ABSTRACT

This paper reports on the progress of an industry survey examining the current use of electrical machines and drives in the mining industry. Problems and issues arising out of the current practice are examined. The problems identified include occurrences of mechanical stresses in components leading to failures, power system voltage regulation issues and slow take up and application of new drive technologies. Arguments are presented to ways in which the application of modern AC drives can alleviate many of these problems.

INTRODUCTION

Surface and underground mining machines are large in terms of their physical size and power ratings. Electrical motors, with ratings ranging from hundreds of kilowatts up to megawatts, drive the majority of motions on these machines. These motors (or their drives) are typically supplied at 3.3kV and draw hundreds of amps. The mechanical load on the machines can fluctuate widely during normal operation. The combination of these factors make controlling these drives a non-trivial task.

Mining machines are typically located at long distances from power generation facilities and sub-stations. The large electrical currents drawn by these machines, along with the fluctuations in these currents, can often create problems with the voltage regulation at a mine site. Further, many of the machines and drives draw harmonic currents and operate at poor power factor. Both of these factors further increase the demands placed upon the power supply system.

Although there are exceptions many existing mining machines employ what would be considered old electrical drive technologies. These include DC drives and fixed speed ac machines operating with mechanical drive devices. These are well-understood technologies and obviously function in their application. However, modern AC drive technology does offer some advantages over these traditional techniques. These advantages include reduced motor maintenance, higher reliability, lower mechanical stresses and improved power supply behaviour.

The purpose of this paper is to examine current use of electrical machines and drives in the mining industry with specific focus on electric rope shovels and longwall mining machines. Areas where these processes could benefit from the application of modern AC drive technology will be identified. Opportunities for future research and development will also be highlighted.

LONGWALL MINING MACHINES

Descriptions of the structure and operation of longwall mining machines can be found in Wauge’s thesis (Wauge 2002) along with the UOW Longwall mining website. The main components of a longwall mining machine are the roof supports, shearer, armoured face conveyor (AFC) and beam stage loader. The largest electric motors in these machines are found in the shearer and the AFC. These electrical drives dominate the power system behaviour in an underground mine. They will now be considered in more detail.

Shearer

The shearer’s function, in a longwall mining machine, is to cut the coalface. The shearer assembly contains two spinning cutter drums each individually driven by an AC variable speed drive. The cutting drums have picks mounted on their circumference, which physically remove the coal from the coalface. Typically the shearer motors will range in size from 250 – 850kW with an operating voltage of 3.3kV. The cutter drums are attached via ranging arms to the shearer’s main body. The whole shearer assembly is then driven across the coalface by haulage motors. There are normally two haulage motors rated between 50 and 100kW.

Armoured Face Conveyor (AFC)

The AFC is a chain conveyor that runs over the length of the coalface. It is used for transporting coal to the beam stage loader. The armoured face conveyor can be up to 450m in length and 1.3m wide. Two or three AC drives...
motors typically drive the conveyor. In the two motor case one is located at the main gate and the second at the tail gate. For a three motor conveyor there are two motors at the main gate. Depending on the capacity of the conveyor the individual motors will range in size from 200 – 800kW. The conveyor is run at a constant speed (1 – 2 m/s) and as such the motors are run with a direct connection to the 3.3kV supply. No electrical variable speed drive or soft starter is used. Fluid couplings or a controlled slip transmission device are used to allow the motors to be started with no mechanical load and to limit torque applied to the chain conveyor.

**Drive and Power Supply Issues**

It has been noted that, with increases in the machine power, AFC chain breakages have become more frequent (Wauge 2002). In his simulation study of chain tension it was demonstrated that a fluid coupling (the most commonly used mechanical drive on AFC’s) is insufficient to limit chain tension during a blockage. To satisfactorily limit chain tension where a fluid coupling is employed requires the additional use of a torque-limiting coupling. However, controlled slip transmissions were noted to be more effective in limiting torque transients although still not providing complete protection against chain breakages. The study was primarily mechanical in nature and did not consider the effect of the transient currents generated in the AC motors on the electrical power supply system.

A longwall mining machine presents an electrical load that varies significantly during normal operation. Large accumulations of coal on the AFC or jams cause the electrical load on the conveyor motors to fluctuate widely. Figure 1 shows the typical torque and current characteristics of an induction motor. It can be seen that in the worst case, a stalled motor can draw up to eight times its rated current. The longwall mining machine physically sits at the end of a long electrical transmission system. Large currents cause the supply voltage to dip appreciably. This can affect the operation of other electrical equipment in the area. It also limits the torque that a motor will produce and can even prevent the starting of the conveyor itself. This results in lost production, as excess coal must be physically removed from the conveyor before it can be started.

![Figure 1 Torque and current characteristics of an induction motor](image)

The AC motors operated with direct connection to the electricity supply present a load with lagging power factor on the power supply system. These means more current is drawn from the power supply than is otherwise necessary to supply the active power requirement. It exacerbates the voltage dip problems and means that power system components must be oversized significantly to cope with the extra currents.

Driving the AFC motors with electrical variable speed drives offers some advantages over the present system. These can be summarised as;

1. The function of the fluid couplings or controlled slip transmissions (reduced starting currents, reduced torque transients, load sharing) can be duplicated by the electrical drive eliminating the need for these components lowering maintenance requirements.
2. Selecting a drive with an active front end (as opposed to a diode rectifier) allows for improvements in the power factor behaviour of the system. It also ensures significantly less harmonic currents are drawn.
by the drive compared to an inverter with a diode rectifier front end. (It should be noted that the motor running direct on line would draw lower harmonic currents again).

