Article:

Reducing the electricity cost of a Three-Pipe Water Pumping System – a case study using software.

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Abstract

Efficient control is often the most cost-effective option to improve on the running cost of a Three-Pipe Water Pumping System. However, the effect of changing the control strategy (i.e. on energy consumption) is usually difficult to predict. To obtain this information more easily, a new simulation tool, QUICKcontrol, was developed. This new tool was used to investigate the energy cost savings potential in a Three-Pipe Water Pumping System. The influence of pump scheduling, dam level set points, control parameters and different combinations thereof was investigated. The simulation models were firstly verified with measurements obtained from the existing system to confirm their accuracy for realistic control retrofit simulations. With the aid of the integrated simulation tool it was possible to predict savings of R 195'000 per year with an average 3.8 MW of load shifted.

Keywords: Energy simulation; Simulation software; Energy cost saving; Electrical Load Shifting;

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1 INTRODUCTION

The operation costs of a deep mine could be improved if the water pumping systems of the mine is made more energy cost efficient [1].

However, it is very important that this system enhancement does not compromise the safety and control specifications set in the mining industry [2] [3]. Secondly, it should not impair, nor have a detrimental effect upon, the performance capabilities of the pumping system.

The reason for this is that the capability of the pumping system has a direct effect on the productivity of the mine. A cost penalty is experienced if the pumping system cannot perform to its full capabilities [4]. Studies, done by Lane [5], have shown that energy cost savings of around 8 % can be achieved through retrofit options in existing mines.

The mining industry consumes approximately 23 % off all electrical power generated in South Africa [6]. Up to 11 % of the electricity cost on a mine can go to the pumping of water. This shows the large potential that lies in the improvement of the electricity cost effectiveness of a pumping system on a mine.

A cost-effective way to improve the energy efficiency of a pumping system, without compromising its performance capabilities, is by implementing better control [3]. A study was done on the Tshepong mine to increase its energy efficiency, by optimising the pumping system control, and in particular, the control of the pumps itself.

To make predictions of what can be realised through this type of control, a simulation tool, which can efficiently and accurately simulate the mine with its pumping system and controls in an integrated fashion, is required. Studies done by Scott [7] and Althof [8] have shown how the running cost of mining systems can be reduced with the use of computer simulation.

Many system simulation programs are currently available. However, they do not satisfy the need of the typical consulting engineer for integrated, efficient and accurate simulation [9] [10] [11]. The simulation tool QUICKcontrol, was found to be the only software program available that could perform the required simulations.

The model on which the simulation tool is based is briefly discussed in the section three. The program has been verified in over 100 case studies. This illustrates the value, and verifies the capability, of this simulation tool. The potential for energy savings and the enhancement of energy cost effectiveness by implementing new control strategies in the mine, were successfully investigated.

In summary, the problem statement is to *reduce the cost of electricity of a Three-Pipe Water Pumping System, with the use a software application.*

2 THREE CHAMBER PIPE FEEDER SYSTEM

A Three Chamber Pipe Feeder System (3CPFS) is widely used in the mining industry to circulate water from the mine surface (ground-level) to designated points inside the mine itself. The water is mostly used for the cooling of air. The water is cooled on the surface and then channelled down into the mine. After use, the water has to be pumped out of the mine again.

This system is so popular because it uses little electrical energy to achieve this cycling [12]. In principle, a 3CPFS extract potential energy from water going down into the mine and uses this energy to pump used water out of the mine.

This case study was done on a Three-Pipe Water Pumping Systems as explained in section 6 . One of the components of this Three-Pipe Water Pumping Systems system is a 3CPFS. A mathematical model was build to simulate this 3CPFS.

The mathematical model for the 3CPFS was built to simulate its overall working. It was not the focus of this study to go into an in-depth investigation of the valves and flow dynamics that govern the working of a 3CPFS. This was therefore not coded into the mathematical model.

The broad working of the 3CPFS and the effect of its operation on the Three-Pipe Water System has been the focus of the study. This was what governed the development of the mathematical model that represented the 3CPFS.

An explanation on how a 3CPFS works is given with the aid of Figure 2-1 and Figure 2-2.

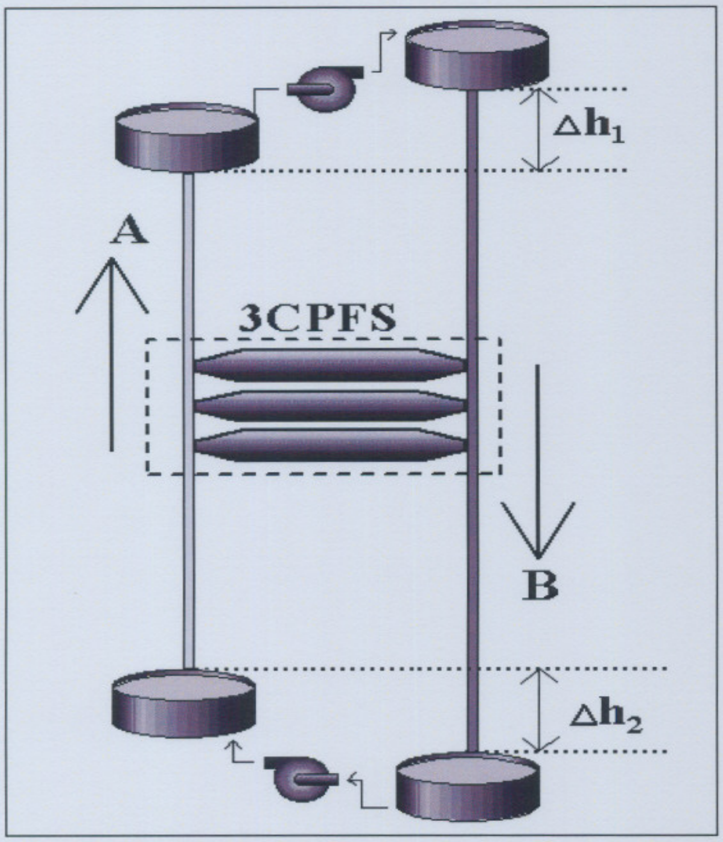

Figure 2-1 Energy principle of 3CPFS

Figure 2-1 and Figure 2-2 is a schematic representation of a 3CPFS installed in a typical mine situation. Column B is cold water being channelled down into the mine where it is will be used for cooling, drilling, etc.

Column A is hot, used water being pumped out of the mine where it will be cleaned and re-cooled. The 3CPFS uses potential energy derived from the water in column B to pump the water in column A. This energy, in reality, is obtained from Δh_1 and Δh_2. These two height differences are necessary for the 3CPFS to work. Energy is needed to produce these height differences, and it is this energy that powers the 3CPFS.

The energy that is necessary to produce Δh_1 and Δh_2 can be described by

$$E_p = mgh \qquad (1)$$

where : E_p – potential energy,

m – mass,

g – gravitational constant,

h – height.

In a typical mine set up Δh_1 is created by pumping the water that is to be channelled down into the mine, into a reservoir several meters above the ground. The water coming out of the mine goes into a dam built on ground level. Δh_2 is obtained by letting the water in column B flow to the bottom of the mine. The dam out of which water is pumped is shallower than this.

The 3CPFS can be seen as a closed energy system. The energy going into the system is obtained through Δh_1 and Δh_2 as explained above. The energy is consumed inside the system by overcoming the flow losses and kinetic and potential energy that end up in the water it self.

This is described by the equation

$$E_{in} = E_{out} \tag{2}$$

where : E_{in} – energy going into the system,

E_{out} – energy going out of the system.

The energy going into the systems in obtained through Δh_1 and $\Delta h_{2.}$ The energy going out or being consumed by the system is because of flow losses and kinetic energy that ends up in the water.

Equation (2) can therefore be expanded to

$$mg(\Delta h_1 + \Delta h_2) = E_{hf} + E_k \qquad (3)$$

where : E_{hf} – head/flow loss as result of flow,

E_k – kinetic energy that ends up in the water.

The kinetic energy in the water can be described by

$$E_k = \frac{1}{2}mv^2 \qquad (4)$$

where : m – mass,

v – speed.

The head loss is as result of friction during flow. The head loss in the piping and in and around the valves, elbows, links, etc. is calculated using the Hazen-Williams head loss equations [13].

$$h_f = SL \qquad (5)$$

where : h_f – head loss,

L – length,

S - head loss / length of pipe.

S is calculated

$$S = \left(\frac{v}{kCR_h^{0.63}}\right)^{\frac{1}{0.54}} \qquad (6)$$

where : k = Minor loss coefficient,

C = table of Hazen-Williams coefficients,

R_h = hydraulic radius.

R_h is specific to the shape of the pipe. R_h for circular piping can be calculated as

$$R_h = \frac{D}{4} \qquad (7)$$

where : D – inside diameter of the piping.

The value for k can be obtained from the Minor loss coefficient table [14] shown in Table 2-1.

Fitting	K	Fitting	K
Valves:		*Elbows:*	
Globe, fully open	10	Regular 90°, flanged	0.3
Angle, fully open	2	Regular 90°, threaded	1.5
Gate, fully open	0.15	Long radius 90°, flanged	0.2
Gate 1/4 closed	0.26	Long radius 90°, threaded	0.7
Gate, 1/2 closed	2.1	Long radius 45°, threaded	0.2
Gate, 3/4 closed	17	Regular 45°, threaded	0.4
Swing check, forward flow	2		
Swing check, backward flow	infinity	*Tees:*	
		Line flow, flanged	0.2
180° return bends:		Line flow, threaded	0.9
Flanged	0.2	Branch flow, flanged	1.0
Threaded	1.5	Branch flow, threaded	2.0

Table 2-1 Table of Minor Loss Coefficients (K has no units) [14]

The value for C can be obtained from the Hazen-Williams coefficient table [15] shown in Table 2-2.

