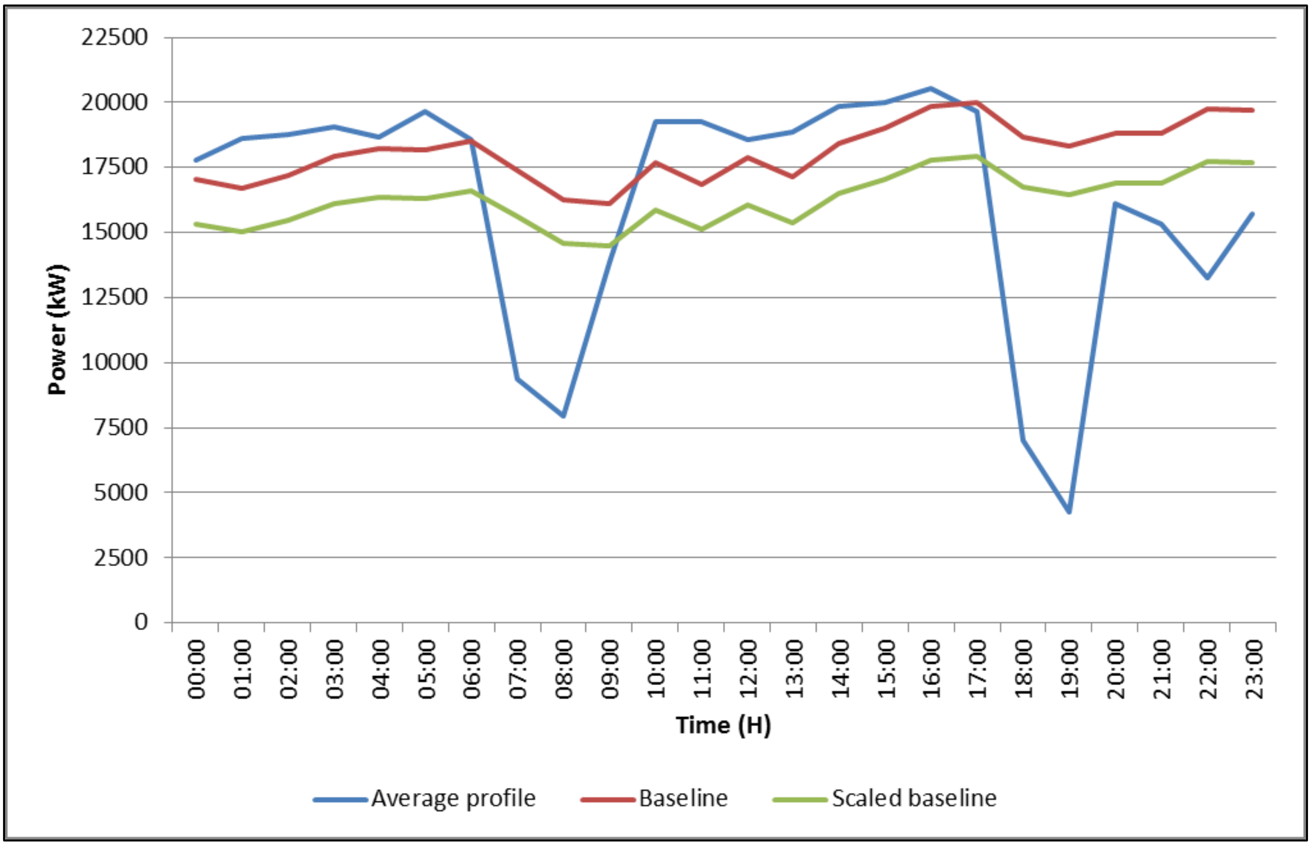


Figure 74: Auto control power savings profiles

Table 24: Auto control intervention performance

Saving period	Load shifted (kW)	Cost saving (R)
Weekday morning peak average	4 504	-
Weekday evening peak average	10 952	-
Weekday morning and evening average	7 728	-
Summer months average	7 728	212 696
Winter months average	-	1 229 277
	Annual saving	**5 571 709**

As seen in Figure 74 and Table 24, the auto control intervention achieved a load shift saving of 4.5 MW in the morning peak period and 10.9 MW in the evening peak period. The load shift resulted in an average R212 696 electricity cost saving for summer months and R1.2 million for winter months. An annual electricity cost saving of R5.57 million is achievable with the auto control intervention.

