

CHAPTER 7. IMPLEMENTATION OF DEVELOPED ENERGY SAVING STRATEGY

7.1 Introduction

A variable water flow strategy and an accompanying energy management system to realise energy savings on large cooling systems of South African mines have been developed. The feasibility of the strategy was demonstrated in the previous chapter by quantifying expected energy savings through an adapted simulation and by considering its economic viability. This was done specifically for the Kusasalethu surface cooling system as a demonstrative case study. The results indicated feasibility and it was therefore decided to implement the strategy at Kusasalethu. This chapter discusses the full-scale implementation as an experimental setup for the study by considering the equipment installation, energy management and control system application and results verification methods. Chapter 8 subsequently presents the *in situ* results obtained from this implementation.

First, an overview of the equipment installed and subsequently used for experimental assessment at Kusasalethu is given. Then the application of the new energy management system on this site is described, including its hardware, user platform and controller functionalities. Finally, the measurement and verification of results are discussed. This includes a description of the data acquisition system and relevant accuracies, the experimental measurement procedures followed in the investigation and the verified saving calculation methodologies.

7.2 Equipment installation

The new variable water flow strategy and its energy management system are discussed generically in Chapters 4 and 5, respectively. The more specific application to the Kusasalethu surface cooling system is introduced and described in Chapter 6.2. The layout of the system is shown in Figure 38 with the system design parameters given in Table 13.

The equipment needed essentially consists of VSDs installed on the existing evaporator, condenser and BAC return pumps, valves installed on the BAC supply lines, new pre-cooling towers and necessary field instrumentation and control equipment alterations.

A detailed breakdown of the equipment bill of quantities is given in Table 21 in Chapter 6.5 as part of the feasibility study. The mine management accepted this bill of quantities, which was then installed by the contractor and system integrator. With the exception of the old pre-cooling towers that were decommissioned, no existing infrastructure needed to be changed or altered significantly to install the necessary energy efficient equipment. The installation work did not interfere with the existing cooling system operations and the commissioning was done over weekends and accessible downtime periods over three months.

Evaporator water flow control

Figure 49 shows the existing group of evaporator pumps. The system is unchanged, with the exception of all discharge line valves previously used to throttle the water flow now being fully open. Figure 50 shows one of the evaporator VSDs (on the left) and one of the condenser VSDs (on the right) installed in cabinets in the power supply substation of the cooling system. The VSDs are supplied with three-phase power by the existing system feeders and are connected to the existing pump motors as described in Chapter 3.2. Figure 51 shows the chilled water dam into which the evaporator pumps are pumping chilled water. The level of this dam is kept constant by the evaporator pump VSDs as specified by the control strategy in Chapter 6.2. An existing chilled water dam level sensor installed inside the dam is used as control input.



Figure 49 Evaporator water pumps at the Kusasalethu surface cooling system



Figure 50 Condenser and evaporator water pump VSDs installed at the Kusasaletu surface cooling system



Figure 51 Chilled water dam at the Kusasaletu surface cooling system

Condenser water flow control

Figure 52 depicts the group of existing condenser water pumps, also unaltered. Figure 53 shows one of the new condenser outlet water temperature sensor probes installed in the condenser water line. New probes were installed in the common inlet line and each individual outlet line. The average water temperature rise over the condensers is kept constant by the condenser VSDs. The unchanged condenser cooling towers are shown in Figure 54.



Figure 52 Condenser water pumps at the Kusasalethu surface cooling system



Figure 53 Condenser water temperature sensor probe installed at the Kusasaletu surface cooling system



Figure 54 Condenser cooling towers at the Kusasaletu surface cooling system

BAC water flow control

In Figure 55 one of the three water supply control valves used to control the gravity fed BAC supply water in proportion to ambient enthalpy can be seen. The digital psychrometer that calculates the ambient enthalpy of the BAC area and sends it to the PLC as input is shown in Figure 56. Figure 57 shows the integrated BAC and its common drainage water dam, while the return water pumps are shown in Figure 58. VSDs were installed on the two pumps on the left. Figure 59 shows the BAC return pump VSDs installed in the existing BAC area power supply substation. The frequency of these pumps is controlled to maintain the BAC drainage dam level, as measured by an existing dam level sensor.



Figure 55 BAC supply water control valve installed at the Kusasaletu surface cooling system



Figure 56 Digital psychrometer installed at the Kusasalethu surface cooling system



Figure 57 BACs and common BAC drainage dam at the Kusasalethu surface cooling system



Figure 58 BAC return water pumps at the Kusasaletu surface cooling system



Figure 59 BAC return water pump VSDs installed at the Kusasaletu surface cooling system

Pre-cooling tower replacement

Figure 60 depicts the old pre-cooling towers. As mentioned previously, upon site inspections it was determined that they were in a very poor condition and could not be suitably repaired. It was decided that it would be best to replace them. The newly installed pre-cooling towers are shown in Figure 61. The more advanced, compact and efficient design of the new towers when compared to Figure 60 is clear. The new units have four smaller fans that are more energy efficient, have more advanced fill material with larger heat transfer area and are significantly more robust against fouling and clogging.



Figure 60 Old pre-cooling towers at the Kusasaletu surface cooling system



Figure 61 New pre-cooling towers installed at the Kusasaletu surface cooling system

General

One of the four identical chillers is shown in Figure 62. The evaporator and condenser pumps are installed outside the chiller house area. It is clear that no equipment changes were made to the evaporator, condenser or compressors of the chiller. The proposed strategies of varying the water flow rates rather than the refrigerant flow rates is thus an energy saving measure that is relatively simple to practically implement with minor alterations to existing systems.



Figure 62 A chiller of the Kusasalethu surface cooling system

It is concluded that the developed DSM strategy requires the installation of new equipment that suitably adheres to mine standards and does not interfere with mine cooling system infrastructure, production or operation methods during installation or commissioning.

7.3 Energy management system application

The developed REMS-CATM energy management system has been described in Chapter 5. The key functionalities are to integrate, optimally control, monitor and report on the savings of the developed variable water flow DSM strategy. The system was therefore installed on Kusasaletu to perform these functions. The generic hierarchical system architecture, functional specification, integration and control method as well as the monitoring and reporting methods discussed previously are equally applicable to the Kusasaletu system. This section gives an overview of the site-specific customisations that were necessary to successfully apply the system to the Kusasaletu case study.

Hardware

The hardware that was installed included two REMS-CATM servers (one primary and one backup), a control monitor, mouse and keyboard and a wireless router. In this way the system could be linked to the cooling system, controlled and accessed through various ports as shown in Figure 35.

Figure 63 displays the REMS-CATM servers installed in the central server room of the existing Kusasaletu control network. The servers are connected to the SCADA through OPC to allow for complete supervision and control, as discussed in Figure 24.

In Figure 64 the REMS-CATM control screen with the user platform in the central control room at the Kusasaletu mine can be seen. The control operator can monitor and control the variable-flow strategies from this central location or, alternatively, energy managers and personnel can view the same platform from other locations through the connected wireless router.



