A performance-centered maintenance strategy for industrial DSM projects

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ABSTRACT

Title: A performance-centered maintenance strategy for industrial DSM projects

Key terms: Energy management; demand-side management; performance-centered maintenance; industrial sector

South Africa’s electricity supply is under pressure because of inadequate capacity expansion in the early 2000s. One of the initiatives funded by Eskom to alleviate the pressure on the national electricity grid was an aggressive demand-side management (DSM) programme that commenced in 2004. A positive outcome of the DSM programme was that the industrial sector in South Africa benefited from the implementation of a relatively large number of DSM projects. These DSM projects reduced the electricity costs of industrial clients and reduced the demand on the national electricity grid.

Unfortunately, the performance of industrial DSM projects deteriorates without proper maintenance. This results in wasted savings opportunities that are costly to industrial clients and Eskom. The purpose of this study was therefore to develop a maintenance strategy that could be applied, firstly, to reverse the deterioration of DSM project performance and, secondly, to sustain and to improve DSM project performance. The focus of the maintenance strategy was to obtain maximum project performance that translated to maximum electricity cost savings for the client.

A new performance-centered maintenance (PCM) strategy was developed and proven through practical experience in maintaining industrial DSM projects over a period of more than 60 months. The first part of the PCM strategy consisted of developing a new strategy for the outsourcing of DSM project maintenance to energy services companies (ESCOs) on the company group level of the client. The strategy served as a guideline for both ESCOs and industrial clients to implement and manage a group-level DSM maintenance agreement successfully.

The second part of the PCM strategy consisted of a simplified method that was developed to identify DSM projects where applying a PCM strategy would increase or sustain electricity cost savings. The third part of the PCM strategy consisted of practical maintenance guidelines that were developed to ensure maximum project performance. It was based on the plan-do-check-act cycle for continuous improvement with an emphasis on the monitoring of DSM project performance. The last part of the PCM strategy consisted of various alternative key performance indicators that should be monitored to ensure maximum sustainable DSM project performance.

The PCM strategy was evaluated by implementing it on ten different DSM projects. The results showed that applying a PCM strategy resulted in an average increase of 64.4% in the electricity cost savings generated by these projects. The average implementation cost of the PCM strategy was 6% of the total benefit generated through it. This indicated that implementing the PCM strategy was a cost-effective manner to ensure that maximum performance of DSM projects was maintained sustainably.

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ABBREVIATIONS

3-CPFS	3-Chamber pipe feeder system
BAC	Bulk air cooler
CA	Cooling auxiliaries
CBM	Condition-based maintenance
CBR	Cost-benefit ratio
CCEB	Current condition evaluation-based
COP	Coefficient of performance
CPI	Consumer price index
DSM	Demand-side management
DWA	Department of Water Affairs
ESCO	Energy services company
EMS	Energy management system
FCPB	Future condition prediction-based
GSM	Global system for mobile communications
GUI	Graphical user interface
GWS	Government Water Scheme
IDM	Integrated Demand Management
IPMVP	International Performance Measurement and Verification Protocol
KPI	Key performance indicator
LEC	Levelised energy cost
M&V	Measurement and verification
MYPD	Multi-year price determination
NEMA	National Electrical Manufacturers Association
NERSA	National Energy Regulator of South Africa
NMEC	National Monitoring and Evaluation Centre
OAN	Optimisation of air networks
OCGT	Open-cycle gas turbine
OPC	Object linking and embedding for process control
PA	Performance assessment
PCM	Performance-centered maintenance
PDCA	Plan-do-check-act
PID	Proportional, integral, derivative
PLC	Programmable logic controller
PT	Performance tracking
SCADA	Supervisory control and data acquisition
SMS	Short message service
SSM	Supply-side management
TBM	Time-based maintenance
TOU	Time-of-use
TPM	Total productive maintenance
VRESAP	Vaal River Eastern Subsystem Augmentation Project

VSD	Variable speed drive
WSO	Water supply optimisation

UNITS OF MEASURE

GW	Gigawatt
J	Joule
kg	Kilogram
kg/s	Kilogram per second
kPa	Kilopascal
kW	Kilowatt
kWh	Kilowatt-hour
K	Kelvin
ℓ/s	Litre per second
Ml	Megalitre
MW	Megawatt
MWh	Megawatt-hour
Pa	Pascal
R	Rand
t	Tonne
$	United States dollar
°C	Degree Celsius

SYMBOLS

C_p	Specific heat constant
P	Power
Q	Thermal energy
ν	Specific volume
ΔT	Differential temperature
ΔP	Differential pressure
η	Efficiency
μ	Joule–Thompson coefficient

CHAPTER 1. INTRODUCTION

1.1 Electricity situation in South Africa

1.1.1 Introduction

The majority of power stations in South Africa are owned and operated by Eskom, the South African public electricity utility. Eskom's power stations account for approximately 95% of all electricity produced in South Africa [1]. The remaining 5% of electricity generated in South Africa originates from industrial and private users that generate their own electricity and from a small number of independent power producers. Eskom's total net maximum capacity was 41 995 MW in 2014 [1]. Figure 1 shows Eskom's electricity sales for the 2013/2014 financial year [1]. Note that the industrial sector, which includes mining, accounted for 39% of Eskom's total electricity sales.

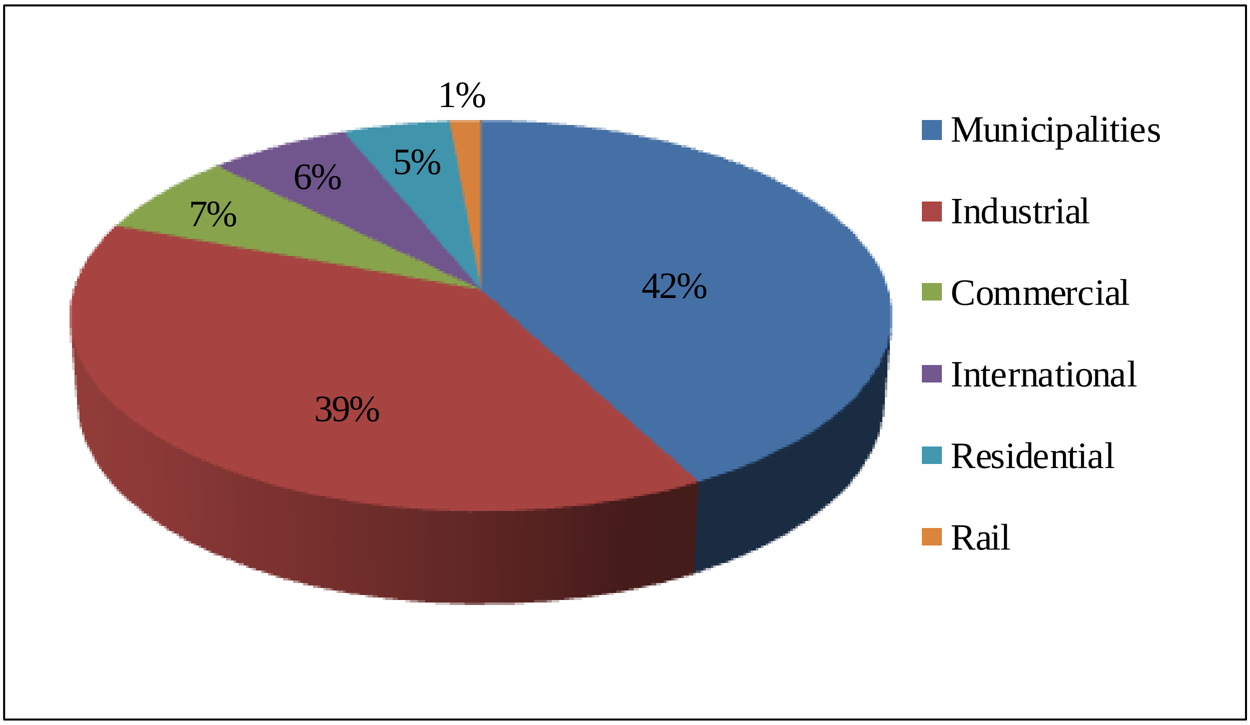

Figure 1: Eskom's electricity sales for the 2013/2014 financial year

1.1.2 Eskom generation capacity and demand

Figure 2 shows how Eskom's generation capacity expanded between 1954 and 1999 with the construction of new power stations [2]. Figure 2 also shows the growth in demand as well as the magnitude of the reserve margin, which is the difference between total installed capacity and total demand. It is important to notice the increase in the reserve margin from 1979 until 1992. This resulted from a combination of Eskom's aggressive expansion programme and a lower than expected increase in electricity demand. This adequate reserve margin had the effect that Eskom did not announce any new capacity-expansion projects between 1983 and 2003.

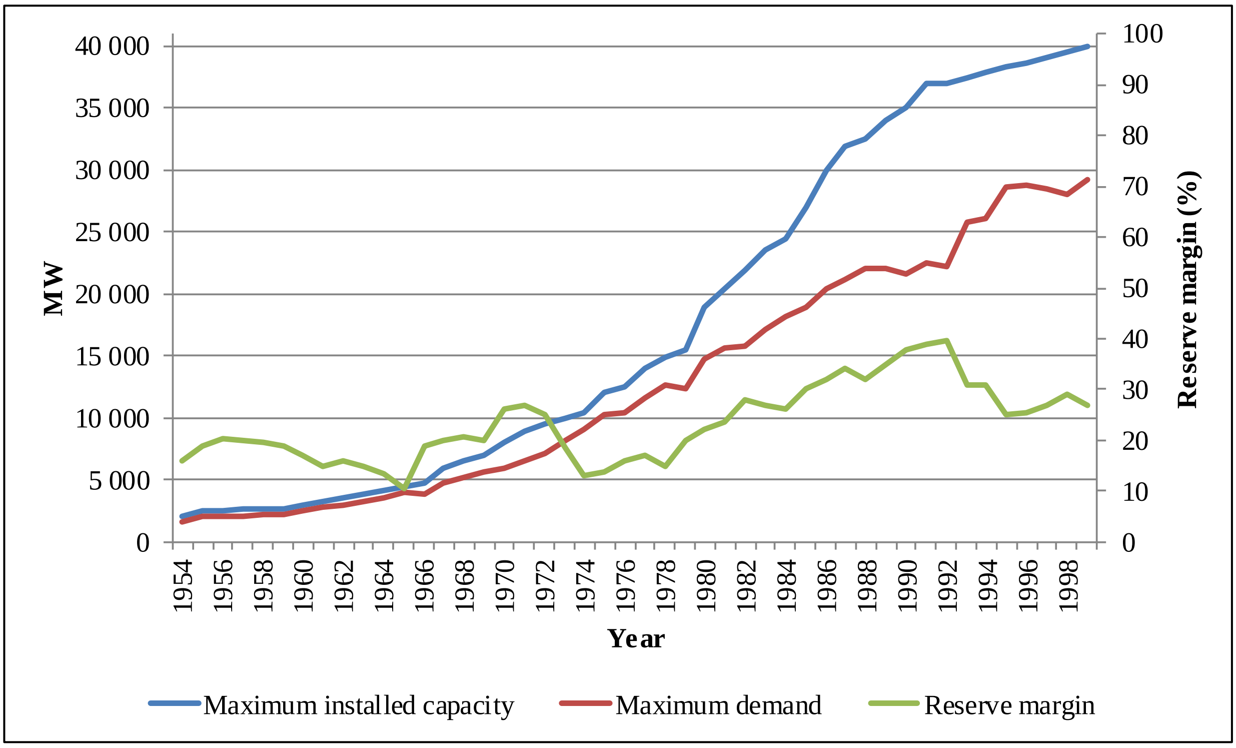

Figure 2: Eskom installed capacity versus maximum demand between 1954 and 1999 (Adapted from [2])

Figure 3 compares the minimum international recommended reserve margin of 15% with Eskom's reserve margin from 1999 to 2011 [3], [4]. The reserve margin reduced from 31% in 1994 to only 7% in 2007 [5]. An adequate reserve margin is required to ensure that electricity supply is not interrupted in the event of planned or unplanned loss of generation capacity or sudden increases in demand.

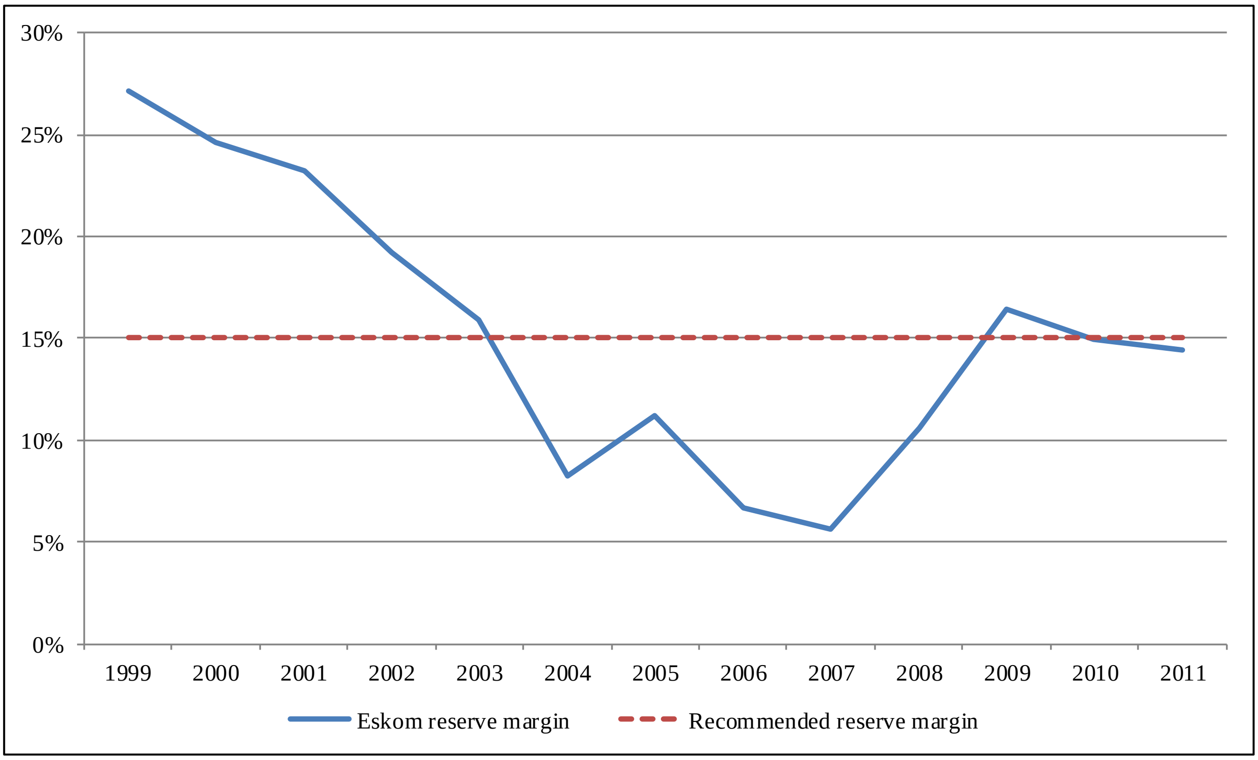

Figure 3: Reduction in Eskom's reserve margin between 1999 and 2011 (Adapted from [5])

Eskom's focus shifted from increasing generation capacity to electrification during the 1990s. Various studies conducted between 1998 and 2003 indicated the definite need for expanding Eskom's generation capacity [6], [7]. Rob Surtees, the manager of Eskom's Integrated Demand Management (IDM) programme between 1994 and 1999, indicated in 1998 that demand in South Africa would surpass capacity by 2007 [6]. Surtees' prediction is graphically displayed in Figure 4 [6]. This prediction would probably have been correct if the Gourikwa and Ankerlig open-cycle gas turbine (OCGT) power stations were not commissioned in May 2007.

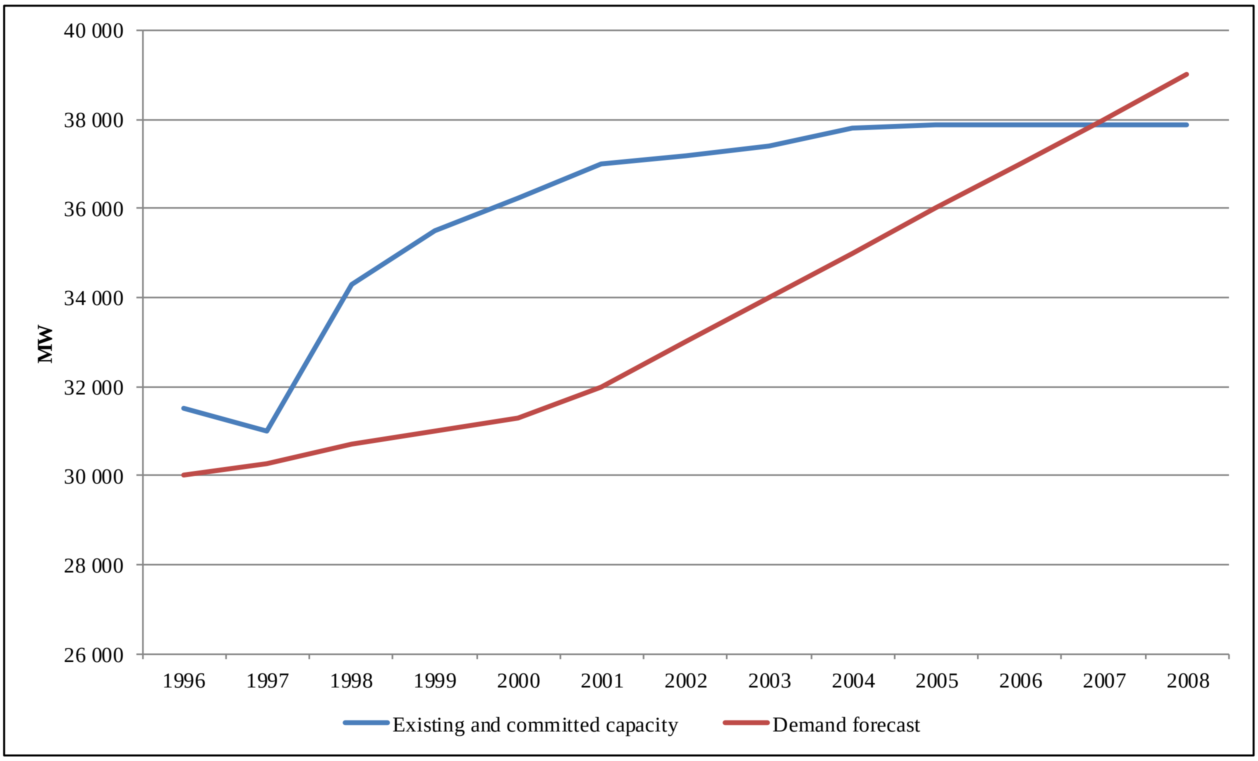

Figure 4: Surtees's 1998 forecast of Eskom's capacity and maximum demand (Adapted from [6])

Eskom realised in 2004 that a solution with a short lead time was required to ensure that enough electricity would be available during the winter of 2007 [8]. Constructing OCGT power stations was identified as a viable solution because OCGT power stations could be erected with a lead time of two to three years, which was significantly less than the lead time of eight to ten years for coal-fired or nuclear power stations [8].

OCGT power stations are implemented specifically to generate electricity during peak periods and emergencies. They can run at full load within five minutes, which is significantly less time than the start-up time that is required for a coal-fired power station [9]. The disadvantage of OCGT power stations is their high operating cost, which make continuous operation unfeasible. The operating cost per generated kWh electricity for Gourikwa and Ankerlig are more than nine times higher than that of coal-fired power stations in South Africa [10].

The construction of Gourikwa and Ankerlig OCGT power stations could be seen as an interim solution to the problem of matching peak supply with demand. It became apparent that a long-term solution was required. Eskom therefore announced a new generation capacity-expansion programme in 2005 at a total estimated cost of R340-billion [11]. The aim of the programme is to expand South Africa's generation capacity by 17 120 MW [11]. Table 1 shows the major projects included in Eskom's capacity-expansion programme from 2005 to 2019 [12]–[14].

Table 1: Major projects included in Eskom's capacity-expansion programme (2005–2019)

Project	Plant type	Project type	Capacity (MW)
Gourikwa	OCGT	New development	740
Ankerlig	OCGT	New development	1 332
Medupi	Coal-fired	New development	4 764
Kusile	Coal-fired	New development	4 800
Grootvlei	Coal-fired	Recommissioning	1 180
Komati	Coal-fired	Recommissioning	1 000
Arnot	Coal-fired	Capacity expansion	2 220 (original) + 300 (expansion)
Camden	Coal-fired	Recommissioning	1 430
Ingula	Pumped storage	New development	1 332
Sere	Wind energy	New development	100

The most important projects included in Eskom's current capacity-expansion programme are the Medupi and Kusile coal-fired power stations. The construction of Medupi power station began in 2007 [1]. Upon completion it will be the largest dry-cooled coal-fired power station in the world and the fourth-largest coal-fired power station in the southern hemisphere [15]. The first of Medupi's six 800 MW turbines is expected to become operational by mid-2015 [16].

1.1.3 Load shedding in 2008 and 2014

In January 2008, the inevitable happened. Electricity demand in South Africa surpassed available capacity. The result was a series of countrywide load-shedding interventions that occurred between January and April 2008. Table 2 provides interesting figures regarding demand and supply on 28 January 2008. A shortfall 4 589 MW occurred, which is almost equal to the planned generation capacity of Eskom's new Medupi power station [17].

Table 2: Demand and supply on 28 January 2008

Capacity	**MW**
Eskom capacity and imports	39 855
Operating reserves	1 800
Planned maintenance	3 715
Minus	
Breakdowns (for example boiler ruptures)	4 235
Reduction in capacity (for example wet or insufficient coal)	2 694
Total capacity available for supply	27 411
Expected demand	32 000
Shortfall	**4 589**

After the electricity crisis of 2008, Eskom managed to avoid load shedding for a period of almost five years. A major contributing factor to the avoidance of load shedding in this period was that the growth in electricity demand was lower than expected [18], [19]. This could be partially attributed to large electricity tariff increases and electricity-intensive industries, such as smelters, relocating their activities to countries with lower electricity rates than South Africa [20]. The first load shedding since April 2008 occurred on 6 March 2014 [21]. Load shedding became more frequent in November 2014 after the collapse of a coal storage silo at Majuba power station [22].

1.1.4 Eskom tariff history

Figure 5 compares Eskom's average annual tariff increase and the consumer price index (CPI) since 2006 [23], [24]. It is evident that since 2008, Eskom's average annual tariff increases were significantly higher than inflation. The major reason for the high tariff increases was to pay off the debt of the capacity-expansion programme. For multi-year price determination (MYPD) 3 for 2013–2018, Eskom applied for an average annual electricity tariff increase of 16%. NERSA only granted an annual increase of 8% that was implemented for the first two years of MYPD3 (2013–2014). On 3 October 2014, NERSA announced that Eskom was granted permission to raise electricity prices for 2015/16 with 12.69% [25].

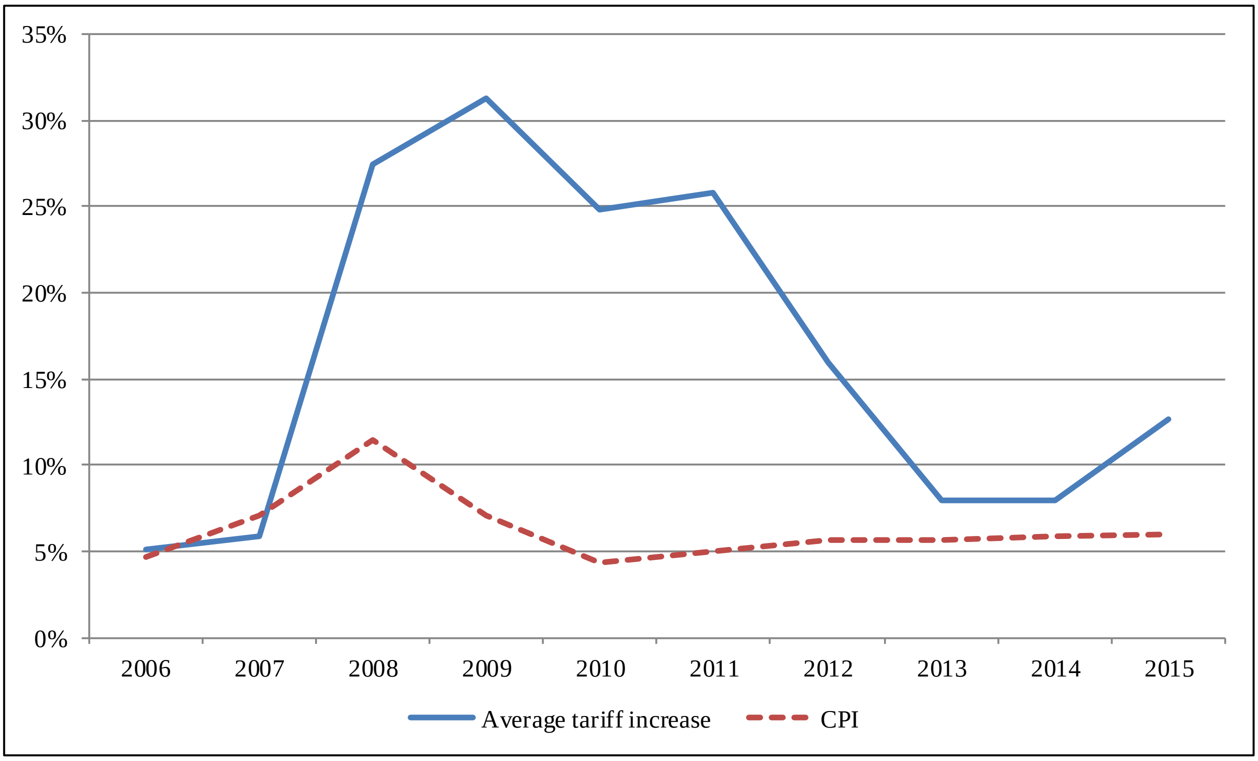

Figure 5: Average Eskom tariff increase versus CPI (2006–2015) [23]

1.1.5 Conclusion

It is evident from the information supplied in Sections 1.1.1 to 1.1.4 that South Africa has an electricity supply problem. The supply problem can be summarised as follows:

- Delays in the expansion of Eskom's generation capacity resulted in a shortage of electricity.
- The shortage of electricity resulted in load shedding that negatively affected the South African economy.
- Eskom's generation capacity expansion programme is funded by electricity tariffs that are increasing above inflation.

1.2 Industrial DSM

1.2.1 Introduction

Section 1.1 provided background information on the electricity situation in South Africa. It was shown that the expansion of Eskom’s electricity generation capacity was necessary in order to provide a sustainable power supply. Capacity expansion is an example of a supply-side management (SSM) initiative. SSM is viewed as the actions that are taken to ensure that electricity is efficiently generated and distributed [26].

It is important to manage the reserve margin properly. An excessively large reserve margin is a waste of money and other resources, while a very low reserve margin can lead to load shedding or a total collapse of the electricity supply system. One mechanism to balance supply with demand is demand-side management (DSM). DSM is considered to be the opposite of SSM and is defined as the planning, implementing and monitoring of activities that reduce electricity consumption or alter the electricity usage pattern on the side of the user [27], [28].

The fact that historically South Africa had some of the lowest electricity tariffs in the world made the country an attractive option for the establishment of energy intensive industries [29]. The low tariffs also had the effect that some electricity users in South Africa were not energy conscious. These two factors have contributed significantly to the scope for DSM in South Africa.

1.2.2 Eskom IDM

One of the first DSM measures to be implemented by Eskom to change the demand pattern was the introduction of time-of-use (TOU) tariffs in 1991 [30]. Eskom’s first DSM plan, which listed various DSM opportunities, was released in 1994 [31]. Eskom’s DSM programme was officially initiated in the last quarter of 2002 with the establishment of a DSM fund [32]. The programme started to gain momentum in 2004 with the signing and implementing of the first DSM projects [32]. A DSM project is an initiative implemented either to reduce electricity consumption or to alter the electricity usage pattern on the demand side.

Eskom IDM is a dedicated division within Eskom that was established to ensure the short-term security of South Africa’s electricity supply. Eskom IDM aims to achieve this through coordinating and consolidating various initiatives that are directed at optimising energy use and balancing supply with demand [33].

These initiatives include funding for the implementation of DSM projects in the industrial sector in South Africa. These DSM projects are often implemented by energy services companies (ESCOs) on the infrastructure of industrial companies. An ESCO is a business that specialises in implementing DSM projects and providing energy-related services. At the start of 2013, there were more than 200 ESCOs registered with Eskom [33]. The impact of Eskom's DSM programme for the financial years 2005 to 2014 was a peak electricity demand reduction of about 4 000 MW [1].

1.2.3 Measurement & verification

All DSM projects funded by Eskom IDM are subjected to an independent measurement and verification (M&V) process, which is based on the International Performance Measurement and Verification Protocol (IPMVP) [34]. The M&V process was designed to provide an accurate assessment of the impact of DSM projects. A special Eskom division, Energy Audits, was established within Eskom's Assurance and Forensic Department to manage M&V processes. Energy Audits outsources M&V work to South African universities in order to increase the independence and credibility of the M&V process.

The impact of a DSM project is determined by the equation below:

$$Project\ impact = Baseline - Actual \qquad (1)$$

The baseline is the electricity consumption prior to the implementation of a DSM project. A fixed baseline can only be used in the absence of factors (other than the DSM project) that affects electricity consumption patterns. For the majority of DSM projects, the baseline needs to be scaled/adjusted in order to make provision for external factors such as production output and environmental conditions that could affect electricity consumption [34].

The concept of baseline scaling is illustrated in Figure 6 [34]. The green line represents the actual electricity consumption. During the baseline and implementation periods, the electricity consumption varies due to the influence of external factors. In the performance assessment (PA) period, a reduction in electricity consumption is observed. The challenge is to accurately calculate the reduction in electricity consumption because of the project. This can only be done by correctly scaling the baseline to reflect the power consumption accurately before the implementation of the DSM project by considering the effect of external factors that affects electricity consumption.

Baseline scaling is often done through regression models that estimate electricity consumption according to the correlation between electricity consumption and one or more independent variables. It is important to use an accurate baseline-scaling technique in order to calculate the true impact of a DSM project.

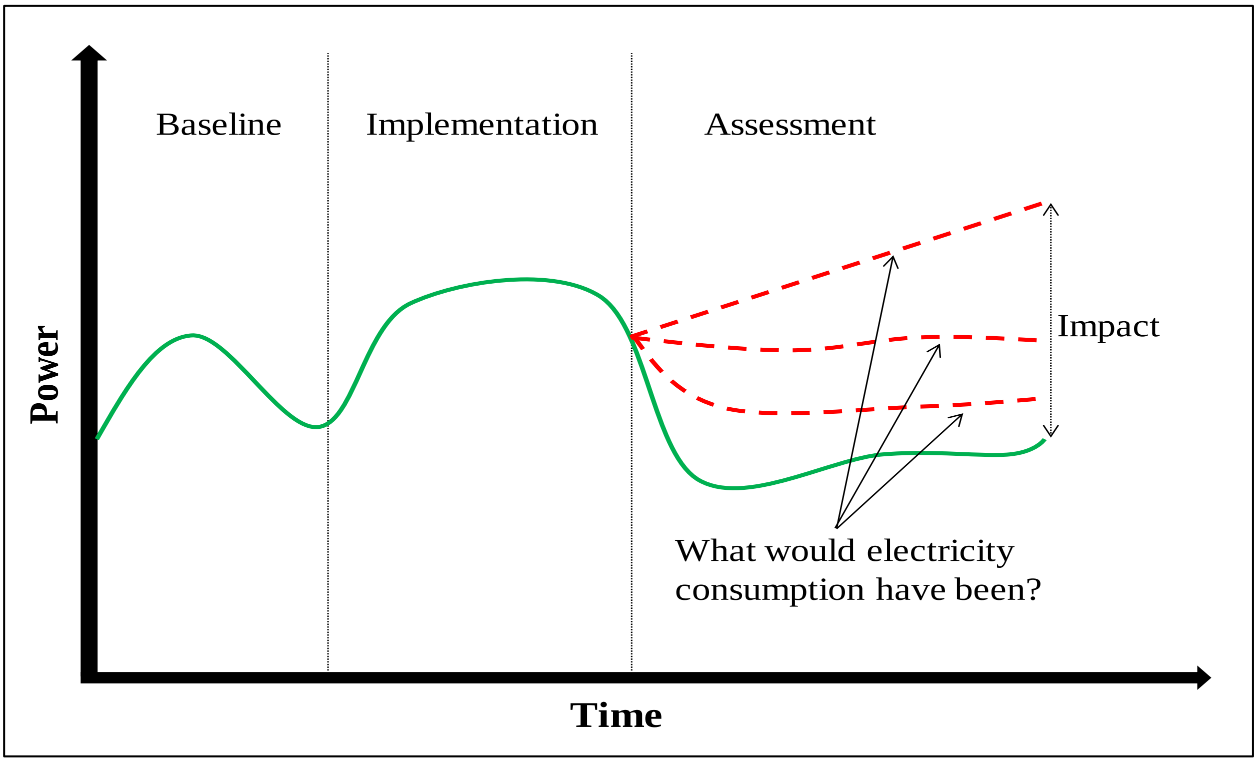

Figure 6: Baseline scaling (Adapted from [34])

1.2.4 TOU tariff structure

Figure 7 shows the total demand profiles on typical summer and winter days in South Africa [1]. It is evident that there are two peaks in demand – a morning peak and an evening peak. It is important to notice that the evening peak is significantly higher than the morning peak. Eskom IDM therefore focuses their efforts primarily on reducing the evening peak.

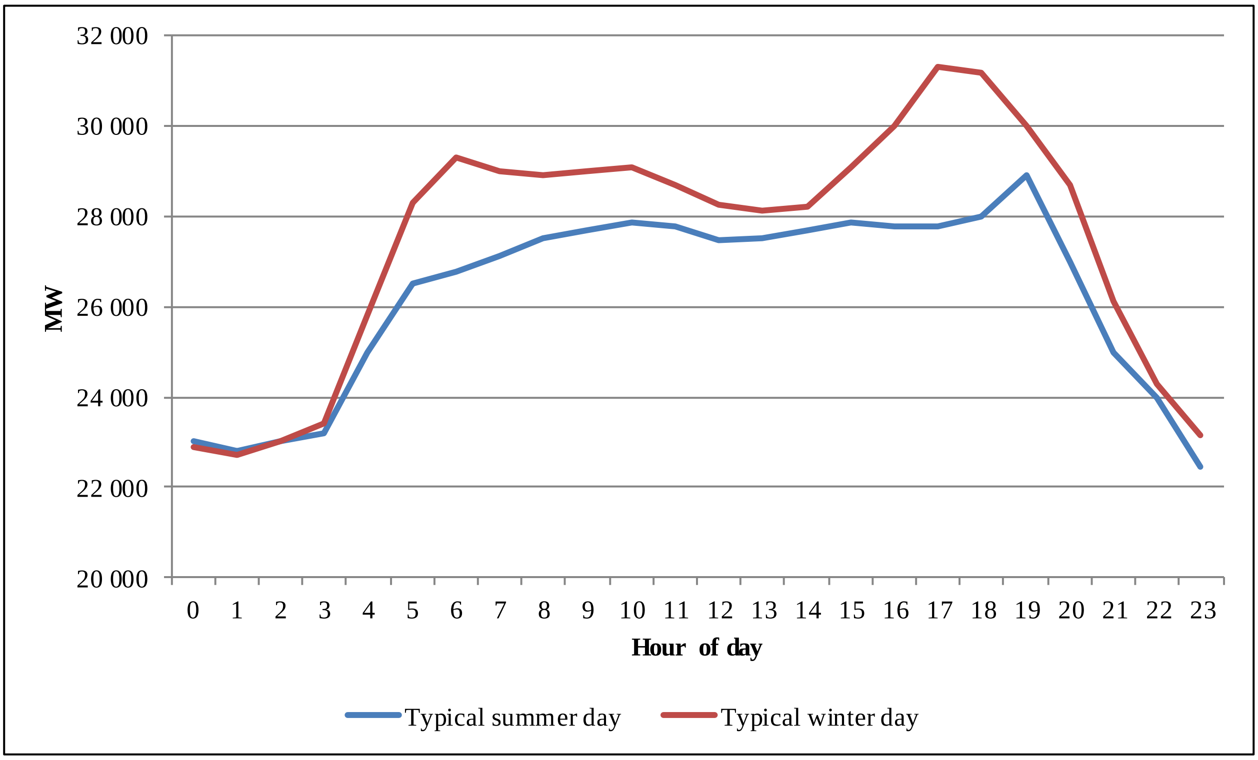

Figure 7: Electricity demand pattern on typical summer and winter days (Adapted from [1])

Balancing supply with demand is important to ensure that electricity is generated efficiently. Ample generation capacity needs to exist in order to satisfy the peak demand for electricity. Unlike OCGT powers stations, coal-fired power stations cannot be started and shut down for short periods to provide electricity in peak periods only. Since the majority of South Africa's electricity is provided by coal-fired power stations, the unbalanced supply and demand leads to a situation where excess electricity is generated in off-peak periods. Apart from the electricity storage capabilities of the Palmiet and Ingula pumped storage schemes, the majority of the excess electricity generated in South African cannot be stored. This means that the majority of excess electricity generated during off-peak periods is wasted.

Balancing supply with demand through DSM initiatives is more cost effective than applying SSM initiatives such as using peak generation facilities, for example, OCGT power stations or pumped storage schemes. One of the DSM initiatives employed by Eskom is a TOU tariff structure. The purpose of the TOU tariff structure is to encourage users to minimise their electricity usage in peak periods in order to flatten the demand curve. This is obtained by varying electricity tariffs during different times of the day, with off-peak tariffs being considerably lower than peak tariffs.

One of the TOU tariff structures employed by Eskom is the Megaflex tariff structure. A large number of industrial electricity users use the Megaflex tariff structure. Figure 8 shows the TOU periods of the

Megaflex tariff structure. Three different periods are defined, namely, peak, standard and off-peak periods [35].

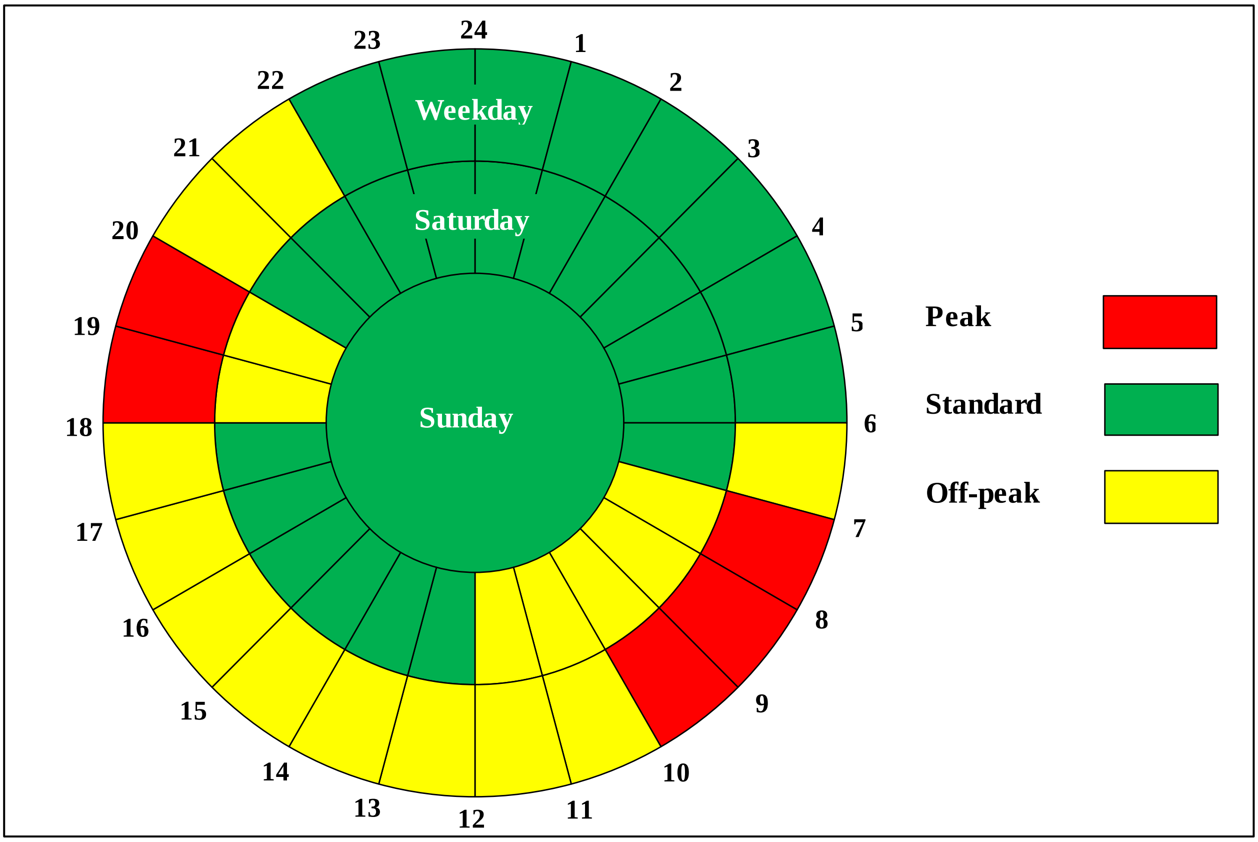

Figure 8: Eskom's TOU periods for the Megaflex tariff structure (Adapted from [35])

Table 3 shows the 2014/2015 Megaflex tariffs in cent per kWh for customers located within 300 km of Johannesburg with a supply voltage ranging from 500 V to 66 kV [35]. The three different tariffs correspond to the TOU periods (peak, standard and off-peak) indicated in Figure 8. It is important to notice the significant differences between peak and off-peak tariffs during the high-demand season (June to August).

Table 3: Eskom Megaflex tariffs (2014/2015) (Adapted from [35])

	Megaflex tariffs, VAT included (c/kWh)		
	Peak	**Standard**	**Off-peak**
High demand (Jun-Aug)	247.88	75.09	40.78
Low demand (Sep-May)	80.86	55.65	35.31

1.2.5 Different DSM implementation methods

DSM initiatives can be classified in three different categories, namely, energy efficiency, load shifting or peak clipping. Energy efficiency is the overall reduction of electricity usage. Figure 9 shows the impact of a typical energy-efficiency project over a period of 24 hours.

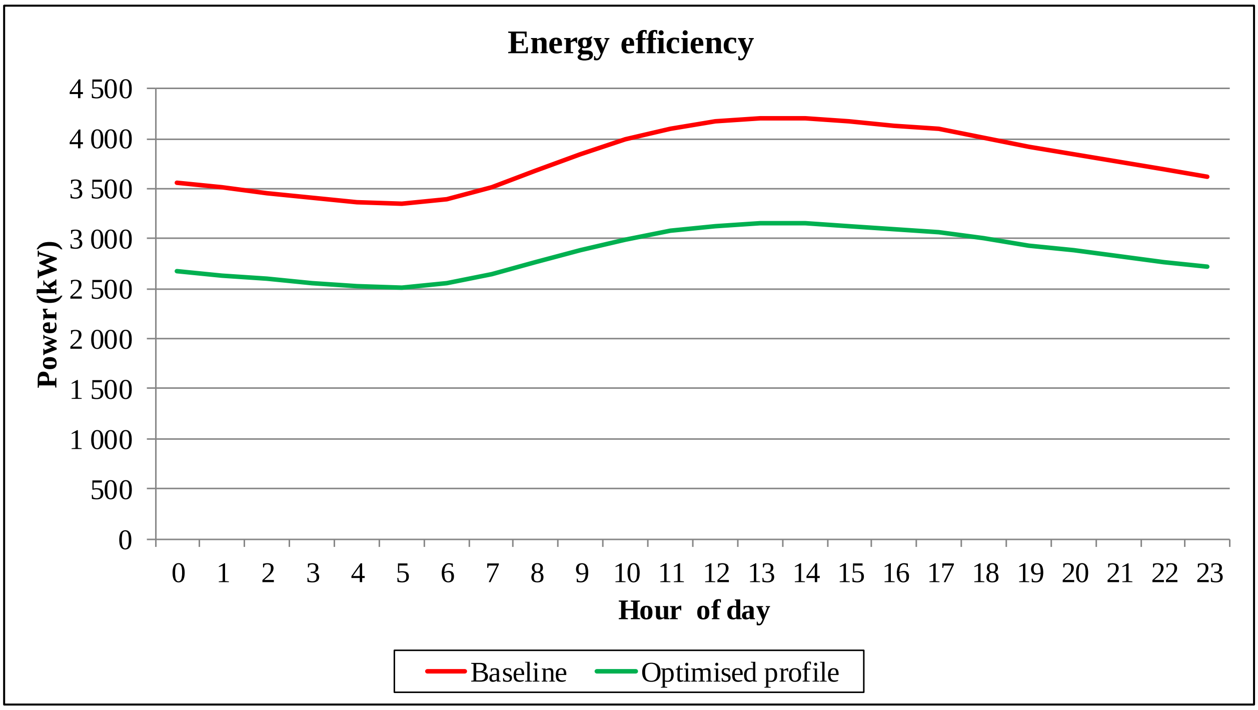

Figure 9: Energy efficiency

Load shifting entails shifting electricity usage from peak periods to off-peak periods. Figure 10 illustrates the impact of a typical load-shifting project. The electricity usage is reduced during the evening peak period (18:00–20:00), but increased during off-peak periods.

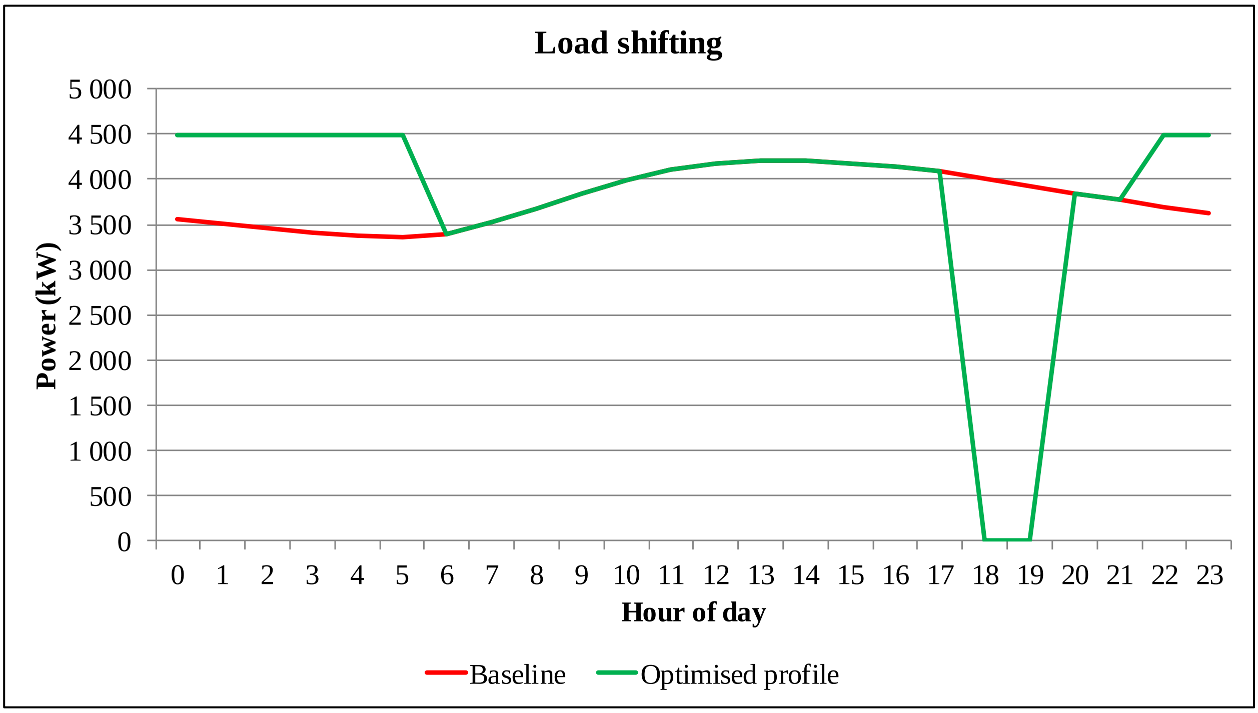

Figure 10: Load shifting

Peak clipping is the reduction of energy usage during peak periods only. Figure 11 illustrates the impact of a peak-clipping project where the electricity consumption is reduced in the evening peak period (18:00–20:00).

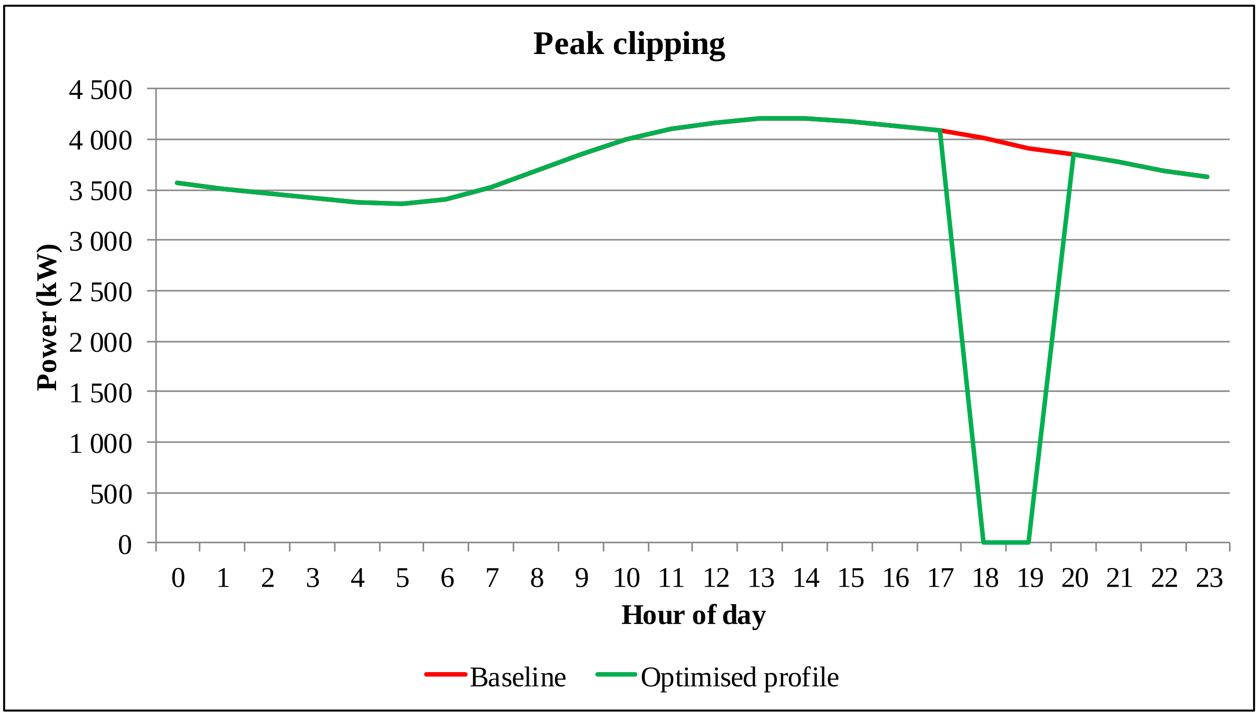

Figure 11: Peak clipping

The aim of energy efficiency and peak-clipping interventions is to reduce electricity consumption. Load-shifting interventions entail shifting load from peak periods to off-peak periods, while the total electricity consumption remains unaffected.

1.2.6 Electricity cost-savings impact of DSM project types

Implementing DSM projects can drastically reduce the electricity costs of the industrial client. Table 4 shows the average cost savings that can be achieved by implementing the three different DSM project types based on an average hourly impact of 1 MW. The cost savings were calculated according to the 2014–2015 Megaflex tariff structure for customers located within 300 km of Johannesburg with a supply voltage ranging from 500 V to 66 kV [35].

Please note that the peak-clipping cost saving was calculated on the assumption that load reduction took place during the Eskom evening peak (18:00–20:00) only, which resulted in an electricity saving of 2 MWh. The load-shifting impact was calculated on the assumption that load would be shifted during both the Eskom morning (07:00–10:00) and evening (18:00–20:00) peaks. The energy-efficiency cost saving was calculated on the assumption that power would be reduced by an average of 1 MW, which is equal to an electricity saving of 24 MWh over a 24-hour period.

Table 4: Electricity cost savings of different DSM project types (2015/2016 tariffs)

Project type	Average impact	Average annual cost saving
Energy efficiency	1 MW	R5 418 114
Peak clip	1 MW	R7 792 014
Load shift	1 MW	R1 227 488

1.2.7 DSM implementation cost

The cost of implementing a DSM project is significantly lower than the cost of constructing a power station. Figure 12 compares the rand/MW cost of implementing a DSM energy-efficiency project with the cost of constructing different types of power stations [1], [36]–[40] in South Africa. It is evident that implementing a DSM project costs significantly less than constructing various types of power stations.

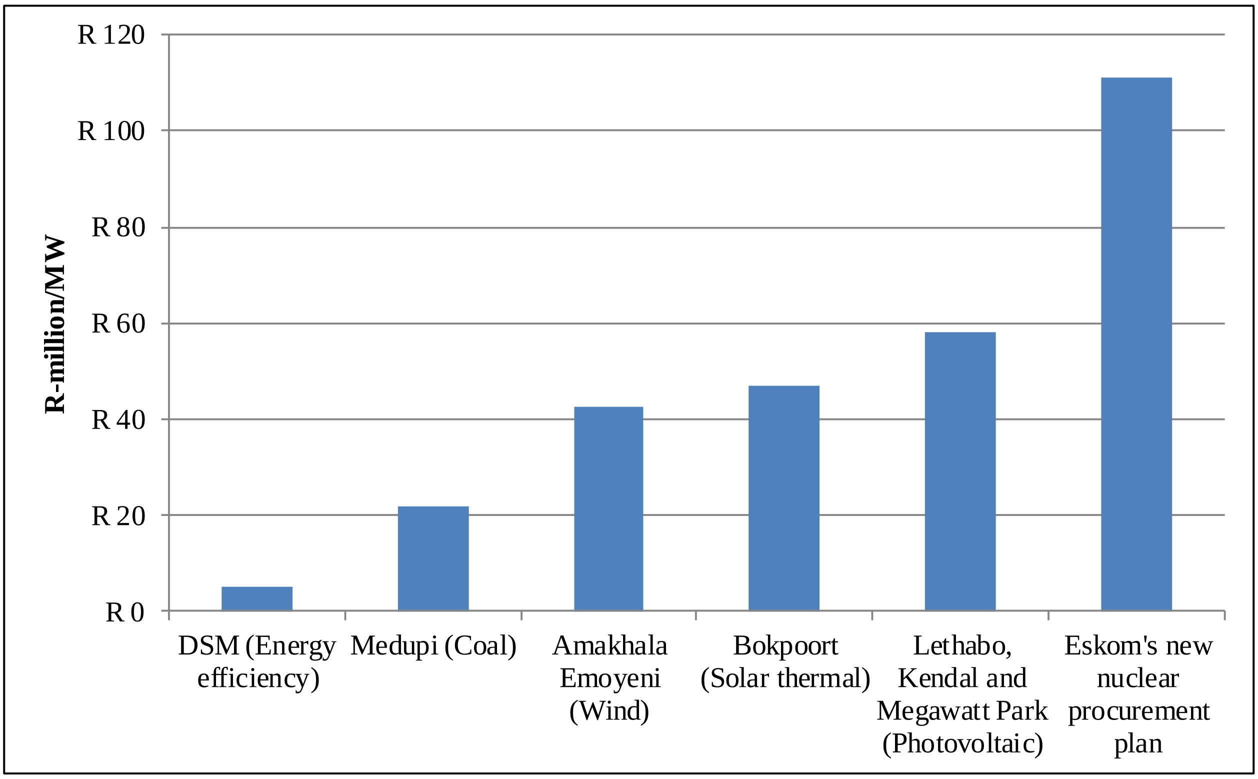

Figure 12: Cost comparison of implementing an energy-efficiency DSM project and constructing various types of power stations [1], [36]–[40]

1.2.8 Environmental impact

Successful DSM projects have a positive impact on the environment. Energy efficiency and peak-clipping projects reduce the amount of electricity used by the customer, while load-shifting projects can reduce carbon dioxide emissions of power stations [41]. Every MWh of energy saved by a DSM project is one less MWh that needs to be supplied by the electricity utility. An energy-efficiency project with an average impact of 1 MW typically results in a 6 000 MWh energy saving over a period of one year. Table 5 shows the environmental impact of a 1 MW energy-efficiency project over a one-year period [42].

Table 5: Environmental impact of a 1 MW energy-efficiency project

Item	Factor	Projected annual MWh saving	Annual reduction	
Coal use	0.54	6 000	3 240	t
Water use (ℓ/kWh)	1.37	6 000	8 220	Ml
Ash produced	155.00	6 000	930 000	t
Particulate emissions	0.31	6 000	1 860	t
CO_2 emissions	0.99	6 000	5 940 000	t
SO_x emissions	7.93	6 000	47 580	t
NO_x emissions	4.19	6 000	25 140	t

Implementing DSM projects results in reduced emissions and it is therefore more environmentally friendly than constructing and operating any type of power station, including renewable energies such as solar and wind. Using less electricity will always outperform any form of electricity generation in terms of environmental impact.

1.2.9 Lead times

When compared to the construction of power stations, another advantage of DSM projects is shorter lead times. A DSM project has an average implementation time of 12 to 18 months, while a coal-fired power station such as Medupi has a lead time of more than seven years. Implementing a DSM project is also faster than constructing an OCGT power station, which has lead times ranging from two to three years.

1.2.10 Levelised cost of energy

The running and maintenance costs of DSM projects are also significantly less than that of any type of power station. The levelised cost of energy (LEC) is the price at which electricity must be produced to break even over the lifetime of the implementation. LEC is defined in the formula below [43]:

$$LEC = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t + C_t + D_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad (2)$$

Where

LEC	=	*Levelised energy cost*
n	=	*Life of system*
I_t	=	*Investment expenditures in the year t*
M_t	=	*Operations and maintenance expenditures in the year t*
F_t	=	*Fuel expenditure in the year t*
C_t	=	*Carbon cost in the year t*
D_t	=	*Decommissioning cost in the year t*
r	=	*Discount rate*
E_t	=	*Electricity generation in the year t*

Table 6 compares the LECs of different technologies. The values were obtained from figures published by the United States Energy Information Administration for new generation coming online in the USA 2019 [44]. Table 6 also shows the LEC of an energy-efficiency DSM project implemented in South Africa. This figure was calculated with 2015 implementation and maintenance costs adjusted with an annual inflation figure of 6% and converted to US dollars. The LEC of the energy-efficiency DSM projects was calculated with the following factors:

n = *5 years*

I_t = *\$540 907*

M_t = *\$54 000*

F_t = *\$0*

C_t = *\$0*

D_t = *\$0*

r = *0*

E_t = *8 760 MWh*

Table 6: Comparing DSM and various electricity generation technologies in terms of LEC (US$/MWh)

Plant type	Minimum	Average	Maximum
Conventional coal	87.0	95.6	114.4
OCGT	106.0	128.4	149.4
Nuclear	92.6	96.1	102
Wind	71.3	80.3	90.3
Solar photovoltaic	101.4	130.0	200.9
Solar thermal	176.8	243.1	388
Hydroelectric	61.6	84.5	137.7
Energy-efficiency DSM	n/a	**17.3**	n/a

The results of Table 6 shows that the LECs of renewable energies such as solar photovoltaic and solar thermal plants are in fact higher than the LEC of coal-fired power stations. The LECs of hydroelectric and wind power stations are, however, lower than that of coal-fired plants. The energy-efficiency DSM project with an LEC of only 17.3 outperforms all the electricity generation technologies by a significant margin.