4.4 CONTROL INTERVENTION COMPARISON

The control comparison is conducted to compare the different control interventions and to identify the best intervention for sustainability and electricity cost savings. The average weekday savings achieved are illustrated in Figure 75.

An engineer was on site from 06:00 to 15:00 from Monday to Friday for the duration of the implementation of the project. Figure 75 shows that close to maximum savings are achieved while the shaft engineer is on site observing the system and the control room operator's actions are taken. The problem is in the evening load shift period. The engineer is not present during the evening peak period. The system then facilitates maximum savings as it has been configured to react according to the engineer's specifications.

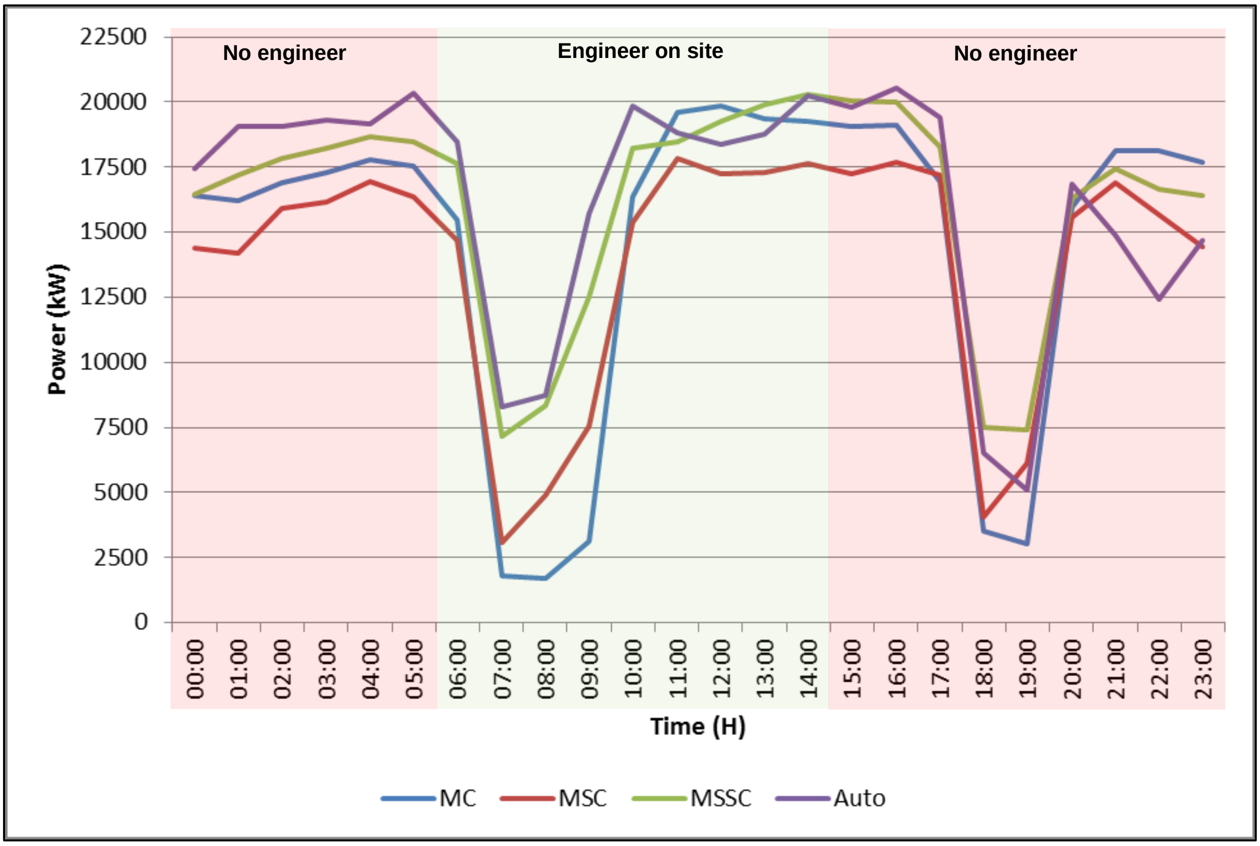


Figure 75: Control intervention comparison average saving achieved

The four control interventions implemented are compared in Table 25. The savings compared include the morning peak saving, evening peak savings, average saving, as well as the annual cost saving.

