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Arch. Min. Sci., Vol. 59 (2014), No 1, p. 53–69

Electronic version (in color) of this paper is available: http://mining.archives.pl

DOI 10.2478/amsc-2014-0004

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ENERGY USAGE OPTIMISATION IN SOUTH AFRICAN MINES

OPTYMALIZACJA WYKORZYSTANIE ENERGII W KOPALNIACH W AFRYCE POŁUDNIOWEJ

In recent years, South Africa has encountered a critical electricity supply which necessitated the implementation of demand-side management (DSM) projects. Load shifting and energy (EE) efficiency projects were introduced in mining sector to reduce the electricity usage during day peak time. As the compressed air networks and the water pumping systems are using large amounts of the mines' electricity, possible ways were investigated and implemented to improve and optimise the energy consumption and to reduce the costs. Implementing DSM and EE in four different mines resulted in achieving the desired energy savings and load-shifting.

Keywords: electricity supply; load shifting, energy consumption, compressed air, pump station, and usage optimisation

W ostatnich latach w Południowej Afryce zanotowano pewne trudności z dostawami energii elektrycznej, co wymusiło wdrożenie działań mających na celu skuteczne zarządzanie zagadnieniami energetycznymi. Wprowadzono działania mające na celu zmianę systemu obciążeń roboczych i bardziej efektywne wykorzystanie energii tak, by obniżyć zapotrzebowanie na energię w trakcie szczytowych godzin w ciągu dnia. Sieci dostarczające sprężone powietrze oraz stacje pomp zużywają znaczne ilości energii w kopalni, przeanalizowano więc możliwe sposoby redukcji i optymalizacji zapotrzebowania na energię i tym samym obniżenia kosztów produkcji. Wdrożenie odpowiednich projektów nakierowanych na oszczędności i optymalizację w czterech kopalniach doprowadziło do oczekiwanych oszczędności energii i umożliwiło zmianę systemu obciążeń roboczych w trakcie procesu produkcji.

Słowa kluczowe: dostawy energii elektrycznej, zmiana systemu obciążeń roboczych, sprężone powietrze, stacja pomp, optymalizacja zużycia energii

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1. Introduction

The increase in the world population and economic development has led to an increase in energy demand. World-wide energy demand is expected to grow by 1.7% per annum until 2030 (Mandill, 2005). This increase in demand was also experienced in developing countries such as South Africa (Department of Minerals and Energy, 2005). High electricity prices, human-made global warming and other factors, have brought the energy consumption of machines to attention (Dietmar & Verl, 2009).

South Africa is the major economic nation in the African continent. Mining has been the backbone of the South African economy for more than 100 years and has contributed significantly to the economy and well-being of the country (Coakly, 2000).

Due to South Africa's significant growth in electricity consumption, capacity problems have been experienced resulting in significant levels of load shedding (Coakly, 2000). The mining industry is a major electricity consumer in South Africa, consuming approximately 23% of the total generated power (Satistics South Africa, 2008)–(Preliminary energy outlook for South Africa, 2001).

In order to overcome these capacity problems, demand side management (DSM) and energy efficiency (EE) have become increasingly important (Marais et al., 2011). The use of the energy efficient technologies leads to both lower energy demand and reduced greenhouse gas emissions due to the decreased stress on power generating plants (Matthews, 2007).

In the case of EE the load curve or baseline is uniformly reduced, which leads to reduction of energy consumption due to the improved energy efficiency. DSM plays an important role in reducing the maximum demand, particularly during peak times in South Africa. Successful implementation of a DSM programme can be considered as a virtual increase in South Africa's electricity capacity (Department of Minerals and Energy, 2004).

In 1992, Eskom, the main South African electricity supplier, launched a DSM program in accordance with regulations drawn up by the Department of Minerals and Energy and the National Energy Regulator of South Africa (NERSA). A similar program was implemented in the early 80's of the last century in the USA and later in Europe with a great success (Eskom, 2009). Load shifting is one of the DSM forms and it is presented in this paper, as well as optimisation of energy usage in mine's compressed air systems (Hasan, 2010).

The paper is organised as follows: section 2 presents Energy Efficiency case studies through optimising the compressed air network in a few South African deep mines. In section 3 the implementation of load shifting projects on pump stations in gold mines is discussed. Section four presents all results achieved and certain conclusions.

2. Energy Efficiency (EE): Optimisation of compressed air network

In the mining process, compressed air is used in drilling equipment and to drive the cages. It is also employed to provide air at the refuge bays in various mining levels (Hasan, 2010). Compressed air network consists of air compressors that are connected to the various underground mining levels via air pipes and valves.

Several investigations were conducted on different South African mines to determine the potential energy (Mega Watt), and thus financial, savings by optimising the air usage.

I. Case study one: Mine A

A. overview

The first case study is a South African gold mine, referred to as Mine A, it is considered a deep gold mine and consists of three shafts, denoted by Shft1, Shft2 and Shft3. Besides producing gold this mine also produces uranium. For this case, as well as case 2, all equipment that utilise compressed air were investigated in order to determine the minimum requirements for compressed air. This was necessary so as to develop better understanding of how to optimise the compressed air usage and therefore to decrease the energy consumption.

B. Mine A Layout

The layout of the air reticulation network of Mine A is shown in Fig. 1. The first shaft, sht1, consists of four mining levels and a loading box level, whereas the second shaft, sht2, consists of five mining levels and a loading box level. Finally the third shaft, sht3, consists of five mining levels and two loading box levels.

Table 1 provides information on the compressors in Mine A ring. The air pressures for Mine A were logged for one month to determine the baseline. The pressure measurements used to determine the baseline were obtained from the delivery side of the compressors on each shaft.

