Preprint 08-037

REVAMP AND MODERNIZATION OF GEARLESS MILL DRIVES

M. Ahrens, ABB Switzerland, Baden-Dattwil, Switzerland

Abstract

Gearless mill drives (GMD) are a well established solution for grinding applications in the minerals and mining industries. The paper describes the functionality and technical features of such drive systems as well as the development and the progress of GMD systems over the years. With an increasing installed base and many drives operating for many years, there is an increasing need to modernize or revamp existing GMD installations. The first installations of GMD took place in the cement industry and have demonstrated that ringmotors can achieve a lifetime well above 40 years, if maintained properly. The life cycle time of many other components, especially electronic parts, is usually shorter. It is therefore necessary to replace aged or out-dated components early enough in a planned manner in order to reduce the risk of component failures and the related shutdown times. Modernization upgrades can range from minor software updates to a revamp of the cycloconverter. The paper describes typical examples of such upgrades and shows the most important aspects that need to be considered.

Introduction

The first Gearless Mill Drive (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. The GMD is also known as "wrap-around motor" or "ringmotor". Almost 25 years later, the first GMD with 12.0 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. The main advantages are that the GMD is adjustable in speed, and thus can fulfill the customer requirements with respect to flexibility and adjustability of the process, and that it does not need any gear box and ring gear and therefore eliminates mechanical wear and the related problems and maintenance. 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.

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 a ringmotor used in copper concentrators. The poles of the rotor are directly mounted on the surface of the mill flange. Figure 2 presents the power 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 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.

Figure 1. Picture of a typical GMD system for a SAG mill.

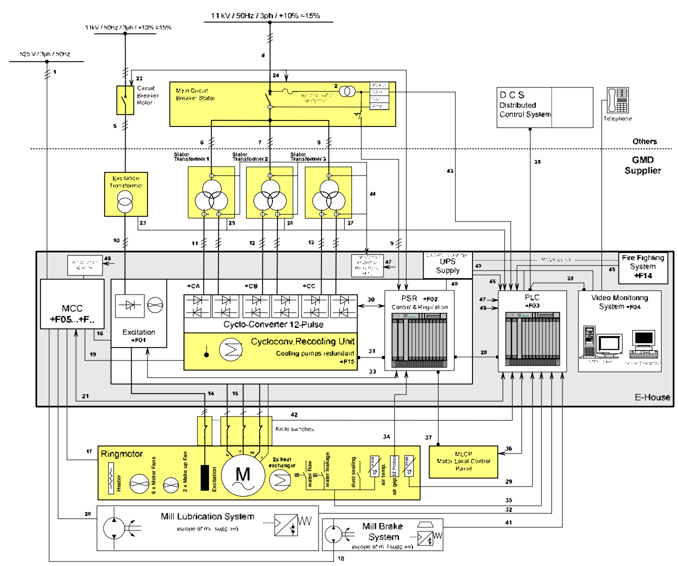

Figure 2. Overview of a typical GMD system and its components.

Motivation for Upgrades

GMD systems used for ball and SAG mills are a key element of a minerals plant due to their high power, their special design and their application in the process. It is not too unusual that plants only have one SAG mill and if this mill is down, total production is down. Considering the high cost of downtime and that a GMD is non-standard equipment it is clear that a thorough, well planned and structured service and maintenance concept is important. The first installations of GMD took place in the cement industry and have demonstrated that ringmotors can achieve a lifetime well above 40 years, if maintained properly. The life cycle time of many other components, especially electronic parts, is usually shorter. It is therefore necessary to replace aged or out-dated components early enough in a planned manner in order to reduce the risk of component failures and the related shutdown times. Software and hardware upgrades as well as revamps of cycloconverters are a crucial part of any service and maintenance plan. Typically, electronic components either fail in the very beginning (typically during the first tests), at the end of their lifetime or due to too high load (over-current, over-voltage, malfunction of the system). The lifetime of electronic components has a statistical distribution but it is not possible to predict the lifetime for a specific part based on status measurements. The cycloconverter is designed such that none of its components has to be replaced regularly. As a result, components such as thyristors or print boards only need to be replaced in the unlikely case of a component failure or a malfunction of the system. However, the lifetime of electronic components significantly depends on their operating temperature. Therefore, it is important that the converter is operated properly and that the cooling is functioning. It is nevertheless important to plan for replacements or upgrades of parts that are not any more produced or that have been improved. Similarly software improvements should be considered as well in the service plan.