Figure 63 REMS-CATM server installed at the Kusasalethu surface cooling system

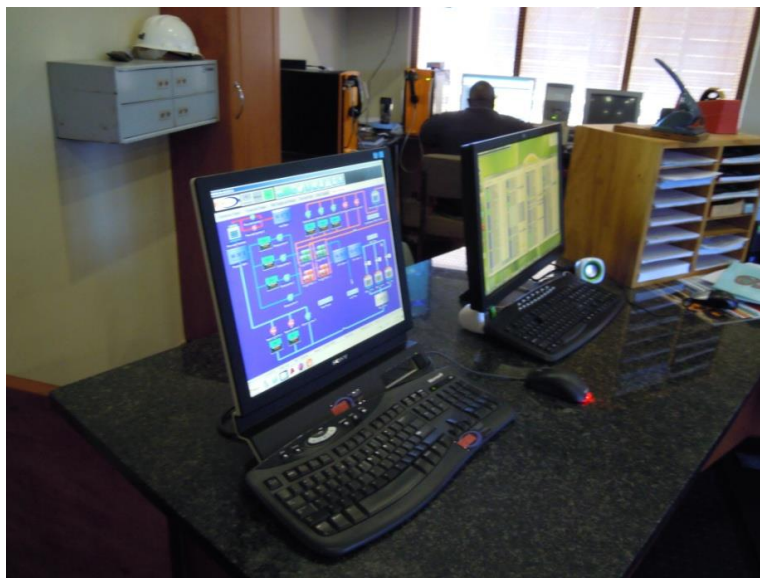


Figure 64 REMS-CATM control screen installed at the Kusasalethu surface cooling system

User platform

After installation, all the control equipment and instruments were connected to the relevant cooling system PLCs. The required monitoring and controlling signal addresses (or *tags*) were created in the PLCs, local control loops programmed and addresses made available to the database of the mine SCADA.

REMS-CATM was set up and all required cooling system parameters were created. Various controllers, monitoring and logging systems described generically in Chapter 5 were set up to create a customised user platform of the Kusasaletu cooling system. The resulting user interfaces of REMS-CATM on Kusasaletu are shown in Figures 65 to 70.

Figure 65 (Du Plessis et al. 2013b) displays the main page on the REMS-CATM platform. This shows the integrated layout of the cooling system and all its auxiliaries. Different colours are used for the various water circuits to avoid confusion. The main purpose of this interface is to provide an integrated overview of the system for real-time monitoring. Important service delivery parameters such as total water flows and temperatures are displayed.

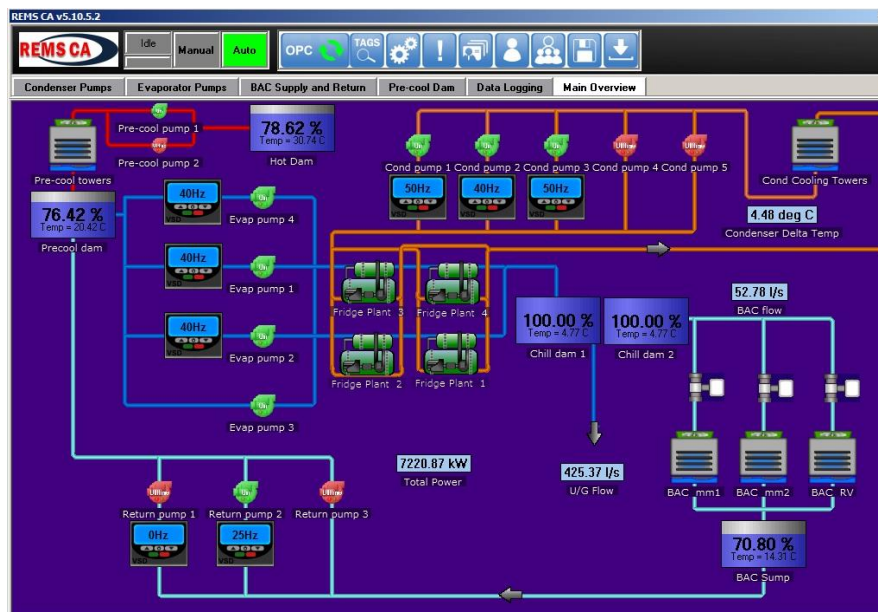


Figure 65 REMS-CATM user interface installed at the Kusasaletu surface cooling system (main page) (Reprinted from *A versatile energy management system for large integrated cooling systems*, Du Plessis G.E., Liebenberg L., Mathews E.H., Du Plessis J.N., Energy Conversion and Management, 66, 312-325, Copyright (2013), with permission from Elsevier)

Figure 66 shows the evaporator water circuit separately as a controller page. This displays more detail regarding the cooling system parameters and also provides the user interface to the editable VSD controllers. A separate controller was created for each VSD. The chilled water dam level set point, as well as the VSD frequency limits, is specified in these controllers. A similar page is shown in Figure 67 for the condenser VSDs.

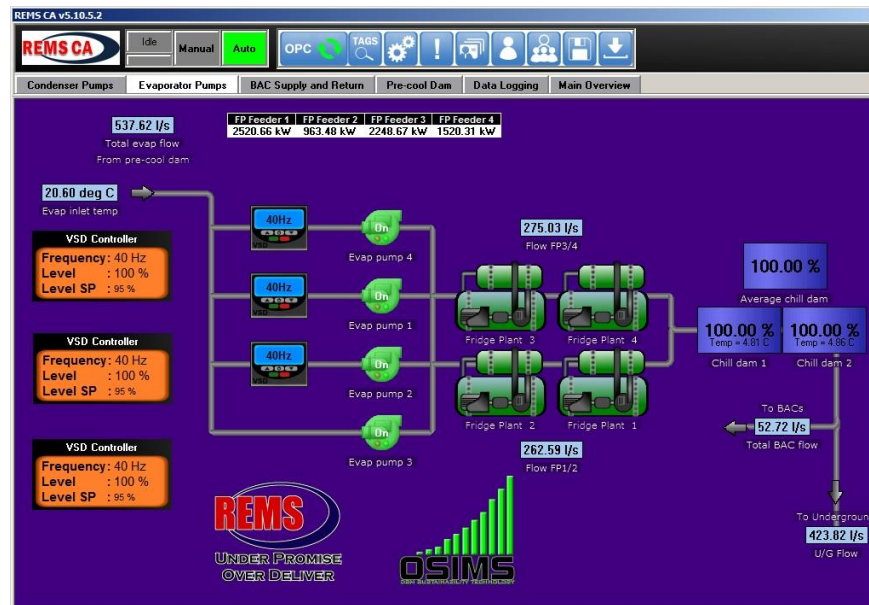


Figure 66 REMS-CA™ user interface installed at the Kusasaletu surface cooling system (evaporator page)