Material	C	Material	C
Asbestos Cement	140	Copper	130-140
Brass	130-140	Galvanized iron	120
Brick sewer	100	Glass	140
Cast-Iron:		Lead	130-140
New, unlined	130	Plastic	140-150
10 yr. old	107-113	*Steel:*	
20 yr. old	89-100	Coal-tar enamel lined	145-150
30 yr. old	75-90	New unlined	140-150
40 yr. old	64-83	Riveted	110
Concrete/Concrete-lined:			
Steel forms	140	Tin	130
Wooden forms	120	Vitrif. clay (good condition)	110-140
Centrifugally spun	135	Wood stave (avg. condition)	120

Table 2-2 Hazen-Williams coefficient table [15]

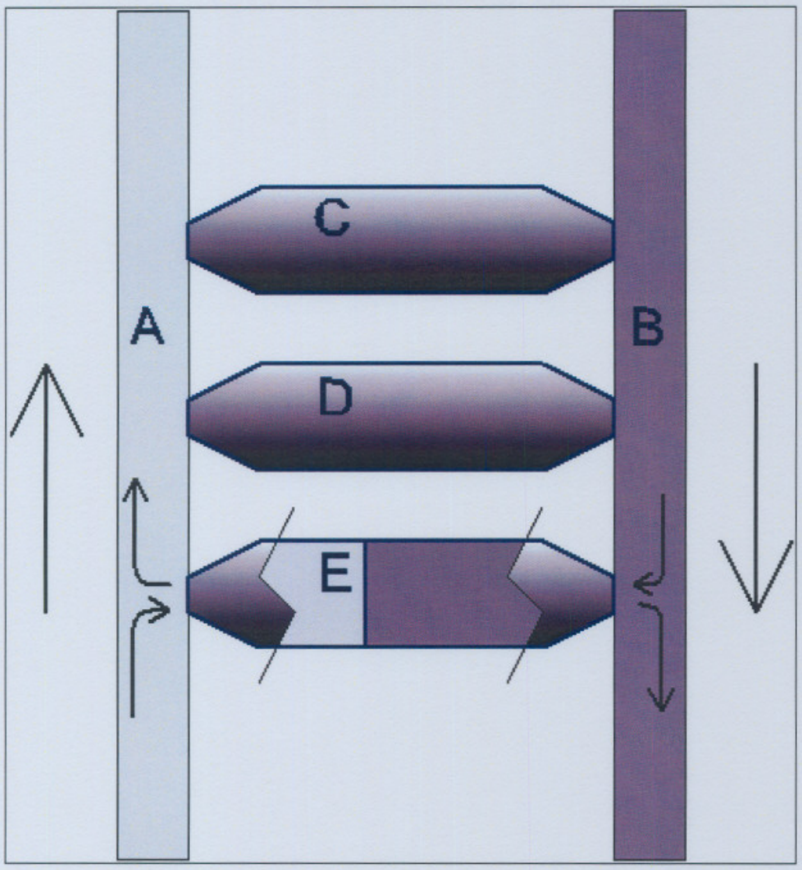

Figure 2-2 Schematic representation of 3CPFS

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

Look at the chamber marked E into which a section cut is made. The cycle that each chamber goes through is as follows. Let's say the chamber is filled with used hot water. The first stage of the cycle will be where valves open in such a way that cold un-used water can flow, because of Δh_1, out of column B into this chamber. This cold un-used water will then push the hot used water up into column A.

The chamber is now filled with cold water. The second stage will be where certain valves open in such way that this cold water is pulled, due to Δh_2, further down into column B. This will result is used hot water to be sucked out of column A into the chamber. After this phase the chamber is again filled with used hot water and the cycle is completed, ready to start over again.

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

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

3 SIMULATION MODEL

Mathematical equations are used to model the Three-Pipe Water Pumping System of the mine as accurate as possible. The component models link inputs to the basic variables in the system. These are based on the simplified fundamental principles combined with correlation coefficients derived from discrete empirical data [9].

The models are fully component-based and allow simulation of a wide range of operating conditions. The calculation of the energy consumption of each component is included in each model. The correlation coefficients for a specific make and model of equipment can be derived from data obtained during measurements or manufacturer's data sheets.

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

$$\tau \frac{d\varphi}{dt} = Function$$

(model input parameters), with τ the time constant of the model and φ one of the output parameters of the model [16] [17] [18]. The relevant relationships are employed in all models dealing with the pumping system.

At present, the simulation model makes provision for proportional, integral, derivative, on/off and step controllers. These controllers are used in many control applications. With these controllers any measurable condition can be controlled from a sensor. Water flow rates, dam levels and electricity consumption of the system are controllable variables.

Controller output at each step is only dependent on the previous step values [19]. This considerably reduces the complexity of the solution algorithm. From a system point of view, this implies that the controller acts like a controller that has a sampling rate corresponding to the system integration time step size.

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

The simulation model is build up out of modular mathematical models [20]. Each model represents a different component of the Three-Pipe Water Pumping system. These models are developed with the goal of portraying the effect what this specific component will have on the systems as a whole. It is not the goal of this study to simulate the intricate workings of the different components and this was therefore not coded into these models.

Each mathematical model was developed with a standard interface [21]. This was done to enable the models to exchange data based on a set standard. The data that is conveyed between these models include flows, temperatures, statuses, etc.

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

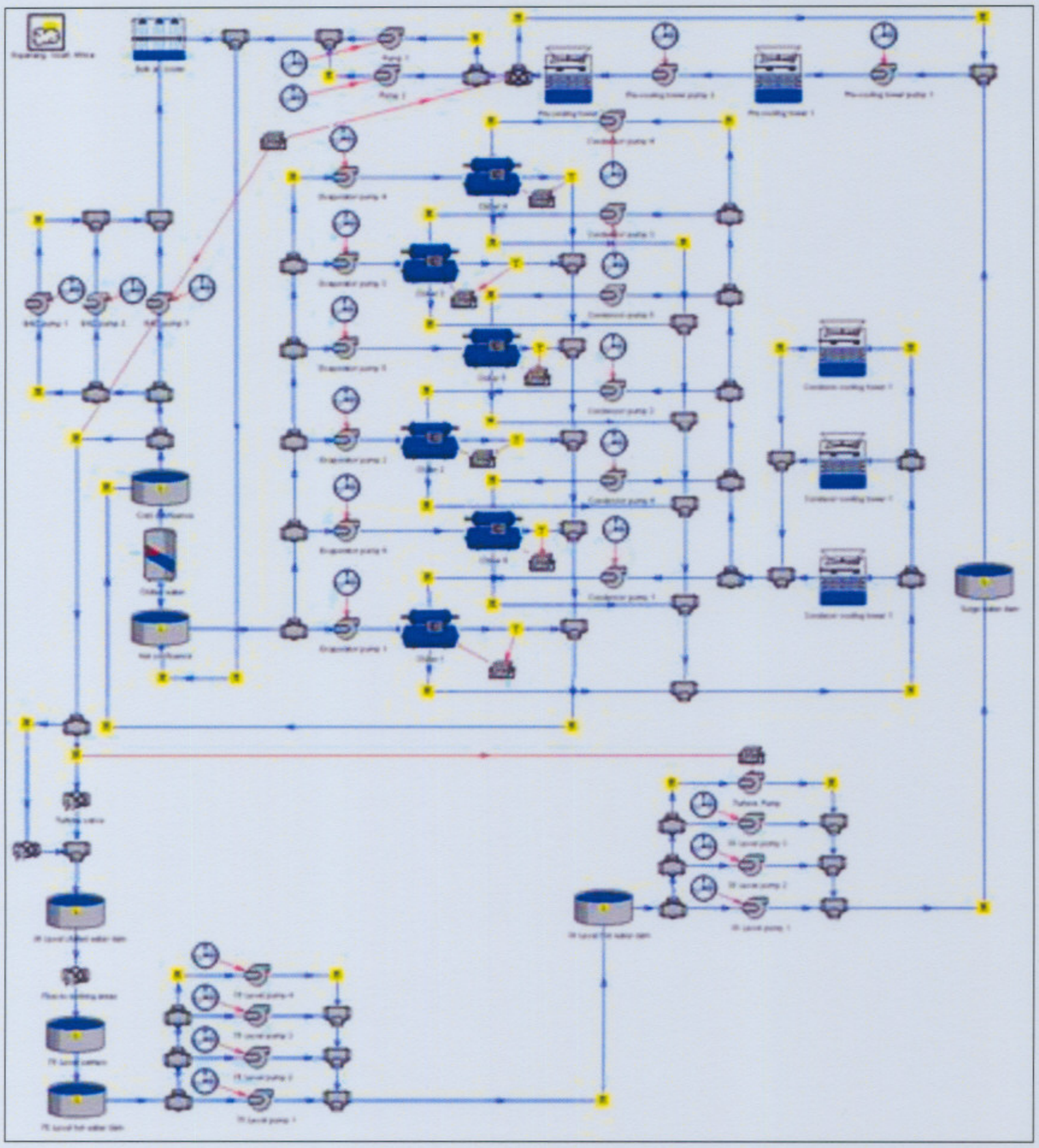

Figure 3-1 An example of a clear water system layout of a simple mine

Figure 3-1 shows a water cycle of a mine, as it is build up in the simulation software package. This figure gives the visual representation of water and information flow. The information or data is carried by the platform to and from the relevant mathematical model.

Building a simulation of a specific system enables us to test any control system that is developed for that specific system. The true value of this lies in the fact that when the control system that is tested fails, the results thereof exist only in the simulated world. This concept was fully utilised in this particular case study.

Simulations can also be used to predict the future status of a system. A simulation that is built to simulate a system can start with the real-world system status as start values. The simulation can then be run at faster-than-real-time to reach a simulated system condition or status of the system. This principle was also used in this study.

As this simulation model is to be used in a control system, it must be designed to be unconditionally stable. The control system is to be used on a mine and a financial loss is felt if the control system fails. A simulation model that, under certain conditions and input values, does not reach an answer, will therefore not work for this application.

This implies that the mathematical models that are used to create the individual components must be explicit [22]. An implicit equation does not always yield an answer or can yield more than one answer [23]. This is not acceptable, as this will cause the simulation model to be unstable.

The mathematical models was therefore created [24] in such a way that a solution is always reached [23]. All recursive and loop functions are created in such a way so that it stops after a number of cycles are completed. This can lead to a certain amount of inaccuracy, but the error made is small compared to the duration the simulation is run for. This will become evident in section 7 where the verification of the simulation model is discussed.

4 OPTIMISATION

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

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

The optimisation philosophy is based on a feedback principle [25]. The effect of every action is tested in a feedback loop. Repeating this loop results in every conceivable action being tested. The best, or optimised, actions are found by selecting the actions that result in the best outcome.

