HIGHLY EFFICIENT POWER CONVERSION SYSTEMS WITH THE LATEST SAFETY DESIGN FOR ALUMINIUM SMELTERS

Power Conversion Station with 105kA/1800VDC Units at 230kV, primary voltage. Ras Al Khair, Ma'aden Aluminium, the Kingdom of Saudi Arabia (2012) - World's highest rated aluminium conversion rectiformer.

For a typical aluminium smelter, electric power accounts for up to 35% of total metal production costs. New, more efficient high-current conversion units can therefore save money by reducing power costs. These high-current conversion units can create high arc power should there be internal damage requiring new designs for arc flash protection. The context describes the new technology of converter units rated for more than 100 kA and their benefits for the overall efficiency of a power system, while ensuring optimal safety levels. Modern ABB technology, which measures potline direct currents, is also described. Industrial plants can only improve efficiency when they make use of the latest available overall system, designed to optimize power quality.

INTRODUCTION

Primary aluminium is produced in an electrolytic process via use of DC electrical power of up to 900MW/per single potline. AC-to-DC power conversion units (*rectifiers*) use diode or thyristor semiconductors to produce the DC current required for the process. Smelter projects applying up to 650kA pot-current may soon be built. With increased potline currents, the single conversion units also need an increased rating to remain highly efficient.

Today, there are five plants in operation with single-unit ratings of more than 100kA.

With these increased ratings, the plant can operate close-to-or at full

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production in an N-2 operation mode (*N-2 is defined as three out of five installed units operating at a time*).

SMELTER POWER SYSTEM RATING

Efficiency demands show that potline currents of 460kA and voltages at 1800V will be commonly used (*i.e. 400 cell potlines*) in the future. The AC-DC conversion substation for such plants need to be very efficient, as electrical costs alone, with a 1500MW smelter (*two pot-lines with 400 cells and 460kA*) will result in losses in excess of $5M per annum. Considering ratings of 460kA at 1800V, the most efficient arrangement for a power conversion system is a six-unit parallel connection with the power factor correction connected, either on the tertiary side of the regulation transformers or at the high voltage (HV) level.

RECTIFORMER OPTIMISED LAYOUT DESIGN

Higher primary voltages and potline current system ratings require in-depth technical review to ensure the optimal technical and commercial solution.

When engineers talk about a back-to-back arrangement, they are referring to a configuration where the rectifier and regulation transformers connect to each other back-to-back.

The advantage of this arrangement is a reduction in the space required for the bay.

However, with the increase in the unit rating, the physical separation of the regulation and the rectifier transformer is advisable, as without it, transportation and installation can become a costly issue.

The picture below shows a back-to-back arrangement with a 132kV cable connected to the regulation transformer.

100kA Conversion Unit with 132kV Primary, BHP Billiton, Hillside Smelter in South Africa

105kA Conversion unit with 220kV primary voltage. Sohar Smelter, Sultanate of Oman.

For higher primary voltages, the side and front arrangement as utilised at Sohar is preferred and commonly used. Here again, the technical and practical aims for the transformer design provide the direction for the most suitable arrangement. In most installations, air is used as a recooling medium. ABB designs their heat exchangers in horizontal arrangements for maximum efficiency and minimal aging. When a conversion unit bay is designed, it is necessary to ensure free and unrestricted air movement is factored in.

RECTIFORMER SYSTEM DESIGN

In order to manufacture a single unit rectifier rated higher than 100kA, it used to be necessary to improve on the semiconductor arrangement as well as the semiconductor fuses. With previous rectifier designs, semiconductor fuses were only cooled on one side. Today, ABB design fuses are cooled on both sides, reducing aging effects tremendously. In addition to the semiconductor arrangement and fuse improvements, the rectifier's mechanical geometry needed improvement in order to optimize the current-sharing capacity.

