Gearless Mill Drive Protection Improvements and Its Behavior at Minera Escondida Ltda.

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***Abstract*—A cycloconverter-fed gearless mill drive is a drive system that has hardware and software protection functions to protect the equipment in case of abnormal operating conditions, malfunctions or failures. For demanding applications in the mining industry, protections systems need to be reviewed considering special or abnormal operating conditions as well as the need of high system availability. Some protection functions have tripped in the gearless mill drives operating at Minera Escondida and have been reviewed subsequently.**

This paper describes improvements in the protection system implemented in the gearless mill drives currently operating at the Laguna Seca concentrator of Minera Escondida Ltda. The background of the new protection functions, related analysis and solutions are explained and experimental results are presented showing their operation.

Keywords-cycloconverter; gearless mill drive; GMD; protection; minerals processing; grinding

I. Introduction

To process an average of 120.000 tons/day of mineral, the Laguna Seca concentrator uses a SAG mill and three ball mills, all driven by gearless mill drive (GMD) systems. Table 1 gives an overview of the basic technical data of the installed drives.

TABLE I. MILLS AND THEIR DRIVES IN THE LAGUNA SECA PLANT

Equipment	Drive	Comments
SAG Mill (Semi-autogenous Grinding) Quantity : 1 unit	Composed of a twelve-pulse cycloconverter together with a synchronous ringmotor Power : 26.000 HP Voltage : 4950 V Current : 2485 A Base Speed : 9.31 rpm Maximum Speed : 10.0 rpm Base Frequency : 5.586 Hz Maximum Frequency : 6.0 Hz	The grinding mill is the rotor of the synchronous motor. Its dimensions are: Diameter : 38 feet Length : 20 feet
Ball Mills Quantity : 3 units	Composed of a twelve-pulse cycloconverter together with a synchronous ringmotor Power : 18.000 HP Voltage : 3660 V Current : 2240 A Base Speed : 11.5 rpm Maximum Speed : 13.7 rpm Base Frequency : 5.267 Hz Maximum Frequency : 6.39 Hz	Diameter : 25 feet Length : 40 feet

A. *Description of the Drive Systems*

In order to provide flexibility to the operation of the plant, the drive systems need to allow variation in speed and control of the loading torque of the mills. A GMD is adjustable in speed, and thus can fulfill the operational requirements with respect to flexibility and adjustability of the process. In addition, it does not need any gear box and ring gear and therefore eliminates mechanical wear and the related problems and maintenance. It is a drive system without any gear where the transmission of the torque between the motor and the mill is done through the magnetic field in the air gap between the motor stator and the motor rotor. The concept to drive the mill this way is relatively simple using the mill body as motor rotor and mounting the poles there. As a result the motor does not have a separate (motor) rotor and thus no separate (motor) bearings. Furthermore, there are no real design limits, neither in the electrical part nor in the mechanical considerations, allowing scalability of the drive and design optimization towards specific customer requirements. The drive system has different components and sub-systems that can be distinguished in terms of power part, control part and auxiliaries.

Figure 1. Picture of the Ball Mills at the Laguna Seca Concentrator

The first GMD with a power of 6.5 MW was installed 1969 in a cement milling process in the cement plant Le Havre in France. In the first few years, the GMD was only used in the cement industry. Almost 25 years later, the first GMD with

11.2 MW power and 13.0 rpm was installed in the minerals industry. Since then, numerous GMDs for ball mills and SAG mills have been installed in the minerals industry.

A GMD with a high power of up to 20 MW and more, as a result of today's requirements for ball and SAG mills for the minerals industry, has of course a certain complexity. It should not anymore be regarded as a simple single drive. The GMD system includes not only the drive hardware including all auxiliary systems installed in an E-house, the drive control algorithm and all protection systems, but it also includes the control and supervision of the hydraulic and lubrication equipment for the mill bearings, the mechanical mill brake control and the visualization of all parts of the drive system.

