The Development and Implementation of a Remote Energy Management System (Rems) for Pumping at Kopanang Mine

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SYNOPSIS

Energy management and specifically the optimised use and control of electric energy resources will in future become more and more important, especially for the large consumers of electricity, such as mines. There is an obvious expected increase in the demand for electricity in South Africa. This will put pressure on the electricity suppliers to provide electricity as requested, as the surplus of electricity in future will not be as readily available as in the past. This in turn will place further responsibility on mine management to have in place the necessary control measures to ensure the optimised use of energy resources, in order to minimise costs without jeopardising Safety, Health and Environmental related objectives.

A project at Kopanang Gold Mine followed previous work that entailed the development of a procedure to determine daily control schedules that optimises the electricity cost of mine cooling systems and in the case of Koponang, with specific reference to pumping of water. The purpose of this project was to develop and deploy an automated system that implements these optimised schedules. The result is the so-called remote energy management system (REMS). The motivation for automating the whole system is to ensure consistency in the control actions and to have remote control access to the pumping systems on the mine.

The REMS system comprises four components. The first component is the optimised schedule. Second is a means of communicating the schedule from a remote computer to a Supervisory Control And Data Acquisition (SCADA) computer at the mine. The third part of the optimised system is the REMS software itself. This software generates discrete control signals for the pumps and turbines based on the optimised schedule and certain operational statuses in the pumping system. The last component provides an interface between the REMS software and the SCADA system.

The system was implemented successfully at Kopanang mine. It allows remote monitoring and control of pumping at the shaft and it relieves the burden from operators to decide how to schedule the various pumps. With REMS it is possible to minimise electricity costs on a sustainable basis. It can be concluded that REMS provides an easy and efficient way to control mine pumping systems and it is envisaged that it can in future be included in the total electricity use management of the complete cooling system for a mine. The inclusion of REMS has lead to substantial savings in the electricity bill at Kopanang mine.

INTRODUCTION

The Remote Energy Management System (REMS) uses novel simulation models and a specific simulation technique that allows for the mathematical optimisation of large cooling systems. The objective function of the optimisation procedure is the daily electricity cost of the Ventilation, Cooling and Pumping (VCP) systems at Kopanang mine and for the purpose of the study concentrated on the pumping. By making use of the inherent storage capacities in the cooling system the electrical load is shifted to off-peak times. The final result of the optimisation procedure is an optimised schedule, which indicates the optimum on or off status of VCP components on an hourly basis for the next 24 hours.

The inputs for the optimisation procedure are the predicted chilled water demand and the hourly electricity prices for the next day. The procedure assumes that all dams are 65% full at the start of the day. Constraints on the optimisation procedure include dam level limits at Kopanang. Assuming that all these predictions hold true, the operators (employees) should be able to follow the optimised schedule without transgressing operational constraints like the maximum water temperature of the chilled water or the maximum and minimum dam level limits. However, the actual conditions may deviate from the predicted conditions due to the following factors:

- VCP equipment like pumps might become unavailable;
- The water demand might change for a variety of reasons;
- The ambient conditions (temperature and humidity) might deviate significantly from the predicted conditions;
- The operators might not have been able to ensure that all dam levels reach a predetermined value (typically 65%) at the end of each 24-hour period.

The purpose of this project was therefore to develop and deploy an automated system that implements optimised control schedules at Kopanang mine. The result is the so-called Remote Energy Management System (REMS). The motivation for automating the whole system is to ensure consistency in the control actions and to have remote control access to the pumping system.

The REMS system comprises four components. The first component is the optimised control schedule. Second is a means of communicating the schedule from a remote computer to a SCADA computer at the mine. The third part is the REMS software itself. This software generates discrete control signals for the pumps and turbines based on the optimised schedule and certain operational statuses in the cooling system.