HIGHEST SAFETY STANDARDS FOR RECTIFIER ENCLOSURE

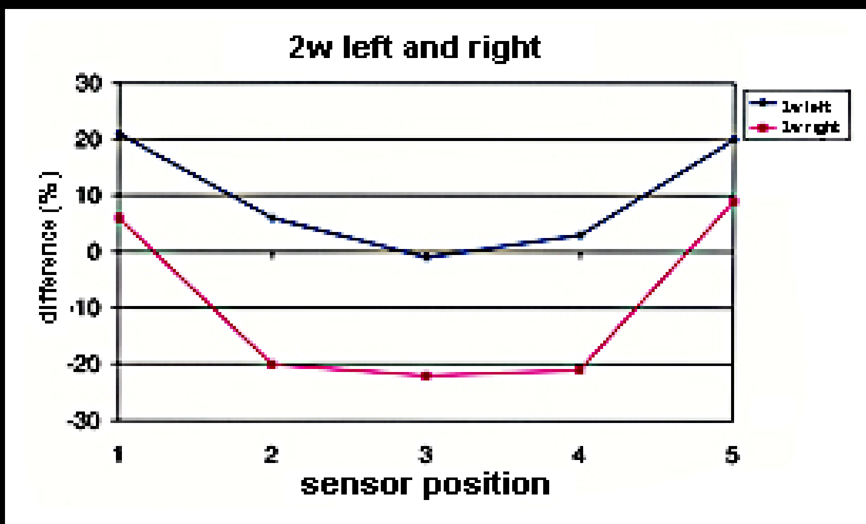
Greenfield smelters make use of rectifier substations where the rectifiers are installed in aluminium enclosures. This "packaged" design makes it possible to simplify the civil arrangement and reduce installation time. The rectifier enclosures are commonly recooled with water-to-air heat exchangers.

The rectifier enclosure, similar to LV and MV switchgear, needs to be designed for the latest arc flash and arc force standards.

Latest experiences from arc flash events have been implemented in the new enclosure designs to meet highest safety standards. The cooling units, along with the controls, can also be installed in the rectifier enclosure.

CURRENT SHARING FACTOR

One of the most important design specifications of a rectifier is the current-sharing factor (ks). The key rectifier components, semiconductor and fuse can only be rated correctly when the ks factor is known. The current-sharing factor is mainly defined by the rectifier's mechanical construction. Due to the geometrical arrangement of fuse and semiconductor, the impedance varies from semiconductor position on the commutation bar to the next semiconductor location.



Current Sharing Measurement for one Rectifier Branch

110kA Diode Rectifier Enclosure

This impedance variation results in a difference in current through the parallel components. In addition, the manufacturing tolerance of the components must be considered. The current-sharing factor rises with the number of parallel elements. Therefore with increased unit currents the additional required parallel elements rises accordingly.

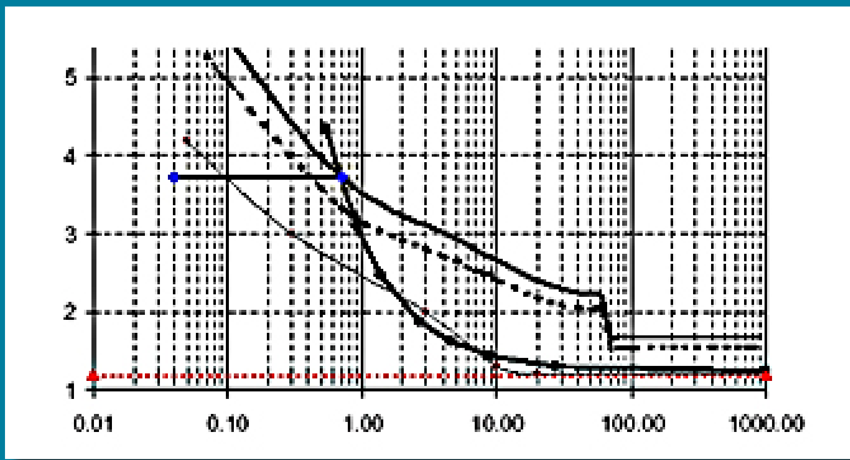
For a 110 kA / 1800 V diode rectifier group, 14 parallel elements per branch are now required. For this quantity of paralleled elements, the arrangement on one single heatsink is not possible. The so-called commutation bus bars need to be installed to reduce the current-sharing factor to an acceptable value. Furthermore, the flexible AC connections between the fuses and semiconductors, as well as the distance between the parallel elements, require detailed design to ensure the impedance distribution has an optimal value. These measures in optimizing the current-sharing factor become very important for rectifiers especially with high current.