Figure 1 shows a picture of the three ball mills and their ringmotors used in the Laguna Seca concentrator. The poles of the rotor are directly mounted on the surface of the mill flange.

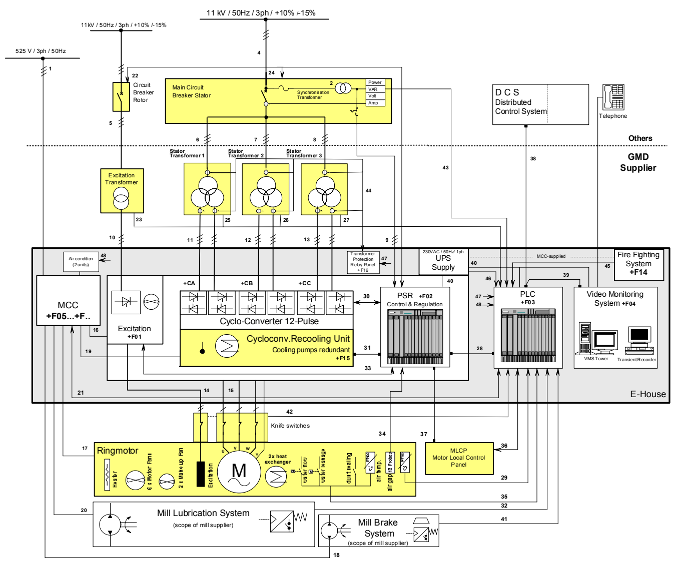

Figure 2. Overview of a Typical GMD System and Its Components

Figure 2 presents the power and control circuit of a cycloconverter fed synchronous motor. The synchronous motor has one 3-phase winding in the stator. The current in each phase is controlled by a 12-pulse cycloconverter. The 12-pulse configuration is obtained by the wye-delta connection in the secondary winding of the three power transformers and reduces the low frequency current harmonics in the load and at the input side of the converter. The motor field is excited by a separate controlled excitation system fed by its own excitation transformer.

1) Power Part of the Drive Systems

The power part of the system is composed of the following main components. Basic data of the GMD systems are given in Table 1.

- Three converter transformers with one primary and two secondary windings with the same power and wye-delta connection in the secondary winding in order to achieve 12-pulse operation. It is fed from a 23 kV bus and connected through the main switchgear.
- Power cycloconverter with no fuses, composed of two full-wave bridges groups in anti-parallel connection and with each group fed from the converter transformer secondary windings. The groups are connected in series to form the feed phases of the motor. The bridges consist of 6 power thyristors with a snubber network system and failed thyristors detection connected across the thyristors.
- Synchronous ringmotor with single layer stator windings connected in star. The GMD is also known as "wrap-around motor" or "ringmotor". The motor rotor is composed of individual poles mounted on the mill flange. The number of poles is based on the required speed of the mill. Thus, the SAG mill motor has 72 poles and the ball mill motors have 56 poles.
- Excitation transformer and excitation converter with full wave control. The excitation transformer is fed at 4.16 kV and its secondary is connected to the 6-pulse excitation converter.
- The power section protection system, over-voltage protection for the cycloconverter inlet, over-voltage protection system for the motor, basic charge system of the cycloconverter.
- Thyristors cooling system. De-ionized water is required for cooling of the thyristors and resistors of the snubber networks and basic load.

2) Controller of the Drive Systems

In the following, both control hardware and software are briefly described.

a) Control Hardware

The controller hardware used for the cycloconverters belongs to the family of high speed processing controllers called PSR 2, especially developed for the control of high power drives.

The control system requires inputs signals in order to carry out control, supervision and protection of the drive. The output signals are triggering pulses to thyristors, excitation reference current and digital outputs for control and supervision.

The processor (PPC322 AE) where the control program is running, communicates with its analogue/digital input/output cards (UAC326), digital input/output cards (UDA327) pulse generation card (GDB021) and serial communications with the plant control system (PMA324) through a 16-bit parallel communication bus B448. For command and supervision of the equipment there are local and in-field control panels with direct communication with the processor through the ARCNet network. This network also serves for control and supervision of the cooling system for the power part components (thyristors, resistors).