The optimisation process is not at fixed cycle, but a generic, dynamic procedure [26]. The procedure is developed in such a way that it can, on its own accord skip, re-run or back-run any of the steps in the optimisation procedure. This dynamic process adapts itself to the problem and gives a more reliable and faster way to reach an answer.

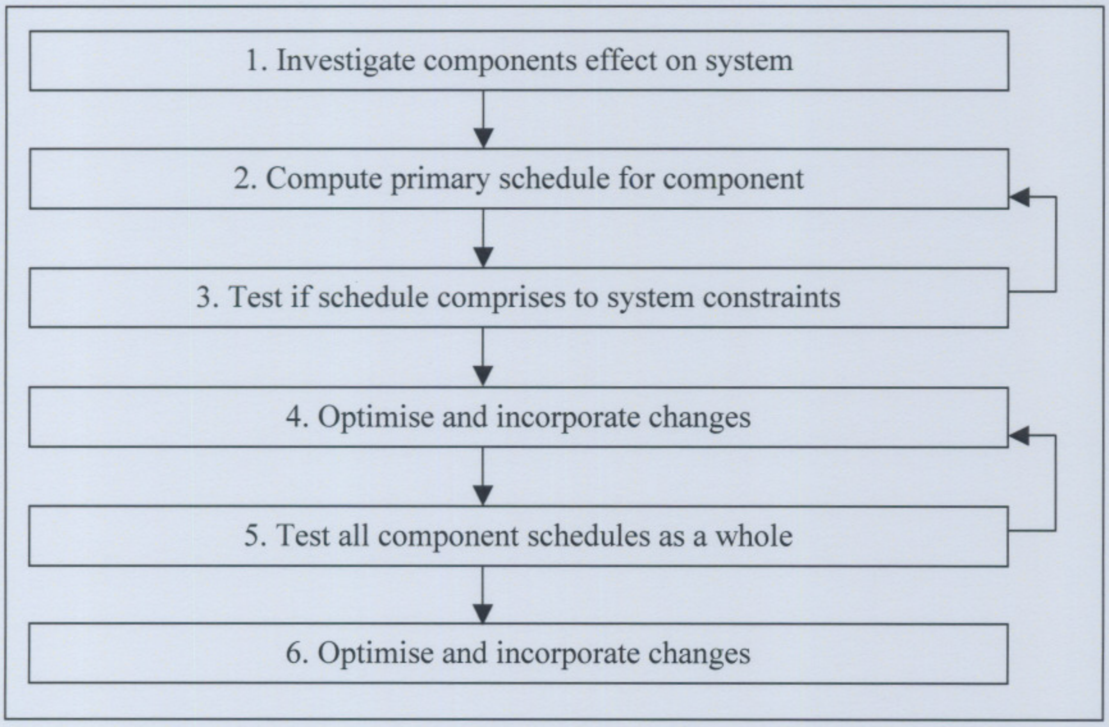

Figure 4-1 Optimisation cycle

Figure 4-1 shows the optimisation cycle that is used for the component scheduling and control. During steps one, two and three the components and their operation schedules are handled individually. The system and the complete operation schedule are handled as a whole in steps four to six.

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

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

An ideal future for the system is where the electricity cost is the lowest. This is calculated by finding the electricity usage by running a simulation of system. The cost is then calculated by multiplying the electricity usage with the electricity pricing profile.

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

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

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

During this step, the optimiser will, as far as possible, schedule as much of the workload to the 3CPFS. As the 3CPFS does not use any electricity, this will cause a reduction in electricity usage. This is an important step as this is one of the objectives of this type of optimised control.

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

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

5 PRINCIPLES THAT MAKE SAVINGS POSSIBLE.

The two principles that allow the mine to realise savings are 1) Load Shifting and 2) Variable Electricity Pricing [27] [28]. The proposed software system that will control the Three-Pipe Water Pumping System must be able to utilise these two principles before any savings can be realised. These two principles were born because there is an uneven total electricity demand from Eskom's clients.

Eskom's total electricity demand describes the total quantity of electricity that is used from their grid by their clients. This includes Eskom's clients in the industrial and commercial sector. Eskom found that this total demand follows certain trend that is consistent to a certain extent [29].

This trend is firstly influenced by the time of day. There are two main peaks during a normal day. The first is in the morning between 7:00 and 10:00 am. The second is in the afternoon between 6:00 pm and 8:00 pm. This can clearly be seen in Figure 5-1 that shows this total electricity demand.

The trend is also influenced by the season of the year. Firstly, the total electricity demand rises in the winter due to additional heating that is required. This can be seen especially in the commercial sector. Secondly, the difference between the maximum peak demand and the average demand is higher in the winder than in the summer.

The trend is thirdly influenced by the type of day. This can be a weekday, Saturday, Sunday or public holiday. The two peaks found every day, as mentions above are more prominent on weekdays than on Saturdays, Sundays and public holidays.
Figure 5-1 shows how this trend goes.

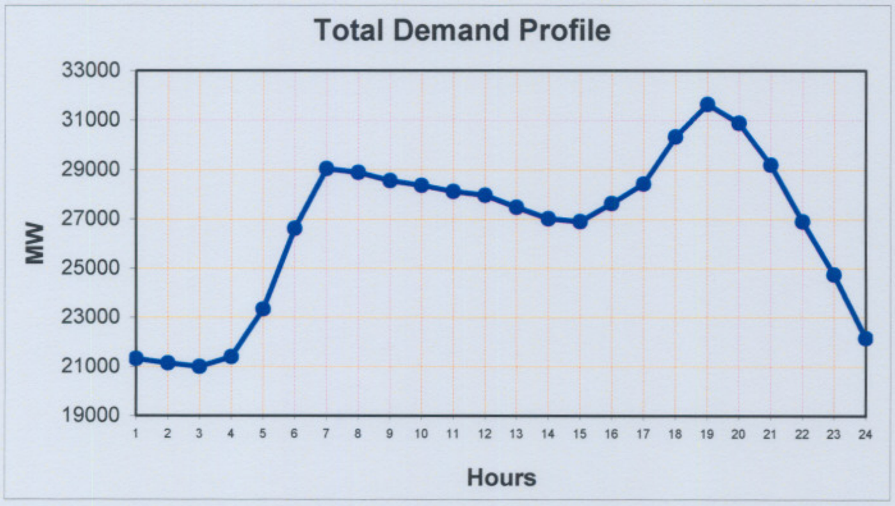

Figure 5-1 Total demand profile (2000) [29]

This fluctuation in the total demand poses problems to Eskom. Eskom answers the base electricity demand with electricity generated with base stations. During the peak periods, the peak stations generate additional electricity. An example of such a station it the Drakensberg Pumped Storage Scheme. The running and management of these peak demand stations is more expensive to Eskom that the base stations.

Eskom will be forced to build additional power plants if the maximum electricity demand exceeds a certain point. If this persists, Eskom will be forced to build an additional power plant. Eskom plans to postpone this as far as possible because the building of a power plant will require capital inset of about R8M to R10M per MW of installed capacity.

To achieve a more even total demand profile Eskom launched Demand Side Management (DSM). DSM's focus includes ways to motivate electricity users to use electricity is such a way that it will result in a more even total demand profile.

DSM introduced the load shifting concept to achieve a more even demand profile. To shift load, in principle, means to schedule electricity-consuming action out of peak demand periods into low demand periods. Thus, to shift load does not mean using less electricity, but to use electricity during certain periods.

Eskom compensates up to R 2 million per MW load that is shifted on a project. This is subjected to the project running for a minimum of 5 years. The load should be shifted for this whole period.

This compensation is relevant to this case study, because the control that is done via the simulation is set up to shift load. Therefore, part of the savings that is realised because of the control is because of load shifting compensation.

To enforce this load shift principle, Eskom introduced variable electricity pricing. Variable electricity dictates a different c/kWh tariff for every hour of the day. Eskom has implemented a whole range of different variable pricing structures that is applied to different sectors.

The complete working and conditions as per supplier of Eskom's MegaFlex billing system can be seen as reference [29]. Following is a short summary of how the MegaFlex billing system works. MegaFlex is summarised by the following table.

Defined Time Periods:	Weekday	Saturday	Sunday
Peak	07:00 - 10:00 18:00 - 20:00	N/A	N/A
Standard	06:00 - 07:00 10:00 - 18:00 20:00 - 22:00	07:00 - 12:00 18:00 - 20:00	N/A
OffPeak	22:00 - 06:00	12:00 - 18:00 20:00 - 07:00	Whole day

Figure 5-2 MegaFlex demand periods

The MegaFlex system divides the time of the week into 3 periods. These are Peak, Standard and Off-Peak times. Electricity is then priced according to these periods where in peak time electricity is most expensive and in off-peak periods the cheapest.

MegaFlex also differentiates between demand seasons and they are High-demand season, which is June to August and Low-demand season, which is September to May. Figure 5-3 show the tariffs for the corresponding demand seasons and periods.

High-demand season (June - August)		Low-demand season (September - May)
50.44c + VAT = 57.50c/kWh	Peak	15.45c + VAT = 17.61c/kWh
14.56c + VAT = 16.59c/kWh	Standard	10.23c + VAT = 11.66c/kWh
8.63c + VAT = 9.84c/kWh	Off-peak	7.72c + VAT = 8.80c/kWh

Figure 5-3 MegaFlex tariffs

The MegaFlex electricity billing structure is relevant to this case study, because the site where the case study was conducted is billed according to MegaFlex. Part of the savings that is realised in this case study is because the control is optimised in term of the MegaFlex billing structure. This is fully explained in section 9.1.

6 TSHEPONG – CASE STUDY

The Three-Pipe Water Pumping System upon which this case study was conducted is situated at the Harmony mine Tshepong near Welkom in South Africa. The case study was conducted during August and September 2004.

The Three-Pipe Water Pumping System is responsible for delivering all the used water in the mine to the surface. This water is then cooled and again channelled down into the mine where it is used to cool air, prevent dust etc. From there it is collected and again fed into the Hot Water Pumping System, thus, completing the water cycle. See Figure 6-1.

