Energy recovery from high pressure cold water in mines

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The mining industry in South Africa, being responsible for 18% of electricity demand, is seriously looking at alternative, more energy effective processes, without reducing output. Deep level mines require large volumes of cold water at the underground production levels. The energy consumed by these pumping installations constitutes approximately 14% of the mine’s overall demand.

Normally, water is refrigerated on the surface and sent down the mine to depths of more than 3000 m below surface. The pressure of this water at a specific production level can be up to 10 times higher than that which is required for work at that level and this excess pressure is then dissipated to the required working pressure by means of pressure reduction valve (PRV) stations.

If the potential energy of the pressure of the incoming cold water can be utilised, instead of being dissipated, significant energy savings can be achieved. Two such technologies exist in the mining industry and are described in this paper: The three chamber pump system (3CPS) and the pump-as-a-turbine (PaT) system.

A case study of such an installation is presented, which shows that electricity savings of between 15% to 25% on the mine pumping system can be achieved.

Making use of the Eskom IDM funding programme, the payoff period can be reduced from about six years to less than three years.

The mining sector uses about 18% of South Africa’s electrical energy [1]. Many mines make use of ventilation, fridge plants and underground pumping systems. These can typically contribute 25% of the electricity consumption [2]. Mine pumping alone contributes approximately 2300 MW to the 39 200 MW electricity peak in South Africa [3]. It therefore makes sense to investigate new DSM opportunities, technologies and methods to reduce the electricity consumption in this industry.

Such technologies include the three chamber pump system (3CPS) and the underground turbine, both of which recover energy from the incoming water head and use it either to pump water out of the mine, or to generate electricity.

Between 50 and 60 Pelton turbines have been installed in South African deep-level mines since 1978. Based on industry feedback it is estimated that currently between one-quarter and one-third of these are still in working condition. However, even in these, less than 50% of the energy that could be recovered from the head is being achieved because it is burdened with inefficient (65% to 80%) centrifugal dewatering pumps [4].

At present six 3CPS systems are installed at deep-level mines and a seventh is currently being installed by Hydro Power Equipment (HPE). In a 3CPS system about 80% of the energy that could be recovered from the head is being achieved [4].

Six of these projects (Tshepong being the exception) have been funded up to 50% by Eskom IDM. This contribution has sweetened the business plan for the clients and effectively reduced the payback from approximately six years to three years. Work started at the end of 2005.

In total, the seven 3CPS systems will have the potential to recover up to 30 MW electricity.

Introduction to the 3CPS AND PaT technologies

The 3CPS system has its roots in the pumping of abrasive slurries from mines. The basic concept was to displace the slurry from a pressurised 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 pressurised" ready for pumping and from "empty" (or slurry) to "empty and depressurised" ready for re-filling.

The technology was further developed for energy recovery. The Anglo American Corporation 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 [5].

Introduction to turbines and PaTs

Water turbines have been used underground for many years to recover the energy in the pressure head available in the incoming water column. Two types of turbine technologies applicable to deep-level mines exist, these are turbines without any back pressure and turbines with back pressure. Each type has its own application in a deep-level mine.

In a Pelton wheel turbine, water pressure from the head is converted into kinetic energy. The water jets from nozzles powers a rotating wheel. The wheel rotates and the water from the turbine is discharged at ambient pressure into a dam. Pelton wheel turbines do not provide any back pressure.
pressure (all the pressure is converted into kinetic energy).

Certain system components do require back pressure and one type of turbine which does provide back pressure is a Francis turbine. In a Francis turbine the water first passes through a ring of stationary guide vanes in which only a part of the total head is converted into kinetic energy. The guide vanes accelerate and guide the water at the correct angle into the runner. The pressure energy is further converted into kinetic energy in the runner. The actual pressure drop is controlled by the configuration of the impeller, guide vanes and rotational speed. The general design of a Francis turbine is similar to that of a centrifugal pump. In fact, pumps operating in reverse may be used as energy recovery devices.

The performance of a pump running as a turbine, or PaT, is very good, as the energy output can be higher than the energy input used to run it as a pump. Hydraulically, the pump in turbine mode can handle a higher volume of water than when in conventional pumping mode. There is a higher flow inside the pump and this means that the amount of energy that comes out is higher. An added bonus is that when it is in reverse operation and running as a turbine, the pump can run slightly more efficiently than in conventional mode.

With the pump running in reverse, the shaft torque can be utilized in a number of ways. When attached to a generator, its speed is determined by the power grid mains frequency. In such a scenario, to generate a frequency of 50 Hz, the pump would have to turn at an exact speed of 1500 rpm. To cater for speed variations, frequency inverters and appropriate mains feed circuitry would have to be installed. This can be done in the form of a variable speed drive (VSD).

Design principles of the 3CPS and PaT

Principle of the 3CPS

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 the 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. The status and performance of the entire system can therefore be seen as well as remote control (start-up or shut-down) effected of the 3CPS.