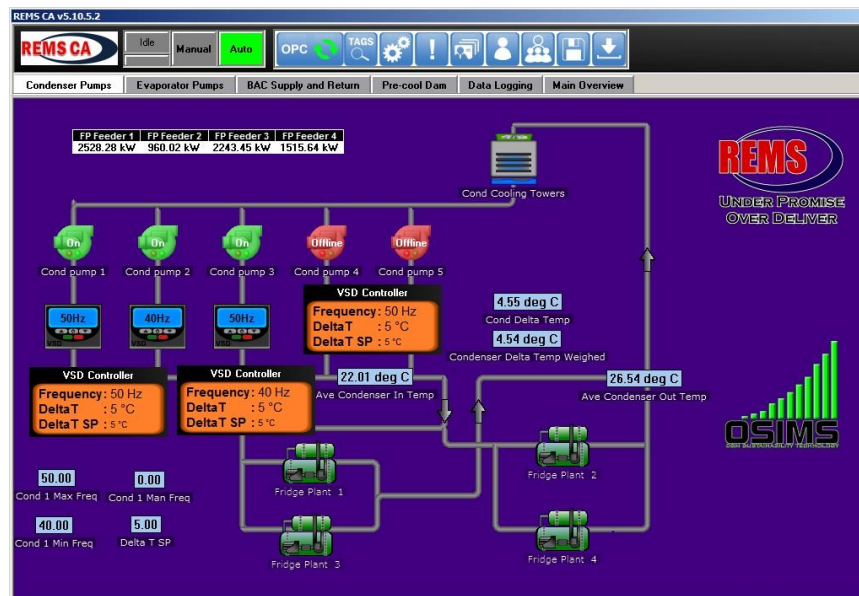


Figure 67 REMS-CA™ user interface installed at the Kusasaletu surface cooling system (condenser page)

Figure 68 exhibits the BAC as well as its supply water control valves and return water pump VSDs. All the controllers are provided from where the valve limits, ambient enthalpy limits and drainage dam level set points can be edited.

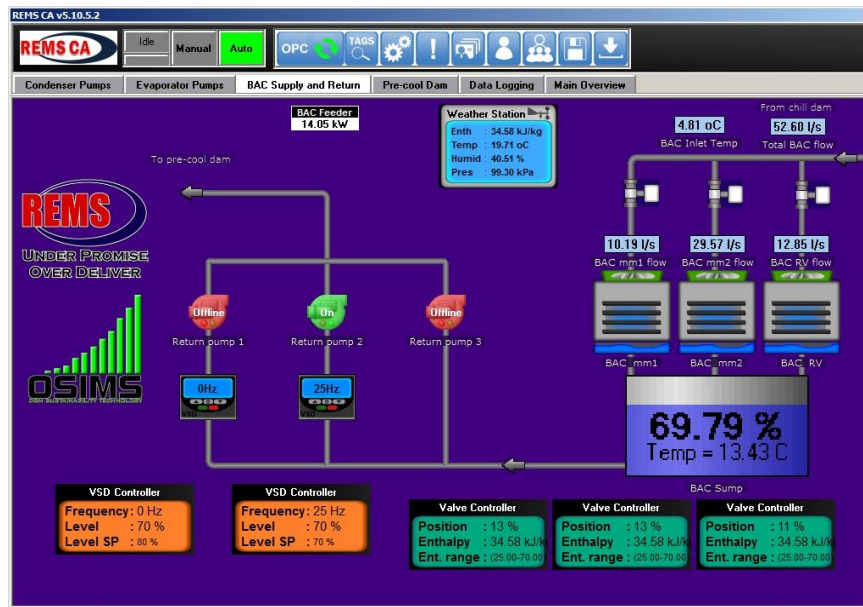


Figure 68 REMS-CA™ user interface installed at the Kusasaletu surface cooling system (BAC page)

Figure 69 shows the page created to monitor the inlets and outlets of the pre-cooling dam. Although no control takes place here, it is important because, as discussed previously, the proposed energy saving strategies have significant effects on the water temperature of the dam. By monitoring the flow rates and temperatures of the inlets and outlets clearly, one can assess the effects and relative contributions of the energy saving strategies.

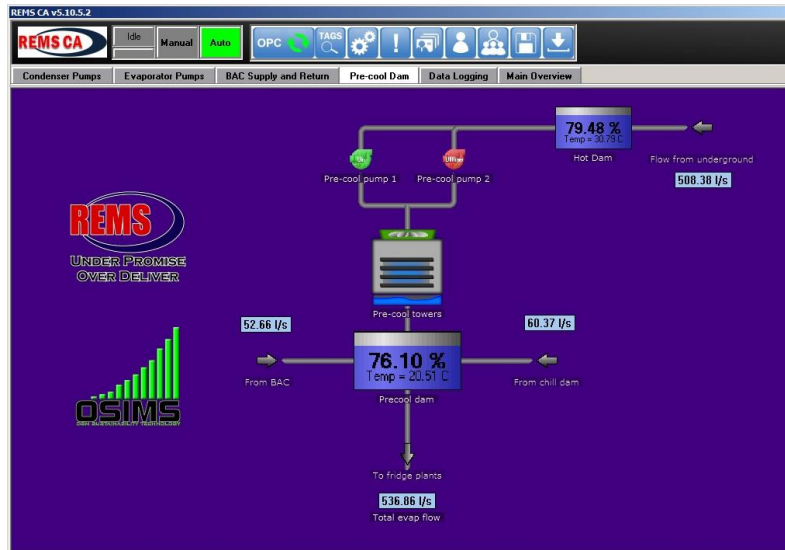


Figure 69 REMS-CA™ user interface installed at the Kusasaletu surface cooling system (pre-cooling dam page)

Finally, a central logging and reporting page is shown in Figure 70. The purpose of this page is firstly to enable the real-time monitoring of the cooling system electrical power usage by means of a graphic display. Secondly, all the on-board functions that log systems parameters, automatically create energy savings reports and send reporting e-mails are integrated and edited from this page. Alarms for high and low temperatures, flows and energy usage values are also managed from this central point.

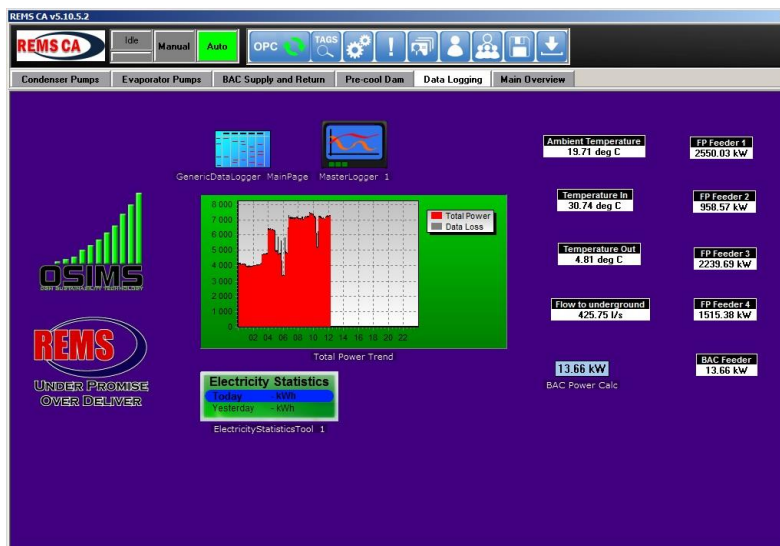


Figure 70 REMS-CA™ user interface installed at the Kusasaletu surface cooling system (logging and reporting page)

Control and integration

After the equipment and energy management system were installed and integrated into the existing control network at Kusasalethu, relevant control parameters and constraints were determined experimentally during commissioning. Industrial automation and control systems are usually commissioned on a trial-and-error basis because real systems react differently to theoretical models due to practical variances involved.