Modernization upgrades can range from minor software updates to a revamp of the cycloconverter. Furthermore, hardware and software upgrades may be triggered by aspects such as spare part availability and cost, knowledge and experience of maintenance personnel as well as improved or new functionality.

The platform for the drives lifecycle management model is a four-phase lifecycle plan. When the series production period ends, the product is transferred from the active to the classic phase followed by the limited and finally the obsolete phase. The product is fully supported up to the obsolete phase, but in the limited phase it is recommended to replace and recycle the parts. A lifecycle plan maps all spare parts of a GMD system according to their individual lifecycle phase. The plan aims to manage the drives products and the product service offerings in different phases. The lifecycle status announcement communicates the status of the parts.

Upgrades as part of a structured service concept focused on plant specific needs ultimately help to improve system reliability and availability avoiding unexpected downtimes, increased equipment lifetime and reduced operating and maintenance costs.

Upgrading Process

Most of the smaller upgrades, especially minor software upgrades, can be done easily during a planned, regular shutdown. Larger upgrades as well as major software upgrades need to be planned and engineered carefully and require more time for implementation. When parts or components should be replaced often customer specific engineering is required. Space and mounting aspects, interfaces and connections need to be checked, and disassembling of the old component on site and testing of the functionality after installation of the new component needs to be considered. In order to keep the downtime to a minimum as much as possible preparation work should be done before the shutdown and the replacement work needs to be planned properly together with the maintenance personnel of the customer.

When parts or components are out-dated and replaced with their successors, solutions are harmonized or functionality is improved or added, then these parts or components are modified in the current design of cycloconverters. However, these solutions cannot always be transferred into upgrade packages for existing cycloconverters without additional modifications.

When the cycloconverter over-voltage protection was modified together with its arrester modules on the motor side then the new over-voltage arrester modules had LEM current transducers instead of reed relays. This solution can be implemented into existing cycloconverters, however the upgrade would require significant disassembly and assembly work. As a result the shutdown necessary to do this upgrade would be rather long. Consequently, another solution was engineered that achieves the improved functionality with less hardware modifications, still uses the existing reed relays and results in less downtime for upgrading.

With on-going development of DC converters and the related excitation converters new, improved products are available every few years. The cycloconverter design is usually updated when the new excitation converters are readily available and have been tested. This allows the use of the latest technology, software and hardware improvements as well as engineering, service and commissioning tools. A revamp of older excitation converters with the latest products may require significant evaluations and engineering work. Often the newer generation of excitation converters is more compact and thus the size is smaller. Interfaces may be different, existing spare parts and software tools on site may become obsolete, and some functionality may have changed. If only smaller modifications, e.g. an improved over-voltage protection at the network side, are requested, it is therefore often easier to modify the existing excitation converter instead of replacing it with a newer excitation converter generation.

In some cases out-dated parts cannot be replaced easily with a replacement product resulting in engineering upgrade solutions. E.g. for the old PSR power supplies, 24 Vdc and 48 Vdc, spare parts are not anymore available. The old 24 Vdc power supplies are rack mounted, whereas the new 24/48 Vdc power supplies are installed in the control panel. In other cases out-dated parts can easily be replaced with products of a newer generation or even with products from another supplier. Whether problems with spare parts are to be expected or engineered solutions are necessary is not always obvious. This information needs to be provided by the supplier of the GMD system.

Drive Control Development

Large-scale power converters and drives must be reliable, fast and precise. That calls for a control system with outstanding performance and high flexibility. Basically, the same controller could cope with slow processes, too. New controller generations such as the AC 800PEC are capable of controlling high-speed processes in an industrial environment with all related auxiliaries.

The development of the AC 800PEC started in 1998. Its first application was put in operation in 2002. Since then many applications that have a high demand for calculation power and for programming flexibility and customization such as micro-turbines, propulsion for light rail, wind power, series voltage restorers, high power converters and excitation systems have been realized. In the meantime already more than thousand controller units have been installed worldwide. Lately, the area of applications has been expanded to frequency converters. The AC 800PEC is the optimum solution for combining the high-speed control requirements of power electronics applications and the low-speed process control tasks usually carried out by separate PLC units. Therefore, this controller has been introduced to LCI in 2006 and to cycloconverters in 2007.

The main characteristics of this controller are its high performance and its wide range of communication options.

The AC 800PEC excels with a very high processing speed. It provides:

- Very fast analog and digital process I/Os with a typical cycle time of 25 µs.
- Fast closed-loop control and regular process logic implemented in one controller.
- Low-speed I/Os with a typical cycle time of 10 ms.
- Very fast analog/digital conversion and nominal/actual value comparison, directly on the peripheral I/O module.

