PAPER

USE OF THE LATEST TECHNOLOGY TO OVERCOME THE DEMANDS OF MILL OPERATION

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ABSTRACT

The size of mills driven by ring-gear or by a gearless solution has significantly increased in the last years. This has created additional challenges for the driven equipment. The requirements for the mechanical devices and the power grid have become more demanding. Controlled soft starting and operation, especially in dual pinion mills, as well as the protection of the equipment has gained importance. The selection of the drive solution for the mill therefore becomes more critical. Besides the classical criteria such as performance, efficiency and capital costs other factors come in the evaluation of the system such as flexibility and optimization of operation, reliability and the ageing of the grinding equipment.

Variable speed solutions offer significant advantages over conventional fixed speed drives due to their application specific features and process optimization capabilities, even for ball mills where these are not seen yet as a must.

The initial capital costs are higher than some of the direct on-line solutions however the benefits for the operation during the lifetime of the mill generated by the use of converter solutions justify the additional higher investment.

INTRODUCTION

The method of powering mills such as AG, SAG and Ball has a long and technically interesting history. It can be said; almost every decade in the last half century had its own trend. The trend was dominated by the market demand, by the process development and requirement of the mechanical and the electrical technology but mostly by the price of the applied technology.

All has started about 50 years ago with mill diameters less than 20 feet driven by fix speed synchronous or wound rotor motors with the power of about 2 MW. Around 10 years later, the mill sizes increased, but the necessary torque could not be transmitted by one pinion therefore dual pinion solutions were developed to power the mills. However, realization of the dual pinion solution was only possible when load could be evenly shared between the two pinions.

When mill diameter and mill power became again increased, only the Gearless Mill Drive (GMD) could be envisaged to cover this requirement above 10 MW. The GMD is by its nature a variable speed drive system. Process operators, once having the facility of adjustable speed, could not live anymore without it for SAG mills. Because of economies of scale, and also because of the technological advances in this area, the mill diameter rose up to 40 feet with a drive power of 28 MW. A design of up to 44 feet with a maximum power of 36MW is already available but not yet realized. Also the ball mills became continuously larger and reach today up to 22 MW for 28 feet diameter.

In the last decade the market above 34 feet mill was covered almost completely by the GMD solution. Reason enough for gear suppliers to research and achieve new designs in the area of girth gears and reducers. Together with new families of variable speed drives the possibilities are available nowadays to equip mills of a diameter up to 36 feet with gear.

As a result of today's requirements for maximizing grinding throughput, larger mills with higher power demand have been developed and installed. The increase in size and power of the mills, as well as the different available alternative from the drive solution side, requires a more detailed and deeper investigation in to the selection of the mill final configuration to design the final grinding circuit. The drive selection has a direct impact on performance, flexibility of operation, total efficiency and reliability of the system. This paper focuses on the variable speed solution for geared and gearless mill drives and shows the advantages and possibilities that this kind of solution offer.

MILL SOLUTIONS

Depending on the power required to turn the mill, different configurations of the mechanical set up are possible. The maximum torque transmission is defined and limited by the mechanics. Nowadays this is restricted to approximately 9 MW for single pinion solution. Above this power a dual pinion configuration is required, this also implies that mills bigger than 18MW can only be driven by GMDs.

Figure 1: Typical mechanical mill configurations

The central driven mill solution is found on the lower power range of the mills due to the high torque that has to be transmitted to the mill through the torque tube at the charge or discharge side of the mill.

Single and dual pinion configurations can be powered by low speed synchronous motors (approx. 160 - 200rpm) connected directly to the pinions driving the ring gear or by high speed asynchronous motors (approx. 750 - 1500 rpm) that require a reducer between the pinions and the motors.

The gearless mill drive is covering the upper power range of the mills. The torque is transmitted to the mill directly through the magnetic field in the air gap of the motor, eliminating the gear reducer, the ring-gear and the mechanical related issues faced by maintenance with ring-geared mills. In fact the rotor of the ringmotor is the mill itself and the stator is built around the mill shell. This is also the reason why the ringmotor is also known as wrap-around motor.

DRIVE TECHNOLOGIES

In the not too distant past, variable speed solutions were limited and expensive. About 30 years ago a small number of drives were variable speed; most installed motors were fixed speed. Eighty percent of the variable speed solutions were accomplished with DC drives and the rest were based on the slip energy recovery system with a wound rotor motor or AC drives. Faster and more accurate controllers, the improvement in the power electronic components and the extensive reductions in costs and dimensions of the hardware has revolutionized the way of drive process control methods. Nowadays, AC drive technology has taken over the market completely. The volume of installed AC variable speed drives increases every day. The efficient and reliable technology of AC drives has overtaken the DC solutions which have practically disappeared from the market on new installations.