Table 25: Control comparison

	MC	MSC	MSSC	Auto
Morning peak saving	11 161 kW	7 601 kW	5 514 kW	4 504 kW
Evening peak saving	11 647 kW	9 148 kW	9 091 kW	10 952 kW
Average saving	11 404 kW	8 374 kW	7 302 kW	7 728 kW
Annual cost saving	R8 250 035	R5 960 746	R5 709 462	R5 571 709

Manual control shows the highest saving with 11.4 MW (R8.25 Million). Auto results shows a slightly better saving than manual surface control and manual scheduled surface control with a saving of 7.7 MW (R5.57 million). The decreased saving from manual control to manual scheduled control and manual scheduled surface control can be attributed to the problems experienced. The issues included column failures, dam unavailability and pump maintenance. It should be noted that long term results will favour MSSC and auto control.

4.5 SUMMARY

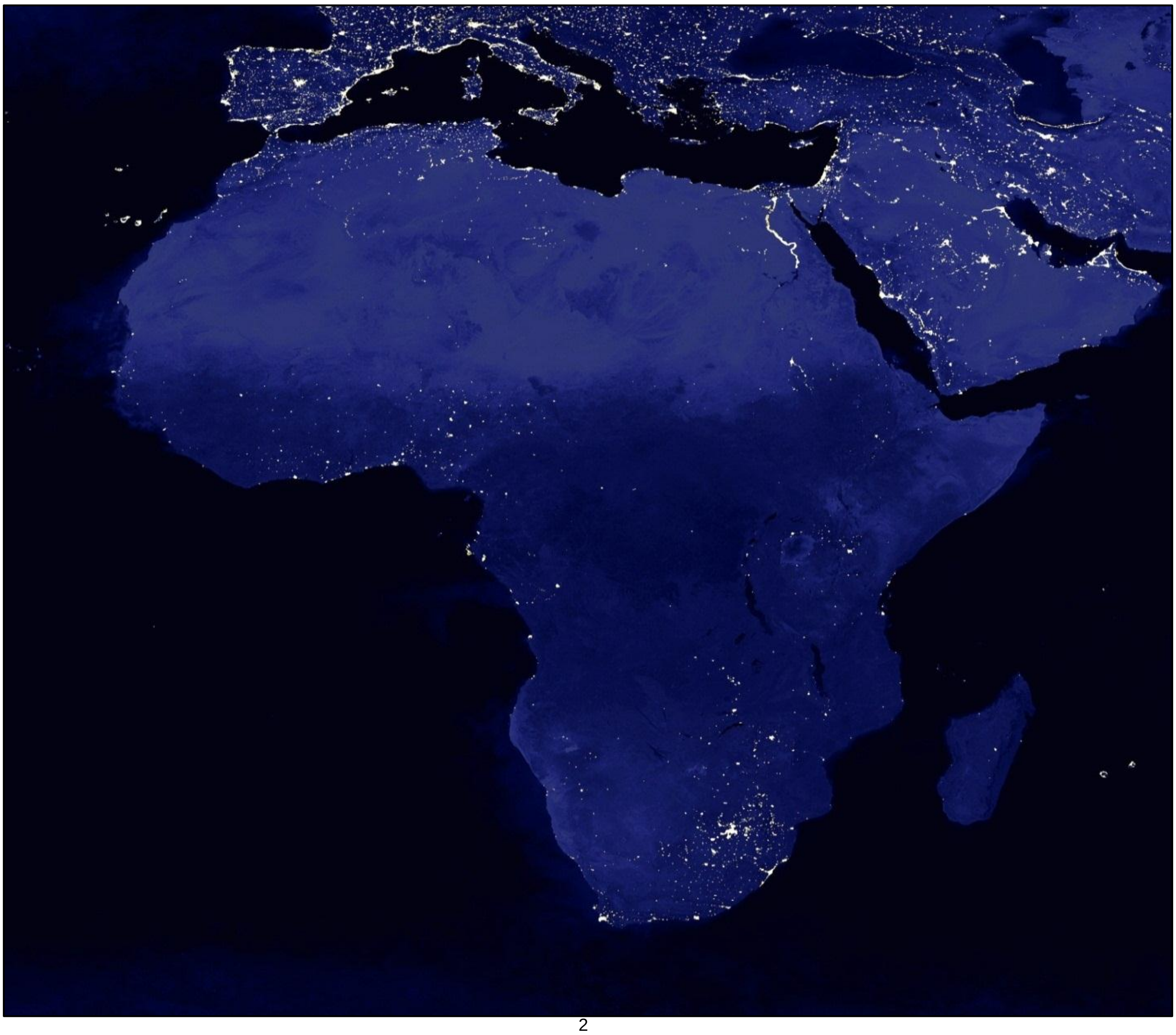
A simulation was done to determine the possible savings achievable by Gold Mine A. The dewatering pumps running profile simulation was compared to a day in April 2013 to verify the feasibility of the simulation. The simulation was used as an indication of how the dams and pumps would operate before the control interventions were implemented.