RECTIFIER OVERLOAD

The semiconductor mainly defines the overload capability of a high-current rectifier unit. The maximal junction temperature, e.g. 150° C, is normally a strict limit and must not be exceeded under normal operating conditions. Some semiconductor suppliers allow exceeding the limit for a short time, e.g. an additional 50 °C, for one minute. The overload factor has a high value for brief overloading and goes down to 1 p.u. after approximately one minute.

For potlines operated with diode rectifiers, an overload capability of 50% for one minute is required (*duty class II according to IEC Standards*). During potline switching operation, the current regulation with tap changers and saturated core reactors is not always fast enough to prevent overload currents.

In the case of thyristor rectifiers, the regulation is faster and the overload condition, according to duty class II, is not required.



Rectifier overload and Protection Curves

HIGH DC CURRENT POTLINE AND RECTIFORMER MEASUREMENTS

ABB has developed a family of high accuracy fibre-optic current sensors based on the magneto-optic effect (*Faraday Effect*) in an optical fibre to measure uni or bidirectional DC currents up to 700 kA. The sensors also recover AC current components up to 4 kHz.

The sensors consist of an optical fibre in a flexible, single-ended cable and an optoelectronics module including the light source, an optical detection circuit, and a digital signal processor.

One loop of fibre cable is mounted around the current carrying bus bar. The signal is independent of the particular bus bar arrangement and insensitive to magnetic stray fields from neighbouring bus bars.

The magnetic field of the current changes the velocity of left and right circular light waves travelling through the fibre and thus alters their differential optical phase. The waves are reflected at the end of the fibre and then retrace their optical path back to the optoelectronics module containing the light source, an optical phase detection circuit, and a digital signal processor.

The digital signal processor provides high accuracy and excellent long-term stability. The closed-loop detection circuit nulls the current-induced optical phase shift and thus produces a perfect linear output over the full dynamic range. The sensor measures a closed loop independent of the magnetic field. Therefore, the signal is immune to stray fields from conductors outside of the loop. Centring and placement of the sensing head with respect to the bus bars is not particularly critical. Saturation due to local field enhancements does not occur.