BACKGROUND

Kopanang is an Anglogold Limited mine, situated in the Free State province of South Africa. The mine is part of the Anglogold Vaal River group, which comprises four mines. It is an underground mine with 6700 employees, including contractors. The mine hoists 226 000 tons of reef per month at an average grade of 7 g/ton. In 2000 the average cash cost to mine an ounce of gold was US$ 215 per kilogram. The total electricity cost per ounce was approximately US$ 8.50, which is 4% of the total cost [1].

The temperature of the rock at Kopanang mine is relatively high. Chilled water is used to cool the air that is supplied to the underground workings. Chilled water is also used for drilling (machine water). All used water collects in the settler dams on level 75 *(Figure 1)*. From here it is pumped with four electrical pumps to level 38 hot water dam. The pump station at level 38 comprises 2 turbine pumps and three electrical pumps. The electrical pumps on both levels are powered by 2000 kW motors. The turbine pumps are powered by the flow of cold water from the surface to the cold-water dam at level 38. The hot water at level 38 is pumped to the surface, where it is cooled before being sent underground again. Operators in a surface control centre supervise the main pump stations on level 75 and level 38 with a SCADA system.

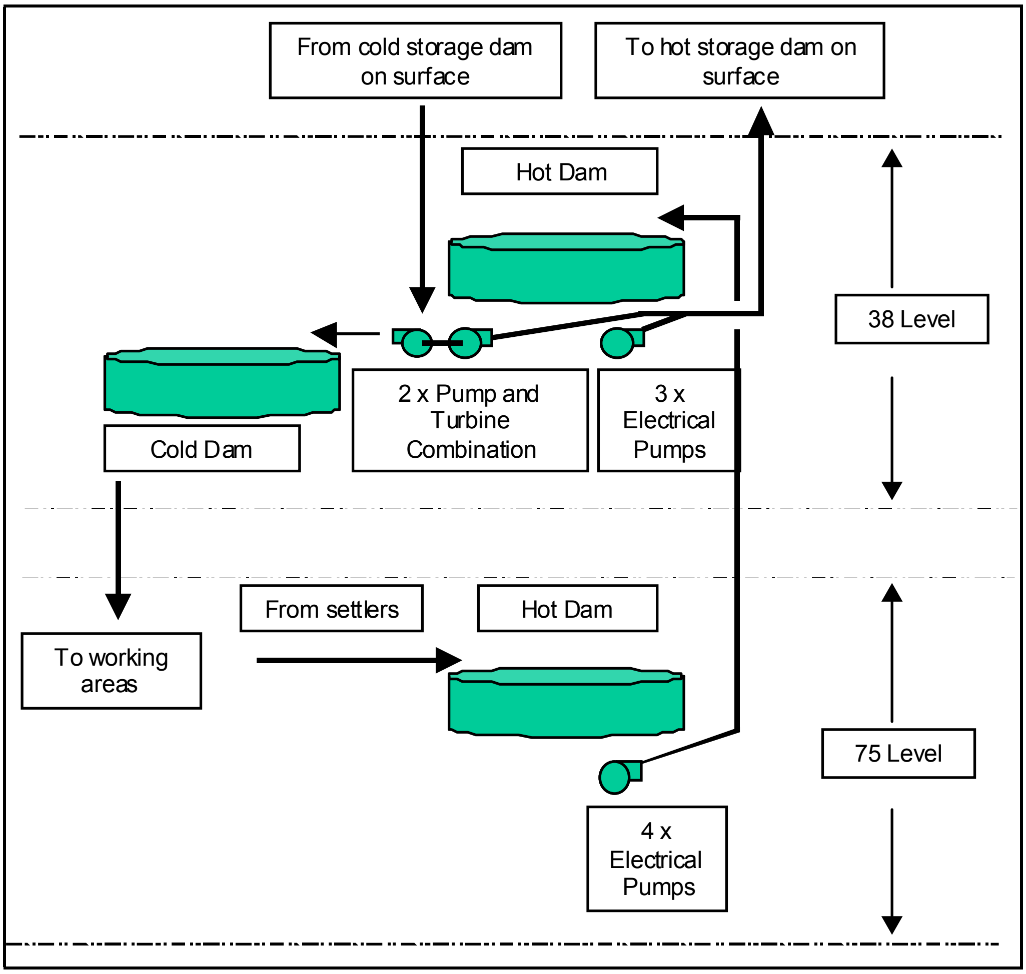

Figure 1
Underground pump system at Kopanang mine

ENERGY MANAGEMENT SYSTEMS

For any energy management system to be effective there are certain objectives that should be met, they are:

- A control system that schedules VCP equipment twenty-four hours in advance. It should optimise the total electricity cost of an installation. The optimisation to be based on predicted electrical loads and electricity prices in a 24-hour forward horizon;
- A control system that does the optimisation of the VCP schedules remotely from the installation. The optimised schedules to be sent daily via any suitable communication network;
- A control system that can easily be implemented;
- A control system that can be incorporated with any existing control or monitoring system;
- A control system that does not change the set points of the VCP system but that primarily uses the inherent capacitance in the system to shift load;
- A control system that can be used for VCP systems of underground mines as well as commercial buildings and industries.

DEVELOPMENT OF REMS

REMS is a computer and software system comprising four main components**.** ***Figure 2*** shows the flow of information in REMS. It also shows the relationship between the four components of this invention. The information flow starts with software (item 1) that produces a daily, optimised schedule (items 2,5,7) for all VCP equipment in a specified installation. The software itself is not part of REMS. The optimised schedule (items 2,5,7) represents the first component of this patent.

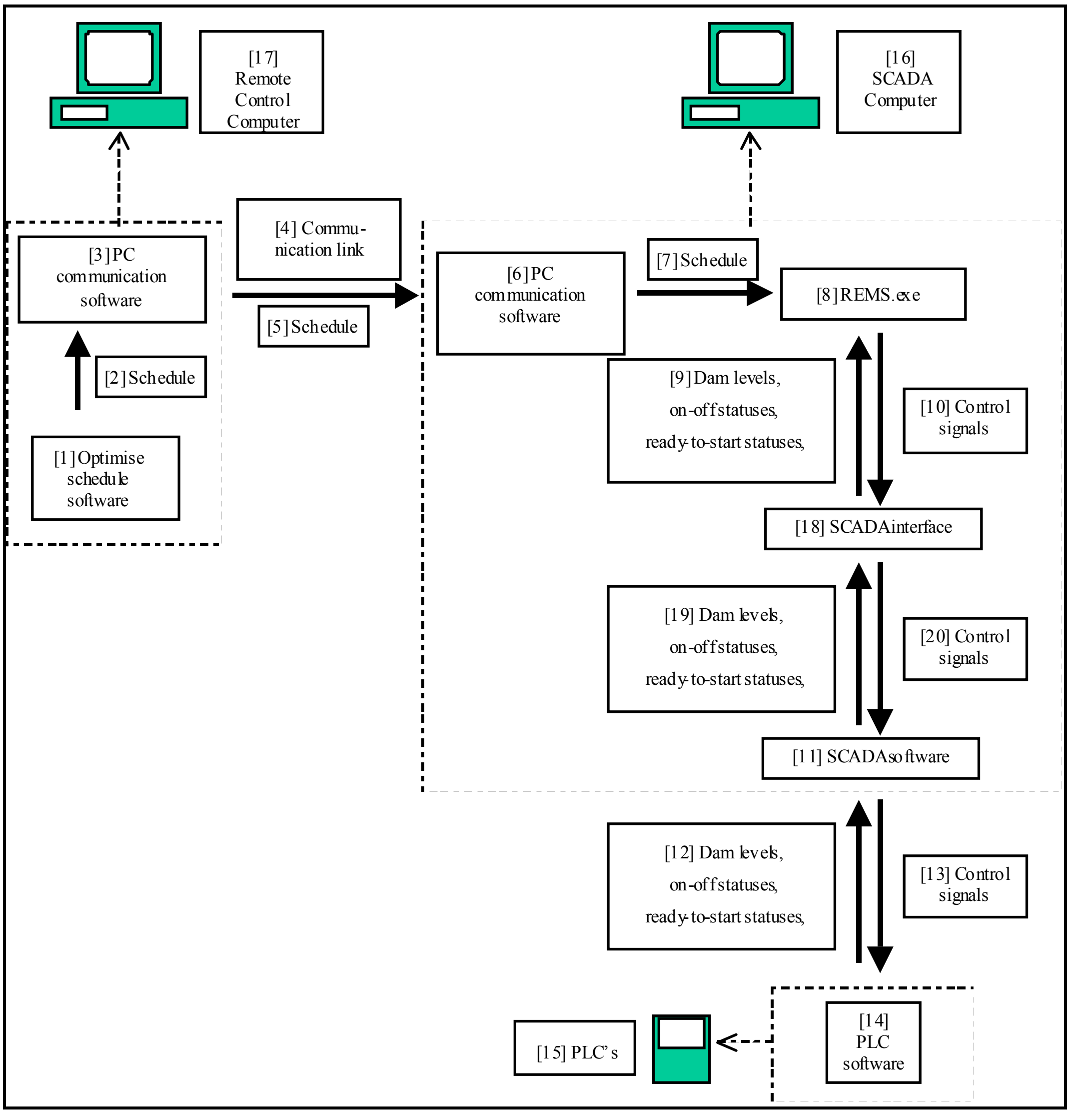

Figure 2
Schematic diagram of information flow of REMS

The schedule has to be communicated daily from the remote control computer (item 17) to the SCADA computer (item 16). A commercial PC communication package (items 3,6) called *PcAnywhere version 10.5* together with two modems and a land-based telephone line (item 4) is used to transfer the file between the two computers [2]. Operators conduct the daily file transfer actions. The process of transferring the optimised schedule file (items 2,5,7) between the two computers constitutes the second component of this patent.