Part of the hardware is also represented by the PSR input signal modulation cards, the UGA 359 motor current cards, UUA 358 voltage reference adapting card, current-voltage signal converter for the motor air gap supervision and cycloconverter output voltage measuring LEM sensors. The thyristor supervision cards in the power part provide an optical signal to the XV C513 receiver cards and through the XV C512 control card, they provide a PSR controller condition signal through digital inputs. Also, there are analogue signal supervision cards (CSA 463 motor over current supervision) and digital signals (supervision of backplane cards B448, CSA 465), DDA 353 cycloconverter bridge control and pulse amplifying cards LT8951.

b) Control Software

Programming of the controller is done in a high-level graphic or function block diagram language with application software called FUPLA 400. The program is divided into CLUSTERS called INTERRUPTS. The clusters have a particularity that logic or part of the program on the cluster runs in a defined cycle time. Table 2 shows the cycle times for the clusters in the cycloconverter program. This permits incorporation of signals measured in the minor cycle time cluster and those fundamental activities and/or actions such as commutation of the cycloconverter bridges, generation of sinusoidal current of the motor for internal control purposes, protections, etc.

TABLE II. CLUSTER CYCLE TIMES OR PROGRAM INTERRUPTS

Cluster Name	Cycle Time	Remarks
Interrupt 0	833 µs (Voltage period / 24) = for 50 Hz network; 20 ms / 24 = 833.3 µs	The fastest cluster. It contains that logic or part of the program for measurement and communication with the bridge commutation card, through digital card UDA 327 mounted in backplane B448.
Interrupt 1	1.667 ms (2x Int 0)	
Interrupt 2	5.0 ms (3x Int 1)	
Interrupt 3	20.0 ms (4x Int 2)	
Init	-	This cluster runs when the processor is energized.
Int3-allen-bradl	20.0 ms (4x Int 2)	Cycle time of this cluster is the same as cluster Interrupt 3.
Backgnd	-	The logic in the cluster background is executed in the time the processor is available.
PANEL-AFC094	Background	
LCB-AFC094	Background	

Inside the clusters the program is segmented according to the functionality and/or task developed in particular by this part of the program. The segment is named in accordance with the task of function that it performs.

II. PROTECTION OF THE GMD SYSTEM AND ITS BEHAVIOR AT MINERA ESCONDIDA

The purpose of the different protection systems is to avoid damage to the equipment in case of all possible mechanical and electrical faults. Supervision systems that allow the visualization of all relevant analog and digital signals, handling of status, alarm and fault information, fault tracing and analysis, transient data recording, data trending and storage can provide important information to the operation personnel. Such data allows detecting upcoming problems in an early stage. Furthermore, such systems provide valuable information to analyze problems and therefore to solve them faster than otherwise.

The operation of a GMD is based on the design of the drive system and the process requirements. As long as there are no abnormal operating conditions or process requirements, no problems with the equipment (hardware or software malfunctions or failures), misuse of the equipment or problems with the supply network, the GMD will work fine. The main purpose of hardware and software protection systems of the GMD is protecting the equipment to avoid under all circumstances any risk to the health and safety of the operation and maintenance personnel. Protecting the equipment means to avoid any damage as far as possible or at least to limit the damage to certain components and to eliminate the risk of more severe and serious damage of larger parts of the drive system.

The basic protection functions were developed more than three decades ago and since then have worked without problems in many installations. These functions had been continuously reviewed considering specific requirements and special conditions.

At the Minera Escondida the protection systems of the installed GMDs have operated. However, there have also been phenomena that have triggered the need to review specific protection functions and to improve them.

A. *Protection Against Network Disturbances*

The drive has a protection against over- and under-voltage as well as against over- and under-frequency. Specifically, these protections are implemented in the PSR processor program in the cluster called Interrupt 0.

