Advanced power supply equipment for new aluminium smelter potline

A new potline installed by the Icelandic Aluminium Company (ISAL) at its Straumsvik smelter has increased the production capacity of the plant by 62 percent, or 62,000 tonnes per year. ABB supplied all the electricity supply equipment located between the incoming 220-kV AC lines and the DC connections of the potline, including a thyristor-controlled rectifier station rated at 135 kA and 770 V DC. The use of phase-controlled thyristor rectifiers allows excellent adaptation to the AC grid conditions. Supervisory control of the new potline is provided by an advanced SCADA system, which ABB also supplied. The project engineering, supply and construction of the power supply were completed within budget in only 18 months.

To increase capacity and give it a competitive edge in the marketplace, the Icelandic Aluminium Company (ISAL) recently added a third potline to its smelter at Straumsvik, Iceland **1**. Start-up of the new line 3, which has 160 pots, has increased the annual production capacity of the plant by 62,000 tonnes. The electric power supply system for potline 3 was designed, manufactured and installed by ABB in close cooperation with the Iceland Project Management Team (IPM) and the National Power Company (NPC). ALESA Alusuisse Engineering Ltd and ISAL drew up the specifications for the power supply. ABB's scope of supply covered all the equipment located between the incoming 220-kV AC lines and the DC connections of the potline, and included the 135-kA, 770-VDC thyristor rectifier station for energizing the pots. The employment of phase-controlled thyristor rectifiers allows excellent adaptation to the AC grid conditions.

The new potline represents a major upgrade in process technology and electrical efficiency compared with the older power supplies and electrical systems installed by ABB on ISAL's potlines 1 and 2 in earlier years.

The power supply project, including engineering, supply and construction, was completed within budget in only 18 months. As IPM also managed to speed up the work on other critical parts of the ISAL project, the potline could be started up three months earlier than originally planned.

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Overall requirements and AC system constraints

Since aluminium smelters must be operated around the clock, owners place emphasis on sound engineering, advanced technology, reliability and, not least, redundancy, to ensure continued operation at full capacity even when key systems are not available.

With its new line 3 in operation, ISAL's energy consumption has grown to 2600 GWh/a, or nearly 50 percent of the energy sold annually by Iceland's National Power Company (NPC). Under certain worst-case conditions the short-circuit capability of the Icelandic power grid can drop as low as 800 MVA, which is just three to four times the power taken by ISAL. Among other reasons, it was to avoid large voltage fluctuations and instabilities during load changes that fast, controllable thyristor rectifiers were specified instead of diode rectifiers.

One of the main operating cost factors in aluminium smelting is the routine replacement of the pots. Maintenance is carried out on a regular basis, as the insulation and cathode typically last for about 2,000 days. Reliable restarting is essential and can pose a challenge when, as in the case of ISAL, the smelter represents a major portion of the grid's total load. Working closely with the customer and NPC, ABB developed software that automatically protects the equipment against damage when a pot is shut down and varies the load according to a predetermined curve during re-starting.

The rectifier must ensure a practically constant electrolysis current during normal operation in spite of variable potline resistance and grid fluctuations, as well as fast load shedding when conditions require it. The dynamic characteristics of the thyristors as well as quick response by the control system are essential if the grid is to be prevented from collapsing due to undervoltage or underfrequency before the new rectifier circuit-breakers in the ISAL power control system trip. Given the relatively weak network, this 'adaptive control' has to prevent production losses and limit potentially severe disturbances on the national power grid.

ISAL placed emphasis on the expansion meeting some key criteria:

- Excellent integration in the power grid
- High efficiency
- High availability
- Good maintainability
- High life cycle cost efficiency

The complexity of the project called for close cooperation and good teamwork between the electric utility, the plant operator and the equipment supplier.

Load demand and power supply concept

The annual energy consumption of potline 3 is expected to be less than 1000 GWh. Under ISAL's new power contract the maximum permitted load is 125 MW, but the normal load will be approximately 110 MW. The power factor is set at a minimum of 0.97 and the total current distortion must not exceed 5 percent at 220 kV. To filter the harmonics created by ISAL's new rectifier C, ABB designed a 65-MVAr filter system 2 for connection to the 33-kV busbar. As a result of this filter, the distortion factor lies well below the contractual value.

The power supply system consists of the AC power supply, the DC power supply and the common control system.

