Three-chamber pump system for DSM

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The electricity supply situation in South Africa has forced industries to look at alternative, more energy effective processes, without reducing output. With the mining sector consuming almost 18% of the supplied electricity in the country, it is critical to investigate new technologies and methods to reduce the electricity consumption in this industry.

One such technology is the three chamber pump system or 3CPS (also known as a three chamber pipe feeder system), which recovers energy from the incoming water and uses it to pump water out of the mine.

Only one 3CPS has been installed in South Africa, but initially this did not perform well. Hydropower Equipment (HPE), a South African company, investigated the reasons for this and devised a solution based on their experience with high-pressure water valves. By fitting new valves and providing appropriate maintenance support, the system now runs economically at over 95% availability.

Significant electricity savings can be achieved by installing a 3CPS. HPE is currently busy installing three 3CPS systems in existing excavations in three mines in South Africa. The anticipated energy saving of these systems is 157 GWh per year resulting in considerable electricity cost reductions for the mines.

Normally the payback period for a 3CPS is approximately 5 years. However, because Eskom DSM funds 50% of an approved energy efficiency project, the payback period for the client reduces to an attractive 2.5 years.

With the added benefit of HPE supplying cost effective maintenance and Eskom DSM funding 50% capital cost, the 3CPS has huge potential to reduce pumping costs in existing and new mines in South Africa.

Background

South Africa has an electricity generation capacity of 36 937 MW of which Eskom produces 96% [1]. The capacity is primarily coal-fired and, assuming a 50 year life per plant, current plants are scheduled to be operational until at least the year 2020.

Further electricity generation plants would be required approximately at the year 2007 [2][3]. A national peak demand of between 35 100 and 36 100 MW was predicted for the winter of 2007, meaning a reserve of only 2%. This makes the situation very vulnerable. If the smallest problem is encountered to a generation unit or grid line, certain areas in the country will have power shortages.

As more frequent power shortages in South Africa continues and threaten economic growth, it becomes more important than ever to find ways of consuming energy more efficiently.

On the supply side, Eskom has announced an investment programme of at least R200-billion over the next 25 years that will ensure that South Africa has enough electricity to power its fast growing economy [4]. But, because of the length of the lead time required for supply side solutions, and the urgency of reducing peak demand, Demand side management (DSM) can be seen as an immediate solution to the problem.

DSM refers to measures sponsored, funded, and/or implemented by utilities that modify end-use electrical energy consumption, either reducing overall consumption through energy efficiency or using load management to reduce demand at times when the cost of reducing demand is less than the cost of servicing it. Cost-effective efficiency and load management measures could significantly improve the reliability of national electric systems and close the gap between supply and demand, while lowering the economic and environmental costs of electric service. The mining sector alone used 18% of South Africa’s electrical energy in 2003 [5]. Many mines make use of ventilation, fridge plants and underground pumping systems. These can typically contribute 25% of the electricity consumption [6]. Mine pumping alone contribute approximately 2300 MW to the 36 937 MW electricity peak in South Africa [7]. It is critical to investigate new DSM opportunities, technologies and methods to reduce the electricity consumption in this industry.

One such technology is the 3CPS which recovers energy from the incoming water and uses it to pump water out of the mine.

Introduction to the 3CPS

The 3CPS has its roots in pumping abrasive slurries from mines. The basic concept was to displace the slurry from a pressurized chamber using high-pressure water. This had the advantage that the mechanical pump would only pump water and not the abrasive
slurry. To convert the ‘batch process’ into a continuous process at least two chambers are required, one chamber being pumped while another is being filled ready for the next pumping cycle.

A third chamber was added to assist the change-over from ‘filled’ to ‘filled and pressurized’ ready for pumping and from ‘empty’ (of slurry) to ‘empty and depressurized’ ready for re-filling.

The technology was further developed for energy recovery. The Anglo American Corporation of South Africa selected this technology for Freddies No.1 Shaft (now Tshepong Gold Mine part of Harmony Gold) and the system was brought into operation in about 1994 [8].