1.3 Need for this study

Rising production costs make it imperative for South African industries to implement DSM initiatives as a cost-reduction measure. The higher-than-inflation increases in electricity prices in recent years (see Section 1.1.4) are a major contributing factor to rising production costs. Other factors that contribute to increasing production costs are declining commodity prices, declining ore grades (which force more energy intensive mining) and labour costs that are also rising above the inflation rate [45]. Figure 13 shows the decline in the annual average dollar price of gold and platinum over the last couple of years.

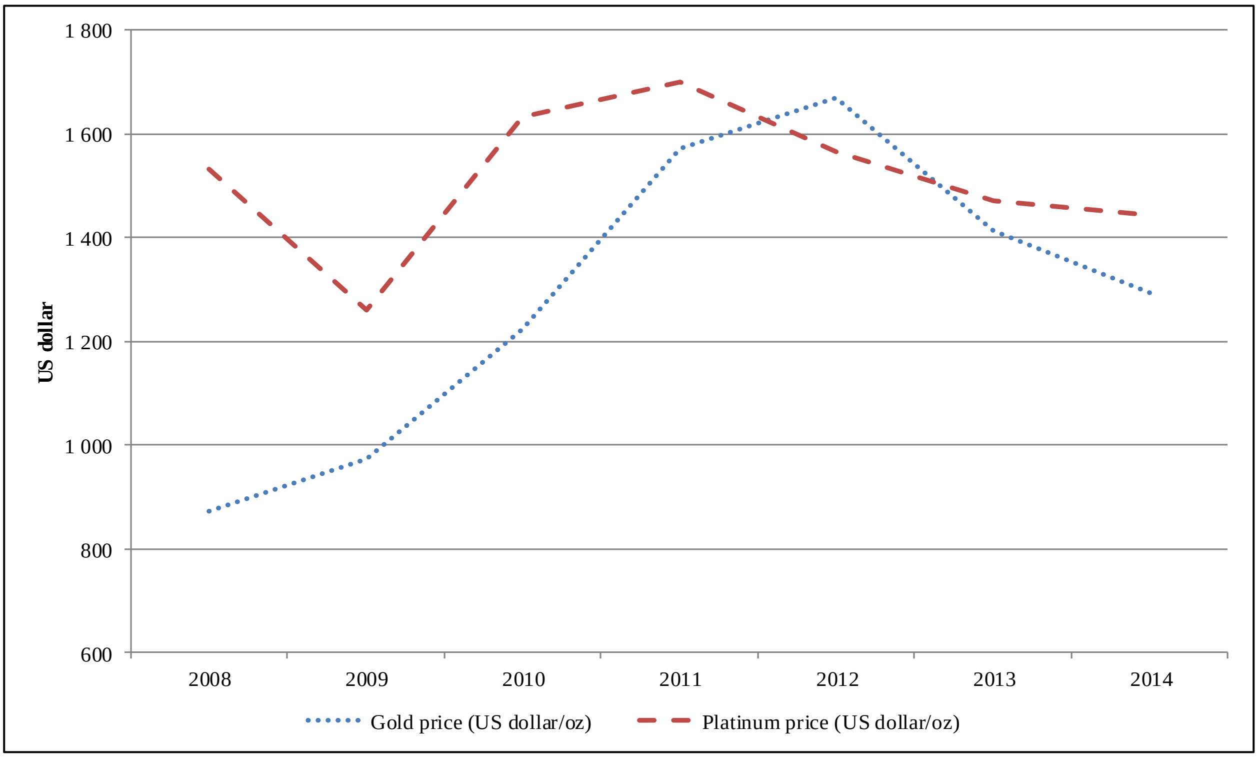

Figure 13: Annual average price of gold and platinum since 2008

A large number of DSM projects has been implemented since the inception of Eskom's IDM programme in 2003 [46]. The majority of these projects overperformed during the PA phase, which proved their feasibility. Unfortunately, not all DSM projects implemented since 2003 sustained the performance achieved during PA.

Figure 14 shows the performance history of a load-shifting project that was conducted on the various mills of a cement production plant. The evening peak load-shifting target was 2.55 MW. Months 1 to 3 indicate the performance that the project achieved during PA when the ESCO was responsible to prove that the project could achieve its target saving.

After PA, the ESCO remained involved in maintaining the performance of the project for a further period of two months. During this period, the project performed even better than during PA. After Month 5, the responsibility for maintaining the project was transferred to the plant. From this point onwards, there was a general declining trend in the performance of the project.

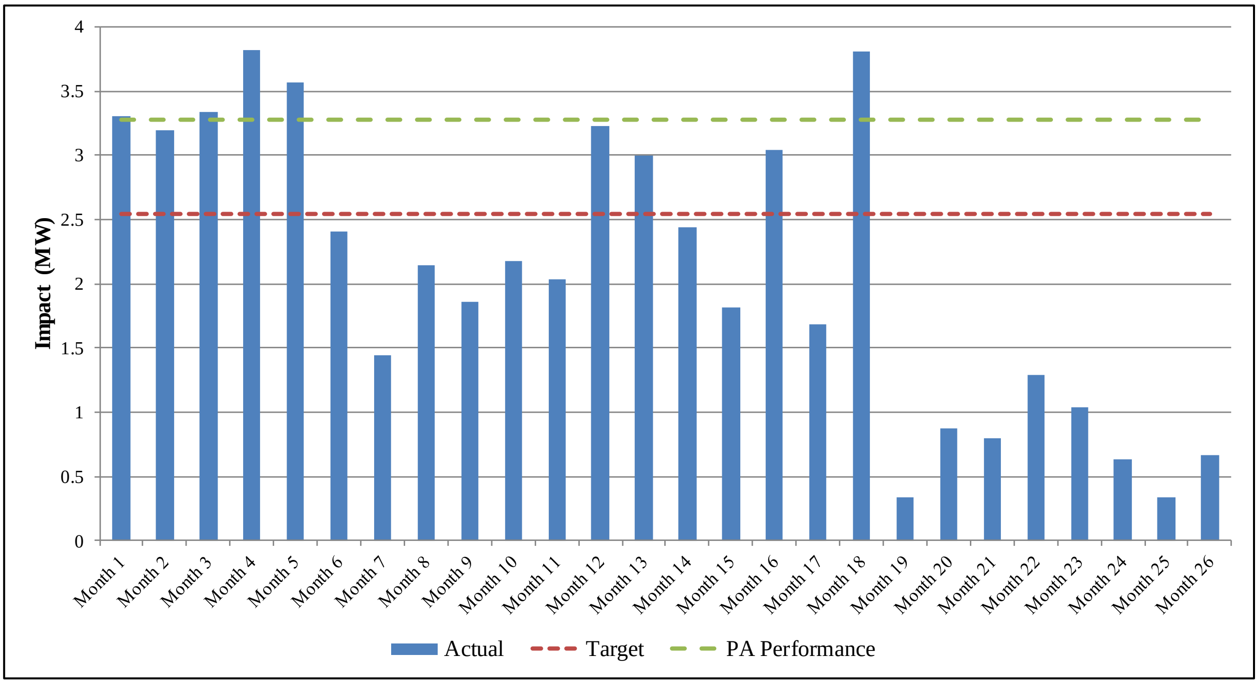

Figure 14: Performance history of load-shifting project on cement mills

Industrial ESCOs and their clients are often focused on investigating new opportunities and technologies that can be implemented as DSM projects to reduce electricity costs. While investigating new opportunities is certainly a good thing, the opportunities offered by existing DSM projects are often not considered.

Underperforming DSM projects need to be considered as ‘low hanging fruit’ for achieving electricity cost savings. This is because the majority of these projects require relatively little capital investment in comparison with new DSM projects to deliver or increase electricity cost savings. The challenging aspect is to sustain the performance of DSM projects for the entire life of the operation. This study answers this question by developing a performance-centered maintenance (PCM) strategy to increase the sustainability of DSM projects.

Another motivational factor for DSM maintenance is the risk of penalties that may be imposed for DSM underperformance. All industrial DSM projects funded by Eskom are subjected to underperformance penalties. These penalties are applied when the performance of a project is less than 90% of the contracted value. PCM is the ideal solution to ensure maximum DSM project performance and to avoid paying underperformance penalties.

1.4 Maintenance types

There are various types of maintenance:

- Breakdown maintenance.
- Corrective maintenance.
- Time-based maintenance.
- Reliability-centered maintenance.
- Total productive maintenance.

These maintenance types will be discussed in the sections that follow.

1.4.1 Breakdown maintenance (run to failure)

Breakdown maintenance is defined as performing maintenance only when a breakdown occurs. This approach can only be used in cases where a breakdown will not have a significant impact on production or operation.

1.4.2 Corrective maintenance

This form of maintenance entails improving or upgrading equipment/components to increase reliability. This type of maintenance is often applied in cases where equipment/components were not correctly designed from the start.

1.4.3 Preventative maintenance

Preventative maintenance consists of actions that are performed to maintain the good health of equipment to prevent failure. Preventative maintenance can be further divided into time-based maintenance and condition-based maintenance.

Time-based maintenance (TBM) [47]

TBM is a technique where maintenance decisions are determined based on failure-time analysis [47]. The assumption is that the failure behaviour of equipment is predictable according to failure rate trends, also known as bathtub curves. An example of a bathtub curve is shown in Figure 15. The bathtub curve is divided into three stages, namely, 'burn-in', 'useful life' and 'wear out'. The assumption is that the highest failure rates occur during the 'burn-in' and 'wear out' stages, while an almost constant failure rate is experienced during the 'useful life' stage.

TBM starts with failure data analysis or modelling to determine the failure characteristics of the equipment according to failure-time data. The purpose is to determine the mean time to failure and the trend of the equipment failure rate, based on the bathtub curve. After failure data analysis, the next step is to make maintenance decisions. The aim is to determine a maintenance policy that will result in optimal system performance at the lowest cost.

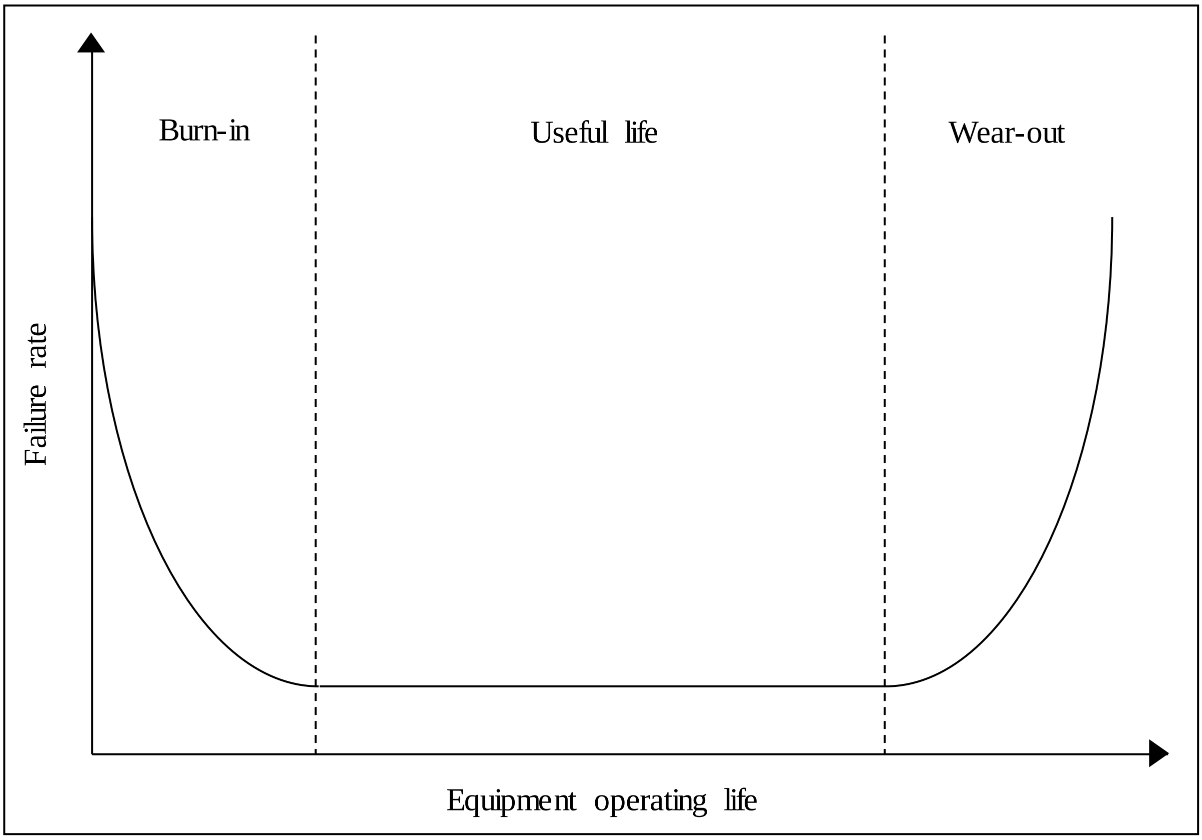

Figure 15: Bathtub curve (Adapted from [47])

Condition-based maintenance (CBM) [47]

CBM is a method that is used to analyse the condition of equipment to determine the remaining service life or the need for maintenance actions. It relies on the availability of instrumentation to monitor equipment condition. Various monitoring parameters such as vibration, temperature, oil analysis, noise levels, and so forth can be used. CBM is based on the notion that 99% of equipment failures are preceded by certain signs or conditions that indicated that failure was due to occur [48].

CBM is divided into two separate methods, namely, the current condition evaluation-based (CCEB) method and the future condition prediction-based (FCPB) method. A diagram of the typical process flow of the CCEB CBM method is shown in Figure 16. Data obtained from condition monitoring equipment is used to perform deterioration modelling to determine the condition of equipment. The process of gathering data from condition monitoring equipment and performing deterioration modelling is repeated until the need to perform maintenance activities is indicated.

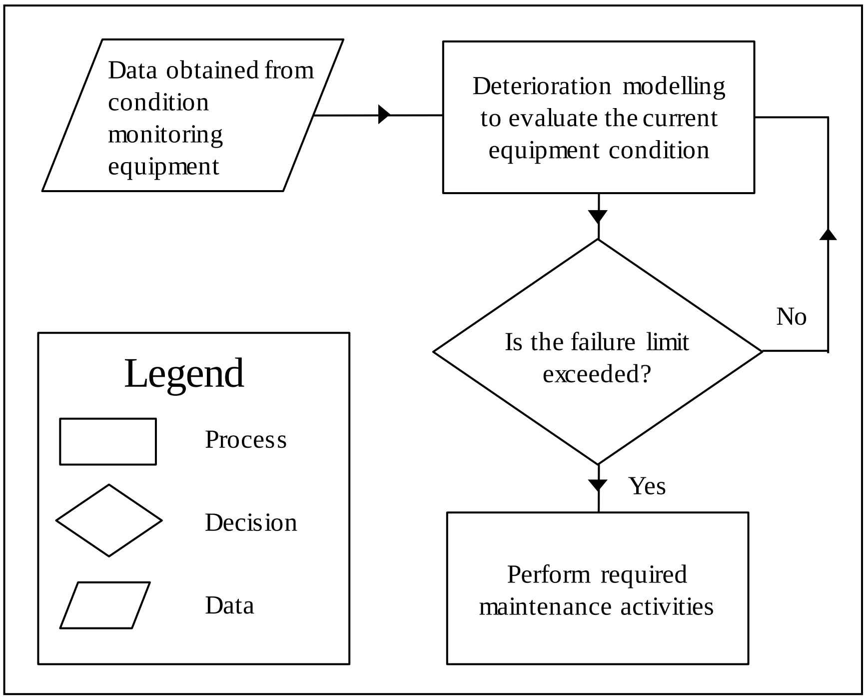

Figure 16: Typical process flow of the CCEB CBM method (Adapted from [47])

Figure 17 illustrates the basic principle of the FCPB method. It differs from the CCEB method in the sense that the deterioration modelling process is not focused on determining the current condition of the equipment. The aim of FCPB is to predict the future trend of equipment deterioration. The idea is to predict when it will be necessary to perform maintenance activities, which would typically be before equipment enters the failure zone.

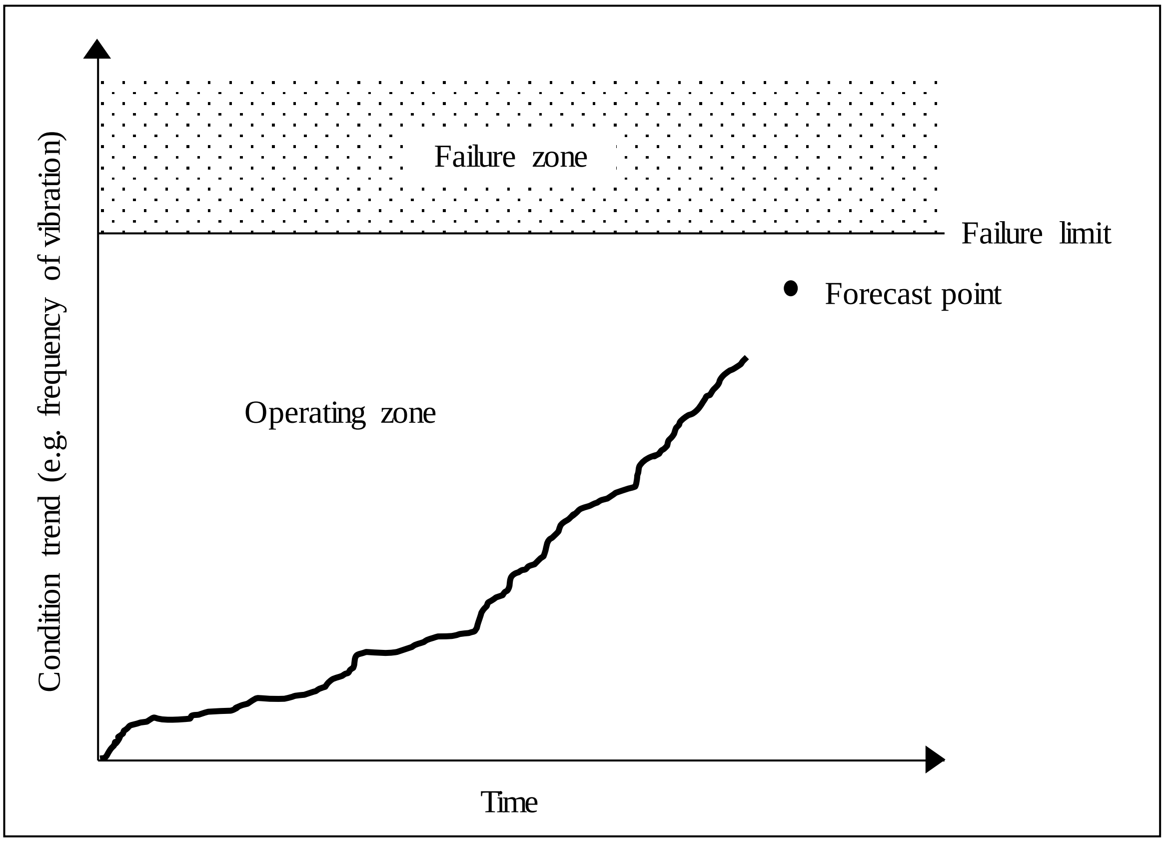

Figure 17: Basic principle of the FCPB CBM method

1.4.4 Reliability-centered maintenance [49]

Reliability-centered maintenance entails spending all maintenance resources on only the items that directly affect the reliability of the overall system. It originates from the aviation industry where maintenance programmes were developed for the Boeing 747 and Lockheed L1011 [50]. The maintenance programmes were initially so extensive that they would have resulted in the commercial failure of the two aircraft. This led to the forming of a committee consisting of representatives from various aircraft manufacturers, airlines and the US government that suggested developing a systems-based approach to maintenance that resulted in the development of the reliability-centered maintenance method.

1.4.5 Total productive maintenance (TPM) [50]

This approach to maintenance is aimed at increasing productivity with low maintenance costs. The idea is to blur the lines between production and maintenance through encouraging equipment operators to take responsibility for the equipment that they work with. The principle of TPM is contrary to the view that equipment operators need to focus only on production targets and that maintenance is not their responsibility.

1.5 Previous research on maintenance practices

1.5.1 Maintenance in the industrial sector

The international trend is that the industrial sector is becoming increasingly aware of the importance of maintenance [51], [52]. This is due to the important role that maintenance plays in supporting the competitive advantages of an organisation [53], as illustrated in Figure 18.

Alsyouf [53] performed a study on the maintenance practices in Swedish industries. He established that maintenance departments spend on average one-third of their time on unplanned maintenance tasks. This proved that there was a need to adopt maintenance concepts such as TPM and reliability-centered maintenance. He also found that there was a need for expanding the application of condition-based monitoring technologies such as oil, vibration and sound analysis.

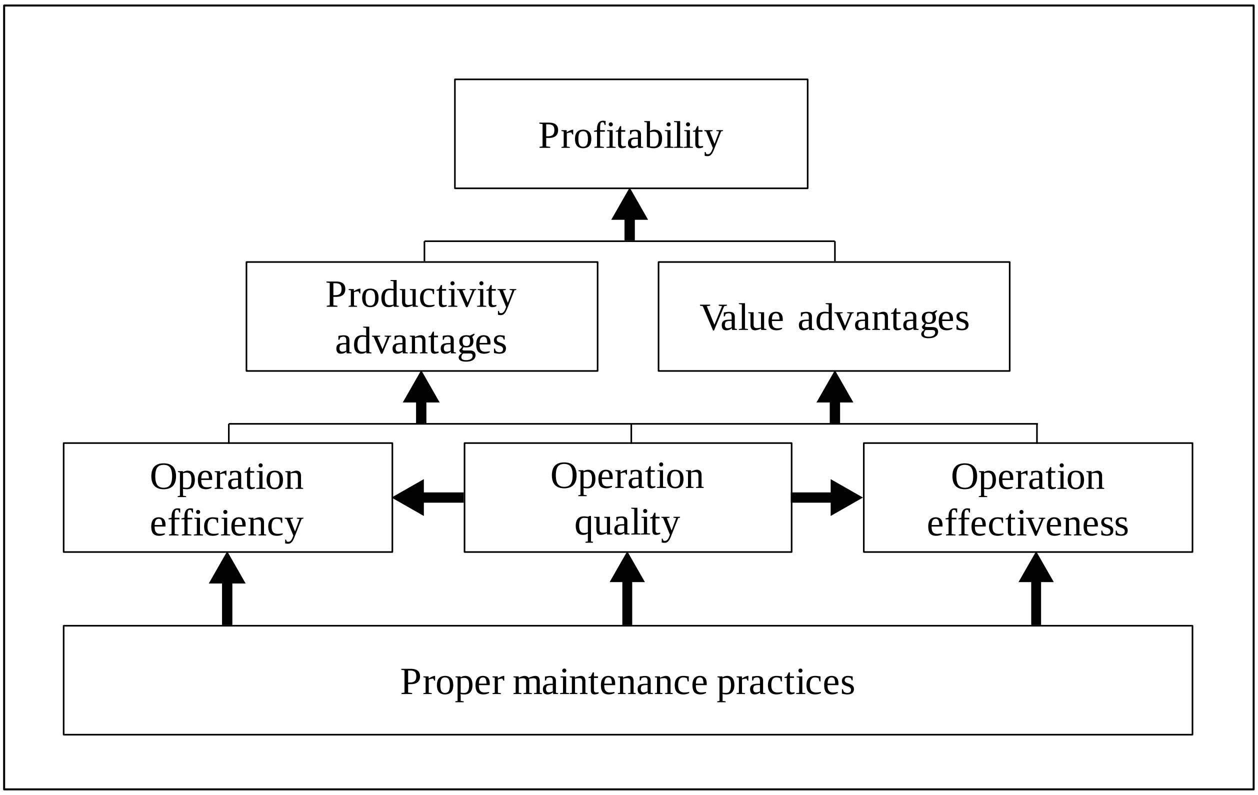

Figure 18: Impact of proper maintenance practices on competitive advantages (Adapted from [53])

Baglee and Jantunen [52] studied the advantages of adopting CBM strategies in the industrial sectors of five different countries. They found that CBM strategies have significant potential to bring substantial savings across various industries. They recommended that organisations establish accurate recording of failure events to facilitate more informed choices regarding the introduction of CBM strategies.

Ahmad and Kamaruddin [47] compared the application of TBM and CBM. They found that the application of CBM is more realistic in practice than TBM. Although both CBM and TBM base maintenance decisions on statistical analysis, CBM is often more accurate than TBM. This is because TBM employs statistical analysis based on statistical rules and assumptions such as the bathtub curve. In contrast, CBM uses fewer assumptions and bases the majority of maintenance decisions on actual data obtained from condition monitoring instrumentation. Ahmad and Kamaruddin concluded that the application of CBM is also simpler than that of TBM. CBM’s reliance on data can, however, be a limiting factor because in practice the data required may not always be available due to the high cost of the instrumentation required for condition monitoring.

1.5.2 South African mining industry

Kotze and Visser [54] analysed maintenance performance systems in the South African mining industry. They confirmed that South African mines have a reactive culture where mining maintenance is concerned. This proved that generally mining maintenance has a high focus on lagging or reactive indicators, instead of following a more structured or proactive approach.

Visagie [55] studied the feasibility of outsourcing maintenance in the industrial sector. His study focused on maintenance management, maintenance outsourcing strategies and philosophies of mines in the KwaZulu-Natal province. He found that although formal maintenance philosophies are generally aimed at planned or preventative maintenance, in practice maintenance is predominantly conducted on a reactive basis. This confirmed the findings of Kotze and Visser [54].

Visagie [55] found that the outsourcing of non-core maintenance activities is economically advantageous to the mining industry. It allows existing maintenance personnel to focus on the core maintenance functions. He also found that in many cases the level and sophistication of maintenance could be improved by migrating from in-house maintenance to outsourcing of maintenance activities.

Visagie [55] recommended that the mining industry consider implementing formal maintenance strategies. He also recommended applying condition monitoring and elements from TPM, root cause failure analysis and reliability-centered maintenance. In terms of outsourcing Visagie [55] recommended that an outsourcing policy and strategy should be developed. Mines should also appoint an outsource project champion to manage outsourcing initiatives. In terms of recommendations for future work, Visagie [55] indicated the need to develop maintenance performance indicators that should be incorporated in the outsourcing process.

1.5.3 DSM maintenance

De Kock [56] performed a study on the long-term impact of load management projects on South African mines. He stated that a DSM maintenance contract with an ESCO could ensure sustainable project performance. De Kock [56] claimed that the cost savings of projects with maintenance contracts were on average only 10% higher than the savings achieved on projects without maintenance contracts. The data provided in Chapter 4 shows that cost-savings differences on DSM projects with maintenance contracts are much higher than the claimed 10%.

De Kock [56] further stated that the performance reports provided by ESCOs were important motivational factors for maintenance. This may have been true in the era before the widespread use of supervisory control and data acquisition (SCADA) systems on South African mines. At present, the overwhelming majority of large mines in South Africa have SCADA systems that can provide access to both real-time and historical performance data. Performance reporting remains a motivational factor for DSM maintenance, but there are various other, more important motivational factors for DSM maintenance.

Mulder [57] studied the potential cost savings that could be achieved by reinstating three DSM projects on the water reticulation systems of gold mines. The three projects were not in working condition and Mulder therefore reinstated the control systems. The aim of Mulder's study was mainly to perform simulations to prove that the projects could be successfully reinstated. The simulations were used to develop new control philosophies that were used to reinstate the projects.

Mulder performed a lengthy and detailed comparison between the results of the simulations and the actual project results that were obtained after reinstatement. The purpose of the comparison was to prove the high level of correspondence between the simulations and actual results. He also reported on the reimplementation costs and electricity cost savings that were obtained after reinstatement. The conclusion of the study was that reimplementation costs were negligible in comparison with the potential cost benefits of reinstatement.

It seems that performing simulations to prove that the three projects could be successfully reinstated were unnecessary. The three case study projects were less than five years old. Unless there were drastic changes in operating conditions, it was not necessary to perform simulations first to prove that it would be possible to reinstate the projects. The fact that the projects achieved their targets during PA provided ample proof of their performance potential.

It was also not necessary for Mulder to develop the control philosophies from scratch. Mulder [57] could have avoided reinventing the wheel by using existing control philosophies and updating it where necessary. Mulder [57] merely proved that it could be financially beneficial to reinstate industrial DSM projects. He did not pay attention to the problem of why the projects ceased to perform in the first place. He also did not make any recommendation on how to ensure that the reinstated projects would be successfully maintained in future.

Du Plessis [58] studied the development of a supervisory system for maintaining the performance of remote energy management systems. The system that he developed could be an extremely useful tool for the maintenance engineer. Du Plessis [58] claimed that his system comprehensively monitored the condition of the energy management system components, control philosophies and DSM performance.

Du Plessis [58] also claimed that applying his system improved performance on DSM projects from 1.8 MW to 2.5 MW on average. The system developed by Du Plessis definitely contributed to this increase, but it is not correct to create the impression that this increase could solely be attributed to the application of the system. Various other factors that contributed to this increase were not taken into consideration.

Holman [59] studied the quantification of maintenance intervention benefits on the components of mine cooling systems. These interventions led to an improvement in the coefficient of performance (COP) of the various components of the cooling systems and therefore resulted in electricity cost savings. Holman [59] proposed the use of charts to plot the COP of the various components over time. This enabled management to keep track of component performance and make informed decisions about operational and maintenance interventions.

Figure 19 shows an example of the charts proposed by Holman. This chart clearly indicates the improvement in COP of a chiller machine after cleaning of the evaporator tubes. The notion of using charts to keep track of COP changes over time is a very good idea. Unfortunately, Holman never implemented this idea in practice.

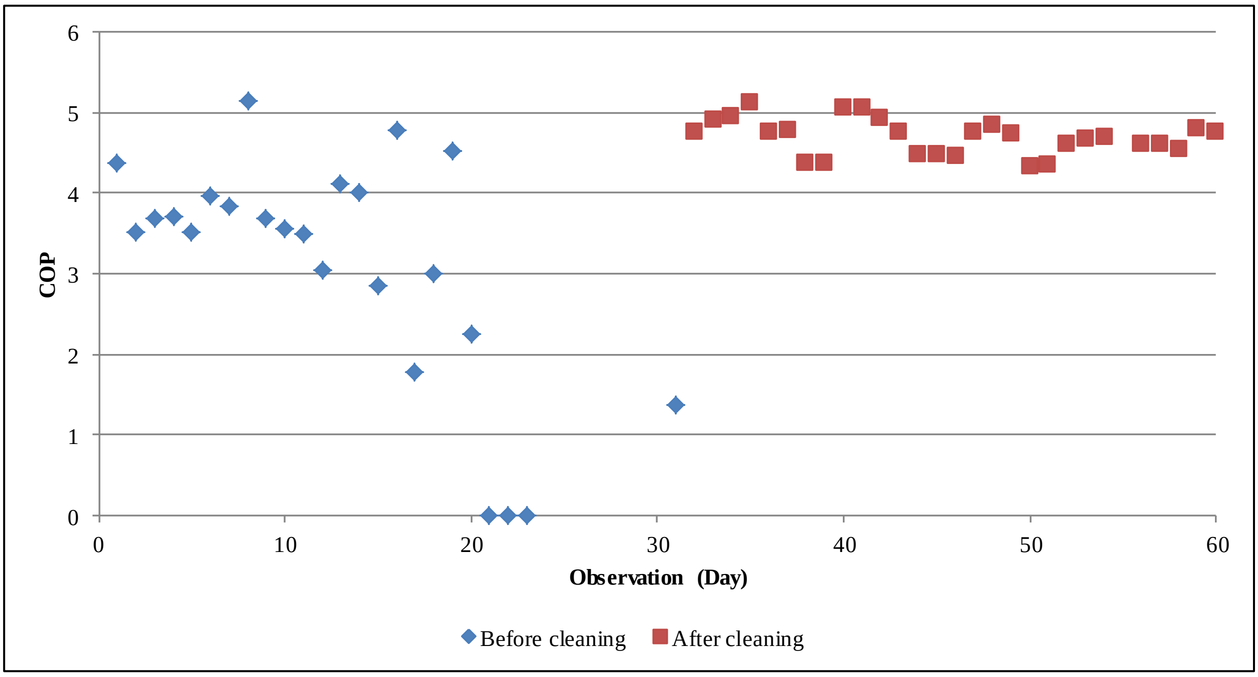

Figure 19: Change in COP of a chiller machine after scheduled maintenance (adapted from [59])

1.5.4 SSM maintenance

Maintenance on the supply side of electricity is just as important as maintenance on the demand side. A contributing factor to the electricity supply problem in South Africa is the maintenance needs of Eskom's aging power stations. Eskom claimed in 2014 that their generation capacity was 41 995 MW [1]. The 2014 maximum electricity demand occurred in first week of July when demand peaked at 34 768 MW [60]. This left Eskom with spare capacity of 7 227 MW that represented a reserve margin of more than 17%.

This leaves the questions of why South Africa is facing an electricity shortage if there are more than 7 000 MW of spare capacity available? The answer is that from 2009 to 2014 the availability of Eskom's power plants decreased from 85% to 75% [61]. Table 7 indicates that 5 491 MW of Eskom's generation capacity was not available in June 2014. The major reasons for the unavailability of generation capacity were boiler (33.6%) and turbine (13.13%) breakdowns.

Table 7: Unavailability of Eskom's generation capacity in June 2014 (Adapted from [61])

Item	MW
Boilers	1 847
Turbines	721
Mills	596
Draft plant	511
Gas cleaning	406

Item	MW
Feed water	333
Coal plant	263
Electrical	177
Ash plant	170
Emissions	147
Nuclear	96
Cooling water	83
Control and instrumentation	78
Auxiliary system	63
Total	**5 491**

The decrease in the availability of Eskom's power stations was caused by an increase in unplanned maintenance [1]. This is the result of Eskom deferring critical maintenance on power stations in an attempt to avoid interruptions in the supply of electricity [62]. Avoiding interruptions in the electricity supply was especially important during events such as the FIFA World Cup soccer tournament hosted by South Africa in 2010 and the 2014 national and provincial elections. The decreasing availability of Eskom's power stations emphasises the importance of a proper maintenance strategy on both the supply- and the demand-side of the electricity network.

1.6 Contributions of this study

The purpose of this study is to develop a PCM strategy for industrial DSM projects. This strategy can be broken down into four research contributions:

Contribution 1
A new strategy for outsourcing of DSM maintenance on a company group level.

Current situation:

- The majority of industrial companies in South Africa outsource their DSM maintenance on an ad hoc basis per DSM project.
- Only one industrial company in South Africa has outsourced their DSM maintenance on a company group level.
- There are no standardised strategy for outsourcing DSM maintenance on company group level.

Shortcomings/risks/needs:

- A major reason why DSM projects are inadequately maintained is because client personnel have other tasks such as production and safety that are often considered more important than electricity cost savings.
- Client personnel do not always have the specialised skills to maintain the sophisticated equipment and control systems that were installed as part of a DSM project.
- Client personnel do not have sufficient knowledge to implement and maintain a PCM methodology on a company group level.
- Electricity cost-savings opportunities are wasted because DSM maintenance is implemented on a site level instead of on a company group level.
- There is no strategy for the outsourcing of energy savings management on a company group level.

Description of the contribution:

It often happens that diverse approaches to DSM project maintenance are taken by different business units or sites in the same company group. It varies from outsourcing maintenance to ESCOs, to doing no maintenance at all. A more efficient way to ensure maximum electricity cost savings is to implement DSM maintenance on a company group level by outsourcing it to an ESCO that is able to provide a specialised PCM service. A strategy for the outsourcing of energy savings management on a group level was therefore developed and is presented in this study.

Contribution 2
A new, simplified strategy to identify DSM projects where PCM will increase or sustain electricity cost savings.

Current situation:

There is no simplified strategy to distinguish between DSM projects where PCM can be justified and DSM projects where it cannot be justified.

Shortcomings/risks/needs:

- Although the majority of DSM projects require PCM to either increase or to sustain electricity cost savings, there are certain DSM projects where the cost of PCM cannot be justified.
- Both clients and ESCOs do not want to waste money and other resources on DSM projects where the cost of PCM cannot be recouped.

Description of contribution:

A new simplified strategy to identify DSM projects where PCM can contribute to increasing or sustaining electricity cost savings was developed in this study. This strategy can be used by ESCOs and industrial clients to determine the feasibility of PCM on various types of DSM project.

Contribution 3
A novel PCM strategy to restore, sustain and improve the performance of DSM projects.

Current situation:

- A large number of DSM projects is not adequately maintained.
- There is no specialised DSM maintenance strategy to assist industry.

Shortcomings/risks/needs:

- Underperforming DSM projects result in wasted electricity cost-savings opportunities that increase the demand for electricity on the national grid.
- In instances where DSM projects were funded by Eskom IDM and those projects are still in their contract period, underperformance may result in penalties.
- Underperforming DSM projects reduce a client’s chances of receiving future funding from Eskom IDM.
- The control philosophies of DSM projects are not updated when necessary to accommodate operational changes.
- Both clients and ESCOs are often unfamiliar with the concept of DSM maintenance and do not know how to implement it to achieve maximum performance and electricity cost savings.

Description of contribution:

The PCM strategy developed in this study consists of a number of practical guidelines that can be applied to achieve maximum benefit from existing industrial DSM projects. The aim is, firstly, to restore and sustain project performance in cases where the maintenance of DSM projects was neglected. The secondary aim of PCM is to improve industrial DSM project performance continuously to generate maximum value for the client.

Contribution 4

Key performance indicators **(**KPIs) for measuring the performance of DSM projects maintained through PCM**.**

Current situation:

- The performance of DSM projects are usually measured according to the reduction in power consumption or the magnitude of the load that was shifted from one period to another.
- Outdated baselines and M&V methodologies often lead to inaccurate performance reporting.
- Other factors also need to be measured in order to determine project success. Alternative KPIs for measuring these other factors need to be established.

Shortcomings/risks/needs:

- Incorrect reporting of overperformance may result in client misconception that their DSM projects are performing better than they actually are.
- Inaccurate reporting of underperformance may result in Eskom wrongly imposing penalties on the client.
- Inaccurate performance reporting reduces the credibility of the DSM industry in South Africa.

Description of contribution:

All DSM projects have two main performance indicators, the amount of electricity saved/shifted and the resulting electricity cost savings. Other performance indicators also need to be considered for measuring project performance.

Consider, for example, a DSM project where an outdated baseline would result in inaccurate high performance reporting. This would create the false impression that the project is performing better than it actually is. An alternative KPI – such as the percentage of time measured over the 24 hours of a weekday that the flow of an evaporator pump was controlled by means of a variable speed drive (VSD) – would be a more accurate indication of whether the control philosophy of the project is being applied, than a project performance report based on an outdated baseline.

There are also performance indicators that need to be considered to ensure sustainable performance. For example, it is important to ensure that stops and starts are kept to a minimum when implementing a load-shifting project on the dewatering system of a mine. Unnecessary stops and starts will result in increased wear and reduced lifespan of the dewatering pumps.

An important KPI for a load-shifting project on a dewatering system is therefore the total number of stops and starts of each pump over a 24-hour period. Similar KPIs were identified for various types of DSM projects by performing a root cause analysis DSM project underperformance.

1.7 Thesis overview

The remaining chapters of the thesis are systematically organised as shown below.

Chapter 2

Chapter 2 gives an overview of various types of industrial DSM projects. The purpose is to provide more detailed information about the various interrelated components of different DSM projects. The challenges of implementing and more importantly, maintaining these projects are presented.

Chapter 3

The PCM strategy is presented in this chapter by providing detailed information on the four research contributions defined in Section 1.6.

Chapter 4

The results of applying the PCM strategy on ten industrial DSM projects are presented in this chapter. The purpose of this chapter is to prove that the implementation of the PCM strategy can significantly increase the performance and sustainability of industrial DSM projects.

Chapter 5

Chapter 5 concludes the study and ends with several suggestions for future work.

CHAPTER 2. INDUSTRIAL DSM PROJECTS

2.1 Introduction

This chapter provides an overview of different industrial DSM project types. The various interrelated components of industrial DSM projects are presented with the aim of explaining the requirements and scope of a PCM strategy. The chapter commences with a description of the purpose and the overall strategy to achieve electricity cost savings for each DSM project type. The differences between automatic and semi-automatic control systems are explained. The chapter concludes with an overview of the common causes of DSM project underperformance.

2.2 Load shifting

2.2.1 Load shifting on dewatering pumps

South Africa has some of the deepest gold and platinum mines in the world. Mponeng mine, south-west of Johannesburg, is currently the world's deepest mine at a depth of more than 3 800 m [63]. The virgin rock temperatures at these depths can be as high as 65°C [64]. The high rock temperatures result in high air temperatures that without intervention would exceed the levels that human physiology can withstand [65].

Various cooling interventions are applied to ensure that the underground working conditions remain within acceptable limits. These cooling interventions typically consist of fridge plants that provide chilled water to bulk air coolers (BACs). BACs use chilled water from fridge plants to provide cooled air to the underground levels. The cooled air keeps the temperatures and humidity in the mine within acceptable levels. Fridge plants and BACs are found both on surface and in underground levels, depending on the cooling requirements of the particular mine.

The chilled water supplied by the fridge plants is also used for various other mining activities such as drilling and cleaning. The water used for the various mining activities, as well as fissure water (natural groundwater), accumulate at the bottom of the mine. The water is passed through settlers to remove mud particles and then pumped to surface with high-lift centrifugal dewatering pumps.

Figure 20 shows the layout of a typical mine dewatering system. The flow of cold water is indicated in blue and the flow of warm water is shown in red. Surface fridge plants provide chilled water to the various mining levels. The water from the various levels flow down the mine to Level 75 where it is passed through the settlers and accumulates in the Level 75 hot dam. Level 75 has a pumping station with four dewatering pumps, each with an installed capacity of 2 MW. The water is pumped from Level 75 to the hot dam on Level 38.

The pumping station on Level 38 consists of two turbine pumps that use the kinetic energy of the chilled water sent down the mine to pump water from Level 38 to the surface dams. Unfortunately, the two turbine pumps do not have enough capacity to pump all the water from Level 38 to surface. For this reason, the pumping station on Level 38 also has three conventional high-lift centrifugal pumps. A maximum of two conventional pumps on each level is used at the same time. The remaining pumps are on standby in case of pump failure.

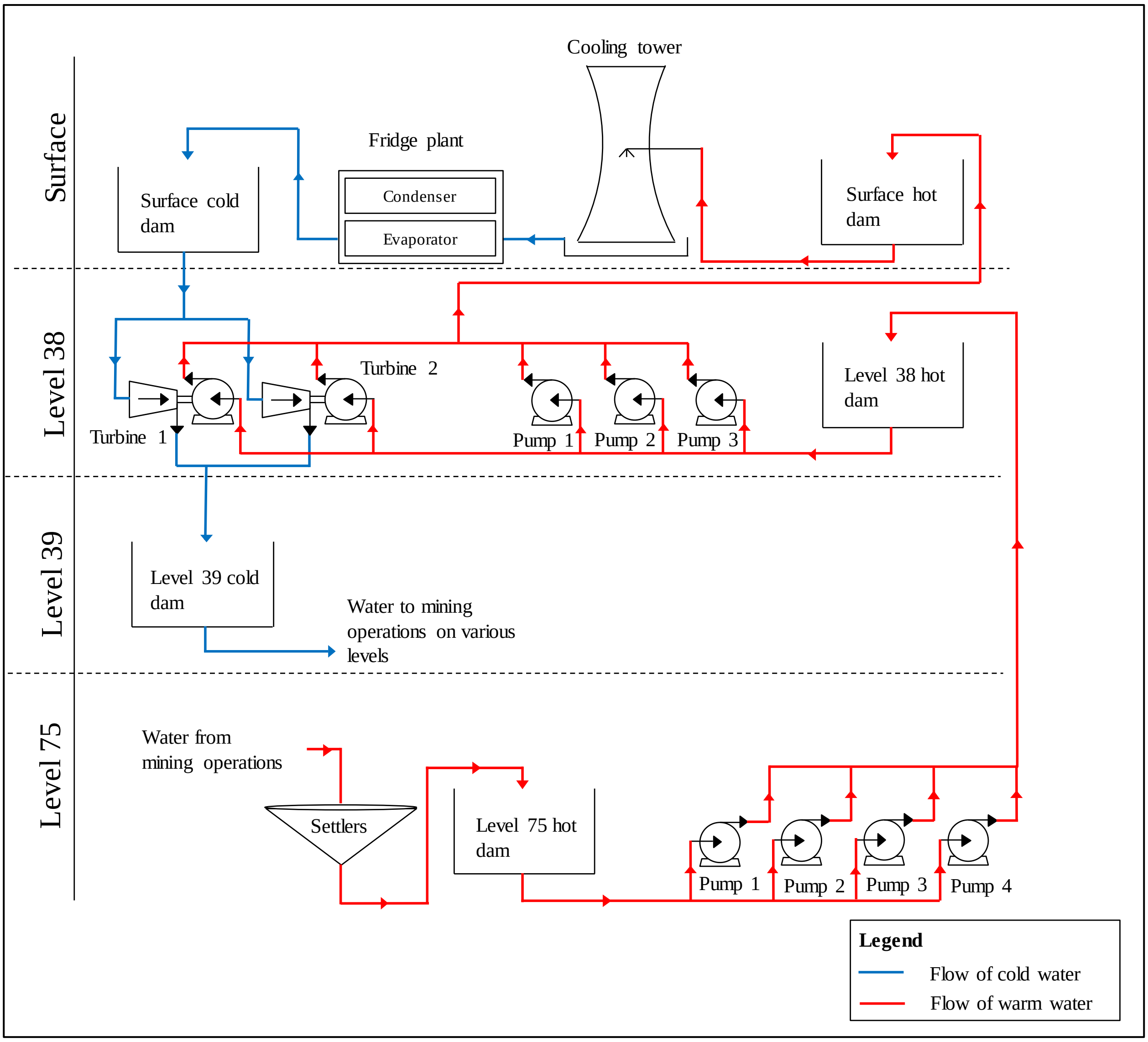

Figure 20: Typical layout of a mine dewatering system

The dewatering pumps on the various pumping stations are usually controlled by human operators, known as pump attendants. The pump attendants work in shifts to ensure that the pumping stations are manned around the clock. The dewatering pumps are usually operated without taking the Eskom TOU periods into consideration. The pump attendants control the pumps according to the levels of the hot dams. The pump attendants start the dewatering pumps when the dam levels reach their maximum limits and stop the pumps when the minimum limits are reached.

Load shifting on dewatering pumping systems is achieved by minimising the amount of water pumped to surface during the Megaflex peak periods. This is made possible by using the dams on the various levels as buffers. The maximum number of pumps is used in off-peak periods to ensure that dam levels reach their minimum limits at the start of the peak period. The pumps are switched off in the peak periods and the dam levels are allowed to rise to the maximum limits.

No pumping have to take place during peak periods if all of the dam levels remain below their maximum limit. If a maximum dam limit is reached during the peak period, a pump on that level needs to start to prevent the dam from overflowing. Starting pumps during peak periods has an undesirable knock-on effect because the water pumped from the dam that reached its maximum level will result in a faster increase in the level of the downstream dam.

Figure 21 compares the power profiles of a dewatering pumping system before and after implementing load-shifting measures through automatic pump control. The red line shows the ‘before’ profile when pump attendants controlled the pumps. Note that the pump attendants did not take the Eskom evening peak period (18:00–20:00) into consideration. It was only after implementing load-shifting measures through an automatic remote pump control system that a reduction in pumping during the Eskom evening peak was achieved.

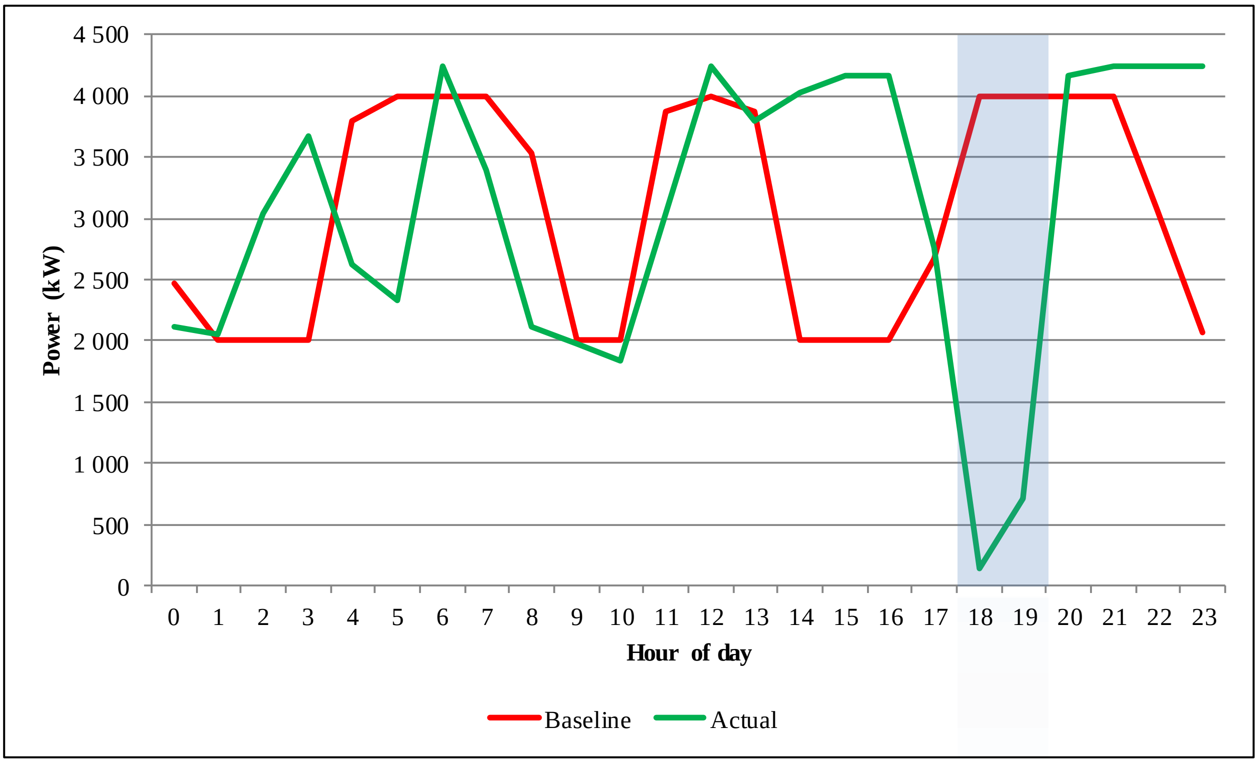

Figure 21: Comparison of profiles before and after implementation of load shifting on dewatering pumps

The implementation of the load-shifting measure shown in Figure 21 was done without any negative impact on the dewatering system. The levels of the various dams remained within prescribed limits and all other system constraints were adhered to.

2.2.2 Load shifting on cement mills

Figure 22 gives an overview of the cement manufacturing process. The process starts with the mining of limestone, which is the major raw material used in cement manufacturing. The limestone is crushed and blended with other raw materials such as iron ore and shale. The raw materials are ground in the raw mill to produce raw meal. The raw meal is typically stored in raw meal silos before it is fed into the preheaters and kiln to form cement clinker.

The kiln is a rotating, cylindrical 'oven' where coal (or other fuels such as oil, gas or even used tyres) is burned to achieve the high temperatures (>1 400 ºC) that are required for the chemical processes that transform raw meal into cement clinker [66]. The cement clinker is stored in clinker silos, after which it is grinded in a cement mill to produce cement. The last step in the process is the packing and distribution of the cement.

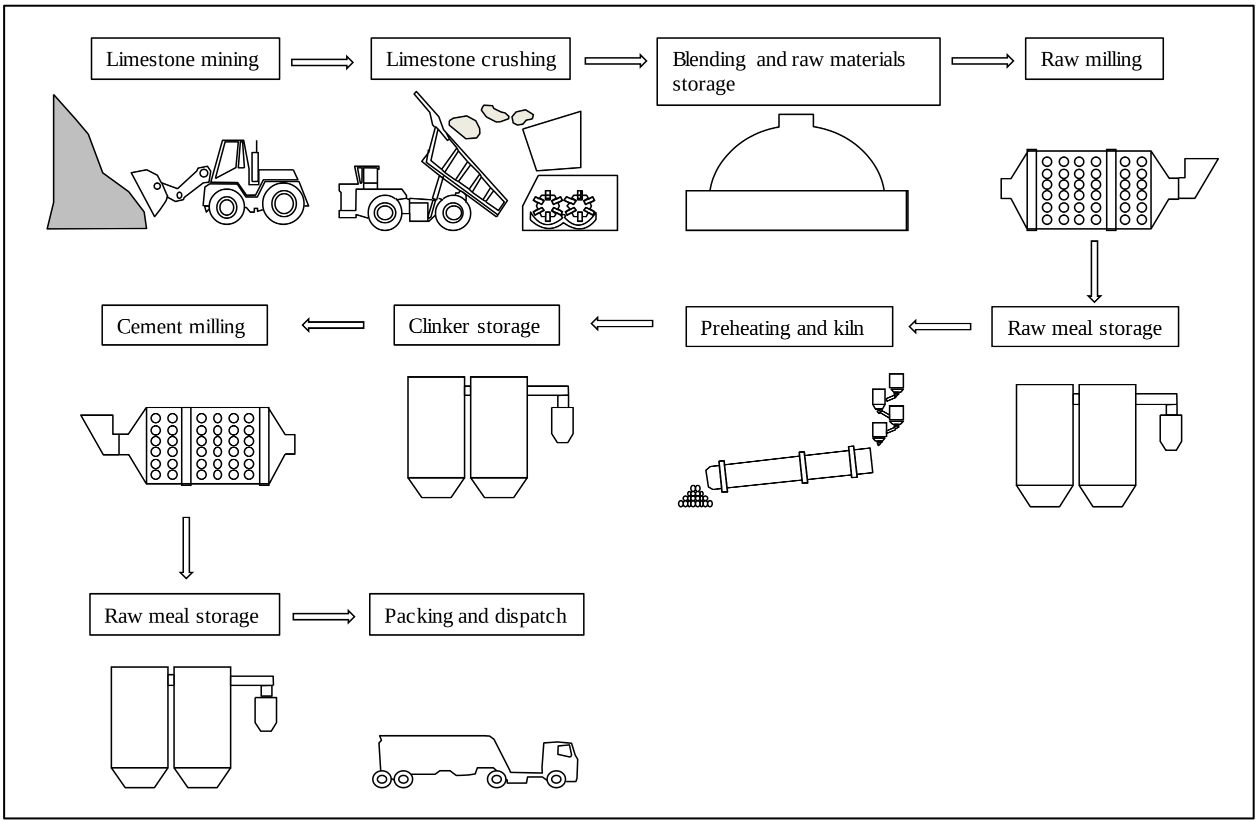

Figure 22: Cement manufacturing process (Adapted from [67])

The various mills consume up to 60% of the total energy used during the cement manufacturing process [68]. The raw material stockpile and the raw meal silos act as storage buffers before and after the raw mills. These storage buffers make it possible to perform load shifting on the raw mills. The same principle applies to the cement mills, where load shifting is made possible by the clinker storage silos and cement silos.

Load-shifting opportunities also exist on the coal mills. Coal burns more efficiently when in pulverised form. Pulverised coal is therefore widely used as a fuel source for rotating cement kilns. The majority of cement manufacturing plants in South Africa buy raw coal that is pulverised by coal mills on site before it is used as a fuel source in kilns.

Figure 23 shows the typical layout of a coal milling circuit as used on cement manufacturing plants. The raw and pulverised coal are stored in silos before and after the coal mills. These buffers enable load shifting on the coal mills. The typical installed capacity of coal mills range between 200 kW and 600 kW, which is relatively small in comparison to the other mills used in the cement manufacturing circuit.

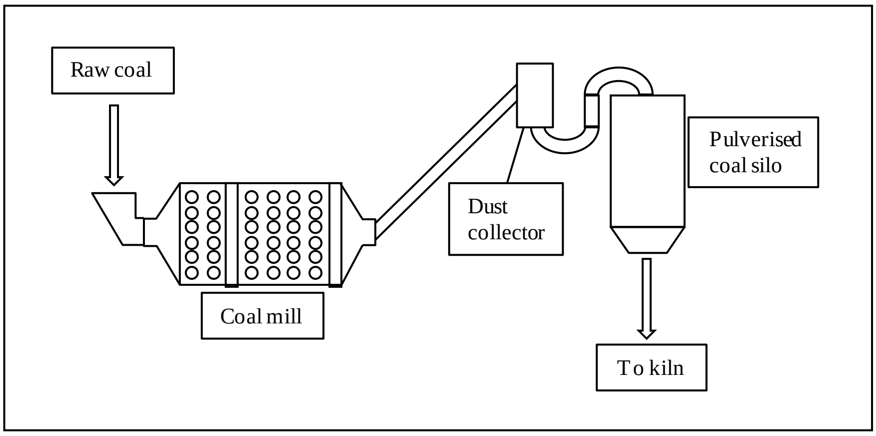

Figure 23: Typical layout of coal milling circuit

Another opportunity for load shifting on a cement manufacturing plant exists on the limestone crushers. Figure 24 displays the typical layout of a crushing circuit on a cement manufacturing plant. The raw limestone is transported by trucks from the quarry and fed into the crushing circuit. The crushing circuit consists of three crushers in series, namely, a primary, secondary and tertiary crusher.

Unfortunately, the lack of storage buffers before the crushers makes it difficult to perform load shifting. Load shifting on lime stone crushers entails more than managing stockpile levels. It would typically also entail changing the operating schedules to ensure that shift changes or scheduled maintenance occur during the Megaflex peak periods, which will enable load shifting.

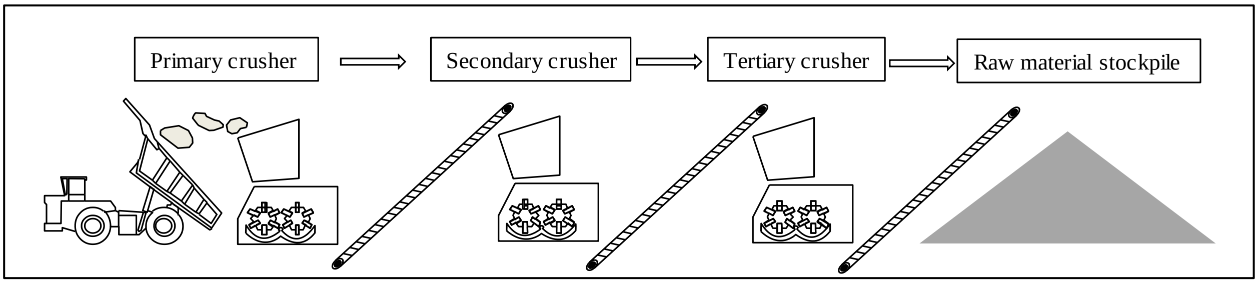

Figure 24: Typical layout of the crushing circuit on a cement manufacturing plant (Adapted from [69])

Figure 25 compares the power profiles before and after load shifting were implemented on the raw mills, coal mills and cement mills at a South African cement manufacturing plant. The 'after load shifting' profile shown in Figure 25 is the average profile obtained over three months during the PA period of the project. An average evening load shift of more than 3 MW was obtained.