This evolution from fixed speed through DC to AC variable speed brought additional benefits from the electrical, mechanical and operational point of view.

Due to the high power requirement, medium voltage (MV) drives are the best solution on mill drives. MV drives require fewer cables than LV solutions and the efficiency of the complete system is higher due to less current and hence lower losses.

On the GMDs, where high power and very low speed is required, the cycloconverter is still the most effective and compact drive solution. However, on ring-geared mills, where the power is lower and speed is relatively higher, multilevel voltage source inverter technology is the right answer.

Cycloconverter

The cycloconverter is a frequency changer which converts a polyphase voltage with the frequency f1 into a single or poly-phase voltage with a different, lower frequency f2. In the case of the gearless mill drives the operational output frequency is from 0.3 Hz up to about 5 - 6 Hz. Energy can be transferred in either direction directly without a DC link. Consequently, the cycloconverter is classified in the group of line-commutated converters. If the output current of a converter is controlled to obtain a sinusoidal shape with a given frequency, as shown on Figure 2, the arrangement acts as a frequency converter and is called a cycloconverter.

By virtue of its design, the cycloconverter consists of reversible, usually half-suppressed thyristor converters as known and used for years with DC drive. The basic unit is generally a three-phase bridge where a three-phase voltage is converted into a direct voltage. In this way, the converter output is a positive, rectified voltage in rectifier operation, or a negative, rectified voltage in inverter operation. By means of phase-angle control this voltage can be continuously varied from zero to roughly the maximum phase-to-phase AC voltage, both in the positive and the negative polarity. The reactive power of commutation required for the transfer of current between the individual legs of each bridge is obtained from the power system.

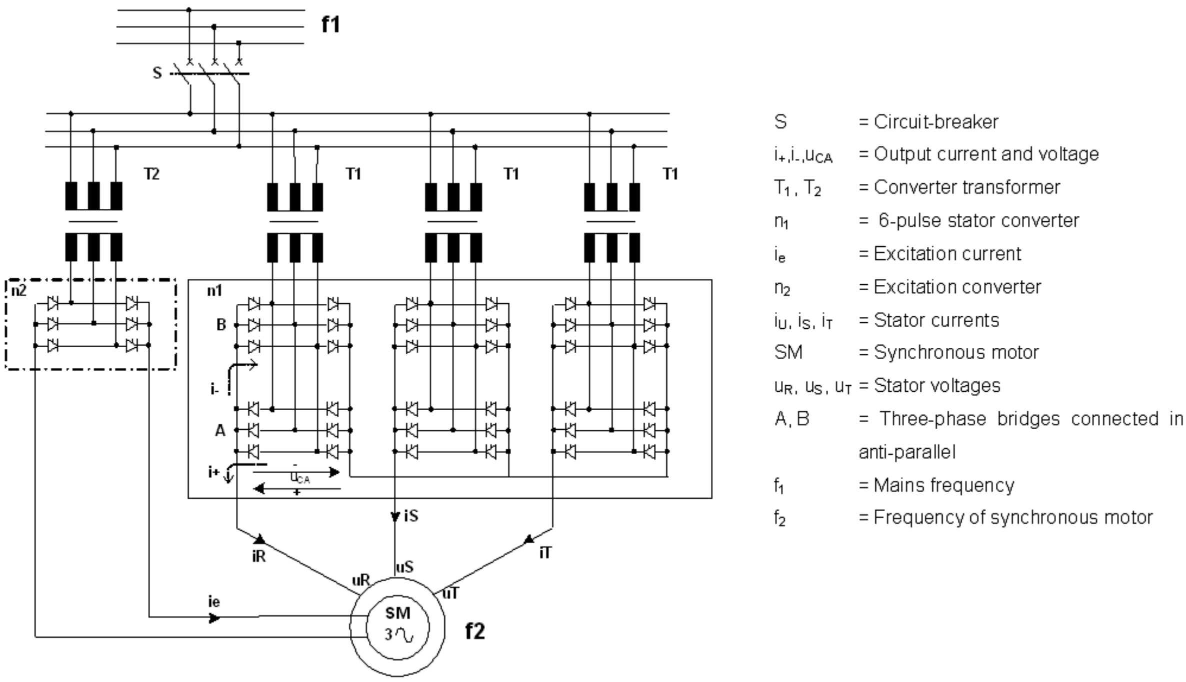

Figure 2: Principle design of a 6-pulse cycloconverter

The power factor of this solution is relative low and not constant over the entire speed range. The drive generates harmonics and inter-harmonics. The total harmonic distortion depends of course also on the number of pulses of the cyclo converter. Nowadays 6, 12 and 18-pulse cyclo converters are available. On the other hand this technology has several main advantages, such as the fact that the drive has an inherent 4 quadrant operation allowing reversible rotation and the controlled roll back of the mill. The last one is achieved by feeding the braking energy back to the network. The high efficiency of a direct drive, the flexibility of selecting the optimal motor voltage, the fact of being very compact, and the excellent performance at low speeds, including the overloadability required during starting makes the cycloconverter the best available technology to feed the gearless motor with a huge rated power.