Main AC power supply equipment:

- 220-kV double busbar with associated switchbays 3
- Four single-phase step-down transformers rated 220/33 kV (one three-phase bank and one hot-standby unit)
- 33-kV double busbar with associated switchbays
- Three harmonic filter banks, switchable in two steps

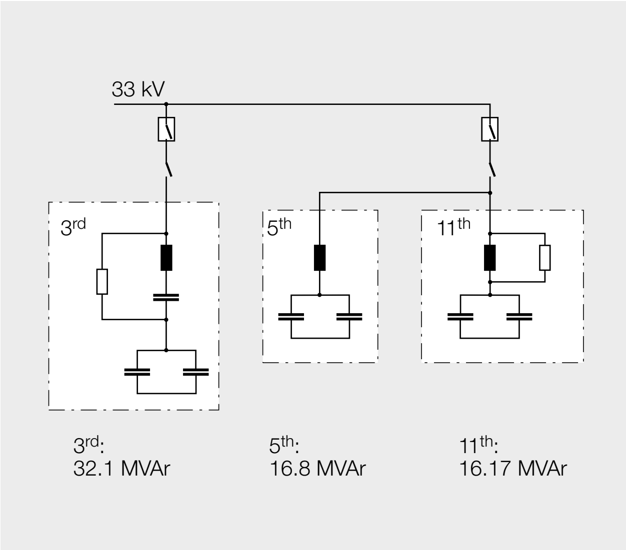
Main DC power supply equipment:

- Four rectifier transformers
- Four thyristor rectifier units rated 45 kA /770 V 4, with cooling equipment
- DC collector bus plus DC current metering 6

AC system and step-down transformers

The indoor switchyard 3 is a double busbar system, fed with power from the utility grid via two 220-kV lines. This ensures redundancy, one line alone being capable of supplying the power for the entire plant. Three single-phase transformers step the 220-kV voltage down to 33 kV. The 33-kV system, also a double busbar system, supplies the rectifier transformers as well as the other loads in the plant with electric energy. A filter and compensation system connected to the 33-kV level helps

Aluminium smelter of ISAL at Straumsvik, Iceland. ABB supplied the power equipment for its third potline, which has increased capacity at the plant by 62,000 tonnes per year. 1



Single-line diagram of the harmonic filter installed in the power supply system for the new potline. Three filter banks, configured as two separate, switchable units, are tuned to the 3rd, 5th and 11th harmonics. **2**

220-kV indoor switchyard of ISAL's Straumsvik smelter **3**

ISAL to significantly improve its power factor and thereby reduce the power line losses, which are a general concern of power utilities nowadays.

A hot-standby transformer unit is installed to provide redundancy. If one of the three single-phase units in operation should fail, the defective unit will be disconnected and replaced by the standby unit. The 220-kV and 33-kV switchbays of the standby unit are equipped with additional interlocked disconnectors to allow connection to any of the three phases of the 220-kV and 33-kV systems.

DC power supply

The DC power supply consists of four rectifier transformer units connected in parallel. Each supplies a nominal current of 45 kA over a voltage range of 0 to 810 VDC. The rectifier transformer units consist of the following factory-tested modules:

- Rectifier transformer with tapchanger for off-load voltage adjustment (under start-up conditions for complete pot groups)
- Rectifier assembly with water-cooled thyristors and fuses
- Internal/external water heat-exchangers and water pumps for the rectifiers
- Oil/water heat-exchangers for the transformers and pumps
- Motor-driven DC isolators with all necessary interlocks
- Local control panels with high-speed PLCs and operator interface

ABB supplied the rectifier sections as standard electrical equipment, optimized for use in aluminium smelters. The rectifier transformers are designed specifically for each application. High energy efficiency is an important feature of the rectifier station performance. Today, the energy efficiency for such systems, including that of ISAL's potline 3, is up to 98.5 percent. Loading of the power equipment is enhanced by a high-rate cooling system that uses deionized water to transfer heat from the thyristors to heat-exchangers cooled by water at a temperature of about 5 °C from ISAL's groundwater pumping station.

The design is based on a concept that draws on ABB's wealth of experience and

Thyristor rectifier

The thyristor rectifier has gained steadily in importance over the past twenty years. The regulating transformer with on-load tap changer and the saturable reactors have, for the most part, disappeared and been replaced by thyristors and a control system which allow continuous regulation over the full range of application.

Today, more than two-thirds of all new plants are equipped with thyristors, and many existing diode installations are being converted to thyristors.

The key advantages of today's standard thyristor units are:

- Reduced investment and operating costs
- Possibility of 0-100% current regulation over the entire voltage range
- Faster control response for better current stability and higher current efficiency
- Equivalent or improved power supply efficiency
- Smaller space required for the current control system
- Reduced maintenance and higher reliability
- Better adaptation to AC grid conditions

know-how in this field. Due to the climatic conditions at the site, the whole installation is indoors.

The high-current aluminium bus sections are welded together to reduce losses and keep maintenance to a minimum. Welded into the bus are flexible connections that allow thermal expansion and contraction due to temperature change. During the planning of the equipment layout, great care was taken to ensure good accessibility for maintenance. High availability is achieved through duplication of the important components.