Principles of the 3CPS energy recovery

The 3CPS is an energy recovery device. It uses the incoming chilled water to displace the outgoing warm water. A small booster pump is used to overcome friction in the system. A U-tube is formed, on the one side, by the high-pressure chilled water feed column, the 3CPS at the bottom and the out-going warm water delivery column, on the other side. A small filling pump fills with chambers with warm water. Typically the head of the U-tube is greater than 1000 m.

The three chambers are each fitted with valves at either end which are actuated in a sequence to achieve a continuous and steady flow in and out of the system.

Typically, these valves are controlled by a PLC which incorporates start-up, operation and shut-down sequences and the necessary safety interlocks. This PLC and the instrumentation are connected via a fibre network to the mine’s SCADA system in the control room on surface. Full view of the status and performance of the entire system can be seen as well as remote control (start-up or shut-down) of the 3CPS. At any one time one chamber is pumping, one is being filled and one is ready for pressure equalization. Each chamber has four valves, two of which are controlled by the local PLC.

A 3CPS does not replace conventional de-watering pumps as these have to be available in the event of the following:

- 3CPS not operational
- Not able to bring water into system when it is necessary to pump water out
- Not able to pump water out of system when it is necessary to bring water in

A dissipator is always fitted in parallel with the 3CPS to break the high pressure of the underground cold water. This is done so that the underground cold water dams can be filled if the 3CPS is not available.

Additional water outside the closed loop, like fissure water or water that does not enter the mine via the 3CPS cannot be pumped from the mine by the 3CPS. This will have to be pumped conventionally.

Performance at Tshepong

The 3CPS was implemented in 1993/4 and had been running fairly well and relatively few breakdowns were recorded, until problems were experienced with the valves [8]. Although the 3CPS at Tshepong mine was not implemented by HPE it has been maintained by HPE for the last five years. HPE investigated the reasons for the frequent breakdowns and devised a solution based on their experience with high-pressure water valves.

The Tshepong 3CPS comprises three chambers each of 16,1 m³ and completes a full cycle in about 153 s which means that each valve opens and close approximately 15 000 times per month.

HPE specially designed and manufactured valves that could handle this high frequency. By fitting the new valves and providing appropriate maintenance support, the system now runs economically at over 95% availability.

Energy savings and utilisation

The electricity savings of the 3CPS at Tshepong is approximately 83% of a conventional pumping system. Although this was very attractive to mine managers on paper the actual figures did not show these savings. In 1995 it was seen that the utilization of the 3CPS was 74,2%. Because of long stand time due to maintenance the mine was forced to pump the water with the conventional “electricity intensive” pumps. When HPE got involved at Tshepong the utilization was much lower than 74,2%.

The utilization of the 3CPS is the best measure of the maintenance related performance of the system. This is defined as:

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\text{Utilisation} = \frac{(\text{Volume into mine through 3CPS})}{(\text{Volume into mine through 3CPS} + \text{Volume through dissipators})}
\]

It was seen that the average utilization since Feb 2003 is 90%. The utilization for the last 12 months is 98%, which can be seen in the graph in Fig. 2.

The thermal performance of the system can be measured in terms of the increase in temperature of the water reporting to the chilled water dam above that of the chilled water into the top of the in-feed column. Typically, Tshepong runs at a 0.6°C increase in temperature which is a fact limited by the heat gain into the water from the warmer air in the shaft. (This is considerably better than the Joule-Thompson heating that, at Tshepong would increase the temperature by 3°C over and above the conduction temperature rise of about 0.6°C.)

This figure can be higher if the valves or the backpressure on the filling circuit are not adjusted correctly.

The energy performance or efficiency of the overall system depends on several factors:

- The pressure drop in the system (which is dependent on the flow rate and the diameter and length of the pipe columns feeding to and from the system and on the pressure drop through the valves in the system)
- The dissipation losses associated with compressing the water in the chambers when pressurising and dissipating the expansion of the water when depressurizing the chambers
- The efficiency of the filling pumps.