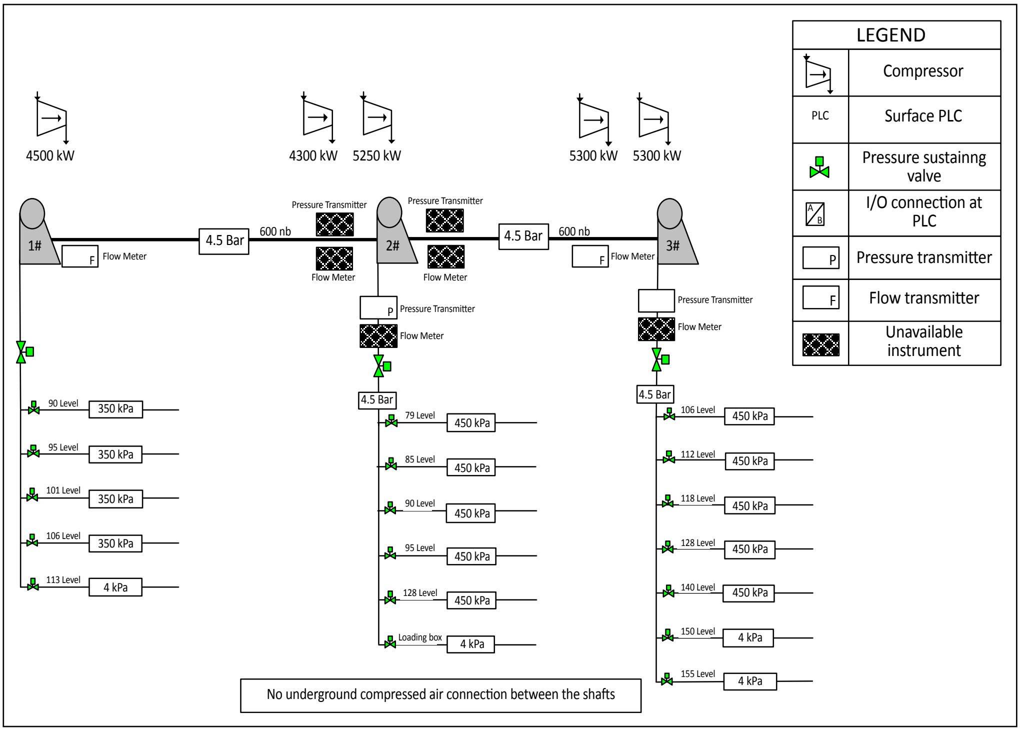

Fig. 1. Layout of Mine A air network and mining levels

TABLE 1

Mine A ring compressors information

Compressor Name	Compressor Commercial name	Installed Capacity (kW)	Guide Vane Control	PLC On/Off
Comp1 (Shft1)	DEMAG	4500	YES	No
Comp2 (Shft2)	GHH	4300	YES	No
Comp3 (Shft2)	BBC	5250	YES	No
Comp4 (Shft3)	SULZER	5300	YES	No
Comp5 (Shft3)	SULZER	5300	YES	No

C. Implemented control philosophy

As mentioned before, the mine has five compressors, where usually two are running at full capacity. The mine is alternating between the compressors.

The idea behind the control philosophy was to determine which compressors were to be used more often at the Mine A ring. The supervisory control and data acquisition (SCADA) system was installed to control the operation of the compressors and their corresponding pressure-set points. The SCADA is connected to a programmable logic control (PLC) system installed in the compressor's house at each shaft. Each shaft's PLC communicates via a radio link with the main PLC. The system controls the pressure-set points of the guide vane at each compressor in order to meet the demand for compressed air as required at any given period during the day. This allows the compressors to be throttled down in delivery pressure as a means of lowering the overall power consumption.

Prior to implementing the above described control system, a variety of pressure tests were conducted on each compressor separately. These tests determined more accurately the minimum required air pressure for each shaft.

Pressure-sustaining valves were also installed on the main air pipe at each shaft to control compressed air supply. The entire installed infrastructure is controlled from the surface by a SCADA system.

D. Test results

The first test was conducted on the Sulzer compressor at the third shaft, shft3. The compressor guide vane was throttled gradually down to deliver 400kPa in the shaft main delivery column, while the drawn current was being recorded. Pressure measurements were taken at 5-minute intervals for a period of 80 minutes as shown in Fig. 2. Clearly the pressure, which is related to shaft three delivery column's, gradually dropped down to reach 400 kPa at 12:40pm.

It can be concluded, that by reducing the pressure-set points, the current consumption drops by about 25%. This, in fact will decrease the power consumption.

The second test was conducted on the GHH compressor at shaft 2 of the same mine. This compressor is almost in constant use. The test was conducted by closing the guide vane valve to zero and measuring the power as a function of time (Fig. 3) and pressure-set points.

E. Mine A case study results

After these tests were conducted, it was possible to obtain energy savings and to determine what the optimised power profile could be. Fig. 4 shows the optimised baseline after combining