Voltage Source Inverter

The Voltage Source Inverters (VSI) are the most common topology today and can be used with induction and synchronous motors. They consist mainly of a rectifier which creates a DC voltage and an inverter output unit which feds the motor with a variable frequency and voltage allowing speed variations. The capacitor bank located in the DC link smoothes the voltage and supplies reactive power to the motor while uncoupling at the same time the motor from the network and protecting it from network transients and faults.

The rectifier can be of a 2 quadrant type, built with a robust diode bridge. The diode bridge has the advantage of having a constant lagging power factor above 0.95 under all conditions. If this is not sufficient a 4 quadrant rectifier, built out of controllable power semiconductors can be used, bringing the power factor to 1 and even giving the possibility to have a leading power factor. The generation of harmonics to the network is the lowest of all variable speed drive; therefore in most of the cases no filter is required. The self-commutated inverter units use High Voltage Insulated Gate Bipolar Transistor (IGBTs) or Integrated Gate Commutated Thyristor (IGCTs), with both two or higher level types are available.

The simplest topology is the two levels source inverter. This switches DC (+) to DC (-) voltage in the DC link creating the output phase voltage which can be varied as well as the output frequency by modifying the switching pattern. However, the output signal is highly distorted and the output voltage is limited to a maximum of approx. 2.3kV. This means higher currents and thus thicker cables.
The large dU/dt, created by the switching of only 2 levels of voltage, induces currents through the capacitive coupling of the cable shields, limiting the cable length. Furthermore, the harmonic current distortions generated are very high, heating up motors, not built for 2-level VSI operation. To avoid all these issues multilevel voltage source inverters were developed, reducing the THD. A multilevel solution permits a higher motor voltage, reducing the size of the cables. With an appropriate output filter possible reflections and over voltages on the cables are prevented and the cable length is no longer limited.