It features outstanding ability to communicate with other control devices:

- Two Ethernet ports for connection to a plant control network, other processor modules, the Control Builder M programming tool and to the PECView service tool.

- RS-232 / RS-422 serial ports for a local process panel and/or service terminal.
- Up to two on-board AnyIO ports for the Communications Expansion bus (CEX) and AnyBus®-S modules for all common fieldbus types.
- Up to 36 terminals for optical PowerLinks and S800 optical ModuleBus for cost effective, noise-immune connections to I/O systems and power converters.

The modular design of the AC 800PEC comes with:

- Units mounted onto a DIN rail or equipped for direct wall mounting.
- Hardware and communication modules according to process needs.
- Any combination of fast and slow I/Os, large and small topologies, installed locally and remotely.

The AC 800PEC hardware is optimized for power electronics control:

- Optical connection between controller and process I/O.
- Fast peripheral I/O devices for control and measurement.
- Program and data stored in Flash memory, no battery backup needed.
- Compatible with standard S800 I/O devices
- Suitable for field installation.

The AC 800PEC is programmed with:

- Control Builder M programming environment based on the IEC 61131-3 standard.
- Optimized fast application code development based on MATLAB®/Simulink® with Real Time Workshop®.

The key AC 800PEC capability is high-speed control application processing, as required in power electronics, for integration into the standard Control^{IT} environment. Implementation of the AC 800PEC software on three performance levels provides a superb range of control and communication functionality:

Level 1: Industrial^IT integration
This level is based on the industry standard IEC 61131-3 and contains the slow-control, monitoring, operating, displaying and registering functions. The development of programs in accordance with the IEC 61131-3 standard is carried out in the Control Builder M, an Industrial^IT compatible engineering tool.

Level 2: Fast control software
This level contains the fast control and protective functions with cycle times from less than 100 µs to a few milliseconds.
Fast, time-critical control and I/O tasks are programmed by means of MATLAB®/Simulink® and integrated into the Control^IT environment as a Simulink I/O unit. This allows perfect interaction between the high-speed AC 800PEC core functions and the standard Control^IT software.

Level 3: High-speed I/O control
This level contains highly time-critical, hardware-specific functions such as pulse-width modulators, pulse logic with associated protective functions, fast analog and binary inputs and outputs, etc. It is implemented in the FPGA (Field Programmable Gate Array) and programmed in VHDL (Very High Speed Integrated Circuit Hardware Description Language).

The application engineer only has access to the top level, i.e. the Control^IT applications and the standard I/O interfaces of the AC 800M platform (i.e fieldbus and S800 modules). The control applications are created using Control Builder M, and are then downloaded to the controller. The project specific high-speed control tasks and the configuration of the PEC-specific fast I/O are programmed by control engineers by means of Matlab/Simulink and the Real Time Workshop. The resulting program code is then delivered as firmware together with the hardware components and with the configured FPGA. The program code is downloaded by the application engineer using Active Perl, a programming and installation tool which is available as freeware.

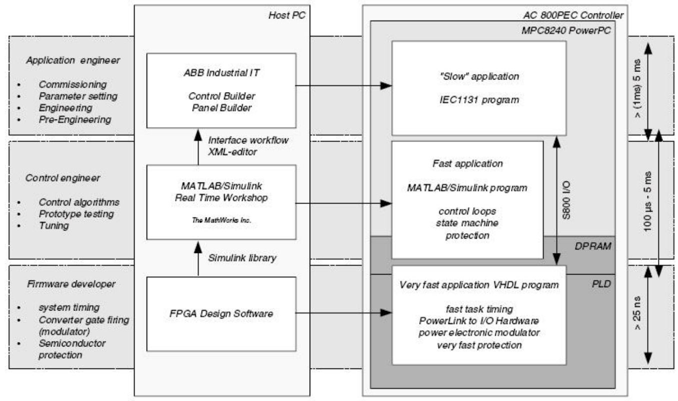

Figure 3. New drive controller application software concept.

The Contol^IT and Simulink applications are treated as two independent program blocks in the controller. The program execution is coordinated by means of interrupt control. The data of the Simulink application which is accessible on Contol^IT level is defined as a virtual I/O interface in the Control Builder application. Therefore the application engineer cannot modify the Simulink part of the program code. But he has the option to select and scale the set of parameters among the available data in the virtual I/O unit. Furthermore he can customize the I/O configuration of the controller.