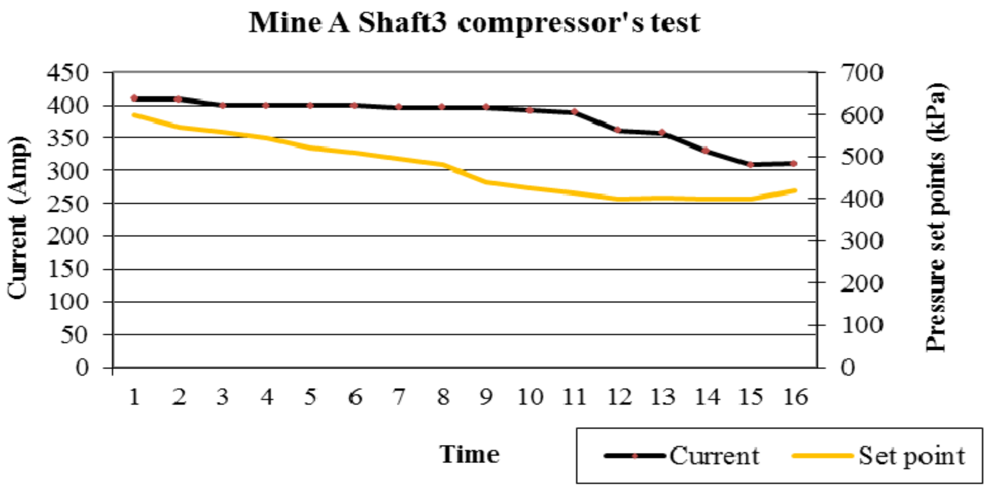

Fig. 2. Pressure test for shaft3, compressor

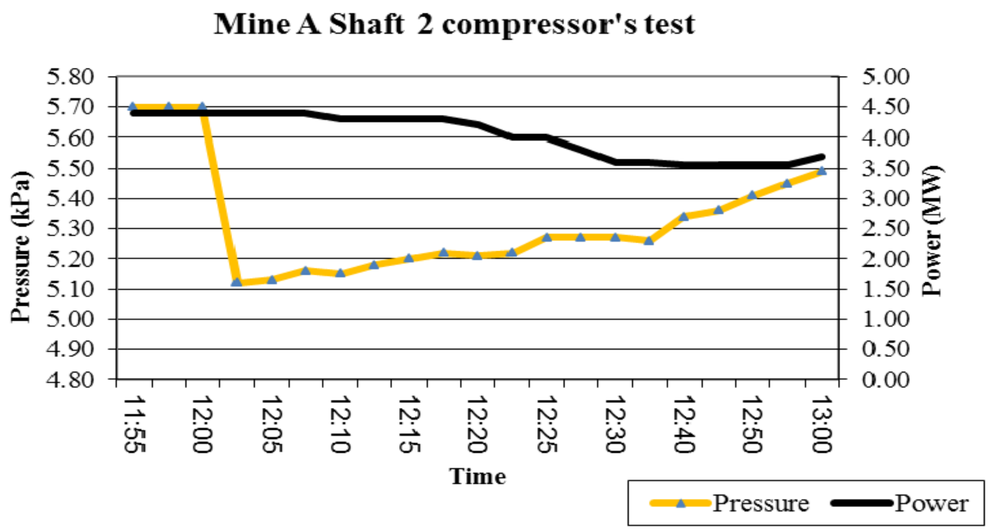

Fig. 3. Guide vane test conducted on the GHH compressor at shaft2

the optimised power profiles of the two shafts. The original baseline was developed using data which had been collected for a period of one month by installing power and current loggers on the compressors.

Compressed air is highly demanded during the drilling periods. The drilling period for this specific mine is between 8:00 to 13:00. During this period savings are not achievable. Outside the drilling period, electrical energy savings can be realised (Fig. 4), by optimising air delivery to consumption points. As can be deduced from the figure, about 1.14 MW savings were achieved.

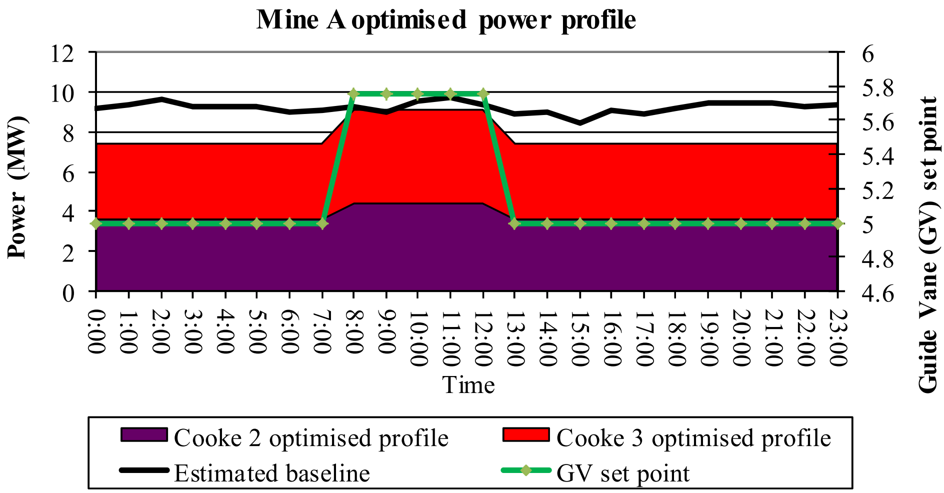

Fig. 4. Mine A optimised power profile

II. Case study two: Mine B

A. Overview

The second case of the study is also a deep gold mine referred to Mine B, it consists of two main shafts, sht1 and sht2. The second shaft, sht2, has terminated production, while the first shaft, sht1, is still operating. Large quantities of compressed air are pumped into the mine whereby the compressors run at full capacity. As such, the electricity consumption is relatively high.

B. Mine B Layout

The two shafts of Mine B are linked together at the surface using a 2.5 km air pipe as shown in Fig. 5. The mine has four compressors, where three of them are located at the first shaft, sht1.

Each of the four compressors has an installed capacity of 2900 kW. Unlike the case of mine A, each compressor at Mine B has a guide vane control.

As mentioned earlier, the second shaft, sht2 has terminated all production activities, but it is still used to hoist the ore from the first shaft, sht1, via a skip. There is still a training centre at sht2 where it uses some air. At sht1, the production is continuing, in addition to new production levels being developed.

All levels have manual valves on all the tap-offs. Note that all the new working levels are in the inclined area as shown in Fig. 6. The 18L is the link to the inclined levels, and sht1 and sht2 are linked to level 15L. This is the main line between the two shafts.

The current pressure set point at the compressors is 5.5 kPa, as the drilling requires a minimum of 4.5 kPa. The pressure provided to the development levels is a constant pressure of 4.5 kPa. In the stopping levels it is possible to cut back on the pressure to 2 kPa. Stopes are areas where the actual mining, drilling, blasting and scraping or sweeping of the reef takes place (van Rensburg, Botha, & Bolt, 2011). The mine installed three boosting underground compressors. Two of these compressors are situated at level 24L, and the third one is situated at level 23L. At this stage, only one compressor per level is used to boost air pressure.

