The challenges facing designers of large variable speed

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 Introduction In the mining industry grinding mills are used to crush mined ore. To take advantage of economies of scale, more ore needs to be processed in-order for the mine to be more profitable.

To process the ore mining operations have adapted large grinding mill drives in the megawatt power range. The power consumption of the large drives has forced designers to look at ways of Increasing their efficiency. Variable speed drives have been employed in large grinding mills used in mining. The use of variable speed drives has allowed for the efficiency of the drive to be increased and also allows for a more flexible grinding process. The grinding mill drivers speed and torque is varied depending on the characteristics of the ore they are grinding and on the quantity of ore within the mill.

This allows for the grinding process to be flexible to changes In the process. The use of variable speed drives has also allowed for a single converter to be used for inching the drive during maintenance and for speed control. This feature is not possible with fixed speed drives. The variable speed drives used in the mining industry also have a functionality of detecting frozen charge. This feature is used to protect the mill from damages should the frozen charge drop as the mill is rotated from stand still. This report investigates the challenges faced in the design of grinding mill drives for mining operations.

The challenges investigated are control challenges, mechanical challenges and electrical challenges. In the report background information on the types of drives used in industry to control the speed of motors Is discussed. Power electronic converters and the harmonics they produce are Investigated. The control mechanical and electrical challenges encountered with the use of grinding mill drives in mining are also investigated. Background In industry variable speed drives are used to control the speed and torque of rotating electrical machines [1].

This results in the operation of machines being more efficient. Variable speed drives are used to control and regulate the speed of the machine under no load and load conditions. In industry variable speed drives are used to control both AC and DC motors. Mechanical variable speed drives (Gearbox) were used to mechanically control the speed of the drive. The mechanical variable speed drives was placed between the shaft of the driving motor and the shaft of the machine being driven. The gearbox was used to control the speed and torque of the driven machine.

Mechanical variable speed drives are divided into belt/chain driven drives and metallic friction drives [1]. A diagram off mechanical variable speed drives is shown in Figure 1. Figure 1: Diagram of a mechanical variable speed drive [1]. Another type of variable speed drive is the hydraulic variable speed coupler. A prime mover is used to drive a hydraulic pump which in turn drives the shaft of the driven motor. The speed of the driven shaft is controlled by controlling the fluid flow rate or pressure within the hydraulic pump [1]. These types of drives have high starting torque [1].

A diagram of a hydraulic variable speed coupler is shown in Figure 2. Figure 2: Diagram of a hydraulic variable speed coupler [1]. Another type of variable speed drive is the eddy current coupler. The eddy current coupler magnetically couples the shaft of the prime mover to the shaft of the driven machine [2]. There is slip between the two shafts. The speed of the driven machine is controlled by varying the DC excitation of the eddy current coupler. A diagram of an eddy current coupler is shown in Figure 3. Figure 3: Diagram of an eddy current or electromagnetic coupler [1].

The types of variable speed drives discussed above are not based on power electronics. Power electronics allow for the direct control of the speed of the prime mover. There are variable speed drives for DC and AC motors. Variable speed drives for DC motors use a silicone controlled rectifier (SCAR) based AC/DC converter. The converter can be a full wave 12 pulse bridge, a full wave 6 pulse bridge of a half wave 3 pulse bridge [1]. The speed of the motor is varied by adjusting the amplitude of the armature voltage or the field flux of the machine.

The speed of DC machines is usually controlled by changing the armature voltage [1]. A diagram of a DC motor variable speed drives is shown in Figure 4. The speed of AC motors on the other hand can be controlled by varying either the urgency of the armature voltage and the number of poles of the machine [1]. However changing the number of poles of industrial machines is impractical. Induction machines do not operate at synchronous speed. The slip of the machine is also used to control the speed of the machine. Synchronous machines can be controlled by varying the frequency of the supply AC.

A diagram showing the configuration of an AC variable speed drives for controlling the speed using variable frequency and slip control is shown in Figure 5. Figure 5: Diagram of AC motor variable speed drives using variable frequency and lip control [1]. Power Electronic Converters Power electronic converters are used to convert AC to DC and DC to AC. Rectifiers convert AC to DC and inverters convert DC to AC. The 6-pulse bridge and the 12-pulse bridge SCAR based converters are commonly used for speed control of large AC motors (rated in Moves).

The commutations of the SCAR based bridges produces AC harmonic currents on the AC supply. AC voltage harmonics are generated on the DC link of the converter. The order of the harmonics generated is given by equation 1 . N= kipB±l Where: n= order of the harmonic, k= pulse number, p= integer. A 12-pulse bridge converter produces fewer harmonics compared to a 6-pulse bridge converter. A 6-pulse bridge converter produces even and odd numbered harmonics. In a 12-pulse bridge converter the odd numbered harmonics are minimized, leaving the even numbered harmonics.