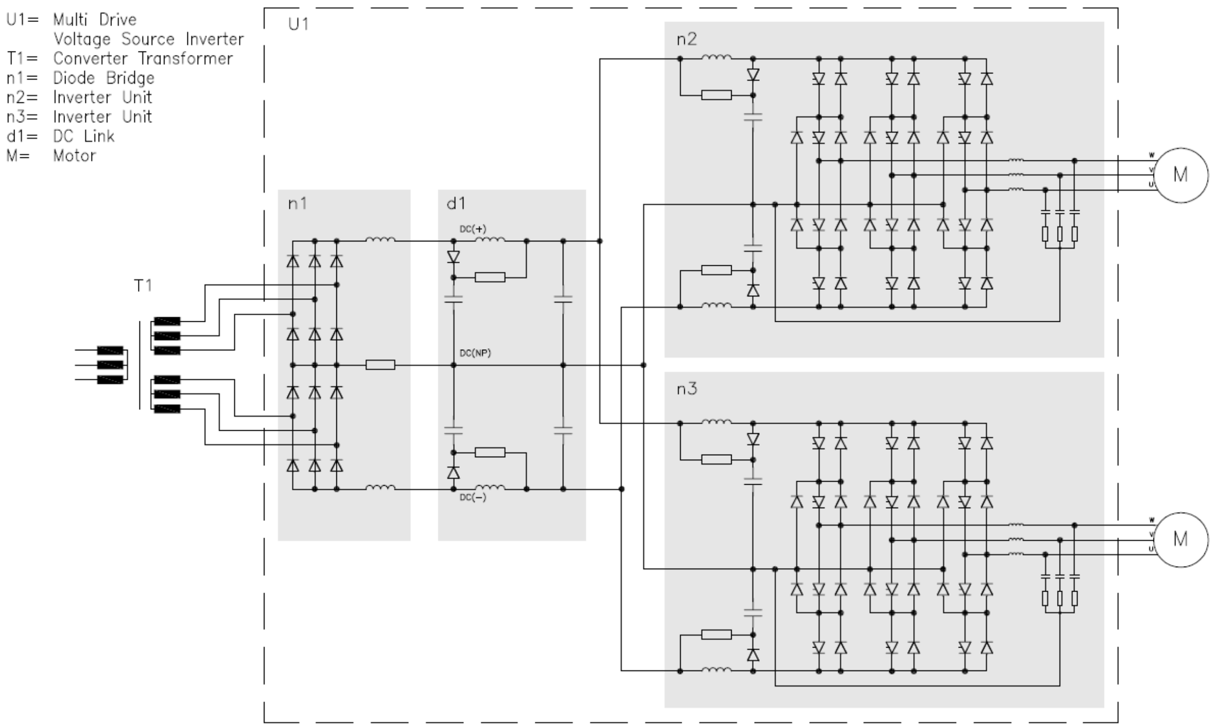

Figure 3: Principle design of a multilevel voltage source inverter for a dual pinion mill drive with induction machines

The replacement of traditional Pulse Width Modulation control (PWM) with improved motor control method such as Direct Torque Control (DTC) drive technology in the mid 90s enabled the highest torque and speed performance available in AC drives. Control has a very fast dynamic response and it is smooth under all condition making DTC the best solution for running mills. No relevant torque pulsations are generated. The high performance and robustness of DTC is achieved because of its simplicity. The control of torque and speed are directly based on the electromagnetic state of the motor (flux and torque), making a very high efficient drive (efficiency > 98%).

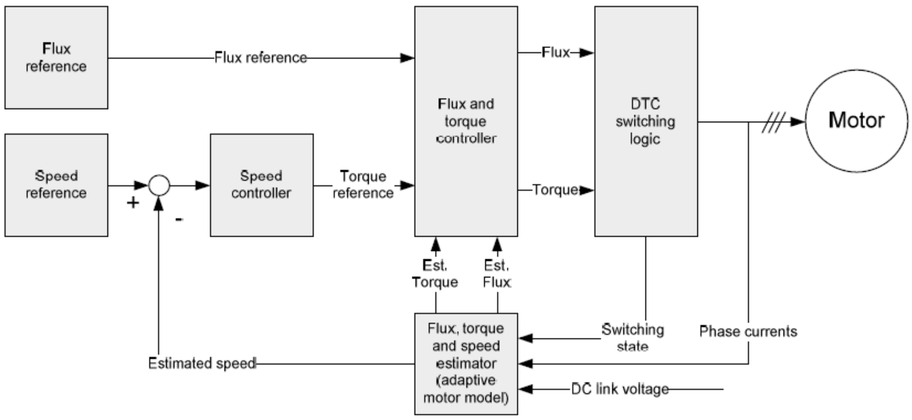

Figure 4: Block Diagram of the DTC Control

The DTC does not require any modulator as does PWM controls speeding up the response time in torque changes and allowing precise torque control. This is extremely important for dual pinion mills in order to be able to share the load of the two drive trains equally. The open loop control (no speed feedback) shown in Figure 4 is accurate enough to control the mill without a speed sensor even on a dual pinion solution, however for frozen charge protection and mill positioning an encoder is required.

DRIVE CONFIGURATIONS

Single and Dual Pinion Mills with Voltage Source Inverter Solutions

The drive configuration: an AC induction motor, in case of a high speed solution, or a brushless synchronous motor for low speed solution is fed by a (VSI) drive connected via a converter transformer to the medium voltage distribution.

The converter transformer can be connected, irrespective of the voltage of the motor, to any medium voltage level. However is not recommended to exceed the 36kV. This additional freedom can have a big impact in the design of the complete medium voltage distribution of the plant and offers additional optimization potential. Having the mill drive system (one of the bigger consumers in the mine) connected to higher voltages, allows reduction in costs on the transformation of voltages and reduces transmission of currents and hence losses.

The mills are typically single quadrant application. Some are designed for running in both directions. Depending on the mill power 12- or 24-pulse diode configurations are used.
In case of a dual pinion mill a multidrive configuration, with a common supply unit and two inverter units provide a compact solution and it only needs one MV circuit breaker.

The High Speed Motor Solution

Squirrel cage induction motors are the most common motor used in the industry due to their versatility, reliability and simplicity. The maintenance is reduced to a minimum. Typically a 6 – 8 pole induction machine running at 50 – 60 Hz is used to turn the mill. The motors are generally forced cooled; this allows running the motor at very low speed (approx. 5-10% of nominal speed) for service mode. Automatic positioning for liner changes and creeping for visual inspection can be performed with the main drive without the need of additional equipment. Depending on the environment, air cooled motors or water cooled motors are used for these powers (up to 9MW). The advantage of a totally enclosed motor is that the cooling air inside the motor is not affected by the external dusty environment. These motors are equipped with flange mounted bearings installed on the end shields of the motors. Antifriction or sleeve bearings are used. To prevent bearing damage from circulating currents, both bearings are electrically insulated. The shaft is grounded to avoid static charges of the stator.