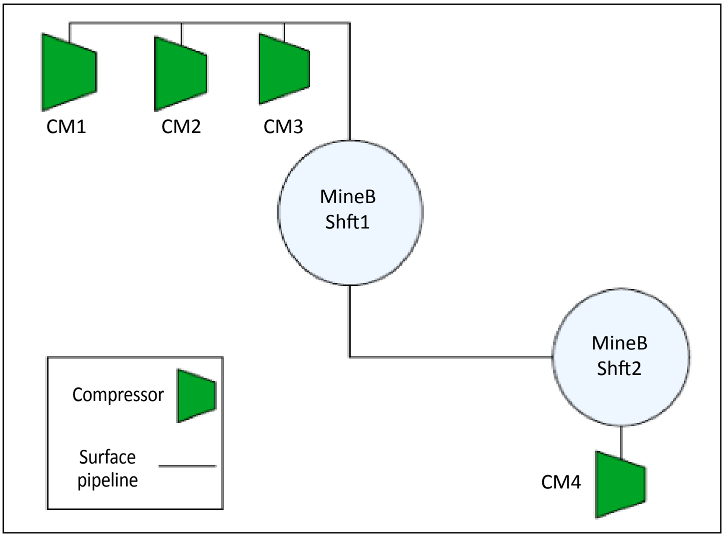

Fig. 5. Surface layout of air network at mine B

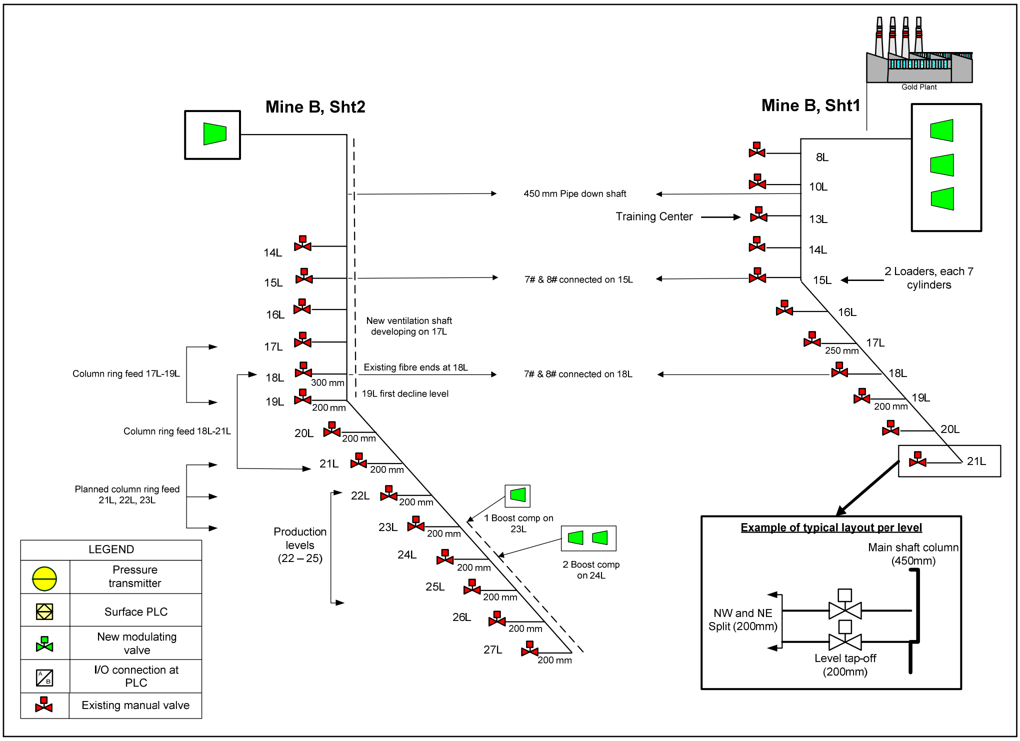

Fig. 6. Simplified underground layout for the air network at Mine B

C. Implemented control philosophy

The proposed control philosophy is shown in Fig. 7. Because mining operations were terminated at the second shaft, all manual valves at each level (see the legend) were closed. A control valve was installed on the main air pipe on the surface. This valve can be throttled down to provide a maximum 2 kPa air pressure to the underground. This provides sufficient pressure to the miners in the underground areas (refuge bays, pump stations, and loading boxes levels). A stand-alone compressor was installed at the training centre at the second shaft, sht2. The pneumatic loading boxes were replaced with a hydraulic power pack system. This reduces the air usage at this shaft to a minimum. A PLC was installed at the compressor house in shaft 2.

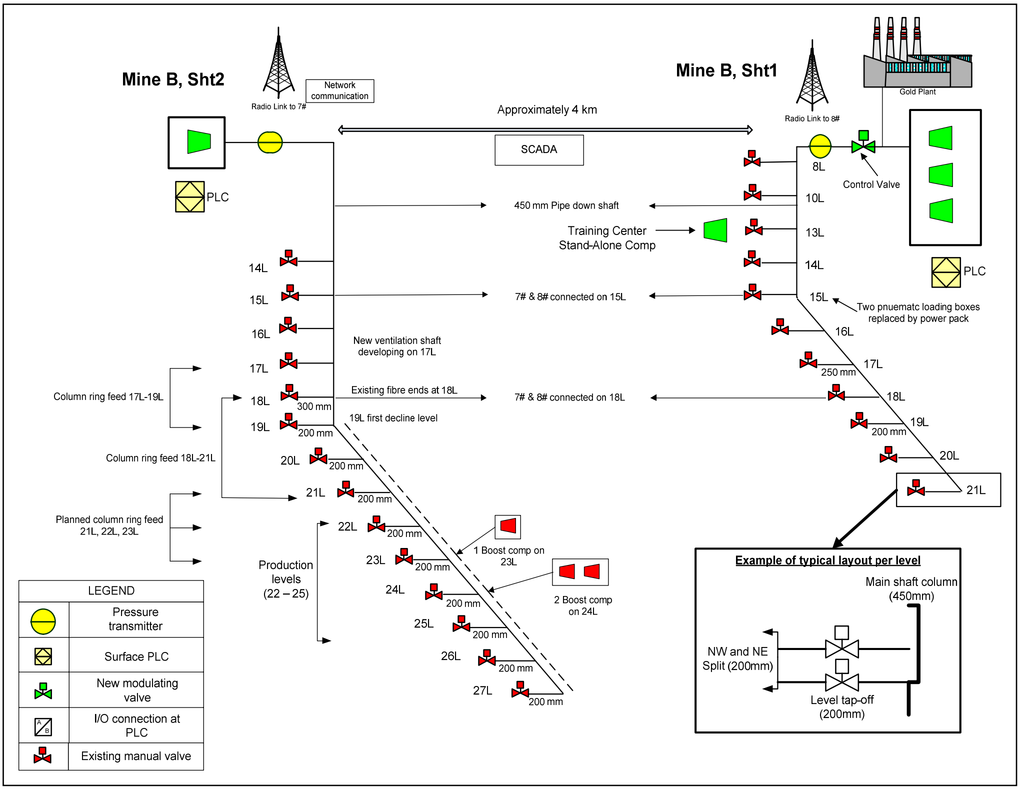

Fig. 7. Mine B implemented control philosophy

At the first shaft, sht1, a pressure transmitter was installed on the main pipe to deliver a maximum and fixed air pressure of 5 bar. A PLC was installed at the compressor house, which controls the compressor's guide vane to reduce the pressure during the off peak times (no drilling periods).