Component three of this system is the REMS software itself (item 8). The inputs for this software are the optimised schedule (items 2,5,7) and the operational parameters of all VCP equipment (item 9) from the SCADA software (item 11) including dam levels, on-off statuses of VCP equipment and ready-to-start statuses of VCP equipment. The output for the REMS software (item 8) is control signals (item 10) for all the VCP equipment. Control signals are generated every two minutes.

The last component of this invention is an interface (item 18) between REMS and the SCADA software on the SCADA computer. This interface forms an integral part of the SCADA software. Most SCADA software packages offer several different data interface options to the user. *Citect 5.4,* a SCADA software package, has an integrated compiler and programming language called *Cicode* [3]. This option was used to construct the SCADA interface. The interface simply reads and writes text files that are shared with REMS. Control signals (item 10) are conveyed with a single text file. This file is updated by REMS and read by the SCADA interface every two minutes. There is a six second phase change between the read and write actions to prevent clashing. The control signal file contains an integer for every piece of VCP equipment that is controlled by this invention. A zero signifies that no control action should take place; a one tells the SCADA to switch the specific equipment on while a minus one tells it to switch it off. In a similar way dam levels, on-off statuses and ready-to-start statuses (item 19) of all relevant equipment are updated in three separate text files.

Control signals (item 20) and operational information (item 19) is transferred internally between the SCADA software (item 11) and the SCADA interface (item 18). The SCADA software translates the control signals (item 20) to electronic pulses (item 13) that are sent via a data network to the PLC's (item 15) that perform the local control of the individual VCP components.