Four control interventions were implemented after underground installations were complete. The interventions include manual control, manual scheduled control, manual scheduled surface control and auto control. The savings achieved by the interventions were compared to indicate the benefits of each intervention and to indicate the best control intervention.

Manual control intervention achieved the highest electricity cost savings. The system was exhausted after eight months while achieving these savings as at times the maximum number of pumps had to be operated to sustain the water volume in the dams. Columns were under severe pressure of 550 l/s. The system could not keep performing with maximum flows and dam usage. Columns started failing and another intervention had to be implemented. The manual intervention achieved a load shift saving of 11.4 MW and cost saving of R8.25 million.

Auto control eliminated system exhaustion by incorporating safety margins into the system for minimum and maximum dam levels, pump column permitted flows, as well as preventing pumps from being exhausted by restricting running hours. Auto control was implemented to allow the best balance between system sustainability and electricity cost savings. Auto control achieved a load shift saving of 7.7 MW and an electricity cost saving of R5.57 million.

Chapter 5. CONCLUSIONS AND RECOMMENDATIONS



[2]

Chapter 5 discusses the conclusions drawn from the results obtained from Chapter 4. The best balance between system sustainability and electricity cost savings is implemented. Manual intervention achieved the best electricity cost saving results. However, after eight months, the system became fatigued and columns started failing. As the auto control intervention has safety margins programmed into the system, the best balance was achieved between electricity cost savings and auto results.

[2] Picture courtesy of http://upload.wikimedia.org/wikipedia/commons/0/07/Africa_at_night_%28Cropped_From_Entire_Earth_Image%29.jpg

5.1 CONCLUSION

Gold mines use vast amounts of energy to pump water from underground to the surface. Dewatering pump systems use up to 20% of the total electricity consumption of a mine. Taking this into account, opportunities arise to implement DSM pump automation projects to perform load shifting and in return realise electricity cost savings and help the mine operate more efficiently.

Dewatering pumping control is traditionally performed by manual interventions. However, manual systems have numerous problems that include delayed discharge valve opening, high maintenance costs, delayed maintenance due to fault finding inefficiency and ineffective sustainability over long periods. Automated systems can be implemented on pumping systems and benefits can be realised such as electricity cost savings, fault finding efficiency, predictive future savings and predictive maintenance intervals.

A pump automation project was implemented on a gold mine situated near Westonaria. Pump automation requires various monitoring instruments for effective and reliable control. Temperature probes, vibration transmitters, pressure transmitters, actuators, PLCs and flow meters are some of the critical instrumentation required.

The process from manual to auto was conducted with four interventions, which included manual control, manual scheduled control, manual scheduled surface control and auto control. Manual control was conducted by the underground operator. Manual scheduled control was conducted by the underground operator as well as the control room operator. Manual scheduled surface control was conducted by the control room operator. Auto control was conducted by the programmed server, situated in the control room with minimal user input.

The results of the four interventions indicated that manual control achieved the highest savings of R8.25 million. Manual control is not recommended due to system exhaustion, as after a few months major maintenance was required when pumps and columns started failing. Auto control resulted in a saving of R5.57 million. Even with a weaker saving than manual control, auto control is still the recommended control intervention, as an automated system can prevent system exhaustion since safety margins are incorporated into the system to protect the system from failure or damage. Preventing system exhaustion will reduce the cost of maintenance.