The Low Speed Motor Solution

Due to the high torque required by the mill, low speed motors are generally synchronous machines. The mill is a low dynamic system therefore a brushless synchronous machine is best suited for this application. Brushless synchronous motors have no wearing parts, and the AC/ AC excitation power is kept small. The drive provides the supply and the excitation control as well as the necessary protection. The brushless exciter is a separate AC generator mounted on the motor shaft. For these high torque low speed motors, efficient cooling is required. The choice is between water cooled totally enclosed motors or open machines weather protected type II enclosure and filter air inlet. In addition to their high torque capability, synchronous motors offer a wide field weakening range. This allows the design of motors with nominal frequency below the network frequency. The low speed solution motor used with the drive has a nominal frequency varying from 10 – 20Hz. This means a machine with 8 – 12 poles can be used instead of the big 30 – 40 pole machine required by a fixed speed solution having the same torque output.

The main benefits of the low speed motor solution with only 8 to 12 poles, beside the lower capital cost compared to the traditional low speed motors with 30 to 40 poles, is the compactness of the motor. Less weight, smaller dimensions and therefore easier installation create less demand in the foundation design and less issue for the transportation of the equipment on site.
Depending on the power, flange mounted sleeve bearings mounted on the end shields of the motor, or pedestal mounted sleeve bearings, are provided. The motors with integral pedestal bearings are as easy to mount and align as motors with flange mounted bearings; no further assembly is required on site. A jacking oil pump permits operation of the motors at low speed

(approx. 5-10% of nominal speed) both during the starting sequence and service mode. Also for the low speed solution the bearings are both electrically insulated and the shaft is grounded.

Gearless Mill Drive Solution

The basic Gearless Mill Drive solution comprises of: cycloconverter transformer(s), excitation transformer, cycloconverter, excitation converter and ringmotor.

The number of cycloconverter transformers required depends on the number of pulses and on the mill power. Typically, 3 cycloconverter transformers are used per GMD system when 12 and 18 pulses configuration is chosen. The cycloconverter transformer primary side can be connected to any voltage level up to 69 kV, regardless the ringmotor voltage, allowing great flexibility on the MV system design.

With the current GMD design, the system is able to deliver up to 36 MW on 44’ mills. This can only be achieved by not only just up scaling, but by several comprehensive and thorough design reviews linked with a very stringent Quality Assurance program. Up to the present date, the biggest GMD in manufacture is for a 40’ SAG Mill with power of 28MW. It’s not only the power and dimensions that impresses, but also the site conditions, as this GMD will be installed at 4600masl, the highest altitude ever for a GMD. In addition there is also a clear trend to go with large ball mills: nowadays GMDs up to 22MW for 28’ ball mills are in production, which again will be installed at 4600 masl.

The ringmotor is a low speed synchronous motor fed by a cycloconverter. Depending upon the required mill speed, the number of rotor poles will be selected. In general, the bigger the mill diameter is, the lower are the mill operating and critical speeds and the higher are the number of rotor poles. It has to be noted that the number of pole units will impact, like with any motor, the motor efficiency. Since the gearless mill drive is typically by far the largest power consumer in a concentrator plant, the number of pole units should be kept to the minimum. The pole number varies typically from 48 for very small ball mills to 76 poles for the largest SAG mills.

It is almost standard option to deliver the cycloconverter and excitation controller installed in a pre-wired and pre-tested E-House container. Furthermore the E-house container also includes the supply, the control and supervision of the hydraulic and lubrication equipment for the mill bearings, the mechanical mill brake control and all the components of the drive system.

The gear less mill drive solution - by removing the mechanical components like ring-gear, pinion and gear reducer - is able to deliver unmatched overall system efficiency and availability, in a reduced footprint.

OPERATION AND MAINTENANCE BENEFITS

The use of variable speed mill drives allows process optimization and brings flexibility for the operation, while reducing the maintenance by extending mechanical components lifetime.

Furthermore, maintenance time on the mill can be reduced by using the main drive system to perform the visual inspection and the positioning of the mill for liner changes, allowing more production time. If for the GMD this solution is already a standard, for ring-gear solution this is a new possibility.

The electrical and mechanical implications of mill operation, considering the actual size, can not be neglected. Controlled operation and soft starting behavior are nowadays practically a must to keep or to increase the system overall availability. The inherent advantages that come with a frequency converter combined with mill operation features and protections programmed in a dedicated controller have met the requirements of these demands.