On the DC side of the converter AC voltage harmonics are generated. The AC voltage harmonics are smoothed by a series connected inductor on the DC side of the converter. On the AC side of the converter filters are used to minimize the amplitude of the harmonics produces. The filters used can be active filters, passive filters of hybrid filters. Control of Motors Driving Grinding Mills in Mines Grinding mills in a mining environment are used to grind extracted ore in-order for minerals to be extracted. The control system of a variable speed drive is used to control the firing of the Scars within the converter bridge.

The control systems used must be highly reliable and rugged to withstand voltage fluctuation within an industrial environment. Grinding mills drives are operated at low speeds and require high starting torques. In the mining industry sugarless grinding mill drives use synchronous and induction motors as the prime mover. There is a need to intro the speed and torque of the machine in-order to increase the efficiency of the grinding mill and to make its operation flexible. To control the operation of the motors the speed and torque is controlled.

The speed of the motor is controlled by varying the supply frequency or the number of poles of the machine. The in equation 2. Ins= puff (2) ins: synchronous speed, f : frequency, p: number of poles The option of varying the speed of the synchronous motor by varying the number of poles is impractical in a mining environment. The method used is frequency control of machines to control their operating speed. To control the torque of an AC machine the air-gap flux should be controlled. The ratio of the supply voltage and the machines operating frequency is proportional to the machines air-gap flux.

The ratio of the supply voltage and the machine’s operating frequency should be maintained to ensure it does not increase to a point where the machine operates in the saturation region. If this ratio is decreased the torque of the machine decreases. To control the speed and torque of the motor, both the supply voltage and supply frequency should be controlled. Grinding mill drives require large starting torques and operate at low speeds. The variable speed drive used in a grinding mill must be able to provide high starting torques and should be able to operate the grinding mill drive at low speeds.

In mining operations three types of variable speed drives are common. They are the load commutated inverter (LLC), the coelenterate and slip control variable speed drives. Load Commutated Inverter Drive The load commutated inverter is a reliable, robust and efficient variable speed drive [3]. The load commutated inverter is a current source converter. The load commutated inverter drive uses a line commutated rectifier, with a DC link having a nothing inductor and an inverter. The converter bridges are manufactured using transistors which are commutated by the motor back NEFF of the synchronous motor.

A schematic diagram of a load commutated inverter drive is shown in Figure 6. Figure 6: Schematic diagram of a 12-pulse load commutated inverter variable speed drives [3]. The rectifier bridge converts the AC supply voltage into DC. The DC is smoothed using a series inductor and is inverted back to AC with variable frequency and amplitude. The synchronous motor speed is controlled by the load commutated inverter by changing the frequency of the AC current produced by the converter [3]. By varying the DC current produced by the rectifier bridge the torque of the synchronous motor can be varied.

The DC current is varied by varying the firing angle of the rectifier bridge. The load commutated inverter drive can generate frequencies lower than the supply frequency as well as frequencies larger than the supply frequency. The load commutated inverter transistors are commutated by the back NEFF from the motor. For grinding mills which operate at low frequencies the load commutated inverter drive mutate the inverter causes the synchronous machine to develop pulsating torque [4]. The pulsating torque developed causes problems when the drive has to be maintained and inching needs to be used.

As a result a separate device is used for inching the grinding mill [4]. At low loading and low operating speed the load commutated inverter draws lagging reactive current which cause the power factor of the system to decrease [3]. To increase the system power factor the induction motor DC excitation needs to be increased. This caused the synchronous machine to draw leading reactive currents. The leading reactive current drawn by the synchronous motor will aid to increase the power factor in the system due to the lagging reactive current drawn by the load commutated converter at low speeds with the mill lightly loaded.

Coelenterate The coelenterate converts the AC supply voltage into a variable voltage and variable frequency voltage waveform without using a DC link [1, 5]. Two back to back theorists bridges are used per phase for the positive and negative cycle of the voltage waveform [5]. The limitations of the coelenterate is that it cannot produce frequencies above the supply frequency [1]. This is however not a limitation for grinding mill drives as they operate at frequencies lower than the supply frequency. A diagram of a coelenterate driving a motor is shown in Figure 7.

Figure 7: Coelenterate variable speed drive [1]. The coelenterate has two operating modes: sinusoidal operation and trapezoidal operation [3]. Within

the sinusoidal operational range the drive hash a constant torque and power can be varied [3]. In the sinusoidal operating mode the coelenterate draws lagging reactive current from the AC supply. This causes the system to have a low power factor. If a drive is to operate at high speeds the rapidly mode is used. In the trapezoidal mode the drive will have constant power with varying torque [3].

In the trapezoidal mode the coelenterate draws less reactive currents from the AC supply when compared with operation at the sinusoidal mode. In the application of grinding mill drives used in the mining industry the coelenterate operates in the sinusoidal mode due to the low operating speeds of the grinding mills. Slip Control Variable Speed Drives Slip recovery variable speed drives are used to control the speed and torque of wound rotor induction motors. This is because the rotor 3 phase windings of the aching are accessible externally via the slip rings [1].