The REMS software itself, the third component of this system, is discussed in detail in the following paragraphs. REMS focuses on the calculation of discrete control signals for pumps and turbines that form part of an VCP system of an underground mine. On a daily basis REMS receives an ideal optimised schedule for pumps and turbines for the next day. The schedule minimises electricity cost and ensures that minimum and maximum dam levels are not violated. The calculation of the schedule assumes a certain water demand profile and that all pumps and turbines will be available throughout the day. Another assumption is that the dam levels at the start of the day (0h00) are between 60% and 70%. Obviously these assumptions are not always true. REMS attempts to adhere to the optimised schedule as far as possible, but it deviates from the ideal schedule as soon as one of the dam level limits is threatened.

REMS was programmed with *Borland Delphi 6.0* [4]. It has a very simple one-page graphical user interface ***(Figure 3)***. There are only three options on the user interface: to start and stop the control, to switch the focus to the SCADA program (which is also running on the computer) and to close REMS. The user interface shows a diagram of all the relevant pumps turbines and dams. Dam levels and pump statuses are also shown.

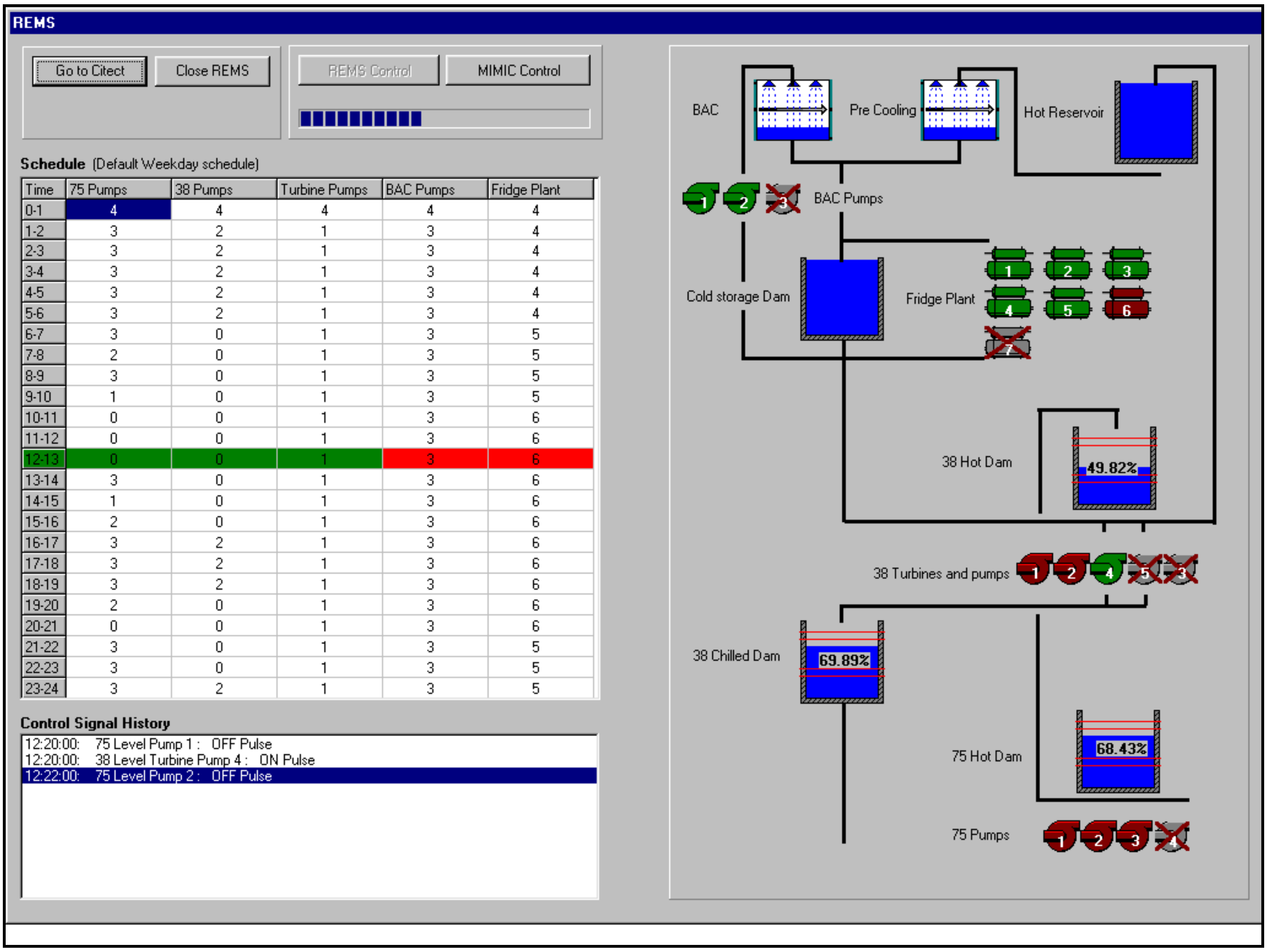

Figure 3
User interface of REMS

REMS is organised into two threads (computer processes that run more or less independently). The main thread allows the user to interact with the user interface. The second thread is responsible for two aspects: updating the dam levels and pump statuses on the main form (user interface) and calculating the required pump control signals. The procedure loads the optimised schedule file into memory. This takes place daily at 2 minutes to midnight or whenever REMS has just been started. Every six seconds the dam levels, on-off statuses of the pumps and turbines and the ready-to-start statuses of the same are read into memory. Thereafter the so-called real-time schedule is calculated. This schedule is identical to the optimised schedule when all relevant dams levels are within limits. If not, the schedule is adjusted accordingly. Following this the main form (user interface) is updated with the dam levels, statuses and real-time schedule.

Every two minutes new control signals, if any, are calculated. The main input for this calculation is the real-time schedule. If, at a certain pump station, the current number of working pumps are more than the specified number of the real-time schedule then one or more pumps should be de-activated. The pumps at one level must be activated or de-activated one at a time to limit the resulting stresses on pipe-work. The order in which the pumps at one level are activated or de-activated depends on their priorities. Priorities are