This concept of the controller hardware and software (see figure 4) allows a structured software development. Control tasks, access and permissions as well as engineering, service and commissioning tools can be optimized. This allows fast and efficient project engineering while providing the necessary flexibility to implement customer specific requirements and application specific solutions.

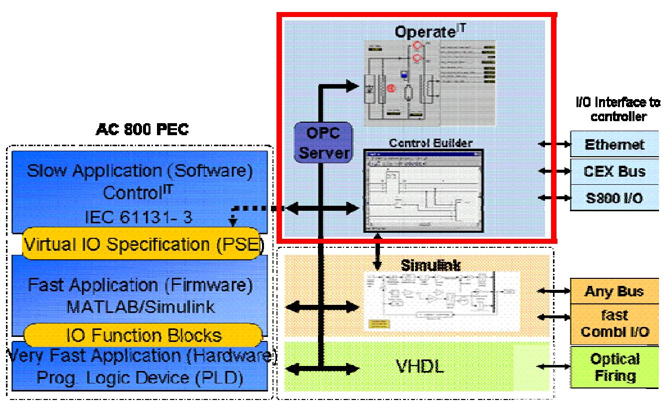

Figure 4. New drive controller hardware and software concept.

Compared to the previous controller generation the AC 800PEC uses the latest technology developments. It is a high sophisticated controller with cycle time in the µs range, connects to any commonly used field bus via Anybus-S modules and allows including PLC functions. Cycloconverters with the new controller have less control hardware, use optical thyristor firing and the transient recorder integrated in the control panel. With this solution engineering and commissioning times can be reduced and remote login and diagnostics is easier. Many components of the control system are used for other applications too. As a result, worldwide support and service as well as spare part handling is put on a broader basis.

Revamp of Cycloconverters

The new generation of cycloconverters (figures 5 and 6) is using the new drive controller AC 800 PEC. They are therefore using optical thyristor firing as well as the current generation of excitation converters DCF 800. Consequently, any revamp results in a different control panel and a different excitation panel. The power part itself remains unchanged, however the firing is different. Between the last generation of cycloconverters and the new one the footprint is identical and the connections of the power cables are at the same location. Older cycloconverter generations however have a different footprint.

Figure 5. Cycloconverter with new controller generation during testing in the factory.

Figure 6. New drive controller built into cycloconverter.

When existing cycloconverters (figure 7) should be revamped then there are of course many options how to approach this task. These options differ in the scope of the revamp, i.e. which components need to be replaced (figure 8), and the related cost including hardware, testing, engineering, installation and commissioning, in the required shutdown time and the risk to keep the deadline for the revamp work on site.

In order to plan and evaluate cycloconverter revamp projects, several site specific inputs are necessary to find the best and most efficient solution for a specific plant or a specific customer. The main aspects and questions are:

- What is the time frame for erection and commissioning on site?
- What is the scope of the revamp? Should a complete GMD control system (E-House) with latest technology, or only an exchange cycloconverter power part with new drive controller be delivered?
- What are the dimensions of the existing building/E-room? Is there enough space to take out the old cycloconverter and to place the new cycloconverter or the new E-House?
- What is the footprint of the old and the new cycloconverter power part?
- What is the solution with respect to cooling water supply for the new cycloconverter?
- What is the interface to DCS system (serial or parallel)?
- Should the PLC and visualization system be kept or replaced?
- Should the power cables be kept? If yes, are they long enough for new cycloconverter system?
- Should the control cables be kept? If yes, are they long enough for new cycloconverter system?