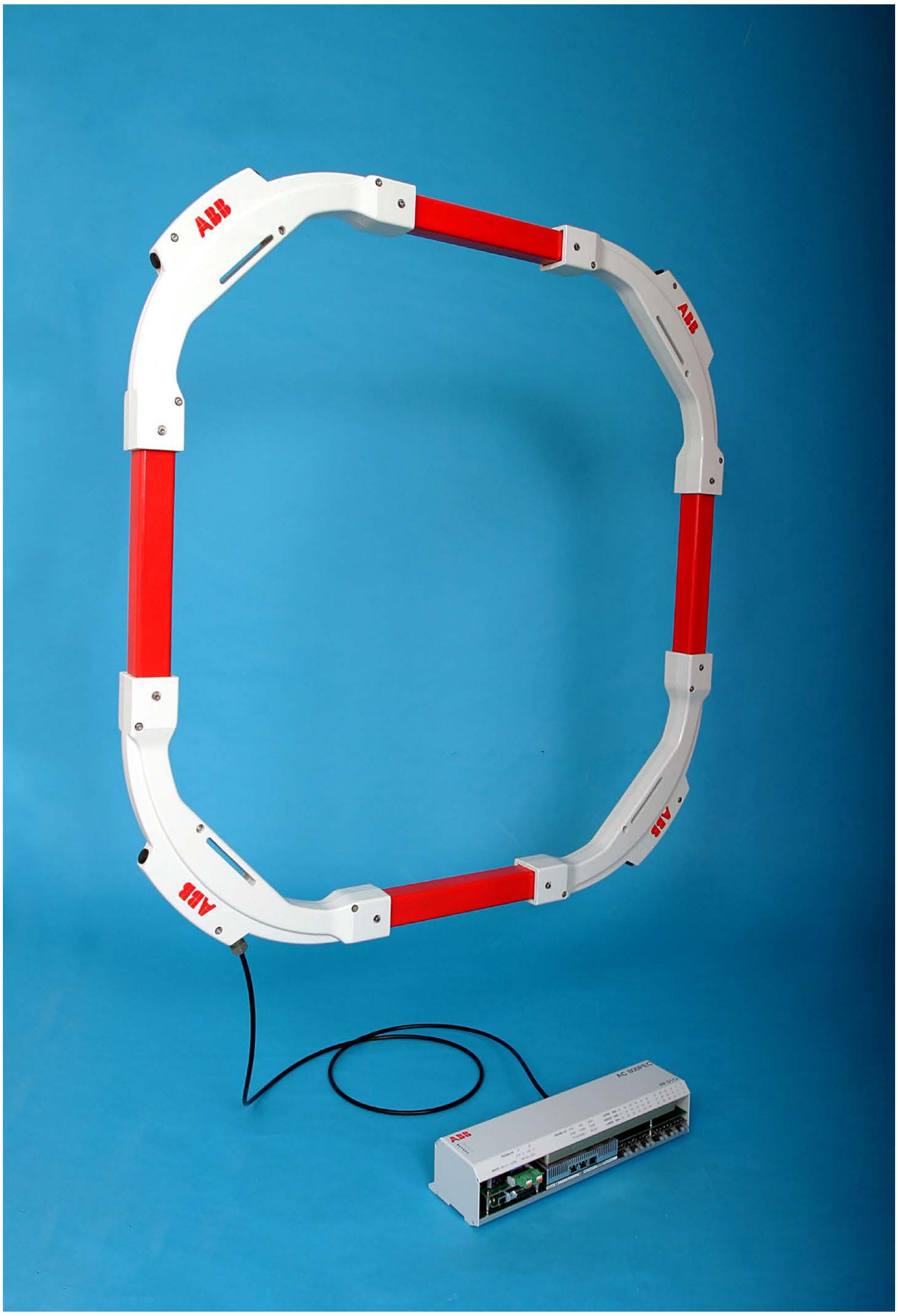
PROTECTION CONCEPT

In case of different faults, e.g. short circuit, overcurrent or overvoltage, the converter unit has to be protected fast and reliably. Proper system protection can prevent, depending on the fault, disastrous damages!

A good protection concept assists in locating the fault without disassembly of system components. A serious fault results in a single group or a potline trip. In case of a short circuit on the DC side of a rectifier, all the parallel-connected groups have to be tripped (potline trip). The short circuit is detected via the reverse current relay logic or arc detection. In case of a group internal fault, (*e.g. overcurrent or earth fault*) only the corresponding unit is tripped.

The protection concept also defines what kind of faults have to result in a trip and for which of them an alarm message is sufficient.

To realize as few system trips as possible, one part of the protection study is the signalization and redundancy concept (*e.g. a signalization of raised cooling water temperature*) may prevent tripping if recognized early enough; or, the installation of one additional heat exchanger allows for operating the rectifier group until a planned outage.