1) Over-voltage protection at the network side

The cycloconverter power part, as well the excitation converter, are protected via surge arresters against high and dynamic voltage peaks created by the network or by switching the converter transformers. This over-voltage protection especially protects the power semiconductor valves (thyristors) against the "avalanche breakdown".

2) Line over- and under-voltage protection

This protection function is realized inside the drive control software. Information of the actual network voltage at the high/medium voltage side is taken from the synchronizing transformer installed in the feeding switchgear (incoming side), and read in by the analogue inputs of the drive control system. The under-voltage and over-voltage detection immediately forces the blocking of all triggering pulses. Loosing the feeding voltage for any reason while triggering is still on-going, the emf voltage (electromagnetic force) of the motor as an alternating voltage would change its polarity and the motor would become a generator until it stops moving.

The emf voltage of the motor would drive a short circuit current through the motor windings and the cycloconverter thyristors. The transformer windings are not anymore in the loop to limit the current. At first, such a situation would lead to a three-phase short circuit until the first phase will cross the zero current, then the short circuit would become a two-phase short circuit until the energy of the ringmotor is zero.

Two- and three-phase short circuits at the motor terminals create unfavorable high forces (several times of nominal forces) acting on the motor and its foundation. Therefore, it is important that especially under-voltage is detected fast enough to be able to react and to block the triggering pulses. If the supply voltage has become too low then a controlled shutdown of the GMD would not be possible any more. Trip levels are set in the drive control software and are 110 % of the rated value for over-voltage and 85 % for under-voltage.

3) Excitation under-voltage at the network side

This protection is realized in the drive controller as well as in the microprocessor of the stand-alone excitation converter itself. It protects the converter module / thyristors against damage in case of loosing the network. In the worst case loosing the feeding voltage or an uncontrolled opening of the feeding breaker during motor operation could destroy thyristors and other parts of the power electronics. The rotor of the ringmotor would feed energy back to the excitation converter, which would lead to very high current and voltage to the excitation power electronics. Trip levels set in the drive control software are 110 % of the rated value for over-voltage and 85 % for under-voltage.

4) Line over- and under-frequency

In the same way the network frequency supervision is working. If the frequency is out of the allowed range (95 % to 105 % of nominal), then the system will trip. These trip levels are set in the drive control software.

The protection settings originally established are given in the following table.

TABLE III. ORIGINAL GMD PROTECTION RELATED WITH UNDER- AND OVER-VOLTAGE AND UNDER- AND OVER-FREQUENCY

Protection	Adjustment	Action	Observations
Under-voltage	85 % of rated voltage (Un) with a delay time of 30 ms	Trip	INT 0, SEGMENT S07
Over-voltage	110 % Un, 50 ms	Trip	INT 0, SEGMENT S07
Under-frequency	48 Hz, 100 ms	Trip	INT 0, SEGMENT S07
Over-frequency	52 Hz, 100 ms	Trip	INT 0, SEGMENT S07

Due to out-of-service events or trigger trips of the mills, it was necessary to review the philosophy and logic of these protections.

After commissioning of the equipment and during the phase of operations of the plant under design conditions, the ball mills presented trips due to limitation of the converter voltage in situations in which the feed network presented problems due to external causes in the electrical power system (SING) (electrical storms, oscillations due to instability, lines and/or generators out of service, etc.) and/or equipment overloads. This generated operational problems in the production process such as the overflow of slurry, obstruction of pumps, etc. For this reason ABB was asked to study the possibility of the drive detecting this situation and generating a self-limitation so that the equipment does not end up out of service, but only limits the speed generating minor impacts on operations.

For the aforementioned, the following modifications were generated in the PSR control program, and at the same time, it was decided to raise the secondary voltage of the power transformers, by lowering their taps.