The set points specified by the mine as well as the VSD and valve limits determined during commissioning are shown in Table 23. The VSD frequency lower limits indicate the points where low water flows initiated chiller shut down due to laminar flow, as discussed in Chapter 4.

Table 23 Variable-flow strategy set points and parameters used at the Kusasalethu surface cooling system

Description	Set point
Evaporator flow control	
Chilled water dam level (%)	95
VSDs lower frequency limit (Hz)	40
VSDs upper frequency limit (Hz)	50
Evaporator lower water flow limit (ℓ/s)	90
Condenser flow control	
Average condenser water temperature rise (°C)	5
VSDs lower frequency limit (Hz)	40
VSDs upper frequency limit (Hz)	50
Condenser lower water flow limit (ℓ/s)	180
BAC flow control	
Ambient enthalpy lower limit (kJ/kg)	25
Ambient enthalpy upper limit (kJ/kg)	70
Supply water valve lower limit (% open)	0
Supply water valve upper limit (% open)	100
Drainage dam level (%)	70-78
VSDs lower frequency limit (Hz)	20
VSDs upper frequency limit (Hz)	40

The hierarchical control architecture and functional specifications given in Chapter 5 were implemented on the various field PLCs, master PLC and SCADA as specified. The control philosophies were programmed as local control loops in the PLCs as described previously. The site-specific PID logic gains (k_p , k_i and k_d in Equation 33) for Kusasaletu were determined experimentally as is commonly done in industry. This process involved a first estimation of the gains for each control loop using the Ziegler-Nichols tuning method (Dorf and Bishop 2008). The gains were then experimentally altered until the system output responded favourably to set point changes or system disturbances. The final control gains and system responses also had to be approved by mine personnel.

Figure 71 shows the evaporator water flow response to a unit change in the dam level set point using the approved gains of $k_p = 3.7$, $k_i = 0.143$ and $k_d = 1.5$. This data was extracted from the PLC during commissioning. The overshoot of the system is small (1.7%) and a relatively long settling time of 75 seconds is indicated. There is no steady-state error as can be expected.

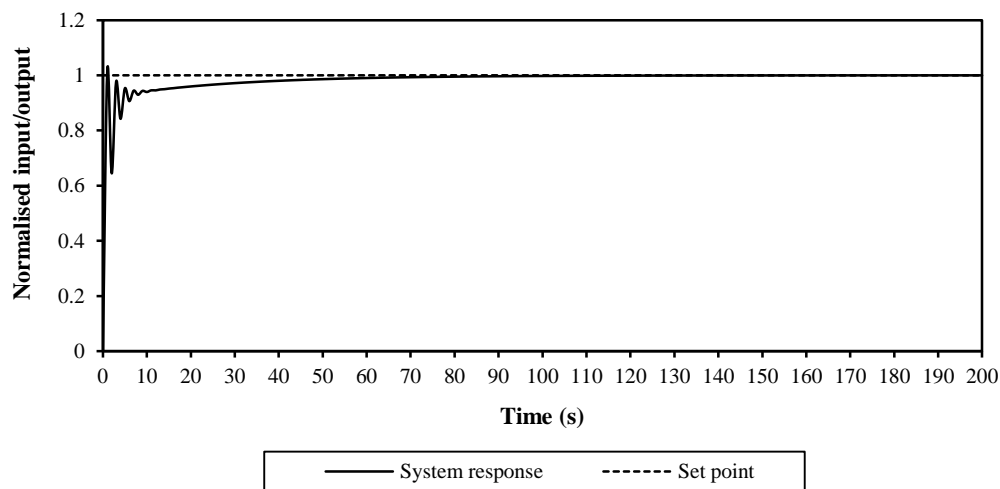


Figure 71 Evaporator flow control and system response to a unit step input (Kusasaletu)

Figure 72 depicts the condenser water flow response to a unit change in the water temperature difference set point using the approved gains of $k_p = 0.5$, $k_i = 0.02$ and $k_d = 0$. There is no overshoot and there is a long settling time of 198 seconds, indicating a damped system. This is attributed to the actual condenser water system needing time to react to thermal load changes before a water temperature difference can be observed.

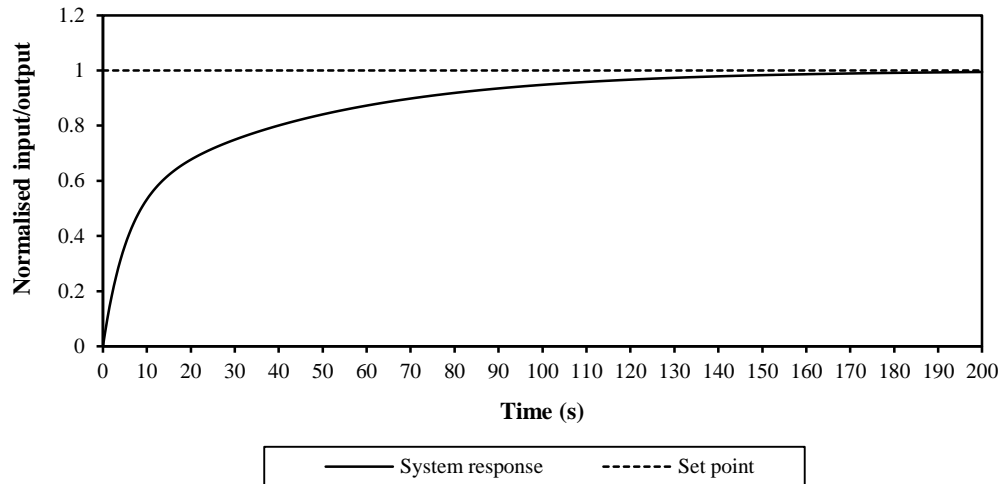


Figure 72 Condenser flow control and system response to a unit step input (Kusasaletu)

Figure 73 shows the BAC supply water flow control method by control valves. This control strategy does not involve a PID loop. The proportional valve control was commissioned by observing the shaft wet-bulb temperature for different valve limits when ambient enthalpy changes. The preliminary proposed enthalpy limit of 70 kJ/kg (corresponding to a 100% valve opening) was shown to result in the design shaft wet-bulb temperature of 8 °C being achieved. It was found that if the lower limit was set to 25 kJ/kg (corresponding to a 0% valve opening), the shaft wet-bulb temperature remained relatively constant at 8 °C as the ambient enthalpy input fluctuated during the day and the valves controlled proportionally.