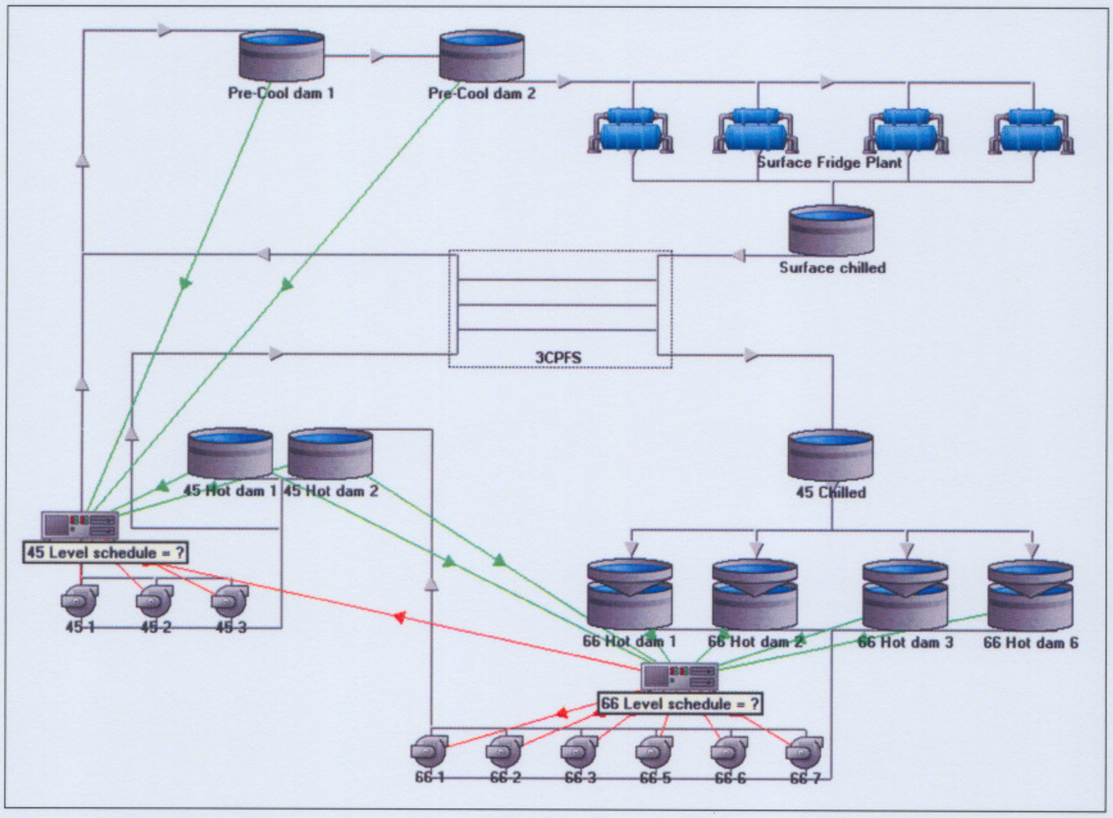

Figure 6-1 Tshepong water cycle

The Three-Pipe Water Pumping System starts with the dams '66 Hot dam 1' to '66 Hot dam 6'. All the used water in the mine is channelled to these dams where it is to be delivered to the surface for re-cooling and cleaning. The pumps labelled '66-1' to '66-7' pump the water out of these dams to the next two dams in the system labelled '45 Hot dam 1' and '45 Hot dam 2'.

From there the water is pumped via the pumps '45-1' to '45-3' and the 3CPFS labelled '3CPFS' to a dam on the surface labelled 'Pre-Cool dam 1'. This is where the Three-Pipe Water Pumping System ends. From these the water is re-cooled, cleaned and channelled down the mine again.

This entire system is situated under ground. The dams '66 Hot dam 1' to '66 Hot dam 6' are set on 66-level, a level 6600 feet under ground. Dams '45 Hot dam 1' and '45 Hot dam 2' are situated on 44-level, 4400 ft under ground.

The Three-Pipe Water Pumping System is responsible for delivering 30240 m^3 water out of the mine every day. The pumps on 66-level, which are pumps '66-1' to '66-7', are 1500 kW pumps each, capable of delivering 120 l/sec each. The pumps on 45 level, which are pumps '45-1', '45-2', and '45-3' are 2500 kW pumps each, capable of delivering 120 l/sec each.

7 VERIFICATION OF THE TSHEPONG SIMULATION

The Three-Pipe Water Pumping System was build up in the simulation platform. The system was exactly duplicated, and mathematical pump models were used to represent real pumps and so on. This complete simulation is from here on called the *Tshepong simulation*. Figure 7-1 shows a simplified schematic representation of the Tshepong Three-Pipe Water Pumping System that was simulated.

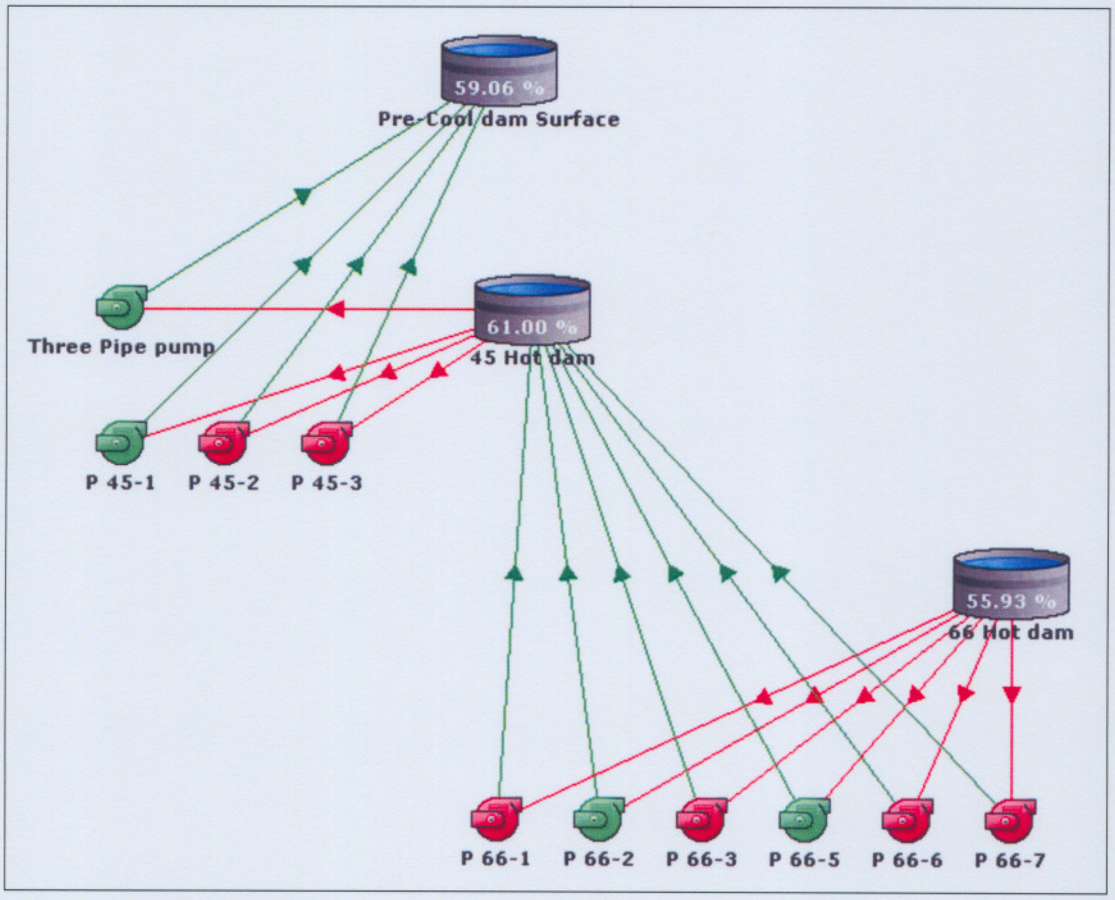

Figure 7-1 Simplified representation of the Tshepong Three-Pipe Water Pumping System

The Tshepong simulation was verified by running it in conjunction with the real-world hot water pumping system. To do the verification, the simulation was started with the real-world systems status as start values. This includes dam water levels and pump statuses. The outcome of the simulation was then compared to the conditions in the real-world system.

The controllable components of the system are the pumps. Because of this, the pumps in the simulation were controlled in the same way as the pumps in the real world system. In other words, every time a pump was started in the real-word system, the representative pump in the simulation was also started and also the other way around.

The accuracy of simulation was then measured by comparing the real-world dam levels with the simulated dam levels. The simulation was run for a couple of days where the simulation status was synchronised with the real-word status at the beginning of each day.

Figure 7-2 and Figure 7-3 show the real-world and simulated dam levels of two different dams in the same simulation. Both these figures give results for a 24-hour period. The simulation status was synchronised with the real-world status at the start of each day.