Auto control is the most feasible and sustainable control intervention for optimal operation as it proved the best balance between electricity cost savings and maintenance costs of pumping system infrastructure.

5.2 RECOMMENDATIONS FOR FURTHER WORK

Maintenance

With pump automation, maintenance should be the main region of focus for further investigations. Usually the success of a project deteriorates as time passes because of little to no maintenance. Maintenance is a problem in almost all pump automation projects.

The instrumentation installed is not maintained and as time goes by, more and more of the instrumentation used has to be bypassed for a specific pump to keep on working. After some time, almost all of the safety equipment is out of order and the safety trip conditions have been bypassed. The pump automation project is then again at stage zero with no automated control and safety trip interlocks.

The solution will be to have trained personnel onsite. When the correct training is provided the instrumentation can be maintained, provided that critical spares are available. The budget should also allow for maintenance. Once the spares have been used proper management is needed to ensure new spares are obtained and the critical spares are immediately available.

When maintenance is performed correctly, the client will keep realising electricity cost savings. The client can then operate more efficiently and more cost effectively. When pumping stations are automated, the ability to identify a fault in the system is made simple. An investigation is required into the exact cost savings achievable by maintained automated systems.

Savings obtained from automated systems excluding electricity cost savings

The client will realise electricity cost savings with the implementation of an automation project and performing load shifting. With the automation process a number of beneficial factors for dewatering pump operation are implemented. The implementation of instrumentation for monitoring purposes could save the client maintenance costs. The exact cost saved is unknown and could be investigated.

Pump efficiency incorporation

The implementation of automatic pump efficiency calculation can be incorporated into the system to schedule the pumps with the highest efficiency to operate in peak periods and the less efficient pumps to operate in the off-peak period. This will ensure that the load on the pumps is evenly distributed.

Although pump efficiencies are incorporated into the system implemented in this dissertation, the most efficient to least efficient pumps have to be manually inserted into the system. There is a need for the efficiencies to be determined automatically by use of real-time temperature transmitter data and calculations.

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APPENDIX A – TRAINING SHEETS AND COMMUNICATION PROTOCOLS

Gold Mine A

Pump attendant information and training sheet

- **Control pumps according to the following dam levels and pump configuration:**

POWER CONTROL (07:00 – 10:00, 18:00 – 20:00)

	Max level	Min level
2-5 level	100%	25%
23-60 level	100%	25%
32-level	100%	25%
40-level	100%	25%

REST OF THE DAY

	Max level	Min level
2-5 level	100%	25%
23-60 level	100%	25%
32-level	100%	25%
40-level	100%	25%

Pump configuration

Pump station	Max pumps	Column	Pump	Pumps per column
2-5 level	4	1	1	4
			2	
			3	
			4	
			5	
			6	
			7	
23-60 level	2	1	1	2
			2	
			3	
32-level	6	1	1	2
			2	
			8	
		2	3	
			4	
			5	
			6	
		3	7	
			10	
			12	
40-level	2	1	1	2
			2	
		2	3	
			4	

Important information for communication failure to surface

1. Wait for control room operator to communicate the failure and hand over manual control to pump attendant.
2. Switch pump PLC from remote to manual.
3. Once the pump is switched to manual the pump attendant will be able to start/stop a pump from underground.
4. Pump control should proceed from underground by pump attendant if communication from surface is lost.