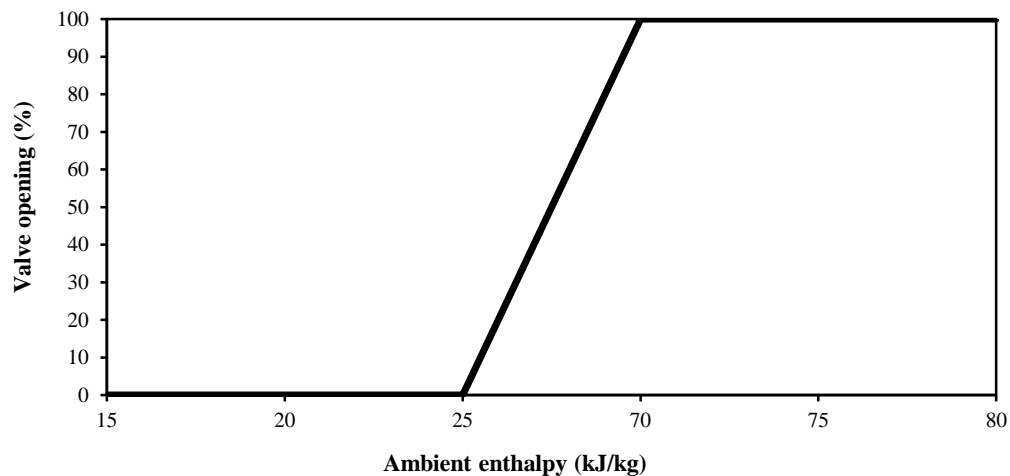


Figure 73 BAC supply flow control limits (Kusasaletu)

Figure 74 displays the BAC return water flow response to a unit change in the BAC drainage dam level set point using the approved gains of $k_p = 4$, $k_i = 0.111$ and $k_d = 1.4$. The overshoot of the system is small (4.8%) and a relatively long settling time of 106 seconds is indicated. As expected, the gains and response of the system are similar to the evaporator flow control because the level of a dam of similar volume is controlled.

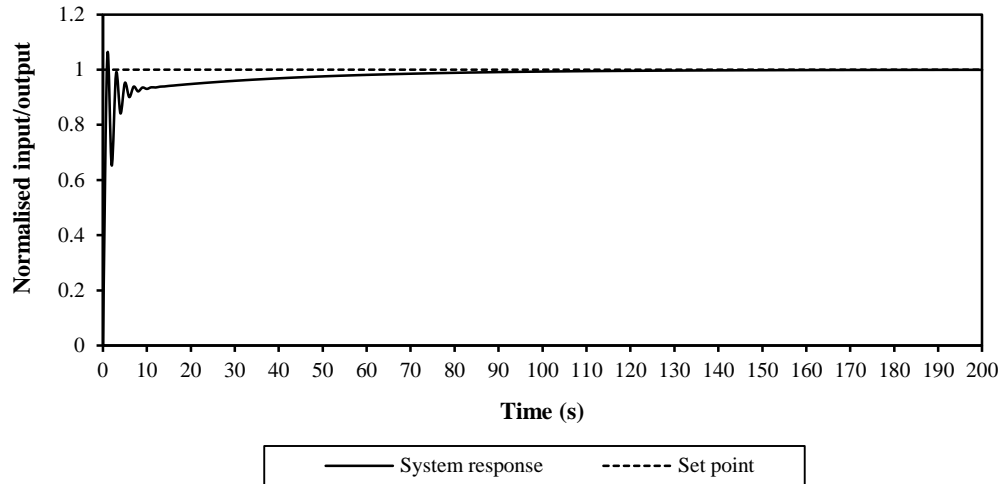


Figure 74 BAC return flow control and system response to a unit step input (Kusasaletu)

It can be concluded that the control limits and gains of the integrated energy management system at Kusasaletu were determined experimentally during commissioning as approved by the system integrator and mine personnel. The control philosophies of the various subsystems and their integration into a central controller remained as proposed and described generically in Chapter 4 and Chapter 5.

7.4 Results measurement and verification

The first three months after commissioning of the described equipment and energy management system were considered as a performance assessment period. This was not only a requirement by Eskom to verify the performance of the project, but also provided an opportunity to analyse the energy savings, system performance and service delivery effects in detail.

It is appropriate to discuss the measurement and verification of results and methods to determine savings before commencing with the result analysis. The verification of measurements is important to ensure that validation and analysis are performed using correct and valid data.

An overview of the data acquisition process is given first. This includes a description of the various measurement points, a brief sensor accuracy and uncertainty analysis as well as a discussion of the data collection and processing procedures followed. Second, the verification procedure of energy savings and measured results are discussed. This includes a description of the Eskom measurement and verification process, the appropriate power baseline scaling method and the verification of results used in this study.

Data acquisition

Various field instruments, new and existing, provide process variable feedback and input data for the control strategies. In addition, some sensors are used only in the monitoring and analysis of the plant operation. An overview of all the measurement sensors locations used to collect data for the study is shown schematically in Figure 75.