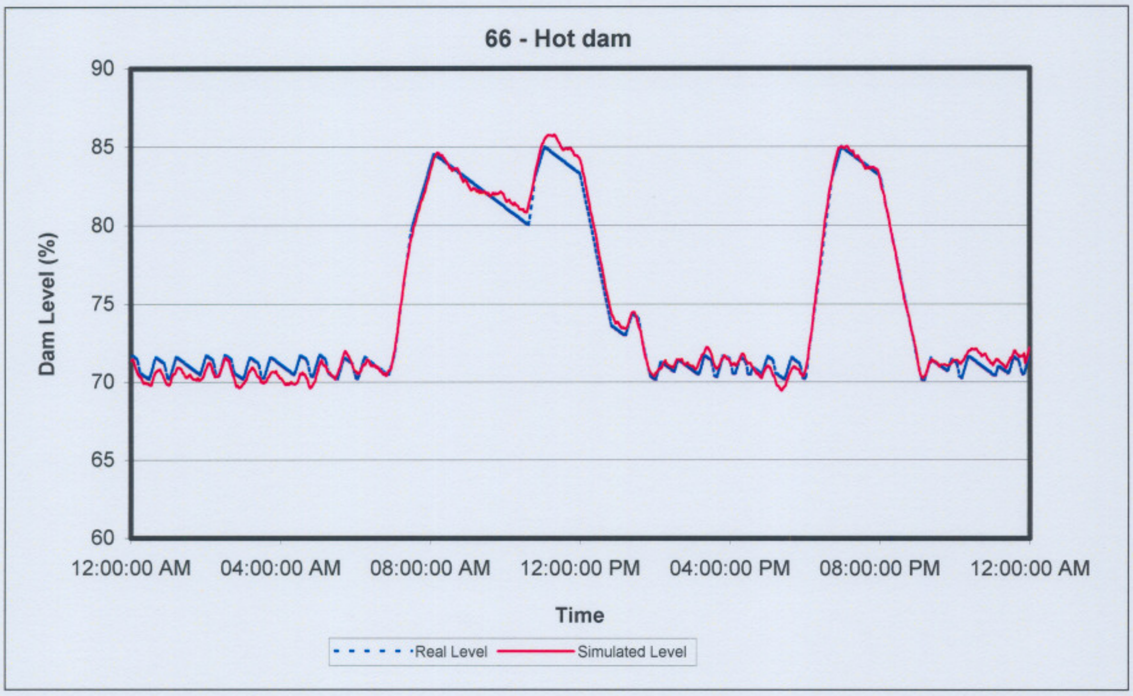

Figure 7-2 Measured and simulated dam levels - 66 Hot dam

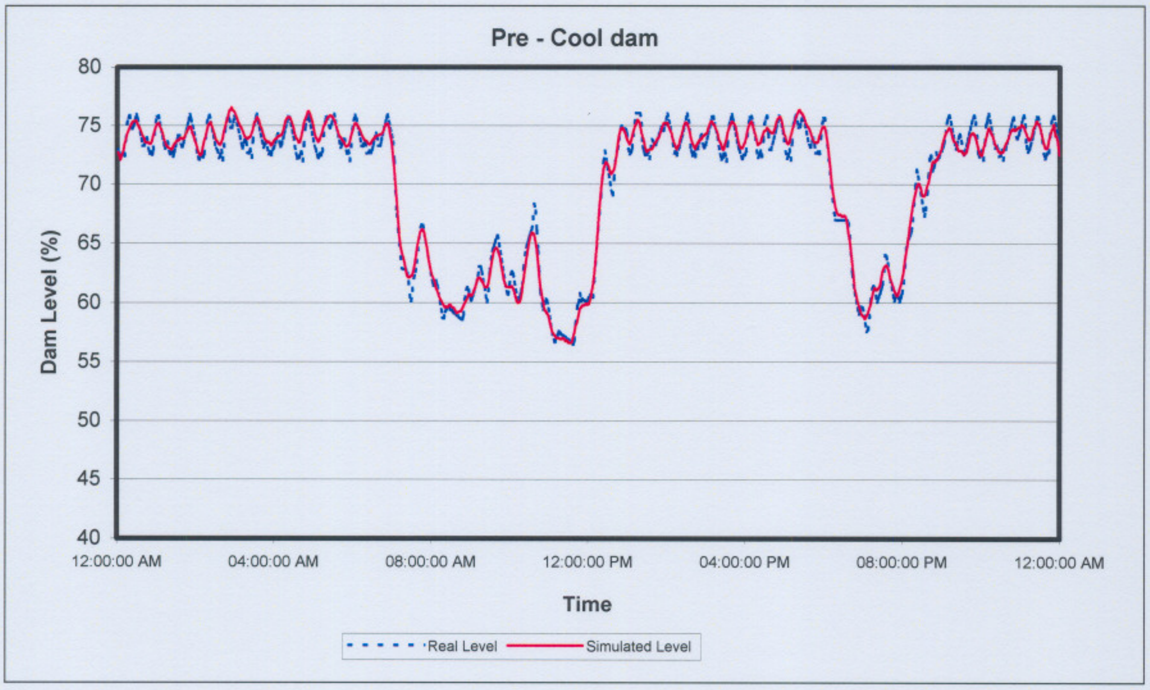

Figure 7-3 Measured and simulated dam levels - Pre-Cool dam

On average, a less that 3,5 % deviation accumulated in a 24-hour time period. This gives an indication of the accuracy of the *Tshepong simulation*. This draws the conclusion that the simulation will be adequate to give a 24-hour ahead of time prediction of the Three-Pipe Water Pumping System.

8 BASE LINE

It was necessary to determine the existing electricity usage base line of the pumping system before the control was implemented. Empirical measurements were taken over a period of time to assess if the implementation of the new control system yielded any positive outcome.

An electricity usage base line is a 24-hour profile that describes the electricity usage for the 24 hours of the day. Each value gives the accumulated kW electricity for that specific hour that was consumed by a system.

In this case study there were three different base lines of which the first was **base line A**. This was the base line for the system when the 3CPFS was fully operational on a 24-hour basis. The 3CPFS carried a part of the workload, but without using any electricity.

The second was **base line B**. This was the base line for the system when the 3CPFS was not operational. The electrical pump was therefore solely responsible for carrying the full workload. A total of two pumps in the 45-level pump station must be started to compensate for the workload that the 3CPFS usually carries.

The pumps on 45-level are 2500 kW each. Base line B must therefore be altered with 5000 kW as this is the extra amount of energy needed to compensate for the 3CPFS not working. Figure 8-1 show how base line A and base line B compare to one another.

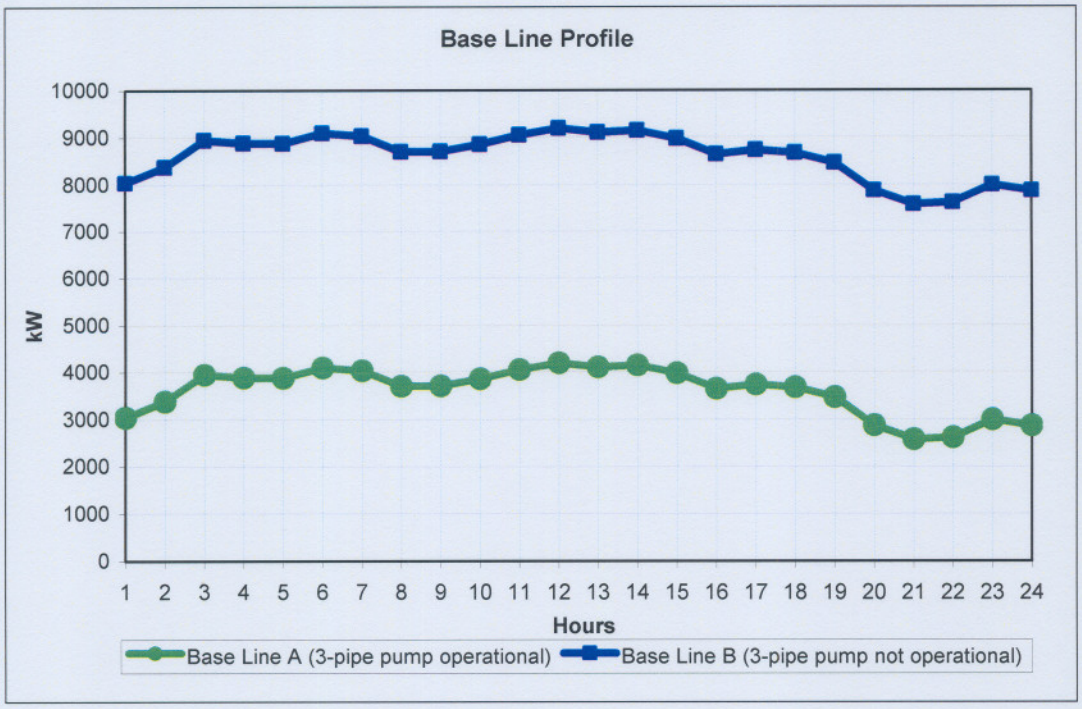

Figure 8-1 Base lines A and B

The third base line was **base line C**. This was a base line for the system when the 3CPFS was operational for only a section or sections of the day. This base line is comprised of sections of base line A and base line B. The sections of this base line where the 3CPFS was working is a copy of base line A and the sections of this base line where the 3CPFS was not operational is a copy of base line B.

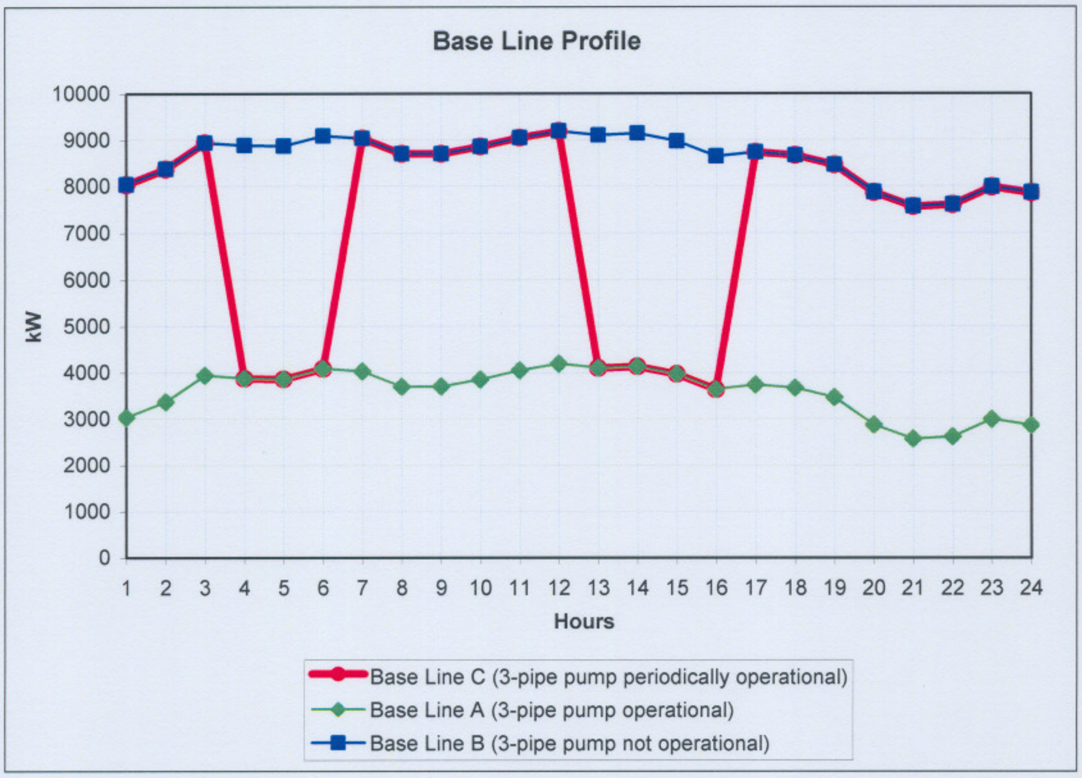

Figure 8-2 Base line A, B and C

Figure 8-2 shows base line A and B and an example of base line C. Base line C will be valid for a day where 3CPFS was not operational for the hours 4:00 am to 6:00 am and 1:00 pm to 4:00 pm.