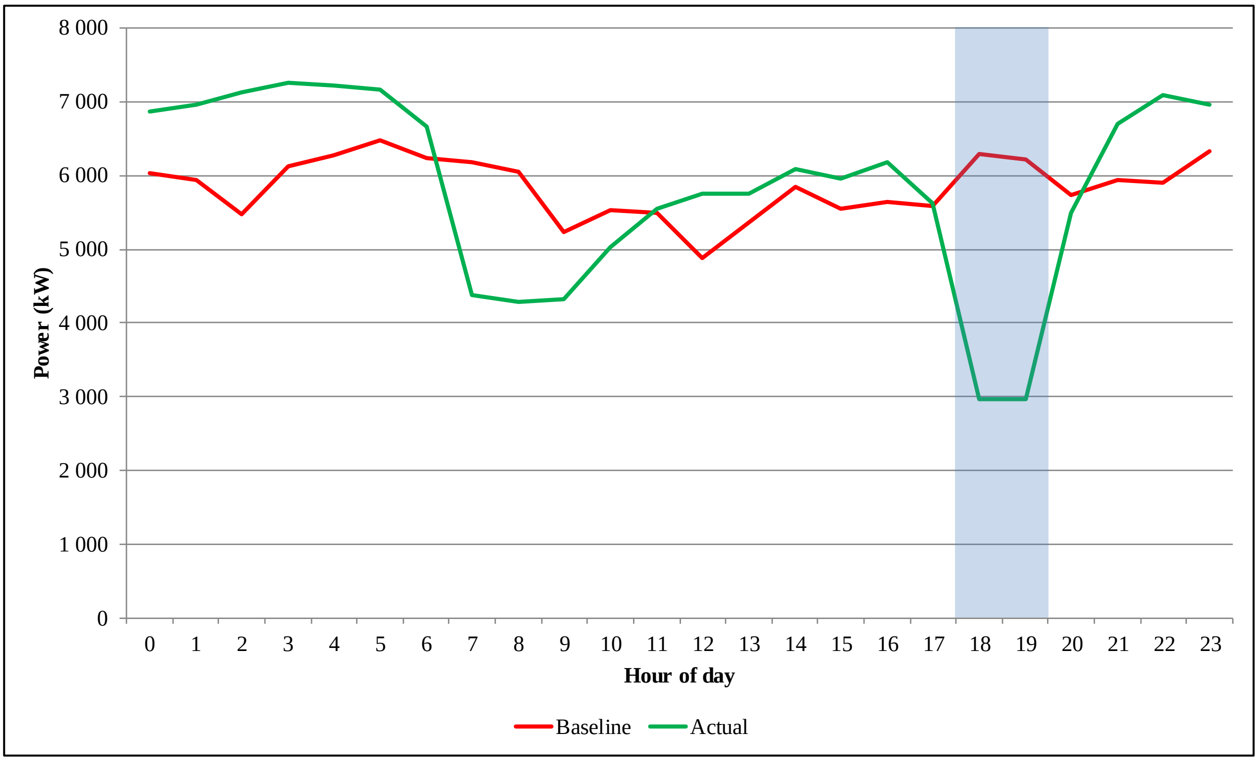

Figure 25: Baseline and actual power profiles after implementation of load shifting on cement mills

2.2.3 Load shifting on fridge plants

As previously mentioned, the purpose of fridge plants is to provide chilled water for cooling and other mining activities. Figure 26 shows the typical surface layout of the water reticulation system of a mine. Warm mining water is pumped from underground to a surface hot water dam. The warm water is passed through the precooling towers to the fridge plants. The cold water from the fridge plants is pumped to a cold water dam from where it is gravity-fed to the mining levels or directly pumped to BACs. The BAC return water is pumped back to the inlet of the fridge plant.

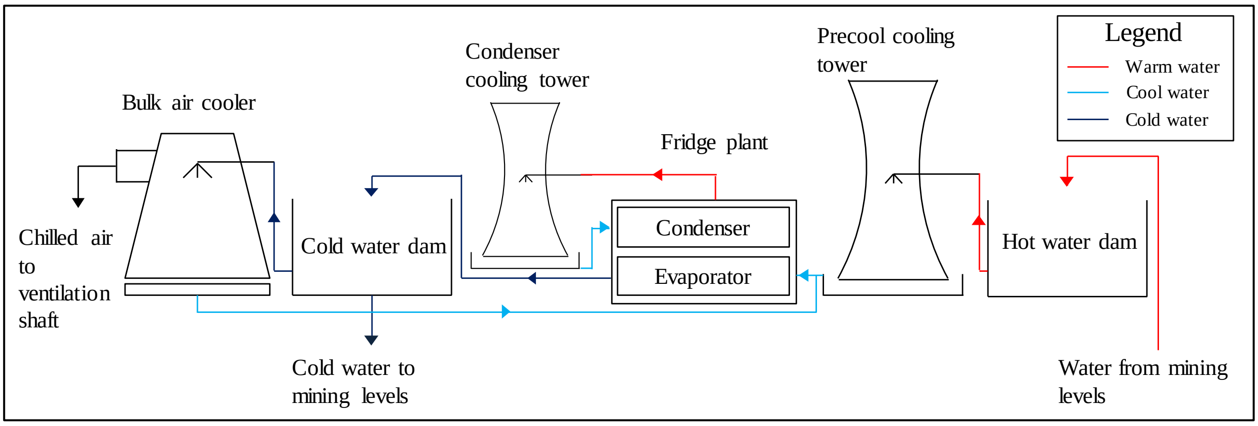

Figure 26: Surface layout of the water reticulation system of a gold mine (Adapted from [70])

The hot water dams and chilled water dams can be used as buffers to realise load shifting on fridge plants. The idea is to manage the dam levels to ensure that the cold water dam is at its maximum level and the hot water dam is at its minimum level before the start of the Megaflex peak periods. The maximum level of the cold water dam will ensure that the supply of cold water to the BAC and underground operations are not interrupted during load shifting. The hot water dam needs to be at its minimum level to ensure that there is enough storage capacity for the hot water from the mining levels to prevent the hot water dam from overflowing.

Fridge plant load-shifting projects work well in conjunction with load-shifting projects on dewatering pumps. A pump load-shifting project aims to achieve minimum pumping during the Megaflex peak period. This helps to maintain the desired levels of both the hot water and cold water dam to enable load shifting on the fridge plants.

Figure 27 shows the baseline and actual profiles after implementing a load-shifting project on the fridge plants of a gold mine. An evening-peak load shift of 3.3 MW and a morning-peak load shift of 2.5 MW were achieved.

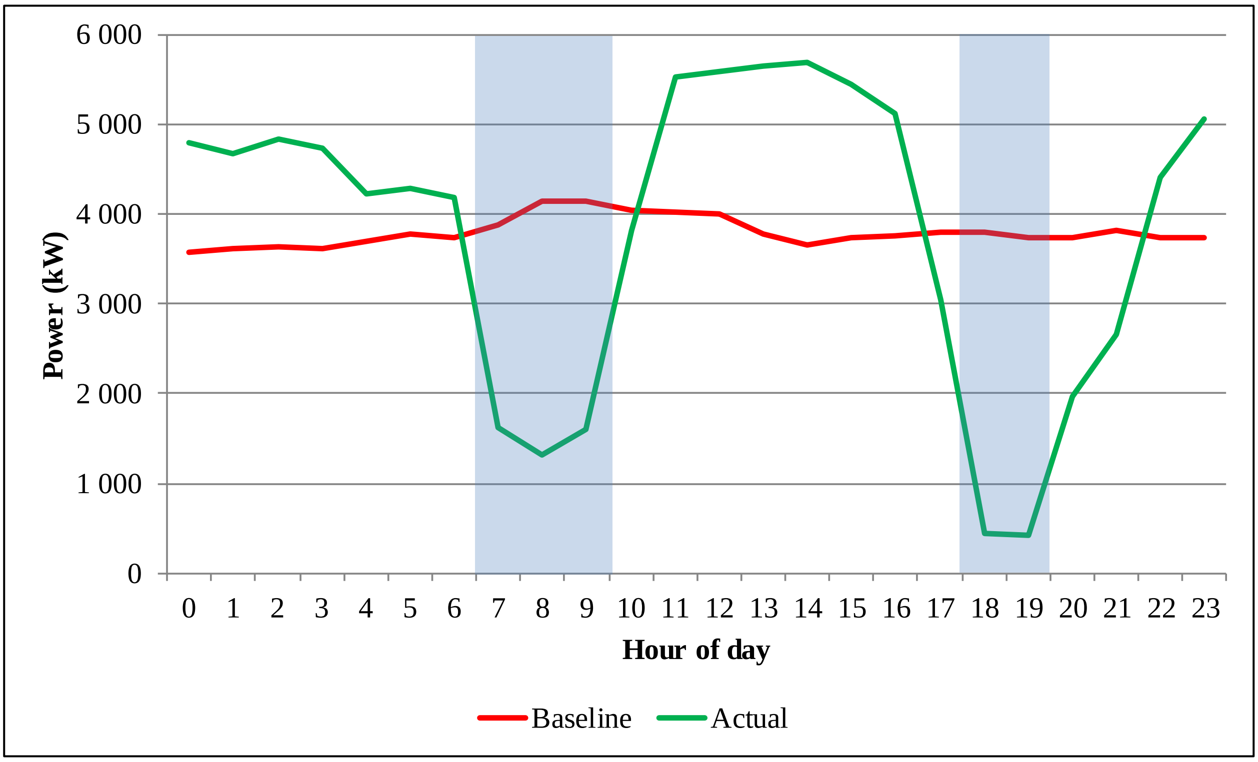

Figure 27: Baseline versus actual profile on fridge plant project

2.2.4 Load shifting on water transfer pumps

The South African Department of Water Affairs (DWA) operates a large number of water pumping schemes to ensure a sustainable water supply to various parts of South Africa. The water pumping schemes typically consist of a network of interconnected dams and pumping stations that enables the transfer of water. This water is used for residential, agricultural, industrial and mining purposes [71].

Load-shifting opportunities often exist on these pumping stations. The same principle that applies to load shifting on mine dewatering pumps can be applied, which is to use the dams as storage buffers to enable load shifting during the Megaflex peak periods. A major difference is that the dams of pumping schemes are considerably larger than the underground dams found in mines.

One such a water scheme that is of critical importance to the sustainability of the electricity supply in South Africa is the Usutu–Vaal government water scheme (GWS) because it supplies water to Sasol II and Sasol III synthetic fuel plants and four of Eskom's power stations (Tutuka, Matla, Kriel and Duvha) [71]. The Usutu–Vaal GWS consists of six pumping stations [72]:

- Naauwpoort (Near eMalahleni)
- Rietfontein (North of Secunda)
- Grootfontein (West of Charl Cilliers)
- Grootdraai (Near Standerton)
- Geelhoutboom (Near Piet Retief)
- Heyshope (Near Piet Retief)

Grootdraai, Grootfontein and Rietfontein pumping stations have the biggest load-shifting potential. This is mainly because these three pumping stations pump water on a continuous basis, while the remaining pumping stations are used for backup supply during the winter/dry seasons.

Figure 28 shows the layout of the Usutu–Vaal GWS. The Grootdraai pumping station supplies water from the Grootdraai dam to the Tutuka power station and the Knoppiesfontein reservoirs. The Grootfontein pumping station is a booster pumping station. It boosts the pressure of the water in the pipeline from Grootdraai pumping station to the Knoppiesfontein reservoirs. The Knoppiesfontein reservoirs are augmented by the Vaal River Eastern Subsystem Augmentation Project (VRESAP) with water from the Vaal dam. Water from the Knoppiesfontein reservoirs is gravity-fed to the Sasol II and Sasol III plants via the Bosjesspruit dam. The Knoppiesfontein reservoirs also supply the Trichardtsfontein dam. The Trichardtsfontein dam supplies water to Rietfontein weir dam. The Rietfontein pumping station pumps water from the Rietfontein weir dam to the Matla power station and also to the Naauwpoort pumping station, which supplies water to Duvha power station near eMalahleni (previously known as Witbank).

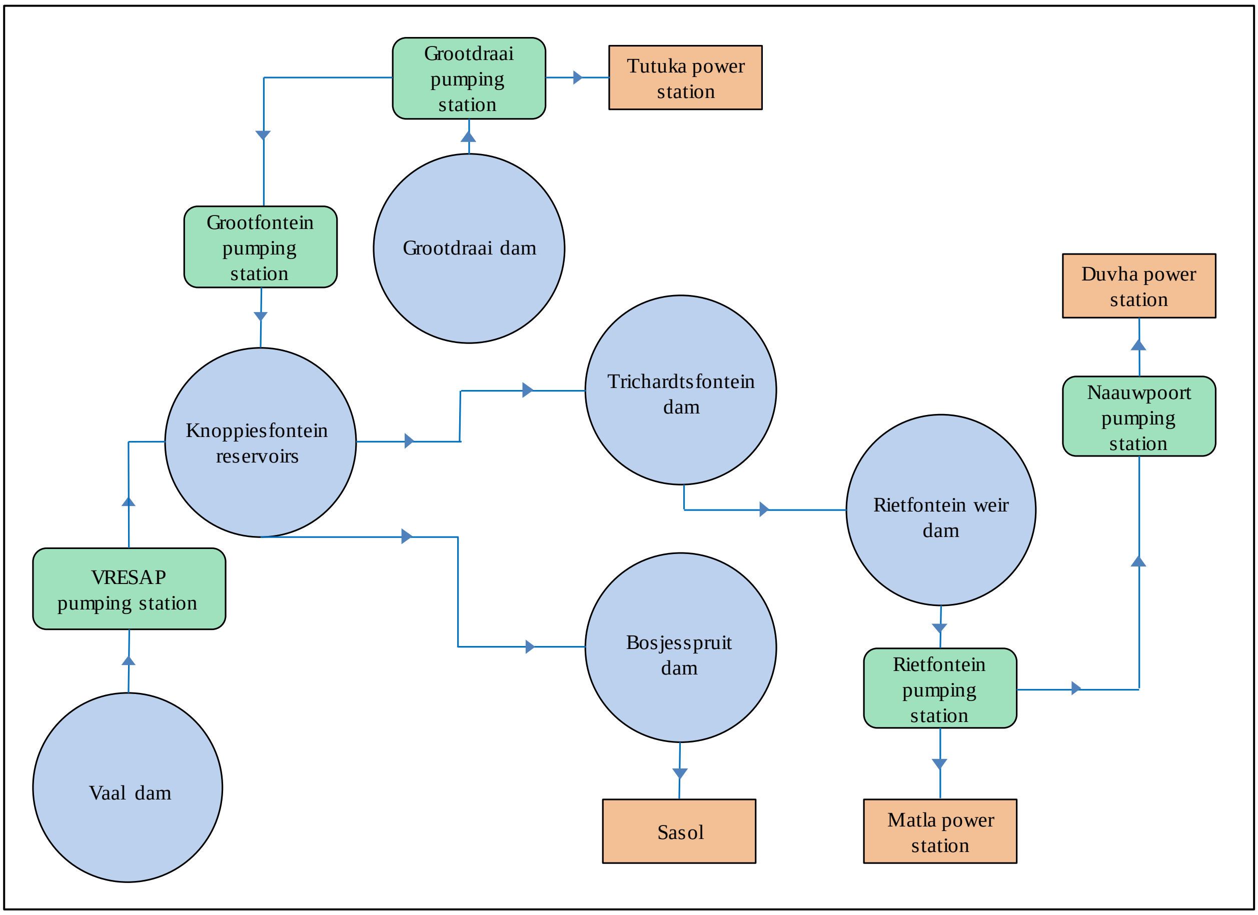

Figure 28: Layout of the Usutu–Vaal GWS (Adapted from [72])

Prior to implementing load-shifting measures at Rietfontein, Grootfontein and Grootdraai, the pumps were manually stopped and started without any consideration for TOU tariffs. The baselines of Grootfontein and Grootdraai pumping stations were therefore relatively flat throughout the day, but the profile of Rietfontein displayed unnecessary pumping in the evening peak. The full capacity of these pumping stations were not fully utilised, which provided further proof of the feasibility of load shifting. Table 8 provides information on the installed capacities of the Rietfontein, Grootfontein and Grootdraai pumping stations [72].

Table 8: Usutu–Vaal GWS pumping scheme

Pumping station	Installed capacity
Rietfontein	4 × 3 050 kW
Grootfontein	1 × 2 200 kW 4 × 2 150 kW
Grootdraai	4 × 1 650 kW 4 × 1 405 kW

Figure 29, Figure 30 and Figure 31 show the baselines and PA impacts of the Rietfontein, Grootfontein and Grootdraai pumping stations. The combined evening load shift of the three pumping stations during PA was more than 13.5 MW.

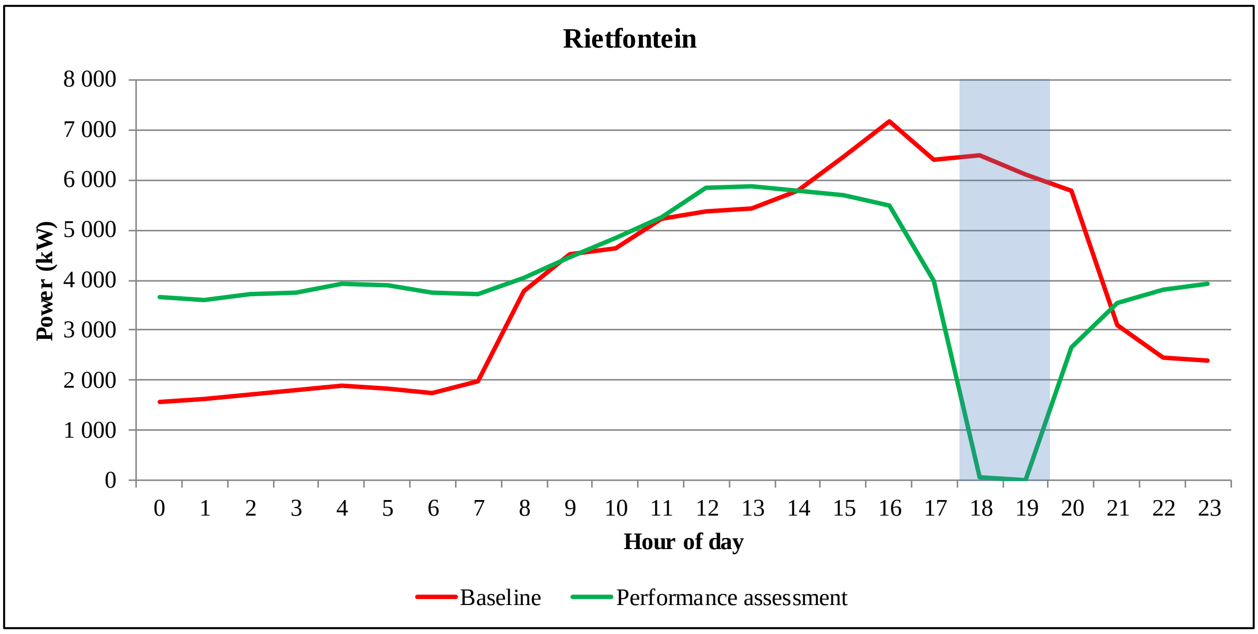

Figure 29: Baseline and PA of Rietfontein pumping station

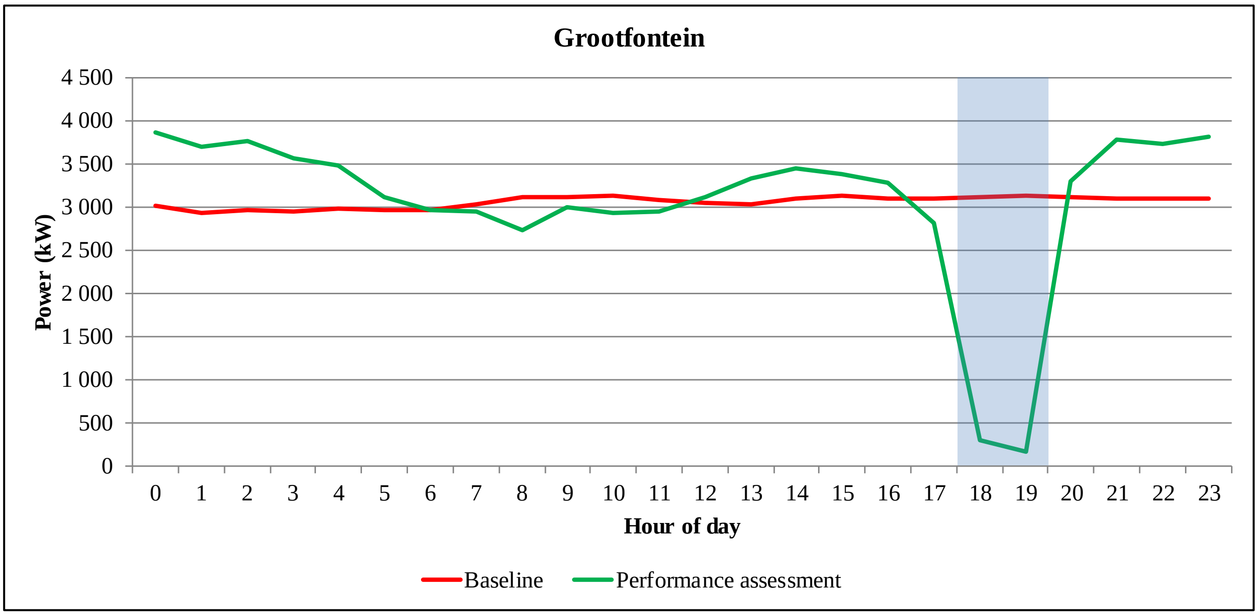

Figure 30: Baseline and PA of Grootfontein pumping station

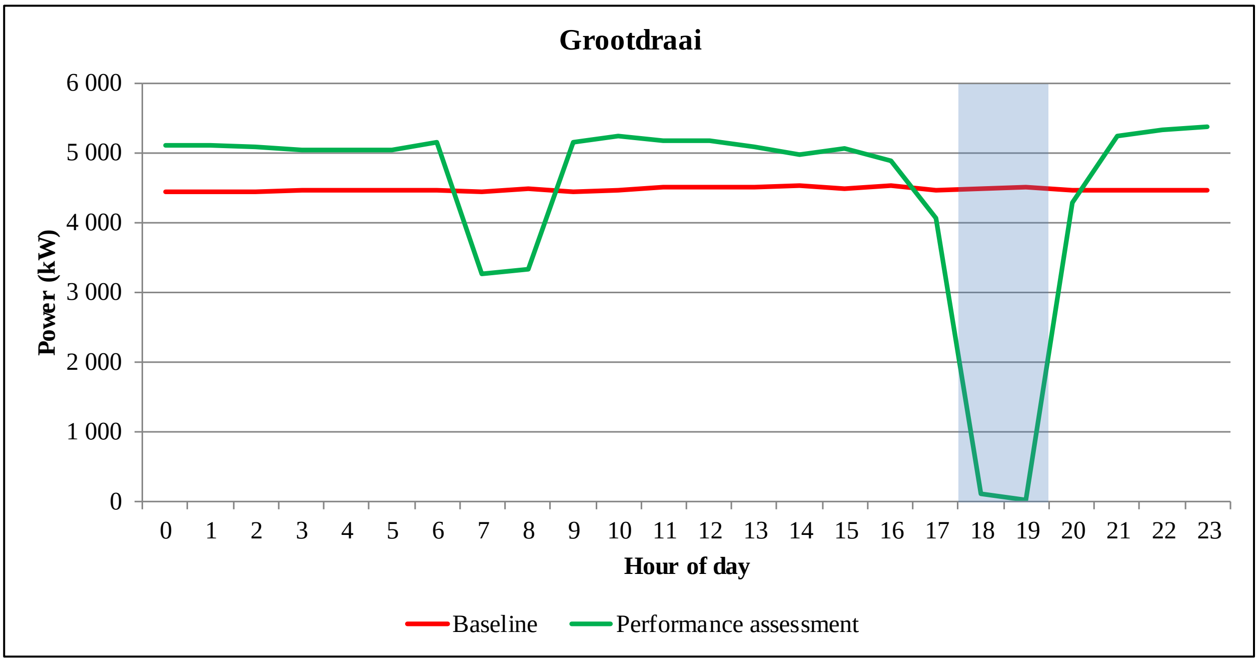

Figure 31: Baseline and PA of Grootdraai pumping station

2.2.5 Load shifting on gold production lines

Gold ore processing lines encompass the entire process from transporting the ore from the depths of the mine to processing of the end product. The process starts by extracting blasted rock from the stopes (underground cavities made during the extraction of ore) through a series of material-handling systems. These systems may include a combination of the following equipment: scrapers, hoppers (ore cars), conveyor belts, ore passes (vertical excavation for dumping ore to lower a collection level), crushers, skips (metal box for vertical hauling of ore) and silos. Figure 32 shows a photograph of a hopper used in gold and platinum mines [73].

Figure 32: Hopper used in gold and platinum mines [73]

Rock winding systems are used to transport the ore from the underground silos to surface. A combination of conveyor belts, trucks and/or trains is used to transport the ore from the surface silos to the gold processing plants. Large mills (installed capacity > 1 MW) are used at the gold processing plants to grind the ore to a fine powder. Chemical processes are employed to extract the gold from the powder. Figure 33 shows the typical layout of an underground mine [74].

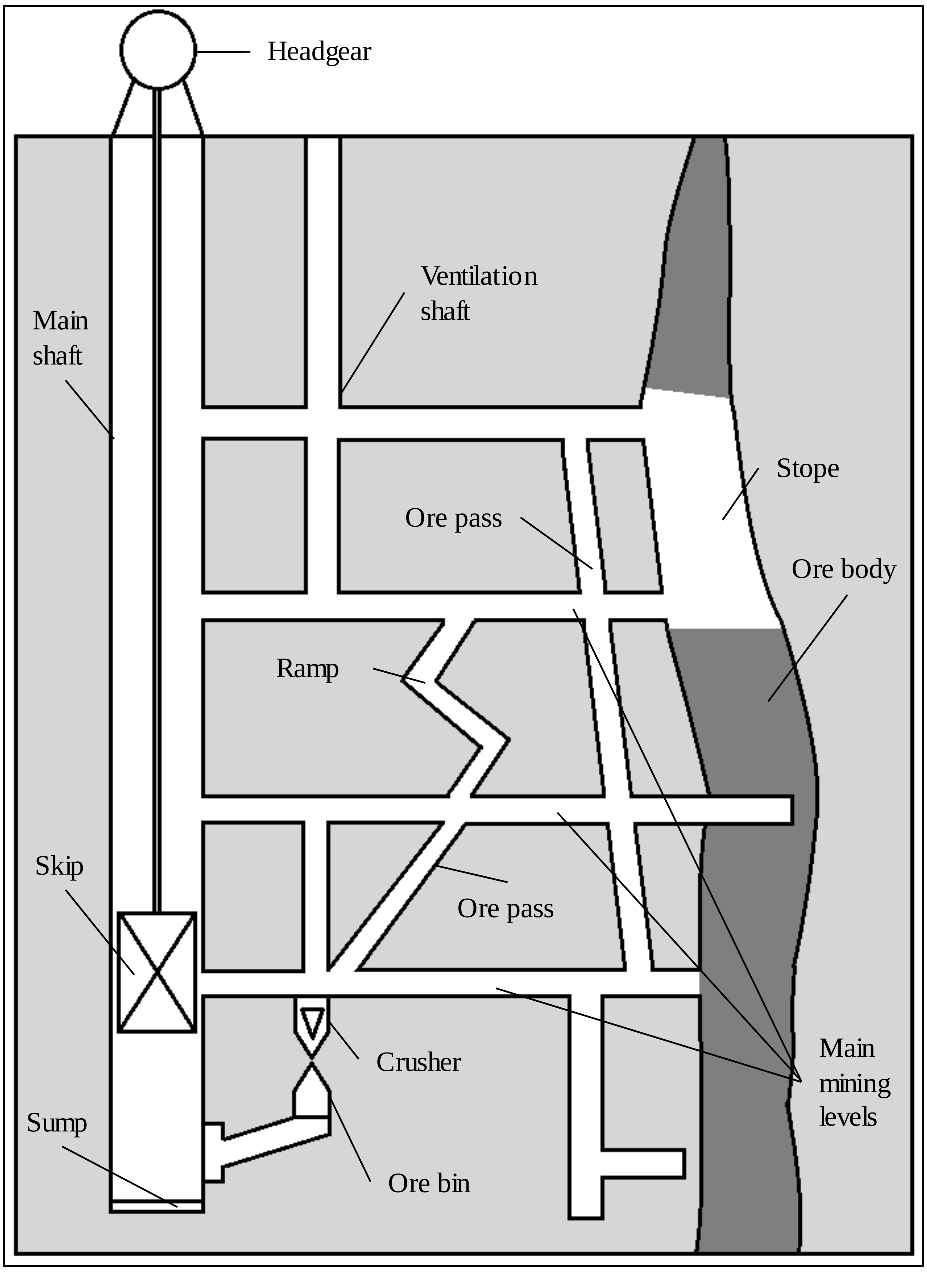

Figure 33: Typical mine layout (Adapted from [74])

Load shifting can be performed on gold production lines by scheduling the operation of rock winders and mills to ensure minimum operation during the morning and evening Megaflex peak periods. The same principle that is used on cement process lines can be applied here by using excess storage capacity as buffers to enable load shifting. Load shifting on rock winders can be achieved by using the underground and surface silos as buffers. Similarly, the silos that store the ore before it is fed to the mill and the silos that store the milled ore can be used as buffers to enable load shifting on the mills.

Figure 34 shows the baseline and PA profiles of a load-shifting project on a gold production line. An average evening load shift of about 5 MW was achieved.

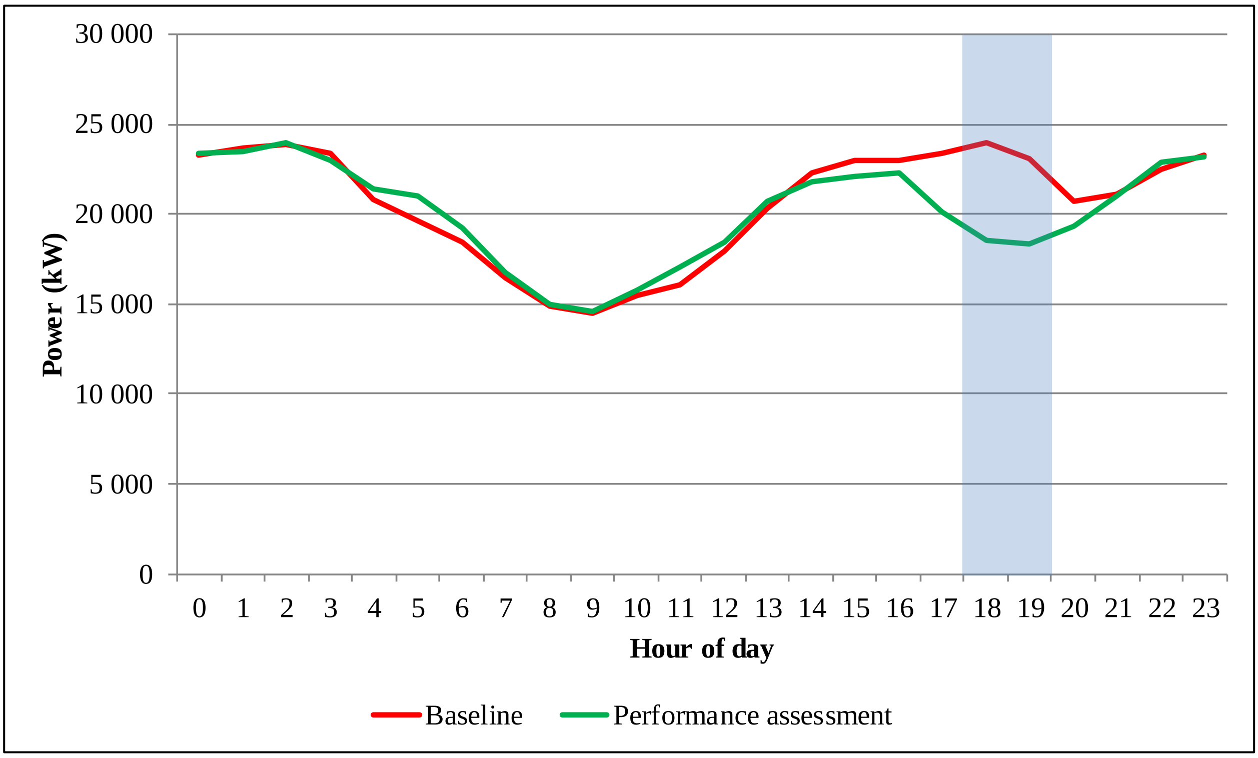

Figure 34: Baseline and PA of a load-shifting project on gold production line

2.3 Energy efficiency

2.3.1 Compressed air systems

Compressed air is used extensively on gold and platinum mines to power pneumatic equipment such as rock drills, loaders, agitators, venture blowers, pumps, saws and loading boxes [75]. Different mining activities occur over the course of a typical working day. The compressed air requirements of a mine vary with each mining activity. Figure 35 shows the different activities and varying demand for compressed air.

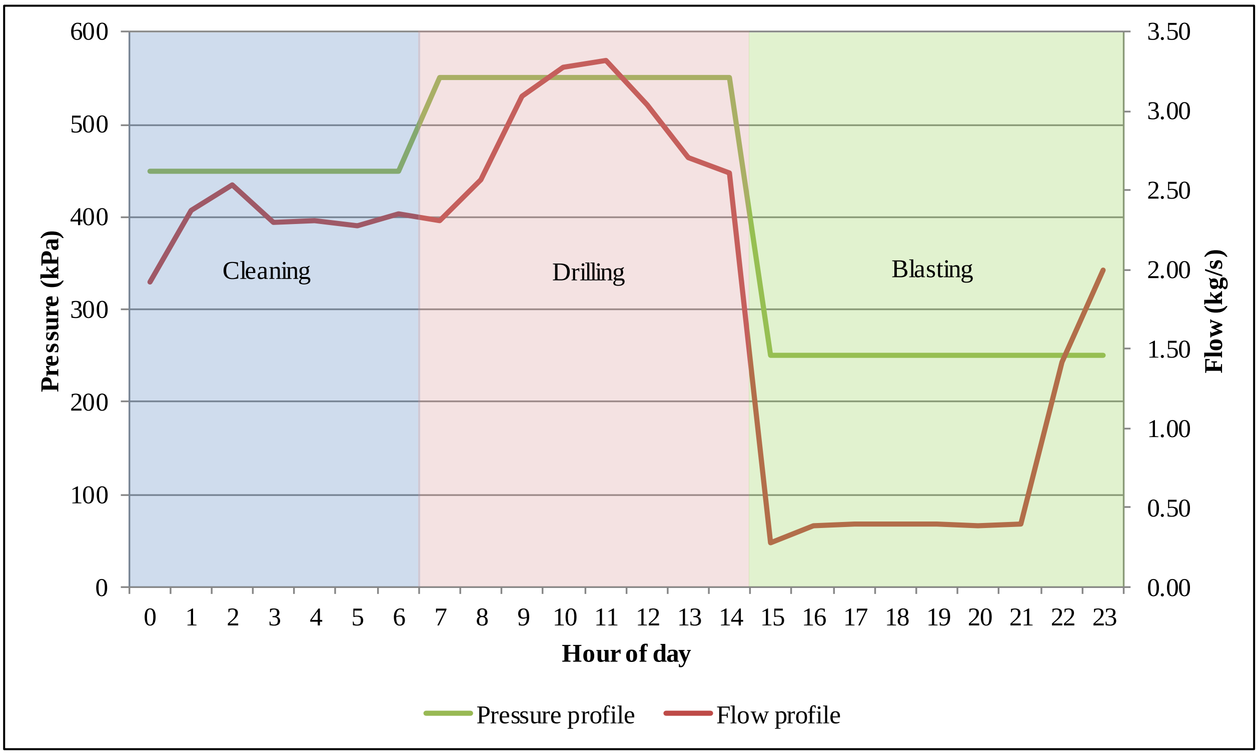

Figure 35: Typical operating schedule and varying demand for compressed air of a gold mine

Energy efficiency on compressed air systems can be achieved by installing control valves to reduce the amount of compressed air supplied to different mining levels in lower demand periods, such as the blasting and cleaning shifts. The use of control valves also reduces the loss of compressed air through leaks. Reducing the amount of compressed air supplied to the levels in off-peak periods reduces the electricity consumption of the compressors.

Figure 36 shows the control valve installations on the various mining levels of a South African gold mine. Bypass control valves, pressure transmitters and flow meters were installed on each level. A photo of a bypass control valve configuration is shown in Figure 37. The bypass pipeline usually has a smaller diameter than the main pipeline because the bypass pipeline is only used during periods when less flow is required. During periods of lower compressed air demand, the main line valve is closed and the downstream pressure is regulated with the bypass valve. Figure 38 shows the results obtained during PA of an energy-efficiency project on the compressed air network of a South African gold mine. An average efficiency of almost 2 MW was obtained.

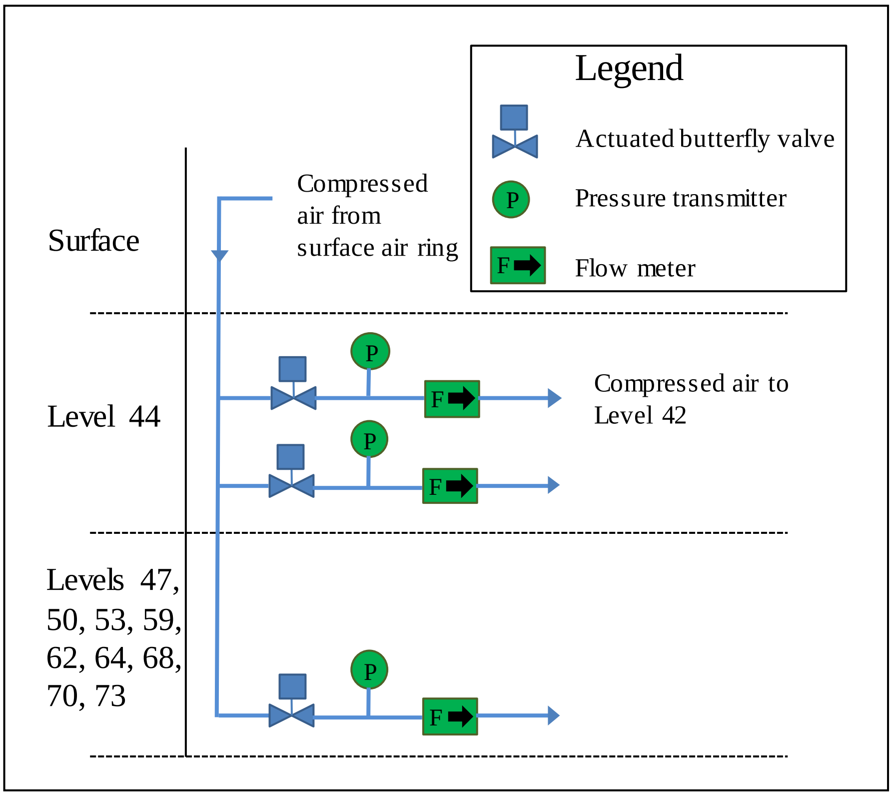

Figure 36: Control valve installations on compressed air network

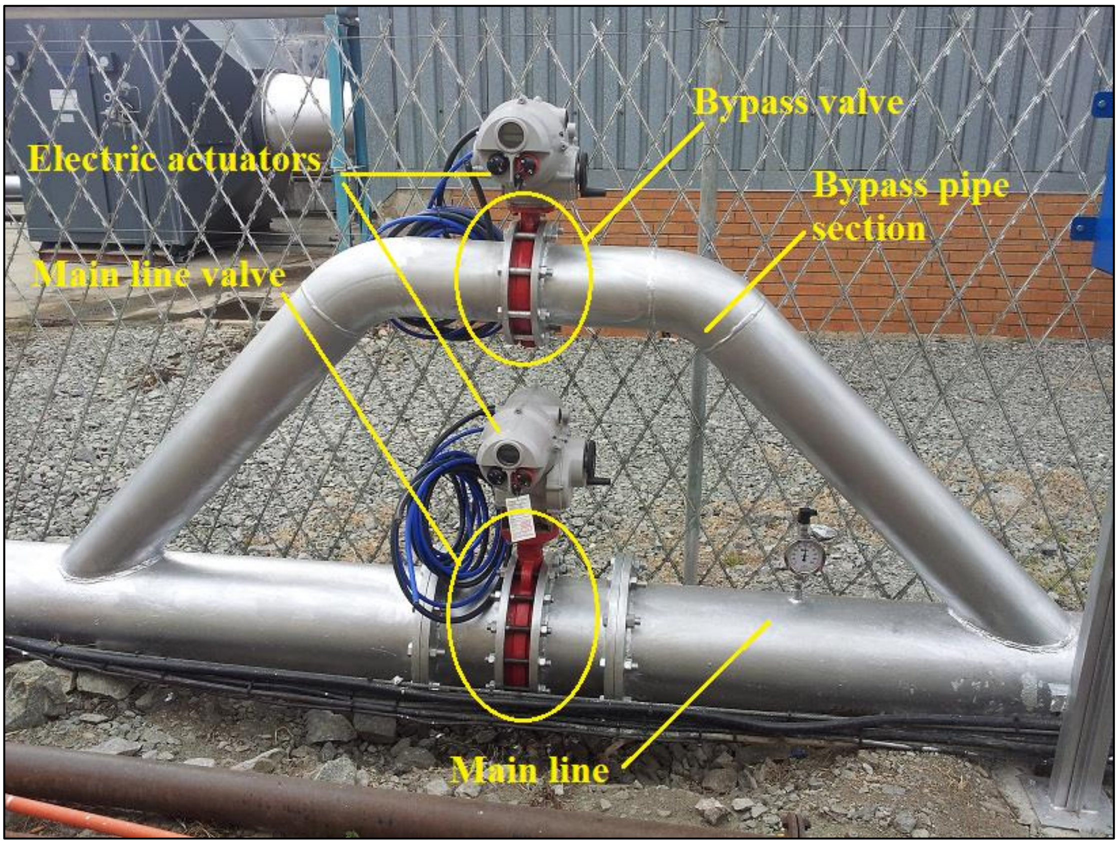

Figure 37: Bypass globe control valve configuration (Adapted from [76])

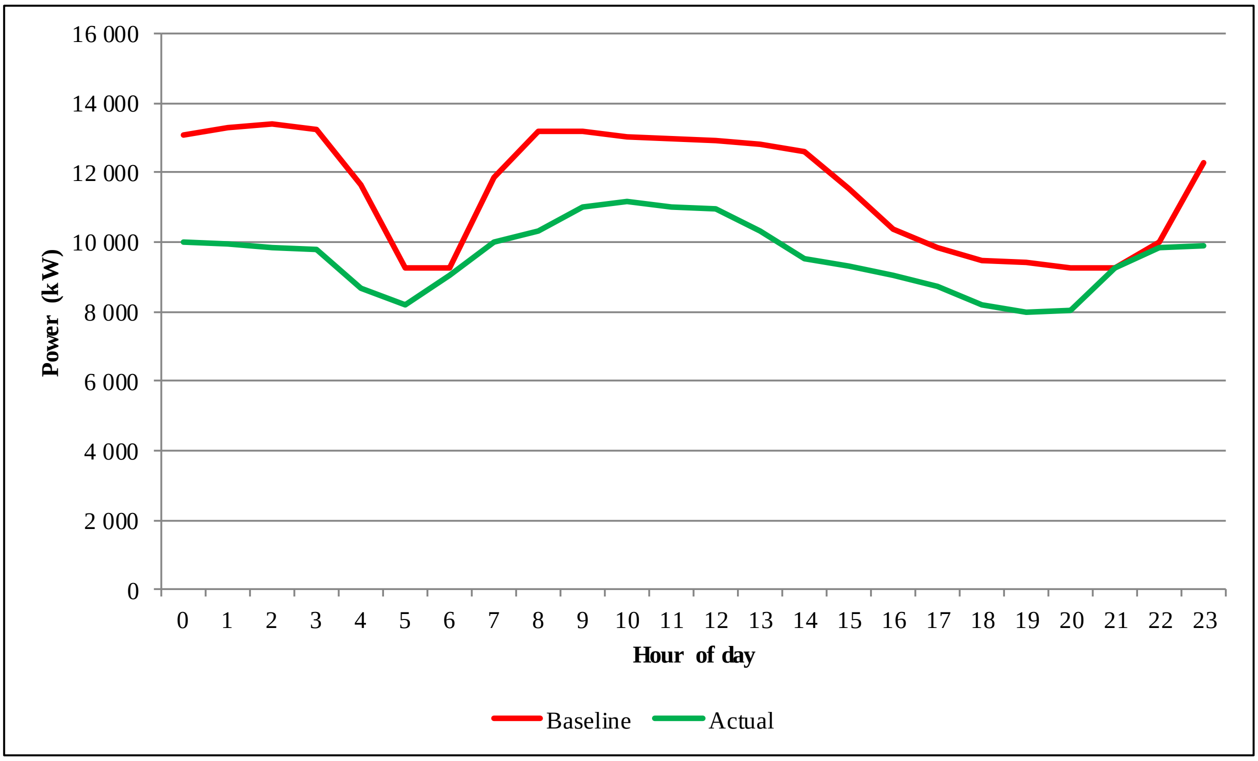

Figure 38: Baseline and PA profiles of energy-efficiency project on compressed air network

2.3.2 Energy efficiency on dewatering pumps

Reducing a mine's water consumption will reduce the amount of water that needs to be pumped to surface. This will reduce the electricity consumption of the dewatering pumps. The method described in the previous section to limit the supply of compressed air to underground levels with control valves can also be applied to the water reticulation systems of mines.

The water requirements of a mine varies throughout the duration of the working day as different mining activities take place. Bypass globe control valves can be used to reduce the supply of water to the various mining levels in period when less water is required. Figure 39 displays the results obtained on a project where bypass globe control valves were installed to limit the supply of water to the mining levels. An average energy-efficiency impact of 1.85 MW was obtained.

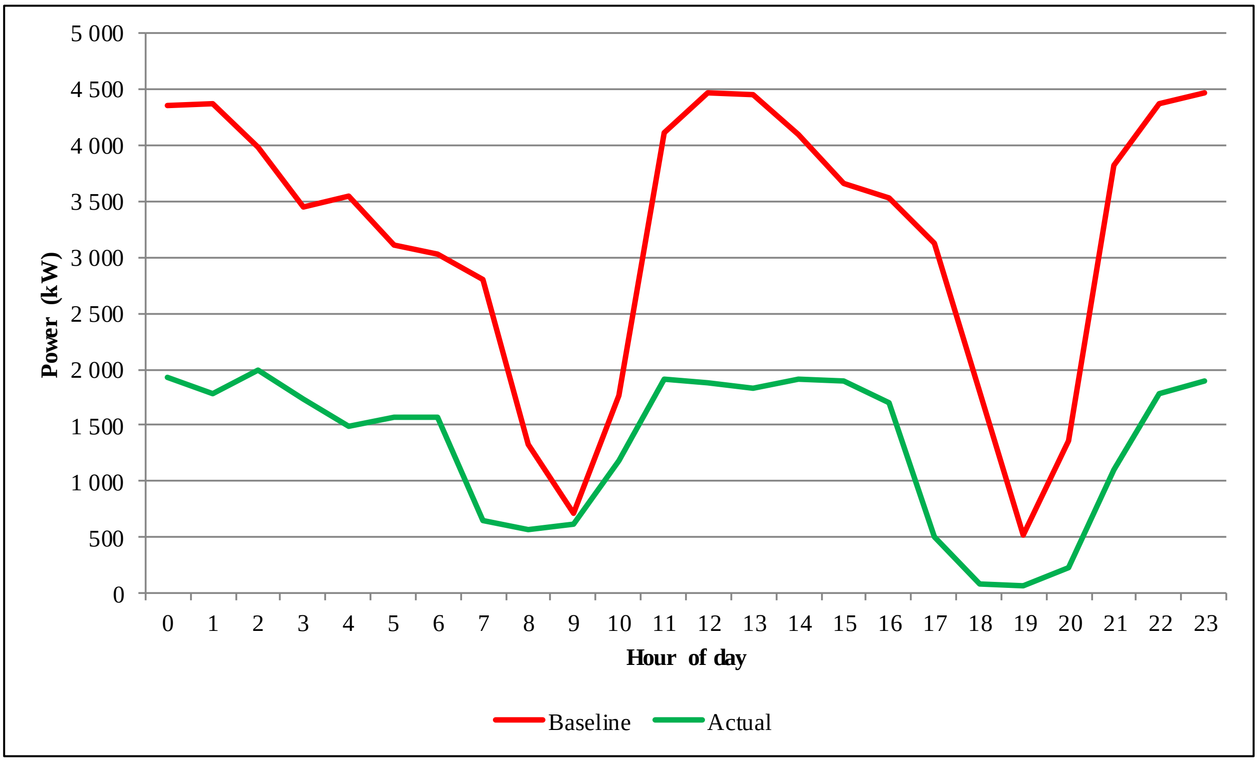

Figure 39: Baseline and actual power profiles of an energy-efficiency project on the dewatering system of a mine

2.3.3 Energy efficiency on fridge plant cooling auxiliaries

Fridge plant cooling systems are designed to deliver sufficient cooling on the hottest and most humid days of the year when there is maximum demand for chilled service water and cool ventilation air [77]. Excess cooling capacity therefore exists on cooler days when the demand for chilled water and cool ventilation air is lower than the supply. This results in excessive circulation of water through the precooling towers and fridge plants, which reduces the efficiency of the cooling system and therefore wastes electricity.

The solution to this problem is to employ a variable water flow strategy during cooler periods of the year when maximum cooling performance is not required. Variable flow through the various components of the fridge plant circuit can be achieved by varying the speeds of the fridge plant auxiliary pumps. Figure 40 shows the typical layout of a surface fridge plant system and auxiliary pumps. The auxiliary pumps include the following:

- Precooling pump that pumps water from the hot dam to the precooling tower.
- The evaporator pump that pumps water from the precooling dam through the evaporator circuit of the fridge plant.

- The condenser pump that circulates water through the condenser circuit of the fridge plant.
- The BAC pump that supplies water from the cold water dam to the BAC.
- The BAC return water pump that pumps water from the sump of the BAC to the precooling dam.

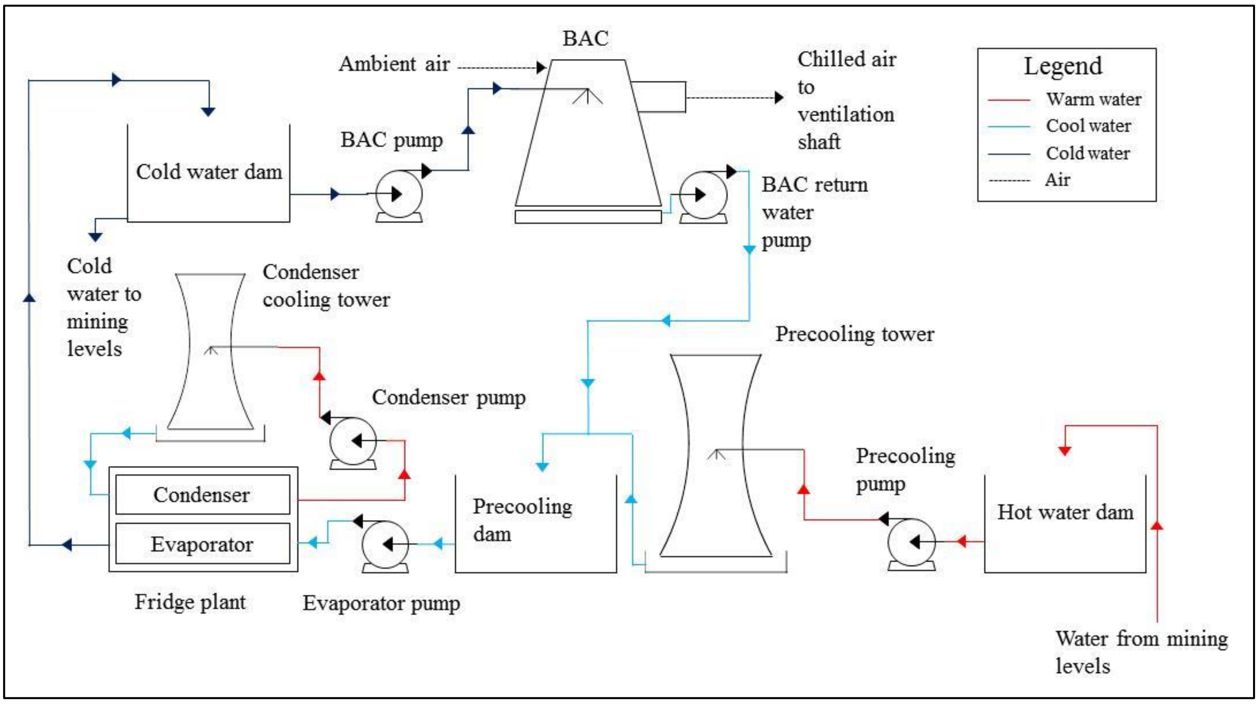

Figure 40: Surface fridge plant and auxiliary pumps (Adapted from [78])

The power consumption of a fridge plant system is influenced by the following factors [77]:

- Ambient air enthalpy.
- Temperature and flow of service water delivered to the mine.
- Temperature of ventilation air.

The ambient air enthalpy cannot be controlled and is therefore considered an independent input variable. The flow of the service water delivered to the mine can be controlled if a water supply optimisation (WSO) project is implemented. For purposes of explanation, the flow of service water is also considered an independent variable. The temperatures of the service water and ventilation air are controllable and are considered dependent output variables.

The implementation of a variable flow strategy will affect the dependent variables, namely, the temperatures of the service water and ventilation air. It is important that the values of the dependent variables stay within the limits of the service delivery requirements specified by the mine. The implementation of a variable flow strategy will increase the efficiency of the cooling system and result in electricity cost savings [78].

Cooling is more efficient if a large temperature difference exists between the water and the coolant [77]. The inlet temperatures of the cooling towers and the fridge plants must therefore be controlled to ensure that maximum heat transfer can take place, while still adhering to the service delivery requirements of the mine. The implementation of a variable water flow strategy will also reduce the amount of water that is passed through the fridge plant, which will result in further electricity cost savings. Reducing the frequencies of the auxiliary pumps also results in energy savings. This is because relatively small variations in motor speed can result in large energy savings in accordance with the theoretical cubic power-flow affinity law [79].

Implementing a variable flow strategy entails installing VSDs on the auxiliary pumps. Various inlet and outlet temperature sensors, dam level sensors and a psychrometer to calculate ambient air temperature are also required. A typical variable flow control philosophy entails using proportional, integral, derivative (PID) control logic to control the frequencies of the cooling auxiliary pumps as follows:

- Control the frequency of the precooling pump to maintain the required level of the precooling dam.
- Control the frequency of the evaporator pumps to maintain the required level of the cold water dam.
- Control the frequency of the condenser pumps to maintain the average design temperature difference over the condenser circuit [80].
- Control the frequency of the BAC pump according to the ambient air enthalpy. The flow of water through the BAC needs to increase as the ambient air enthalpy increases. The same principle applies the other way round – the flow needs to decrease when the air enthalpy decreases.
- Control the frequency of the BAC return water pump to maintain the level of the BAC sump.

Figure 41 shows the results obtained during PA of a cooling auxiliaries (CA) project conducted on the both the surface and underground fridge plants of a gold mine. An average energy efficiency of 2.4 MW was obtained.

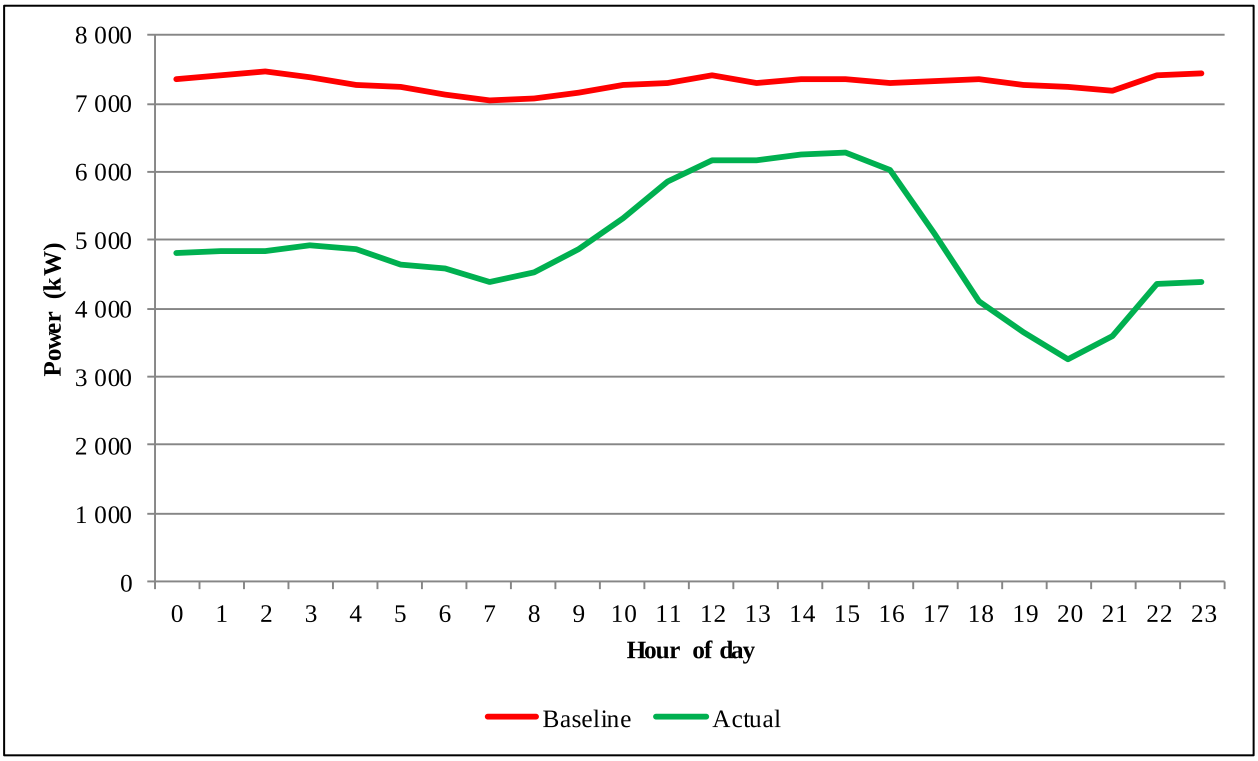

Figure 41: Baseline and actual power profiles of a CA project

2.4 Peak clipping

2.4.1 Peak clipping on compressed air systems

Peak clipping on compressed air systems can be achieved through a combination of effective compressor control and the use of control valves. Effective compressor control entails using the most effective compressors combinations and delivery pressure set points to ensure that the supply of compressed air matches the demand as closely as possible.

Figure 42 shows the results of implementing a peak-clipping project on the compressed air system of a South African gold mine. An average evening-peak clip of 2.6 MW was achieved during the PA period. This peak-clipping saving was achieved by implementing the following measures during the evening peak period:

- The delivery pressure set point of the compressors was reduced from 500 kPa to 400 kPa.
- Control valves on each mining level reduced the compressed air pressure to 250 kPa.