TABLE IV. PROTECTION SETTING FOR NETWORK VOLTAGE AND FREQUENCY

Protection	Adjustment	Action	Observations
Under-voltage	95 % of rated voltage (Un) with a time delay of 15 ms	Alarm; Limitation of speed	INT 0, SEGMENT S07
Under-voltage	95 % Un, 60 s	Trip	INT 0, SEGMENT S07
Over-voltage	85 % Un, 30 ms	Trip	INT 0, SEGMENT S07
Over-voltage	110 % Un, 50 ms	Trip	INT 0, SEGMENT S07
Under-frequency	48 Hz, 100 ms	Trip	INT 0, SEGMENT S07
Under-frequency, Power system (SING) requirement	48.4 Hz, 100 ms	Trip	INT 0, SEGMENT S07 This level is applicable for the ball mills and is the option to select one of the ball mills with this adjustment.
Over-frequency	52 Hz, 100 ms	Trip	INT 0, SEGMENT S07

Besides, a signal called "INTERN_Min-phase-volt" is generated by the program on cluster INT 0 / S07 for limiting the speed accordingly with the network voltage reduction.

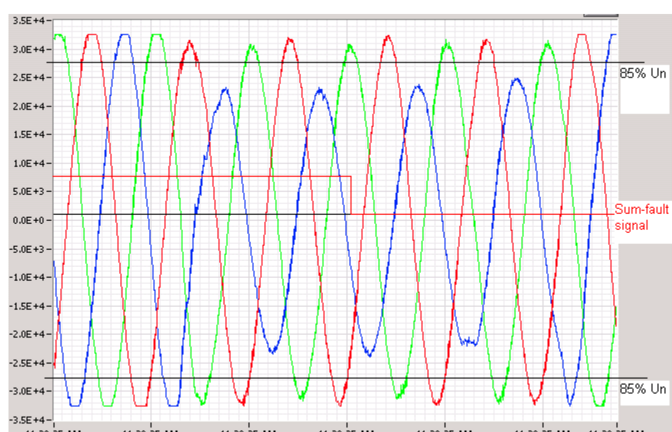

Figure 3. Oscilogram captured by transient recorder in case of network under-voltage

The alarm signal for limiting the speed of the drive in the PSR program is going to cluster INT 2 segment S14 nx-limits. The speed limitation will be activated only if the mill running speed is over 60 % of the base speed. At the same time an alarm is going to the distributed control system (DCS) so that the grinding operator will act accordingly with the speed limitation.

These modifications have generated the expected benefits, as there are speed limitations when either a slow disturbance occurs in the network voltage or the mill is overloaded. Therefore, the equipment drop-outs and the impact on operations were reduced. Figure 3 shows the network voltage signals when an event occurs that causes the equipment to trip.

B. Protection Against Motor Stator Current Unbalance

As a result of a drop-out of the ball mill 2, a protection was implemented on the cycloconverter controller against a current unbalance on the cycloconverter output.

The protection against motor over-voltage forms a part of the cycloconverter protection. This protection function protects the cycloconverter thyristors against excessively high motor voltage. It is realized by the over-voltage arresters, basically compound from two anti-parallel thyristors, fired by BODs (break-over diodes) and a set of resistors. The protection voltage limit is defined by the rated breaking voltage of the BOD.

When the stator voltage reaches this limit, the BOD conducts and causes the switching-on of the thyristor. The protection circuit forces a short circuit at the converter outlet and takes over the energy from the motor. In the resistor set the energy is dissipated into heat.

These over-voltage arrester modules have a circuit for triggering the thyristors that sense the cycloconverter output voltage and, when reaching a certain level, trigger the thyristors and connect the dissipating resistances.

In ball mill 2, the over-voltage arrester modules failed and the dissipating resistances were connected during the operation of the mill. This situation was not detected by the current circulation sensors in the over-voltage arrester modules and the equipment continued in service. The resistance reached the limit of energy dissipation and started to destroy itself, generating an increase in current that was finally detected by the magnetic sensors and tripping of the mill. The incandescent pieces of the resistance damaged some components of the cycloconverter.