Process Optimization

The aim of the optimization of a grinding circuit is to increase throughput, lower variability of the resulting particle size, lower energy consumption and lower grinding media consumption (such as balls, water, liners, etc.). The process gets an additional and easy to change variable: the speed. This improves the complete grinding circuit and reduces at the same time the consumables.

Speed control allows the mill to run faster or slower to find the optimal operating point, maintaining a constant output particle size despite of changing of ore grade or liner wear effect. These variations can be caused by different ore hardness or by a different feed size distribution. Process optimization can lead to more efficient use of grinding power and thus to significant energy savings, by providing higher quality of milling and therefore reducing the need of regrinding circuits.

Two types of optimization come into consideration: off loop and on loop. Off loop speed control gives the possibility to optimize the initially calculated speed as well as to change the mill speed over the mine life-time reacting to the different ore changes. On loop speed control allows the dynamic control of the complete grinding circuit.

Process Flexibility

Beside the optimization of the process that increases the quality and the throughput by turning the mill at its optimum speed, the other key of success which allows maximization of the overall production of a mine is the flexibility grade of the grinding circuit.

Within traditional fix speed (FSD) process, as it is not possible to adapt the speed, the bottle-neck for the whole process line is set by the limitation of one of the mills. With variable speed process, all mills can be adjusted to their optimal performance, which leads to a debottlenecking of the line and to a higher production rate.

Another very important point to consider is that the load distribution on ball mills fed by a SAG mill is not equally distributed; with a frequency converter it is possible to run each ball mill with different speed according to their load.

Speed regulation allows circuit feed rate control and the balancing of the whole circuit. Moreover, partial load operation at any speed is possible. This ability means the grinding throughput can be matched to the up- and down-stream process requirements.

Speed variation of the ball mill, for example, avoids over-grinding which affects down stream processes. Over-grinding occurs when the SAG mill cannot compensate ore variations, and the adjusting of the ball charge is impractical.

Furthermore, on short SAG mill stoppages, the ball mills can be kept in operation with reduced speed, avoiding unnecessary shut-downs linked to production losses.

Mill and Mechanics Protection

The increasing on size of mills requires particular attention on the stress that the selected drive equipment can generate to the mechanics. This applies especially on ring-geared mill drive solutions. Frequency converters can protect the mechanics during normal operation and starting by limiting the torque. The mechanical stress on the ring-gear is reduced due to the smooth starting behavior. Torque pulsation and peak torques generated by all types of fixed speed solution during starting ages the mechanical equipment. Clutches needed to start synchronous machine direct on-line are not required, the frequency converter have the full control of the torque from zero speed. The precise torque control during all operating states of the mill does not generate significant torque pulsations, limiting backlash on the pinions and gear reducers (if any). This ability and the smooth start reduce dramatically mechanical stress and allows at the same time savings in capital and operational expenditure. Dual pinion geared mills are even more demanding on regards of mechanic stresses. Proper alignment of the pinions with the ring-gear, especially if designed for bidirectional operation is crucial for the correct operation and reduced wear. However not only the alignment is important also the load sharing between the two motors is essential in order to avoid torque unbalance transmission on the pinions and load oscillations. The basic principle of the load sharing in a frequency converter setup can be summarized as follow: the speed reference is sent from the process control to the master drive. The actual torque generated by the master drive is used as a reference for the follower drive. Voltage source inverter with fast DTC control samples the actual torque every 25 μs, meaning 40’000 times per seconds, ensuring an accurate and proper load sharing which improves availability of the mechanics.

Frozen Charge Protection

After a standstill, the material inside the mill tends to solidify and to stick to the mill shell. This could happen even within minutes, depending on the type of material processed. The detection of frozen charge is of significant importance in order to avoid major damage to the mill shell, bearings and liners. As the loaded mill starts up, as shown in the Figure 5, the dedicated control system implemented in the mill specific drive controller evaluates, between 30°- 75°, the torque build-up of the mill ensuring that appropriate decisions in the action phase are taken before a frozen charge can drop. If a frozen charge is detected a fast shutdown will be initiated.