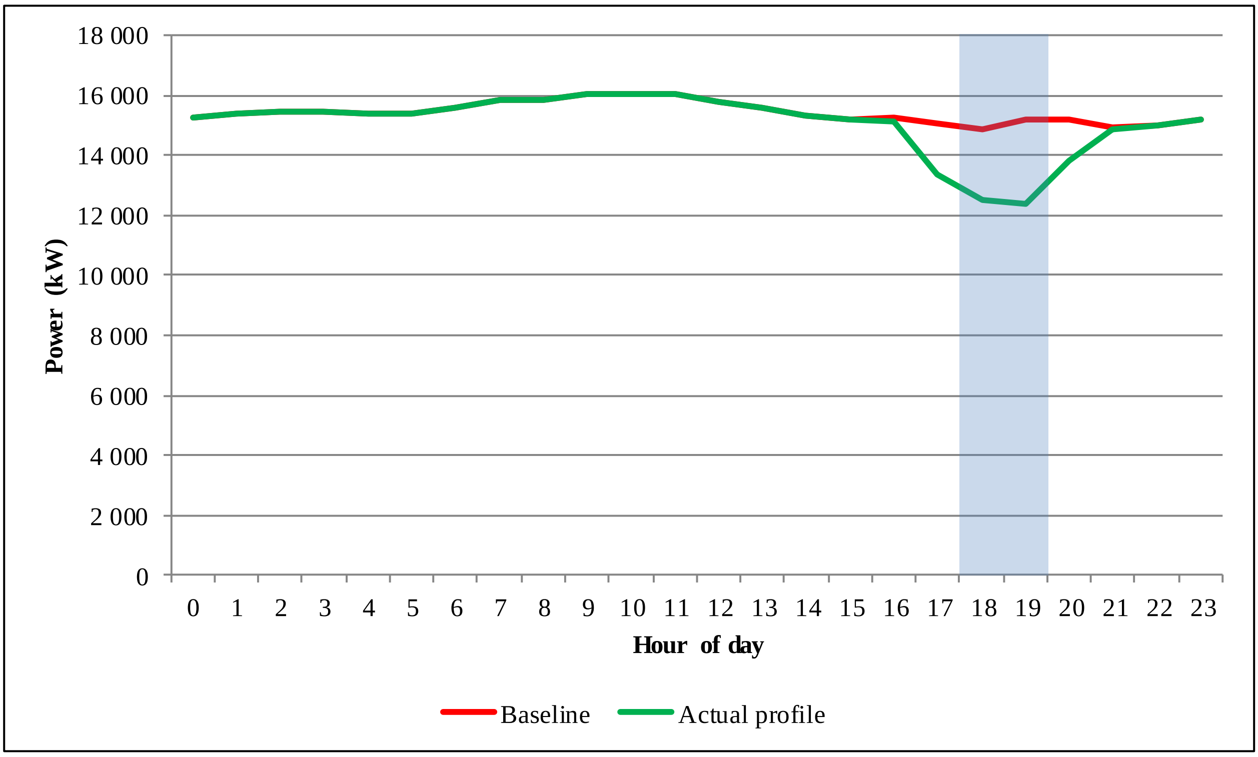

Figure 42: PA results of a peak-clipping project

2.4.2 Peak clipping on bulk air coolers

Peak clipping on BACs entails switching off BAC fans during the Eskom evening peak period. Switching off BAC fans reduces the flow of cooled air into the mine, which affects the underground working conditions, namely, temperature and relative humidity. The Eskom evening peak coincides with the blasting shift when the minimum number of workers is present in the mine. Less workers underground means that less cooling is required.

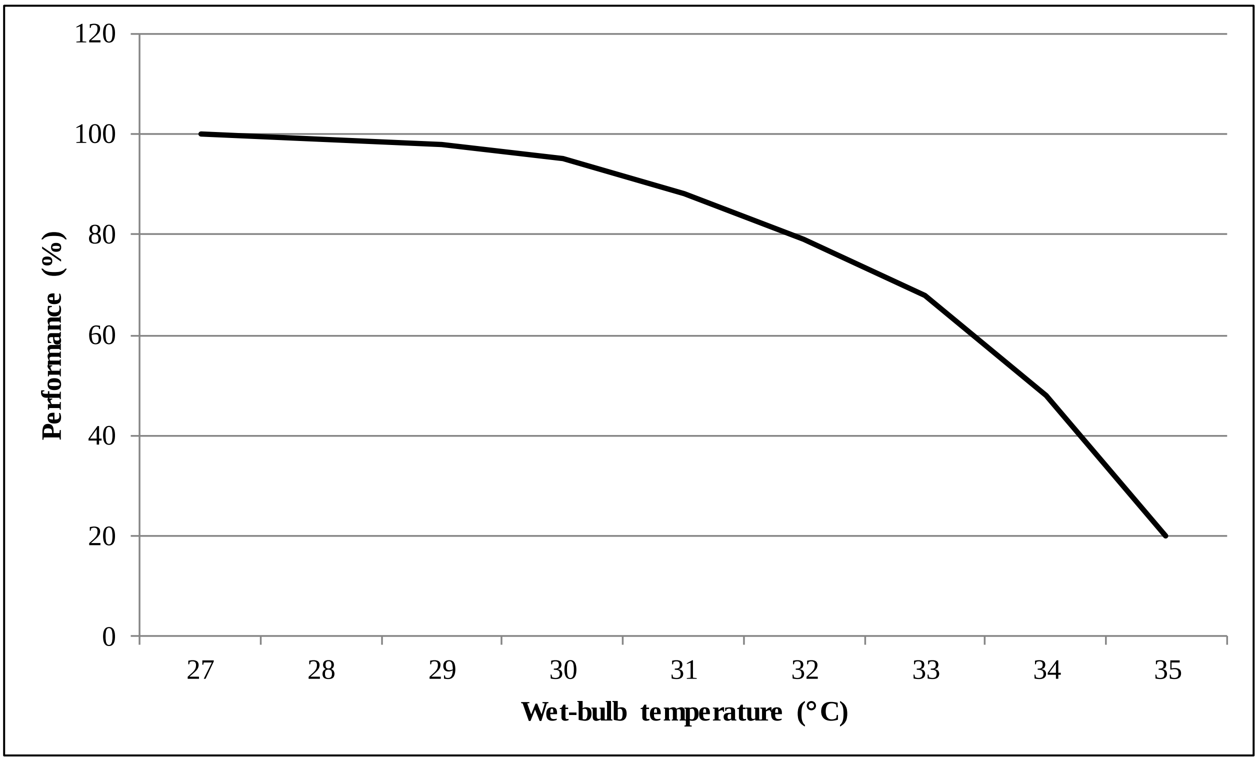

Figure 43: Performance of underground workers as a function of wet-bulb temperature (Adapted from [81])

Peak clipping on BAC fans is based on the idea that BAC fans can be switched off during the evening peak if underground conditions are within the prescribed ranges for a safe, healthy and productive working environment. Figure 43 displays how the performance of underground workers decreases as the underground wet-bulb temperature increases above 27 °C. It is evident from Figure 43 that the underground wet-bulb temperature should not increase above 28.5 °C.

The BAC fans can remain switched off, as long as the underground conditions stay within the prescribed ranges. The ideal is to keep the BAC fans switched off for the entire duration of the evening peak period. If the prescribed limits are breached during the evening peak period, the BAC fans must be switched on again. Switching off BAC fans reduces the demand for chilled water. This means further savings can be achieved by switching off fridge plants and auxiliary pumps.

Peak clipping on BACs is made possible through real-time monitoring of underground working conditions. Underground conditions can be monitored with sensors that are installed in various strategic locations throughout the mine. These sensors measure temperature, air velocity and relative humidity. Figure 44 shows how the underground wet-bulb temperature varied throughout one of the days during PA.

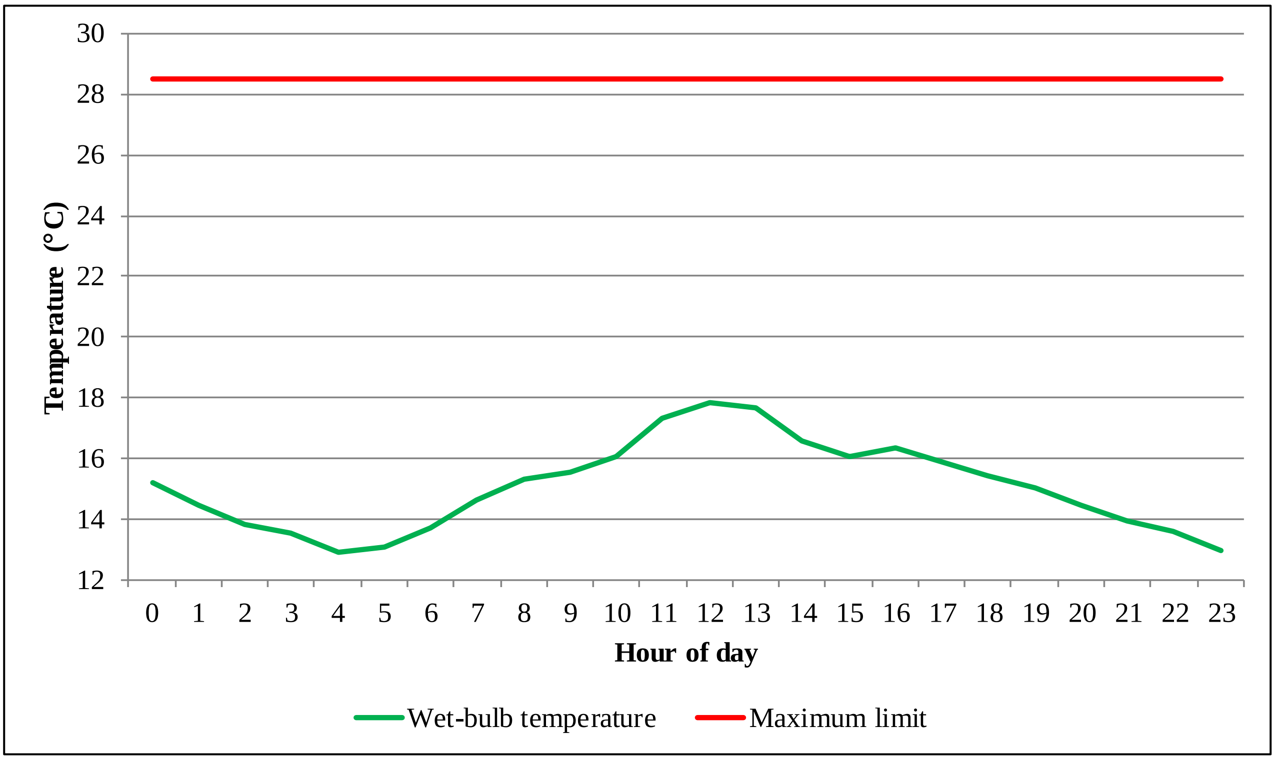

Figure 44: Effect of BAC project on wet-bulb temperature

Figure 45 shows the results obtained during PA of a BAC project. An average peak clip of about 4 MW was obtained during PA.

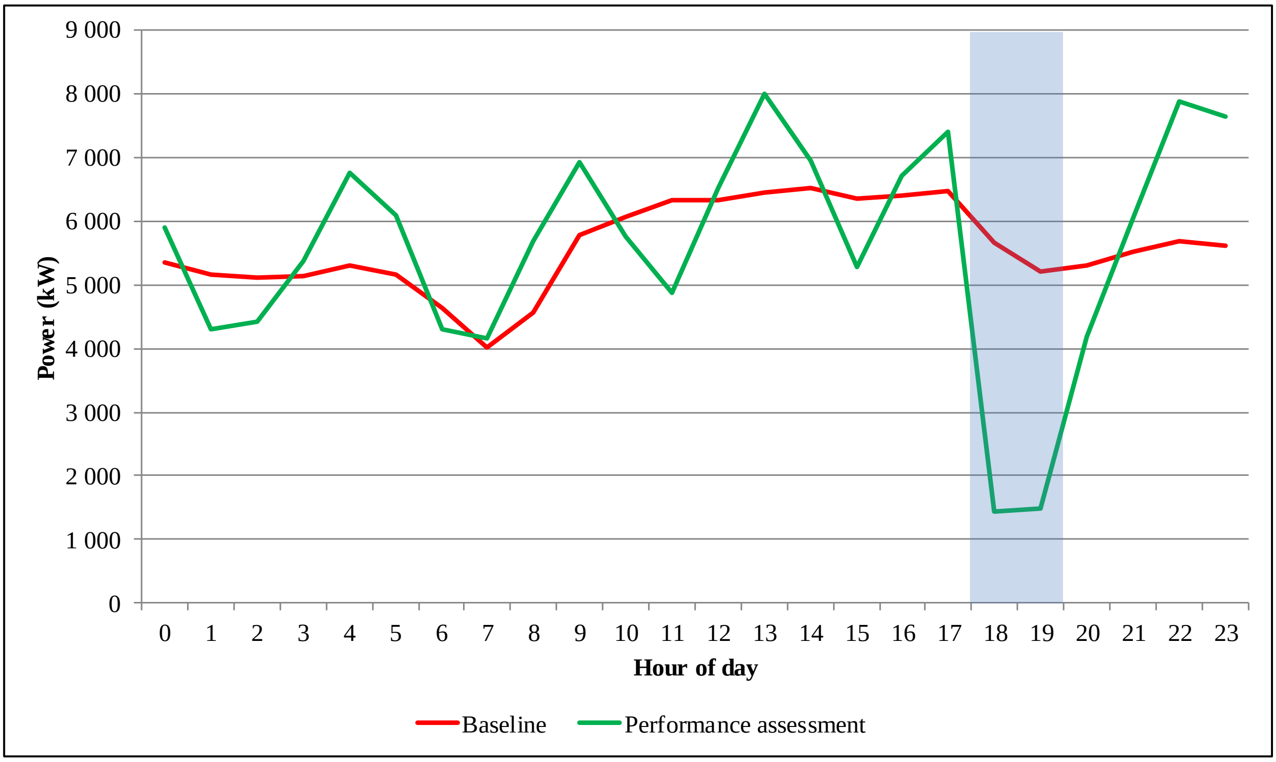

Figure 45: Baseline and PA profiles of a BAC project

2.5 Automatic and semi-automatic control of DSM projects

The majority of industrial DSM projects consists of a physical system that is controlled in accordance with a certain control philosophy to realise either electricity savings or load shifting. The physical system normally consists of hardware, network and software. Figure 46 shows the relationship between the different components of a DSM project.

The physical system can be controlled automatically or semi-automatically depending on the application, the available infrastructure, the available funding and the requirements of the client. Load-shifting projects on mine dewatering pumps are usually fully automated. This means that all the dewatering pumps are automatically controlled by a control system software.

The first prerequisite for implementing an automatic pump control system for load shifting is that all dewatering pumps must be fully automated with remote control functionality. This implies that the start and stop sequences of the pumps need to be automated to enable remote pump control from a control room on surface. The second prerequisite is that all dams involved in the dewatering system must have dam level sensors installed. This allows the monitoring of dam levels.

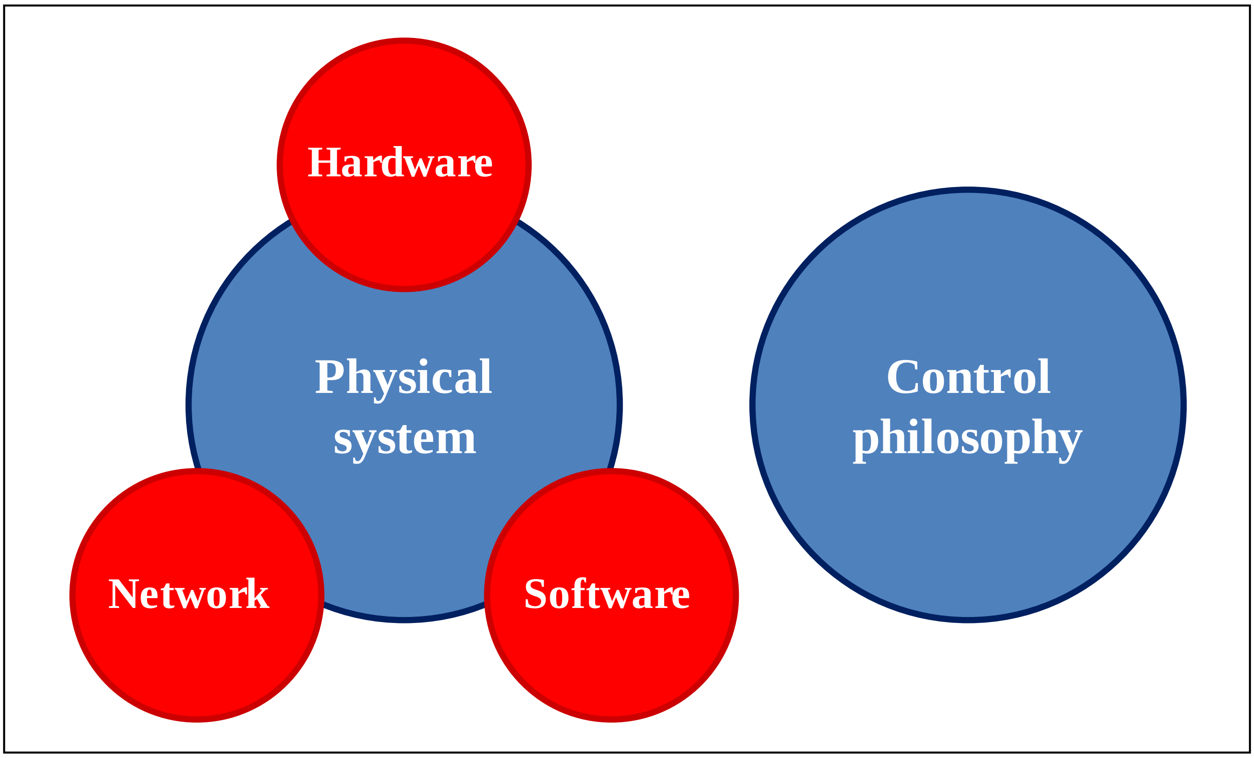

Figure 46: Components of a DSM project (Adapted from [82])

The control system interfaces with the SCADA system of the mine. This allows the automatic pump control system to access the real-time values of the dam levels. The real-time dam levels are used to calculate the number of pumps that must be used on each level to achieve maximum load shifting during the Megaflex peak periods. The pump control system automatically starts and stops the pumps on the various mining levels in accordance with its calculations to ensure maximum load shifting.

Figure 47 shows how the pump control system communicates with the pumps and dam level sensors on a pump load-shifting project. Only one mining level and the surface dams are shown, but the same principle applies to the pumps and dam levels sensors located on the rest of the mining levels.

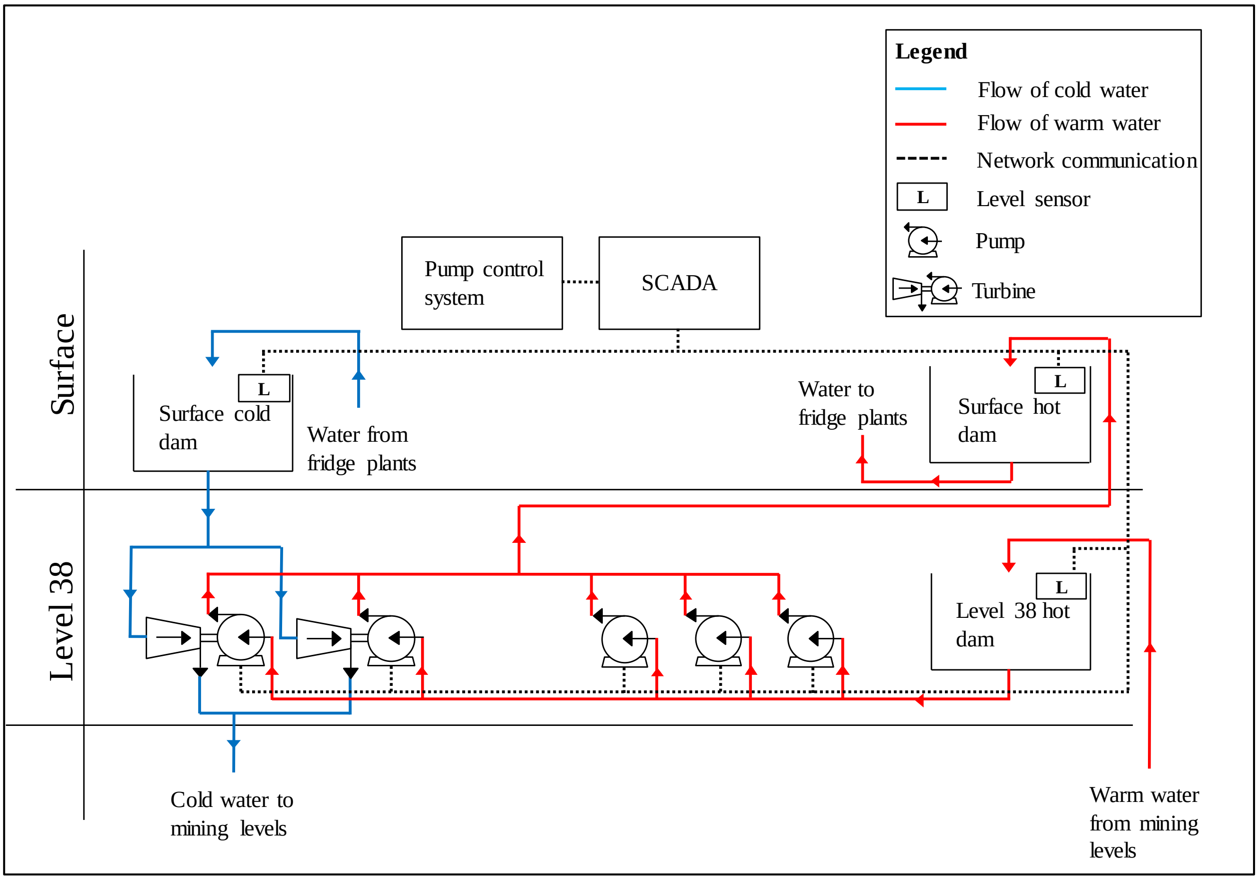

Figure 47: Communication between pump control system and pumping infrastructure

An example of a DSM project where the physical system is controlled semi-automatically is a load-shifting project on the mills of a cement manufacturing plant. The control system interfaces with the SCADA system of the cement plant to retrieve real-time data such as stock and silo levels, mill availability, mill throughput rates, and so forth. These values enable the control system to determine running schedules for the mills that aim to achieve maximum load-shifting performance while adhering to all system constraints such as maximum and minimum silo levels, production targets, availability of equipment, and so forth.

The mills are not directly controlled by the control system according to the optimised running schedules. The optimised running schedules are instead displayed on an overhead screen in the control room of the cement manufacturing plant. The control room operators are required to control the mills manually in accordance with the optimised schedules.

Figure 48 shows a screenshot of the optimised running schedules that are displayed on the overhead screen in the control room. The optimised running schedules for the two raw mills and the cement mill are shown. The real-time running statuses of each mill are also displayed, along with the status suggested by the optimised schedule. The background of the schedule for Raw Mill 2 is displayed in red because the status and the schedule do not correspond. If the status and schedule do not correspond during the Megaflex peak periods, the schedule background flashes red to draw attention to the fact that the schedule is not followed.

The advantage of displaying the optimised running schedules on an overhead screen in the control room is that it is visible to everyone in the control room. This allows the control room operators to assist each other in following the optimised running schedules. It also allows anyone that enters the control room to determine immediately if the optimised running schedules are being followed.

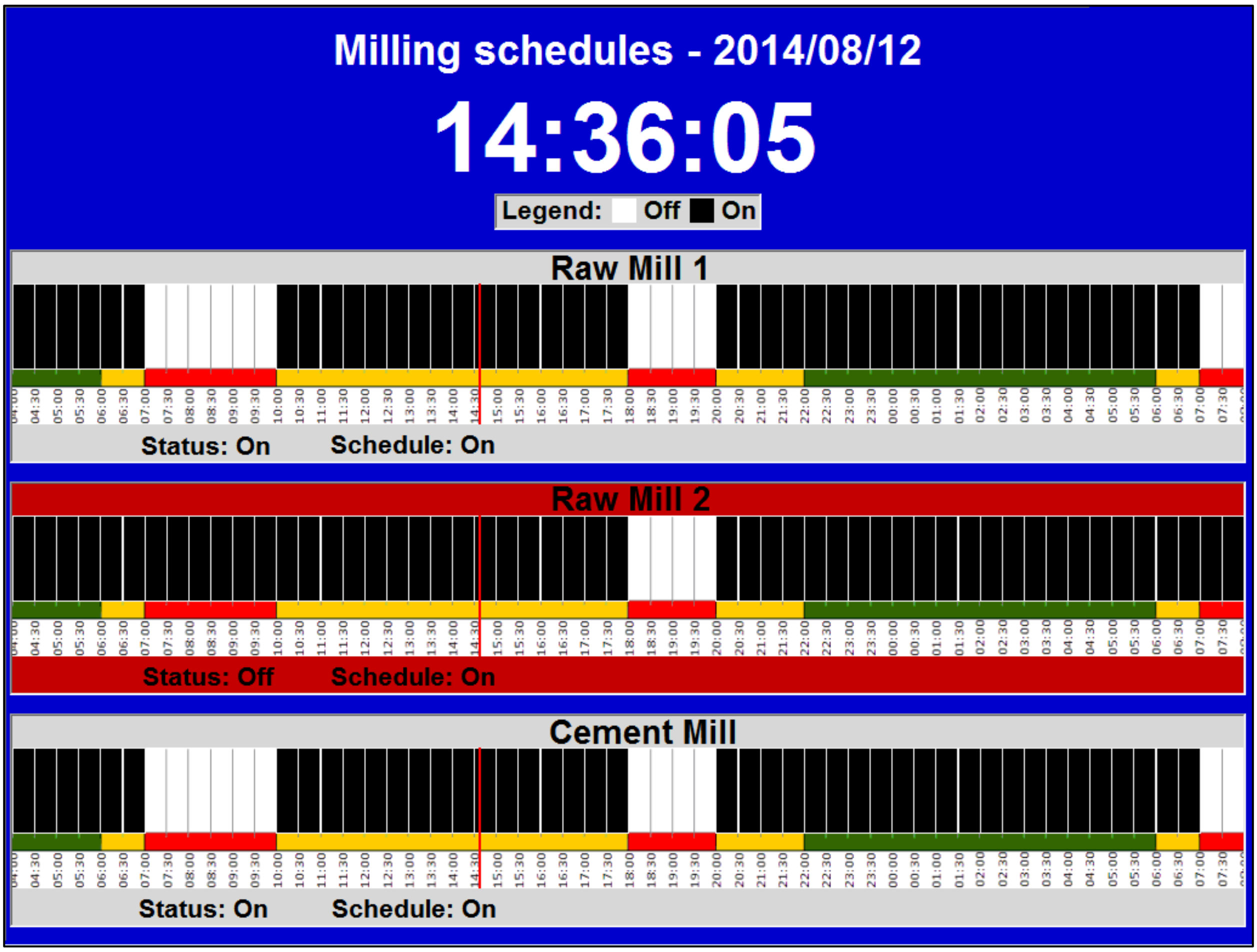

Figure 48: Optimised mill running schedules

Table 9 displays the distribution between automatic and semi-automatic control for the DSM projects considered in this study. It is technically possible to implement full automatic control on the projects listed in the semi-automatic control category. A major reason why full automatic control has not been implemented on fridge plant load shifting and BAC peak-clipping projects is the high cost of automating the start-up and stop sequences of fridge plants. Clients prefer controlling cement mills and water transfer pumps load-shifting projects semi-automatically.

Table 9: Distribution between automatic and semi-automatic control

Automatic control	Semi-automatic control
Load shifting on dewatering pumps	Load shifting on cement mills
Load shifting on gold production lines	Load shifting on fridge plants
Energy efficiency on compressed air systems	Load shifting on water transfer pumps
Energy efficiency on dewatering pumps	Peak clipping on BACs
Energy efficiency on fridge plants	
Peak clipping on compressed air systems	

The advantage of automatic control over semi-automatic control is sustainability due to the human factor being eliminated. Consider, for example, load shifting on mine dewatering pumps. Pump attendants or control room operators can be instructed to manage dam levels and control pumps to achieve load shifting. This manual load-shifting intervention will probably only last as long as there is someone who monitors the load-shifting performance on a regular basis; or if the pump attendants or control room operators are incentivised for the performance of their manual load-shifting attempts. A fully automated control system that is maintained correctly can be expected to be more sustainable than human operators are.

2.6 Causes for DSM project underperformance

2.6.1 DSM implementation model

From 2003 to 2014, 261 industrial DSM projects were implemented with the support of Eskom IDM [83]. These projects included load-shifting, energy-efficiency and peak-clipping projects with a combined target of 676 MW [83]. The viability of these projects was proven by an average performance of 98% during PA [83].

After PA, the responsibility of maintaining a DSM project is transferred to the client for a minimum period of five years. This five-year period is known as the performance tracking (PT) phase. Unfortunately, the performance obtained during PA is not always sustained during the PT period.

The underlying cause of underperformance during PT is a shortcoming of the DSM implementation model. The model stipulates that the ESCO needs to prove the performance of a DSM project during the three-month PA period. The ESCO is penalised if the project does not reach at least 90% of its contracted savings target during PA. ESCOs therefore put in a lot of effort to ensure that maximum performance is achieved during PA.

Figure 49 and Figure 50 compare the project targets and the average performance during PT for a number of pump load-shifting projects implemented on the various shafts of a South African mining group. It is evident that there are large differences in performance between PA and PT. Figure 49 shows a group of projects where the ESCO’s involvement in the project ended after PA. It is evident that all of these projects underperformed during PT, which means that the client could be liable for underperformance penalties.

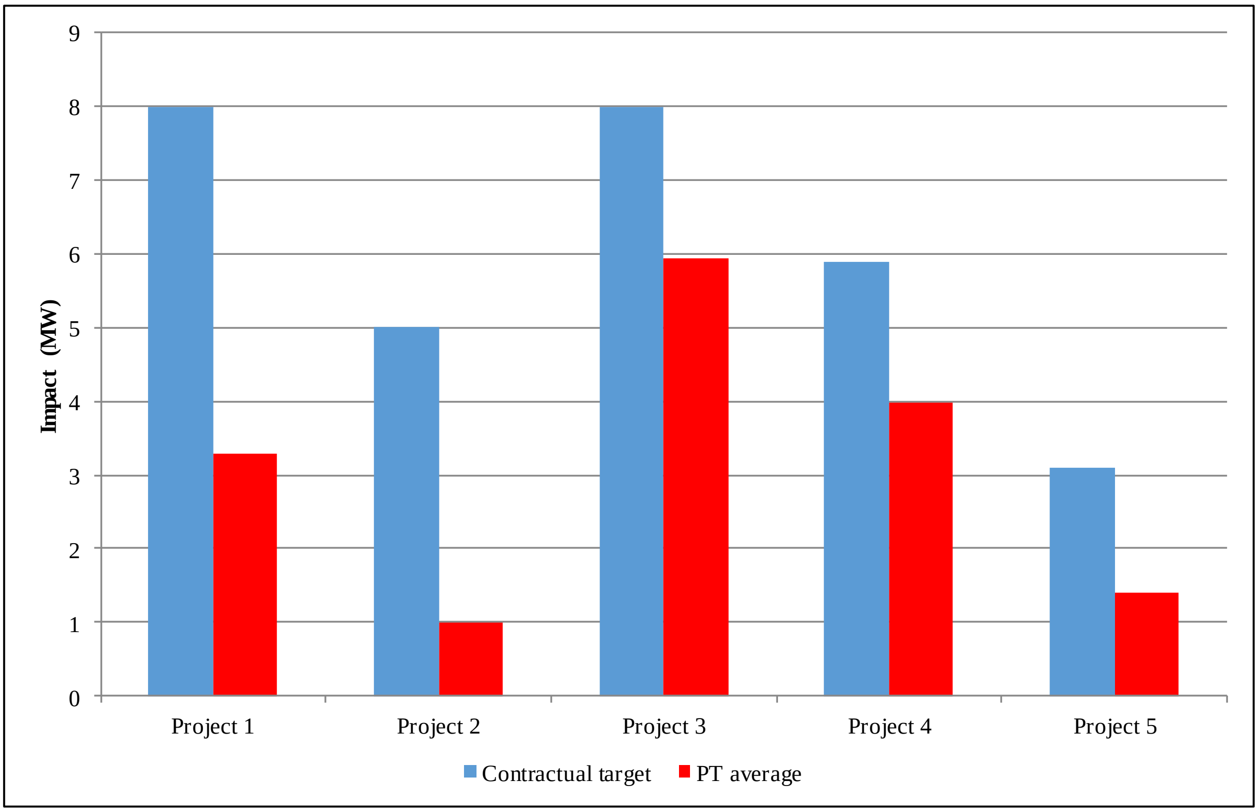

Figure 49: Pumping projects without maintenance by ESCO during PT

Figure 50 shows the performance comparison for a group of pumping projects where the ESCO maintained the projects during PT. All of these projects overperformed on their contractual targets. Maximum electricity cost savings were achieved without any risk of underperformance penalties.

The DSM implementation model does not make provision to keep ESCOs involved to maintain DSM projects after PA. The data displayed in Figure 49 and Figure 50 shows that this is a major shortcoming of the current DSM model employed by Eskom IDM. It is recommended that the DSM contract between Eskom and the client should specify that the client should enter into a maintenance agreement with the ESCO for the duration of the contract period.

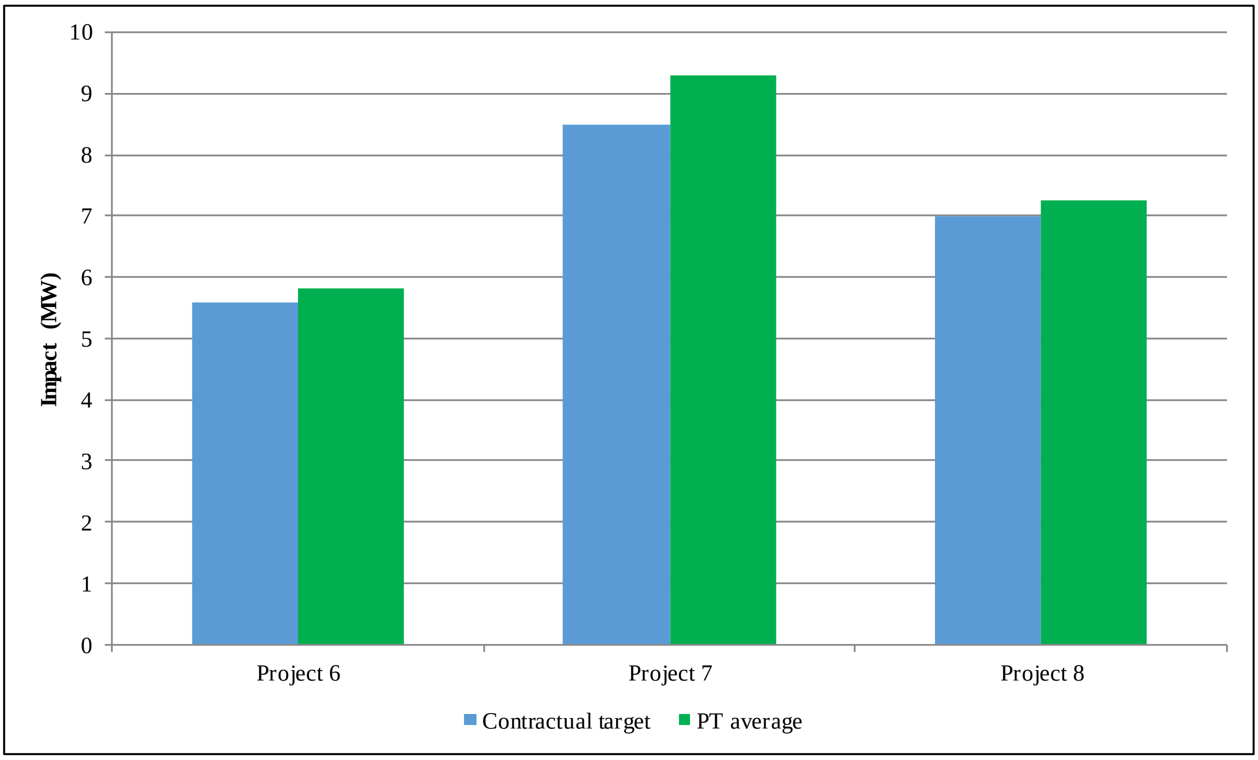

Figure 50: Pumping projects with maintenance by ESCO during PT

2.6.2 Penalties for underperformance

The DSM agreement between Eskom and clients stipulates that clients can be penalised if their DSM projects do not achieve a minimum of 90% of their contracted savings targets during PT. The penalties vary from a fixed amount per MWh of missed savings to an amount that is calculated according to the following formula:

$$P = A \times T \times \frac{B}{F} \times M^{\frac{F-G}{12}} \qquad (3)$$

Where:

P = *Penalty amount*

A = *Eskom's contribution to the project*

B = *Period in months over which penalties are payable*

F = *Total contract duration in months*

M = *Inflation adjustment factor calculated according to the prime overdraft rate on the anniversary of the measurement acceptance date*

G = *Remaining contract period in months*

T is a factor obtained from Table 10 in accordance with the verified performance of the project

Table 10: Calculation of *T* according to project performance

Performance (%)	T
0.00	1.00
0.05	1.00
5.00	0.95
10.00	0.90
15.00	0.85
20.00	0.80
25.00	0.75
30.00	0.70
35.00	0.65
40.00	0.60
45.00	0.55
50.00	0.50
55.00	0.45
60.00	0.40
65.00	0.35
70.00	0.30
75.00	0.25
80.00	0.20
85.00	0.13
90.00	0.00
95.00	0.00
100.00	0.00

The second reason for underperformance of DSM projects during the PT phase is that Eskom IDM has not been enforcing underperformance penalties on clients. No clients were penalised for underperformance in the period between 2003 and 2014. Penalties for underperformance should have been strictly enforced from the implementation of the first DSM projects funded by Eskom IDM.

2.6.3 Root cause analysis of DSM underperformance

Every industrial DSM project type experiences different reasons for underperformance. The causes of underperformance are to a large extent common among all DSM project types. These common causes of DSM project underperformance are:

- *Interference with automatic control:* A control system designed to achieve electricity cost savings will be unsuccessful if it is not allowed to operate without interferences. There might be valid reasons for operators or other technical personnel to interfere with the operation of a control system, for example, in case of emergency or malfunctioning of the control system. Unfortunately, it often happens that there are unnecessary interferences that result in underperformance.
- *Lack of buffer capacity (only applicable to load-shifting projects):* The performance of a load-shifting project is directly related to the size of the available buffer capacity.
- *High demand or unfavourable conditions that prevent application of DSM measures:* A CA project is based on the assumption that the fridge plant system of a mine is designed to deliver sufficient cooling during hottest and most humid summer days. The excess cooling capacity that is available under less extreme conditions can be converted to electricity cost savings by implementing a variable flow strategy. Unfortunately, this means that the electricity cost savings achieved by a CA project is at a minimum during the hottest summer months when the demand for cooling of the mine is at its maximum level.
- *Infrastructure constraints or breakdowns:* The performance of industrial DSM projects is to a large extent dependent on the condition of the project infrastructure. For example, a pump load-shifting project is sure to be unsuccessful if the availability and efficiency of the pumps are not up to standard.
- *Control system problems:* These entail control philosophy, programming or communication errors on the side of the control system that result in ineffective control and underperformance.

A list of the reasons for underperformance of industrial DSM projects is presented in Annexure A.

2.7 Summary

This chapter provided an overview of various types of industrial DSM projects. The strategies for obtaining electricity cost savings on each project type were presented. The differences between automatic and semi-automatic control systems were clarified and the advantages of automatic control over semi-automatic control were explained. An explanation of the various reasons for DSM project underperformance on implementation and contractual level was also presented. The chapter concluded with a description of the common causes of DSM project underperformance.

CHAPTER 3. PERFORMANCE-CENTERED MAINTENANCE

3.1 Introduction

Chapter 2 provided details regarding the operation of different DSM projects. It concluded with an analysis of the reasons for DSM project underperformance. The solution to the underperformance of DSM projects is to implement a PCM strategy to restore and sustain project performance. The purpose of this chapter is to present the various aspects of the PCM strategy for DSM projects. Chapter 3 starts with a discussion about the requirements for PCM, after which the focus shifts to the various aspects of the PCM strategy.

3.2 PCM requirements

Moubray [47] defined maintenance as "Ensuring that physical assets continue to do what their users want them to do". Maintenance of DSM projects differs from this definition in the sense that its purpose is not only to maintain but also to improve performance. This is because industrial clients are generally not only satisfied with maintaining the performance of their DSM projects, but also want the performance of their DSM projects to improve continuously. The main objective of PCM is to maintain DSM projects for maximum client benefit. This implies that every DSM project must continuously deliver maximum performance to generate maximum value for the client.

An important aspect that sets DSM maintenance apart from other maintenance types is the fact that DSM projects operate in a continuously changing environment. Take, for example, a load-shifting project on the dewatering pumps of a gold mine. The control philosophy of a load-shifting project needs to be frequently updated in response to events such as the following:

- Varying water volumes due to changes in mining activities, rain, underground temperatures, environmental regulations, and so forth.
- Varying number of available dewatering pumps due to breakdowns and maintenance.
- Reducing pump efficiencies due to wear and tear.
- Varying water storage capacities due to dams being unavailable during cleaning or minimum dam levels that are increased because of sediment that accumulates in the dams.
- Burst pipes.

Another aspect that complicates DSM project maintenance is that DSM projects consist of various interrelated components that include both hardware and software. PCM on these interrelated components requires various specialised skills and a unique approach. This necessitates that PCM on DSM projects should be performed by multi-skilled engineering teams. Figure 51 illustrates the multi-disciplinary nature of DSM project maintenance [84].

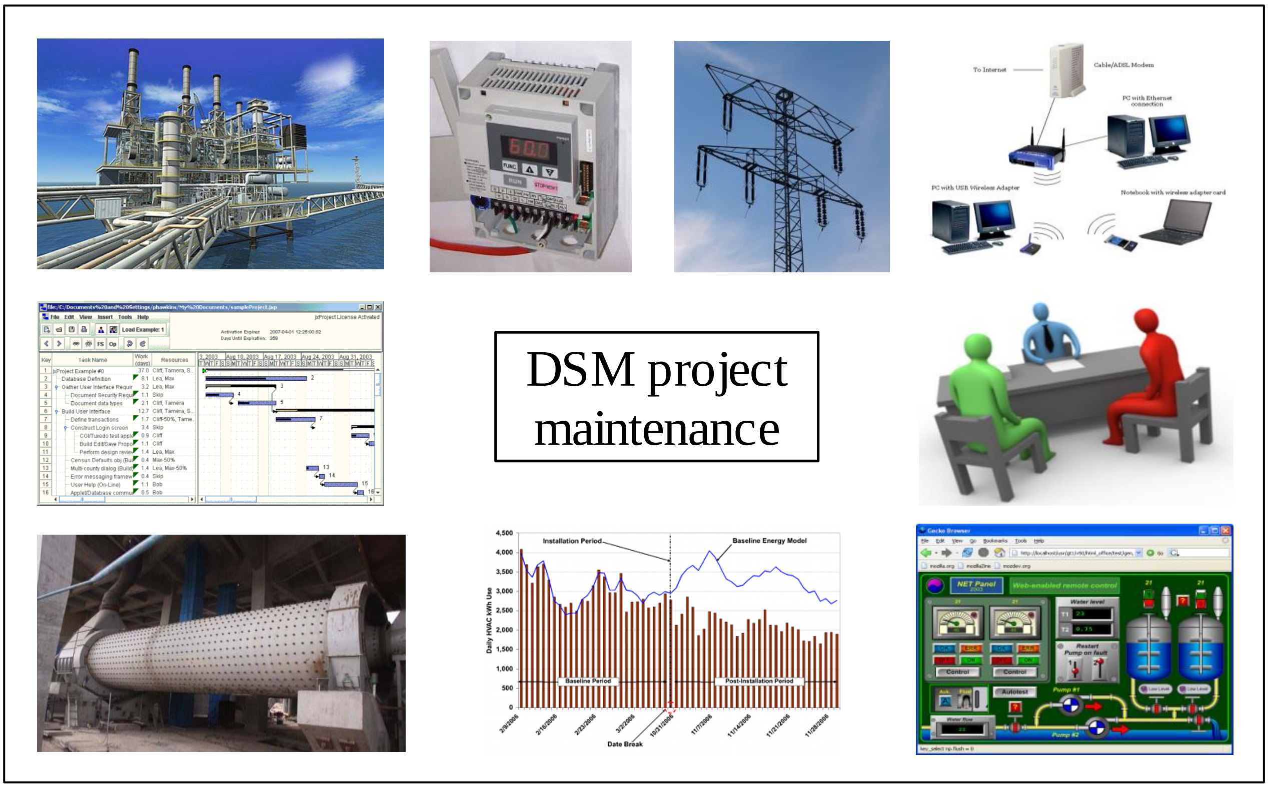

Figure 51: Multi-disciplinary nature of DSM maintenance (Adapted from [84])

To summarise, the requirements for a PCM DSM maintenance strategy are the following:

- Focusing on improving performance instead of only maintaining performance.
- Providing for a continuously changing environment.
- Ensuring that maintenance is performed by multi-skilled engineering teams.

None of the maintenance types described in Section 1.4 meets all of the requirements stated above. This motivates the need for a PCM strategy for DSM projects. There are, however, certain elements of each maintenance type that can be incorporated into a PCM DSM maintenance methodology.

3.3 Strategy for outsourcing of DSM maintenance on a company group level

3.3.1 Introduction

Industrial clients do not always have the necessary skills available in-house to maintain DSM projects correctly. Outsourcing DSM maintenance to an ESCO that specialises in the maintenance of DSM projects is therefore highly recommended. Industrial clients can outsource the maintenance of their DSM projects to an ESCO on project, site or group level. DSM maintenance often starts on project level before it is expanded to all projects on a particular site or operation. The ideal is to expand DSM maintenance further from operation level to company group level. Outsourcing DSM maintenance on group level is recommended to ensure that all of the client's DSM projects perform to their maximum potential.

3.3.2 Personnel assignment

Large industrial companies have at least one group energy manager. The energy management structure of a South African gold mining company is shown in Figure 52. The group energy manager is ultimately responsible for managing the energy usage of the entire group. The group energy manager is assisted by regional energy managers. Region 1 is relatively large and therefore has two regional energy managers assigned to it, while Region 2 has only one energy manager. The regional energy managers all have the same responsibility in the regions assigned to them. The regional energy managers are responsible for the DSM projects that are located on sites that fall within their regions, while the group energy manager is ultimately responsible for all DSM projects in the various regions.

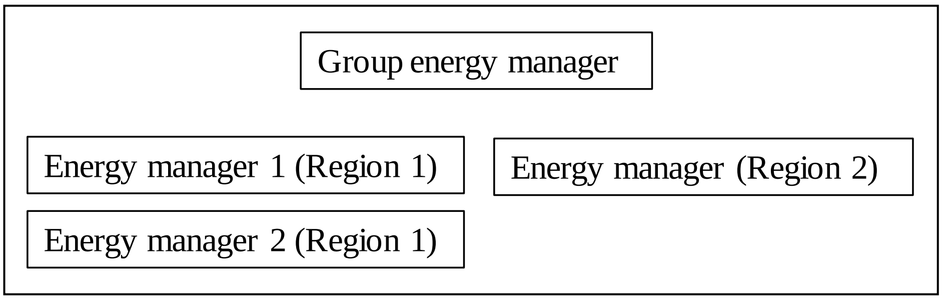

Figure 52: Group energy management structure of a South African gold mining company

A similar structure is recommended for the ESCO if DSM maintenance is conducted on the company group level of the client. Figure 53 shows the recommended structure for the ESCO. A DSM maintenance manager needs to be appointed. The DSM maintenance manager should be assisted by senior project engineers, one for each region. Each DSM maintenance project should have at least one project engineer assigned to it.

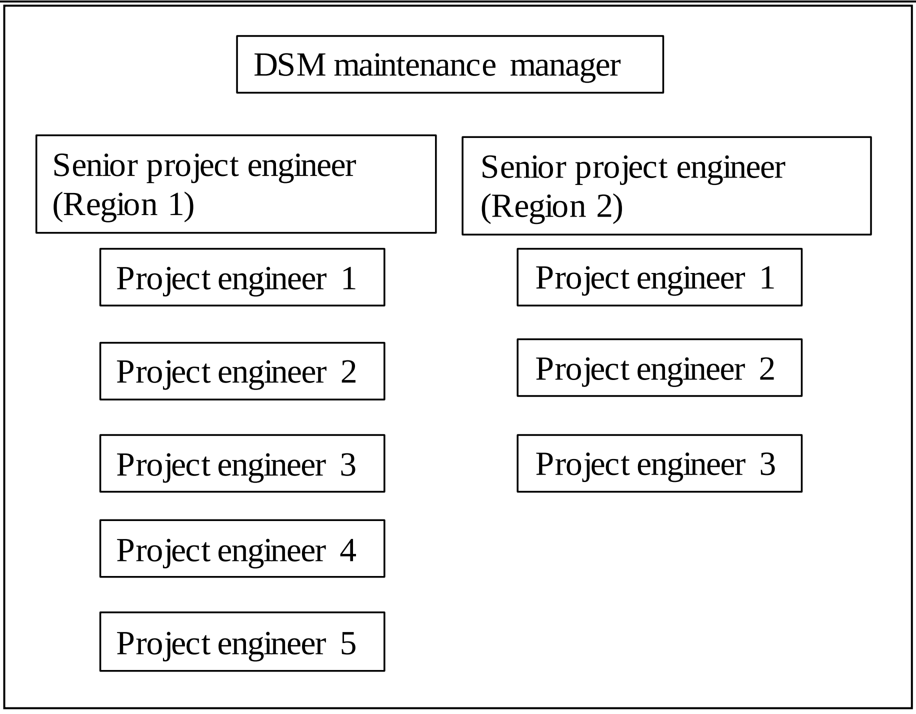

Figure 53: Recommended DSM maintenance structure for an ESCO

The project engineers are directly responsible for ensuring the successful day-to-day operation of the various DSM projects. The project engineers report to the senior project engineers assigned to the different regions, which in turn report to the DSM maintenance manager. The DSM maintenance manager is responsible for the management of the group-level maintenance contract on the side of the ESCO.

The typical management structure of client personnel that are involved with DSM maintenance from an operational point of view is shown in Figure 54. The control room operators and instrumentation technicians are managed by the instrumentation superintendent. The electrician and instrumentation superintendent respectively manage the electrical and mechanical technicians. The instrumentation superintendent, electrician and mechanical foreman report to the services engineer, which in turn reports to the engineering manager.

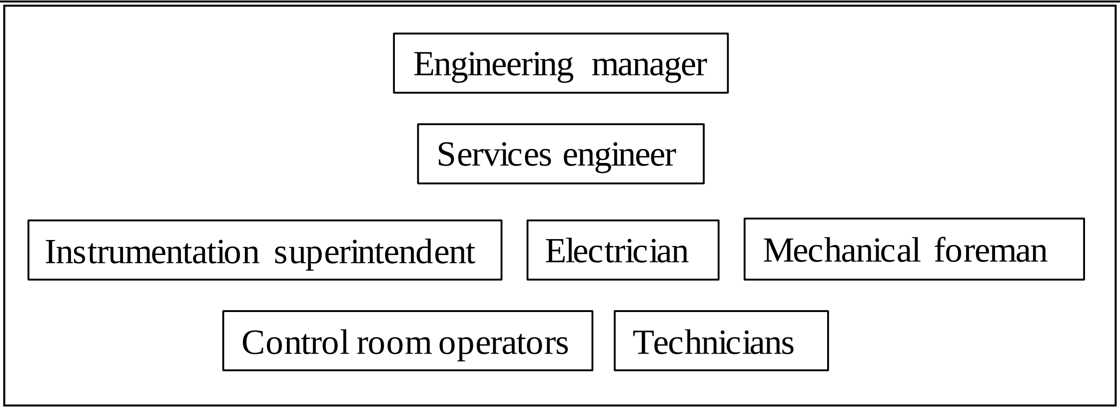

Figure 54: Typical management structure at operations level of client personnel involved with DSM maintenance

As previously mentioned, every DSM project should be assigned to at least one project engineer. Multiple projects can, however, be assigned to a single project engineer. The number of projects assigned to a single project engineer depends on the amount of maintenance work required to maintain each project. This usually depends on the complexity of the DSM project. A load-shifting project on a large mine dewatering system (>10 dewatering pumps) will typically require more maintenance work than a WSO project with a relatively uncomplicated control philosophy.

It is recommended that all projects assigned to a particular project engineer must be located on the same client site or on sites that are situated within close proximity. This reduces the travelling times between project sites and increases the efficiency of the project engineer.

The recommended DSM maintenance management structure for the northern part of Region 1 is shown in Figure 55. Region 1 North consists of three different client operations. Operation 1 has only one shaft, while both Operation 2 and Operation 3 consist of a main shaft and a sister shaft. Between the three operations, 11 DSM projects require maintenance.

The ideal solution is to assign the 11 projects to at least four project engineers. Two project engineers need to be assigned to the DSM projects at Operation 1. Operation 1 is a shaft with relatively high production volumes and therefore its pump load shifting, optimisation of air networks (OAN) and CA projects require a large amount of work to maintain performance. Operation 2 and Operation 3 are both smaller than Operation 1, despite the fact that both these sites comprise multiple shafts. Two project engineers will therefore be sufficient to maintain the seven DSM projects at Operation 2 and Operation 3.

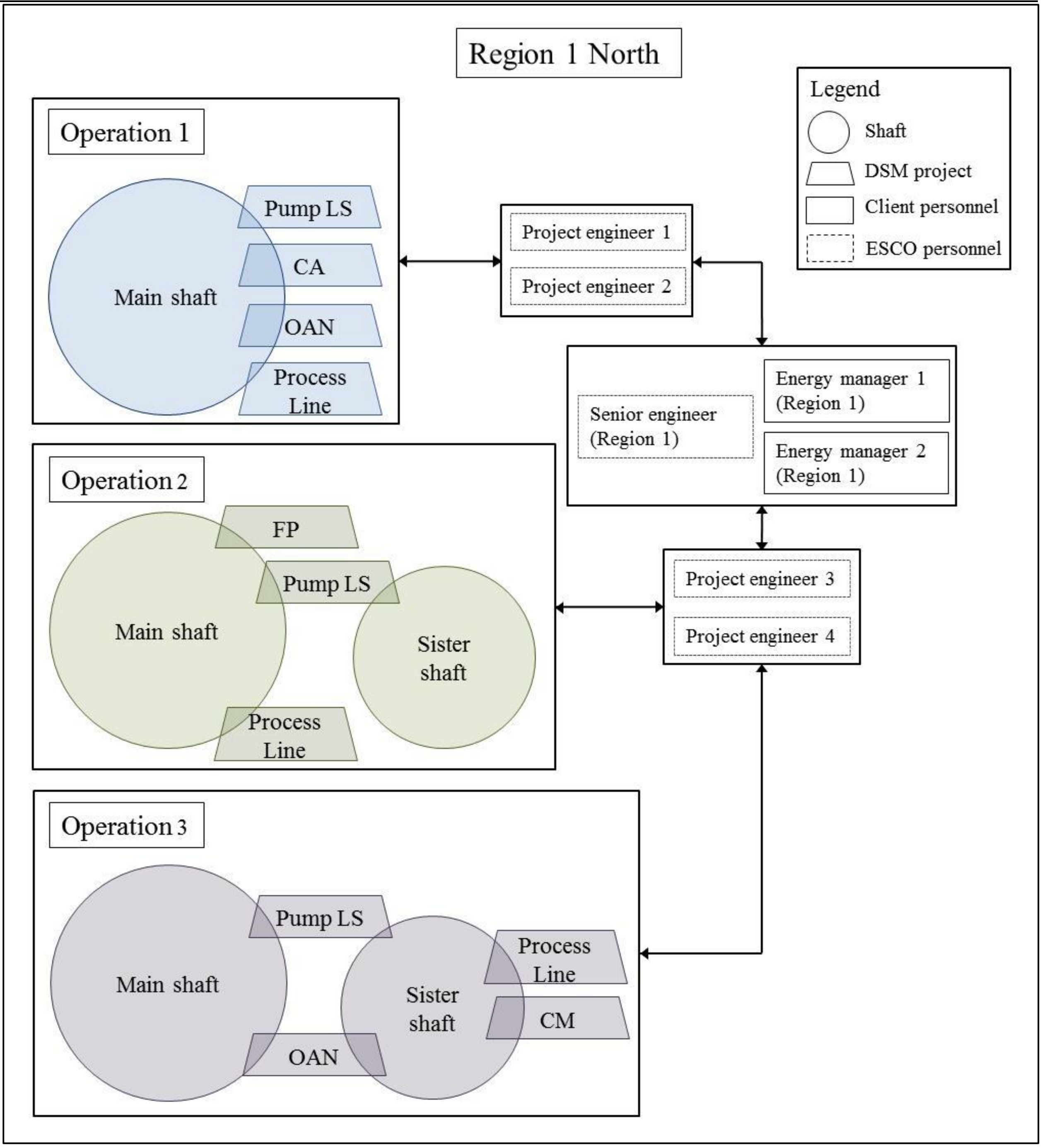

Figure 55: Management of DSM project maintenance in Region 1 North

The four project engineers need to report to the senior engineer of the ESCO and the two regional energy managers of the client. The DSM maintenance manager and the senior project engineers should work closely with the group energy manager and the regional energy managers of the client. The success of a DSM maintenance contract on group level depends largely on the support and cooperation between the management teams of the client and the ESCO.

3.3.3 Group-level DSM maintenance agreement

Introduction

A group-level maintenance agreement is a contract between the ESCO and the industrial client to maintain all or part of the client's DSM projects. Eskom is not involved in such an agreement as a legal entity. Both the ESCO and the client need to benefit from the maintenance agreement. The client benefits from maximising the value generated by the DSM projects, while the ESCO benefits from the fees paid by the client for the maintenance services provided. An example of a DSM maintenance proposal is provided in Annexure B. An example of a generic group-level maintenance agreement is provided in Annexure C.

Maintenance fees

It is imperative that the maintenance agreement should always be cash-flow positive for the client, thus the total maintenance cost must not exceed the electricity cost savings obtained from the maintenance efforts. It is therefore recommended that the ESCO is paid a performance-dependent maintenance fee, for example, a fixed monthly maintenance fee that is paid on a per project basis. The payment of the fixed monthly maintenance fee should depend on the performance of the DSM project. It is recommended that the total annual maintenance fee should never exceed 30% of the total electricity cost savings generated by the project, unless maximum project performance was not achieved due to negligence by the client.

The performance-dependent maintenance fee motivates the ESCO to ensure that all projects included in the maintenance agreement perform to their maximum potential. A performance-based maintenance fee directly linked to project performance is not recommended because various external factors influence project performance.

For example, the performance of a pump load-shifting project on a mine dewatering system depends largely on the amount of water used by the mine. This is due to the energy-neutral scaling method that is widely used for load-shifting projects. The energy-neutral scaling method is based on the notion that a load-shifting project has no influence on the total electricity consumption of the system. The total amount of electricity consumed by the system before implementation of the load-shifting project should therefore remain unchanged after implementation of the project.

The principle of energy-neutral scaling is illustrated in Figure 56. The unscaled baseline (red line) was scaled according to the total electricity usage resembled by the actual profile (green line). The result is that the area under the actual profile is equal to the area under the scaled baseline. The downscaling of the baseline shows that the average electricity usage of the system was significantly lower than the average electricity usage in the period when the baseline was determined.