During the case study base line C was used, as there were a few days during which the 3CPFS was either fully operational or totally out of order. The operation of the 3CPFS was therefore logged to make this calculation of every day's base line possible.

The 3CPFS experiences significant down time as a result of maintenance. This was fully discussed in section 2 . This explains why there are few days on which the three-pipe system is fully operational. This also explains the need to calculate a unique base line for every day.

9 CALCULATING SAVINGS

9.1 Electrical Cost Savings

To calculate the running electricity cost savings that were realised on a specific day as result of the software control, two things are needed. The first is the cost of electricity that would have been consumed as a result of the base line profile for that specific day. This can be obtained by multiplying the base line with the variable electricity tariff. The result of this is a 24-hour cost profile. Adding these 24 values give the total electricity cost for that day.

The second is the electricity cost as a result of the new electricity usage profile for that specific day. This is calculated in the same way as described above, except that the real electricity usage profile is used instead of the base line. The savings realised per day is then calculated by subtracting the electricity cost related to the real electricity profile from the electricity cost related to the base line.

9.2 Electrical Load Shifting

To calculate the load that was shifted for a specific day as result of the software control, the base line and the real electricity usage for that specific day is needed. For the sake of explanation, see Figure 9-1 and discussion.

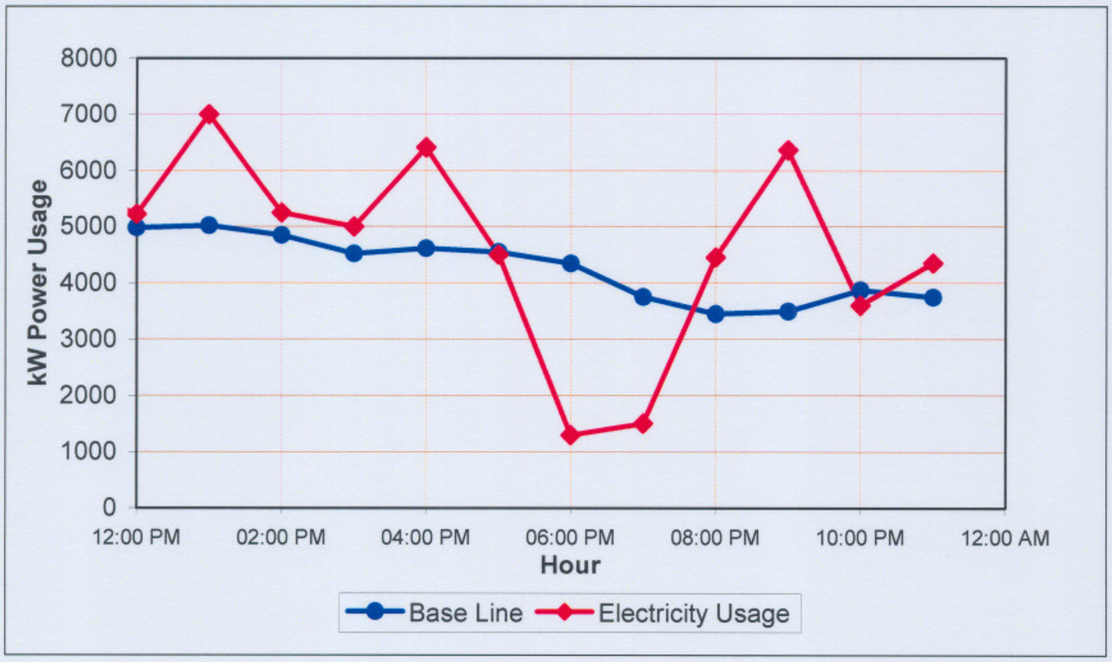

Figure 9-1 Explanation - Load shift

The peak demand period, as dictated by Eskom, is between 6:00 pm and 8:00 pm. This implies that load can only be shifted during this period. Figure 9-1 shows the base line and the real electricity profile for the case study for 5 August.

The 'electricity usage' line gives the accumulated electricity that was used for the relevant hours. The value on this line corresponding to the 6:00 pm mark, is the total electricity used during that hour, which is 6:00 pm to 7:00 pm. Thus, the relevant points on Figure 9-1 are the points corresponding to 6:00 pm and 7:00 pm.

The load that was shifted during a particular hour can be calculated by subtracting the real electricity used from the base line value for that hour. The Load shifted for that day will be the average between this values for the two hours in which load can be shifted.

10 RESULTS

A new electricity usage profile was drawn up during the period when the Three-Pipe Water Pumping System was controlled using the software as described. As with the base line profile, this current usage profile was draw up using empirical measurements.

The following figures show 24-hour periods of data each representing different days in the case study. Each of these will be discussed to give insight on how the control philosophy responded.

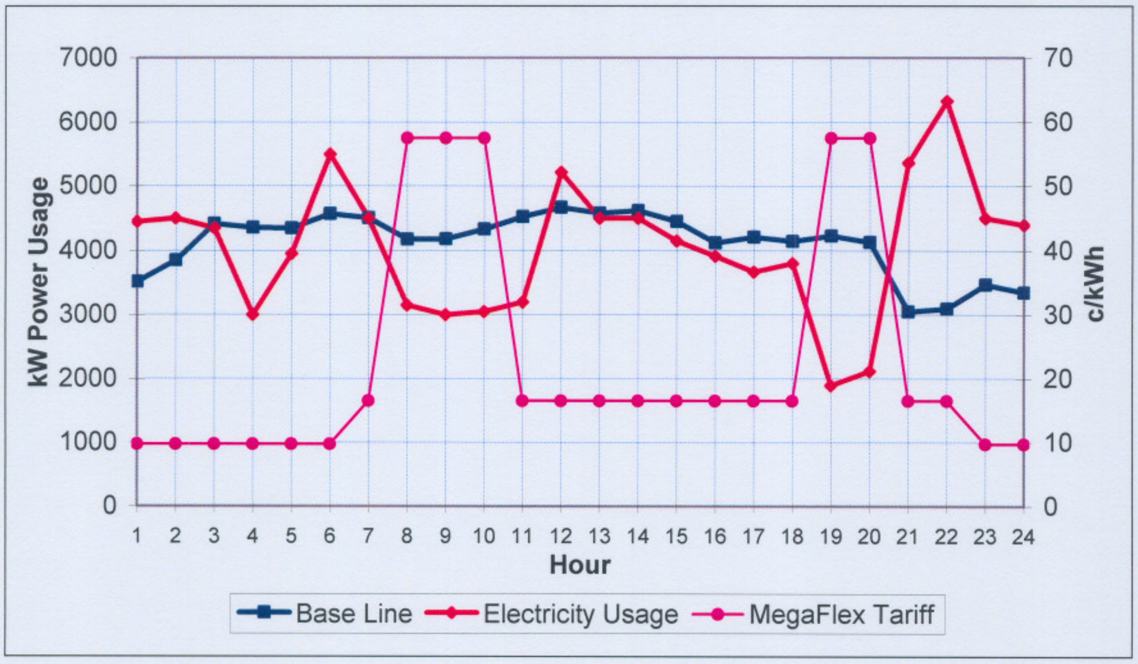

Figure 10-1 Case Study – 2 August

Figure 10-1 shows the real electricity usage profile and the base line for 2 August 2004. Also seen in the figure are the MegaFlex tariffs for that day. 2 August 2004 is a Monday and is falls in the winter month period of the MegaFlex pricing structure.

It can be seen that the electricity usage dropped below the base line during the periods when the electricity tariff was the highest. The electricity cost as calculated on the base line is R19'778. The electricity cost as calculated on the real electricity usage profile is R17'702. It can therefore be calculated that the electricity cost savings for this day was R 2'076.

The electricity usage during the peak demand period, which is between 6:00 pm and 8:00 pm, dropped below the base line. This resulted in electrical load being shifted. The amount of load shifted for this particular day was 2.17 MW.

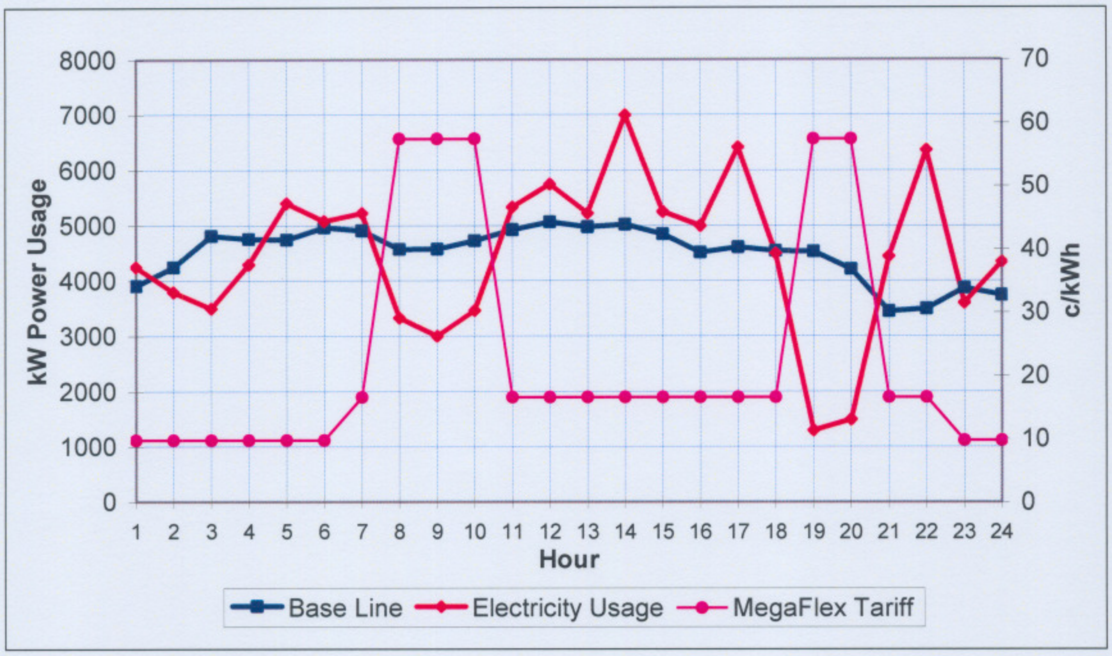

Figure 10-2 Case Study – 5 August

Figure 10-2 shows the data of 5 August. The data is shown in the same format as in Figure 10-1. This figure shows, in the same way as the previous figure, how the electricity usage dropped below the base line during the periods where the electricity tariff was higher. Also, the electricity usage dropped considerably during the peak demand period.