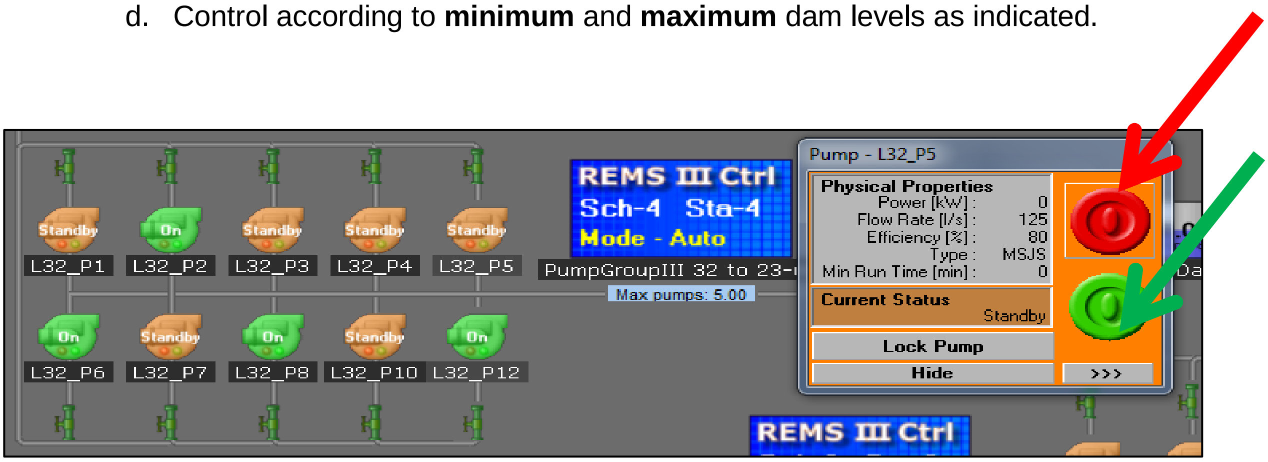
ATTENTION!!!
DANGER!!!
INJURY CAN OCCUR!!!

Steps before maintenance on pumps are done:

1. Communicate to surface and inform control room operator that maintenance will be performed.
2. Ensure the lockout procedure (Procedure 3.3.8.4) has been implemented.
3. Switch PLC from remote to manual.
4. Make sure the control room operator has locked out the pump on the surface REMS pumps.
5. Double check that the pump has been locked out before performing maintenance.

How to operate REMS Pumps

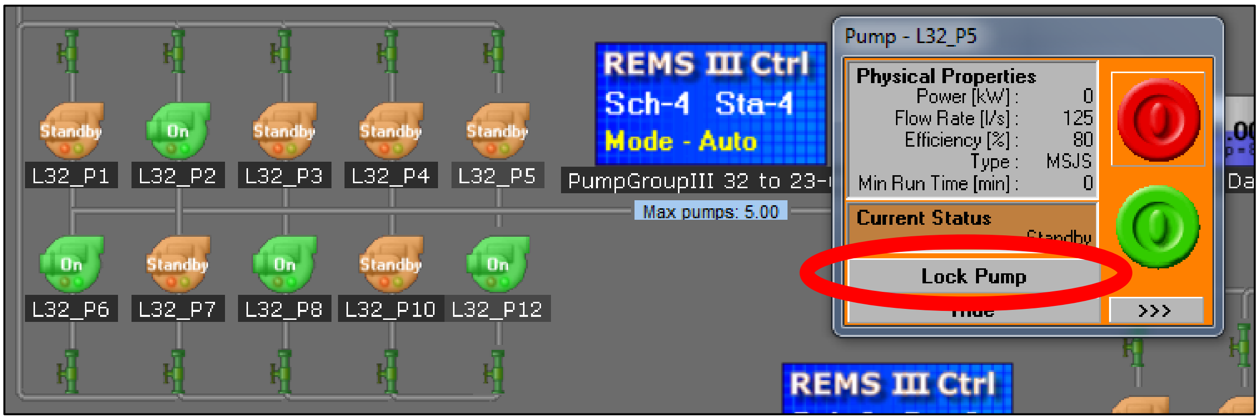
1. Locate the **REMS Pumps screen.**
2. **Log in** as operator.
3. Attend to **alarms.**
4. Stopping/Starting a pump
   a. Check the **dam levels** before stopping or starting pump.
   b. **Phone** underground and inform underground pump operator that you will start/stop a pump.
   c. Double click on the pump you want to **stop** or **start**
      i. Locate the **red** button for stopping a pump.
      ii. Locate the **green** button for starting a pump.
   d. Control according to **minimum** and **maximum** dam levels as indicated.



Maintenance on pumps

Lock-out a pump when maintenance is being performed on the pump:

1. Wait for underground pump operator to inform you that maintenance will be performed.
2. Double click on the pump that will be locked out.
3. Select the **Lock Pump** option.