calculated weekly according to the amount of hours the pumps have worked in the preceding week. The overall effect is to ensure that all pumps accumulate an equal amount of hours throughout the year. Other safeguards that are used include a measure to prevent one pump receiving two start signals in a period less than five minutes. Also, a pump will not receive a start signal if its status is not ready-to-start. The operator at the SCADA computer will see any deviations from the real-time schedule on the user interface. Red rectangles indicate deviations while green rectangles mean that there are no deviations ***(Figure 3)***. Deviations will occur if there are not enough pumps in working order to meet the demands of the real-time schedule.

The complete control logic algorithm can be summarised by saying that it takes the optimised schedule for the pumps and turbines on a certain level and then uses it to calculate a real-time schedule based on the dam levels of the cold and hot dams on the same level as well as the hot dam level on the level above. If all the relevant dam levels are within limits the real-time schedule should be identical to the optimised schedule.

IMPLEMENTATION AND RESULTS

The REMS system was implemented at Kopanang mine during March 2002. The implementation consisted of the following:

- Studying the working of the control of the underground pumping system. Operators controlled individual pumps via a SCADA system. The operators had to use their own judgement to schedule the pumps to ensure that dam levels are not violated and that the pumps do not operate during times of peak prices;

- During the study of the system certain control parameters were noted that had to be implemented in REMS. A list of these control parameters is shown in Annexure A. Some of the parameters were gathered from how the operators were operating the system in the past, while others had to be determined with a trial-and-error method. The dam level limits were selected such that they do not overlap and thereby cause interference in the control logic. Furthermore, they were selected to avoid pump damage due to frequent switching. The names of the parameters are self-explanatory;

- The existing PLC's at the pump stations will act to protect the dams and pumps in the event of a failure by REMS;

- The study of the system included an investigation into the configuration of the existing SCADA system. This had to be done to enable the interfacing between REMS and the SCADA system. In the end the SCADA's built-in programming language was used to write a suitable data interface between the two systems;

- The operators were trained in the working of REMS. This consisted of a short training session with the four operators. Thereafter 24-hour telephone support was given for approximately two weeks. At that time the operators were sufficiently comfortable with the system.