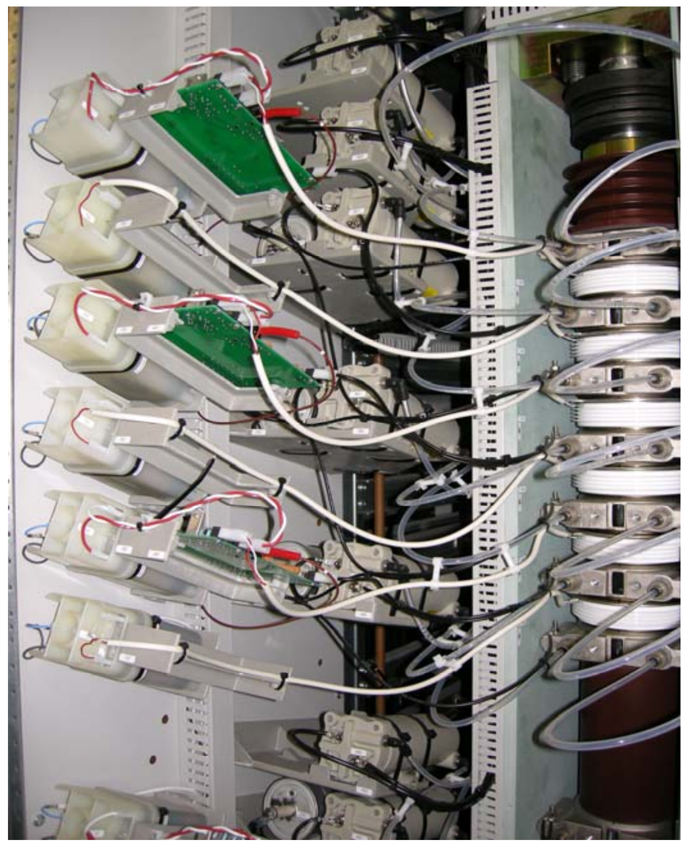

Figure 7. Magnetic firing (existing cycloconverters).

Many of these items will depend on customer preferences, shutdown schedules, the financial impact of downtime and the situation on site with respect to location, space and installed equipment. As a result the optimum solution will differ from customer to customer and from installation to installation. The best approach needs to be worked out in close cooperation between supplier and customer. In the following four basic concepts or solutions are described. Nonetheless, these need to be optimized or fine-tuned considering the specific situation and requirements.

Solution 1 (figure 9) is to exchange the complete E-House including the new cycloconverter, all control panels and auxiliary systems. This revamp is only of interest for the mining industry as E-Houses are not used e.g. in the cement industry. The main advantages are that the E-House can be fully pre-tested in the factory, that for all components the latest technology is used, and that the system is fully integrated.

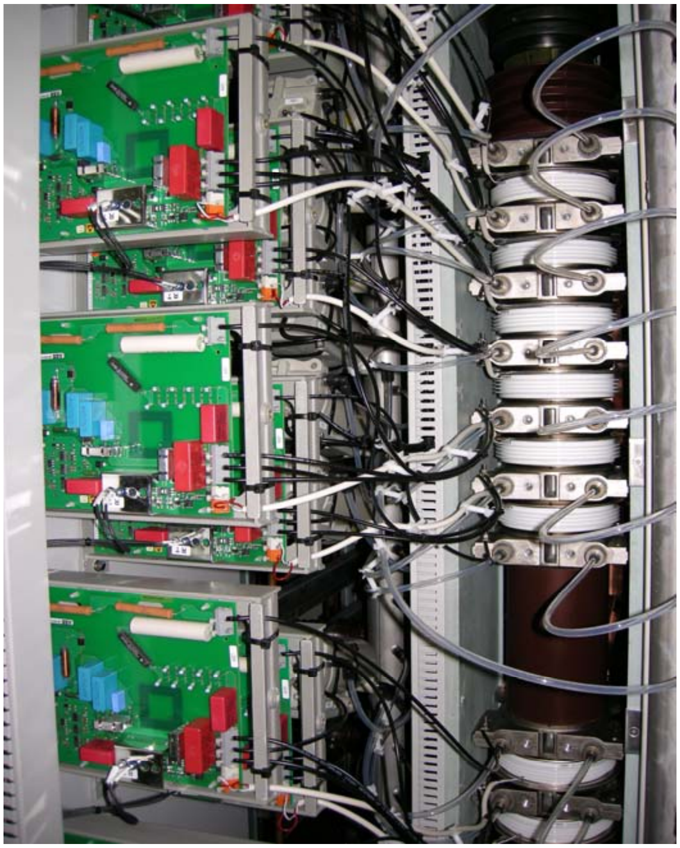

Figure 8. Optic firing (new cycloconverters).

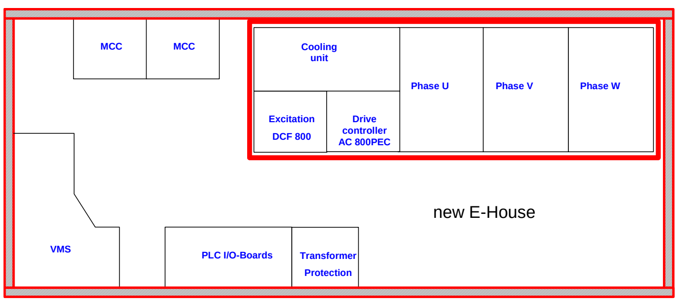

Figure 9. Scope of revamp for solution 1.