This resulted in a calculated R 2'019 savings for this day. The electricity cost as calculated on the base line was R 21'686 and the cost as calculated on the real electricity usage profile was R 19'666. The amount of load shifted for this day was calculated to be 3.27 MW.

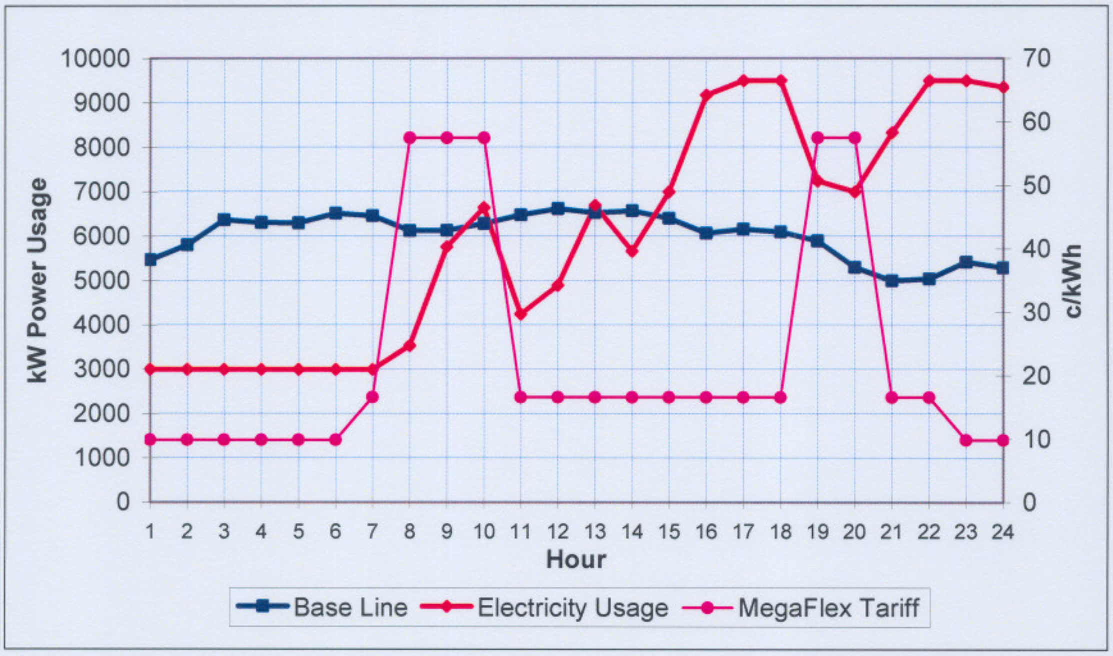

Figure 10-3 Case Study – 8 August

Figure 10-3 shows the data for 8 August. During this day no load was shifted and no savings were realised. This was due to a problem the mine experienced with the pumps on 66-level. These pump ware offline nearly all morning due to problems that arouse around the electricity feeders.

The problem was remedied at about half day.

There was more water in the underground water system that on a typical day due to the fact that half of the electrical pumps in the Three-Pipe Water Pumping System were off-line for half the day.

This resulted in the high energy usage in the last part of the day, as this excess amount of water had to be pump out of the mine.

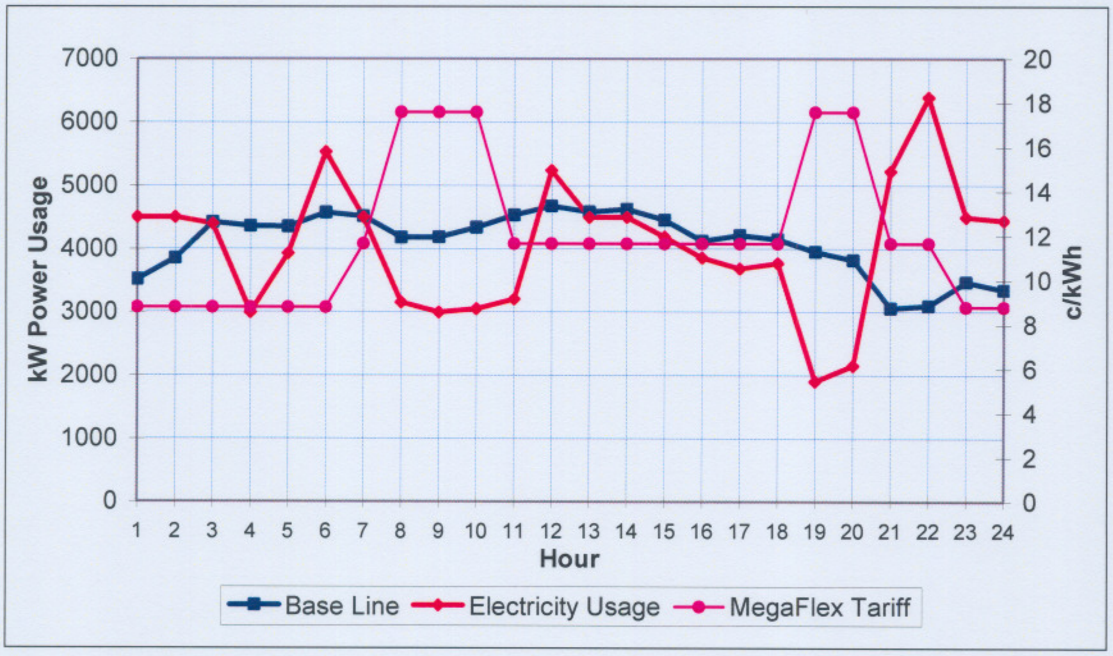

Figure 10-4 Case Study – 1 September

Figure 10-4 shows the data from 1 September. Note that the MegaFlex Tariff profile is now different from that seen in the August data. This reason is that August falls into the winter, or high-demand, MegaFlex season and September into the summer, or low-demand season. The tariffs for these two seasons differ.

One can see that the approach of the control does not change because of this. As seen in the August data, the electricity usage drops below the baseline in the peak demand period where load can be shifted and in those periods where the tariff is highest.

The savings realised for this day were calculated to be R 436. This saving for this profile is lower than it would have been in August, but this is due to the fact that the tariff profile changed. The load shifted on this particular day is 1.85 MW. The MegaFlex season has no effect on the amount of load that can be shifted.

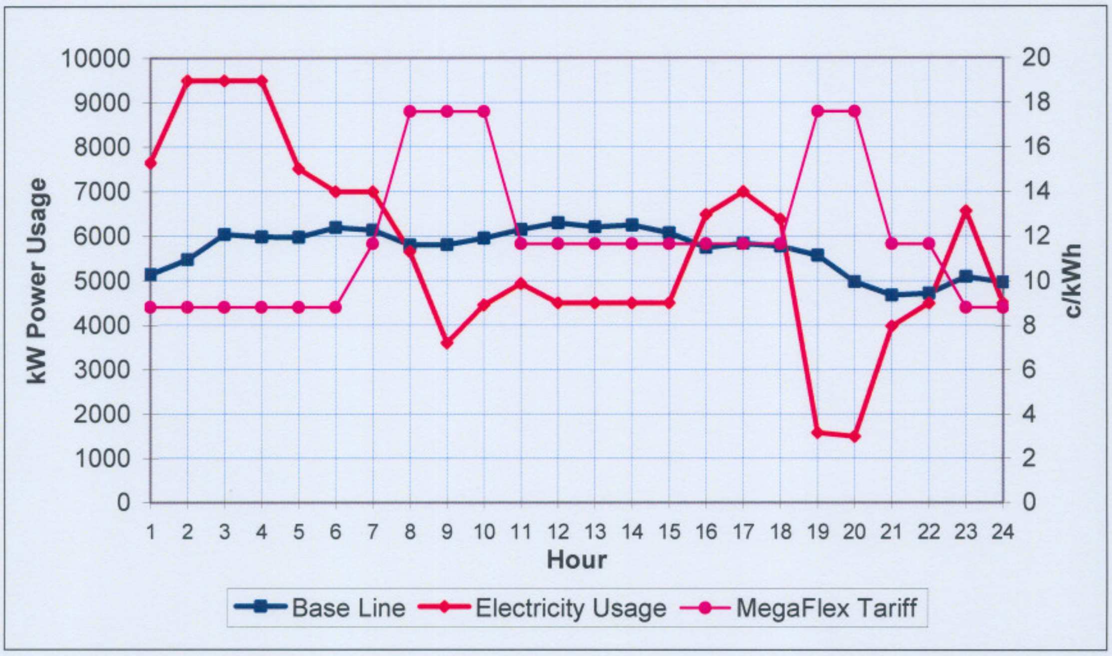

Figure 10-5 Case Study – 17 September

Figure 10-5 shows the data for 17 September. The day started of with to much water in the systems and a lot of work had to be done to deliver the water out of the mine. This was achieved before the first price increase and the control for the day continued normally. The electricity cost savings made for this day is calculated to be R 1’155 and the load shifted was calculated to be 3.73 MW.