Selected results from REMS are shown in ***Table 1***. The selected weeks represent the four best weeks since REMS was implemented. It is believed that the level of performance for this period is sustainable in the long run since most teething problems have been ironed out. It can be seen from ***Table 1*** that REMS was active for more than 80% of the time. The question arises: why would it be inactive at all? There are two basic reasons: an initial lack of trust of the operators in REMS and planned and unplanned maintenance of certain related equipment.

Starting with the first reason: the operators sometimes want to interfere with the control of the pumps if the dam levels are not where they think it should be. Some time was spent with the operators explaining the whole concept to them and to make adjustments to the algorithms of REMS to accommodate some of the valid concerns of the operators. Concerning the second reason: planned and unplanned maintenance on the pumps, dams or the SCADA computer usually necessitates REMS to be inactive.

Table 1 shows that the optimised schedule was followed on average for more than 80%. This means that the actual number of pumps that are active are equal or less than the daily-optimised schedule for more than 80% of the time ***(Figure 5)***. Possible reasons why this figure is not 100% are:

- REMS was not on;
- The water flow from the settlers was higher than expected;
- The dam levels were not at the expected level (60% to 70%) at the start of the day due to any of the reasons above;
- Not enough pumps were available at certain times. This is normally not a big problem as can be seen in the last column of ***Table 1.***

Figure 5 shows the so-called real time schedule (this is the optimised schedule that is adjusted when a dam violates one of its level limits). The real time schedule and the actual number of active pumps should closely agree at all times. Possible reasons for deviations would include when the pumps do not respond to on or off signals due to communication problems or when there are not enough pumps available. The next section discusses planned enhancements of REMS.