The two PLCs communicate with a SCADA system via a radio link as a means of reducing the cost of the control system. Applying this control philosophy allowed the mine to switch off one compressor permanently, resulting in achieving energy savings.

D. Mine B case study results

The mine baseline was determined from data collected from each compressor. Power loggers were installed to compute the power consumed by the compressors at Mine B. The baseline and the optimised power profile are shown in Fig. 8, where it can be seen that an approximate 1.1 MW in energy savings is achieved.

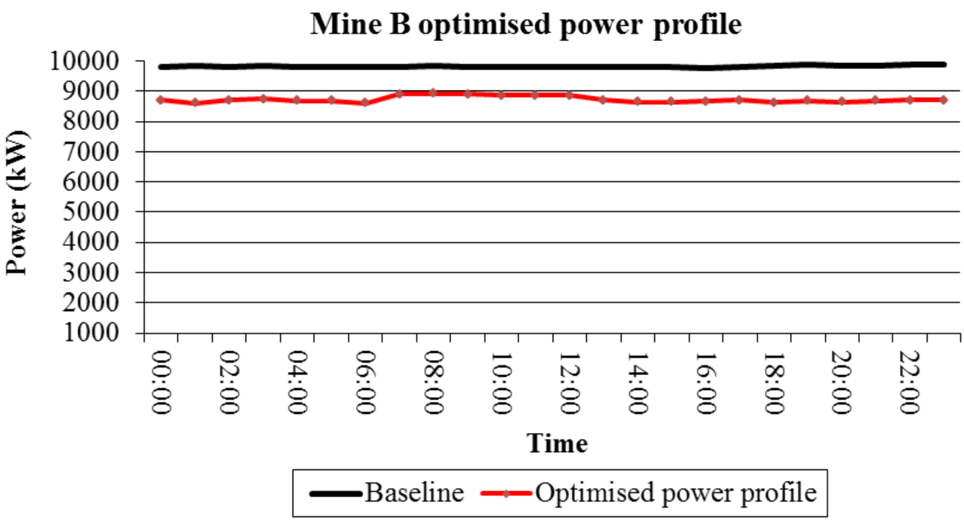

Fig. 8. Optimised power profile for mine B

3. Demand Side Management (DSM): Optimisation of water pumping system using load shifting technique

Load Shifting is the traditional form of load management. This involves shifting load from peak to off-peak periods (Acharya, 2001). In this case the power consumed during a certain period will remain the same. This means that the amount of work done before and after load shifting is unchanged; only the energy profile is altered.

The clear-water pumping system consists of pumping stations with dams on certain underground levels. The water being pumped from underground is already used for mining purposes. Due to the high Virgin Rock Temperature (VRT) on the deep working levels, the excess hot water collected in the bottom dam is pumped up to the surface where it is cooled down before it is sent back to underground levels for re-use. Thus, there is a continuous circulation of water from the underground to the surface and vice versa throughout the day. A typical layout of the clear-water pumping system is illustrated in Fig. 9.

The type of DSM project that is normally used for de-watering systems is load shifting, as water circulation is not directly linked to mine production. Another characteristic of the clear-water pumping system that makes it ideal for load shifting is that the pumps are frequently stopped and started due to the dynamic nature of the system (Hasan, 2010).

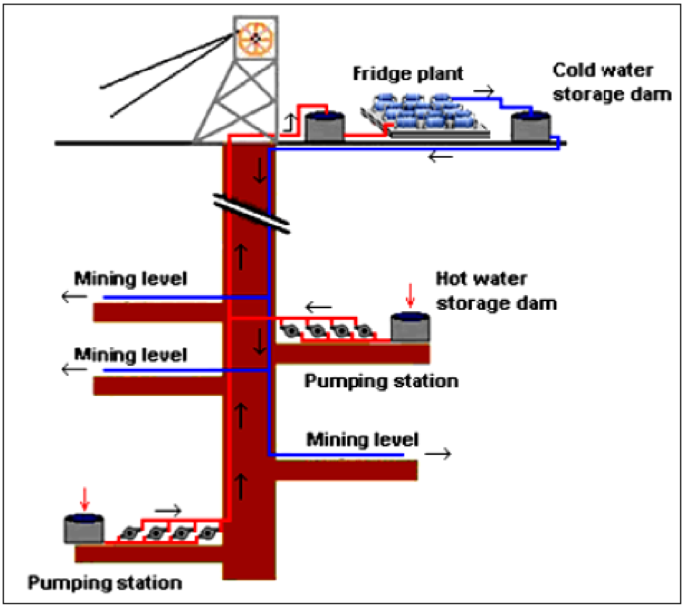

Fig. 9. Typical layout of a clear-water pumping system (Hasan, 2010)

In order to realise load shifting, pumps and storage dams are needed to reschedule the pumping activities over a 24-hour period. The philosophy is that dams in clear-water pumping systems are used to store the continuous incoming water during Eskom's peak periods, so that the electricity-intensive pumps can be switched off during these periods. After the peak time, the pumps can be restarted to pump out the stored underground water in order to restore the water balance in the mine. The peak periods are the morning peak time from 7:00 am till 10:00 am and the evening peak time from 6:00 pm till 8:00 pm. The main peak period is the evening one. The morning peak period is optional.

III. Case study Three: Mine C, Shaft 1

A. Overview

Our case study is Mine C's first shaft, sht1. As mentioned before the mine is a deep gold mine and situated in South Africa. Mining operations at this shaft are taking place producing gold and uranium.

B. Mine C, Shft 1 Layout

Fig. 10 shows the Mine C, shft 1 de-watering layout. The mine has one pump station, consisting of 4 pumps. Two of these pumps have an installed power of 2.76 MW each; the remaining two are rated at 3.1 MW each. The pump station also consists of four underground dams.

The mine pumps an average of 20 Mega litre (Ml) a day of which 15 Ml is fissure water. The water is used for cooling, cleaning and other purposes.