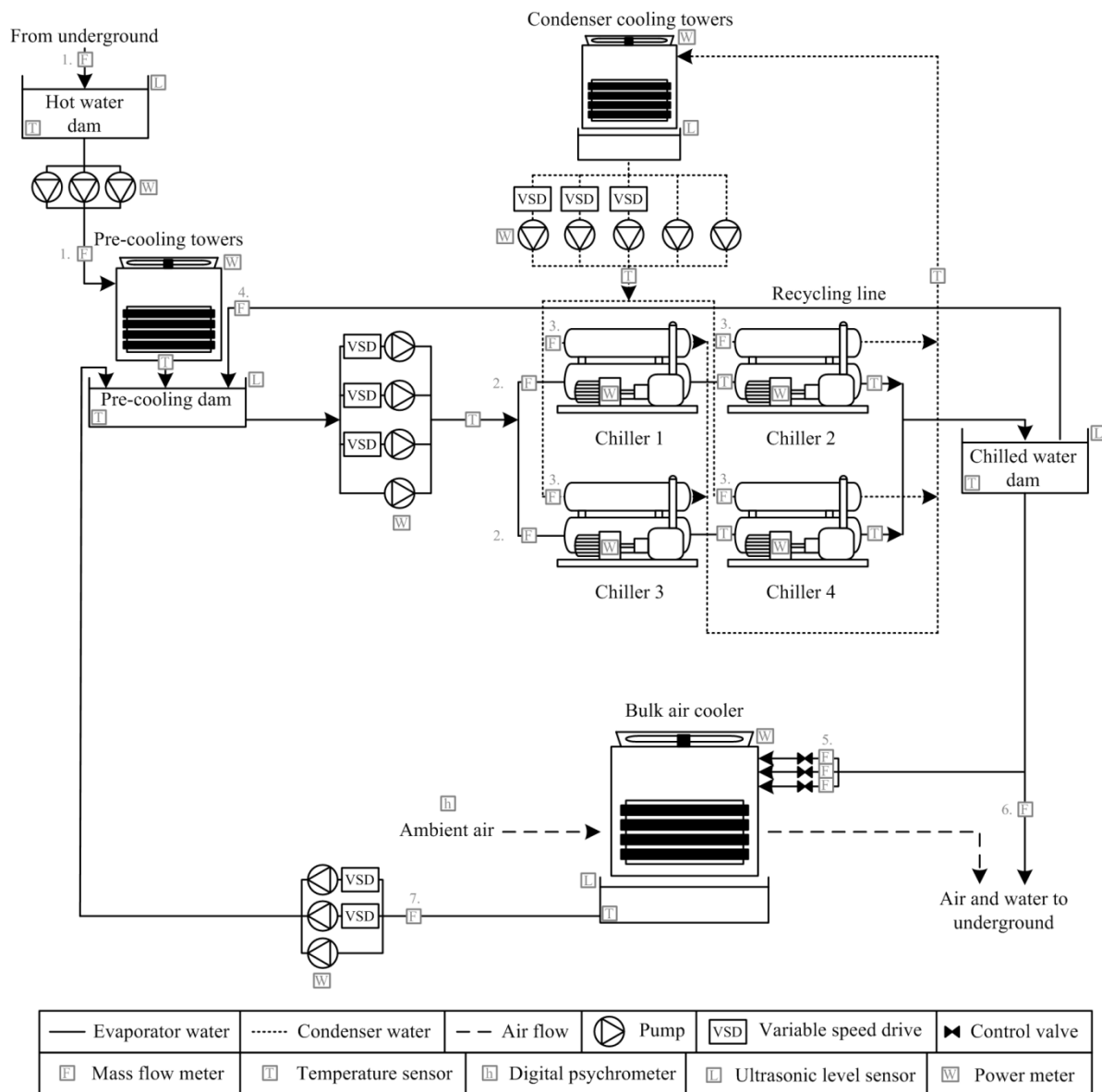


Figure 75 Overview of field instrument installations at the Kusasaletu surface cooling system

All the measuring equipment shown in Figure 75 are permanent installations of the cooling system, either old or newly added. They are connected to the integrated communication network. All process variable readings are thus available on the SCADA and can be logged, monitored or used as control inputs in REMS-CATM.

The specifications of the sensors are given in Table 24, with reference to Figure 75 where relevant.

Table 24 Specifications of measurement sensors installed at the Kusasalethu surface cooling system

Sensor	Quantity	Specification	Accuracy in measurement range (%)
Dam level sensor	5	Yokogawa EJX530A pressure level sensor	0.1
Digital psychrometer	1	Testo 6 681 humidity transmitter including Testo 6 610 probes	- RH: 1 - Dry-bulb temperature: 0.6 - Enthalpy: 1
Water temperature Sensor	12	Wika TR31 PT-100 probe including 4-20 mA transmitter	0.2
Mass flow meter (2)	2	Meinecke MAG 5 000 flow meter	2
Mass flow meter (3)	4	Tokyo Keiki UFL-30 ultrasonic flow meter	1
Mass flow meter (1, 4-7)	8	Krohne Optiflux 2 000 flow meter	1.5
Power meter	10	Dent Instruments Elite Pro Polyphase power meter	0.05

As part of results verification, it is good practice to evaluate the accuracy tolerances of measurements in any form of investigative research. Table 24 shows that a total of five dam level sensors, one digital psychrometer, 12 water temperature sensors, 14 water mass flow meters and 10 power meters were used to monitor the system performance in this study. There are therefore many sensors that can contribute to the overall accuracy of the measured results.

Firstly, it is important to understand the measurement approach and how accurate data will influence the results of this specific investigation. In this case, an energy saving strategy for large cooling systems was proposed and its implementation on a specific site evaluated, as will be described in detail in Chapter 8. The analysis of results is largely based on comparing the various performance parameters of the system and subsystems before and after the implementation of the strategy. It is thus important that the relative accuracy of measurement remain the same before and after strategy implementation to ensure that values are compared on the same basis.

The performance of the energy saving strategy will be adequately reflected (with regards to measuring equipment) if it is ensured that the sensor accuracy tolerances remain the same before and after strategy implementation. This was done by obtaining and verifying routine maintenance and calibration reports of all the measuring equipment given in Table 24 (Kusasaletu Mine 2012). The reports of the total time period considered in the study were used. This ranged from the time period before implementation (January 2011 to February 2012) to the performance assessment period after implementation (March to May 2012).

Routine maintenance requires the mine personnel to inspect and approve the sensor and transmitter conditions and to test and verify the sensor readings. For the relevant time period it was found that no sensor replacements needed to be made, that all equipment was maintained regularly and that no major re-calibration was required. The measuring equipment was also inspected individually and found to be in good condition, confirming the latest mine reports. It can therefore be assumed that the accuracy of measured data remained constant for the entire time period considered for the investigation.

Although more emphasis is placed on the importance of relative accuracy between pre- and post-implementation measurements in this study, the absolute measurement accuracy and uncertainty will also be considered briefly. Each of the sensor accuracies shown in Table 24 is expressed as a percentage of the average reference point of measurement for the specific location in the Kusasaletu system. For example, the air temperature sensor accuracy tolerance of 0.6% is reported with reference to an average ambient dry-bulb temperature of 25 °C (Testo 2011).

These average accuracies were taken from the relevant manufacturer specification sheets. They include systematic component errors caused by manufacturing tolerances, hysteresis, reproducibility and testing uncertainty in accordance to the relevant authoritative industrial standards.

Table 24 shows that the sensors with the lowest accuracy at its design point are the evaporator flow meters with an accuracy tolerance of 2%. This is deemed acceptably high, especially when considering the comparative purpose of this investigation. Each sensor accuracy value differs for various points of operation and therefore the accuracies are expected to change slightly, especially as the water flow and temperature reference points change after strategy implementation. However, the relevant changes in accuracies reported by the data sheets are less than 1% in all cases and are thus negligible. It is therefore reasonable to conclude that the measurement accuracy of all data used is sufficiently high for the purposes of this study.

The majority of analyses in this study involve single parameters, such as the water flow rate before as opposed to after the implementation of the energy saving strategy. The accuracies (in percentage) of such variables are specified in Table 24. When the reference design points are multiplied with the accuracies, the uncertainties (in ℓ/s , $^{\circ}C$ etc.) can be found. However, the accuracy and uncertainty of a value that is a function of more than one measured variable needs to be considered more carefully. In this study such values are the various forms of water enthalpy changes and COPs.