All three factors are determined by choices made at the design change. The top booster and bottom filling pump efficiencies can be less than the design figure if the pumps are not well maintained. In the Tshepong system, the losses due to pressure drops that have to be overcome by pumps are about 15% of the total pressure head recovered.
The maintenance cost is a function of the system pressure, the size of the valves, the number of cycles per month and the water quality. The maintenance cost of conventional multi-stage centrifugal de-watering pumps is estimated as 18% of the electricity consumed by the pump over the same period. This figure includes fitter labour costs, routine maintenance (such as balance discs and lubricants) and major over-hauls. The maintenance cost of the Tshepong 3CPS is similar at approximately 15% of the valve of the energy recovered.

**Safety improvements at Tshepong 3CPS by HPE**

Two system safety improvements introduced by HPE over the original system are the addition of a safety isolation valve (SIV) and surge relief valves (SRV) in the in-feeder column.

The SIV is a combined isolation valve and excess flow control valve. As an excess flow control valve, it closes automatically should the flow increase beyond a pre-set amount due to, say, a sudden pipe failure. Initially, the valve closes very rapidly to prevent a run-away flow and sustain a back-pressure, and then finally closes slowly to minimize pressure surges.

The nitrogen gas charged, low-inertia SRVs prevent excessive over-pressure by rapidly opening and blowing off in the event of a pressure surge.

**Installing three new 3CPS systems**

As part of a solution to the electricity supply-demand crisis in South Africa, HPE identified three new 3CPS projects in the mine industry. By exact simulation of the transient flow, stress analyses on valves and pipe deflect and stress analyses (CEASAR Pipe Stress Analyses), HPE could propose the projects to the clients and Eskom DSM. Eskom agreed to fund 50% of all three projects. This sweetened the business plan for the clients and reduced the payback from approximately 5 years to 2.5 years. All three projects were approved by the clients. Work started at the end of 2005.

**Mine 1**

The mine sends a daily average of 20.6 Ml of cold water from surface to the underground operations. This water is used in mining operations and the hot water is pumped back to surface with multistage pumps.

By installing a 3CPS between surface and the underground pumping station (985 m below surface), an energy saving of 42 GWh per year can be achieved on pumping. The mine will realise an electricity cost saving of R4.3-million per year (Megaflex 2006 prices). The payback period for the mine is 2.55 years. Implementation will be completed in June 2008.

**Mine 2**

The mine has a total depth of approximately 2500 m and sends a daily average of 18.1 Ml of cold water from surface to the underground operations.

By installing a 3CPS between surface and the underground pump station (1917 m below surface), an energy saving of 55 GWh per year can be achieved on pumping. The mine will realise an electricity cost saving of R5.5-million per year (Megaflex 2006 prices). The payback period for the mine is 3.27 years. Implementation will be completed in December 2008.

**Mine 3**

The mine has a total depth of approximately 3500 m and sends a daily average of 27.4 Ml of cold water from surface to the underground operations. By installing a 3CPS between 22L and 42L (987 m total head), an energy saving of 60 GWh per year can be achieved on pumping. The mine will realise an electricity cost saving of R6.1-million per year (Megaflex 2006 prices). The payback period for the mine is 1.76 years. Implementation will be completed in July 2008.
The effect of three new 3CPS systems on the South African economy

Besides the fact that the total electricity cost saving due to the three 3CPS systems is R15,8-million per year for the clients, there are other positive impacts that the energy savings have on the South African economy.

**Eskom DSM targets**

Due to the critical electricity supply–demand situation in South Africa, Eskom DSM has announced that they have a target of achieving 4563 GWh electricity savings by the year 2012 [9]. If all three 3CPS systems are installed and commissioned at the end of 2008 the systems will achieve an electricity saving of approximately 630 GWh by 2012. This means that only three projects contributes 14% to Eskom DSM’s target.