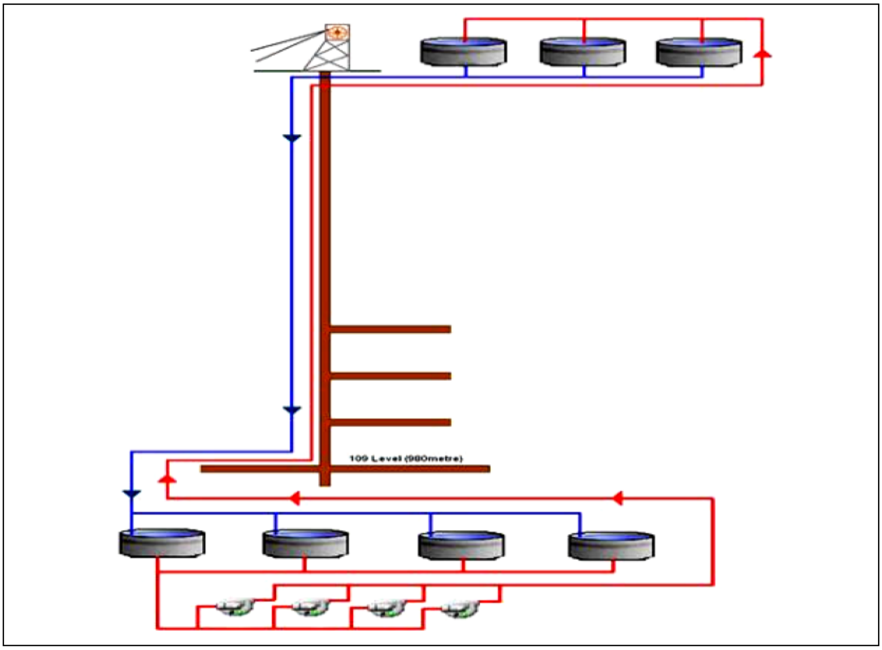

Fig. 10. Mine C, shft 1 de-watering system (Hasan, 2010)

C. Proposed and implemented control philosophy

The implementation of load shifting requires pumps to be switched off during the peak periods. During this period the underground dams will fill up and might overflow if not properly controlled. To achieve the maximum savings, more pumping should be done before peak periods in order to empty the underground dams. To implement this strategy, two pumps should operate simultaneously during Eskom's cheaper tariff periods. This was done by installing PLC's and SCADA at the pump station to determine when to switch on/off the pumps based on the underground dam levels. Fibre-optic cable was used to link the SCADA with the PLC.

A. Mine C case study results

The baseline was obtained based on three-month pump-operating data. The data were logged from the mine's pump station for each pump. Loggers were installed at the pump station of Mine C, Shft 1. The data obtained from these loggers were converted into an Excel format and analysed. Data obtained over weekends were disregarded. The actual baseline represents the average values as calculated from the data obtained over the three-month evaluation period.

The simulation predicted that the pumps can be switched off for two hours during morning peak time and for one hour during evening peak time. From the analysed data, it was determined that the actual load shift potential, over this three month period during evening peak is 2.6 MW as shown in Fig. 11.

A DSM project was successfully implemented at Mine C shft 1, whereby load shifting of 2.6 MW during evening peak time and 2.3 MW during the morning period was achieved.

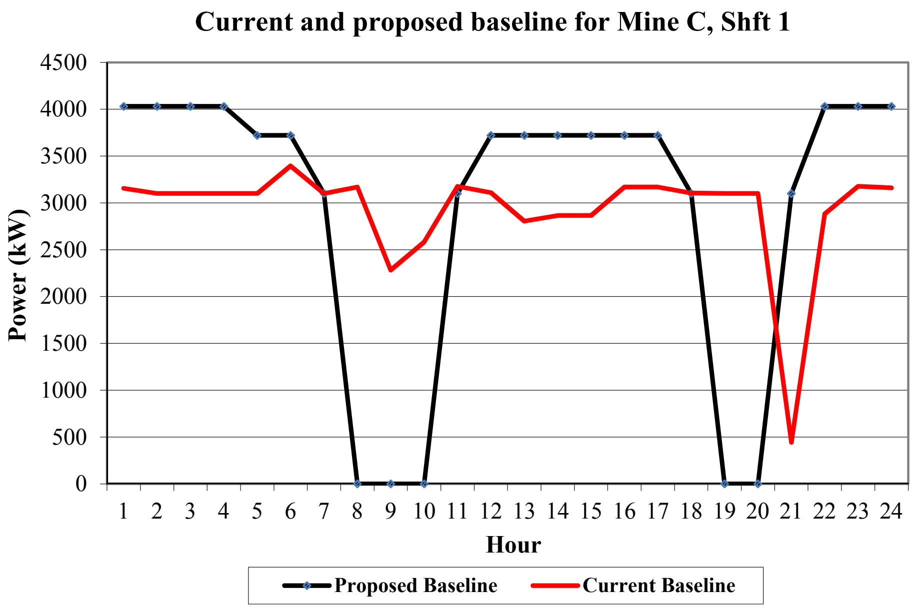

Fig. 11. Mine C, shft 1 baseline and optimised power profile

IV. Case study Four: Mine D

A. Overview

Mine D shaft is operated by gold mine, and is located in Gauteng province, South Africa. Mining operations ceased at this mine and the shaft is only being used to pump water. A DSM project was investigated at this mine with a target to shift 7 MW daily.

B. Mine D layout

Fig. 12 illustrates the mine layout, where it shows the mine having two pump stations described as follows:

1. 27 level pump station has 5 pumps. Each pump is rated at 2.75MW. The total underground dam capacity is 3 ML.
2. 12 level pump station has 7 pumps. Each pump is rated at 3.30MW. The total underground dam capacity is 2 ML.

Water flows from a nearby shaft to Mine D shaft through a tunnel that connects Mine D shaft and underground cavity situated at the nearby shaft. This water then passes through a plug valve that is situated at the end of the tunnel at 27 level pump station.

The main water source that feeds the 27 level pump station flows through this plug valve. The water is then pumped via 12 level to the surface reservoirs where it flows to the nearby farms.

This plug valve is a very important component when determining the maximum load shift potential as well as determining the quality of the water passing through the valve. The plug valve is a butterfly type and controls the flow of the water into 27 level pump station.