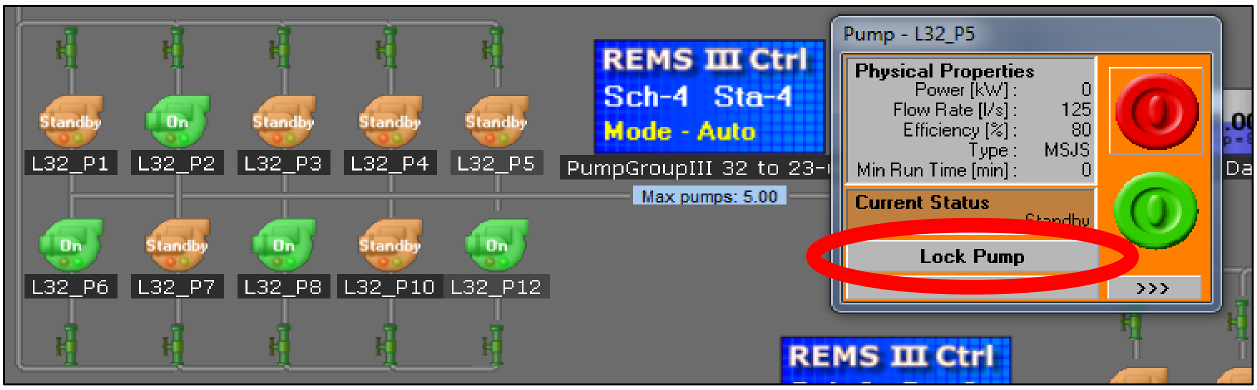


4. Leave pump locked out until underground pump operator informs that maintenance is completed.

Basic lockout procedure

Locking out

1. Control room operator will log the time, date, level and person responsible for the lockout.
2. Control room operator will lockout the pump on the REMS system:
   a. Double click on pump that needs to be locked out.
   b. Select the **Lock Pump** option.



Leave pump locked out until underground pump operator informs that maintenance is completed.

3. Control room operator will try to start the locked out pump to make sure the pump does not start. When start-up fails proceed to next step.
4. Control room operator will communicate underground that the pump has been locked out.
5. Person performing maintenance will switch PLC from AUTO to HAND.
6. Person performing maintenance will lockout the pump according to the lockout procedure.
7. Person performing maintenance will then communicate to the surface control room operator that the pump has been locked out underground.
8. Control room operator will retest the starting of the pump to make sure the pump cannot start.
9. Control room operator will verify that all the steps have been followed and the pump is locked out and cannot start.
10. Person performing maintenance can proceed to do maintenance.

Starting up

1. After maintenance the person performing maintenance will disengage the lockout on the pump.
2. While the pump is still in HAND mode the person performing maintenance will start the pump on the PLC to make sure everything is in order.
3. Person performing maintenance will communicate to surface that the maintenance has been completed and the lockout is removed.
4. Control room operator will remove the lockout from the REMS system.
5. All parties can now proceed with normal pump.