These over-voltage arrester modules were installed in many previous GMD installations and never before similar problems had been experienced. The burned components were replaced and after a period of 4 days the drive was able to operate again. Nevertheless, it became clear that this failure and its effects needed to be analyzed in order to understand its root cause and the conditions under which such malfunction could occur to avoid similar problems in the future.

Analyzing the motor currents, it was seen that, when the over-voltage arrester modules failed, the phase S current increased by around 400 A whereas the other phases suffered smaller variations. This current of 400 A circulated through the dissipating resistances for approximately 300 s. Considering that the dissipating resistances have a nominal current of 1090 A for a period of 0.5 s, the time that they were connected surpassed the energy dissipation capacity and generated the effects mentioned above.

These findings resulted in a protection solution that has been implemented in the drives to avoid the effect observed in the failure of ball mill 2. At the same time, a study was begun on the basic causes of the failure of the over-voltage arrester modules.

Specifically in a balanced three-phase system, the sum of the currents is at all times zero. Monitoring of the cycloconverter output currents was implemented in the PSR program. If the difference between the actual motor phase currents is higher than 5 % for longer than 60 ms, then this function trips the drive.

Later, there was a detection of this stator current unbalance protection due to the failure of the over-voltage arrester modules. It can be said that the protection fulfilled its function, as it eliminated the effects observed in the first failure of ball mill 2. In a time of 3 hours taken to replace the over-voltage arrester modules, the equipment was fit to operate. Later factory analysis of the over-voltage arrester modules thyristors showed that the cause of their failure was due to the variations in voltage. This resulted in checking the characteristics of the thyristors in the modules. Thyristors that are more robust from a voltage point of view were specified, and up until now they have been successful as there have been no further module faults.

Figure 4 shows the operation of the stator current unbalance protection.

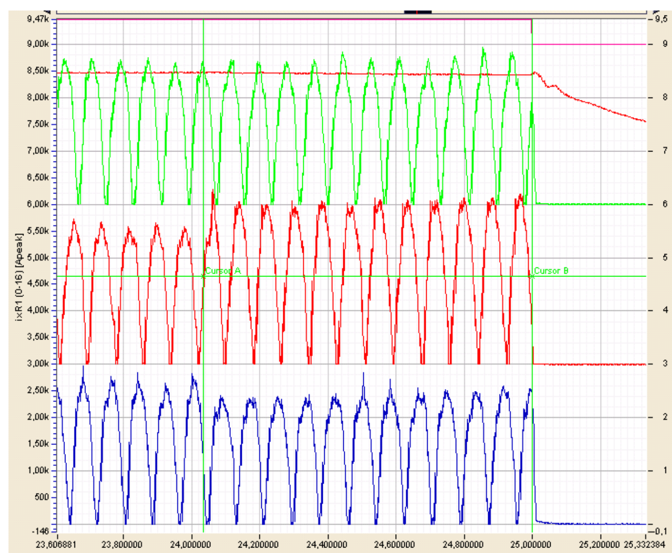

Figure 4. Oscilogram captured by transient recorder : cycloconverter output currents unbalanced in ball mill 1, July 22nd, 2006

C. Protection Against Two-Phase Short Circuits

On 24 March 2003, 6 months after the plant was put in service, ball mill 1 suffered a displacement of the stator by approximately 6 mm. The causes of this failure are attributed to the fact that the motor suffered a two-phase short circuit through the cycloconverter. Analyses made by ABB determined that the two-phase short circuit generated high levels of torque in the motor, which translated into higher lateral forces than the supports were designed for and thereby causing the displacement of the stator.

During more than three decades where GMD systems have been in operation in many installations such a situation was never experienced before. The detailed analysis of this event showed that several abnormal or special circumstances came together and resulted in a worst-case scenario. In the beginning of the plant operation very high mill starting torques were required, exceeding the specifications the GMD system was designed for. As a result, the over-current limits were above the design limits as well. In addition, the fine tuning of the drive systems was not done for maximum speed and maximum load, and the medium voltage breaker opening time was not adjusted to these circumstances. When different severe network problems happened and caused the GMD to trip, de-energizing of the drive was not properly possible under these abnormal conditions. This resulted in a two-phase short circuit that generated forces that exceeded the design limits.