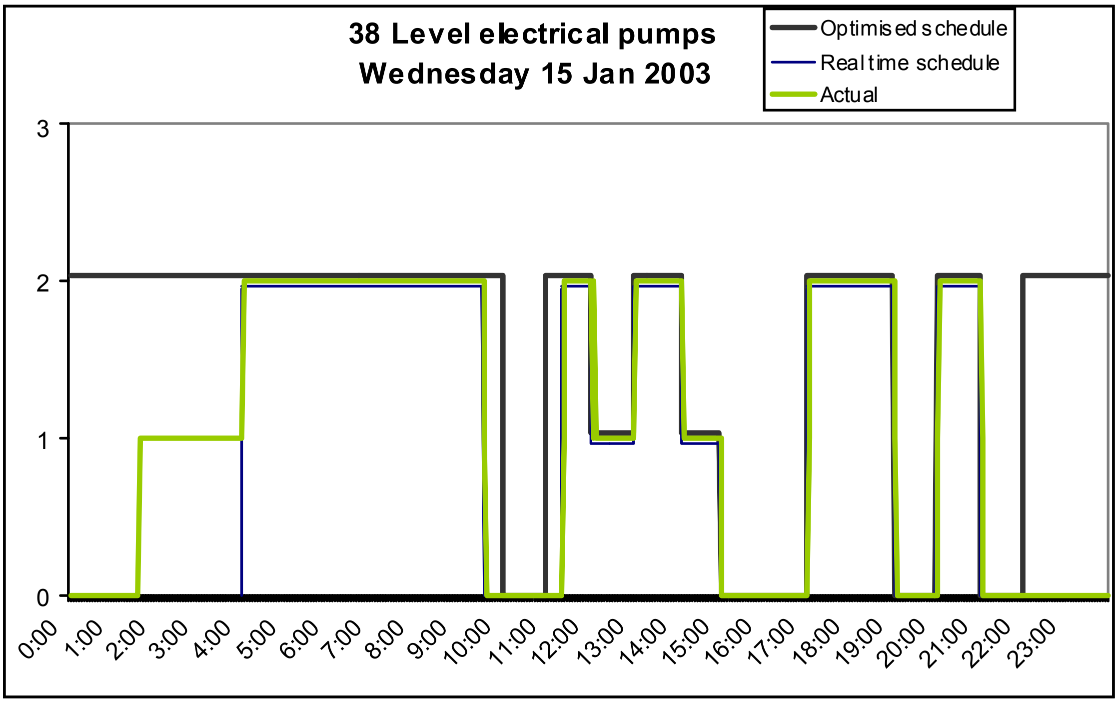

Figure 5
REMS results for 38 level pumps on 15 Jan 2003

Week	REMS On (%)	Optimised Schedule Followed (%)	Pump Availability (%)
1-7 July 2002	80	87	99
8-14 July 2002	80	89	100
7-12 Jan 2003	93	83	97
13-19 Jan 2003	94	77	99

Table 1
REMS results

PLANNED REMS ENHANCEMENTS

In general REMS works satisfactorily. A number of enhancements are planned for REMS:

- The main improvement would be to increase the flexibility of REMS by recalculating the optimised schedule every hour. This would take the dam levels and pump availabilities at the specific time into account. This would have the added benefit of preventing the dams from violating their minimum and maximum level limits, which causes increased pump switching;
- REMS should be expanded so that it can accommodate the refrigeration plants and the mine winder system.

CONCLUSION

A new remote energy management system for pumping was successfully developed and implemented at Koponang mine. It automatically controls the pump system of a mine according to an optimised schedule that is calculated daily. The system is safe since the operators can override it at any time. A number of enhancements are envisaged for REMS. The most important one is that it should be made general and robust to such a degree that a technician can set it up. This would allow a much wider use of the program and would allow the benefits to be shared across the deep mining industry. Currently the feasibility of applying the REMS concept for the control of airflow and air cooling requirements (directly related to pumping requirements) to optimise the air cooling power required for any hot underground working environment, is also under investigation.

ACKNOWLEDGEMENTS

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APPENDIX A

CONTROL PARAMETERS FOR REMS

NO	DESCRIPTION	DAM LEVEL [%]
1.	**Level 38 Hot dam limits**	
	MinLevelLow38Hot	41
	MinLevelHigh38Hot	45
	MaxLevelLow38Hot	75
	MaxLevelHigh38Hot	85
	MinLevelEndOfDay38Hot	62
	MaxLevelEndOfDay38Hot	68
2	**Level 38 Hot dam limits as used by level 75 pumps.** If level 38 hot dam gets too full level 75 pumps must switch off	
	MaxLevelLow38HotFor75Pumps	86
	MaxLevelHigh38HotFor75Pumps	92
3	**Level 38 Hot dam limits, as used by level 75 pumps.** If level 38 hot dam gets too empty at least one of the level 75 pumps must switch on- this is to prevent level 38 dam from emptying and then tripping the turbine. We prevent this since the turbine pump represents "free" energy	
	MinLevelLow38HotFor75Pumps	38
	MinLevelHigh38HotFor75Pumps	40
4	**Level 38 Hot dam limits, as used by level 38 turbines.** If level 38 hot dam gets too low, level 38 turbines must switch off.	
	MinLevelLow38HotFor38Turbines	35
	MinLevelHigh38HotFor38Turbines	37
5	**Level 75 Hot dam limits**	
	MinLevelLow75Hot	35
	MinLevelHigh75Hot	45
	MaxLevelLow75Hot	75
	MaxLevelHigh75Hot	85
	MaxLevelEndOfDay75Hot	67
	MinLevelEndOfDay75Hot	63
6	**38 Chilled dam limits**	
	MaxLevelLow38Chilled	80
	MaxLevelHigh38Chilled	90
	MinLevelLow38Chilled	35
	MinLevelHigh38Chilled	45

Table 1
Control parameters for REMS at Kopanang