APPENDIX B – RISK ASSESSMENT

Table 26: Risk assessment table

IDENTIFICATION OF HAZARDS				EVALUATION OF RISKS			CONTROLLING MECHANISMS			
NO	ASPECTS / STAGES	HAZARDS	RISK	SEVERITY=S	LIKELIHOOD/FREQ=P	RISK=SXP	EXISTING CONTROLS	RECOMMENDED CONTROLS	RESPONSIBLE DEPARTMENT	DATE OF COMPLETION
1	SCADA/REMS	SCADA to REMS communication fail	REMS sends start command to SCADA and fails to send stop signal due to communication failure	3	3	9	Manual alarming of pump operators, SCADA control will detect REMS communication failure and control room operator will send stop/start pump command when minimum/maximum dam levels are reached	Ensure that operators understand the meaning of the alarm and do manual control if needed	Technical	Done
		Control room power failure	SCADA and REMS have no control	3	2	6	UPS backup power	Control room operator communicates with pump attendant that manual control should be enabled. Communication alarm should be activated	Technical	Done
		SCADA failure	REMS will still schedule the number of pumps running at moment of failure	3	3	9	REMS will detect the SCADA communication failure and will send a SMS to the needed mine personnel - REMS should be switched to manual control	Control room operator communicates with pump attendant that manual control should be enabled. Communication alarm should be activated. Independent dam level alarm must be activated when critical dam levels are reached.	Technical	Done
2	ESKOM power failure	Power failure underground	SCADA values of dam levels is not received - Pumps cannot be started	3	2	6	REMS will detect the communication failure and will send a SMS to the needed mine personnel - REMS should be switched to manual control	Pump attendant should communicate the situation. Separate alarm system should indicate power loss	Mechanical	Done
		Total power failure at surface	Communication is down with REMS and SCADA not responding	3	1	3	Control room operator informs pump chambers to continue with manual control	Ensure that operators understand alarm meaning and do manual control. REMS must start-up in manual	Mechanical	Done
3	Pumps & control strategy	Incorrect dam levels received from SCADA	Pump stopped unnecessary	3	3	9	None	Pump attendant should have the ability to stop the control, REMS should be put on manual and control must proceed manually	Technical / Mechanical	Done
			Pump started unnecessary/ pump sucking mud	3	3	9	Minimum dam levels indicated to prevent mud in pumps	Install additional monitoring equipment and independent alarm	Technical /Mechanical	Done
		Multiple pumps start instantaneously	Power failure	3	1	3	Control room operator prevent multiple pumps from starting instantaneously	REMS will have a 5 second delay between the starting of pumps	Technical	Done
		First two pump on a level starts in the same column	Unnecessary stress in pipes and loss of efficiency	2	1	2	Control room operator start the first two pumps in different columns	Pumps will be prioritised to start pumps in different columns	Technical	Done
		More than two pumps start on a column	Column stress can cause a column burst	5	1	5	REMS internal tags prevent more than two pumps from starting on a column when in auto mode	Pump attendant should be informed of which pumps run on each of the columns	Mechanical	Done

IDENTIFICATION OF HAZARDS				EVALUATION OF RISKS			CONTROLLING MECHANISMS			
NO	ASPECTS / STAGES	HAZARDS	RISK	SEVERITY=S	LIKELIHOOD/FREQ=P	RISK=SXP	EXISTING CONTROLS	RECOMMENDED CONTROLS	RESPONSIBLE DEPARTMENT	DATE OF COMPLETION
4	REMS	REMS stops functioning	Pumps cannot be started automatically	3	3	**9**	SMS will be sent saying that maximum or minimum dam level has been reached. A watchdog/second tag is implemented to enable the REMS to recognise when the communication to the SCADA is lost. A pop-up alarm will indicate the communication is down.	Alarm system should indicate that pump attendant should start or stop pump. Operator must restart REMS which will then take back control	Technical	Done
		REMS left on manual control	No automatic control or monitoring of dam levels	3	3	**9**	SMS will be sent saying that maximum or minimum dam level has been reached	Inform HVACI team of problem with pump attendant manually controlling pumps	Technical	Done
5	PLC failure	SCADA does not receive correct values	Pump not started or stopped correctly	3	3	**9**	None	On screen REMS alarm will indicate communication failure. Control room operator communicates with pump attendant that manual control should be enabled.	Technical	Done
6	Network communications goes down/Fibre optic cable broken	SCADA does not receive correct values	Pump not started or stopped correctly	3	3	**8**	None	An on-screen dam level watchdog REMS alarm will indicate communication has been lost. Control room operator communicates with pump attendant that manual control should be enabled.	Technical	Done
7	Highest dam level exceeded or lowest dam level reached	Pumps not started at correct level and time in Eskom peak period	Dam levels will reach critical levels that could lead to floods	4	3	**12**	REMS will send SMS alarm to the needed mine personnel for certain levels and second SMS if critical levels are reached	Control room operator and SCADA should communicate to pump attendant that there is a problem. Independent alarm system should also indicate critical dam levels	Technical	Done
8	Maintenance on pumps	Pumps started while maintenance is being done	Injury due to starting from surface while working on pump	5	2	**10**	A lockout procedure is implemented (Procedure 3.3.8.4.). The pump needs to be locked out before maintenance is done	Pump attendant should communicate to the control room operator that there is a problem with the pump and that maintenance will be done.	Technical /Mechanical	Done