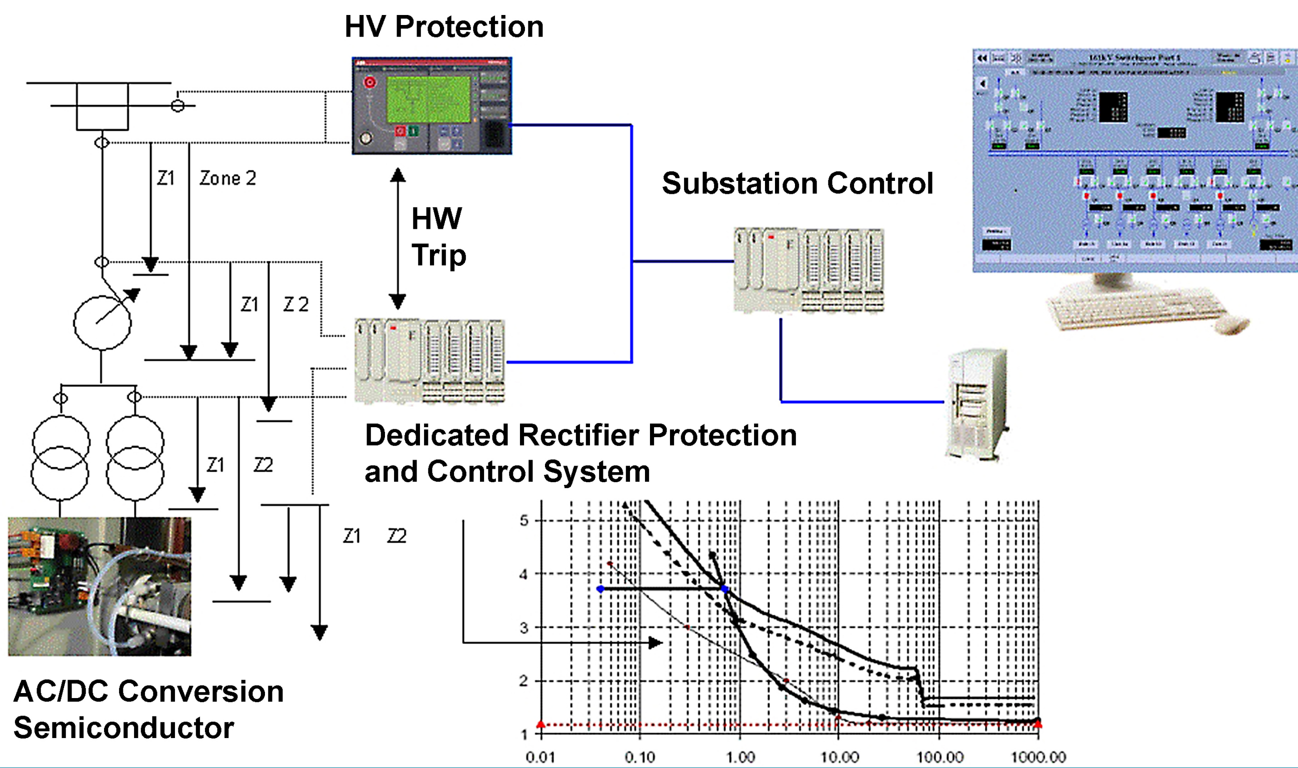


Fiber-optic DC current sensor

CONTROL CONCEPT WITH NEW SAFETY STANDARDS

Development advances have not only been realized in power conversion technology. During the last few years this has been particularly so on the control side from the conversion units all the way to the Enterprise Information System (EIS). These developments have made it possible to reduce the number of required HW devices and different programming and control software products to a large extent.

In addition, these developments have made it possible to connect a front-end device such as a semiconductor directly to the Enterprise Resource Planning (ERP) or Enterprise Information System (EIS).



AC/DC Conversion unit: control, protection and regulation interface

THE HIGH VOLTAGE SUBSTATION AND AC/DC POWER CONVERTER SYSTEM CAN HAVE THEIR OWN WORKSTATIONS AT THEIR OWN DEDICATED CONTROL ROOMS.

The utilization of the latest control system and protection relays enable fault recording, which is available within the protection relays and is directly connected to the control network or the substation controller. This allows access to this data throughout the plant network, hence eliminating the need for stand-alone disturbance recorders with their own I/O's.

The substation controller, which collects all the data from the protection systems, also include SCADA (*Supervisory Control and Data Acquisition*), LMS *(Load Management System*) and EMS (*Energy Management System*).

SUMMARY

To accommodate both the requirements of higher power in smelters and lower electrical power costs (*reduced losses*), individual conversion units will become larger - supplying higher current levels, with the conversion stations being designed for N-1.5 to N-2 capability with certain overload limitations.

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