Rectifier transformers

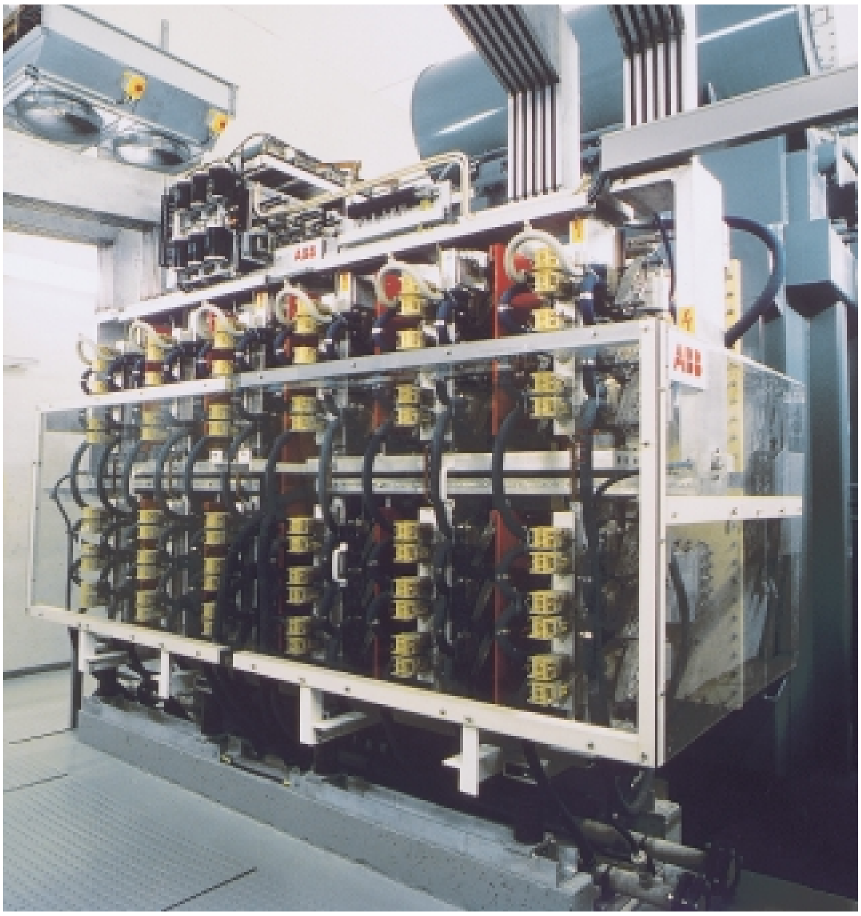
Each of the four rectifier transformers is a single core-type unit in a space-saving double-tier arrangement. The rated power is 2 x 24.4 MVA, with a 5 percent overload capability corresponding to 45 kA at 810 VDC.

The primaries feature internal phase displacement of ± 3.75/± 11.25 electrical degrees. This produces a 48-pulse response to the grid. The relatively high number of pulses reduces the harmonic impact on the grid.

The two secondaries of each transformer are delta and star connected for 12-pulse operation of each unit.

The secondaries feed a double-bridge-connected rectifier. To reduce the current displacement, and with it the active power losses, twisted conductors resembling the Roebel bars in generators are used for the secondary high-current windings. This relatively complex winding design has special advantages when currents are non-sinusoidal. Current transformers are mounted on the primary side for the overcurrent protection and redundant DC current measurement, which is needed in the event of failure of the main DC current transformer.

Thyribloc® rectifier unit, rated at 45 kA and 770 V DC, with rectifier transformer. Use of phase-controlled thyristor rectifiers allows excellent adaptation to conditions in the Icelandic power grid. **4**



Rectifier compartment

Each rectifier unit is housed in a fire-proof, concrete compartment containing the transformer, rectifier, cooling equipment, busbars and local controls. The chosen busbar dimensions keep the temperature of the ambient air as low as possible. Each compartment has two water-cooling systems, one for the electrical equipment and one for the ambient air. Each cooling system has built-in redundancy , ie two pumps. Other standard features of the housing are a fire-detection and alarm system, general light and power installations, and a grounding system. Care was taken during the design of the grounding system to avoid closed loops. The rectifier units also have their own DC disconnectors to prevent reverse voltage from the potline endangering staff when maintenance work is being carried out.