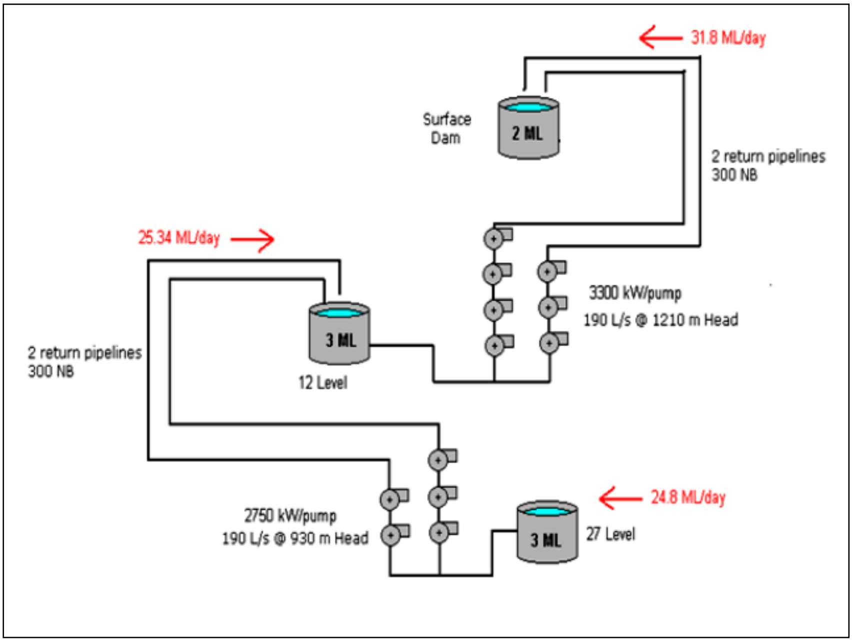

Fig. 12. Mine D shaft clear-water pumping system [10]

B. Implemented control philosophy

Before the DSM project was investigated and implemented, the plug valve was kept partially open at a fixed value of 24%. This was done to maintain the water level of the cavity at the nearby shaft at a specific level. This procedure ensured an acceptable quality of inlet water.

After the successful implementation of the DSM project, it was realised that keeping the valve opened at a fixed set-point limits the amount of savings for the mine. The average load shift with the valve 24% open was only 5.52MW.

In order to increase load shifting and thus cost savings, the plug valve needs to be controlled. Fig. 13 shows the percentage opening of the valve and the corresponding water flow rate. By altering the valve opening throughout the day, the amount of load shift and cost savings could be increased.

As mentioned before, the valve was previously set at 24% opening. Simulations however showed that by modulating the valve between 18% and 30% throughout the day, maximum load shift would be achieved without influencing the water quality. After this technique was applied, the flow though the valve decreased during peak time.

This made it possible to turn all the pumps off during the entire evening peak period. However, when the valve is kept open at 18% during a peak period, the flow rate is reduced affecting the cavity level. This is dealt with by setting the valve opening at 30% during the off-peak period, such that the cavity level remains within acceptable limits, on average.

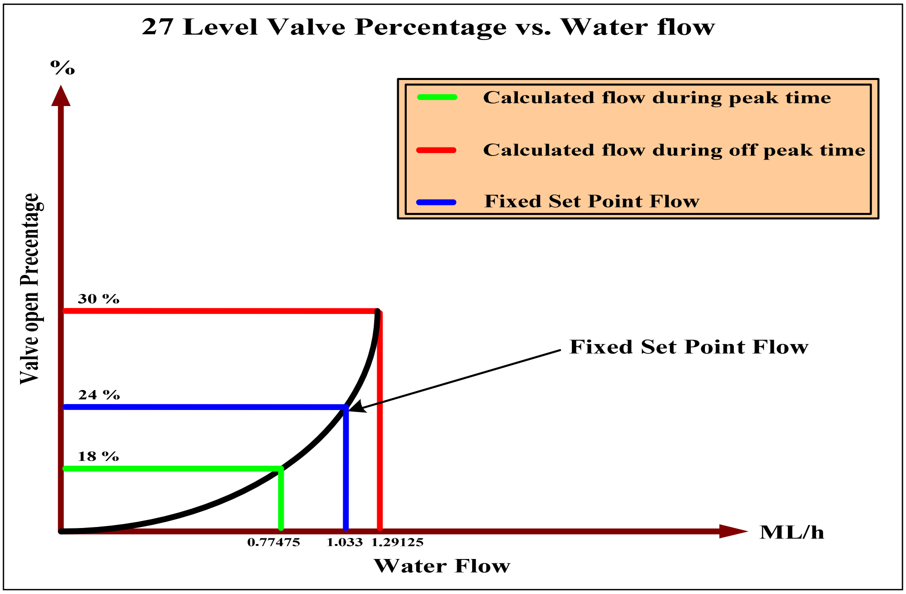

Fig. 13. Mine D plug valve characteristics and water flow

B. Mine D case study results

After simulating the pump system, a new optimised power profile was determined for the load-shifting project. Fig. 14 illustrates the baseline and the optimised power profile. This graph shows the actual baseline that was obtained after logging each pump's running status in both 12 and 27-level pump stations. The data used to draw this graph were obtained over a period of three consecutive months. The baseline represents the average energy usage over the three-month period.

The load-shifting potential determined from the optimised power profile is 5 MW during the morning peak period and 8 MW during the evening peak period.

Fig. 15 illustrates the optimised power profile. After DSM implementation, the 27level plug valve was kept open at the same fixed value of 24%, and was not included in the automation process (as per mine specifications).

During the evening peak, the project did not reach the load shifting target. This was due to the plug valve being kept open at a fixed set point which caused a high water inflow into the 27-level underground pump station from the plug valve. Therefore the amount of load shift achieved was limited. The average load shift achieved with the valve opening set at a fixed 24% was only 5.52 MW. The pumps could be switched off for only one and a half hours during the evening peak period.

As shown previously in Fig. 13, by modulating the valve between 18% and 30% throughout the day, maximum load shift could be achieved. This is shown in Fig. 16. After this technique was implemented, the water flow rate through the valve was reduced during peak time. Load shifting was increased and reached an average of 7.9 MW, and the pumps could be switched off for the full two evening peak hours.