3. Allows for variable speed operation of the conveyor to suit production conditions. This could potentially save energy costs by operating the conveyor at lower speeds when the amount of material being removed from the coalface is small.

**ELECTRIC ROPE SHOVELS**

Historically, electric rope shovels and draglines have used dc motors and drives to power their motions. This remains true for draglines although some electric rope shovels are now being manufactured with AC drives and motors. In draglines the motors are normally controlled using a Ward-Leonard system. Figure 2 shows a representation of this system. The DC power used for a motor is derived from a separate generator driven by an AC synchronous motor. The generator field is controlled to adjust the generator's DC armature voltage and ultimately the speed of the motor. The advantage of this approach is that the control equipment is located in the low power field circuit making it simpler and less expensive to implement. The method provides excellent control of speed over a wide range and imposes no limits on the draglines operation. Another advantage is that the field can be adjusted on the synchronous motor to adjust the power factor drawn from the supply grid. The obvious disadvantage of this approach is that it requires investment in three full size machines as opposed to a single machine. This is mitigated slightly on a dragline where multiple generators can be driven by a common synchronous motor. However, the capital cost of this method has seen its application disappear from most other industries.

![Figure 2 Ward-Leonard method of speed control](image)

In electric rope shovels, where DC drives are employed, it is more common for phase controlled thyristor converters to be used to generate a variable DC supply for the motors directly from the AC mains. Figure 3 shows a typical converter topology and corresponding voltage waveforms. The thyristor turn-on angle (or phase) is adjusted to vary the DC voltage applied to the motor and effectively its speed. This method offers the same level of performance as the Ward-Leonard system with significantly reduced capital costs and space requirement. During normal operation the rectifier would be phased back to some extent to allow margin to regulate the DC voltage. The implication here is that this drive arrangement does present a lagging power factor load to the supply grid and significant harmonic currents are drawn.

The lagging power factor presents difficulties to surface mining machines as was shown for their underground counterparts. Mines tend to be located at some distance from electricity generation infrastructure, effectively at the end of long transmission lines. The lagging power factor load of one shovel can cause the line voltage at a mine site to reduce. Phase controlled converters do not tolerate voltage dips very well, particularly when regenerating back into the supply grid. Regeneration is a common operating mode for shovels. If the line voltage deviates outside a specified range the controller on a motor will typically register a fault and shutdown. This nuisance tripping of course impacts negatively on the availability and productivity of the shovel.

The DC drive technology described represents what would have been considered standard practice in other industries during the 1970's and 80's. Since this time AC drives have improved dramatically given the availability of more powerful microprocessor control circuits and new power electronic switching devices. As such modern AC drives offer the same performance capabilities as DC drives. A study has been made on the advantage of employing AC drives in electric rope shovels (Brown 2000) and indeed some rope shovels are now
manufactured with AC drives. The key arguments in favour of AC drives relate to the potential to reduce the cost/ton of material moved by a shovel. These arguments are;

1. AC motors are more compact and less expensive than DC motors. This allows larger capacity machines to be built for a given size requirement.
2. AC motors have no commutator. Consequently they require less maintenance and are less prone to failure.
3. AC drives utilizing IGBT power switches can be switched off in the event of earth faults limiting equipment damage. The thyristors used in phase controlled DC converters are line commutated and are often destroyed in the event of an earth fault. The thyristors can be protected by high speed fuses but these are frequently more expensive than the thyristors themselves.
4. Utilizing an AC drive with an active front end (as opposed to a diode rectifier) allows the power factor of the load to be controlled. This is advantageous for a number of reasons.
   a. These inverters are more tolerant of supply voltage drops.
   b. The electrical feeder equipment need not be oversized with regard to the active power requirement of the shovel. This is because power factor can be controlled in these inverters and the harmonic currents drawn are significantly less than those drawn by a phase controlled DC converter.

![Figure 3 (a) DC phase controlled converter topology and (b) voltage waveforms](image)

**ENVIRONMENTAL ISSUES**

In advocating the use of AC drives in mining applications it must be recognised that the applications do present harsh operating environments for the electrical drives. In particular the drives will be routinely exposed to heavy vibrations, dust, and high temperatures. Further, in underground mines there are issues arising out of the potentially explosive environment. It is not possible to take an “off the shelf” drive and expect it to operate in these conditions. Instead a drive must be specifically engineered for the operating environment. However, this does not represent an insurmountable problem. It has been noted that there are already drives used in these environments. The same techniques used in preparing these drives would have to be applied to any new drive system placed in a mining machine.

**CONCLUSIONS**

It has been observed that mining machines present unique problems in terms of their electrical drive requirements. Large power machines are required in situations where power supply is often weak or heavily stressed. Many of the application problems have been clearly solved using technology that was readily available in the 1970’s. The methods employed have largely remained in use until present times. This is despite the development in AC drives. It is recognised that one of the reasons there has been resistance to the application of
new technology is that mine sites present a harsh environment to electronic equipment. “Off the shelf” solutions are not available, as the drives must be modified for the environment they are to work in. However, it is argued that there remain advantages to employing newer technology. Broadly speaking advantages include reduced motor maintenance, higher reliability, lower mechanical stresses and improved power supply behaviour. All of these would impact on reducing the cost / ton of material moved in a mine site.

REFERENCES