Solution 2 (figure 10) is to exchange only the cycloconverter inside an existing E-House, without PLC panels and other auxiliary systems. This revamp is only of interest for the mining industry too. The main advantages are that the hardware costs are lower compared with solution 1, that the cycloconverter can be pre-tested in the factory, and that the erection time is shorter compared with solution 1.

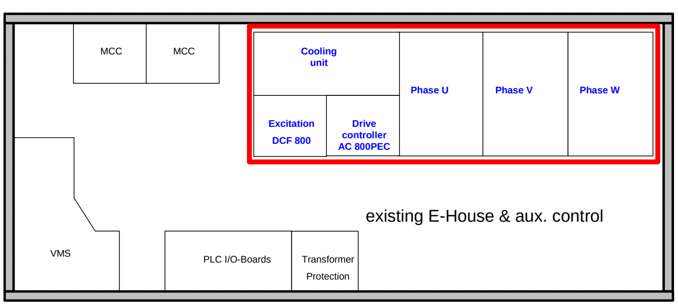

Figure 10. Scope of revamp for solution 2.

Solution 3 (figure 11) is to exchange the cycloconverter system (power pack and control). The new system is mounted on a base frame with rubber sealed panel doors (IP41), and with a separate MCC panel for LV distribution, if needed. This revamp is of interest mainly for the cement industry. The main difference to solution 2 is that the cycloconverter is installed in an E-room and that the auxiliary systems are independent of the drive system. The main advantages are very similar to solution 2.

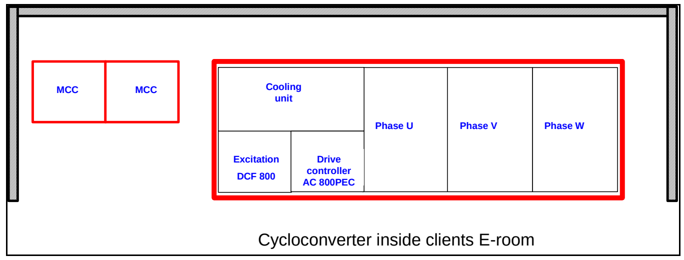

Figure 11. Scope of revamp for solution 3.

Solution 4 (figure 12) is to exchange only the drive controller panel with AC 800PEC, the excitation panel and the optical firing of the thyristors in the power part. The existing cycloconverter power part and the existing cooling unit remains. This revamp is possible for both mining industry and cement industry.

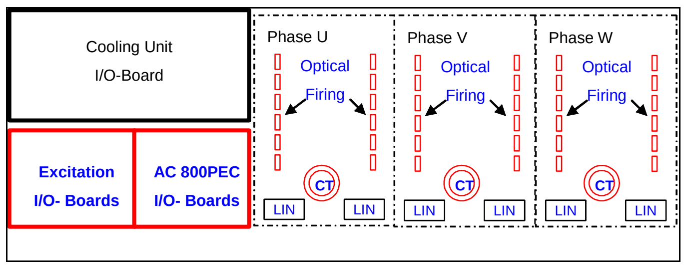

Figure 12. Scope of revamp for solution 4.

The main advantage is the lower hardware costs compared with the other solutions. However, this comes together with significant disadvantages. There are many, time consuming tasks that need to be done on site. Cabling, erection and commissioning time on site is therefore much longer. Furthermore, all tests must be performed on site resulting in higher risk to extend the expected shut downtime and thus higher production losses for the customer.

Summary and Conclusions

GMD systems used for ball and SAG mills are a key element of a minerals plant. It is therefore necessary to replace aged or out-dated components early enough in a planned manner in order to reduce the risk of component failures and the related shutdown times. Modernization upgrades can range from minor software updates to a revamp of the cycloconverter.

The best solution for revamping cycloconverters is customer and site specific. It depends on the installed equipment (components / parts), the re-use of equipment, cables, etc., space limitations, access to equipment and shutdown times. In any case the revamp of complete packages is recommended. These can be fully tested in the factory and therefore result in lower risk, less interface problems, less work on-site and therefore shorter shutdown times.

References

[1] Ahrens, M. and Gonser, J., 2006, “Protection and Supervision Systems for Gearless Mill Drives”, SAG Conference, Vancouver
[2] Ahrens, M. and Gonser, J., 2006, “Service and Maintenance for Gearless Mill Drives”, SAG Conference, Vancouver
[3] Errath, R., 2006, “The Gearless Mill Drive, the Work Horse for SAG and Ball Mills”, SME Conference, St. Louis