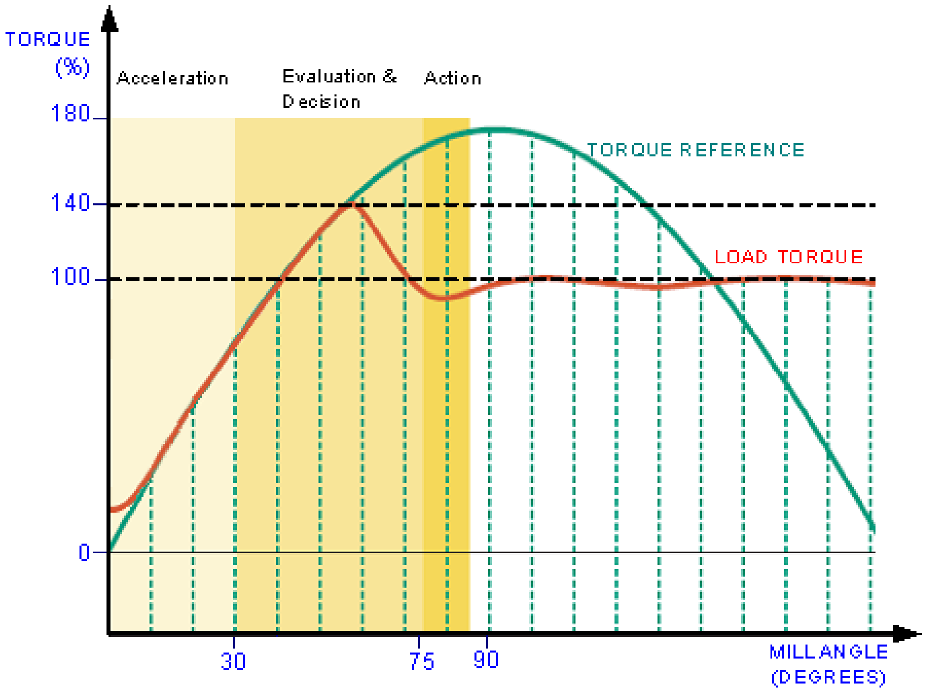

Figure 5: Frozen Charge Detection

Electrical Network Friendliness

The mills, as already mentioned, are one of the biggest consumers inside a mine; therefore limiting the current requirement specially during starting helps the network stability and reduces voltage dips. In fact, from the electrical point of view, high inrush currents and low power factor create high stresses on the network, endangering the other consumers in the plant. Generally, this occurs when big direct on-line induction motors or synchronous machines are started. Very smooth starting behavior with low starting currents, indeed are possible by starting the mill with frequency converters supporting the network.

Another advantage of frequency converter solutions is that they are able to operate at reduced voltage and try to stay on-line as long as possible, by reducing the speed and the required torque. While this, the motor acts as generator and utilizes the kinetic energy of the rotating motor and driven equipment. The power loss ride-through time depends on the relationship between the load and the inertia of the rotating masses.
When the supply voltage recovers, the drive starts back normally in speed control according to the speed set point. The surviving time depends on the energy stored in the inertia. Only if the power is lost for a longer period of time or if the situation is dangerous for the converter, the drive system switches off. This feature is especially beneficial for weak networks.

Maintenance and Reduced Shut Downs

Equipment with high reliability and availability increases the time between shutdowns improving the productivity of the mine. Gearless mill drive and the low speed motor solution for geared mills offer the highest availability. With the reduced mechanics for these solutions (no air clutch and no gear reducer) the maintenance requirements and possible root cause for failures are minimized.

The gearless mill solution does not even have gear ring, motor bearings and pinions to be inspected for wear and tear. Although component failures are not very frequent, problems with ring gears and gear reducers usually result in increased maintenance.

To prevent major shutdowns, regular inspections and maintenance of the ring-gear, pinions, bearings and gear reducers are required. The high speed motor solutions (FSD), in the earlier design with gear reducer and inching drive, are due to the more complex drive train, the most maintenance intensive solutions. The lifetime of gear reducers is not matching the lifetime expectations of the mill and need to be replaced earlier. Furthermore, the bearings of the gear reducer have a standard lifetime of down to 3 to 5 years.

The electrical equipment itself does not require high maintenance. Frequency converters and transformers today are designed and built to be as maintenance free as possible, virtually without wear parts. From the motor point of view, beside the annual visual inspections and the standard measurement, no major maintenance is required.

The wrap-around motor requires only a minimum of maintenance; brushes and the dust sealing system wear are minimal due to the low speed operation. Over-pressure fan filters have long lifetime as the motor is IP55 and the main purpose is to keep air pressure with almost no air flow. No grease or lubrication is required by the wrap-around motor; therefore no disposal costs for oil or grease are required.

For the pinion solution, brushless synchronous motor and induction machine require minimal maintenance such as replace filters, oil and other consumable if needed. This would not be the case for wound rotor induction motor (WRIM), where maintenance on motor itself and starter are higher.