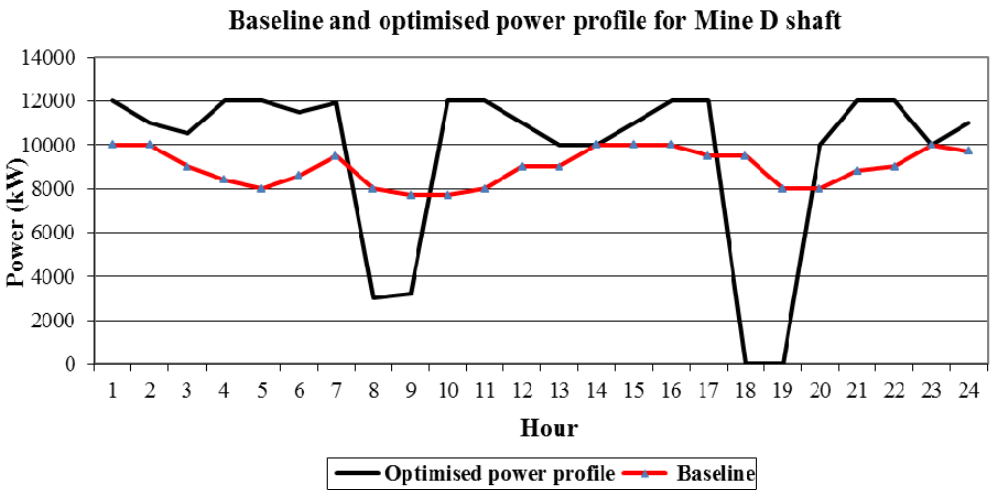

Fig. 14. Mine D shaft baseline and optimised power profile

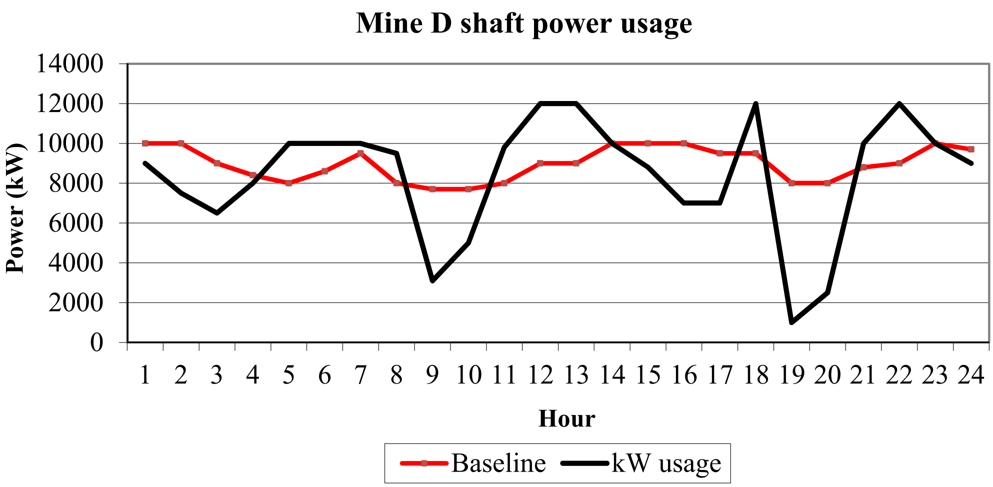

Fig. 15. Mine D power profile before controlling the valve

4. Conclusions

As mentioned in the introduction, an investigation was conducted on each mine to determine the best control philosophy in order to reach the MW savings target. It was shown that the control philosophy differs for each mine based on the mine status and specifications. These control techniques can be applied on other mines that have similar production conditions, infrastructure and specifications.

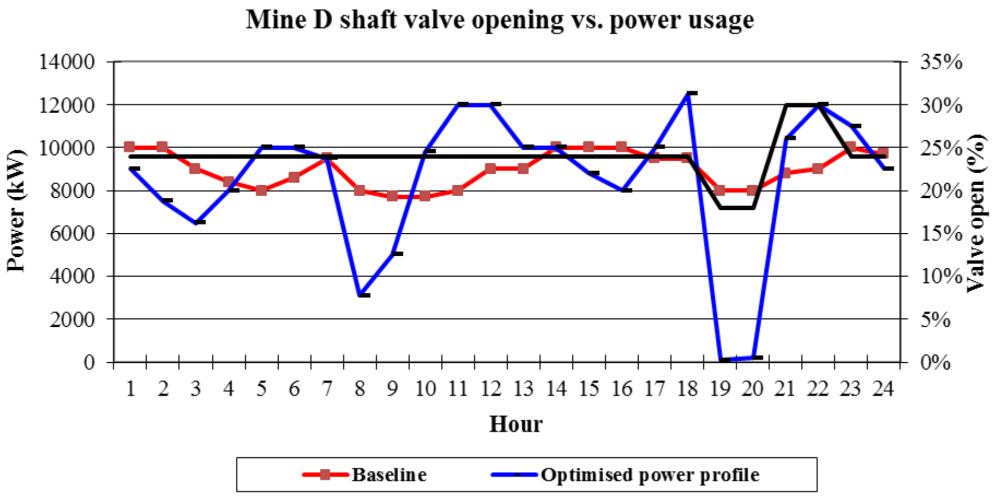

Fig. 16. Mine D shaft optimised power profile after controlling the valve

In the case of Mine A, the control of the compressors' pressure set points will allow the compressors to cut back. This is done by controlling the guide vane on each compressor. This technique resulted in a 1.13 MW of electricity savings.

However this DSM project will have an impact only during the no-drilling periods. During the drilling time the guide vanes are fully open and the compressors run at full capacity to meet the demand.

In the case of Mine B, the control valve units can be used to optimise the compressed air consumption. These units need to be controlled and managed from a central point. The SCADA and PLC system can therefore be used for this purpose at Mine B, where an average load reduction of a 1.1 MW was achieved.

For load shifting initiatives, in the case of Mine A shft 1, The load shifting target was 2.6 MW during the evening peak and 2.3 MW during the morning peak periods. These targets were reached by using two pumps before the morning peak period and the evening peak period to drain out the underground reservoirs.

The last case study discussed in this paper is Mine C load shifting initiative. In this mine the project target was to shift 8 MW during evening peak period of a working day. After implementation of the load shifting project, an average of about 5.5 MW was only reached due to the constant water flow from the nearby shaft through the 27-level plug valve, as demanded by Mine management.

However, after implementing the plug valve control approach an additional 2.38 MW load shifting was attained bringing the total to 7.9 MW.

The outcome of this study indicates that, DSM and EE can play an important role in optimising energy usage which leads to savings, especially in the mining sector. This can provide solutions to ESKOM to overcome the critical electricity shortage and effectively increase the generated power capacity of the country.

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Received: 02 May 2013