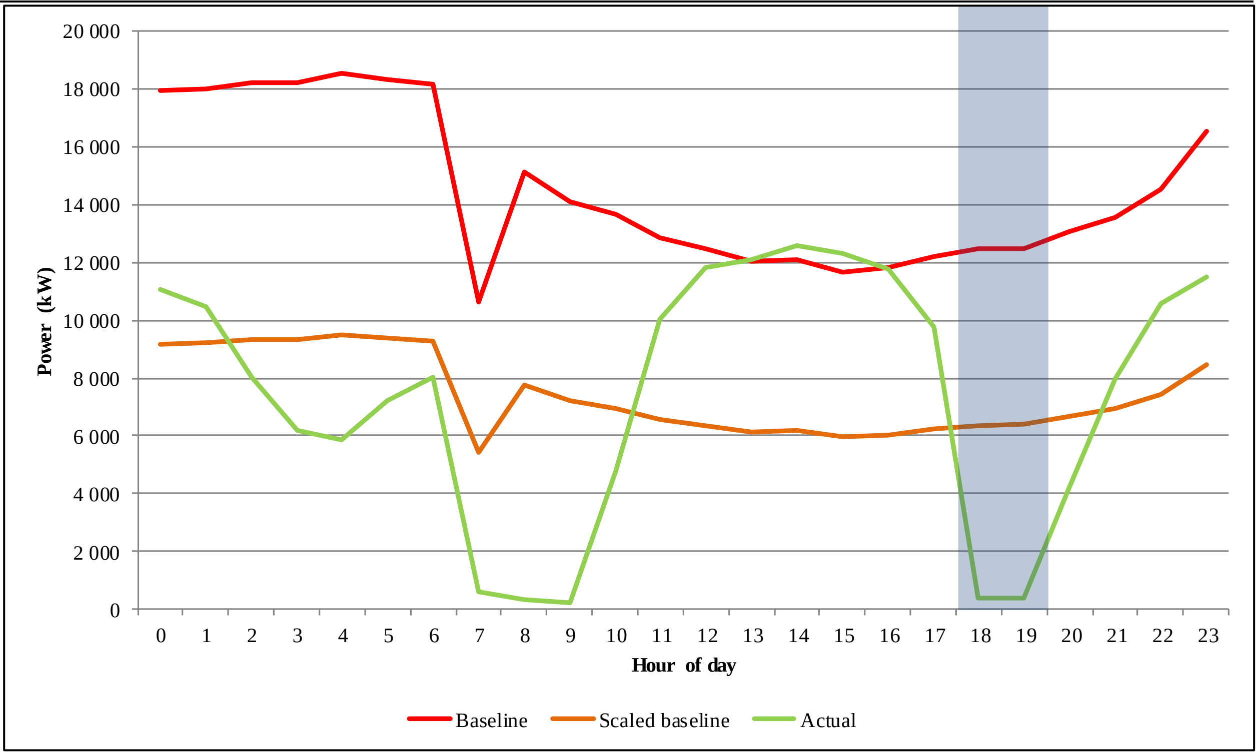

Figure 56: Energy-neutral scaling method

Figure 57 illustrates the effect of the total electricity usage on project performance when energy-neutral scaling was used. The actual profiles and scaled baselines of a load-shifting project on the dewatering pumps of a gold mine are shown for two consecutive months – December 2013 and January 2014. The shapes of the two actual profiles are quite similar, with very little pumping that took place during both the morning and evening peak periods. The total electricity usage of the dewatering pumps differed significantly between the two months with a total electricity consumption of 4.09 GWh in December 2013 and 5.59 GWh in January 2014. The lower electricity consumption in December 2013 was caused by reduced mining activities over the holiday period that resulted in an overall reduction in water used for mining activities. Less water used by mining activities meant that less water had to be pumped to surface, which explains the lower total electricity usage of the dewatering pumps.

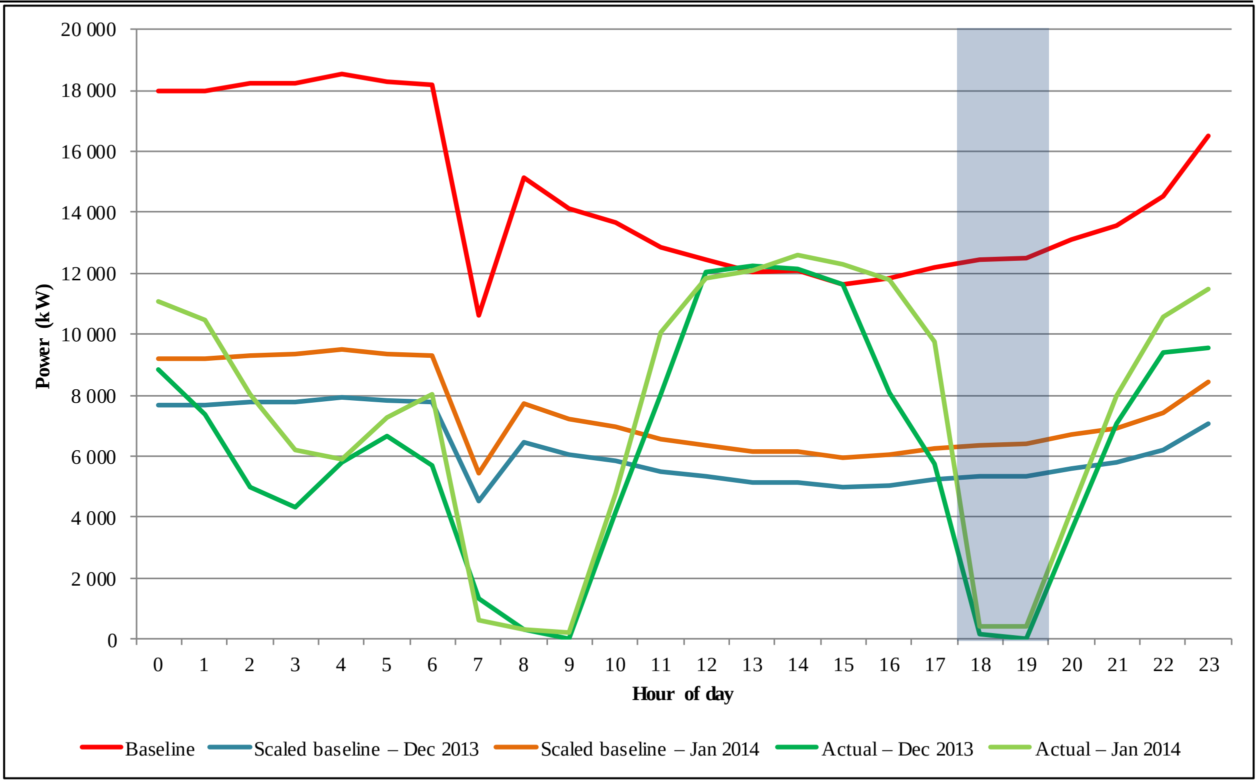

Figure 57: Effect of energy-neutral scaling on system performance

The lower overall electricity consumption in December 2013 resulted in a scaled baseline that was lower than the scaled baseline for January 2014. Since the performance of a project is measured according to the difference between the scaled baseline and the actual profile during the Eskom evening peak period (18:00–20:00), there is a large difference in project performance between the two months. The performance in December 2013 was an average hourly impact of 4.53 MW in comparison with 5.97 MW in January 2014. This difference of 24% is solely the result of differing electricity consumption volumes.

This example illustrates the reason why a performance-based maintenance fee is not recommended. The maintenance effort that the ESCO puts into the project was more or less the same during December 2013 and January 2014. This was proved by the similarity of the two actual power profiles obtained in December 2013 and January 2014. A performance-based maintenance fee would have typically resulted in a 24% difference in the monthly maintenance fee earned by the ESCO for these two months. The 24% difference would have been unfair to both the ESCO and the client, since the amount of maintenance work conducted by the ESCO in these two months was more or less the same.

A performance-based maintenance fee is even more problematic in the case of an energy-efficiency project. Take a CA project as an example. A popular baseline-scaling method for a CA project is to develop a regression model that uses variables such as ambient temperature and the flow rate of water used for mining activities. These variables are beyond the control of the ESCO. Consider, for example, a month where abnormally high ambient temperatures are experienced. This would result in downscaling of the baseline and reduced project performance. The performance-based maintenance fee would be reduced accordingly in such a month. This would be unfair to the ESCO as the reduction in project performance was not caused by negligence of the ESCO's maintenance work.

The conclusion is that various variables influence DSM project performance. Some of these can be controlled by the ESCO and others not. The variables that are beyond the control of the ESCO make it unfeasible to use a performance-based maintenance fee. A fixed performance-dependent fee is a better option that serves the interest of both the client and the ESCO.

Scope of a DSM maintenance agreement

The recommended scope for a DSM maintenance agreement is that the ESCO should be responsible for all costs pertaining to both hardware and software of the control system. The client should be responsible for all costs pertaining to the maintenance of project infrastructure such as valves, PLCs, communication, sensors, and so forth. DSM project performance also depends on the condition of the project infrastructure. For example, a load-shifting project on dewatering pumps is doomed to underperform if the required number of pumps is not available or if the buffer capacity of the dams is reduced due to sediment build-up.

Responsibilities

The ESCO should be responsible for ensuring that the DSM project generates maximum value for the client. This entails the following:

- Ensuring that the control system is in good working condition.
- Improving and updating the control philosophy continuously to ensure that maximum value is generated.
- Ensuring that the communication link between the ESCO control room and the control system is in good working condition.
- Monitoring and evaluating project performance daily.
- Providing daily/monthly project performance reports to client personnel.
- Informing client personnel of any problems that are preventing or may prevent maximum performance.
- Monitoring condition and efficiency of project infrastructure (depending on the availability of necessary instrumentation, such as temperature probes, pressure sensors, flow meters, and so forth).
- Providing 24-hour assistance.

- Attending monthly project feedback meeting on site.
- Cooperating with client personnel to ensure that DSM project performance is maximised.
- Providing project management services on repairs/upgrades on project infrastructure such as dewatering pumps, valves, PLCs, communication, and so forth.
- Managing the Eskom M&V process.

The client is responsible to support the ESCO to deliver maximum project performance. This entails the following:

- Ensuring that project infrastructure is in good working condition.
- Informing the ESCO immediately when any project-related problems are noticed.
- Ensuring that safety interlocks are in place and in working condition on all equipment controlled as part of or affected by the load-shifting project.
- Cooperating with ESCO personnel to ensure that all DSM projects generate maximum value.

3.3.4 Communication between ESCO and client

As previously mentioned, the success of a group-level DSM maintenance agreement depends on effective communication between the client and the ESCO. The client needs to be informed on a daily basis of the performance of every DSM project. The distribution of daily DSM project performance overview e-mails and project performance reports are recommended for this purpose. An example of a daily performance report is provided in Annexure D. If there are underperforming projects, daily e-mails containing feedback from the DSM maintenance manager to the involved client personnel about reasons for the underperformance are also recommended.

Monthly DSM on-site maintenance feedback meetings are recommended for every client operation with active DSM projects. It is recommended that these meetings should take place in the first week of every month. The purpose of this meeting is, firstly, for the ESCO to give feedback about project performance achieved in the previous month. The reasons for underperformance (if applicable) need to be discussed and action plans should be made to improve project performance. These meetings should be attended by the ESCO's senior engineer and the engineer(s) responsible for the projects on that site. On the side of the client, these meetings should be attended by the regional energy manager, the engineering manager, the services engineer and other client personnel that are directly involved with the project such as electricians, the mechanical foreman and the instrumentation superintendent.

Monthly group-level maintenance feedback meetings are also recommended. The group energy manager and the regional energy managers usually meet at least once a month. This is the ideal opportunity for them to also meet with the DSM maintenance manager of the ESCO and if necessary, the senior project engineers of the ESCO. The purpose of this meeting is also for the ESCO to give general feedback about the various DSM projects. The most important aim of this meeting should be to discuss strategies for maximising project performance.

3.3.5 Monthly maintenance invoicing

As mentioned in Section 3.3.3, it is recommended that the ESCO be paid on a monthly basis for the maintenance services provided to the clients. It is also recommended that the DSM maintenance manager should take responsibility for the invoicing of monthly maintenance fees. This includes deciding which project should be invoiced for the monthly maintenance fee, sending maintenance invoices to clients, keeping records of the payment statuses of all invoices and following up on unpaid maintenance invoices.

Invoicing usually falls within the responsibility of the financial department of the ESCO. The fact that the electricity cost savings generated by the different projects are used as motivation for the invoicing of the monthly maintenance fees necessitates that the invoicing process should be handled by the DSM maintenance manager instead of the financial department.

For the majority of DSM projects, the annual total of the maintenance fees will be less than 10% of the annual total electricity cost savings generated by the project. For these projects, the ESCO should invoice the client for the maintenance fee on a monthly basis. Unfortunately, there may be DSM projects where the ratio between electricity cost savings and maintenance fees is less favourable. It is recommended that the annual total maintenance fee should never exceed 30% of the annual electricity cost savings of the project. For such projects, the DSM maintenance manager should keep track of the total annual cost savings generated by the project in the client's current financial year and the total maintenance fees paid by the client for the project in the current financial year. The DSM manager should stop invoicing the client for the monthly maintenance fee if the total maintenance fee exceeds 30% of the total electricity cost savings generated by the project. Alternatively, the ESCO and the client can agree on a reduced monthly maintenance fee or the ESCO could invoice the client every second month.

3.3.6 Management of the M&V process

Some DSM projects included in a group-level DSM maintenance agreement will still be in the five-year Eskom contract period. For such projects there are independent M&V teams assigned that report on project performance on a quarterly basis. The quarterly M&V PT reports are issued to the client and Eskom. Eskom uses these reports to monitor project performance. In the event of reaching less than 90% of the project target, the client becomes liable for underperformance penalties.

It is important that the ESCO also monitor the PT reports issued by the M&V teams. This ensures that project performance is reported correctly and that Eskom does not levy underperformance penalties incorrectly on the client. The daily monitoring of project performance necessitates that the ESCO should keep its own record of project performance. These records can be compared to the performance report issued by the M&V team. Large differences should be brought to the attention of the M&V team. If the discrepancy originated due to an error made by the M&V team, the PT report should be reissued.

3.4 Identification of DSM projects that require PCM

As previously stated in Section 1.3, a large number of DSM projects show decreased performance after the PA phase. Some of these projects were neglected and would therefore gain significant performance increases through the application of a PCM strategy. Unfortunately, not all performance decreases are caused by negligence.

The industrial sector in South Africa is often forced to implement dynamic rapid operational changes in reaction to factors such as changing economic conditions, production targets, labour unrests, forces of nature, and so forth. These operational changes may have a negative effect on the performance of DSM projects.

One such an example is a large deep-level gold mine located near Carletonville where a peak-clipping project was implemented on its compressed air system. The M&V methodology of the project stated that the baseline of the project had to be scaled according to the electricity usage of the compressors during the drilling shift. The performance of the project was determined by the average reduction in the electricity usage of the compressors in the evening peak.

Economic factors such as a low gold price and increasing labour and electricity costs contributed to a decision to stop mining operations on six production levels. The demand for compressed air reduced significantly and therefore less compressors were required during the drilling shift. This affected the scaling of the baseline and had a negative effect on the performance of the project.

The project infrastructure on the remaining production levels were correctly maintained but it remained impossible to achieve the project target. This is an example of a project where underperformance was caused by physical limitations instead of negligence.

There are also DSM projects that are correctly maintained with minimal assistance from the ESCO. These projects typically have a relatively simple control philosophy that is implemented on less complex systems on plants or mines that experience minimal operational changes through the course of the project contract period. Another common factor between these projects is a senior personnel member that takes responsibility for the performance of the project.

Identifying DSM projects that require PCM involves distinguishing between three types of projects:

- Projects where the full electricity cost savings potential is not achieved.
- Projects where the full electricity cost savings potential is prevented by physical limitations that cannot be overcome through PCM actions.
- Projects that are correctly maintained to achieve their full electricity cost-savings potential.

Figure 58 displays a simplified strategy to distinguish between the three above-mentioned project types in order to identify DSM projects where PCM would increase and sustain electricity cost savings. It starts with identifying a previously implemented industrial DSM project. A list of industrial DSM projects implemented with Eskom funding is available from Eskom IDM on request or on the website of the National Monitoring and Evaluation Centre (NMEC). The second step is determining the scope of the project from the original scope document.

The third step is performing an on-site investigation to determine if the project infrastructure is still controlled to obtain maximum electricity cost savings. The investigation can be a fairly easy process if the control system is still in working condition and the statuses of each component are logged on the control system or available on the site's SCADA. Historical data can be downloaded from the control system or the SCADA and analysed to determine if the various components are controlled to achieve electricity cost savings. The investigation process is more difficult if the required data is not available. In such cases, it would entail inspecting physical equipment. This can be a time-consuming process, especially in mines where equipment is installed on different mining levels.

If sufficient proof can be found that the project infrastructure is controlled to achieve maximum electricity cost savings, the project does not require PCM. If it is proven that the full electricity cost-savings potential of the project is not being achieved, the next step in the process is determining the cost-savings potential. This can be done through simulations or on-site tests where equipment is manually controlled to achieve electricity cost savings.

Simulations require input data that can be obtained from the on-site SCADA. If the required data is not available, it may also be necessary to take measurements with equipment such as mobile flow meters or temporary power meters. On-site tests can also be useful to validate simulated results.

The fifth step is determining the reimplementation cost of restoring the performance of the DSM project to its maximum potential. This would typically entail repairing or replacing faulty infrastructure or installing new infrastructure if necessary. The cost of infrastructure repairs/replacement is obtained from quotations by instrumentation and control companies.

The last step in the process is weighing the reimplementation costs against the potential electricity cost savings and the penalties that Eskom IDM may levy if the project is currently underperforming or if further deterioration of performance is expected. The relevant information is presented by the ESCO to senior client personnel in order to decide if reimplementation should proceed. The reimplementation of projects that have payback periods of less than 18 months is usually approved without difficulty.

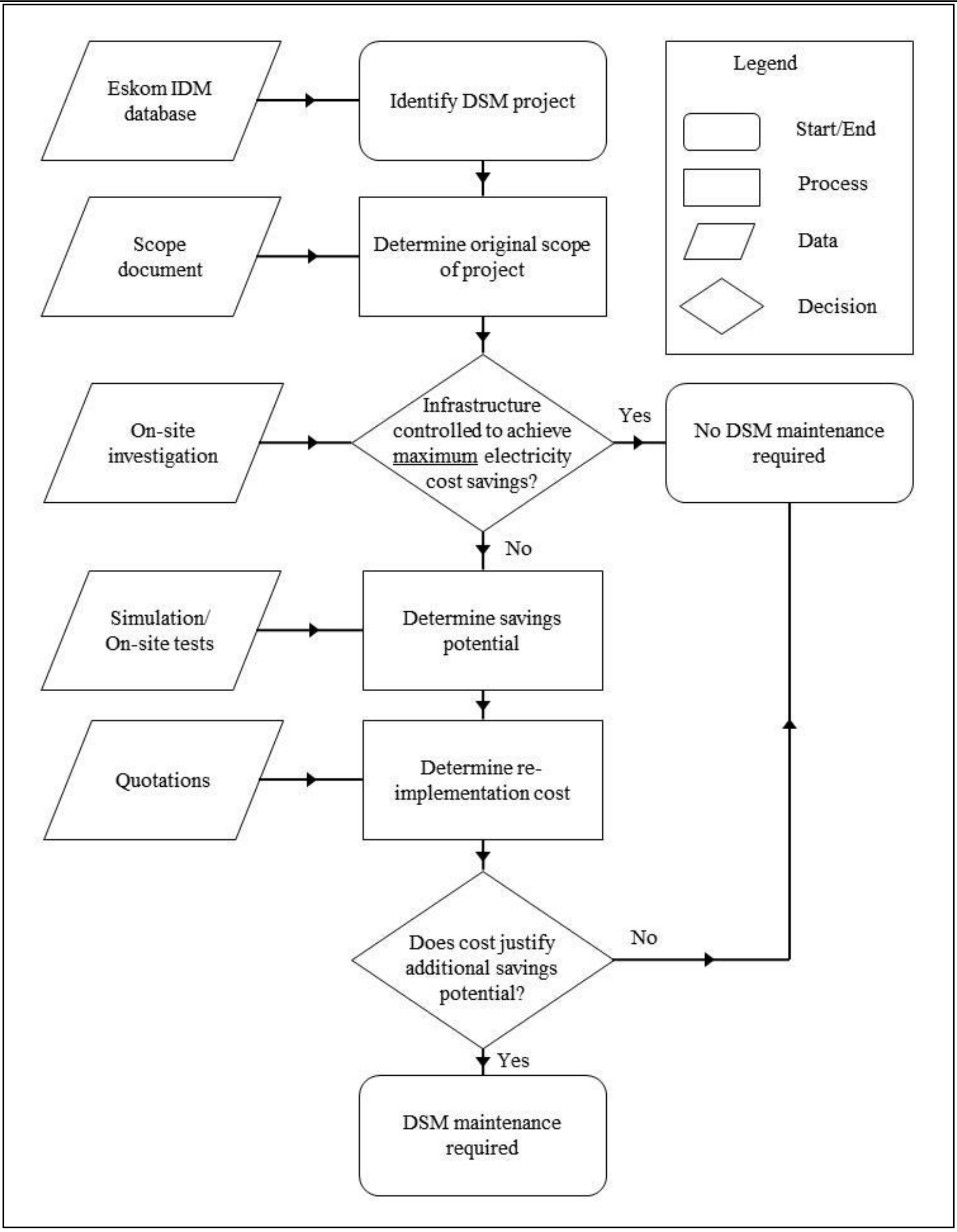

Figure 58: Identification of DSM projects that require PCM

3.5 PCM strategy

3.5.1 Introduction to PCM

The aim of the PCM strategy is to maximise DSM project performance. The PCM strategy is based on the plan-do-check-act (PDCA) cycle for continuous improvement [85]. The four steps are repeated continuously throughout the lifetime of the project by the ESCO in cooperation with client personnel to ensure that DSM project performance is continuously improved over time. The principle of continuous improvement over time is shown in Figure 59.

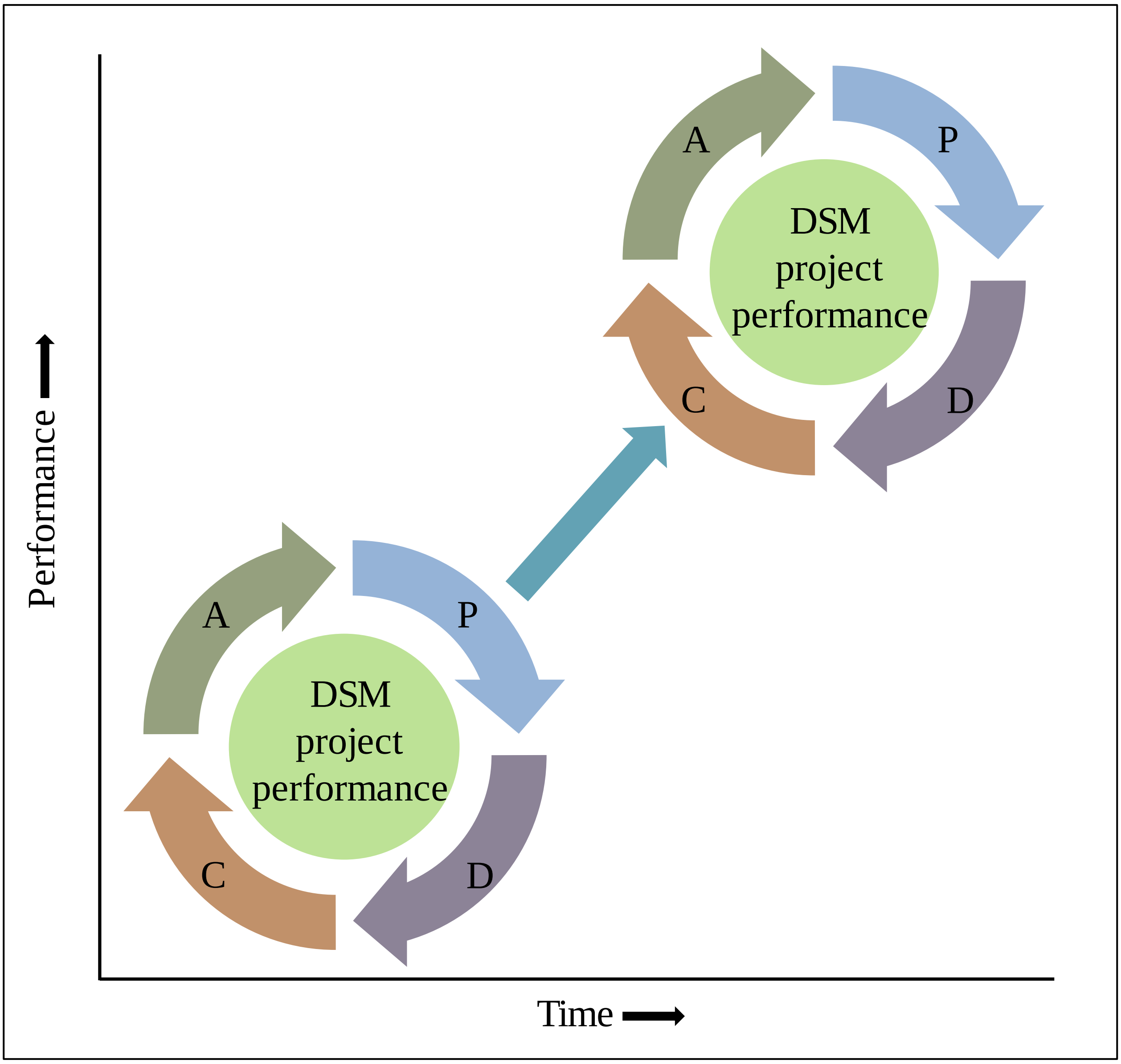

Figure 59: Continuous improvement of project performance over time

The four steps of the PDCA cycle are described below.

Step 1: Plan

Planning of actions to improve DSM project performance.

Step 2: Do

Implementing actions to improve DSM project performance.

Step 3: Check

Monitoring DSM project performance to identify the following:

- Problems that prevent maximum DSM project performance.
- Opportunities to improve DSM project performance.

Step 4: Act

Acting on the results of the actions implemented in Step 2. If the implemented actions delivered positive results, they should be incorporated in the maintenance strategy of the DSM project. If the actions delivered negative results, they should be disabled until improved versions of the previously implemented actions or alternative actions can be implemented.

3.5.2 Introduction to performance monitoring

The various phases of a typical Eskom-funded DSM project are shown in Figure 60. The process starts with the DSM investigation. The purpose of the DSM investigation is for the ESCO to determine the feasibility of implementing a DSM project on certain infrastructure or systems of the client. A prerequisite for the DSM investigation is a letter of intent. The letter of intent is issued by the client and grants the ESCO permission to perform the DSM investigation. The letter of intent also contains a non-disclosure clause that applies to both the ESCO and the client with the purpose of protecting the intellectual property of both parties.

The second step is proposal approval. If the DSM investigation revealed that there is scope for implementing a new DSM project, a project proposal is submitted or presented to the client. Not all DSM projects are fully funded by Eskom. In such cases, the remaining project costs need to be funded by the client. The client therefore has to perform an internal funding application. If the client approves the project, the ESCO submits the proposal to Eskom for approval and procurement.

If Eskom also approves the project, the implementation step can commence. This step consists of the ESCO placing orders and managing the necessary installations of all equipment that need to be installed.

The ESCO is responsible for ensuring that all equipment and control systems work together in order to achieve the intended electricity saving. The implementation phase has various milestones such as factory acceptance tests and cold/hot commissioning. Adhering to the milestones are necessary to ensure that the project is completed on time and within budget, as stipulated by the Eskom contract. The fourth step is the PA phase and the last step is handing the project over to the client.

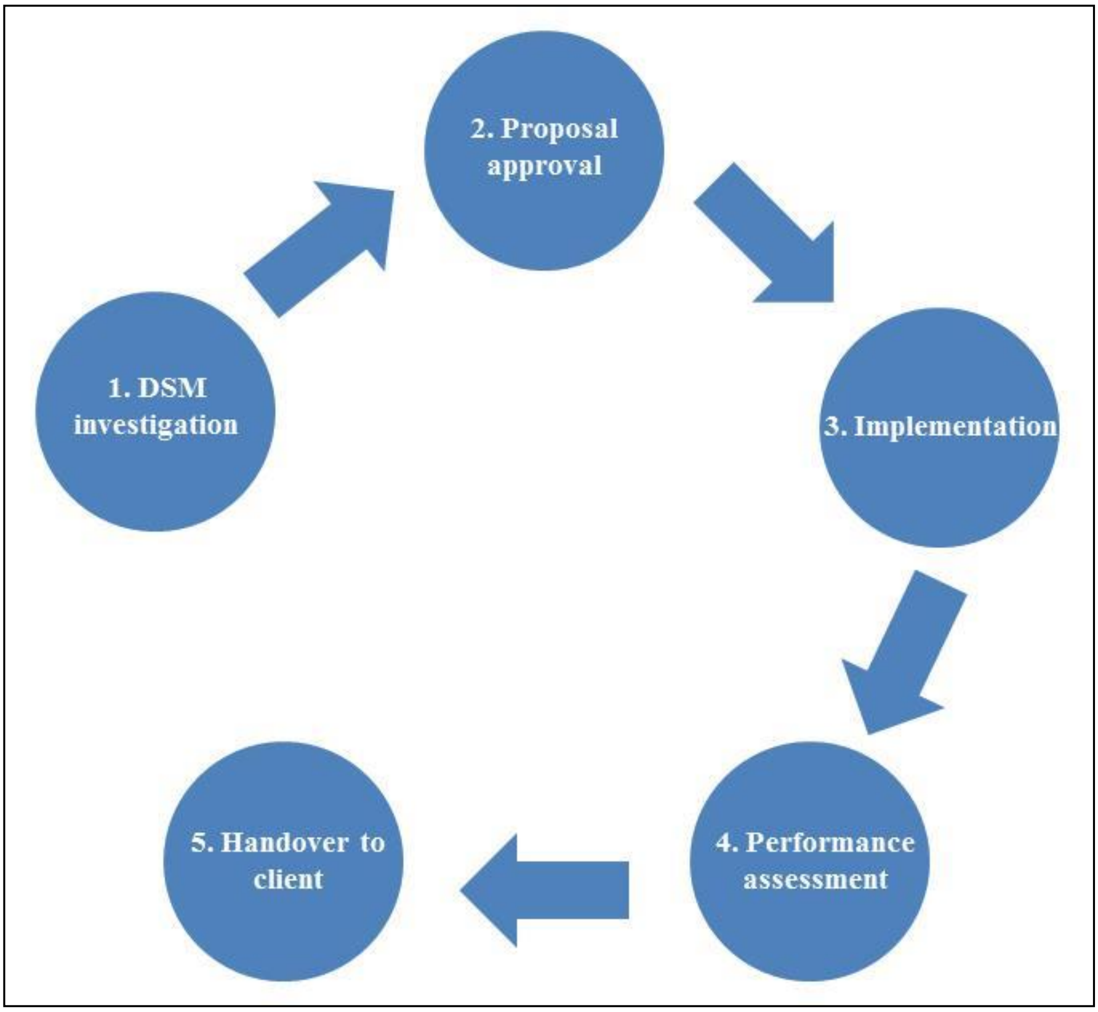

Figure 60: Typical phases of an Eskom-funded DSM project (Adapted from [84])

Project implementation and PA are two critically important phases of a typical DSM project. PA consists of a three-month period where the ESCO and the client work in close cooperation to prove that the DSM project is able to deliver its target savings. An important part of PA is monitoring project performance and operation. This ensures early detection of problems that have or will have a negative impact on project performance, as well as identifying opportunities to increase project performance.

PCM comprises elements of both project implementation and PA. The similarity between PCM and project implementation lies in the fact that maintenance may also require installing new equipment or changing existing equipment. There are, however, more similarities between PCM and PA because of the strong focus on monitoring project operation and performance required by PCM.

3.5.3 Control system and energy management system

Meticulous monitoring of project operation and performance is an integral part of PCM. Figure 61 shows a diagram of the typical network communication between the different components of a DSM project. The project infrastructure (such as valves, compressors and pumps) are controlled via serial communication by one or more programmable logic controllers (PLCs). The PLCs are connected to the SCADA through Ethernet. The PLCs communicate and receive control commands directly from the SCADA. The control system server is connected to the SCADA by means of Object Linking and Embedding for Process Control (OPC) communication. The PLCs can therefore also be indirectly controlled from the control system server via the SCADA. The control system is connected to the ESCO's remote monitoring room by means of a wireless GSM network.

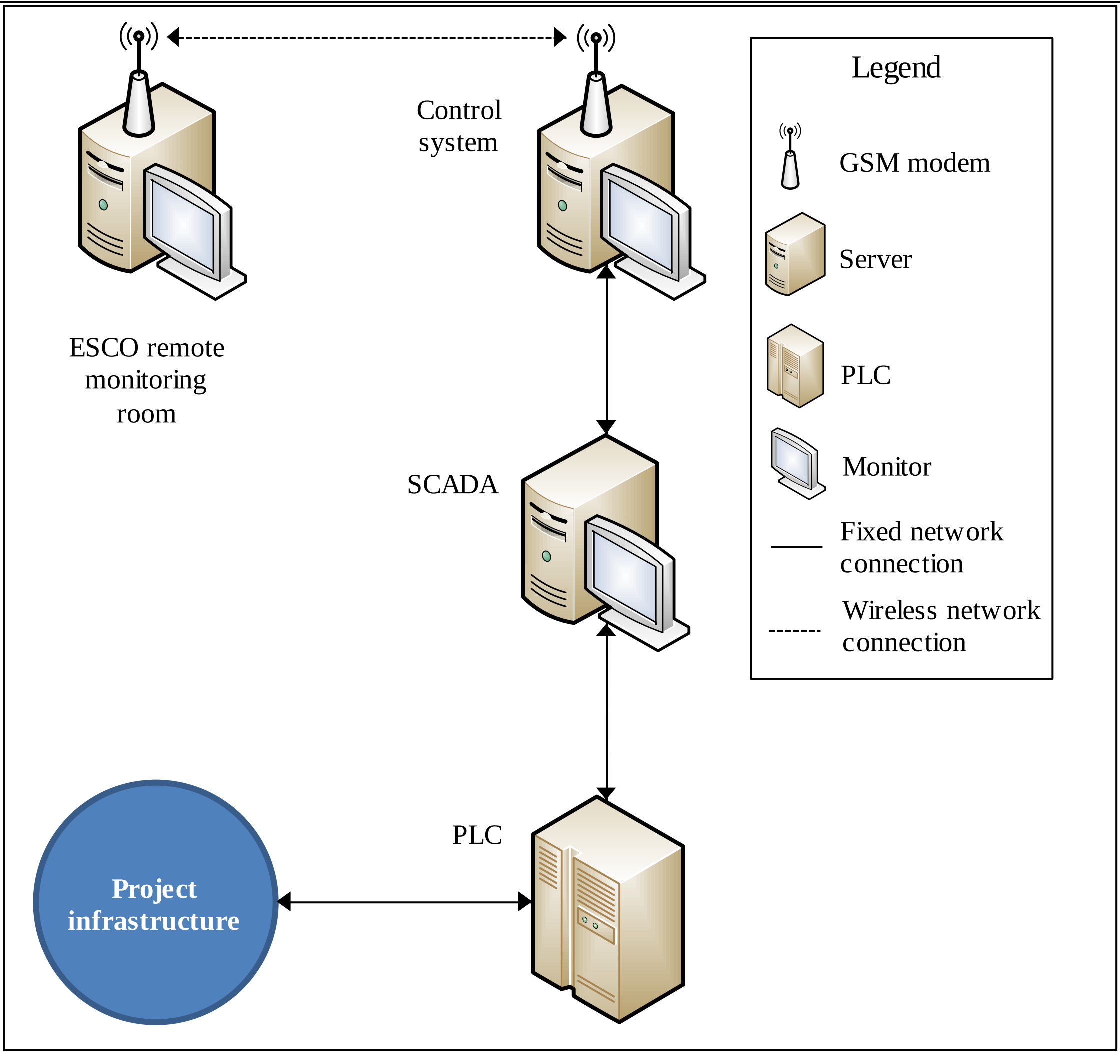

Figure 61: Network communication on a typical DSM project

The control system forms the heart of the DSM project. It is a software program used to control the project infrastructure automatically or semi-automatically via the SCADA to realise electricity cost savings. The control system is usually installed on a server computer located at the project site. The server is usually required to be on site in order to connect to the SCADA via the local network. The control system can be installed on either physical or virtual servers. Apart from controlling the project infrastructure, the control system also records project data. A screenshot of the user interface of the control system of an OAN project is shown in Figure 62.

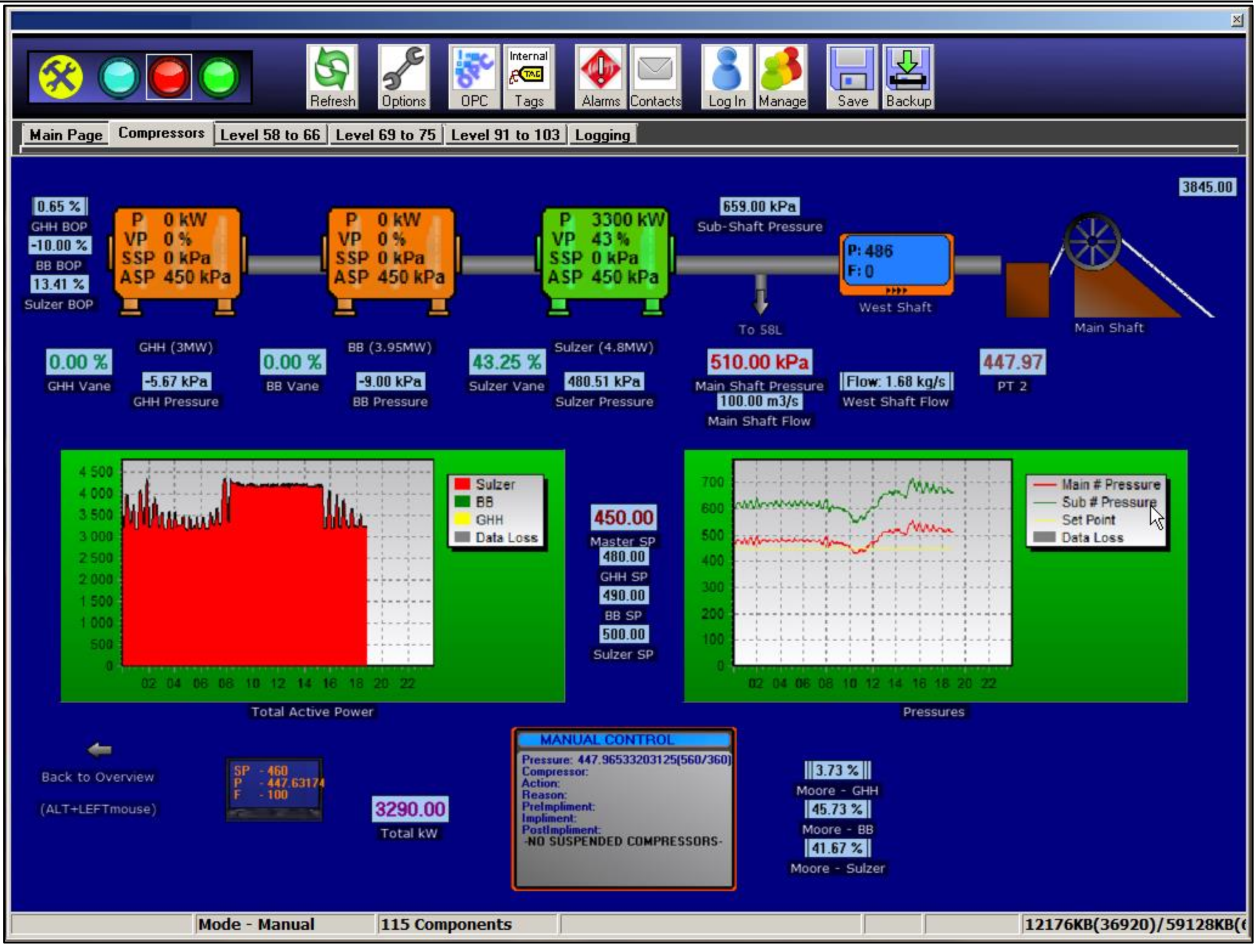

Figure 62: User interface of a control system for an OAN project

The control system is connected to a GSM modem that enables authorised users to connect to it with other computers and mobile devices through the GSM network. This allows ESCO and client personnel to connect to the control system remotely in order to perform maintenance tasks such as making changes to the control philosophy or monitoring project and infrastructure operation in real time. The concept of remotely connecting to the control system via the GSM network is illustrated in Figure 63.

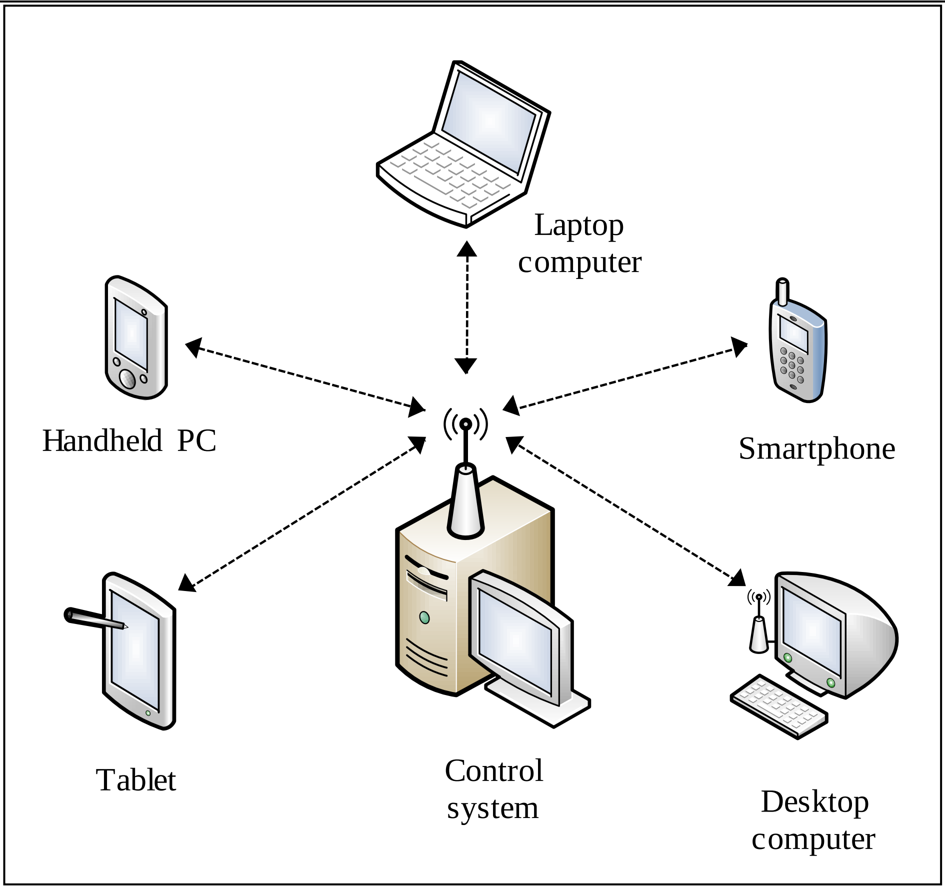

Figure 63: Remote connections to control system via GSM network

A photo of the control room of an ESCO is shown in Figure 64. The control room consists of various computers and multiple screens that are connected to GSM modems to communicate with control system servers located on project sites. ESCO personnel use the control room to connect to control system servers to monitor project performance, to perform maintenance tasks and to provide remote assistance to client personnel. A photo of a GSM modem is shown in Figure 65.

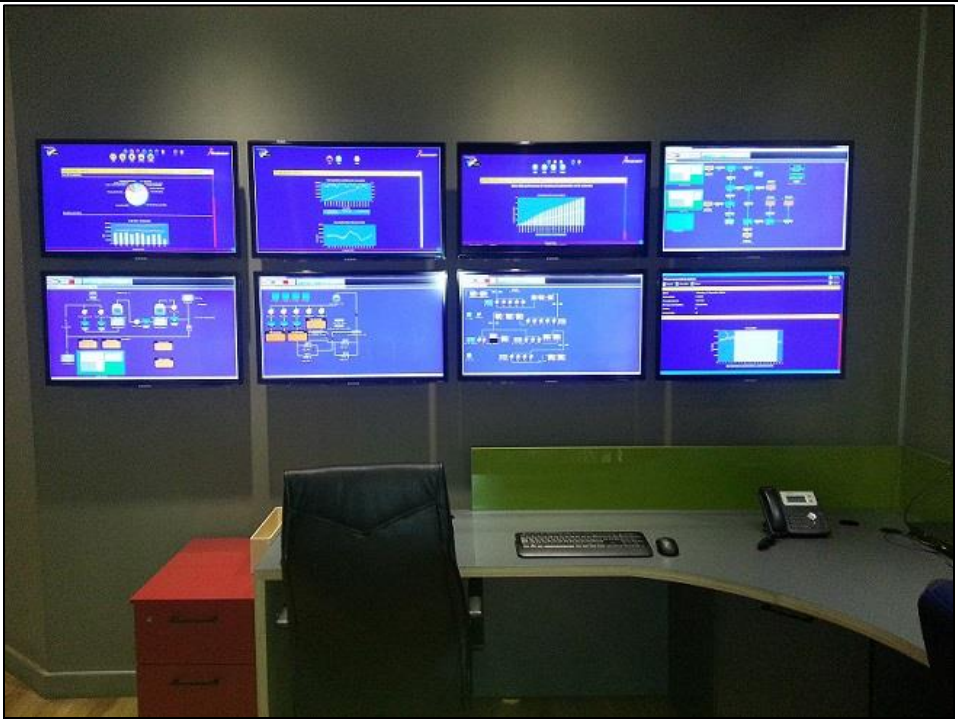

Figure 64: ESCO control room

Figure 65: GSM modem

The wireless communication link also allows the raw project data recorded by the control system to be sent to the energy management system. The raw data is recorded in daily batches, consisting of project data recorded over a 24-hour period. The raw data batches are e-mailed automatically from the control system server to the energy management system on a daily basis. The energy management system is a web-based application that keeps a database of DSM project data. The energy management system helps the ESCO to monitor various aspects of DSM project operation. The energy management system can be accessed by both ESCO and client personnel via the internet, as shown in Figure 66.

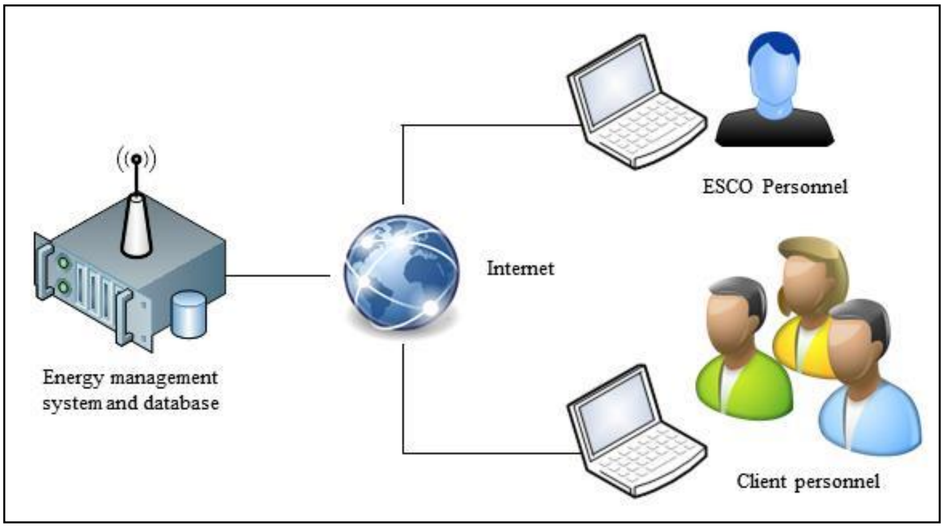

Figure 66: Access to energy management system and database

The graphical user interface (GUI) of the energy management system is shown in Figure 67. It displays a monthly overview of the project performance. The different DSM projects are listed on the left with an indication of the monthly performance shown on the right. Green indicates a month where the performance of the project was above target, orange indicates a month where the achieved performance was within 10% of the target and red indicates a month where the performance was more than 10% below the target.

Figure 67: Monthly view of DSM project performance

More details about project performance can be obtained by selecting the months on the right on the GUI. This opens the daily view of project performance, shown in Figure 68. The colour-coding scheme that applied to the monthly view is also applied in the daily view – green for overperformance, orange for performance within 10% of the project target and red for underperformance. Data loss is indicated in blue, as shown on 26 November in Figure 68.

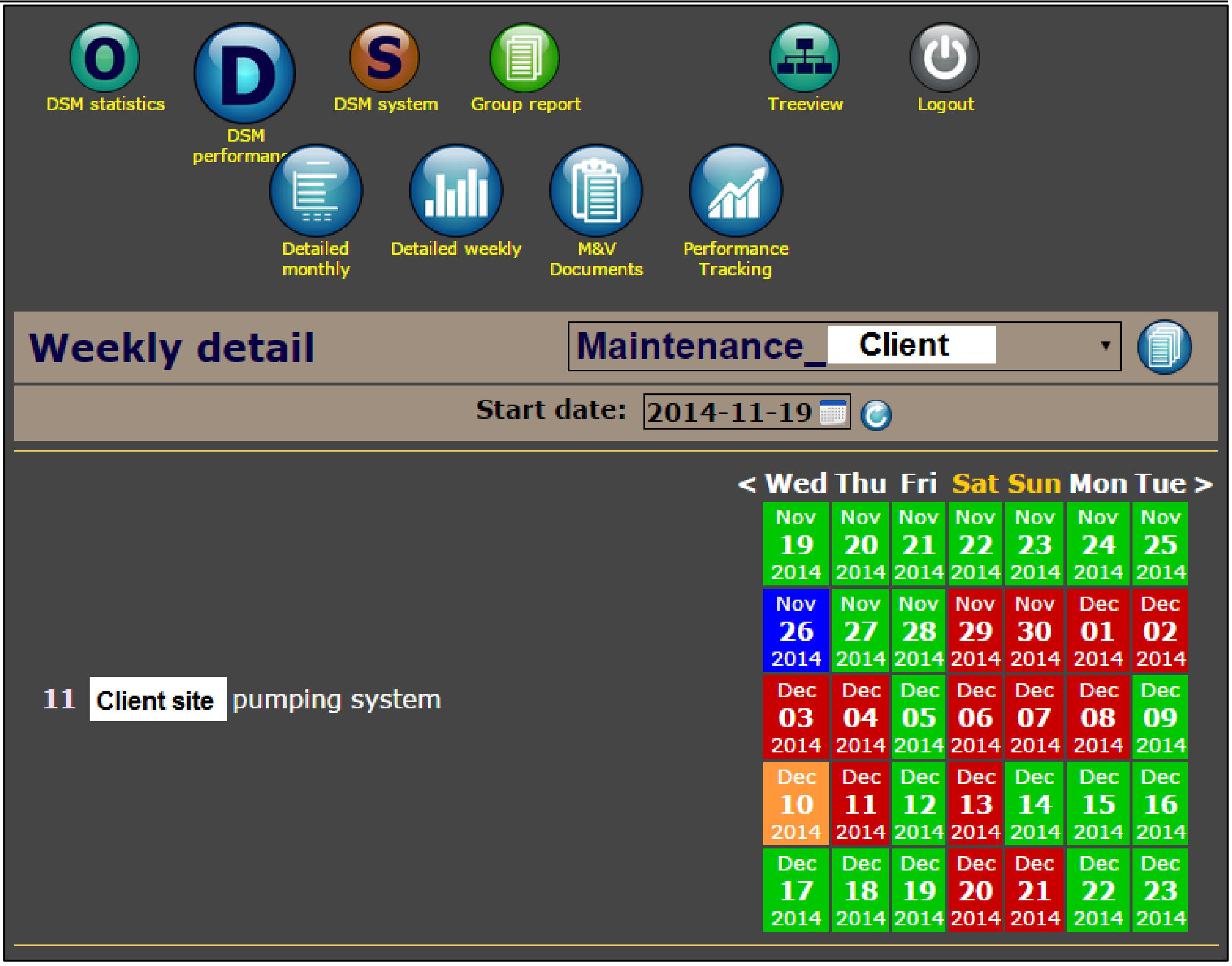

Figure 68: Daily view of DSM project performance

Even more detail about daily performance can be obtained by selecting a specific date. This opens the detailed daily overview interface shown in Figure 69. The unscaled baseline, scaled baseline and actual profiles are displayed, along with a distribution of the electricity usage between peak, standard and off-peak periods. A detailed analysis of the raw data can be performed by selecting the ‘raw data’ option at the top of the screen.

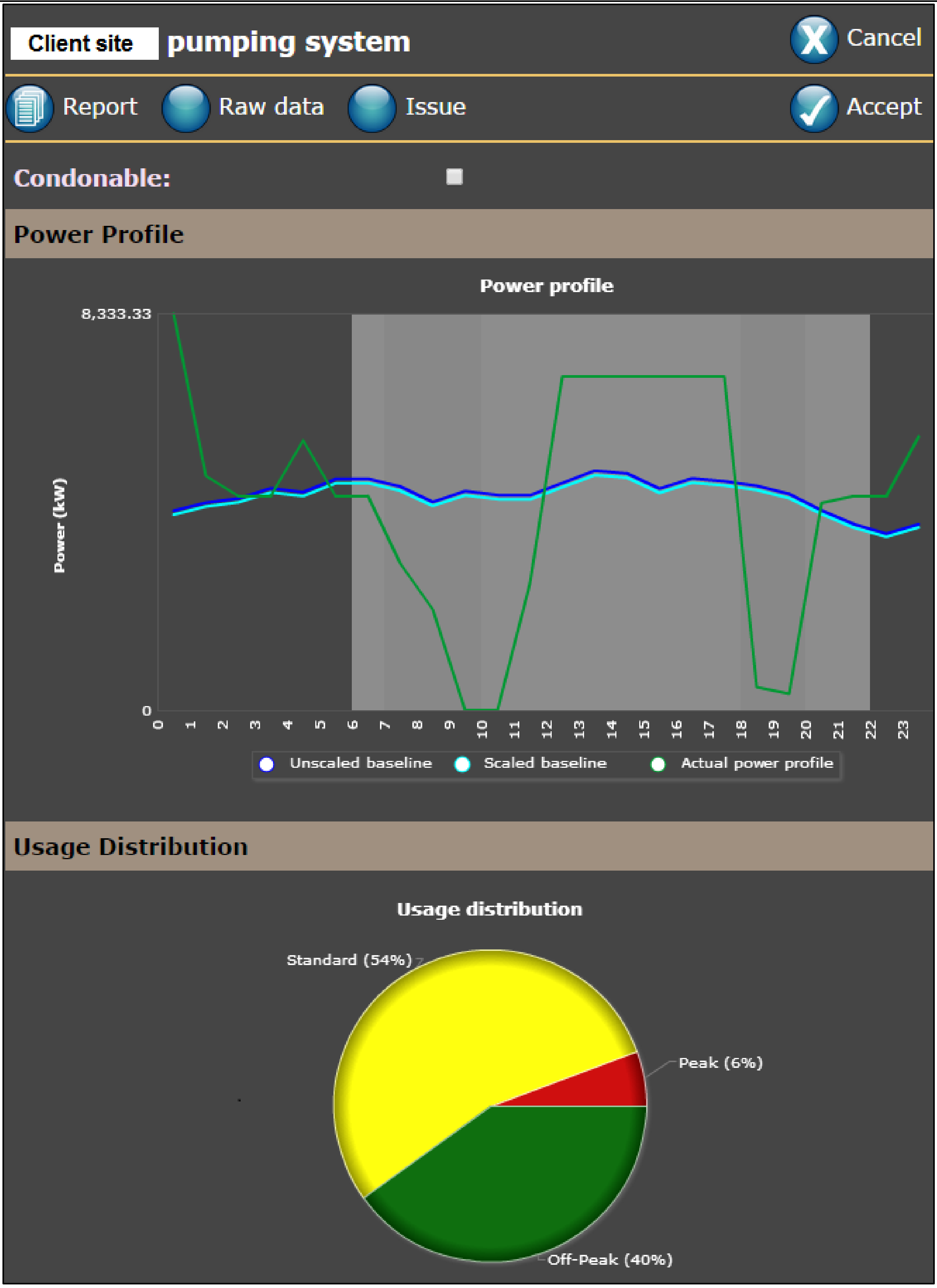

Figure 69: Detailed daily overview of project performance

The raw data view of a pump load-shifting project is shown in Figure 70. The raw data tags that are available in the database are shown on the left of the screen. Trend lines can be displayed by selecting one or more of the raw data tags. This allows a detailed analysis of the raw data to determine the cause of problems that prevented maximum project performance.

In Figure 70, the raw data tags for the pump status and schedule of the Level 75 pumps are selected on the left and displayed as trends. The pump status tag indicates the actual number of running pumps on Level 75. The schedule tag indicates the number of running pump suggested by the control system. The trend lines show a discrepancy between the status and the schedule of the pumps from 00:00 to 05:31. The discrepancy was caused by a pump that was not made available for control by the control system.

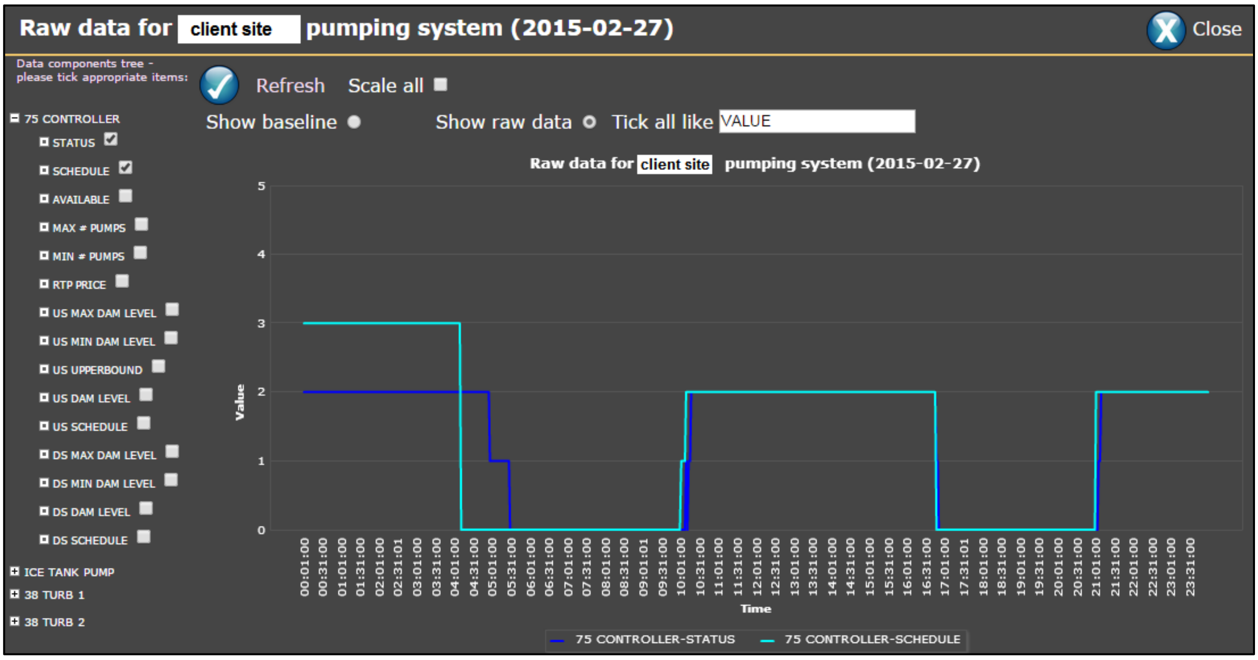

Figure 70: Raw data view of a pump load-shifting project

The raw data view of an OAN project is shown in Figure 71. The trend line of the pressure set point is compared to the trend line of the actual downstream pressure of the Level 60 East valve. The trends lines show that the Level 60 East valve was only allowed to control the downstream pressure between 5:30 and 16:00. The automatic control of the Level 60 East valve was disabled by the control room operators outside the period of 5:30 and 16:00. This resulted in a waste of compressed air and had a negative impact on project performance.