Without considering bias and precision values separately, the maximum uncertainty of a function consisting of more than one variable is given below (Christians 2007).

$$\delta F = \left\{ \left(\sum_{i=1}^n \frac{\partial F}{\partial A_i} \delta A_i \right)^2 \right\}^{0.5} \quad (36)$$

where $F = f(A_1, A_2, \dots, A_n)$

δF = uncertainty of F (in the units of F)

It follows that the expected accuracy of a water enthalpy change (\dot{Q}) calculation consisting of mass flow and two temperature measurements (such as in Equation 2) is given as:

$$\frac{\delta \dot{Q}}{\dot{Q}} = \left\{ \left(\frac{\delta \dot{m}}{\dot{m}} \right)^2 + \left(\frac{\delta T_1}{T_1} \right)^2 + \left(\frac{\delta T_2}{T_2} \right)^2 \right\}^{0.5} \quad (37)$$

where $\frac{\delta \dot{Q}}{\dot{Q}}$ = accuracy tolerance of enthalpy change (-)

$\frac{\delta \dot{m}}{\dot{m}}, \frac{\delta T_{1,2}}{T_{1,2}}$ = accuracy tolerances of mass flow and temperature sensors (-)

Similarly, the accuracy tolerance of a COP calculation (such as in Equation 1) is:

$$\frac{\delta COP}{COP} = \left\{ \left(\frac{\delta \dot{Q}}{\dot{Q}} \right)^2 + \left(\frac{\delta W}{W} \right)^2 \right\}^{0.5} \quad (38)$$

where $\frac{\delta COP}{COP}$ = accuracy tolerance of coefficient of performance (-)

$\frac{\delta \dot{Q}}{\dot{Q}}, \frac{\delta W}{W}$ = accuracy tolerances of relevant enthalpy change and work input (-)

By using Equations 37 and 38 as well as the reported equipment accuracies given in Table 24, the accuracy tolerances for typical water enthalpy changes and COPs were calculated to be 2.02% and 1.42% respectively. These are both below 5% and are expected to remain relatively constant before and after implementation. The brief uncertainty analysis therefore indicates that the accuracy tolerances of calculated parameters are sufficiently suitable for the purposes of this evaluation.

The process of collecting and analysing suitable data accurately is another important factor in ensuring that valid results are obtained. This is because the method, process and software all influence the accuracy of data processing (Schutte 2007). The experimental method followed to obtain and evaluate *in situ* results consisted of collecting historic system data, commissioning the new strategies, logging system data after commissioning and subsequently analysing all the collected data.

A more detailed experimental procedure followed is described below.

- Historic data files were obtained in .csv format from the Kusasaletu mine. This included measured and logged data of all the original cooling system measuring equipment. Values were logged on the mine SCADA every two minutes and had been verified as accurate by the mine control and instrumentation personnel. The time period considered was January 2011-February 2012.
- The energy saving equipment and the integrated REMS-CATM system were installed on the system during January and February 2012. The equipment was commissioned to operate according to the strategies proposed and described in Chapters 4 and 6.2. REMS-CATM was commissioned to control the equipment as described in Chapters 5 and 6.2.
- Tests were run and data logged during the commissioning phase to investigate specific effects of the strategy on the system. These included reducing the evaporator and condenser water flows separately to investigate the relative effects on the plant COP.
- After commissioning, REMS-CATM automatically controlled the cooling system auxiliaries according to the variable-flow strategies. All the plant data previously obtained from the mine SCADA as well as new infrastructure parameters were logged in this system every two minutes. Daily data files were saved in .csv format for the performance assessment period of March to May 2012.
- All the data files obtained (pre- and post-implementation as well as for certain test runs) were processed using Microsoft Excel (Microsoft 2012). Methods such as pivot tables and filters were extensively used to sort and filter data appropriately.
- The actual results were analysed and verified as described further in this section. Comparisons were made and relevant conclusions drawn as discussed in Chapter 8.

The procedure followed is shown to be based on widely-used methods, software and file formats. It can therefore be confidently assumed that the experimental procedure did not influence the accuracy or validity of the data in any way.

It is concluded that the data acquisition system and process as well as the experimental procedure followed were suitably verified to investigate the validity of the proposed variable water flow strategies. The points of measurement and the equipment used were described. The importance of ensuring relative measurement accuracy before and after implementation in this study was stressed. This relative accuracy was shown to stay suitably constant by considering mine reports.

The absolute accuracies of the measuring equipment at design points were shown to be suitable for this investigation. A brief uncertainty analysis was done for calculated values such as water enthalpy rise. The uncertainty was found to be acceptable, especially when considering it to stay relatively constant before and after implementation. Finally, an overview of the experimental data acquisition procedure was given. It was shown that all methods and software used were verified and acceptable as not to influence the validity or accuracy of the results.

Savings measurement and verification

Studies have shown that high uncertainty in expected savings reduces the implementation of energy reduction measures by organisations (De Groot et al. 2001, Sandberg and Söderström 2003). Accurate measurement of data and energy savings from industrial energy efficiency projects can reduce uncertainty about the efficacy of such projects and improve future estimates of expected savings on similar systems (Kissock and Eger 2008). Therefore, several international standard protocols have been developed to measure energy savings and to verify that results are accurate representations of successful strategy implementation (US Department of Energy 1996, Efficiency Valuation Organisation 2002, ASHRAE 2002).

In South Africa the principles given in *The Measurement and Verification Guideline for Energy Efficiency and Demand-Side Management (EEDSM) Projects and Programmes* as published by Eskom's Corporate Services Division Assurance and Forensic Department are followed to verify energy saving results (Den Heijer 2009).

These principles conform to the measurement and verification specifications for energy saving projects given by the South African Bureau of Standards (2010).

Independent auditing bodies are contracted by Eskom to ensure that energy saving results realised by DSM projects implemented by ESCOs are measured and verified according to the mentioned standards and protocols (Xia and Zhang 2012). This was also the case during implementation of the described variable-flow strategies on the Kusasaletu surface cooling system. The independent body was responsible for fully auditing the cooling system and measured data before and after implementation. This included developing a verified electrical power baseline, characterising a verified regressive method to routinely adjust the baseline and verifying the accuracy of all electrical and plant data used in this study (Eskom Corporate Services Division 2011).

Electrical power data obtained from power loggers installed at Kusasaletu was used by the independent body to develop an electrical baseline for the strategy. This baseline reflects the daily electrical load profile of the surface cooling system before implementation of the variable-flow strategies. The data consisted of power readings logged every 30 minutes at the point of common coupling of the cooling system power supply. This included the power usage of the total cooling system and all its auxiliary systems.

Data was used from three summer months in 2011 to develop the baseline. The auditor did not consider the exclusion of the winter months a problem, because baseline scaling according to ambient and production conditions would compensate accordingly. The verified daily baselines for weekdays, Saturdays and Sundays are shown in Figure 76.