Liners replacement represents a major cause of mill shutdown. Bi-directional operation of mills prolongs the liners replacement and it easily achieved with a converter, by the change of only a parameter. Furthermore, during commissioning and startup while running with only partial fill, the speed can be lowered, avoiding liner damages and limiting unnecessary wear. Harder liners with longer life-time can be used from the beginning, eliminating the need of softer starter-liners and the associated costs related to their replacement. The variable speed solution also avoids damage to the liners during filling, emptying and process interruptions by lowering the mill speed.

The frequency converter solutions support the maintenance activities by providing service modes for creeping and accurate positioning. No additional inching drive is required, simplifying the whole drive train. Creeping mode (slow rotation of the mill) can be used for visual inspections or grinding out the mill. Fast and automatic positioning of the mill based on angle or liner reference reduces the down time needed for changing liners. This is supported by a so called “controlled roll-back” function which brings the mill smoothly into a rest position where both speed and torque are zero. Having the mill in balance load condition, allows safer and faster maintenance procedures. To ensure the complete safety of maintenance personnel and equipment required performing liner changes inside the mill mechanical park brake system or a dynamic brake system are recommended. However the dynamic brake system is only required for big GMD mills where in case of absence of lubrication, they support the stoppage of the mill, preventing damages on the mill bearings.

Preventive and predictive maintenance, however, are necessary to keep production alive and to maintain the equipment reliable in operation. Therefore, the combination of shorting maintenance time and having reliable equipment is essential.

Remote access to the equipment through a secure internet connection allows fast access to check drive status from any global location. This remote supervision and diagnostics option supports site maintenance personnel during service and trouble-shooting and minimizes downtime and production losses.

EFFICIENCY COMPARISON

The evaluation of the overall system efficiency is an important decision factor during the selection of the most appropriate drive system when considering the life cycle costs.

Table 1 shows the typical efficiency figures for a 16MW ball mill with different drive configurations. It compares dual pinion variable speed ring-geared alternatives and gearless mill drive (GMD) solution. The efficiency of the ring-gear and the gear reducer are affected by other factors, e.g. alignment, and can be significantly lower than the assumed values used for this comparison. Motor and transformer efficiencies can be improved by modifying their design (which however has an impact on the capital costs) and can slightly vary depending on the application and site specific conditions.

The main observation is that, the lower are the amounts of components present on the system, the higher is the overall efficiency.

Variable speed grinding mill drives equipped with high speed squirrel cage induction motors, require a gear reducer and a ring-gear. If a two stage gear reducer[1)] is used, its efficiency further drops to about 97%. On the other hand, the variable speed alternative using low speed synchronous motor eliminates the gear reducer, improving the overall efficiency.

The Gearless Mill Drive (GMD), by removing completely the ring-gear is able to provide unmatched efficiency.

-	VSD High speed	VSD Low speed	VSD GMD
Transformer	99.1%	99.1 %	99.1 %
Converter	98.6%	98.6%	99.2%
Motor	97.2%	97.2%	96.8%
Gear reducer	98.5% [1)]	n/a	n/a
Ring-gear	98.0%	98.0%	n/a
Overall efficiency	**91.7%**	**93.1%**	**95.2 %**

Table 1: Typical overall system efficiency for 16MW ball mill

COST COMPARISON

Several factors and cost considerations must be taken into account in the drive system evaluation. A proper evaluation and the right selection of the drive system impacts the total cost of ownership (TCO) of the mill.

The TCO analysis must include direct and indirect costs. As an example of indirect costs can be cited the loss of production related to the non-availability of the system. The GMD, by having fewer components, has the highest availability. It is followed by the low speed VSD solution and by the high speed VSD.

Also as direct costs, the efficiency and the use (including disposal costs) of lubricants on the ring-geared mills shall be considered. Plant layout is a factor for evaluation when comparing geared and gearless drives. Obviously, the footprint for gearless, single pinion and dual pinion drives is different. Single pinion drives require the smallest amount of space, but only marginally less than gearless drives. Dual pinion drives have the maximum space requirement.

In the Figure 6, can be seen from left to right the electrical equipment investment decreases as the mechanical increases.

The capital expenditure for gearless mill drives is typically higher than for other drive systems. However, energy savings due to higher efficiency and reduced maintenance costs usually leads to smaller lifecycle cost compared with other drive system solutions.

The lowest capital expenditure is given by the high speed (VSD) solution, where the electrical equipment cost less and the mechanical part more, as a result of the inclusion of the ring-gear and gear reducer.

CONCLUSION

The functionality and the process advantages of the recent mill drive solutions have been shown. Due to the variable speed operation the grinding process can be optimized for ores with varying grinding properties. This leads to significant optimization potential for the plant design as well as for its operation. Furthermore, energy and cost savings due to optimized operation, high system efficiency, high system availability and reduced maintenance can be achieved.

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