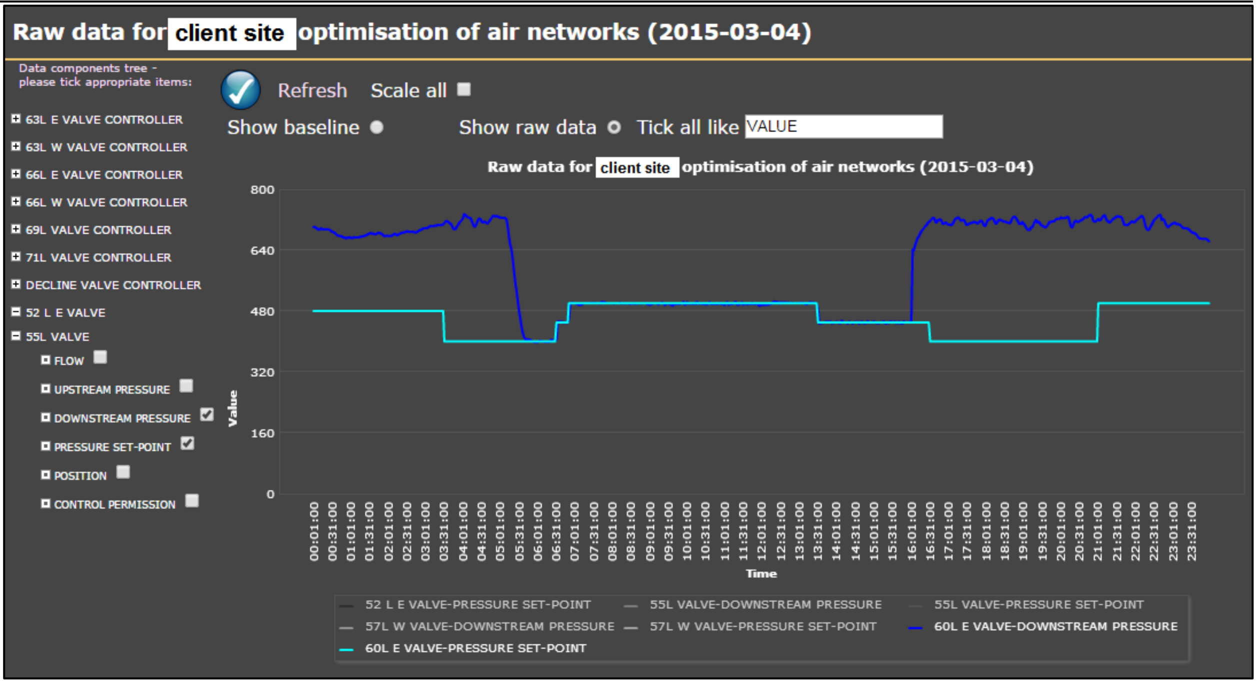

Figure 71: Raw data view of an OAN project

3.5.4 Daily reporting of project performance

The energy management system allows for automated reporting of project performance on a daily, weekly or monthly basis. It can be programmed to automatically generate performance overview e-mails that indicate the performance of multiple DSM projects. A diagram of the data flow from the on-site control systems to the end-users are shown in Figure 72. The energy management system receives raw project data on a daily basis from various control systems located at different project sites. The energy management system stores the raw project data in its database and automatically calculates the performance of the individual projects from the raw data. This information is distributed via automated e-mails to various end-users.

The contents of a daily performance overview e-mail is shown in Figure 72. It displays the performance obtained by various projects on the previous day as a percentage of the target saving. The colour coding used in the user interface of the energy management system is also used in the performance overview e-mails – green for overperformance, orange for performance within 10% of the project target and red for underperformance.

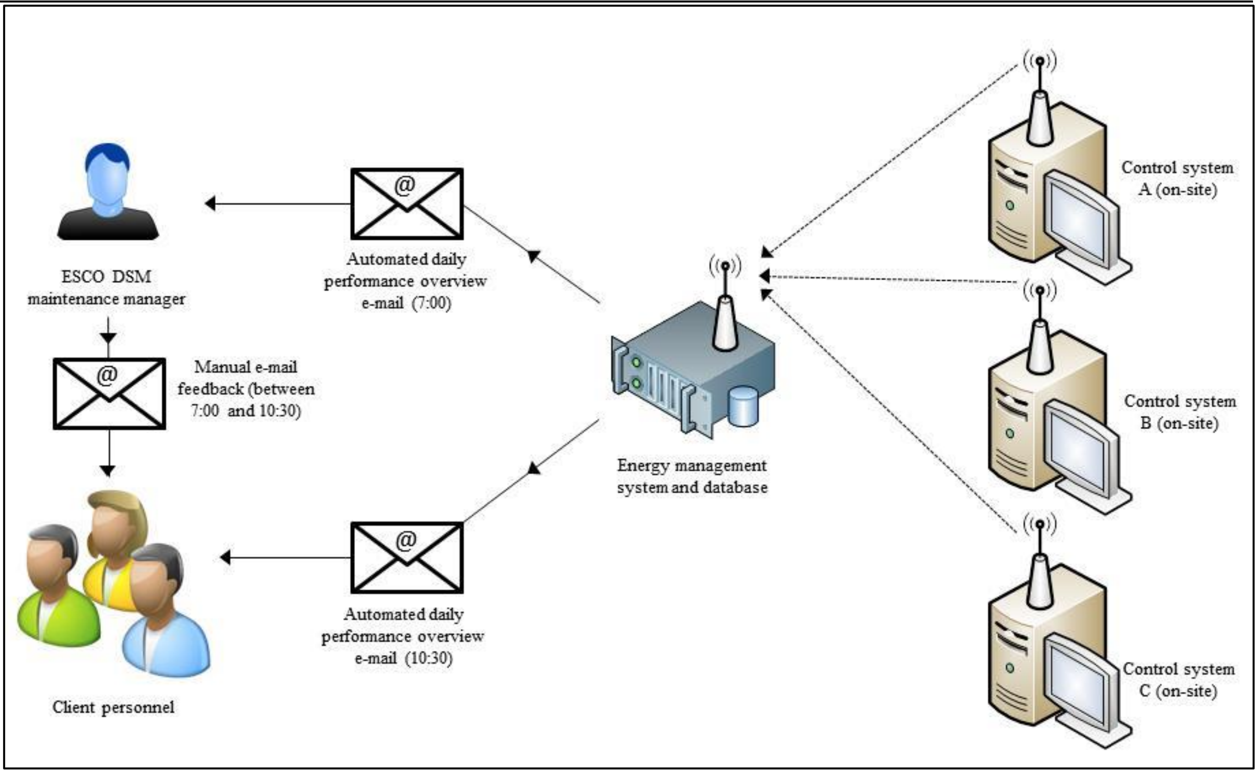

Figure 72: Distribution of automated daily performance overview e-mails

This performance e-mail shown in Figure 73 was set up to display the performance of different DSM projects of multiple clients. This type of performance overview e-mail is useful to the DSM manager of an ESCO that is responsible for maintaining multiple DSM projects of multiple clients. Apart from project performance and electricity cost saving, the e-mail also shows information about the different software packages running on the control system server and the status of the OPC connection. This information is obtained from a diagnostic software program running on the control system server.

The operational periods (calculated as a percentage of the 24 hours of the previous day) of the control system, the e-mail service and the diagnostic software are displayed. The e-mail service software is responsible for the daily sending of the logged data from the control system server to the energy management system. If no interruptions occurred, the operational periods of the three software packages will display 100%. This feature assists ESCO personnel to identify software-related problems that may have occurred over the course of the previous day.

The percentage of time during which the control system was in automatic control mode and the percentage of time that the OPC connection between the control system server and the SCADA was active are also displayed. The percentage of time in which the control system was in automatic control mode indicates if there was interference in the operation of the control system. In some instances, there are legitimate reasons for interfering with the operation of the control system, for example, when emergencies or breakdowns occur that necessitate temporarily disabling the control system. The performance overview e-mail displays a 'D' in the column adjacent to the electricity cost column to indicate when data loss occurred.

Maintenance agreement									
Client 1		Performance	Cost saving		Control	Auto	OPC	Agent	E-mail
Site 1	cooling auxiliaries surface	32%	R 1,374	D	100%	98%	98%	100%	100%
Site 1	cooling auxiliaries underground	197%	R 26,457		-	-	-	-	-
Site 1	water supply optimisation	110%	R 16,708		100%	97%	97%	100%	100%
Site 2	cooling auxiliaries	319%	R 54,637		100%	98%	15%	100%	100%
Site 2	optimisation of air networks	408%	R 67,146		100%	95%	69%	100%	100%
Site 2	pumping system	121%	R 4,928		100%	98%	47%	100%	100%
Client 2		Performance	Cost saving		REMS	Auto	OPC	Agent	Hermes
Site 1	4# pumping system	93%	R 1,390		100%	71%	94%	99%	100%
Site 1	optimisation of air networks	283%	R 48,842		100%	98%	98%	100%	100%
Site 2	optimisation of air networks	127%	R 25,202		100%	99%	99%	100%	100%
Site 3	pumping system	85%	R 2,299		100%	98%	97%	100%	100%
Site 4	optimisation of air networks	110%	R 17,986		100%	97%	42%	99%	100%
Site 4	pumping system	79%	R 3,508		100%	99%	99%	100%	100%
Client 3		Performance	Cost saving		REMS	Auto	OPC	Agent	Hermes
Site 1	pumping system	106%	R 8,629		100%	98%	98%	100%	100%

Figure 73: Contents of daily performance overview e-mail

The performance overview e-mail can also be distributed to client personnel. The projects shown in the performance overview e-mail are fully customisable to ensure that client personnel only receive the information of the DSM projects that they are interested in. For example, a performance overview e-mail can be set up to contain only the information of the DSM projects located at a certain client operation. Such a performance overview e-mail will be useful to the engineering manager of that particular operation. The regional energy manager, on the other hand, would typically be interested in receiving the performance of all DSM projects implemented at the various operations within his region. His performance overview e-mail would therefore contain the performance of all DSM projects in the region.

It is recommended that daily performance overview e-mails and performance reports are set up for sending to ESCO personnel at 7:00 and to clients at 11:00. The four-hour time difference ensures that ESCO personnel have enough time to correct any problems (such as data loss or incorrect performance calculation that were noticed in the 7:00 e-mail) before the daily performance overview e-mails and performance reports are distributed to clients at 11:00.

The control system should be able to send automated problem notifications in real time via SMS or e-mail to the ESCO project engineer. This allows the project engineer to attend to the problem that triggered the real-time problem notification immediately. An example of a serious problem that would require prompt action from the project engineer is when the control system loses OPC communication with the SCADA. This prevents the control system from logging data and controlling equipment. If left unattended it would definitely have a negative effect on project performance.

The energy management system should also have the ability to send problem notifications via e-mail to ESCO personnel. These problem notifications are unfortunately not distributed in real time, because the energy management system does not have access to real-time project data. The latest data that can be accessed by the energy management system is the raw data recorded the previous day. A diagram that displays the automated distribution of problem notifications via SMS and e-mail from the control system and the energy management system is shown in Figure 74.

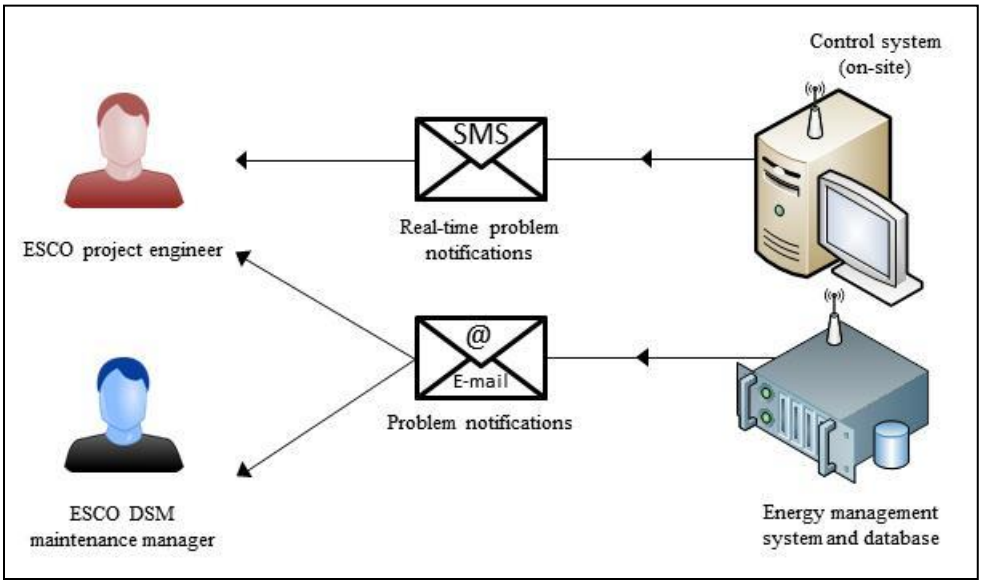

Figure 74: Distribution of automated problem notification e-mails and text messages

3.5.5 Limit checking

The energy management system can be programmed to perform various automated checking functions on the previous day's raw project data. One such a checking function is to set a maximum limit for the total power profile of a system. Consider, for example, a pump load-shifting project. Maximum limits can be set for the pumping system for different times of the day, as shown in Figure 75.

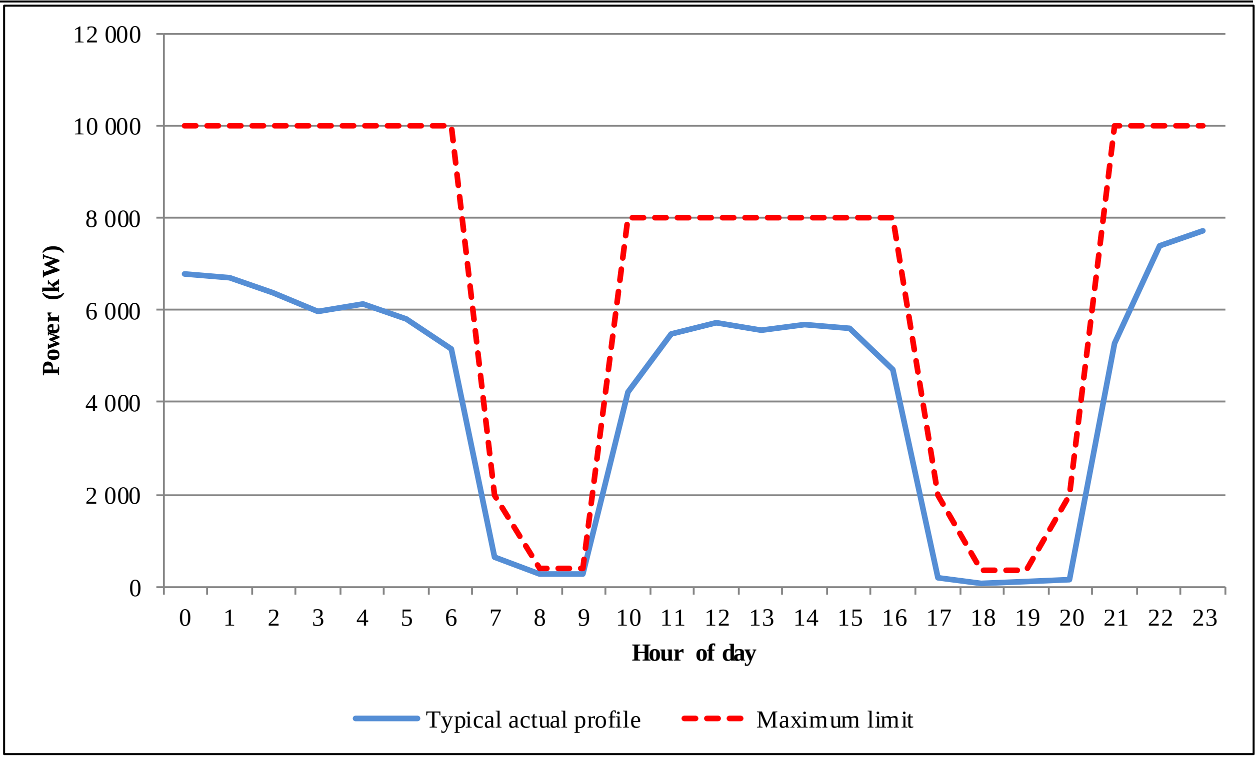

Figure 75: Maximum limit of pump load-shifting project

The maximum limit is set to a minimum during the morning and evening peak periods, because minimum or zero pumping is expected during peak periods. The maximum limit can be set to equal the installed capacity of the system in the off-peak period, since maximum pumping is expected in off-peak periods. The control philosophy aims to prevent maximum pumping in the standard period between 10:00 and 17:00, therefore the maximum limit is set below the installed capacity in this period.

If the maximum limit is breached during any time of the day, the project engineer and the DSM manager are informed the following day via e-mail. An example of an automated notification e-mail is shown in Figure 76. The project engineer is expected to investigate the reason for the breach of the maximum limit. If the breach was caused by a control system error, the project engineer must improve the control philosophy to prevent future breaches of the maximum limit.

From: <E-mail address of energy management system>
To: <E-mail address of project engineer>
Cc: <E-mail adress of DSM maintenance manager>
Subject: Problem #355 - <CLIENT SITE NAME> OAN PROJECT

Dear <PROJECT ENGINEER NAME>

Please respond to problem **#355 on 2014-08-12** as project engineer of <CLIENT SITE NAME> OAN.

Problem description:
[Auto] Maximum profile limit exceeded on hours 04:00 and 05:00

Figure 76: Automated problem notification e-mail

The maximum limit can also be used for energy-efficiency and peak-clipping projects. It can also be extended to include a minimum limit. Figure 77 shows the maximum and minimum limits that were set for an OAN project. The limits were set to ensure that they would not be breached during normal project operation. The total power consumption of the compressors is at a minimum from 05:00 to 07:00 and from 18:00 to 21:00. The maximum profile is therefore lowered during these periods. Another advantage of limit checking is that it can also indicate power meter problems. Abnormally high or broken power meters will most probably result in the breaching of the maximum and minimum limits.

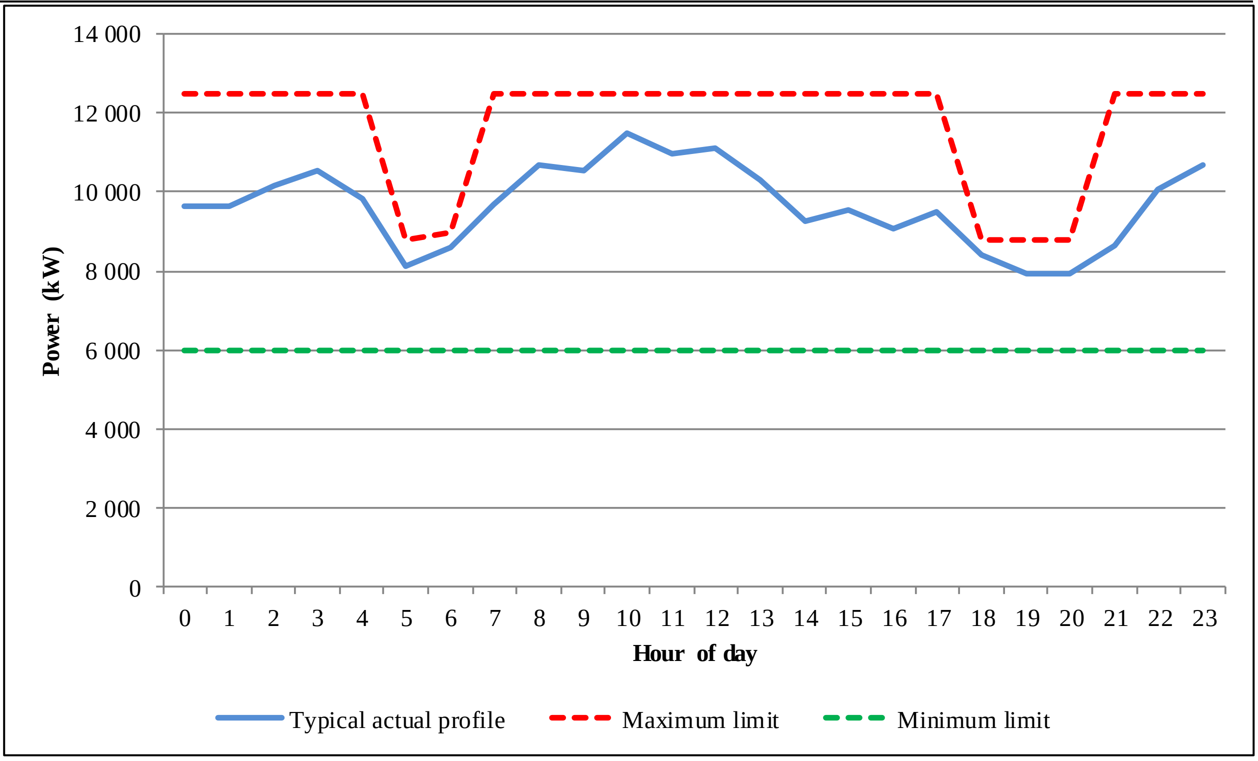

Figure 77: Maximum and minimum limits of an OAN project

3.5.6 Operational indicators

The control of industrial DSM projects rely on various input signals. For example, CA projects often involve controlling the speed of BAC supply pumps according to ambient air temperatures. High ambient air temperatures necessitate faster pumping speeds in order to supply more water to the BACs, while lower temperatures necessitate slower pumping speeds and less water to be supplied to BACs. The ambient temperatures are measured by a psychrometer installed on surface. Incorrect or zero values produced by the psychrometer would result in incorrect control that would probably result in unfavourable underground conditions and wasted electricity cost savings opportunities.

Ambient temperature measured by a psychrometer is just one of a large number of input signals that are essential to DSM projects operating correctly. Other examples of input signals include position feedback from control valves, pump availability signals, dam level sensors, pressure transmitters, flow meters, and so forth. An input signal that is less important for controlling DSM projects correctly, but essential to correctly report DSM project performance is power consumption values obtained from power meters.

In order to ensure the integrity of all input signals logged by a DSM project, PCM requires that the energy management system should be able to monitor all values logged from input signals. This enables the detection of erroneous values resulting from faulty equipment or disrupted communication. The following types of errors should be detected:

- No values, typically logged as error values such as ‘?’ or ‘NULL’.
- Values that are outside of maximum and minimum limits, for example, dam level sensors that indicate values below 0% or higher than 100%.
- Values that remain constant for prolonged periods of time, for example, ambient air temperatures measured by a psychrometer that remain constant for a period of longer than 10 minutes.
- Values that vary incorrectly, for example, dam levels that change from 80% to 20% and back to 80% over a period of five minutes.

The energy management system keeps record of all problems detected by its automated checking function. Apart from limited checking, the energy management system can also automatically detect and generate problem notification e-mails for other problems such as data loss during certain periods of the day and if no data was received from the control system.

The project engineer or the DSM project manager is required to log on to the energy management system to comment on every problem. This ensures that all problems are addressed and that records are kept in case of enquiries at a later stage. The energy management system views the status of all detected problems as ‘open’, until being commented on by either the project engineer or the DSM manager. Problem notification e-mails are re-sent on a daily basis to both the project engineer and DSM manager as a reminder of all ‘open’ problems. The status of problems that received comments from either the project engineer or the DSM manager are changed to ‘closed’ and no further problem notification e-mails are sent by the energy management system.

Figure 78 shows a screenshot of the problem management interface on the energy management system. The problem number is shown at the top of the screen. The problem description is also shown, which in this case is ‘data loss’. The current status of the problem is ‘closed’ because the project engineer commented that the data loss was caused by the ESCO that performed maintenance on the control system. The date and time of problem generation and comment by the project engineer are also recorded and shown on the screen.

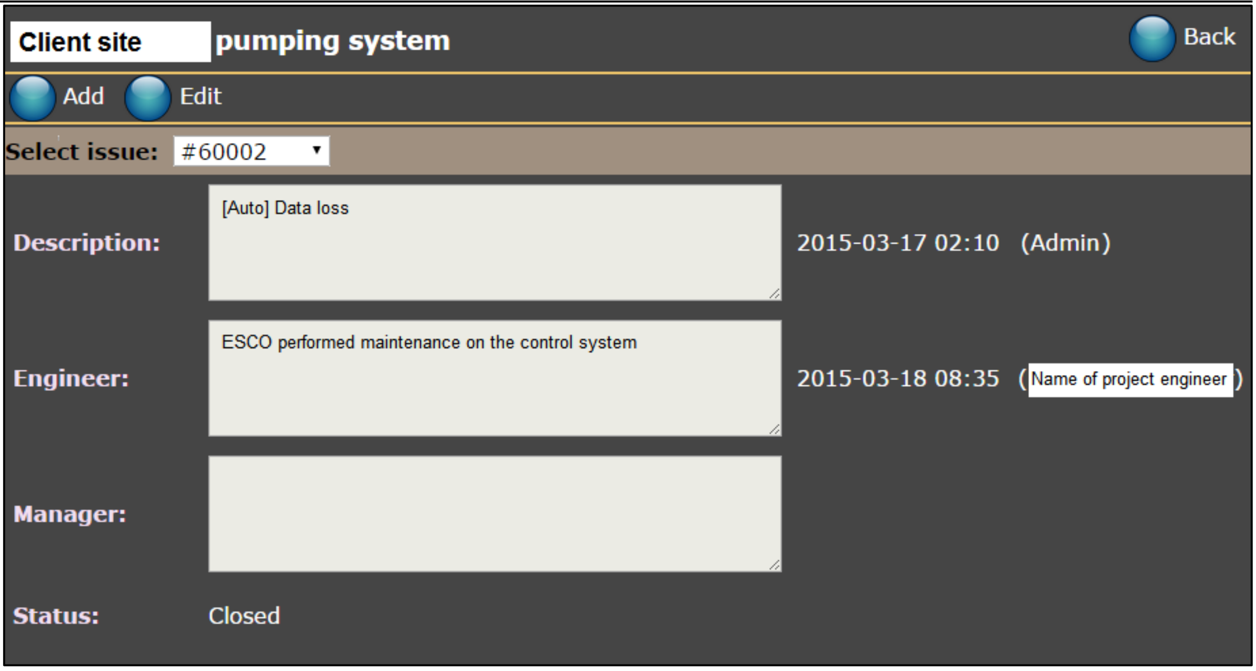

Figure 78: View of problem management interface on energy management system

3.6 Key performance indicators

3.6.1 Introduction

The standard method of measuring the success of a DSM project is determining the impact of the project on the electricity consumption profile of the client. This method is used by M&V teams to measure the success of Eskom-funded DSM projects throughout the contractual period between Eskom IDM and the client. From the viewpoint of the industrial client, the impact of the project on the electricity consumption profile is valuable information. It is therefore also widely considered by industrial clients as a suitable method to determine the success of a project.

The impact of a DSM project on the electricity consumption profile of the client is, however, not the only measure that should be used to judge the performance of the project. For every type of industrial DSM project, various other KPIs need to be considered to get a holistic view of the success of a DSM project. The alternative KPIs that were developed in this study are presented in this section. An example of a daily project control report that shows the implementation of some of the alternative KPIs presented in this section is presented in Annexure E.

3.6.2 Alternative KPIs for DSM projects

Electricity cost savings

The aim of Eskom-funded load-shifting and peak-clipping projects is to achieve maximum reduction in electricity consumption during the evening peak period. For load-shifting and peak-clipping projects, the impact on the electricity consumption of the client is therefore measured during the evening peak period only. This is to the advantage of Eskom because the demand on the national grid is at its maximum level during the evening peak period.

The aim of PCM is to achieve maximum value for the industrial client. This implies that aiming to achieve maximum performance during the evening peak periods may not necessarily be top priority. This does not apply to energy-efficiency projects because there is a direct correlation between project performance measured by M&V and the electricity cost savings generated by the project for energy-efficiency projects. This is because the impact of energy-efficiency projects is determined according to the average energy efficiency obtained over the 24 hours in a day, instead of only measuring it in the evening peak period.

For load-shifting and peak-clipping projects, there may not always be a direct correlation between project performance measured in the evening peak period and electricity cost savings generated by the project. Consider, for example, a load-shifting project on the mills of a cement manufacturing plant. Figure 79 shows the baseline and actual profile on 4 June 2012. A morning-peak load shift of 3.94 MW and an evening-peak load shift of 2.32 MW were achieved. The total electricity cost savings for the day was R36 590. The Eskom target for the project was an average evening load shift of 2.55 MW. The M&V team therefore reported underperformance of -0.23 MW for the day.

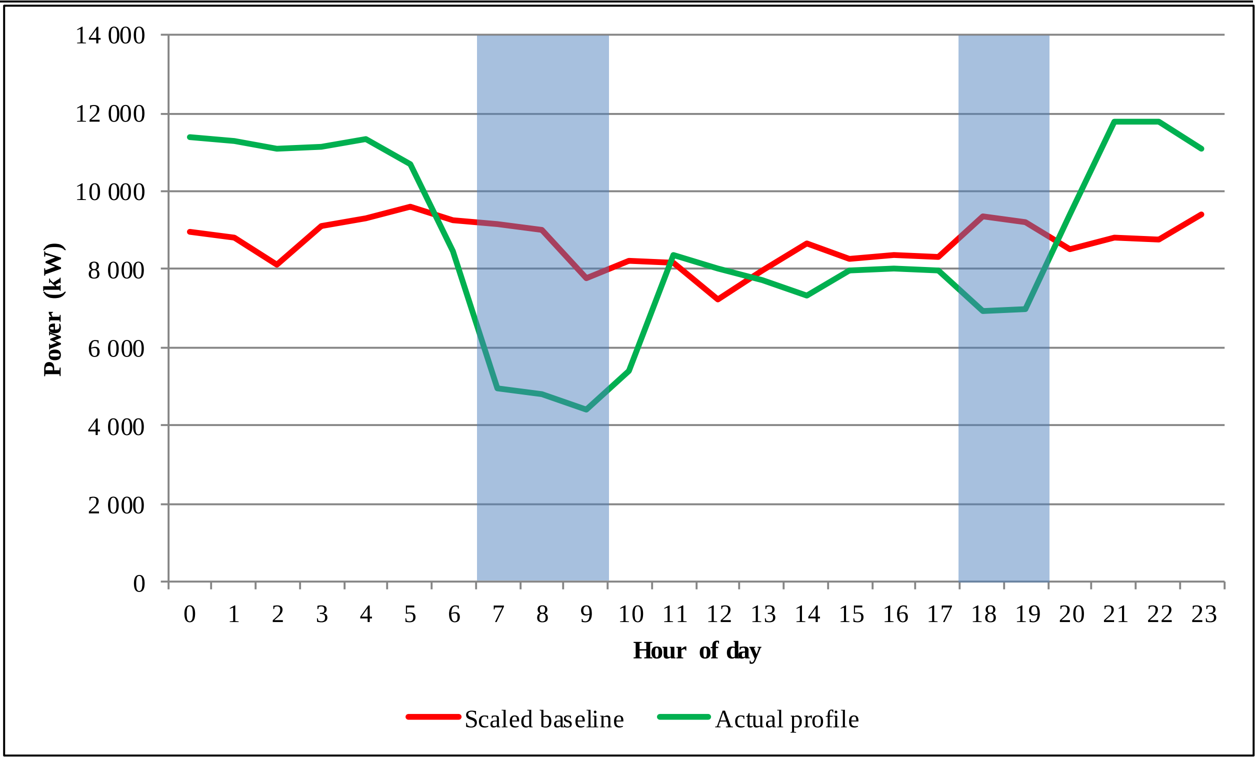

Figure 79: Baseline and actual profile of load-shifting project on cement mills on 4 June 2012

Consider the profile shown in Figure 80 that was achieved 10 days later on 14 June 2012. An average morning-peak load shift of -1.07 MW and an average evening-peak load shift of 6.5 MW were obtained. The MW team therefore reported overperformance of 3.95 MW. Despite the overperformance, the electricity cost savings obtained on 14 June 2012 amounted to R24 843, which was R11 747 lower than the electricity cost saving obtained on 4 June 2012 when the project underperformed.

The difference in the electricity cost savings can be attributed to the impact of the morning-peak load shift. The fact that the morning peak is an hour longer than the evening peak has the result that more electricity cost savings can be achieved by focusing the load-shifting effort on the morning peak instead of the evening peak. The ideal situation is to maximise load-shifting performance in both the morning and evening peak periods. Unfortunately, this may not always be possible due to various constraints such as mill availability and production targets.

Figure 80: Baseline and actual profile of load-shifting project on cement mills on 14 June 2012

This example illustrates the unfortunate situation where sacrificing load shifting in the morning-peak period to maximise evening-peak load-shifting performance would most probably be detrimental to the electricity cost savings of the client. Since the aim of PCM should be to generate maximum value for the industrial client, it is imperative to determine a control philosophy that is to the advantage of the client.

For projects that are out of the Eskom contractual period the choice is simple, electricity cost savings should be prioritised over evening peak performance. For projects in the Eskom contractual period, a balance between electricity cost savings and evening peak performance should be obtained. The first priority should be to achieve the evening peak load-shifting target stipulated in the contract between Eskom and the client. The second priority should be to maximise morning-peak load-shifting performance without negatively affecting evening load-shifting performance.

The conclusion is that electricity cost savings is an important KPI for measuring the success of DSM performance. For projects out of the Eskom contractual period, electricity cost savings should be considered the most important KPI. For peak-clipping and load-shifting projects in the Eskom contractual period, both the evening-peak impact and electricity cost savings should be considered.

Electricity usage distribution between peak, off-peak and standard periods

The ultimate aim of load-shifting projects is to shift maximum load from the Megaflex peak and the standard period to off-peak periods. This, however, may be difficult to achieve in practice due to various system constraints. Electricity usage distribution between peak, off-peak and standard periods has a direct impact on electricity cost savings and should therefore be viewed as an important alternative KPI.

Suggested running schedule versus actual running schedule

Industrial load-shifting projects entail reducing equipment usage during the Megaflex peak and standard periods, while increasing usage during off-peak periods. This is achieved by a control system that generates a suggested running schedule, based on various system constraints. A comparison of the suggested schedule versus the actual running schedule provides a good indication whether equipment is being controlled for load-shifting purposes or not.

Availability

Availability is another metric that has a signification impact on load-shifting performance. Unavailable equipment results in reduced production capacity and will therefore negatively affect the capacity for load shifting. Equipment availability is therefore an important alternative KPI that should be monitored as part of a PCM strategy. Availability is calculated according to the formula below:

$$Availability = \frac{Operational\ time}{Total\ available\ time} \qquad (4)$$

Total stops/starts per hour and total stop/starts per day

It is unavoidable that load shifting will result in the stopping and starting of equipment powered by electric motors. There is a common belief among industrial clients in South Africa that stopping and starting is harmful to electric motors. It is believed that stopping and starting shorten motor life and result in increased maintenance costs.

The majority of electric motor failures can be ascribed to a combination of various mechanical and electrical stresses on the shaft, bearings, rotor and windings of an electric motor [86]. It is true that electric motors are exposed to increased mechanical and electrical stresses during stopping and starting [87]. Electric motors are, however, designed to be stopped and started. If stresses are kept within the design specifications, premature failure of electric motors should not occur [86].

Load shifting in the morning and evening peaks will result in only two additional stops and starts per day for every electric motor involved in the load-shifting effort. The lifespan of electric motors will therefore not be negatively affected by stopping and starting of equipment for load shifting, as long as the total number of stop and starts, as well as the minimum duration between stops and starts recommended by the manufacturers are not exceeded. Unnecessary stopping and starting of equipment should still be avoided. The National Electrical Manufacturers Association (NEMA) published a guideline for the maximum recommended frequency of starts for different types of electric motors [88].

The number of stops/starts per hour and the total number of stops/starts during a 24-hour period is a metric that should be considered as part of a PCM strategy. The monitoring of this metric will ensure that the additional stops and starts resulting from load shifting will not exceed the total number of recommended stops and starts over a 24-hour period.

Set point versus actual values

The implementation of industrial DSM projects requires changes in the control philosophies of industrial equipment. These control philosophy changes are often achieved by implementing set-point control on equipment or adjusting existing set-point control on equipment. OAN projects, for example, rely on the set-point control of the delivery pressure of compressors and underground control valves that regulate the pressure of the compressed air supplied to different mining levels. A comparison between the suggested set-point values and the actual achieved values provides an indication of whether the DSM project is achieving its intended impact. The monitoring of set point versus actual value comparisons is therefore recommended as a metric for PCM.

Efficiency

The performance of a load-shifting project is directly related to the efficiency of the equipment that the load-shifting intervention is performed on. This is because the usage of efficient equipment results in more capacity for load shifting. Consider, for example, a load-shifting project on a raw mill of a cement manufacturing plant. Production requires that a certain amount of raw meal must be produced on a daily basis, irrespective of whether load shifting is performed or not. The higher the throughput of the mill, the easier it would be to achieve the daily production target while performing load shifting. Monitoring the efficiency of the mill in kWh/t is therefore recommended to ensure that maximum load-shifting performance is achieved.

Equipment efficiency is considered an important alternative performance KPI that should be monitored as part of a PCM strategy. The availability of the required instrumentation and data enables the control system to calculate the efficiency of various equipment in real time. More information about the calculation of the efficiency of various equipment controlled as part of industrial DSM projects is provided in below.

Cement mills

Measurement of mill output and the power consumption of the mill and its auxiliary equipment allow the calculation of mill efficiency. The unit of measurement for mill efficiency calculation is kWh/t.

Compressors

The efficiency of a compressor can be determined by measuring the power consumption of the compressor and the flow delivered by the compressor. The unit of measurement is kWh/m^3.

Centrifugal pumps

Measuring power consumption and water flow allows the calculation of pump efficiency in kWh/Ml. This method depends on the availability of water flow meters for each pump. Water flow meters are relatively expensive and are therefore not always available. An alternative cost-effective way to measure the efficiency of a centrifugal pump is the thermodynamic method [89]. This method is cost effective because it requires relatively inexpensive instrumentation. The required instrumentation includes temperatures probes and pressure sensors that allow the differential pressure and temperature over each pump to be calculated. This allows the calculation of pump efficiencies in real time according to the following formula [89]:

$$\eta = \frac{1}{\frac{C_p}{v}\left(\frac{\Delta T}{\Delta P} - \mu\right)} \qquad (5)$$

Where:

η	=	Pump efficiency (%)
C_p	=	Specific heat constant (J/kg.K)
v	=	Specific volume (m^3/kg)
ΔT	=	Differential temperature over the pump (°C)
ΔP	=	Differential pressure over the pump (Pa)

μ = Joule–Thompson coefficient (K/Pa)

It should be noted that using the most efficient pumps would result in electricity cost savings. Unfortunately, it is not sensible to use only the most efficient pumps. There is a direct relationship between pump usage and pump efficiency deterioration. The load must therefore be distributed between the efficient and less efficient pumps to ensure even efficiency deterioration. Electricity cost savings can, however, be achieved by incorporating the pump efficiencies in the control philosophy of a pump load-shifting project. It works on the principle that the more efficient pumps are prioritised during peak and standard periods when electricity tariffs are high, while the less efficient pumps are prioritised in off-peak periods when lower tariffs apply.

Fridge plants

COP is a measure of the efficiency of fridge plant systems and individual chiller machines. The equation for calculating the COP for the entire fridge plant system is given below [70]:

$$COP_{system} = \frac{Q_{evap}}{P_{ref}+P_{aux}} \qquad (6)$$

Where:

COP_{system} = coefficient of performance of system

Q_{evap} = thermal energy absorbed by evaporator (kW)

P_{ref} = motor power (kW)

P_{aux} = power of auxiliary equipment (kW)

The efficiency of an individual chiller machine can be calculated as follows [90]:

$$\eta_{machine} = \frac{Q_{evap}+P_{ref}}{Q_{cond}} \qquad (7)$$

Where:

$\eta_{machine}$ = efficiency of chiller machine

Q_{evap} = thermal energy absorbed by the evaporator (kW)

P_{ref} = motor power (kW)

Q_{cond} = thermal energy absorbed by the condenser

Rock hoisting

The efficiency of the rock hoisting process affects the performance of load-shifting projects on gold production lines. The efficiency of the rock hoisting process can be determined by calculating the load factor:

$$Load\ factor_{Rock\ hoisting} = \frac{Skips/hour}{Maximum\ skips/hour} \qquad (8)$$

3.7 Graphical representation of PCM strategy

A summary of the PCM strategy is displayed in Figure 81. The PCM strategy starts with the ‘plan’ step. This involves planning on various levels from the monthly group level DSM feedback session to ad hoc planning between the ESCO and the client. The ‘do’ step entails acting on the various decisions taken in the ‘plan’ step. It ranges from people-related actions such as training sessions to physical infrastructure repairs and upgrades. It also includes control philosophy changes. The ‘check’ step is focused on the advanced monitoring of DSM project performance. The last step is ‘act’ which entails the analysis of results obtained in the previous phase to determine the impact of the actions implemented in the ‘do’ step. The ‘act’ step also entails making recommendations for further improvement of DSM project performance based on the analysis of the results.

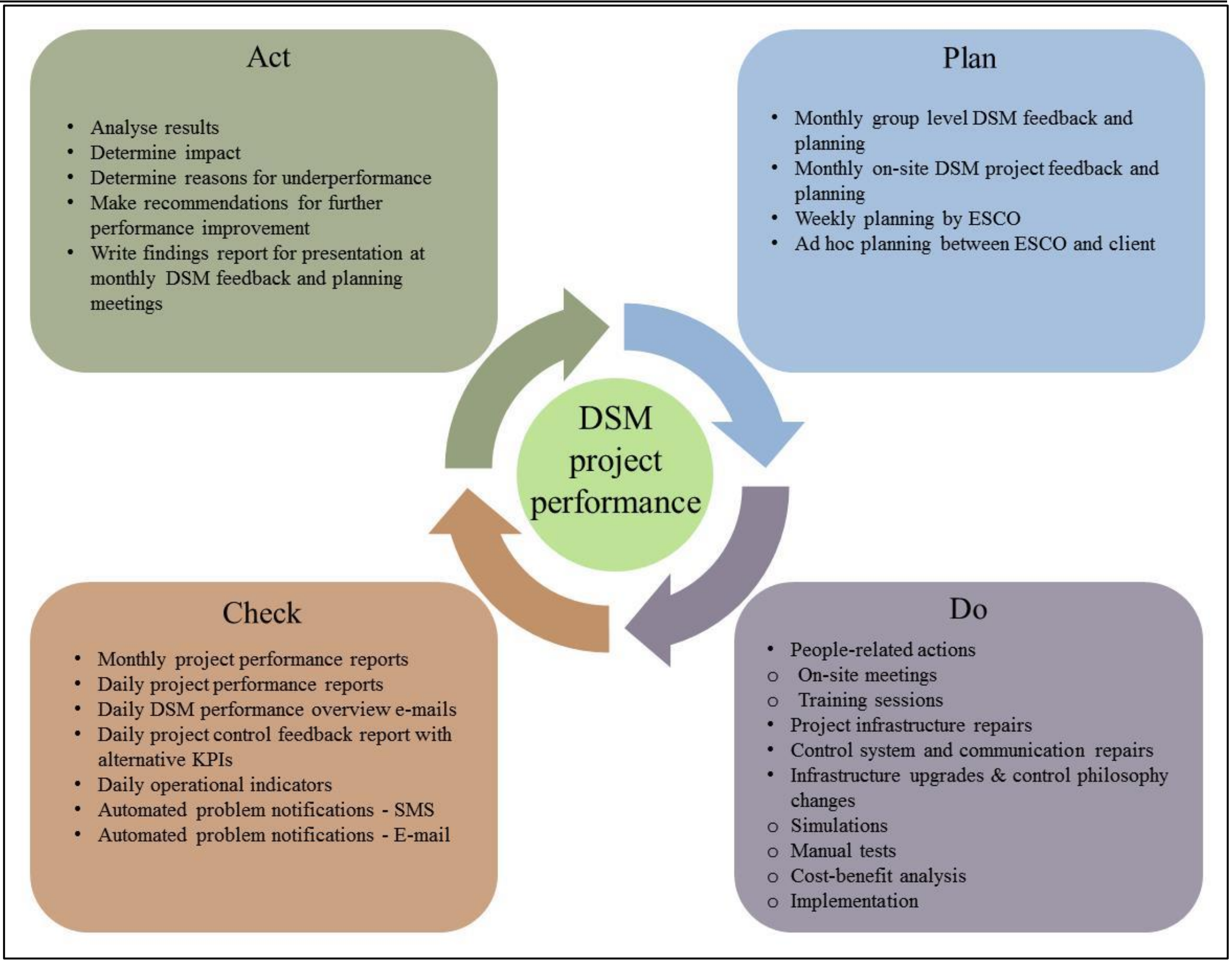

Figure 81: Graphical representation of PCM strategy

3.8 Summary

The concept of PCM that was developed in this study to maximise the performance and sustainability of DSM projects was presented in this chapter. The chapter started by listing the requirements for PCM. The requirements indicated the need for developing a PCM strategy that is specifically aimed at industrial DSM projects. The PCM strategy was presented as four different research contributions:

- Defining a strategy for outsourcing DSM maintenance on company group level.
- Identification of DSM projects where PCM would contribute to increasing value for the client.
- Development of the PCM strategy.
- Developing alternative KPIs for measuring the performance of industrial DSM projects.

CHAPTER 4. RESULTS

4.1 Introduction

The purpose of this chapter is to provide the results of implementing the PCM strategy on different industrial DSM projects. The most important measure of the success of the PCM strategy is the net cost savings generated by the project. The net cost saving is the balance remaining after deducting maintenance costs from the electricity savings generated by the project. Another advantage of the implementation of PCM is avoiding underperformance penalties for DSM projects that are still in the five-year contract period with Eskom. The value of this cost avoidance measure must also be taken into consideration when evaluating the success of implementing the PCM methodology.

4.2 PCM applied to underperforming DSM projects

4.2.1 Project A

Project A is load-shifting project on the dewatering pumps of a gold mine in the Free State province. The project was originally implemented in 2005 and achieved an average evening-peak impact of 1.87 MW. By the end of 2012, a DSM maintenance agreement for this project was signed between the mining group and the ESCO that originally implemented the project.

According to M&V reports, the project overperformed on its target during the five-year Eskom contract period from 2005 to 2010. Unfortunately, the performance of the project deteriorated rapidly after the Eskom contact period ended. At the start of 2013, the ESCO started a reimplementation effort to restore the performance of the project. Unfortunately, the control system was not in working condition anymore because the control system server was broken. This meant that no automatic pump control was taking place and no data (running statuses, flow, dam levels and so forth) were recorded anymore. The dewatering pumps were manually controlled by pump attendants without any regard for TOU tariffs.

Despite the deterioration of the DSM project, the pumping system was adequately maintained by the mine. Although the pumps were manually controlled by pump attendants, the pumps could still be controlled from surface via the SCADA network. The meant that the DSM project could be reimplemented without major spending on infrastructure upgrades.

The first step of the PCM strategy was to replace the control system server and to restore the OPC connection to the SCADA. This enabled the recording of pump system data. The pumping profile was recorded throughout January 2013 and was used as the new baseline for the project.

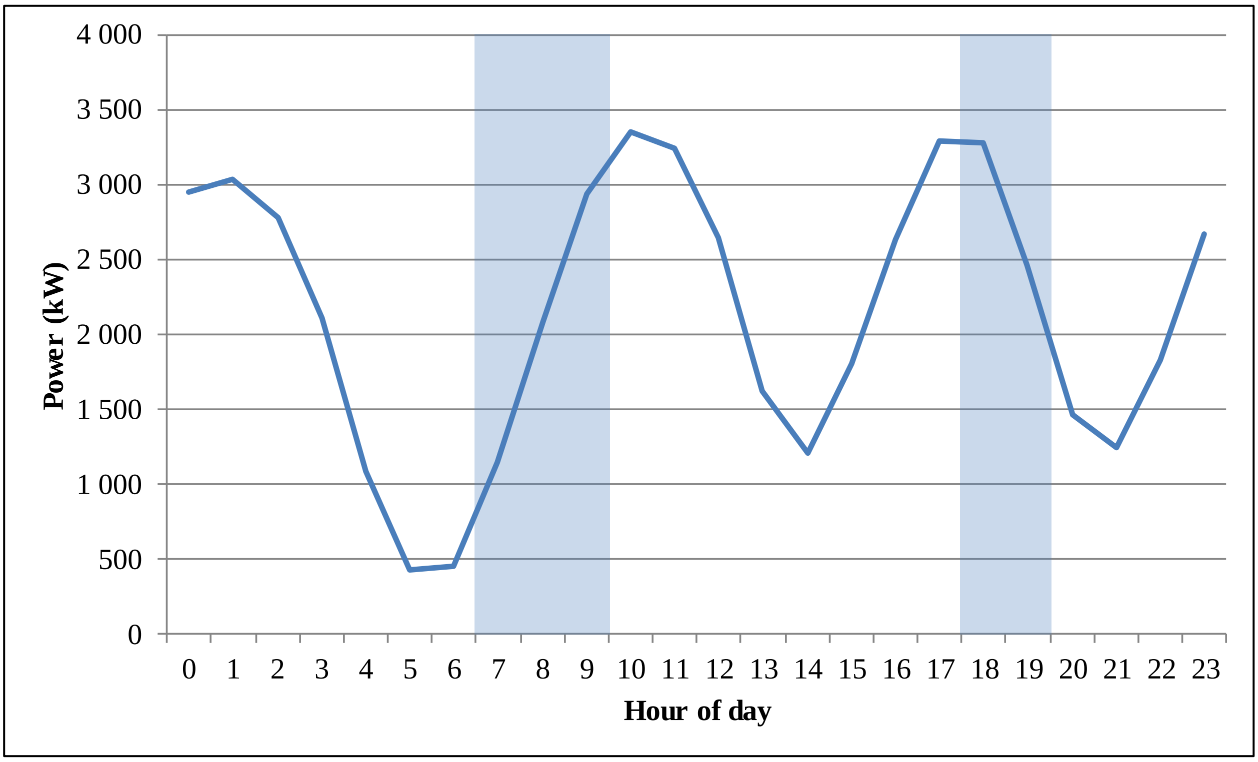

Figure 82: January 2013 profile (new baseline)

Figure 82 shows the average weekday power profile recorded in January 2013. The profile indicates the complete absence of load-shifting measures during the morning-peak period. The evening peak period shows a reduction in pumping from 19:00 to 20:00.

The January 2013 power profile of Project A differs from the typical flat line profiles that are often recorded for projects where no load shifting takes place. The varying profile of Project A is a typical result of a pumping system with relatively small dam capacities. The small dam capacities necessitate more frequent stopping and starting of pumps, which is reflected in the varying power profile.

During January 2013, various meetings were held on site with the shaft engineer, the pumping foreman and the chief electrician to discuss the reimplementation of the project. The new control philosophy was discussed, including the maximum and minimum levels of the various dams. The effect of the new control philosophy was simulated by using the data of January 2013 as input. The simulation indicated that it would still be possible to achieve an average peak load shift of 1.2 MW. A joint decision by the mine and the ESCO was therefore made to enable the control system to control the pumps automatically from 1 February 2013. The average power profile for February 2013 is shown in Figure 83. The results obtained in February 2013 were disappointing. An average load shift of only 0.67 MW was obtained.

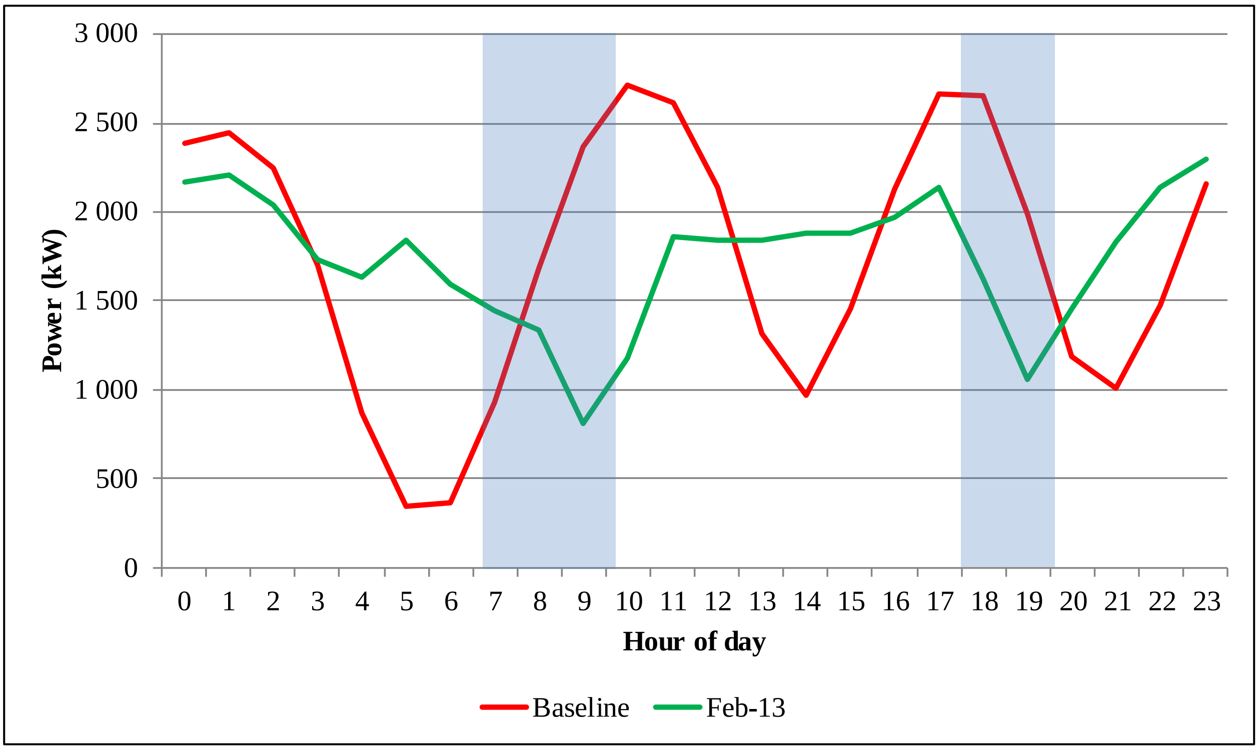

Figure 83: February 2013 profile

The disappointing results of February 2013 were caused by inadequate buffer capacities and errors in the control philosophy that were programmed into the control system. The maximum and minimum dam levels were reviewed by the shaft engineer and the pump foreman. They lowered the minimum allowable levels of certain dams to increase the available buffer capacity. The ESCO personnel also made various improvements to the programming of the control system.

The result of the increased buffer capacities and improved control system was that a significant performance increase to an average peak load shift of 1.39 MW was obtained in March 2013. The March 2013 profile is shown in Figure 84.

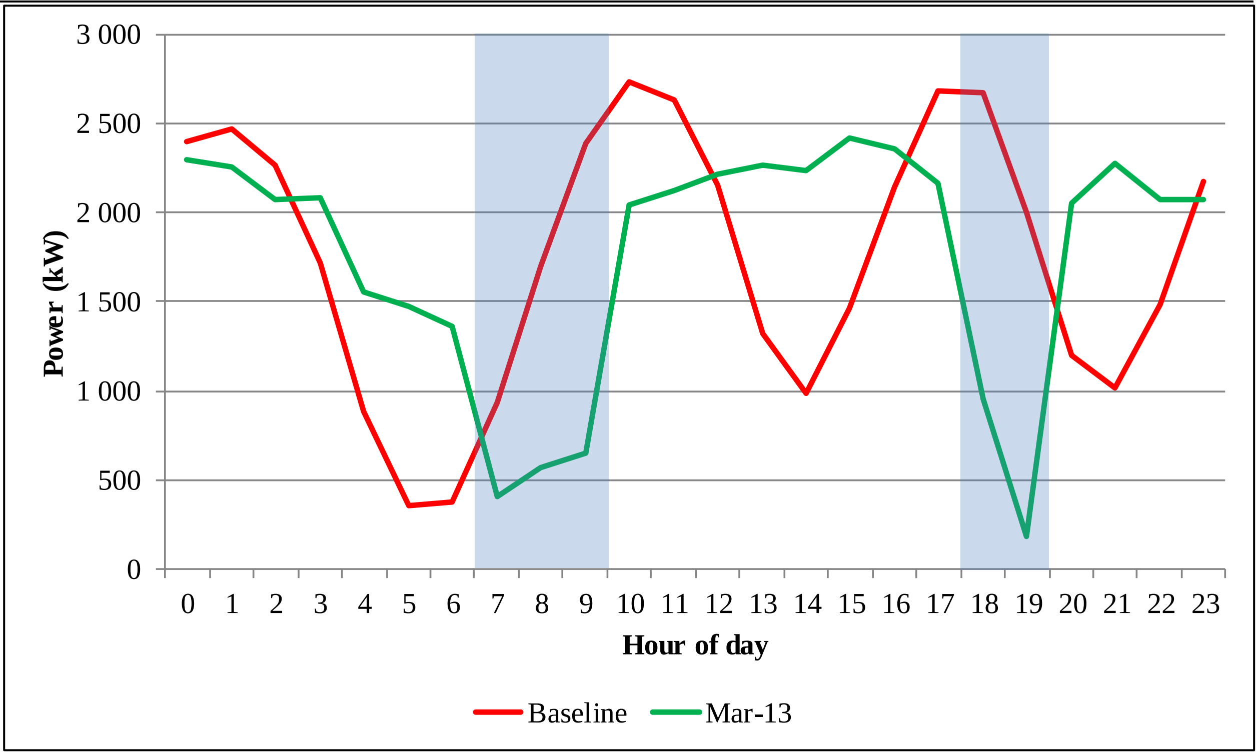

Figure 84: March 2013 profile

The performance of the project decreased in April 2013 when an average peak load-shifting performance of 0.99 MW was obtained. An investigation into the cause of the underperformance revealed that there were regular occurrences of pump attendants that unnecessarily switched pumps to manual control mode or unnecessarily kept pumps in manual control mode for extended periods. This prevented the control system from controlling the pumps and had a negative impact on project performance.

The solution to this problem was training the pump attendants on the aim of the project and the working of the control system. The negative effect of unnecessary interfering in the automatic control was illustrated with practical examples. The pump attendants worked in shifts, which meant that three separate training sessions had to be held to ensure that everyone could attend. The language of instruction at the training sessions proved to be problematic because not all of the pump attendants could understand English. The mine therefore organised an interpreter to attend all three training sessions.

The training sessions had the desired effect because the number of incidents where pumps were unnecessarily switched to manual control mode was significantly reduced. Figure 85 shows the attendees at one of the training sessions. After the training session, an instruction sheet regarding automatic pump control was translated into the various languages spoken by the pump attendants. The instruction sheets were laminated and distributed to the pump attendants. Copies of the instruction sheets were also put against the walls of the three pumping stations. A copy of the instruction sheet for the pump attendants is attached as Annexure F.

Figure 85: Training session for pump attendants

Figure 86 shows a graph of the average peak impact and the net cost saving that were achieved by applying the PCM strategy to Project A in the period from February to October 2013. It is important to notice the significant increase in cost savings that was achieved in June, July and August because of the high-demand season tariffs of the Megaflex tariff structure. The total net cost saving generated by the project in the period from February to October amounted to R828 456.