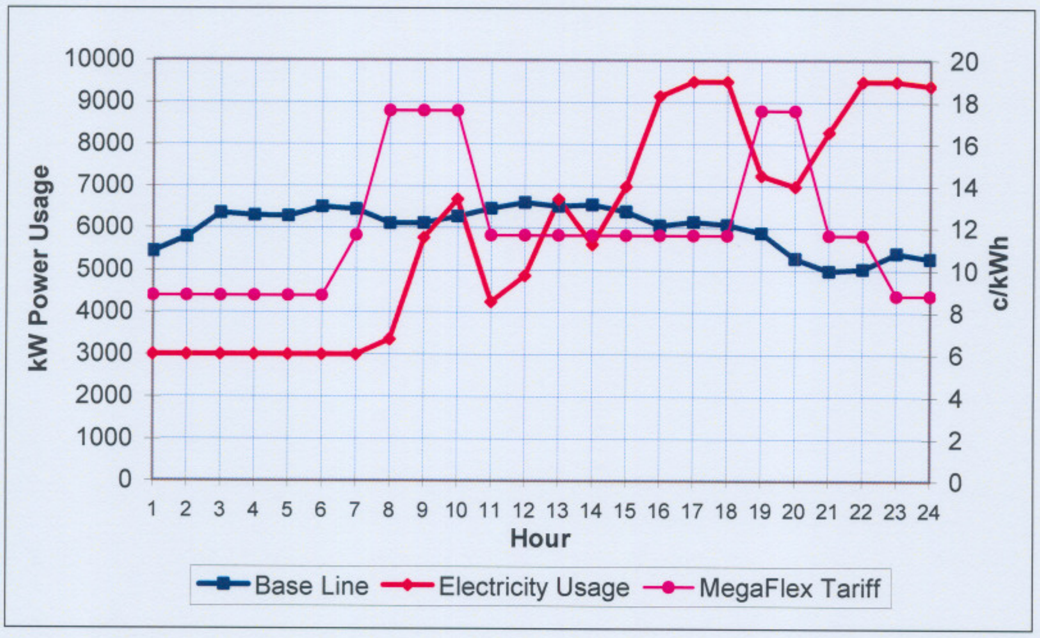

Figure 10-6 Case Study – 8 September

Figure 10-6 shows the data of 8 September. During the morning of this particular day, which was a Wednesday, maintenance was scheduled and performed on a certain pumps on 66- and 45-level. Other pumps were turned on and left on. No electricity cost savings ware realised during this day and no load was shifted.

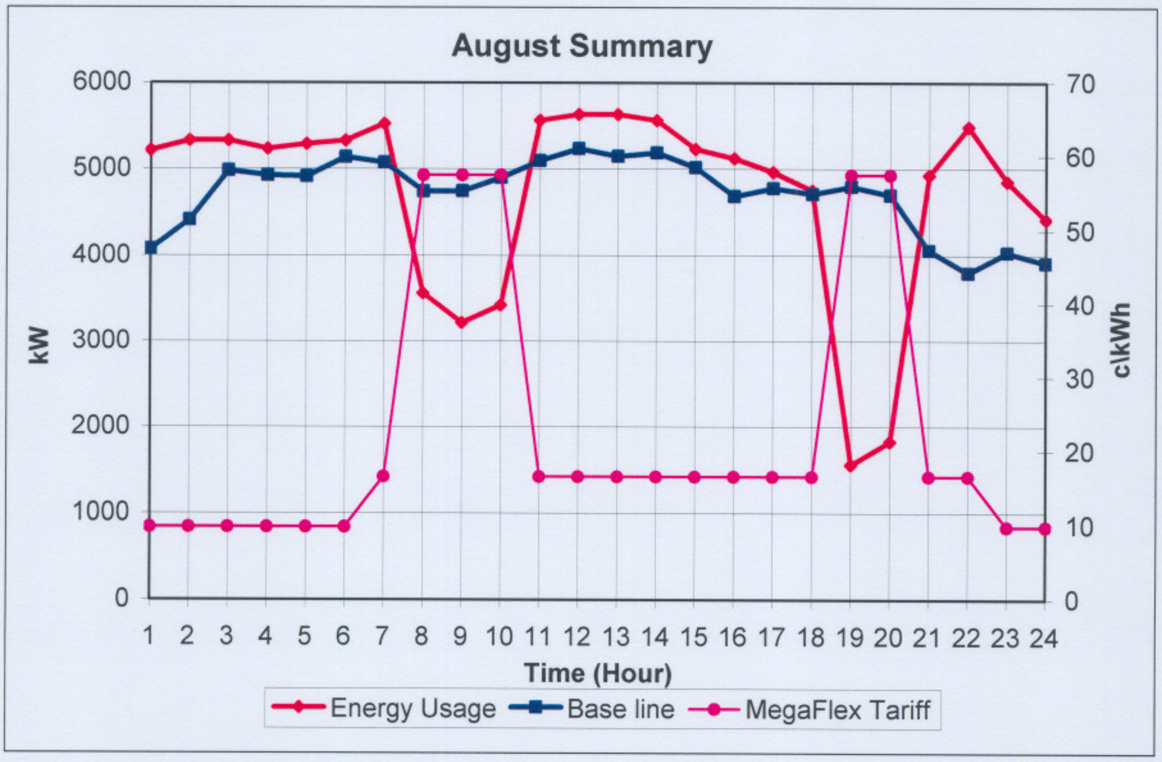

Figure 10-7 Case study - August average

Figure 10-7 show the average for August. This includes the Saturdays and Sundays. This gives a clear picture of the long-term effectiveness of the control application. One can clearly see that, as in the individual day figures, how the energy usage drops below the base line in the two MegaFlex peaks. This results in the electrical cost savings. The total savings realised in August was approximately R 42'200. The average saving in August was calculated to be R 1'425 per day.

It is also clear that the average real electricity usage is below the base line during peak hours. This resulted in the load shifting. The load shifted on average was calculated to be 3.9 MW per day.

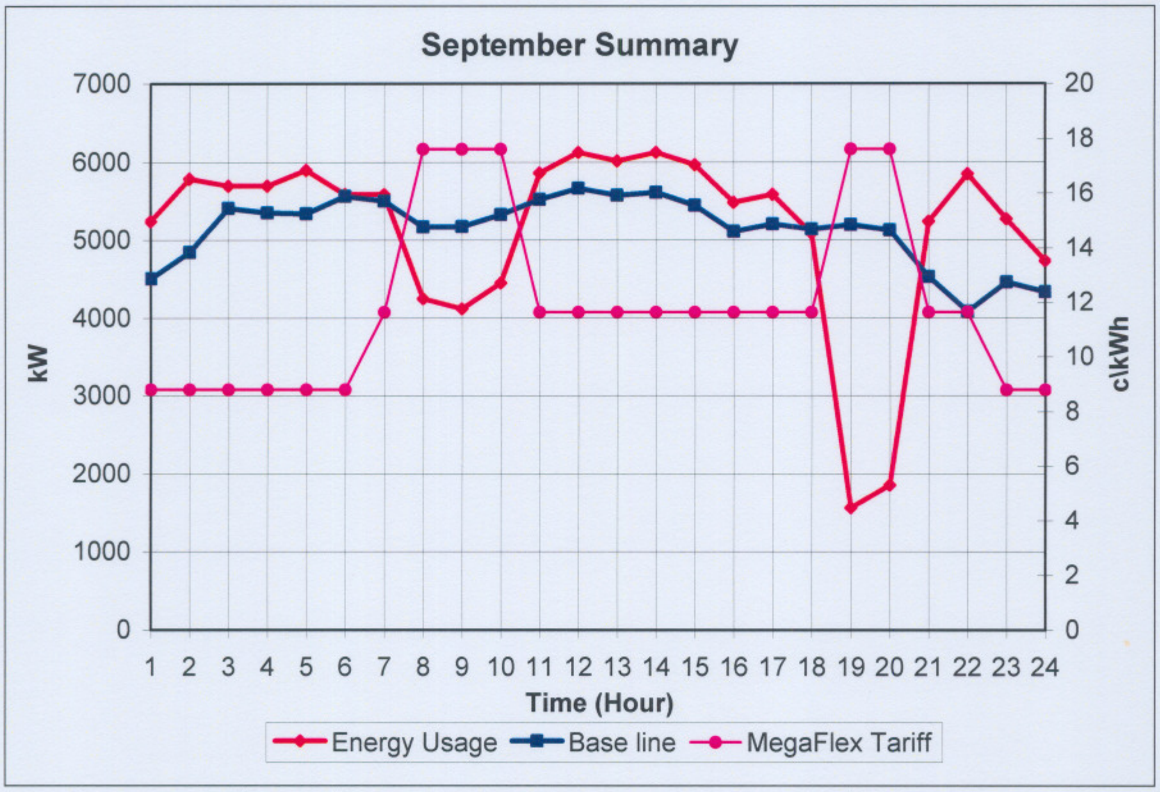

Figure 10-8 Case study - September average

The total savings realised in September was calculated to be R 7'142. The average savings in September were calculated to be R 238 per day. August falls under the winter month period of the MegaFlex pricing structure. That explains the difference in the savings made during August and September. The load shifted on average was calculated to be 3.8 MW per day.

As there are three winter and nine summer months in the MegaFlex pricing structure, the predicted savings for one year is approximately R 195'000. Only a prediction can be made for this figure, as the study was not run for a year as of yet. A predicted 3.8 MW can be shifted on average each month.

11 CONCLUSION AND RECOMMENDATIONS

A verification study was conducted to ensure realistic and accurate retrofit energy cost saving of the water pumping system. The 24-hour control had been running for a duration of two month and the savings predicted were within 12 % of the actual savings realised.

The verification study showed satisfactory results for the use of the simulation model with confidence during the retrofit simulations. The combinations of the new proposed control strategies could resulted in electricity cost savings of up to R 195'000 per year on the water pumping system of Tshepong.

Recommendations for further study in this field are firstly to conduct an investigation on how to increase the availability of the 3CPFS. The downtime of this system has a detrimental effect on the saving and load shifting capacity. It will therefore have a financial value if the availability of the 3CPFS can be improved.

Secondly, is to incorporate a database system into the software. The loggings of all statuses and flows into this database would improve the investigations that can be conducted on the control. The software can be engineered to automatically calculate savings and load shift figures from this data.

Another recommendation is to give special attention to the days on which no savings and load shifting have be realised. The reasons for this, in most cases, are maintenance and routine procedures. Ways could be sought to still complete these tasks, but in such a way that is does not hinder the control philosophy.

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