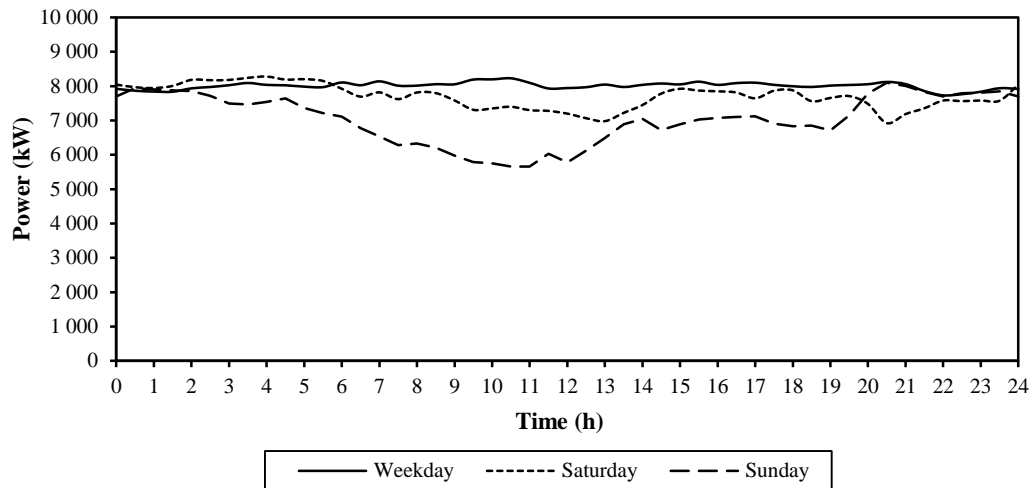


Figure 76 Average daily electrical power baselines developed for the Kusasaletu surface cooling system

Figure 76 shows that the average weekday power profile is higher than it had been during 2009, the data of which was used in the simulation of the system reported in Chapter 6. This is attributed to changes in climatic conditions and a declining effort of mine management to schedule the cooling system operations to match its actual demand. It is shown that the entire cooling system operates at full load for the entire day during weekdays. This will lead to a further increase in saving potential from the variable-flow strategies and is therefore not a concern.

The intuitive method to measure energy savings of a system is to directly compare energy consumption of pre- and post-implementation time periods. However, the electrical energy use of industrial plants such as cooling systems is typically found to be a function of weather and/or production variables that frequently change between pre- and post-implementation periods. If these changes are not accounted for, reported savings will be erroneous (Kissock and Eger 2008).

A principal method used to measure savings included in all verification standards (US Department of Energy 1996, Efficiency Valuation Organisation 2002, ASHRAE 2002, Den Heijer 2009) relies on regression modelling. A verified weather and production-dependent regression model is typically developed from pre-implementation data. Such a model suitably correlates the system electrical energy usage to the weather and production data. It can then be used to calculate the daily system energy usage from daily weather and production data to within a suitable degree of accuracy.

After strategy implementation the model is used to calculate what the daily system energy usage would have been had there been no energy saving intervention. Each data point of the pre-implementation baseline is then scaled proportionally so that the average of the scaled baseline is equal to the average calculated by the regression model while still reflecting the baseline profile.

Daily energy savings calculated by the standard regression model method can therefore be found as follows (Du Plessis et al. 2013a):

$$\dot{W}_{savings} = \dot{W}_{scaled\ baseline} - \dot{W}_{post-implementation} \quad (39)$$

This method is only valid if there are no major changes in the system or production before and after implementation, since this would influence the accuracy of the regression model.

Logged system and power data for the entire 2011 was made available to the auditing body to develop a suitable regression model for the Kusasalethu surface cooling system. It is important that winter and summer months are included to ensure that the model adequately takes seasonal influences into account.

The most accurate regression model was found to correlate the daily average electrical power usage of the combined cooling system to the daily average ambient, hot water dam and chilled water dam temperature, as well as water flow from the chilled water dam. The model was developed and verified by the independent body and subsequently approved by Eskom (Eskom Corporate Services Division 2011). Verification was also done by the author by developing a separate regression model using the same data and comparing it to the results of the independent body. The models were shown to correlate exactly. The verified baseline scaling correlation found is given by Equation 40 (Du Plessis et al. 2013a).

$$\dot{W}_{scaled\ baseline} = (47.695)(T_{amb}) + (603.903)(T_{hot\ dam}) - (37.739)(T_{chilled\ dam}) + (2.639)(\dot{m}_{chilled\ dam}) - 11797.384 \quad (40)$$

The procedure to calculate energy savings daily after strategy implementation involves calculating the scaled baseline power from Equation 40 using weather and production data. The actual measured power is then subtracted to give the true saving, as given by Equation 39. The purpose of the baselines shown in Figure 76 is to compare the daily load profile of the baseline (scaled up or down according to the results of Equation 40) to the actual profile. This influences the cost saving realised because Eskom MegaFlex electricity tariffs vary for different periods of the day (Eskom 2012).

The independent body contracted by Eskom was also responsible for verifying that all data used to measure savings and performance parameters is correct and accurate. Various site visits and system audits were conducted in this regard. Historic data obtained from the mine for the purpose of regression modelling, baseline development and pre-implementation comparisons was compared to sample readings taken during site visits to verify their validity. Similarly, independent power loggers were used to log and compare sampled data to the power values measured by the mine power meters. No major discrepancies were found in any of the verification processes.

Energy measurement standards emphasise the importance of comparing equivalent pre- and post-implementation data. Therefore all condonable data such as mine production shutdowns were disregarded when analysing and comparing the various effects of implementing the variable water flow strategies. Only when thermal loads, ambient conditions and other factors relevant to the specific points under discussion were equivalent, was the data used. All the data used and discarded, as well as the methods of comparison discussed in Chapter 8, were verified by the independent body as being acceptable and duly accurate.

It can be concluded that the processes of data acquisition and saving verification were suitably verified. The measuring equipment was shown to be appropriately accurate, the uncertainty of calculated values was investigated and the process of data measurement was verified. Furthermore, the detailed methods of validating savings as well as all data used in the investigation were verified. The analysis of data and realised savings discussed in the next chapter was therefore done using verified results and methods.

7.5 Conclusion

An overview of the equipment installed to implement the proposed energy saving strategy at Kusasaletu was given. It was shown that the developed strategy requires equipment that suitably adheres to mine standards and does not interfere with mine cooling system infrastructure, production or operation methods during installation or commissioning.

It was shown how the developed REMS-CATM energy management system was customised and implemented on the Kusasaletu cooling system. The control strategies described generically in Chapter 5 were set up for all the equipment to be controlled and monitored from a central location. Relevant hardware, platform and system control and integration details were given.

Finally, the processes of data acquisition and saving verification were described. The measuring equipment was shown to be suitably accurate, the uncertainty of calculated values was investigated and the process of data measurement was verified. The methods of validating energy savings and data used in the investigation were also verified by an independent auditor as suitably accurate.

It is concluded that the developed variable water flow strategy and its energy management system were implemented on a full scale on the Kusasaletu surface cooling system. Measurement and verification methods were also developed to acquire suitable *in situ* experimental results from the implementation. The verified experimental results obtained will be discussed in the next chapter to validate the proposed and implemented variable-flow energy saving strategies.