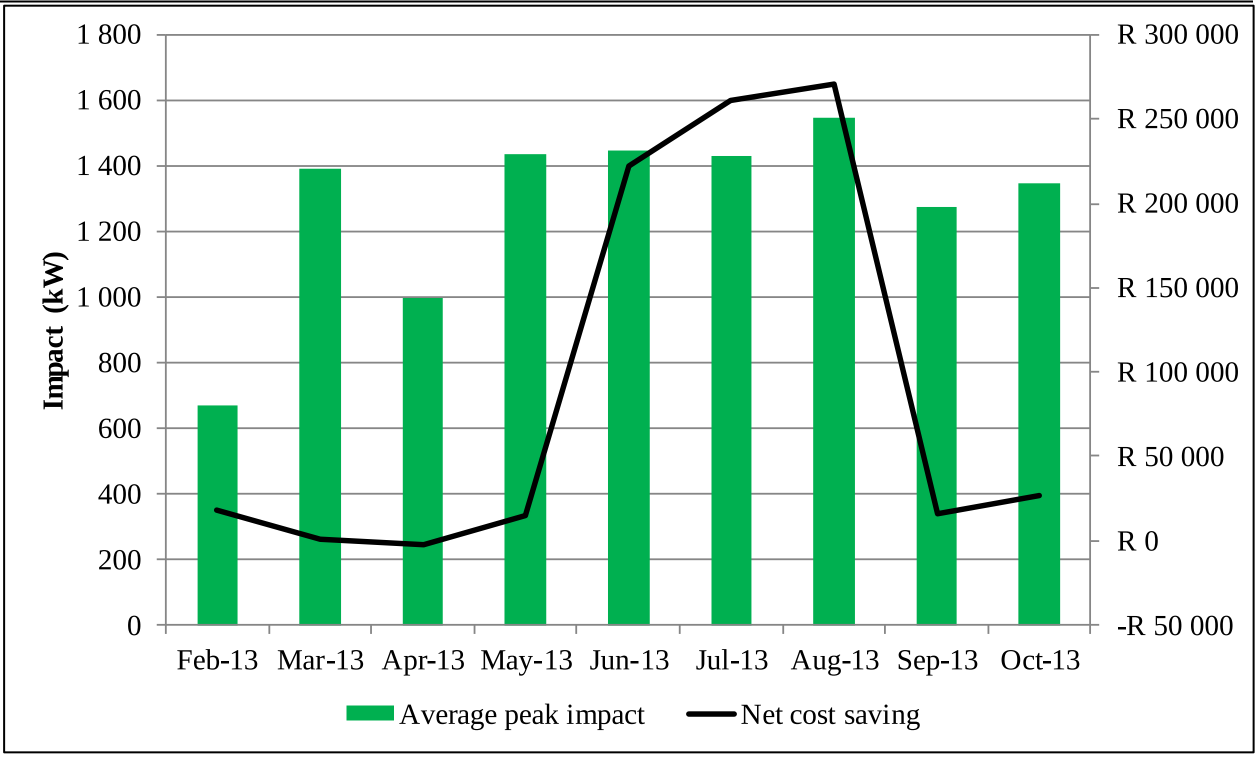

Figure 86: Average peak impact and net cost saving generated by Project A

4.2.2 Project B

Project B is another load-shifting project on a gold mine in the Free State province. The project was originally completed in September 2005. Figure 87 shows a simplified layout of the dewatering system of Project B. Cold water from the fridge plants is pumped to the surface cold dam from where it is sent down the mine to the various production levels. The hot water from the mining operations accumulates in the Level 66 hot dam. The pumping station on Level 66 consists of six dewatering pumps that pump the water from the Level 66 hot dam to the Level 45 hot dam. The mine has a three-chamber pipe feeder system (3-CPFS) installed on Level 45 that pumps water from the Level 45 hot dam to the surface hot dam. There is also a conventional pumping station on Level 45. This pumping station serves as backup for the 3-CPFS. The Level 45 pumping station consists of three pumps that can also pump water from the Level 45 hot dam to the surface hot dam.

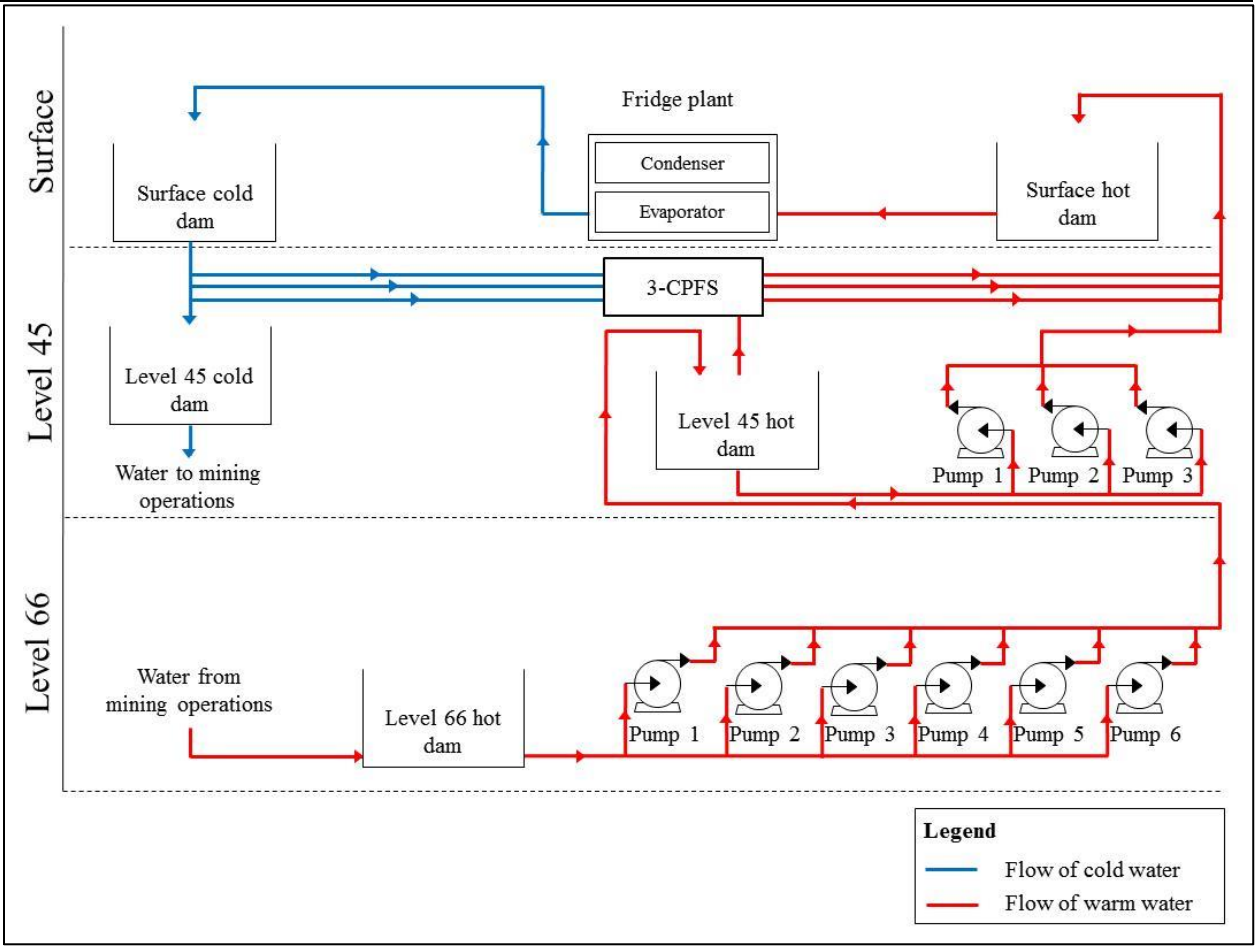

Figure 87: Simplified layout of the dewatering system of Project B

The project was reimplemented in April 2013 because the mine and ESCO signed a maintenance agreement. Figure 88 compares the average peak load-shifting performance before and after the application of the performance-centered strategy. The result of implementing the PCM strategy was that the average peak load-shifting performance increased from an average of 1.86 MW to 3.18 MW.

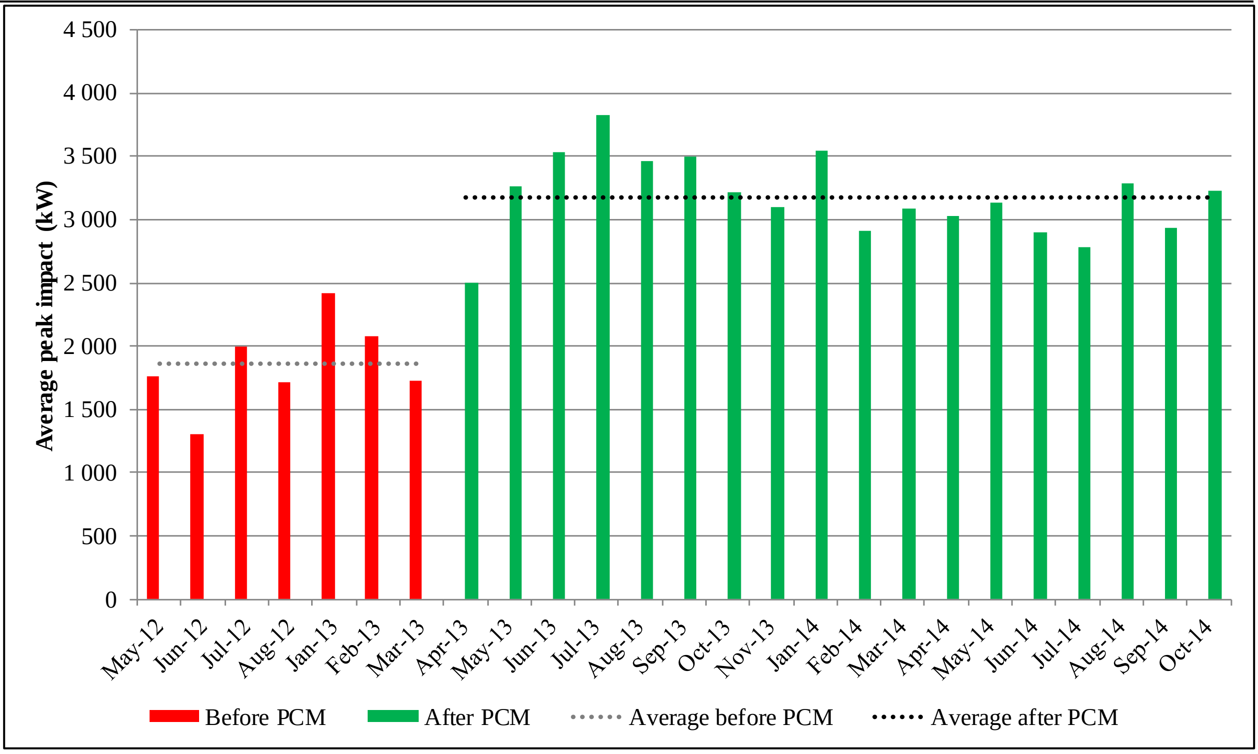

Figure 88: Performance comparison before and after implementation of PCM

Figure 89 shows the profile for June 2012 before the implementation of PCM. A morning-peak load shift of 1.45 MW and evening-peak load shift of 1.1 MW were achieved. Figure 90 shows the profile for July 2013 after the PCM strategy was applied. An average morning-peak load shift of 3.3 MW and an average evening-peak load shift of 4.6 MW were achieved.

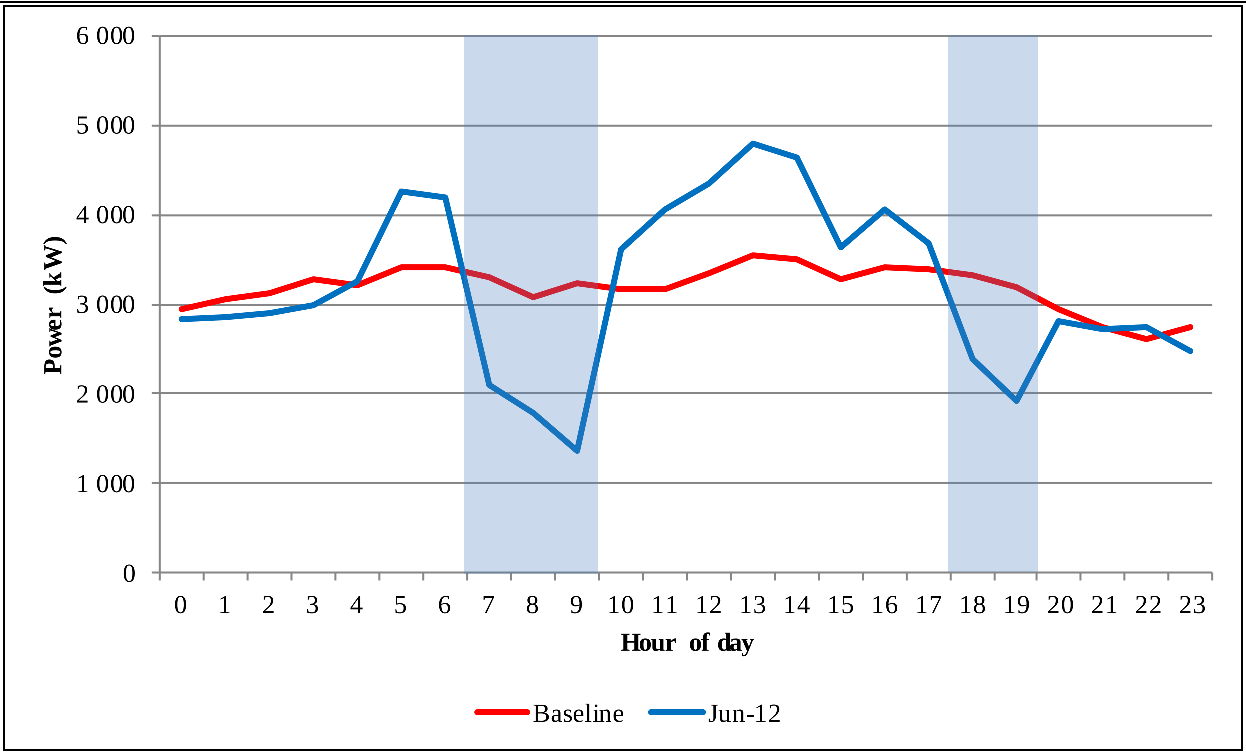

Figure 89: June 2012 profile (before PCM)

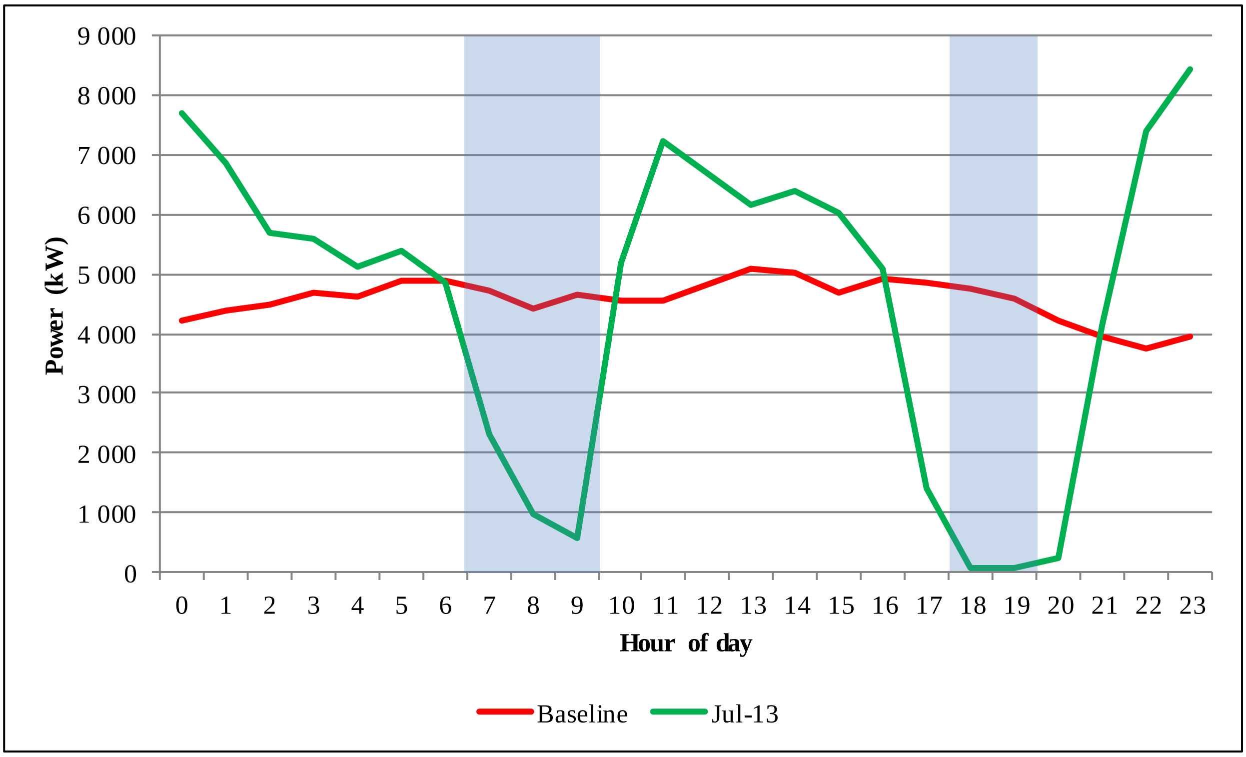

Figure 90: July 2013 profile (after PCM)

A comparison of the year-on-year performance of the project during the Megaflex high-demand months is shown in Figure 91. The drastic performance increase as a result of the application of the PCM strategy is clearly shown with significant increases in both load-shifting performance and cost savings.

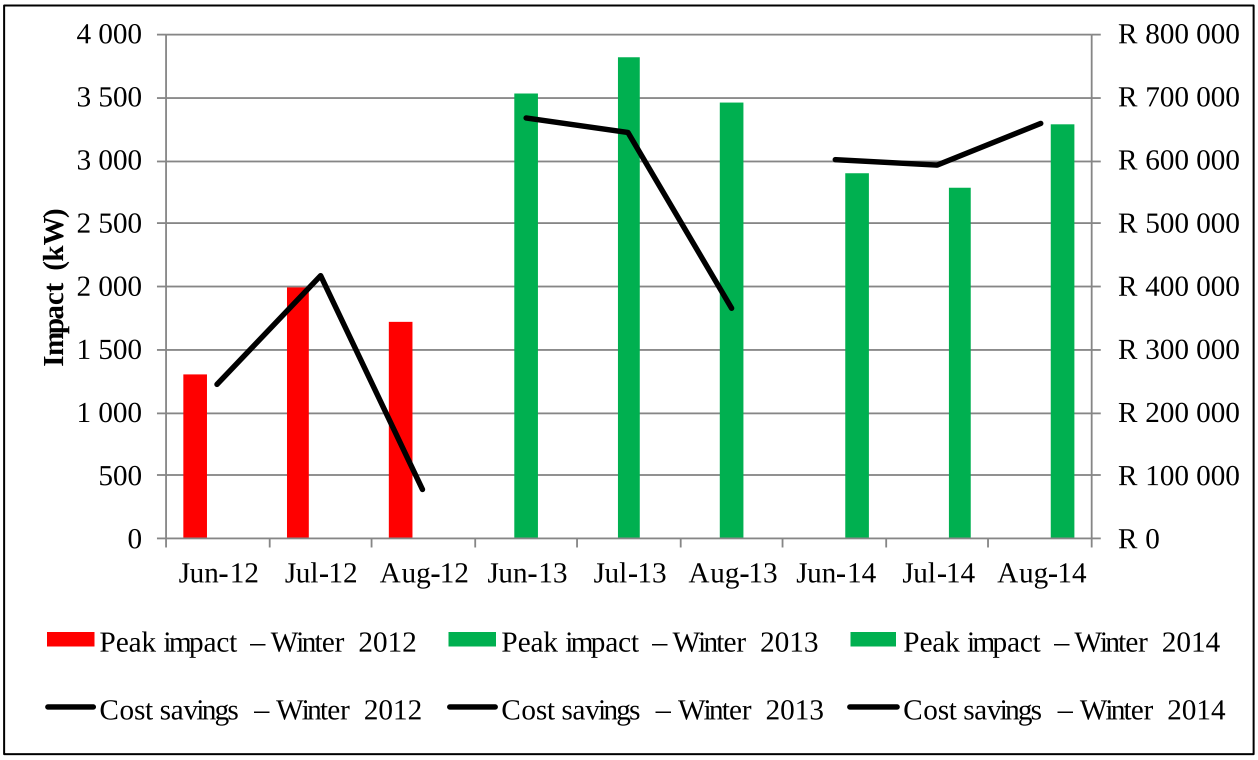

Figure 91: Year-on-year comparison of impact and cost savings during Megaflex high-demand months

Operating a 3-CPFS has a significant impact on the load-shifting performance of a project. The load-shifting potential of a project is negatively affected if the 3-CPFS is not operational. During January 2015, the mine experienced various problems that negatively affected the availability of the 3-CPFS. The low availability of the 3-CPFS was reflected in the underperformance of the project. Figure 92 shows the profile for January 2015 when an average peak load-shifting performance of only 1.3 MW was obtained.

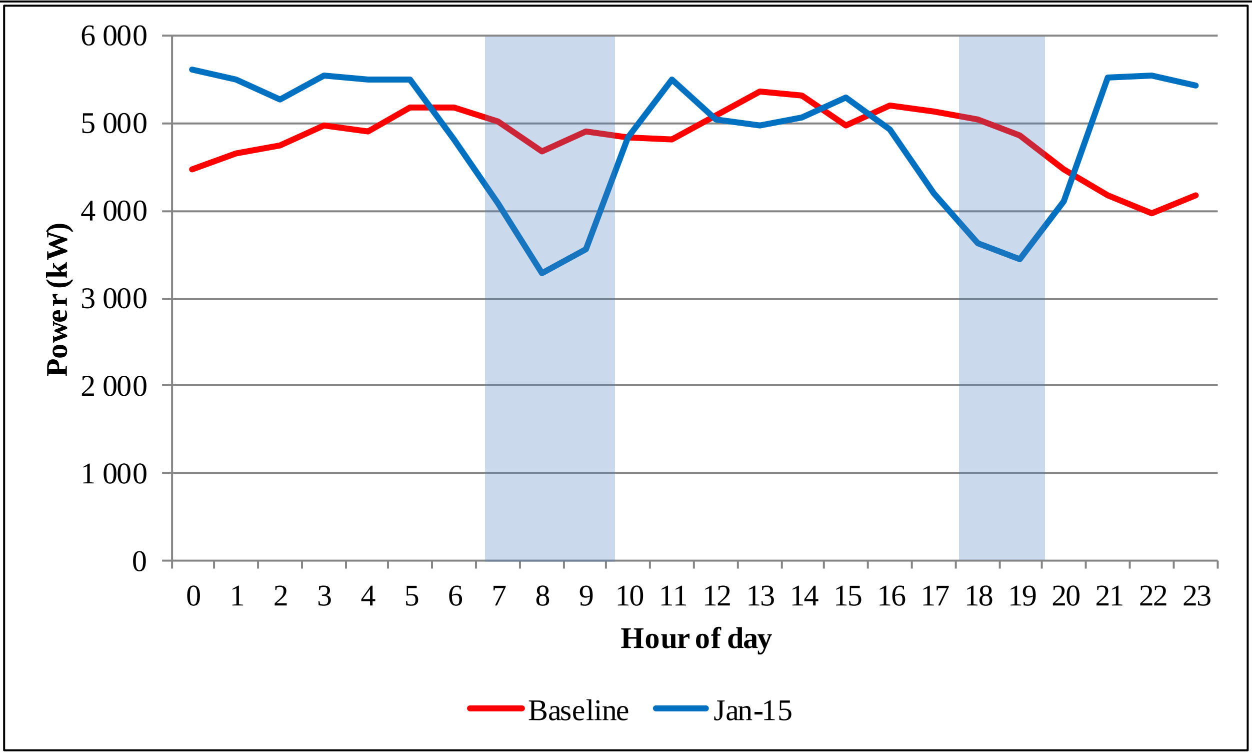

Figure 92: January 2015 profile

If the 3-CPFS is not operational, the three conventional pumps on Level 45 are used to pump the water from the Level 45 hot dam to the surface hot dam. Only two of these pumps can be simultaneously used on Level 45. The problematic aspect is the lower flow rate of the Level 45 pumps in comparison with the flow rate delivered by the 3-CPFS. The 3-CPFS achieves a flow rate of about 400 ℓ/s, which is significantly higher than the flow rate achieved by the two pumps on Level 45, which averages 260 ℓ/s. The result of the lower flow rate of the conventional pumps on Level 45 is a drastic reduction in the buffer capacity of the Level 45 hot dam, which is required for load shifting. This necessitates that the Level 45 pumps often have to pump throughout the peak periods if the 3-CPFS is unavailable, which has a negative impact on project performance.

Figure 93 shows how the statuses of the Level 45 pumps and the 3-CPFS affect the flow rate from Level 45 to surface. The status of the Level 45 pumps indicates the number of running pumps. The status of the 3-CPFS varies between 0 and 1, where 0 indicates no operation and 1 indicates full operation of the 3-CPFS. It is important to note the increase in flow rate when the 3-CPFS is operational.

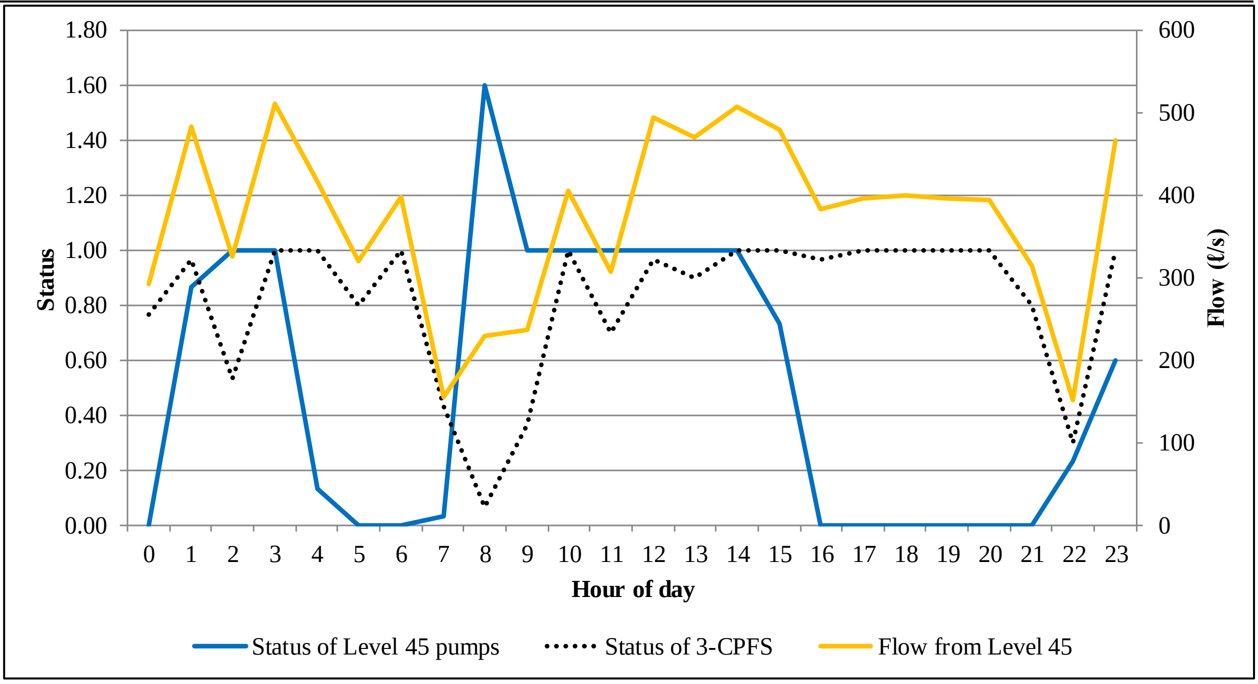

Figure 93: Relation between flow from Level 45 and status of the Level 45 pumps and 3-CPFS

Figure 94 illustrates the negative impact on project performance on a day when there were numerous interruptions in the operation of the 3-CPFS. On 26 January 2015, the 3-CPFS was operational for 61% of the time during the morning-peak period, which enabled partial load shifting in the first two hours of the morning peak. The 3-CPFS was, however, not operational from 15:00 to 19:00. This prevented any load shifting during the evening peak period.

Figure 95 shows the impact on project performance on a day when there was only one interruption in the operation of the 3-CPFS. The interruption occurred from 21:30 to 22:45. The fact that the interruption only occurred after the evening peak prevented it from having any effect on load shifting in the peak periods.

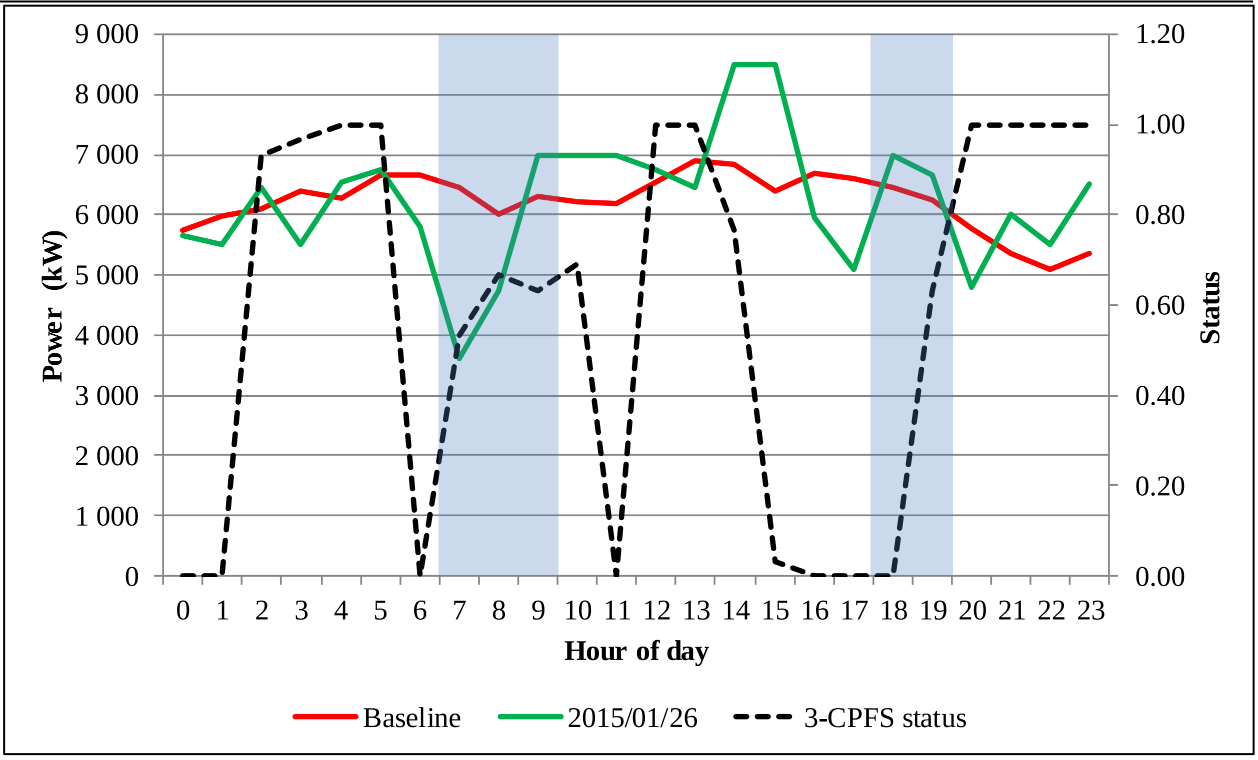

Figure 94: Impact of 3-CPFS on project performance – 26 January 2015

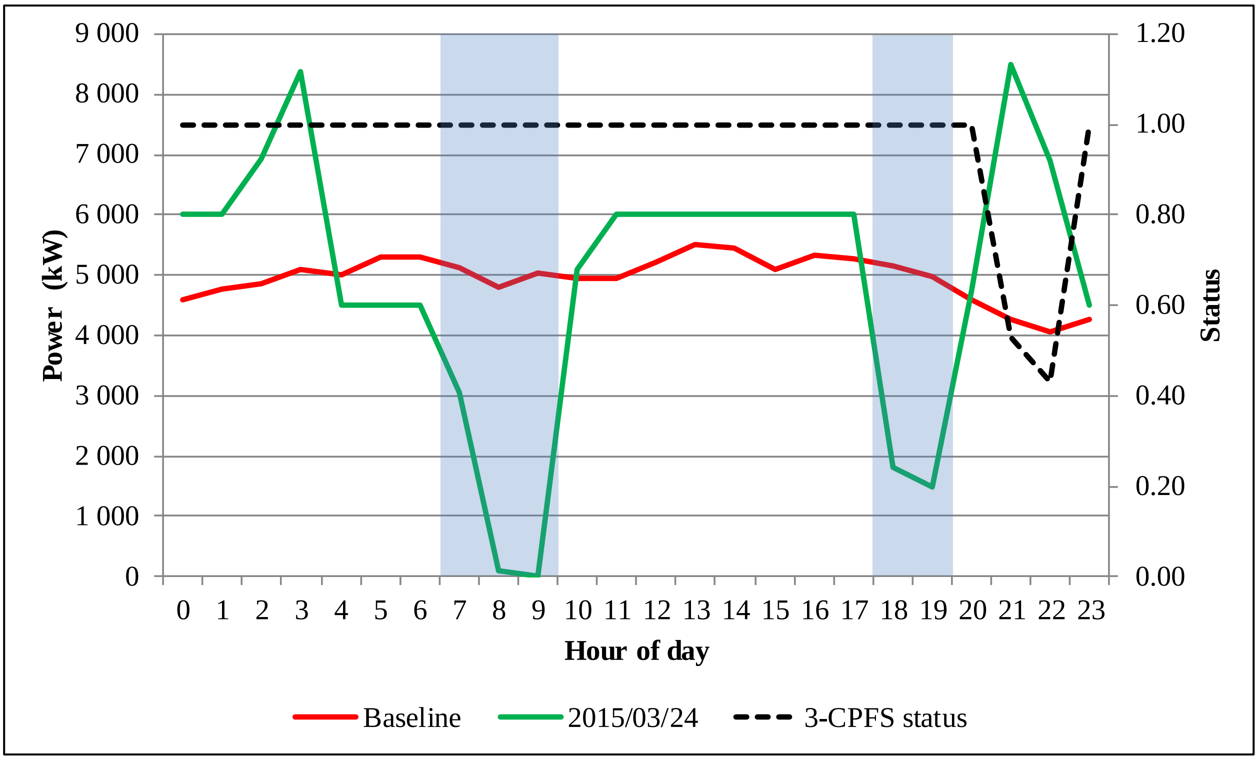

Figure 95: Impact of 3-CPFS on project performance – 24 March 2015

4.3 PCM applied since project implementation

4.3.1 Project C

Project C is an OAN project implemented on a gold mine in the Free State province. The project was completed in September 2013. The project has an energy-efficiency target of 1.44 MW. This target is achieved through automatic control of the delivery pressure of the compressors and control valves on the production levels. Figure 96 shows the results of the project in September 2014 when an average energy efficiency of 2.08 MW was obtained.

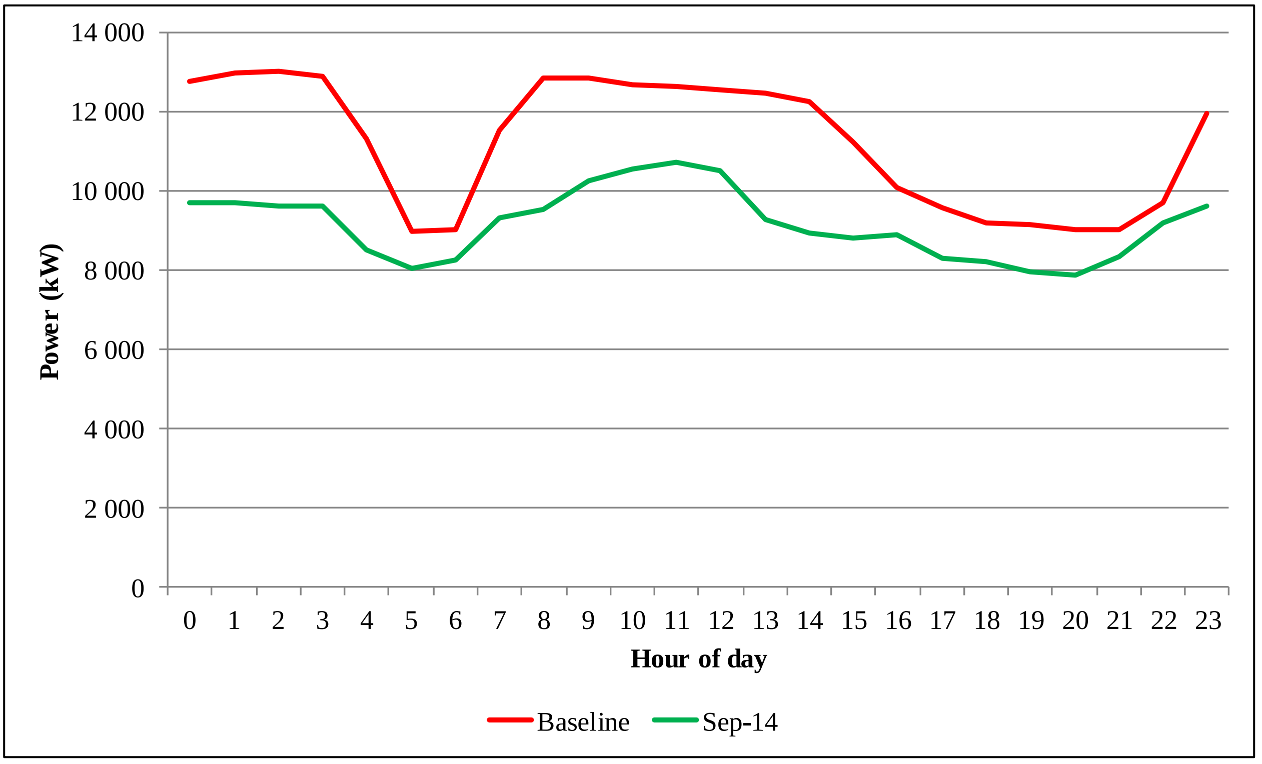

Figure 96: September 2014 profile of Project C

Before project completion, a DSM maintenance agreement was signed between the mine and the ESCO that implemented the project. This ensured that a PCM strategy could be applied from the start of the project, which ensured consistent overperformance on the target of 1.44 MW. Figure 97 shows the cumulative target versus the impact of the project in the period from October 2013 to November 2014. During this period, the project generated a net cash flow of almost R8-million.

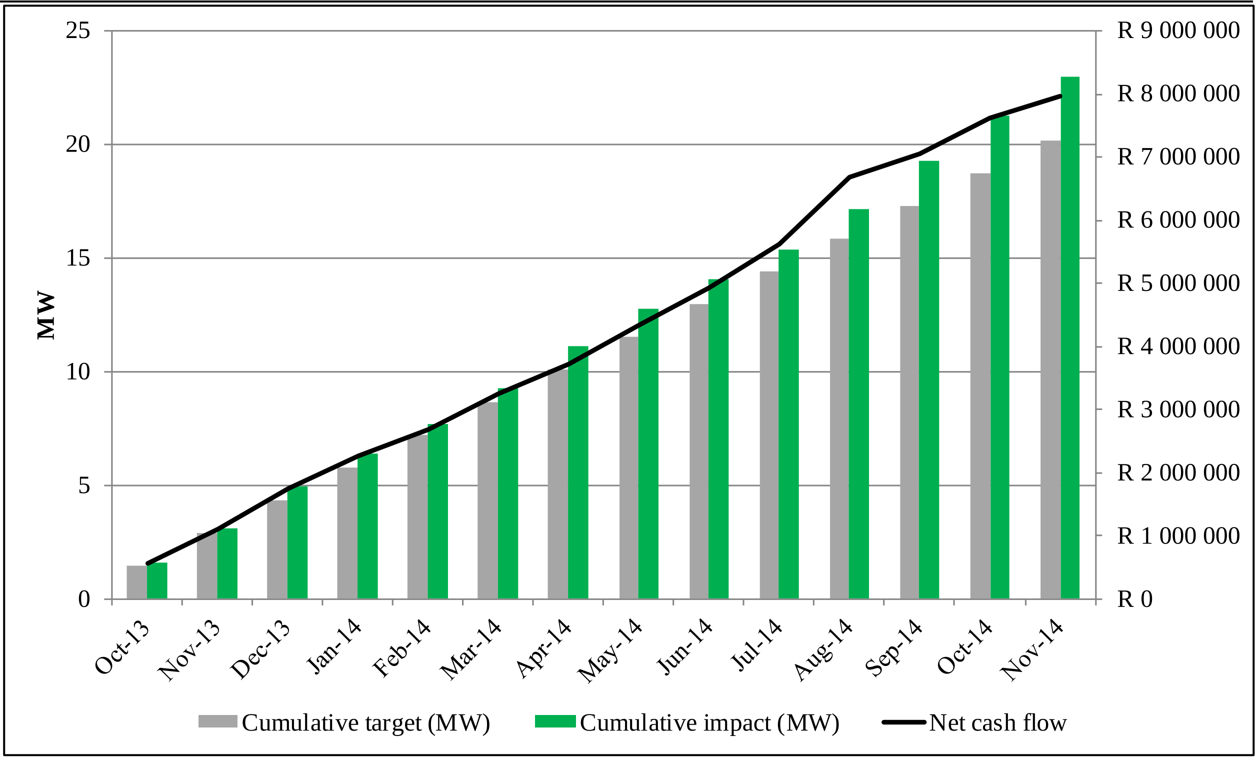

Figure 97: Cumulative target versus impact and net cash flow generated through PCM on Project C

4.3.2 Project D

Project D is a WSO project that was implemented in 2014 on a gold mine near the town of Orkney in the North West province. The ESCO who implemented the project stayed involved after PA because of a maintenance agreement between the ESCO and the mine. Figure 98 shows the results achieved from April 2014 to March 2015. The project generated a total cost saving of almost R6.5-million through consistent overperformance on its target of 1.51 MW.

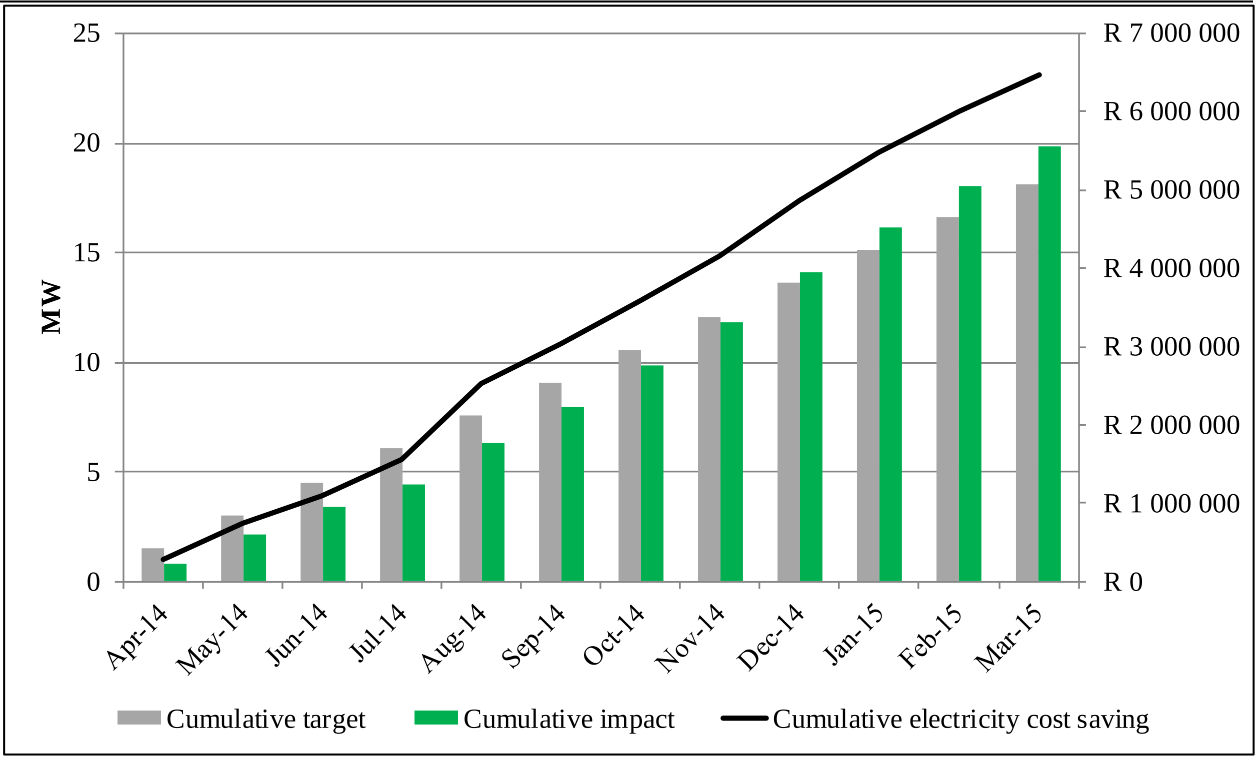

Figure 98: Cumulative target versus impact and net cash flow generated through PCM on Project D

4.3.3 Project E

Project E is a CA project that was implemented concurrently with Project D at the same site. It was also included in the same maintenance agreement as Project D. It was the first CA project implemented on underground fridge plants. PCM contributed to 70% overperformance during the period from April 2014 to March 2015. During this period, the project generated electricity cost savings of almost R8.9-million.

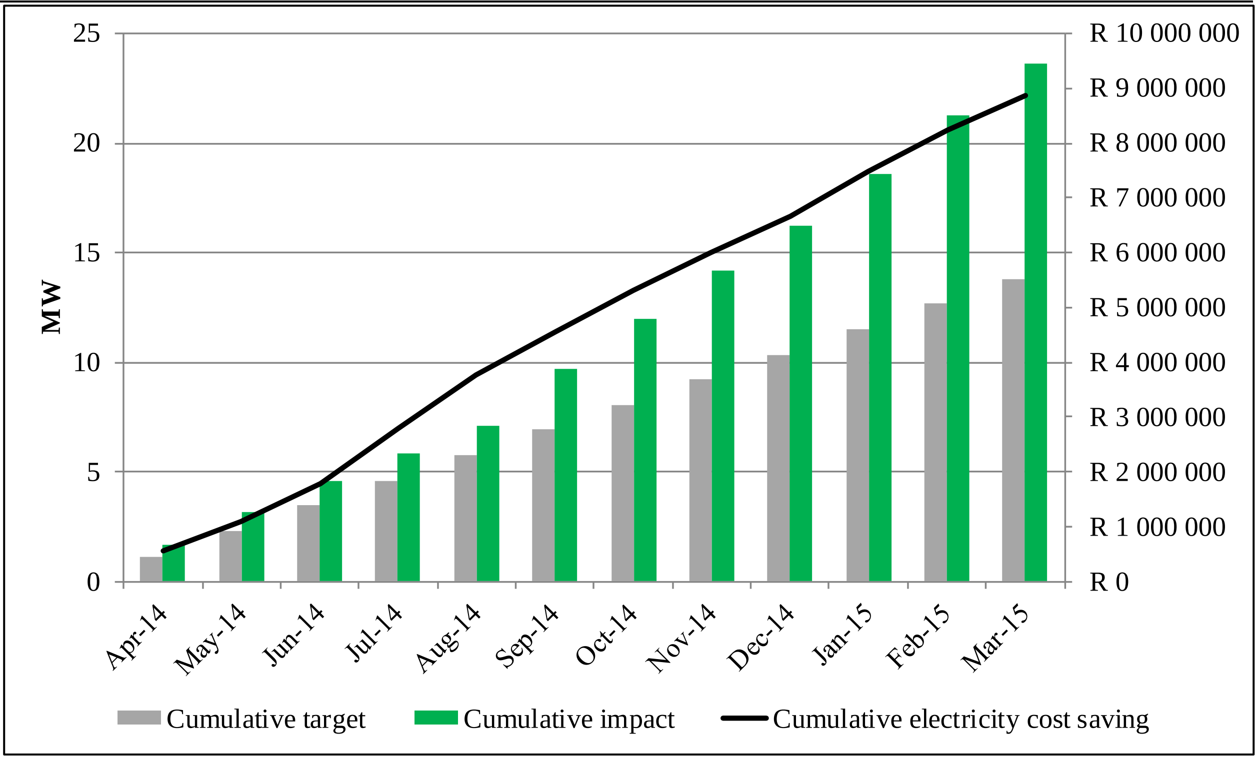

Figure 99: Cumulative target versus impact and net cash flow generated through PCM on Project E

4.3.4 Project F

Project F is a pump load-shifting project implemented on a mine that is also located near Orkney in the North West province. This project was implemented in early 2000s. A DSM maintenance agreement between the mine group and the ESCO for this project has been in place since 2004. The experience gained from maintaining this project has served as valuable input to developing the PCM strategy presented in this study. Figure 100 shows the cumulative impact versus the target of Project F for a period of more than nine years from January 2006 to March 2015. During this period, the project overperformed by 27.2%. Project F proves that DSM maintenance is required to ensure the long-term sustainability of industrial DSM projects.

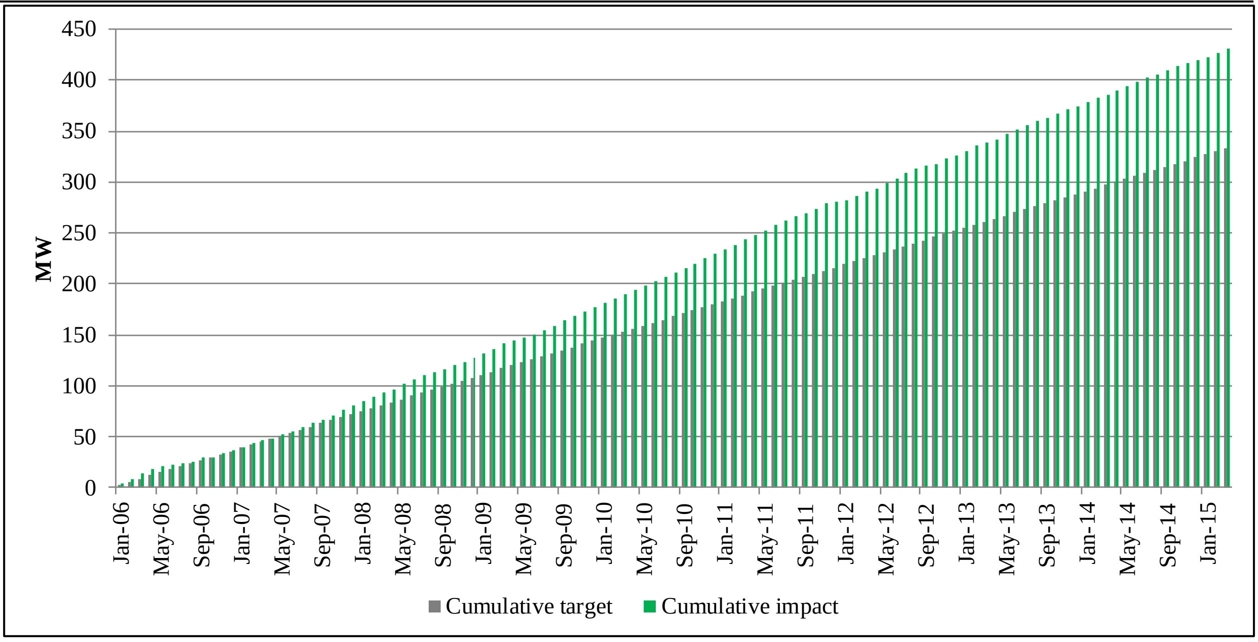

Figure 100: Cumulative target versus impact of Project F

4.3.5 Project G

Project G is a compressor manager project implemented on a large gold mine near Carletonville in the southwestern part of the Gauteng province. A DSM maintenance agreement for this project was signed before project completion. The cumulative project impact, target and cash flow generated by the project over a period of twelve months are shown in Figure 101. The project achieved an average evening-peak impact of 3.46 MW during PA in the first three months. PCM contributed to the project achieving an average evening-peak impact of 3.35 MW in Month 4 and Month 5. From Month 1–5, the cumulative impact was higher than the cumulative target.

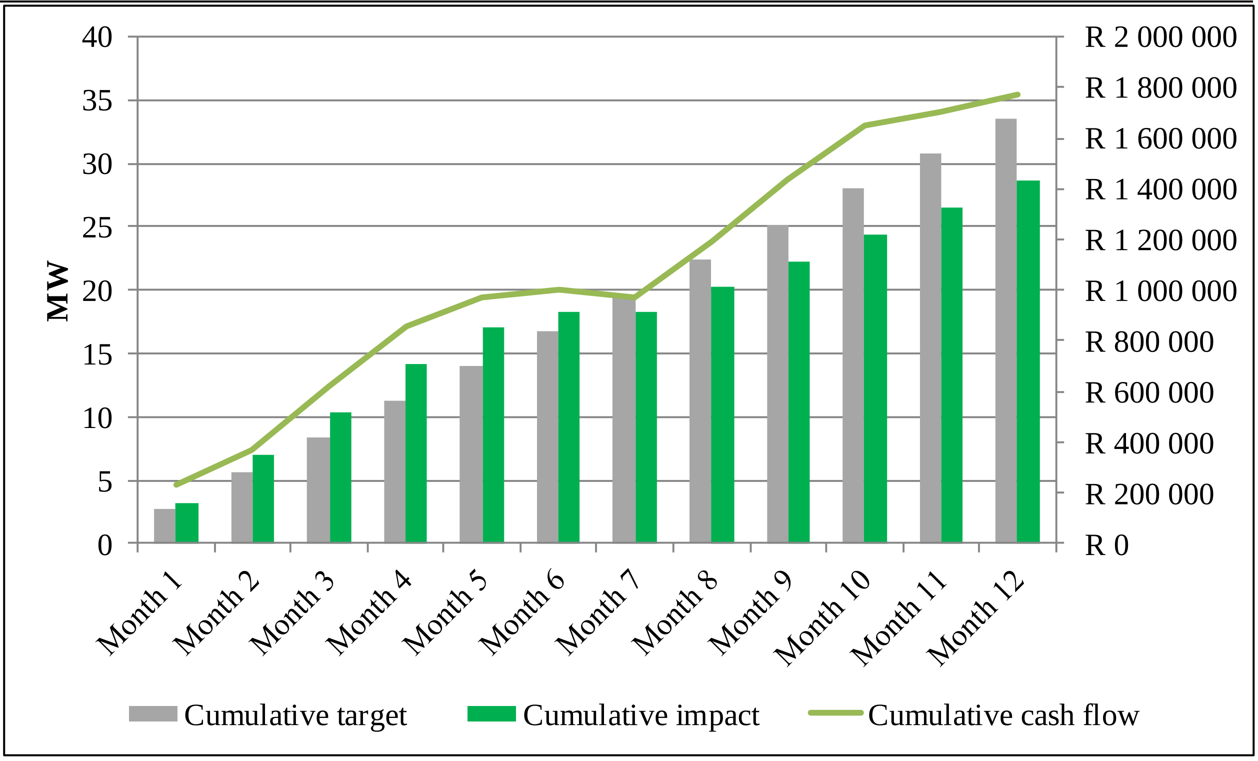

Figure 101: Cumulative target versus impact and net cash flow generated by Project G

At the start of Month 6, the general manager of the mine instructed that the control system be disabled. The reason for this was that the mine manager received a complaint that the project affected production on one of the main production levels. It was alleged that the reduced compressed air pressure to the level interfered with the operation of the pneumatic mining equipment.

The result of disabling the control system was that the project did not realise any electricity cost savings in Month 6 and Month 7. After considerable effort from the ESCO, the mine manager gave permission that the control system could be reinstated, on the condition that the control to two of the main production levels remained disabled until further notice. The disabled control on the two main production levels caused the project to underperform after the reinstatement of the control system. From Months 8–12, the project achieved an average impact of 2.06 MW.

The results of Project G shows that PCM does not always ensure that a project achieves or overperforms on its target. Various factors that may influence project performance are beyond the control of the ESCO. In this case, applying PCM was still beneficial to the mine, despite the underperformance of the project. The efforts of the ESCO to reinstate the control of the project made the difference between zero performance and an average evening-peak impact of 2.06 MW. Without PCM, it is almost certain that the control of the project would not have been reinstated after it was disabled on the instruction of the general manager of the mine.

4.4 Projects where PCM was stopped

4.4.1 Project H

Project H is a load-shifting project implemented on the dewatering pumps of a gold mine located near Westonaria in Gauteng. A total of 24 pumps on four different levels was controlled as part of the project. The total installed capacity of the 24 pumps was 43.8 MW and the evening peak target of the project was 8.5 MW. During the PA period the project overperformed with an average evening-peak impact of 13.23 MW.

At the start of PA, there were still some automation work outstanding on some of the pumps. The result was that a combination of manual and automatic control was used to control the pumps in PA. After the completion of the automation of all pumps, the ESCO provided free DSM maintenance for a period of three months from October to November 2014. The purpose of the free maintenance was, firstly, to prove that the project could achieve its target saving sustainably when all the pumps were controlled automatically and, secondly, to prove the value of PCM to motivate the signing of a DSM maintenance contract.

Figure 102 shows the results obtained in November 2014. An average evening-peak impact of 8.82 MW and a morning-peak impact of 4.4 MW were obtained. The cost savings generated by the project in November 2014 amounted to R135 811. During PA, the aim was to maximise evening-peak load shifting, while in the period from October to December 2014 the aim was to generate maximum electricity cost savings through load shifting in both the morning- and evening-peak periods, while at the same time achieving the evening-peak target.

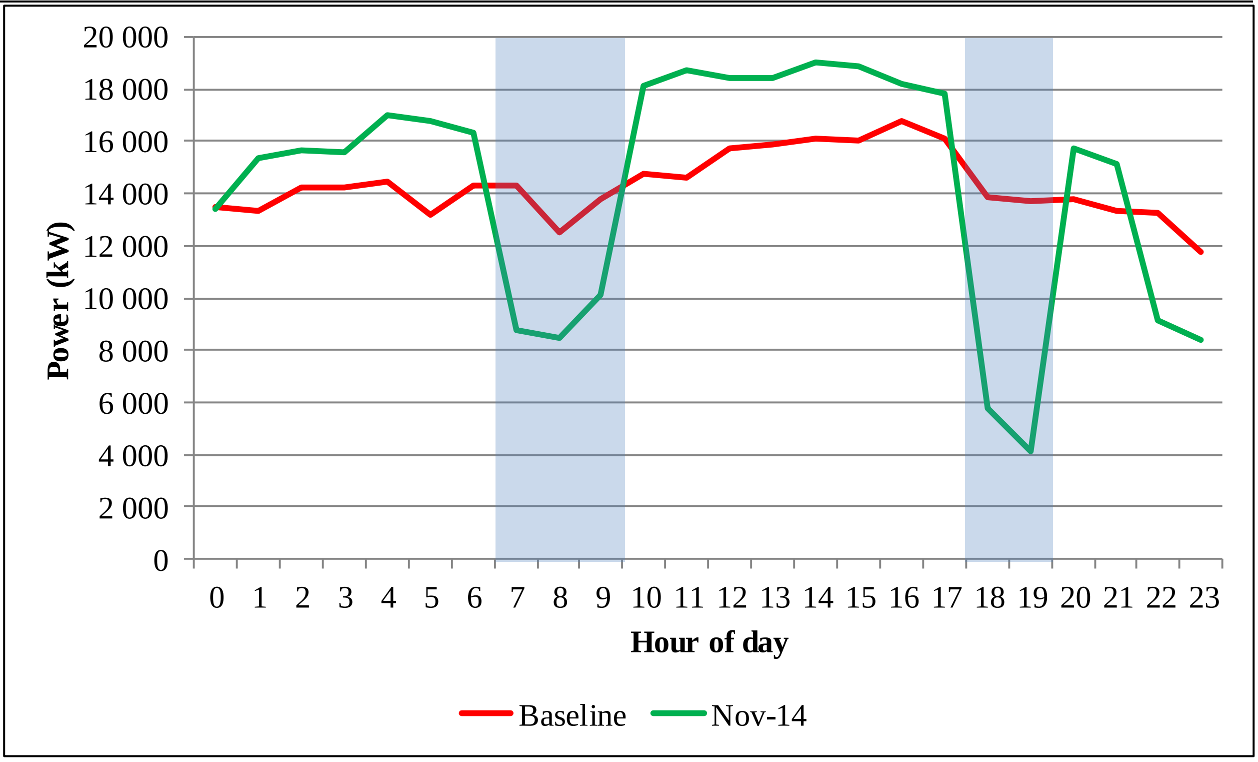

Figure 102: November 2014 profile of Project H

Figure 103 shows the profile obtained in March 2015, only two months after PCM has been stopped. A drastic reduction in performance is observed. An average morning-peak load shift of 0.33 MW and an average evening-peak load shift of only 1.98 MW were obtained. The project did not generate any cost saving in March 2015 because the cost savings of load shifting from peak periods were offset by the increase in pumping during the Megaflex standard period from 10:00 to 18:00.