At any one time one chamber is pumping, one is being filled and one is ready for pressure equalisation. 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 being operational
- Not being able to bring water into system when it is necessary to pump water out
- Not being able to pump water out of system when it is necessary to bring water in

A dissipater is always fitted in parallel with the 3CPS to break the high pressure of the underground cold water if the 3CPS is not functional. This is done to ensure that
the underground cold water dams can be filled even if the 3CPS is not available. Any additional water outside of the closed loop, for example 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. A new 3CPS system can be designed by exact simulation of the transient flows, stress analyses on valves and pipe deflection and stress analyses (CEASAR Pipe Stress Analyses). This was the case for the three new 3CPS projects that HPE are currently installing.

**Principle of the PaT on production levels**

Because the PaT can give a back pressure, it can be used on the production levels of mines. The incoming pressure of the cold water on production levels can be up to 20 MPa and the required pressure is between 1 and 2 MPa. The flow can vary between 30 l/s to 130 l/s.

Deep-level mines at present make use of pressure reduction valve (PRV) stations that consist of pressure reduction valves, surge relief valves and isolation valves. The PRV then dissipates (through friction) the high pressure incoming water to the required operating pressure.

A preliminary design of a PaT in parallel with a PRV is shown in Fig. 2.

The key features of the system are:

- The existing PRV is still required with the PaT in parallel. To ensure unfailing water supply to the production level, it can either be supplied through the existing PRV (as usual), or the PaT when energy is recovered.
- The PaT is designed to give the same back pressure as the existing PRV.
- Isolating valves need to be installed on the high pressure and low pressure side of the PaT and PRV (for maintenance purposes).
- An actuated control valve is installed upstream of the PaT and PRV allowing the water to flow either through the PaT or PRV line.

**Application of a 3CPS and PaT on an existing deep-level mine**

Most deep-level mines are in the phase where the upper production levels have been mined out. In the gold mines of South Africa the operating production levels can easily be as deep as 2000 to 3500 m below the surface. The cold water is gravity fed to these levels (sometimes through a cascade system) and then the PRVs

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reduce the high pressure to the required production level pressure.

After the water is being used on the levels, it flows through drains and collects in settlers and hot water dams. The lowest hot water dam can be up to 3500 m below surface. This hot water is then pumped (through a series of pump stations) to surface where it is refrigerated and then sent back down the mine again. Typically deep-level mines circulate between 15 to 40 Ml water per day. This process is illustrated in Fig. 3.

The opportunity to save electricity lies on the cold water side by recovering the head of the incoming cold water.

A 3CPS or Pelton turbine can be installed at the higher levels where no active production takes place. The system then breaks the cold water pressure and supplies the production levels lower down in the mine.

In addition to the 3CPS or Pelton turbine, a PaT in parallel can be installed at each production level because the production levels require a pressure of only 1 to 2 MPa.

The water reticulation schematic of a conventional deep-level mine is illustrated again in Fig. 4, but this time it shows also a 3CPS and PaTs as installed. In this scenario all the pressure of the cold water is recovered and none is dissipated.

Case studies

Installation of two 3CPSs

The author, together with HPE, is involved in installing three 3CPS projects at deep-level mines in South Africa. Two have been successfully completed and one is in the process of installation. The design specifications of the three projects are shown below:

- Maximum pumping capacity: 240 – 380 l/s
- Operating pressure: 11 – 19 MPa
- Pump energy saving: 3,5 – 5,8 MWe

Results obtained from the two completed projects show that the combined energy saving are approximately 2,1 GWh per month. This equates to approximately 15% of the total pumping costs.

The average monthly saving on pumping electricity costs for the two projects is R500 000 (2012 Megaflex tariff). Eskom funded 50% of installation costs and the payback for the mines is less than three years. Below are two pictures of the installations.

Case study of a PaT

A case study was done to install a PaT at a production level of a deep level mine by an ESCO [6]. The PaT was not actually installed, but the business case was developed to explore the feasibility of such a project.

The PaT design operating conditions for the specific production level were:

- Water flow required on production level 110 l/s
- Upstream pressure 6,2 MPa
- Downstream pressure 1,1 MPa

For this level the recovered power on the PaT is calculated at 375 kWe. If this can be installed at all the production levels the saving can be at least 1,5 MWe resulting in approximately 10% of the pumping costs.

Eskom IDM funding mechanism will also fund projects like these and this will give the project a payback of around three years, similar to that of a 3CPS.

Installing a PaT in parallel with an existing PRV, the potential exists to save an additional 375 kWe at production level. This can be done on all production levels and therefore can save the mine another 1,5 MWe, resulting in a 10% reduction in the pumping costs.

If both these options are installed in deep-level mine all the pressure of the cold incoming water is recovered and none is dissipated. Pumping costs can then be reduced by 25%. The payback for the client is approximately three years, which makes it a very good business case.

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References


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