The analysis was taking into account both mechanical and electrical aspects. Data analysis, measurements and simulations were done to understand in detail the root cause as well as the behavior of the drive system under out-of-design conditions.

1) Mechanical Aspects

The lateral forces that could result from a similar, worst-case situation were studied. As a result, the installation of additional dowel pins in the base of the ringmotors of the four GMD drives was done. The original number of pins was increased to 12 units with a diameter of 60 mm.

2) Electrical Aspects

First of all, the parameter settings were adjusted such that the drive would remain within its design limits. Thus, the stator over-current limits were adjusted, the medium voltage circuit breaker opening time in case of over-current was elongated and the drive control was fine tuned for maximum speed and load.

Furthermore, changes in the hardware and software of the PSR controller were implemented. These changes were made according with the results of the investigation and simulations under worst case conditions of a two-phase short circuit. The control is capable of detecting those conditions when the probability of a dangerous two-phase short circuit is very high. Once these conditions are fulfilled, this new protection function will force a three-phase short circuit by firing all thyristors of the cycloconverter at the same time, while avoiding a two-phase short circuit.

This protection function was implemented in all GMD systems at Escondida to avoid two-phase short circuits and to reduce the resulting forces acting on the ringmotor stator fixation.

For implementing this protection some consideration were taken into account:

- The introduction of the “firing all release” has to take place without circulating currents via the cycloconverter transformers.
- The analysis of switching the drive system off shows that only with the simultaneous occurrence of several errors the “firing all release” will develop circulating currents.
- Thyristors will not be damaged due to circulating currents. The limit temperature of the thyristors is not reached with the triggering of two parallel thyristors with an asymmetrical current distribution.

The protection development resulted in modifications of the control hardware and software.

3) Software changes in PSR

- Monitoring : The program needs to monitor that the mill is running above a certain speed, the actual stator current greater than maximum permissible value, while the main circuit breaker is already open.
- Load decrease and power failure : The voltage monitoring examines the 23 kV network voltage at the main substation at the incoming of the medium voltage circuit breaker. The network voltage level and voltage variations are analyzed and different network conditions are calculated. From these data the status of the drive and the network are derived and the necessary measures are taken.
- Switching the drive system off : If a severe network problem or a short circuit between the main feeder and cycloconverter power transformers is detected then the firing all release is introduced. The opening of the main circuit breaker is coordinated with the switch-off of the drive. After a given time the firing all signal is introduced, but only if a switching-off error arises. A switching-off error is present if the motor currents are not yet zero and the main circuit breaker is already open. In the case of a power failure or a short circuit between the feeder and the cycloconverter power transformers an instantaneous opening signal is sent to the main circuit breaker. After a given time the firing all signal is triggered.
- Firing all release : The firing pulse train is produced with a surge generator independently of the net and all thyristors of all bridges are fired at the same time. As a result, a three-phase short-circuit is generated.

4) Hardware changes

- Installation of an additional card for releasing both bridges of the cycloconverter (positive and negative bridge)
- Change the pulse generation card GDB 021 in order to create synchronized pulses to all phases
- Change the time delay trip in the over-current detection card, CSA 463

5) Implementation and Testing

This protection function was once activated and has operated on one ball mill. The reason for triggering this protection function was a so-called incomplete stop sequence. Figure 5 shows the event captured by the transient recorder. It can be seen that the current of phases R and S were zero when the trip occurred, but for phase T the current was still different than zero, the pulse blocking signal was not active and therefore the firing all release was triggered.