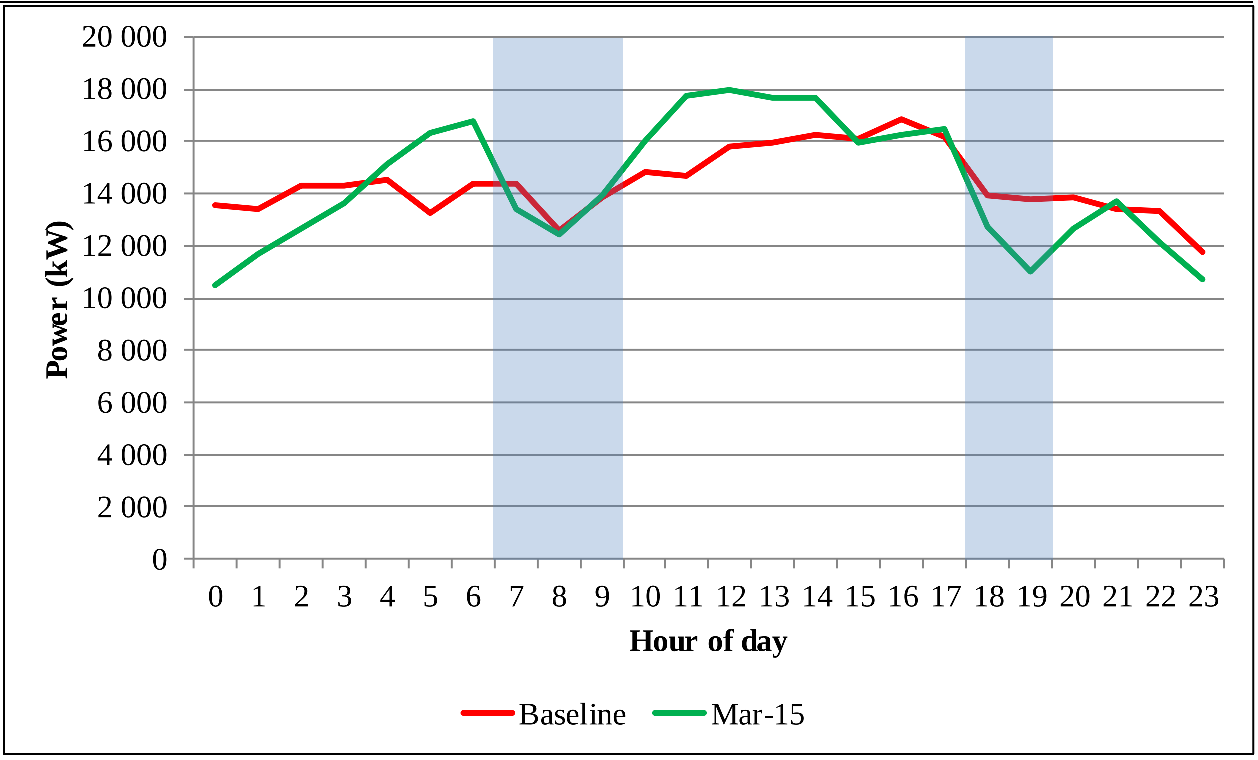

Figure 103: March 2015 profile of Project H

The results obtained in November 2014 and March 2015 made it possible to compare the projected value that would be generated by Project H if a PCM strategy could be applied with the situation where PCM was not applied and the March 2015 performance remained unchanged. Figure 104 compares the projected net cost saving with PCM, the projected cost savings without PCM and the projected underperformance penalties without PCM for the period from April 2015 to March 2016. Figure 104 shows that the total projected net cost savings as a result of PCM was R5.2-million. The project electricity cost saving was zero without PCM, while the projected total underperformance penalty would amount to R 2.86-million.

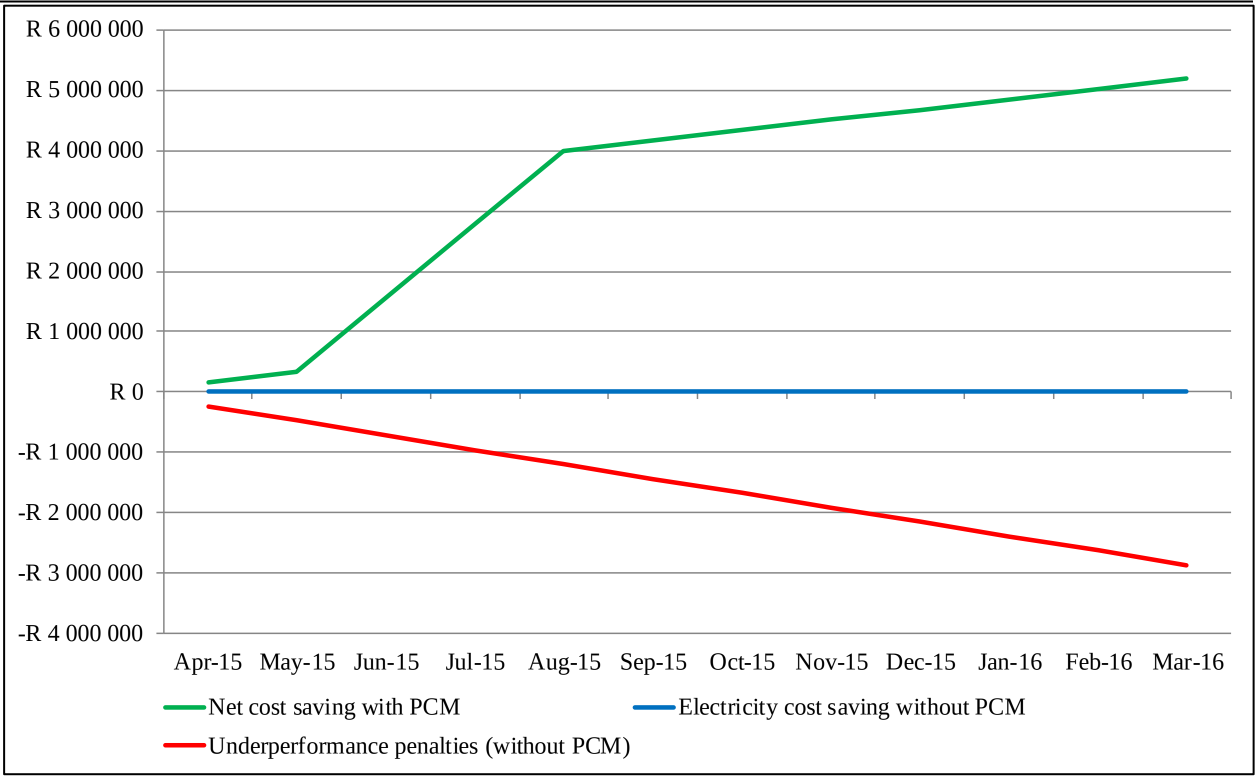

Figure 104: Projected cost savings and underperformance penalties for Project H

4.4.2 Project I

Project I is another load-shifting project on a mine dewatering system. It was implemented on a sister shaft of the same mine where Project H was implemented. The project had an average evening-peak load shift target of 5.58 MW. The dewatering system consisted of 16 dewatering pumps on four levels. Four pumps were installed on each level. The total installed capacity of the dewatering pumps was 29.1 MW.

Figure 105 shows the profile obtained in August 2014 when the ESCO was approached by the mine to assist in achieving maximum electricity cost savings on the project. The request for assistance by the mine was motivated by the high peak tariffs of the Megaflex tariff structure that applied in the high-demand season. An average morning-peak load shift of 6.17 MW and an average evening-peak load shift of 7.8 MW were obtained. The total electricity cost savings generated by the project in August 2014 was R1 451 128.

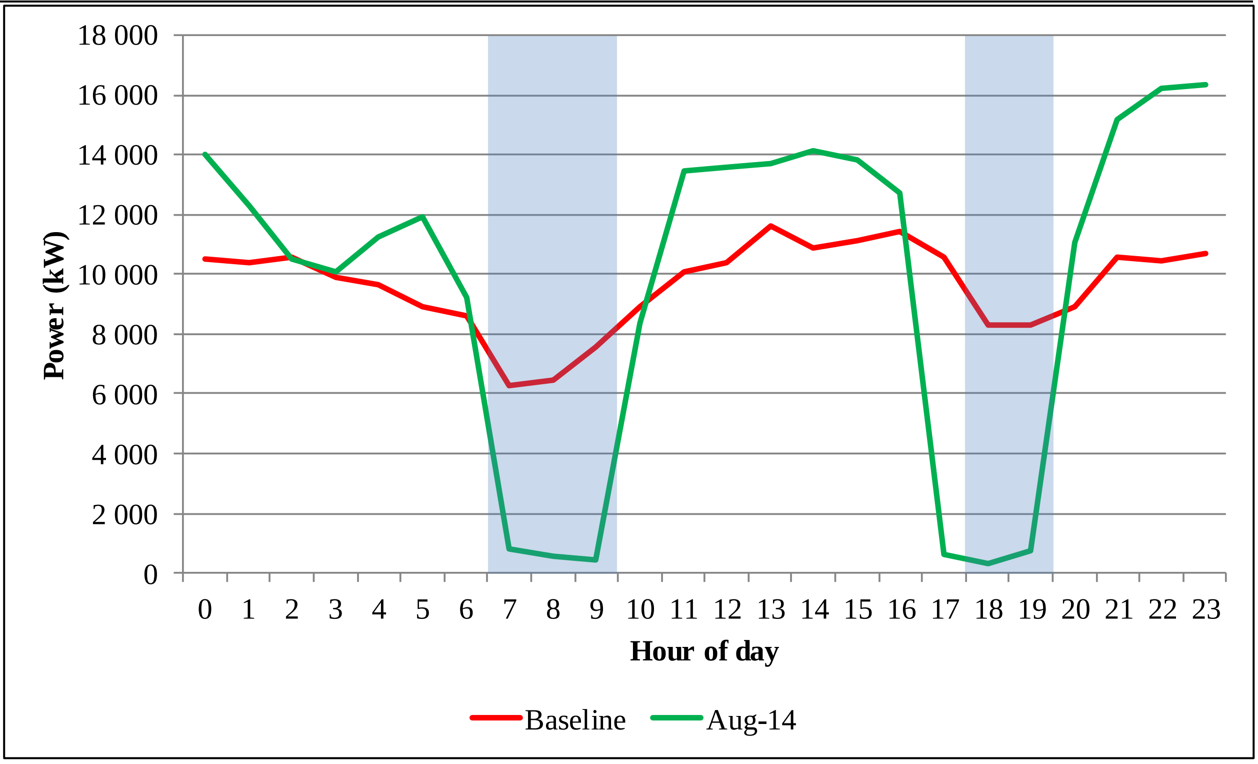

Figure 105: August 2014 power profile of Project I

Figure 106 shows the profile obtained in March 2015. The March 2015 profile shows a drastic reduction in performance compared with the profile of August 2014. The average morning-peak impact was 4.47 MW, which is below the target of 5.58 MW. The cost saving generated by the project in March 2015 was R116 071.

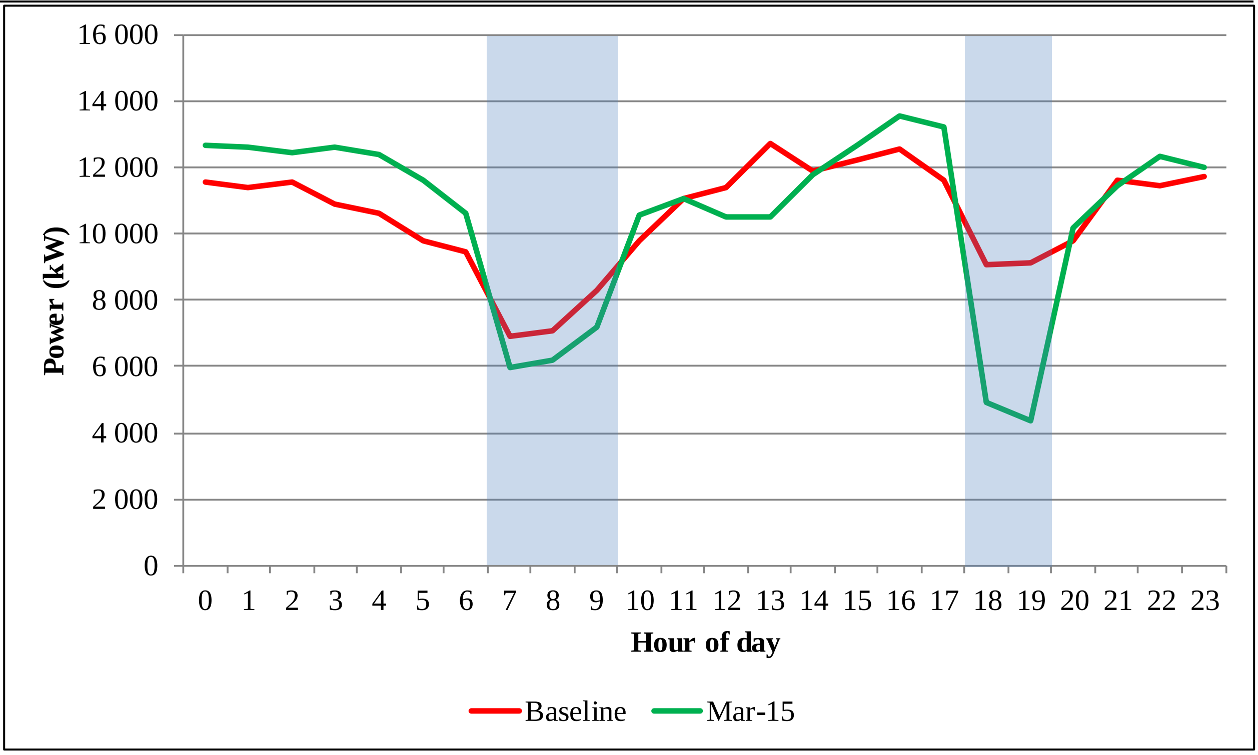

Figure 106: March 2015 power profile of Project I

The results of August 2014 and March 2015 provide an indication of the impact of PCM on the performance of Project I. This enables a comparison between the value that would be generated by Project I if a PCM strategy was applied versus the situation where PCM was not applied. This comparison is shown in Figure 107 for a period of 12 months, from April 2015 to March 2016. The projected total net cost savings as a result of applying PCM for this period was R7.02-million. The projected total cost savings without PCM was R2.58-million. The underperformance penalties during this period would amount to R303 607. The projected difference in value generated by Project I as a result of PCM for the period April 2015 to March 2016 could therefore amount to R4.14-million.

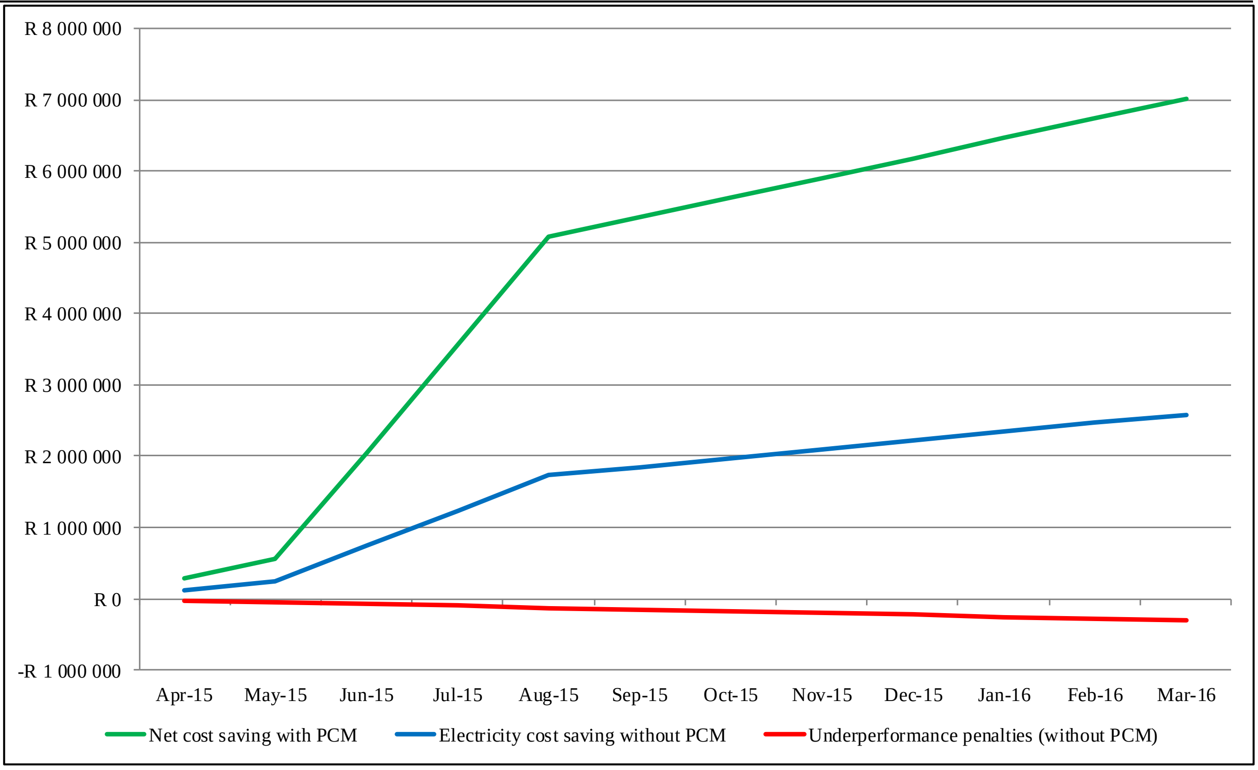

Figure 107: Projected cost savings and underperformance penalties for Project I

4.4.3 Project J

Project J is a load-shifting project implemented on the mills of one of the most modern and technologically advanced cement manufacturing plants in South Africa. The project had an evening peak load-shifting target of 2.55 MW. The scope of the project included load shifting on two raw mills, a cement mill and two coal mills. At the start of project implementation, the plant was well instrumented with power meters on all mills and radar sensor silo level measurement devices on the raw meal, clinker and cement silos. All mills included in the scope of the project were already automated. The fact that this equipment was already available expedited project implementation. The project was therefore implemented in relatively short period of only three months.

Figure 108 displays the average evening-peak impact and the electricity cost saving generated over a period of 11 months. The first three months represent the PA period, Month 4 and Month 5 represent the period when PCM was applied and Months 6–11 represent the period without ESCO involvement. The average evening-peak impact during PA was 3.28 MW. After PA, the ESCO remained involved for a period of two months to prove the value of PCM for maximising and sustaining project performance. During these two months, the average evening-peak impact increased to 3.7 MW and the total cost savings amounted to R1.192-million. The electricity cost savings were significantly higher than the cost savings achieved during PA, due to improved project performance and higher electricity tariffs resulting from the application of the high Megaflex tariffs in the high-demand period from June to August.

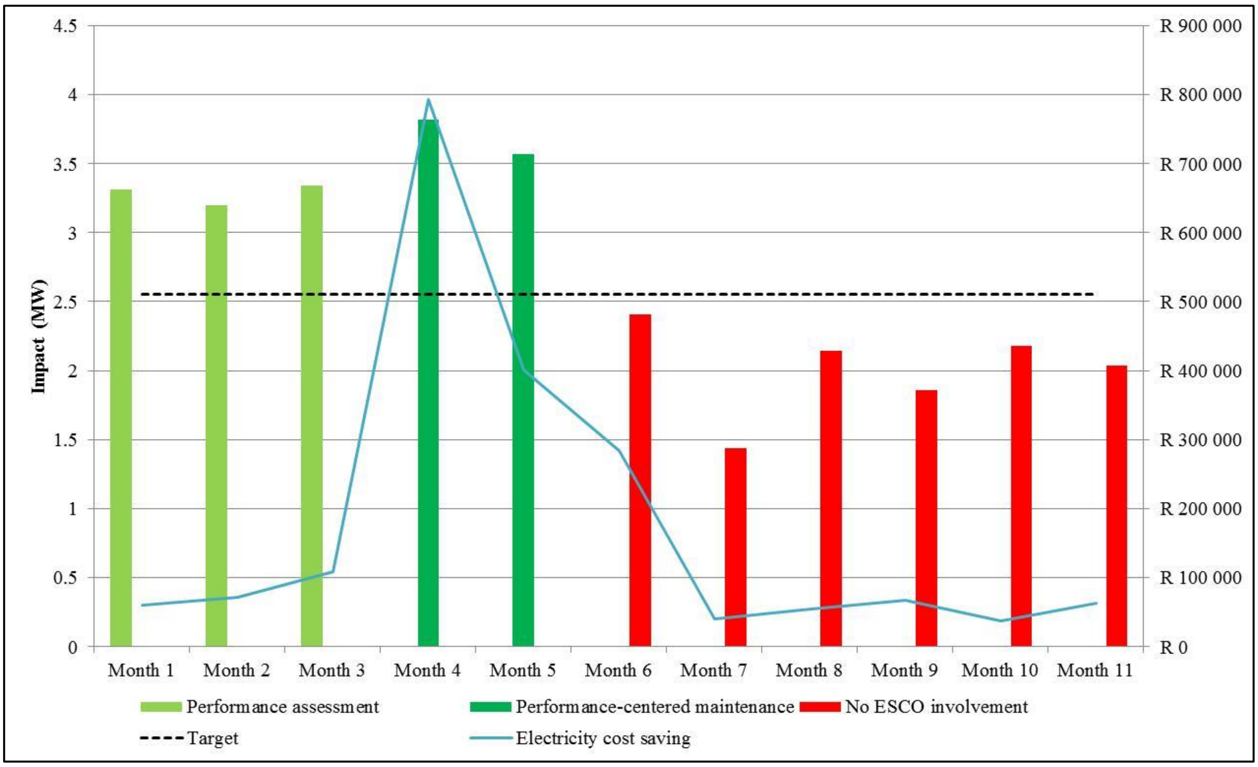

Figure 108: Average peak impact and electricity cost saving of Project J

Month 6 was the first month after project implementation where there was no direct involvement from the ESCO. An immediate reduction in project performance is noticed from Month 6 onwards. The average evening-peak impact in Months 6–11 was 2.01 MW, which was below the project target of 2.55 MW.

4.5 Cost-benefit analysis of PCM

4.5.1 Introduction

The results provided in Sections 4.2 to Section 4.4 focused primarily on improving DSM project performance (measured as the electrical load shifted ore reduced) that was obtained as a result of applying the PCM strategy to various types of industrial DSM projects. Improved DSM project performance is, however, not the main motivational factor for DSM maintenance. As mentioned in Section 1.3, the industrial sector in South Africa is facing various challenges such as rising production costs, declining commodity prices, increasing electricity tariffs, and so forth.

Unlike the implementation of DSM projects that are either fully or partially funded by Eskom, DSM maintenance agreements are fully funded by the industrial client. The implementation and maintenance of DSM projects should be viewed by the industrial sector as a cost-reduction measure. The purpose of this section is to present a cost-benefit analysis of the PCM strategy.

4.5.2 Maintenance cost

The recommended monthly maintenance fee for 2015 varies between R34 000 and R43 000 per DSM project. The monthly maintenance fee is determined by considering the following factors:

- Distance from the ESCO offices to the site.
- Electricity cost-savings potential of the project.
- Total number of DSM projects that is, or can be maintained on site.
- Total number of DSM projects maintained on sites in the same region.

4.5.3 Cost-benefit analysis

The total projected costs and benefits of the application of PCM to Projects A to J for the period April 2015 to March 2016 are provided in Table 11. The financial benefit of PCM is calculated as the sum of the additional electricity cost savings that can be achieved by applying PCM and avoiding underperformance penalties. Project A, Project B and Project F are projects that fall outside the Eskom contract period. Underperformance penalties do not apply to these projects. The cost of DSM maintenance is calculated as the sum of the maintenance fees that were paid to the ESCO over a certain period.

Table 11: Costs versus benefit of PCM for Projects A–J

Project	Maintenance cost	Total electricity cost-savings potential	Additional electricity cost savings from PCM	Underperformance penalty avoided due to PCM	Net cost savings	Cost-benefit ratio
Project A	R238 700	R1 547 393	R1 547 393	N/A	R1 308 693	0.15
Project B	R409 200	R4 522 362	R2 975 456	N/A	R4 113 162	0.09
Project C	R409 200	R11 075 916	R5 537 958	R755 183	R11 421 899	0.03
Project D	R409 200	R7 295 272	R3 647 636	R792 750	R7 678 822	0.05
Project E	R409 200	R10 003 096	R5 001 548	R845 250	R10 439 146	0.04
Project F	R409 200	R3 976 189	R1 988 094	N/A	R3 566 989	0.10

Project	Maintenance cost	Total electricity cost-savings potential	Additional electricity cost savings from PCM	Underperformance penalty avoided due to PCM	Net cost savings	Cost-benefit ratio
Project G	R409 200	R2 306 473	R2 306 473	R1 948 800	R3 846 073	0.10
Project H	R409 200	R5 702 945	R5 702 945	R1 869 660	R7 163 405	0.05
Project I	R409 200	R7 527 973	R4 752 349	R1 227 377	R8 346 150	0.05
Project J	R409 200	R3 625 811	R3 625 811	R1 593 240	R4 809 851	0.08
Total	**R3 921 500**	**R57 583 430**	**R37 085 663**	**R9 032 260**	**R62 694 190**	**0.06**

The figures in Table 11 were calculated on the assumption that performance could be restored to the maximum levels that were achieved during the period when PCM was applied. The cost of PCM was calculated according to a monthly maintenance fee of R34 100. The total maintenance cost of Project A was calculated according to a monthly maintenance fee of R34 100 that was applied every second month during the low-demand season from September to May and every month during the high-demand season from June to August. This is in accordance with an agreement between the ESCO and the mine that the total annual maintenance fees would never exceed 25% of the total annual electricity cost savings generated by the project.

The financial benefit of PCM is easy to calculate if project performance data before and after the application of PCM is available. A lack of performance data for the period without PCM complicates the calculation of the financial benefit of PCM. The unavailability of performance data for the period without PCM is often the result of data recording systems or infrastructure not correctly being maintained. For projects where PCM was continuously applied since PA, there would also not be performance data available for a period without PCM. A 50% reduction in project performance without PCM was therefore assumed in order to calculate the financial benefit of projects where performance data for periods without PCM was not available.

The cost-benefit ratio (CBR) for every project is also provided in Table 11. The CBR is a metric that quantifies value for money. A low CBR indicates a project where the maintenance costs are low in comparison to the value generated by the project. A CBR of more than 1 signifies a negative return on investment. The formula for the calculation of the CBR is provided below:

$$CBR = \frac{Electricity\ cost\ savings + Penalties\ avoided}{Cost\ of\ PCM} \qquad (9)$$

Table 11 indicates that the projected average CBR by applying PCM to Projects A–J for the period April 2015 to March 2014 is 0.06. This shows that the average cost of PCM is about 6% of the total benefit generated by it.

4.6 Summary

This chapter provided results obtained from implementing the PCM strategy on ten different DSM projects. The ten projects included six load-shifting projects, three energy-efficiency projects and one peak-clipping project implemented on the infrastructure of four different industrial customers. The customers included three mining groups and one cement manufacturer.

The results provided in Chapter 4 indicated the significant impact of applying the PCM strategy on improving performance and sustaining industrial DSM projects. The most important measure for determining the success of applying the PCM strategy is the net cost savings generated. A cost-benefit analysis of the results of all ten DSM projects presented in this chapter indicated that the total annual electricity cost-savings potential is R57 583 430 (2015/2016 tariffs). Without PCM, a maximum of only 35.6% of this savings figure could be expected. If the underperformance penalties, which would be avoided as a result of implementing the PCM strategy, as well as the maintenance costs are taken into consideration, the total annual net cost saving amounts to R62 694 190. This represents a CBR of 0.06.

CHAPTER 5. CONCLUSION

5.1 Summary

Chapter 1 commenced with an overview of the electricity situation in South Africa. The decrease of the reserve margin in the period after 1992 was highlighted as the motivation for Eskom's capacity-expansion programme from 2005 to 2019. The capacity-expansion programme is funded by above-inflation tariff increases. The delayed implementation of the expansion programme resulted in a shortage of electricity. The shortage of electricity caused increased usage of expensive OCGT power stations and load shedding in 2008, 2014 and 2015.

The implementation of DSM projects is viewed by both Eskom and the industrial sector as a solution to the problems caused by Eskom's insufficient generation capacity. Eskom IDM therefore implemented an aggressive DSM programme targeted at the industrial sector that resulted in the implementation of 261 DSM projects in the period from 2004 to 2014. For Eskom, the advantage of these DSM projects is reducing the demand for electricity especially in peak periods. The advantage for industrial customers is the significant electricity cost savings that can be generated by DSM projects.

The viability of the 261 projects implemented through Eskom IDM's industrial DSM programme from 2003 to 2014 was proven with an average performance figure of 98% during PA. Unfortunately, PT results show that the performance of industrial DSM projects are not always sustained after PA. Underperforming DSM projects are costly to both Eskom and the industrial customer. This motivated the need for this study, which is developing a maintenance strategy to restore, sustain and improve the performance of DSM projects.

Chapter 2 provided background information on various types of industrial DSM projects with the purpose of illustrating the requirements and scope for the required maintenance strategy. The control philosophies and various interrelated components of the different types of DSM projects were presented. The differences between automatic and semi-automatic control systems were explained in order to emphasise the advantages of automatic control for improving performance and sustainability. Chapter 2 concluded with an explanation of the reasons for underperformance of industrial projects.

The purpose of Chapter 3 was to introduce the PCM strategy. It started by listing PCM requirements, after which the PCM strategy was presented as four separate research contributions. The first research contribution was a new strategy for outsourcing DSM maintenance on a company group level. The strategy consisted of practical recommendations for personnel assignment and the management structures of both the ESCO and the industrial client, the contents of a group-level DSM maintenance agreement, communication between the ESCO and the client and the monthly maintenance invoicing process. The importance of involving the ESCO in the monitoring of the independent M&V process was also motivated as an important part of the strategy for the outsourcing of DSM maintenance on company group level.

The second research contribution was a new, simplified strategy to identify DSM projects where PCM would add value for the client by increasing and sustaining electricity cost savings. This contribution was presented in the form of a flow diagram of different steps that can be followed to distinguish between:

- DSM projects where the full electricity cost-savings potential is not being achieved.
- DSM projects where the full electricity cost-savings potential is prevented by physical limitations that cannot be overcome through PCM.
- DSM projects that are correctly maintained to achieve maximum electricity cost savings.

The third research contribution was a PCM strategy for improving and sustaining DSM project performance. The PCM strategy was based on the PDCA cycle for continuous improvement. The main focus of the PCM strategy was on the ‘checking’ phase of the PDCA cycle. This involved monitoring different aspects of DSM projects effectively to ensure maximum performance and sustainability. The checking phase was also important for monitoring the impact of actions identified in the ‘planning’ phase and implemented in the ‘doing’ phase. The monitoring was focused on various automated performance monitoring methods that included using an online energy management system, automated performance reports and e-mails, problem notifications generated by the control system and automated calculation performed by the energy management system to detect problems.

The fourth research contribution was developing alternative KPIs to measure the performance of DSM projects. The standard method for measuring the performance of a DSM project is by determining the impact of the project on the electricity consumption of the client. This metric is widely used since it is the most important KPI to Eskom. To the industrial client, the costs saving generated by a DSM project is the most important KPI. A large number of alternative KPIs developed with the aim of monitoring aspects that affect the performance and long-term sustainability of DSM projects was also presented.

The results of implementing the PCM strategy were presented in Chapter 4. It was shown that the PCM strategy developed in this study realised significant performance increases when applied to underperforming DSM projects. Drastic performance reductions were observed on DSM projects where PCM was stopped. Projects where PCM was applied since PA did not exhibit the undesired trend of gradual performance reductions. The application of PCM on the ten DSM projects presented in Chapter 4 resulted in an average CBR of 0.06.

5.2 Recommendations for future work

Although all industrial DSM projects share common principles and concepts, each DSM project has unique requirements and presents unique challenges. Every DSM project on which the PCM strategy was applied contributed to the continuous development and improvement of the PCM strategy. This resulted in a cross-pollination of best practices between different DSM projects and clients. At present, the PCM strategy is being applied to 22 DSM projects from three different South African mining groups. These 22 projects represent only 8.5% of the total number of industrial DSM projects implemented by Eskom IDM. Future work includes the continuous development and improvement of the PCM strategy by extending it to more DSM projects and different industries such as water transfer networks and the cement manufacturing industry.

The literature review presented in Chapter 1 on maintenance in the industrial sector and the South African mining industry indicated a lack of applying sophisticated maintenance techniques such as CBM or TPM. The general trend is to perform maintenance on a reactive basis. This finding is supported by observing maintenance practices employed in the industrial sector during the application of PCM on DSM projects. The control system installed as part of a typical industrial DSM projects, as well as the energy management system introduced in Chapter 3, can be used for implementing sophisticated maintenance techniques. This is because the control system has the capability to monitor the condition of equipment in real time. The energy management system can be extended to also serve as a maintenance management system, because it has the capability to serve as an online database for maintenance data. Improving the maintenance techniques applied to infrastructure will also have a positive effect on the performance of DSM projects.

5.3 Conclusion

The aim of Eskom IDM’s industrial programme is to reduce the demand for electricity on the national grid. The 261 industrial DSM projects implemented by Eskom IDM since 2003 have a combined target of an average hourly demand reduction of 682 MW in the evening peak period. This is more than the installed capacity of four units of the Ankerlig OCGT power station. Unfortunately, M&V PT reports indicate that the performance of certain industrial DSM project deteriorated after PA. It is of extreme importance to Eskom, industrial customers and the South African economy that all DSM projects should deliver maximum performance on a sustainable basis.

The results presented in Chapter 4 proved the positive impact of the PCM strategy for maximising the performance and sustainability of industrial DSM projects. This proves that the PCM strategy has the potential to add significant value to Eskom IDM’s industrial DSM programme. From the perspective of the industrial client, it proves that the PCM strategy has the potential to maximise the cost-savings potential of DSM projects.

Eskom’s above average electricity price increases are making it increasingly attractive for industrial customers to implement DSM projects without any funding from Eskom IDM. The advantages of implementing DSM projects without Eskom funding is shorter waiting periods for project approval and zero risk of underperformance penalties. The recent introduction of the 12L tax incentive provides additional motivation for industrial clients to implement DSM projects without Eskom funding. The PCM strategy is not limited to DSM projects implemented through Eskom IDM because it can be applied to any industrial DSM project. It is therefore expected that the PCM strategy would continue to add value to industrial DSM projects in South Africa, even if Eskom IDM reduces or stops the funding of industrial DSM projects.

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ANNEXURE A. REASONS FOR INDUSTRIAL DSM PROJECT UNDERPERFORMANCE

Project type	Reason for underperformance	Cause
Load shifting on dewatering pumps	Pump running schedules not followed	Negligence by pump attendants who do not make pumps available for remote automatic control
		Negligence by control room operators through unnecessary overriding or disabling of automatic control
		Control system disabled because pump are not controlled in accordance with system constraints or agreed control philosophy
		Control system disabled because pumps are unnecessarily switched on or off
		Infrastructure breakdowns
	Pump running schedules do not allow load shifting	Too much water in the system in comparison to the size of available buffer storage capacity
		Interference in pump running schedules
		Not enough pumps available
		Inefficient pumps
		Infrastructure breakdowns
		Inadequate buffer capacities due to sediment build-up in dewatering dams
		Undersized pump columns that restrict flow
	Pump running schedules that do not result in maximum load-shifting performance	Control system does not produce optimal pump schedules due to inadequate control philosophy
Load shifting on cement plants	Mill running schedules not followed	Negligence by control room operators
	Mill running schedules do not allow load shifting	High production targets
		Infrastructure breakdowns
		Unscheduled maintenance
		Inadequate buffer capacities due to low silo levels
Load shifting on fridge plants	Running schedules are not followed	Negligence by fridge plant attendants
	Running schedules do not allow load shifting	Cold service water dam levels not high enough to allow load shifting
		High demand for cold service water
		Infrastructure breakdowns
		Unfavourable underground conditions (such as high wet-bulb temperature) that do not allow any interruption in fridge plant operation

Project type	Reason for underperformance	Cause
Load shifting on water transfer plants	Pump schedules not followed	Negligence by pump attendants
	Pump schedule do not allow load shifting	High water demand
		Impaired buffer capacities due to low dam levels
		Infrastructure breakdowns
Load shifting on gold production lines	Equipment operated in peak periods	High demand that do not allow operation of gold production lines to be interrupted
		Negligence by operators that unnecessary override load shifting on gold production line equipment
		Lack of buffer storage capacity
Energy efficiency & peak clipping on compressed air systems	Control valves not controlled according to prescribed set points	Negligence by control room operators
		High demand for compressed air by underground operations
		Mine workers that sabotage the operation of control valves
		Incorrectly sized valves that cannot deliver the required minimum pressure
		Excessive wastage of compressed air resulting from inefficient mine operations and leaks
		24/7 or irregular mining schedules that do not allow for periods when flow of compressed air to mining levels can be reduced
	Delivery pressure of compressors not following prescribed set points	Control disabled by mining personnel
		High demand for compressed air that prevents compressors from reaching delivery pressure set points
		Incorrectly sized compressed air columns
	Compressor power consumption not reduced when control valves reduce compressed air flow to levels	Compressor automation not working correctly

Project type	**Reason for underperformance**	**Cause**
Energy efficiency on dewatering pumps	Control valves not controlled according to prescribed set points	Negligence by control room operators
		High demand for service water does not allow flow reduction
		24/7 or irregular mining schedules that do not allow for periods when flow of water on mining levels can be reduced
		Infrastructure breakdowns
		Incorrectly sized valves that cannot deliver the required minimum pressure
		Incorrectly specified valves that result in cavitation
		Valves that are not correctly controlled and cause water hammer
		Mine workers that sabotage the operation of control valves
		Excessive wastage of water resulting from inefficient mine operations and leaks
Energy efficiency on fridge plant CA	Disabling or interference with automatic system control	Negligence by control room operators through interfering with automatic control
		Negligence by technicians through disabling or overriding automatic control on sections of the project
		Control system not controlling according to system constraints or agreed control philosophy
		Infrastructure breakdowns
Peak clipping on bulk air coolers	BAC running schedules not followed	Negligence by control room operators
	BAC running schedules do not allow peak clipping	Underground wet-bulb temperature not favourable to allow BACs to be switched off during evening peak
		Infrastructure breakdowns

ANNEXURE B. DSM MAINTENANCE PROPOSAL

DSM MAINTENANCE PROPOSAL

(INSERT PROJECT OR SITE NAME)

(INSERT ESCO LOGO HERE)

(Insert date)

(Insert author name)

1. Introduction

Site A has benefited from the implementation of Eskom-funded DSM projects since 2006. Past experience has shown that the full potential of these projects is not sustained without dedicated maintenance. A maintenance agreement for two DSM projects on the dewatering system of Site A is therefore proposed to generate maximum electricity cost savings. These two projects are:

- Site A Pumps
- Site A WSO

The benefits of a maintenance agreement are:

a) maximum electricity cost savings with changing client systems;
b) lower risk of Eskom penalties;
c) cost reductions through improved maintenance practices;
d) daily performance monitoring;
e) daily performance reporting that increases energy conservation awareness;
f) daily monitoring of project hardware (e.g. pumps, valves, etc.);
g) maintenance of control and communications software;
h) project management on infrastructure repairs/upgrades; and
i) monthly feedback meetings with management to assess performance and progress.

2. DSM savings opportunities

Table 1 lists the projects included in this proposal. It shows that the total annual savings potential of these projects is R7-million (calculations based on the 2015/2016 Eskom tariffs). Experience has shown that DSM maintenance can sustainably maintain these savings.

Table 1: Expected maintenance performance and annual savings potential

Project name	Project type	Eskom target (MW)	Expected maintenance performance (MW)	Annual savings potential (2015/2016 tariffs, excl. VAT)
Site A Pumps	Load shift	7	7.2	R6 400 000
Site A WSO	Peak clip	2.8	3	R600 000
Total		**9.8**	**10.2**	**R7 000 000**

3. Risks of not doing maintenance

Table 2 lists the costs and the risks for the two projects in this proposal. The annual loss of electricity cost savings and the Eskom penalties were calculated on the assumption that only 50% of the Eskom target will be achieved without maintenance. Table 2 indicates that the annual maintenance cost will be significantly lower than the cost of underperformance and Eskom penalties. Please note that Site A Pumps has no risk of penalties because the project is already out of the five-year Eskom contract period.

Table 2: Maintenance costs and risks

Project name	Eskom contract expiry date	Annual savings potential (2015/2016 tariffs, excl. VAT)	Annual Eskom penalty (based on 50% performance on Eskom target, excl. VAT)	Annual loss of savings (based on 50% performance on Eskom target, excl. VAT)
Site A Pumps	N/A	R6 400 000	N/A	R3 200 000
Site A WSO	Sep-18	R600 000	R307 944	R300 000
Total		**R7 000 000**	**R307 944**	**R3 500 000**

4. Maintenance fee

a) The value of maintenance service has already been proven with the assistance that the ESCO provided to Site A over the past 24 months.

b) The proposed monthly maintenance fee is on par with the costs of successfully maintaining DSM projects at other mining groups.

c) Maintenance of the DSM projects included in this proposal will cost a maximum of R (insert total annual fee) per annum ((insert monthly fee) × 12 months).

d) Annual increases of the maintenance fee will be linked to inflation. Electricity cost savings will increase faster than inflation as electricity prices will escalate at a higher rate.

5. Business case

Figure 1 shows a comparison of the expected performance of the Site A pumping project with and without a maintenance agreement. If the dewatering pumps are to be controlled by pump attendants or control room operators, the performance of the project is expected to gradually reduce to 50% of the project target of 7 MW average load shift. With a maintenance agreement and full automatic control of the dewatering pumps by <CONTROL SYSTEM>, the performance of the project is expected to increase to an average of 8 MW.

A fully automated control system that is correctly maintained will be more reliable and sustainable than manual control by human operators. This is due to the elimination of the human factor.

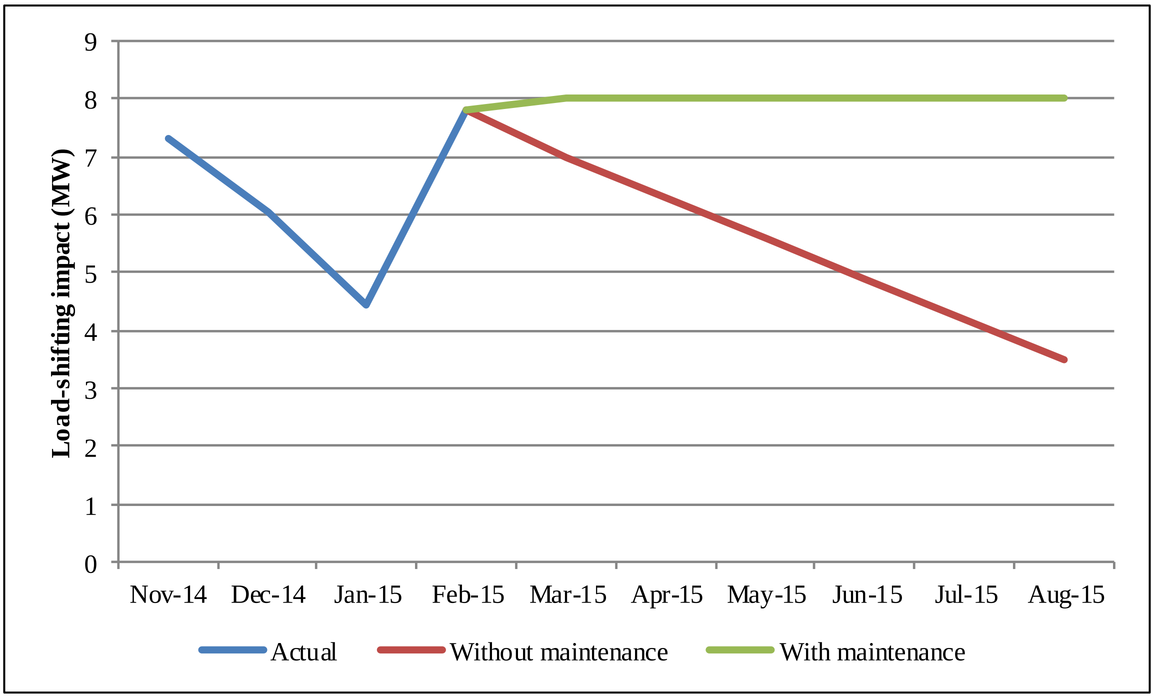

Figure 1: Expected performance with and without maintenance

Figure 2 shows a comparison of the projected electricity cost savings generated by the Site A pumping project for the period March to August 2015 for the scenarios with and without a maintenance agreement.

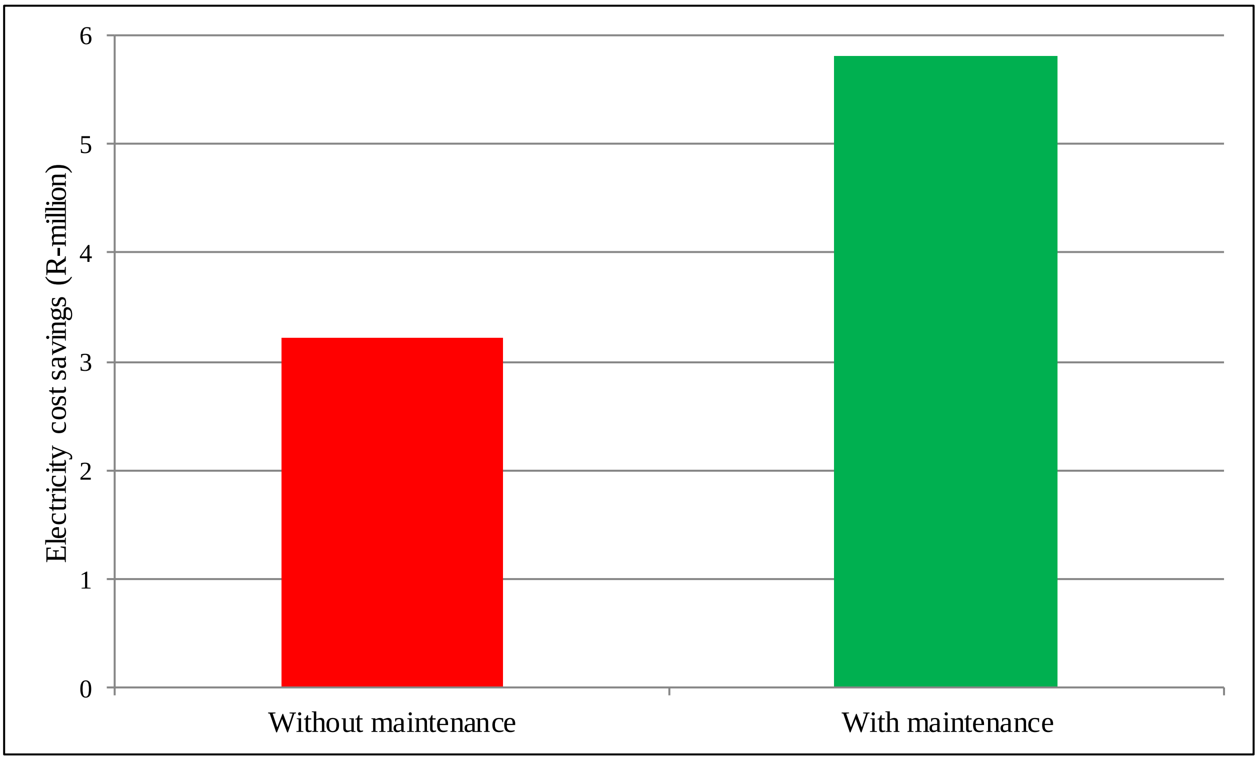

Figure 2: Comparison of project electricity cost savings

The proposed maintenance agreement holds low financial risk:

a) All maintenance fees will be recovered from electricity cost savings. This implies that the proposed maintenance agreement will always be cash-flow positive.

b) <u>No monthly maintenance fee will be applicable if the savings for the month is less than the monthly maintenance fee.</u>

c) <u>The ESCO will ensure that the total annual maintenance fee never exceeds 30% of the total annual electricity cost savings, calculated for each financial year.</u>

d) The ESCO will fully maintain the <CONTROL SYSTEM> infrastructure on site at no additional cost.

e) Projects may occasionally require costly infrastructure upgrades/repairs to ensure continued maximum savings. The funding of these upgrades/repairs is not included in scope of the maintenance agreement and will be for the account of Site A. The ESCO will however provide full project management services on these upgrades/repairs at no additional cost.

f) Site A will be under no obligation to spend any money on infrastructure upgrades/repairs if the required capital is not available or if management believes that the potential saving does not justify the infrastructure upgrade/repair cost.

6. Scope of work

a) The ESCO will be responsible for all costs pertaining to the maintenance on both the hardware and software of <CONTROL SYSTEM>.

b) Site A will be responsible for all costs pertaining to the maintenance of project infrastructure, i.e. dewatering pumps, valves, PLCs, communication, etc.

7. Responsibilities

The ESCO will be responsible for ensuring that <CONTROL SYSTEM> delivers maximum electricity cost savings. This entails the following:

a) Ensure that <CONTROL SYSTEM> is in good working condition.

b) Daily monitoring and evaluation of project performance.

c) Provide daily/monthly project performance reports to mine personnel.

d) Inform mine personnel of any problems that are preventing or may prevent maximum performance.

e) Continuously improve and update <CONTROL SYSTEM> to ensure maximum performance.

f) Monitor efficiency of pumps (depending on availability of necessary instrumentation, i.e. temperature and pressure sensors).

g) Provide 24-hour assistance.

h) Attend monthly project feedback meeting on site.

i) Co-operate with mine personnel to ensure that maximum electricity cost savings is achieved.

j) Project management services on repairs/upgrades on project infrastructure i.e. dewatering pumps, valves, PLCs, communication, etc.

Site A will be responsible to support the ESCO to deliver maximum electricity cost savings. This entails the following:

a) Ensuring that mine infrastructure is in good working condition.

b) Informing the ESCO immediately when any problem with <CONTROL SYSTEM> control is noticed.

c) Refraining from unnecessarily interfering with the <CONTROL SYSTEM> control philosophy.

d) Ensuring that safety interlocks are in place and in working condition on all equipment controlled or affected by <CONTROL SYSTEM>.

e) Cooperating with ESCO personnel to ensure that maximum electricity cost savings is achieved.

8. Inclusions of the maintenance offer

a) The ESCO will provide full cooperation with site personnel to maximise savings. This means that site meetings are included in the maintenance agreement.

b) Infrastructure problems will be highlighted to site personnel. The ESCO will also assist to obtain quotations for repairs or replacements.

c) Reaction time to affect repairs will be a maximum of eight working hours where off-site access from the ESCO's monitoring rooms is possible.

d) Reaction time for repairs that must be done on site will be a maximum of 24 working hours.

e) Although it is unlikely to occur, there may be instances where site personnel offer only limited cooperation. This will be highlighted to senior personnel if it persists for more than one month.

f) The ESCO will appoint a senior manager to manage the Site A maintenance contract. The maintenance manager will be responsible for ensuring that all projects included in the maintenance agreement perform to their maximum potential. The maintenance manager will meet with the management of Site A on a monthly basis to give feedback on progress and performance.

9. Future changes to the initial agreement

a) The maintenance contract can be extended to include additional projects by signing an addendum to the main agreement.

b) The initial maintenance contract duration will be 24 months. Thereafter it will be renewed every two years, for further periods of 24 months.

10. Conclusion

This maintenance proposal is advantageous for Site A since the benefits far outweigh the cost of maintaining existing projects. Site A will remain cash-flow positive by utilising the generated cost savings to pay for maintenance fees. This provides a low risk solution to project maintenance.

ANNEXURE C. GENERIC GROUP-LEVEL DSM MAINTENANCE AGREEMENT

CONTRACT NO. (INSERT CONTRACT NUMBER)

This AGREEMENT is made between

(INSERT CLIENT NAME) (Reg no.: (INSERT REGISTRATION NUMBER))

(hereinafter referred to as the “the Client”)

(INSERT SERVICE PROVIDER NAME) (Reg no.: (INSERT REGISTRATION NUMBER))

(hereinafter referred to as the “the Service Provider”

FOR THE PURPOSE OF MAINTAINING THE ELECTRICITY COST SAVINGS PROVIDED BY THE FOLLOWING DSM PROJECTS:

Project A: (INSERT PROJECT NAME) (DSM no. (INSERT DSM NUMBER))

Project B: (INSERT PROJECT NAME) (DSM no. (INSERT DSM NUMBER))

1. DEFINITIONS

1.1. C&M – Care and maintenance

1.2. Compressor Manager

1.3. DSM – Demand-side management

2. SCOPE OF WORKS

2.1. The Service Provider is responsible for all costs pertaining to the maintenance of <CONTROL SYSTEM>.

2.2. The Client is responsible for all costs pertaining to the maintenance of project infrastructure, i.e. control valves, variable speed drives, cooling car valves, PLCs, communication, etc.

2.3. The Service Provider will provide project management services on repairs/upgrades on project infrastructure.

2.4. Reaction time for repairs is maximum eight working hours where off-site access from the Pretoria monitoring rooms is possible.

2.5. Reaction time for on-site repairs will be a maximum of 24 working hours.

2.6. A senior project manager will be appointed to manage the DSM projects included in this agreement.

3. DURATION OF CONTRACT AND RATES

3.1. The initial duration of this agreement is from (INSERT DATE) for a period of 24 months. Whereafter it will be renewed on a biennial basis for further periods of 24 months.

3.2. The notice period for both parties is 90 days written notice.

3.3. The Client will pay the Service Provider a total monthly maintenance fee of R (INSERT TOTAL MONTHLY FEE) (R (INSERT MONTHLY FEE PER PROJECT) per project × (INSERT NUMBER OF PROJECTS) projects).

3.4. Annual increases of the maintenance fee will be linked to inflation as measured by the CPI and regularly published by the South African Reserve Bank. This inflation increase will apply from (INSERT DATE) onwards.

3.5. The Service Provider will ensure that the total annual maintenance fee never exceeds 50% of the total annual electricity cost savings, calculated for each financial year.

4. VALUE ADDED TAX

The Service Provider is a VAT vendor and therefore VAT is applicable on all contract payments. The VAT number of the Service Provider is (INSERT VAT NUMBER).

5. REPORTING

5.1. The Service Provider will provide electricity cost savings reports to the Client on a daily and monthly basis.

5.2. Monthly performance overview and planning meetings will be held at (INSERT MEETING LOCATION). This meeting will be attend by senior personnel of both parties.

6. CESSATION OF OPERATIONS

6.1. Should the Client sell an asset, it will inform the new owner of all DSM projects on that site and the Client will declare the existence of the maintenance agreement to the new owner.

6.2. The Client will give at least 3 (three) months' notice to the Service Provider of the impending sale of an asset.

Signed at ____________________ for and on behalf of the Client on this ___ day of _____________________ 20__.

______________________________________ (Signature)

______________________________________ (Name)

______________________________________ (Title)

As Witnesses:

1.__________________________________ 2.__________________________________

Signed at ____________________ for and on behalf of the Service Provider on this ___ day of _____________________ 20__.

______________________________________ (Signature)

______________________________________ (Name)

______________________________________ (Title)

As Witnesses:

1.__________________________________ 2.__________________________________

.

ANNEXURE D. DAILY SAVINGS REPORT

<CLIENT LOGO>

Daily report for
client site pumping system

12 February 2015

Generated on 13 February 2015

1 Project information

Project name:	**client site** pumping system
Tariff structure:	MEGAFLEX
Target impact:	3.10 MW

2 Performance (Thursday 2015-02-12)

Performance of day:		**Month-to-date performance:**	
Impact:	5.39 MW	Average impact:	3.81 MW
Cost saving:	R 8 676	Cumulative cost savings:	R 35 031
Missed opportunities:	-	Cumulative missed opportunities:	-

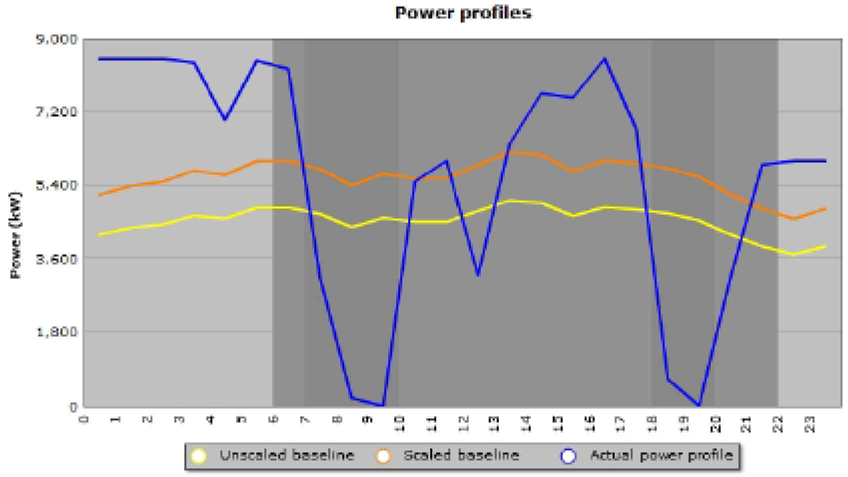

Figure 2-1: Power profile and baseline for 12 February 2015

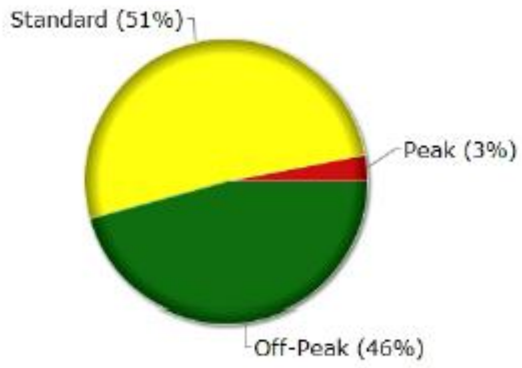

Figure 2-2: Daily energy usage distribution - 12 February 2015

ANNEXURE E. PROJECT CONTROL REPORT

Daily project control feedback report

Client site

<INSERT CLIENT LOGO HERE>

05 March 2015

1 Systems

1.1 Client site OAN

Valves	Setpoint match
42L globe valve	97.6%
44L globe valve	111.1%
47L globe valve	100.3%
53L globe valve	102.4%
59L globe valve	98.4%
62L globe valve	98.1%
64L globe valve	102.6%
68L globe valve	119.5%

1.2 Client site Pumps

Pumps	Schedule match
Ice Tank	65.4%
38L Turbine	72.9%
38L Controller	87.2%
75L Controller	94.9%

Pumps	Status change												
	2	4	6	8	10	12	14	16	18	20	22	24	Total
Ice Tank													
Pump 1	0	0	0	0	0	0	0	0	0	0	0	0	0
38L Turbine													
Pump 1	0	0	0	0	0	0	0	0	0	0	0	0	0
Pump 2	0	0	0	0	0	0	6	0	0	0	0	0	6
38L Controller													
Pump 1	0	0	0	0	0	0	2	3	1	0	0	0	6
Pump 2	0	0	0	0	0	0	0	2	0	1	0	0	3
Pump 3	0	0	0	0	0	0	0	0	0	1	0	0	1
75L Controller													
Pump 1	0	0	0	0	0	0	2	3	1	1	0	0	7
Pump 2	0	0	0	0	0	6	4	2	0	4	1	0	17
Pump 3	0	0	0	0	0	0	4	5	4	4	4	0	21
Pump 4	0	0	0	0	0	0	0	0	0	0	0	0	0

ANNEXURE F. PUMP ATTENDANT INFORMATION SHEET

<Client operation name>

Pump attendant information sheet

- **The <control system> automatically controls pumps according to the following dam levels:**

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

	Max level	Min level
30 Level	90%	80%
53 Level	90%	80%
67 Level	92%	80%

REST OF THE DAY

	Max level	Min level
30 Level	60%	40%
53 Level	60%	20%
67 Level	80%	60%

Important information

What you need to do:

- **Let <control system> control pumps automatically.**
- **Do not leave pumps in maintenance mode.**
- **Report to control room or <name of pump foreman> if there is a problem.**
- **Make sure <control system> always has one pump per level available to control.**
- **Only switch pumps on or off when:**
  - **Dam levels go above the max levels or below the min levels shown on the front page.**
  - **When there is an alarm.**
  - **In case of emergency.**