**Residential sector**

The effect of the 3CPS results can be put in another perspective. The electricity savings resulting from the 3CPS is electricity that can be used elsewhere without the need for Eskom to generate additional supply. Thus, the electricity savings from the 3CPS can be seen as a virtual power station, generating 17,9 MW. The electricity can be used in the residential sector.

It is known that the average low-income house in South Africa uses 100 kWh electricity per month. Mid-income and high-income houses use 500 kWh and 1050 kWh per month, respectively. However, it is known that the electricity is not used constantly over a 24 hour day. If it is assumed that 60% of the daily electricity is used in the hours between 07h00 to 10h00 and 18h00 to 20h00, the following number of houses can be supplied with electricity from the savings of the 3CPS:

- **Low-income houses**: 47 700
- **Mid-income houses**: 9 600
- **High income houses**: 4 500

This means that by implementing the 3CPS, electricity is saved in the industrial sector and applied in the residential sector, without influencing production results.

**Green house gas emissions (GHG)**

It was mentioned that Eskom’s supply capacity is primarily coal-fired power stations. The electricity savings resulting from the 3CPS will mitigate Eskom’s GHG emissions which are mainly CO2. It is calculated that Eskom will emit approximately 7800 tons of GHG to have a generation capacity of 1 MW for a year. Thus by saving 157 GWh electricity per year, Eskom mitigates their GHG emissions by 141 000 tons.

The future of the 3CPS

It is well known that South Africa is one of the largest mining countries in the world. Because of the energy intensive mining method of gold and platinum mines and the depth at which these commodities are exploited, large potential exists to implement 3CPS systems in gold and platinum mines. Currently in South Africa there are more than 40 deep level mines with large clear water pumping facilities.

The 3CPS can be installed to new greenfield sites, or it can be retrofitted to existing excavations. However, with the three current installations it is seen that most of the project costs are not for the 3CPS itself, but for the ancillaries to bring the existing mine systems up to standard.

Currently Eskom DSM funding does not cater for designing a 3CPS to a greenfield project. If Eskom DSM can alter this rule energy efficiency technology can be planned for on new sites. If Eskom DSM can increase their funding for energy efficient projects from 50% to 75%, or even 100% as with load shift projects, the 3CPS business case would become very attractive for mine managers. These two suggestions will open new opportunities in the industrial market.

**Conclusion**

Not only load shift projects (where electrical load is shifted out of Eskom’s peak times), but also energy efficiency projects are answers for the critical electricity supply-demand problem in South Africa. The need for energy efficiency projects in the industrial sector is stronger than ever before.

One such solution is the 3CPS, which recovers energy from the incoming water and uses it to pump water out of a deep level mine. However it was seen at Thsopong mine that problems were experienced with the valves and poor maintenance resulted in utilization of less than 75%.

Based on their experience on hydro power valves, HPE has developed in-house technology that can handle the stringent conditions needed to achieve 95% utilization on a 3CPS. They have implemented this technology and maintained the 3CPS at Tsopong for the last five years. For the last 12 months the 3CPS achieved utilization of higher than 98%.

As part of the electricity supply problem, HPE has proposed three new 3CPS projects to Eskom DSM. Eskom approved funding of 50% and the clients agreed to implementation of these projects. It is seen that the payback period for the projects are 1,76, 2,55 and 3,27 years. The combined annual electricity cost savings for the clients are R15,8-million.

The effect of the electricity savings due to the 3CPS is significant on South Africa. Almost 20 3CPS projects will achieve Eskom DSM’s electricity saving target of 4563 GWh by 2012. Three 3CPS projects enable 47 700 low income, or 9 600 mid-income, or 4 500 high-income houses to use electricity. And 141 000 tons of GHG is not emitted per year, as a result of the electricity savings of the 3CPS.

There is large potential to roll this technology to existing excavations in South Africa. Although other funding mechanisms exist, Eskom DSM will not fund 3CPS projects on greenfield projects. More opportunities will emerge if Eskom DSM can change their rules for funding current and new excavations.

**References**


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