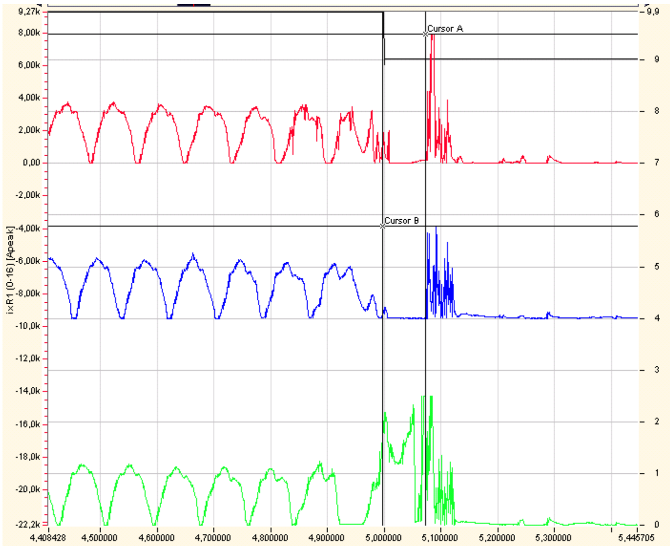

Figure 5. Motor currents when the trip signal occurred (the sum fault signal from the PSR controller is used for triggering the transient recorder)

The maximum current was achieved on phase R with a value of about 7.9 kA. This value shows good agreement with the expected value obtained by the simulations and also during the commissioning of the protection function.

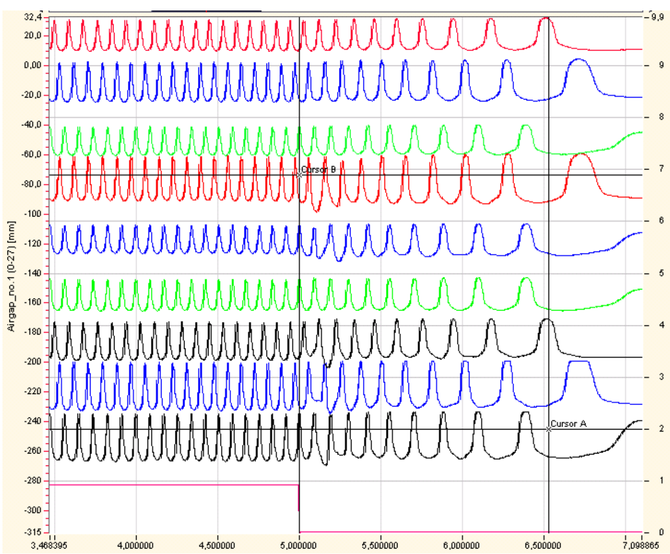

Figure 6. Measured air gap values during a trip and after it, when the firing all release was activated; the air gap numbering is given seeing the motor from the feed end side

Figure 6 shows the signals of the nine air gap sensors installed in the motor. Three are mounted at the bottom (6 o'clock), two at the right hand side (3 o'clock), one on the top of the motor (12 o'clock) and three at the left hand side (9 o'clock).

The air gap values from the sensors mounted at the left and right hand sides show that the air gaps were reduced. At least one pole is showing an air gap reduction on both sides. Thus, the motor was definitely exposed to lateral forces, which in this case were reduced and controlled by creating the three-phase short circuit.

The root cause that triggered this event and activated the protection was an overload of the equipment which demands too high current from the cycloconverters resulting in a trip of the drive system.

III. Conclusions

The protection functions of a GMD system are properly and purposefully designed, fulfill a specific function and will protect the drive system. The operator should take care of the protection systems and make sure that they are set and working correctly.

However, specific needs and requirements may trigger the development new or improved solutions. In the minerals industry, e.g. weak networks, sensitivity against under-voltage together with the need for high system availability resulted in the desire for an improved protection functionality as described in this paper.

Furthermore, abnormal situations and very specific worst-case scenarios may result in the need to address, review and analyze these circumstances. Modifications of protection schemes and settings should only be done with great care and after thorough analysis and testing. Feedback from operation, information about specific conditions and needs as well as an open and close cooperation between customer and supplier are the basis for improvements. Such a joint approach helped to review, analyze and solve situations not experienced before. Finally, it lead to a successful implementation and testing of the modified protection functions.

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