To control the speed of the machine external resistors can be connected to the rotor circuit to increase the resistance of the rotor. By varying the resistance the rotor current can be varied. If the external resistance is increased, the rotor current decreases. This causes the toque of the machine to decrease, which causes the machine slip to increase. The increase in the machine’s slip causes the rotational speed of the machine to decrease. The use of external resistances to control the speed and toque of wound rotor induction motors is highly inefficient [46]. This is due to heat losses across the to be increased.

This causes large heat loss across the external resistors. To operate the induction machine at low speeds, large external rotor resistors are required which causes the efficiency of the drive system to be lowered due to large heat loss. Figure 8: Variable speed drives using external rotor resistors [1]. Due to the inefficiencies associated with the use of external variable resistors to control the speed of a wound rotor induction machine, slip energy recovery variable speed drives were developed. The type of variable speed drives also controls the speed of he wound rotor induction machine by controlling the rotor current of the machine.

Instead of the use of external rotor resistors, theorists bridges are used to control the rotor current. A rectifier theorists bridge converts the rotor current to DC. The AC rotor current is rectified to DC and smoothed using a choke. The DC current is inverted back to an AC current again. The rectification process produces a DC current of the required amplitude in-order to obtain the desired rotor speed. The DC current when inverted to AC is fed back to the AC supply through a transformer [1]. A gram of the slip energy recovery variable speed drive is shown in Figure 9. Figure 9: Slip energy recovery variable speed drive diagram [1].

The disadvantage with a slip ring recovery variable speed drive is the large lagging reactive current drawn by the converter when the motor is operating close to the synchronous speed [6]. However since the grinding mill operates at low rotation speeds, the lagging reactive current drawn by the converter will be minimized. To operate the drive at speeds close to the synchronous speed, but with reduced lagging reactive power drawn by the converter two methods can be used. External resistors can be used to accelerate the motor to about 80% of the synchronous speed and then drive it using the slip ring recovery variable speed drive [6].

The second technique that can be used to operate the drive at speeds near the synchronous speed is to use a 12-pulse converter bridge instead off 6-pulse converter bridge [6]. Mechanical Problems of Large Grinding Mills. With the invention of sugarless mill drives, the grinding mill size has increased drastically. However the large sizes that grinding mills can reach in-order for mines to take advantage of economies of scale when processing ore comes with challenges. The large size of the mills causes mechanical resonances on the grinding mill.

This is due to the Riga of the grinding mill drive being unsymmetrical and is amplified by the forces exerted on the drum during the grinding process [7]. The grinding mills utilized in industry are the semi-toughens grinding mill (SAG) which uses steel balls inserted inside the mill to aid with grinding the ore, the second type of grinding mill is the toughens grinding mill in which the ore is used to grind itself [7]. Large SAG mills have problem associated with the steel balls damaging the drum of the mill. There are also problems with the steel balls getting damaged and as a result the efficiency of the grinding is decreased.

Large grinding mills require protection against frozen charge. If a grinding mill was will settle and harden forming frozen charge [4]. When the grinding mill is restarted the frozen charge will move to a larger angle as the mill rotates. A point will be reached when the frozen charge breaks loose from the drum due to gravity and drops. This can cause damage to the grinding mill. To protect against frozen charge, the variable speed drives used to drive grinding mill are designed with frozen charge protection. To avoid the occurrence of frozen charge inching the grinding mill is used.

Inching is when the mill is rotated at speeds lower than the operating speed. This prevents the ore to settle and form frozen charge. Inching is also used for maintenance and inspection purposes. Due to the large size of grinding mills used in mining if the mill is stopped for long periods of time during maintenance, the mill deforms due to load unbalances [4]. Inching is also used during maintenance to prevent load unbalance. Electrical Problems Caused by large Grinding Mills Large grinding mill drives using wound rotor induction motors or synchronous tutors require large stating currents when started directly on line.

The starting current required causes voltage dips on the network which can affect other equipment connected on the same network. To reduce the starting current of these motors variable speed drives utilities soft start techniques. The motors are started at low speeds which draw low currents. This result's is minimized voltage dips on the network due to motor starting. The commutation of transistors used in the converters produce harmonic currents which are fed back into the AC power system. A discussion on the harmonics reduced by converters is in section 3.

The magnitude of harmonics generated can be reduced by using filters and by increasing the pulse number of the converter bridge. The converters also draw lagging power factors which decreases the power factor of the drive system. Conclusion The use of variable speed drives on large drives for grinding mills in the mining industry has helped to increase the efficiency of the drives. The grinding mills have also become more flexible as their operation can be changes depending on the requirements of the process at any particular time. This has allowed mines to take advantage of economies of scale.

This is achieved by processing larger quantities of ore with the flexibility of increasing or reducing the speed of the grinding mill depending on process requirements. The variable speed drives used to control grinding mill use theorists converter bridges. The commutation of the bridges produces harmonics which are fed back into the AC supply network. To minimize the amplitude of harmonics produced filters are used. The large sizes that grinding mills for mining operations have become pose challenges to designers of variable speed drives.