Rectifiers (type Thyribloc®)

Each double rectifier bridge has a rated output of 45 kA. In an emergency, each unit can be overloaded up to 50 kA, corresponding to a maximum of 100 kA at 770 V DC with two units out of operation. Each branch has 6 thyristors rated at 2.8 kA(rms) each. In the normal operating mode all 4 units run in parallel, the load per unit being 33.75 kA. Accordingly, with one unit out of operation (*n*-1 mode) the load is 3 x 45 kA = 135 kA, but can be even higher, as evaluations carried out after the final performance tests have shown. The arrangement of the connections, etc, helps to share the current equally between the parallel thyristors.

The short distance between the rectifier transformer and the rectifier **4** minimizes losses, especially the reactive power losses, and the magnetic field strength, which normally is greatest around the conductors between the transformer and rectifier.

DC busbars

The dimensions of the DC busbars were chosen based on the cost of their installation and operation as well as on factors such as their capacity to withstand short circuits, thermal expansion, electromagnetic exposure and cooling.

The conductors were delivered in fixed lengths and welded together for minimum losses. For safety, it is important to keep the conducting current path insulated from the structure. Insulation plates and insulated supports provide this protection. Measures have also been taken to prevent induced-current loops in the iron reinforcement used in the concrete parts of the building. These reduce the risk of a ground fault and minimize the exposure of the personnel to voltage. Ground fault supervision is provided by the monitoring system, which trips a warning signal and indicates the approximate fault location in the event of an abnormality.

Harmonic filter

The power contract between NPC and ISAL stipulates a certain maximum harmonic current content in relation to the fundamental current. This agreement is a 'first' in Iceland and underscores the increased emphasis on grid voltage quality, which benefits all customers of the NPC. In spite of the relatively low short-circuit capacity of the Icelandic national grid, the final performance measurements conducted by ABB Industrie showed the harmonics to be far below the limits given in IEEE 519-199.2.

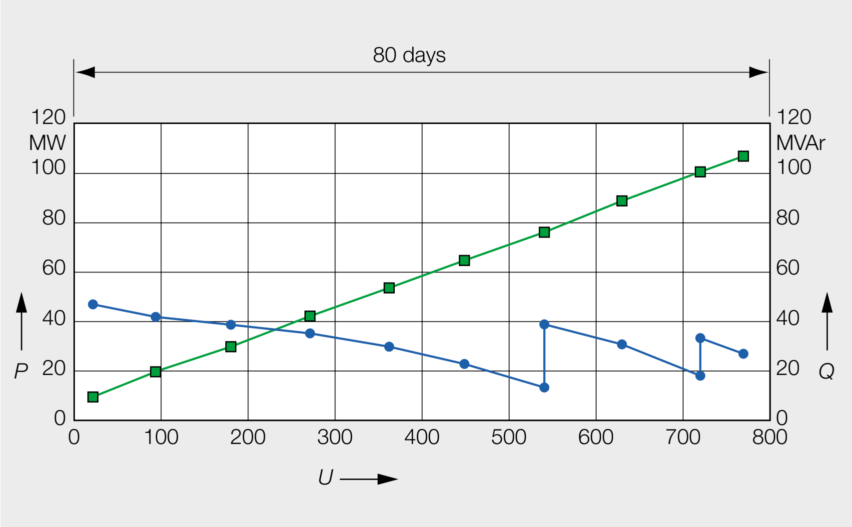
While the design of the new system has successfully reduced the fundamental grid voltage harmonics, harmonic distortion originating from the thyristor loads still remains. The total harmonic distortion (THD) factor at the 220-kV infeed is only 0.4 % even with line 3 operating in n-1 mode, ie with only 3 rectifier units in service.

The new harmonic filter **2** consists of three filter banks, configured as two switchable units. This allows separate operation, eg when maintenance has to be carried out on one of the units. During the design of the filter, special account was taken of the very low minimum short-circuit capability of the Icelandic network under certain conditions. Close cooperation with NPC during the design stage provided benefits all round.

One filter unit consists of a bank tuned to the 5th harmonic and a damped high-pass filter bank which reduces the 11th and higher harmonics. The second unit is also a damped filter bank, but is tuned to the 3rd harmonic. This reduces the 3rd harmonics, which are present in almost all AC systems (although not necessarily generated by the rectifiers) and reliably bans the risk of 3rd harmonic amplification even when a resonance condition exists as a result of certain system configurations.

The rectifier was tested together with the harmonic filters prior to start-up. Good results were achieved, in spite of the low short-circuit capability, with the short-circuited rectifier supplied with power from just one generating plant at a distance of over 200 km from the smelter.

The advantage of combining thyristor-controlled rectifiers and harmonic filter banks was demonstrated again during the initial potline start-up. Due to the harmonic filter providing 65 MVAr, reactive power demand remained within a relatively narrow band over a wide operating range, reliably preventing voltage fluctuations from occurring **5**.

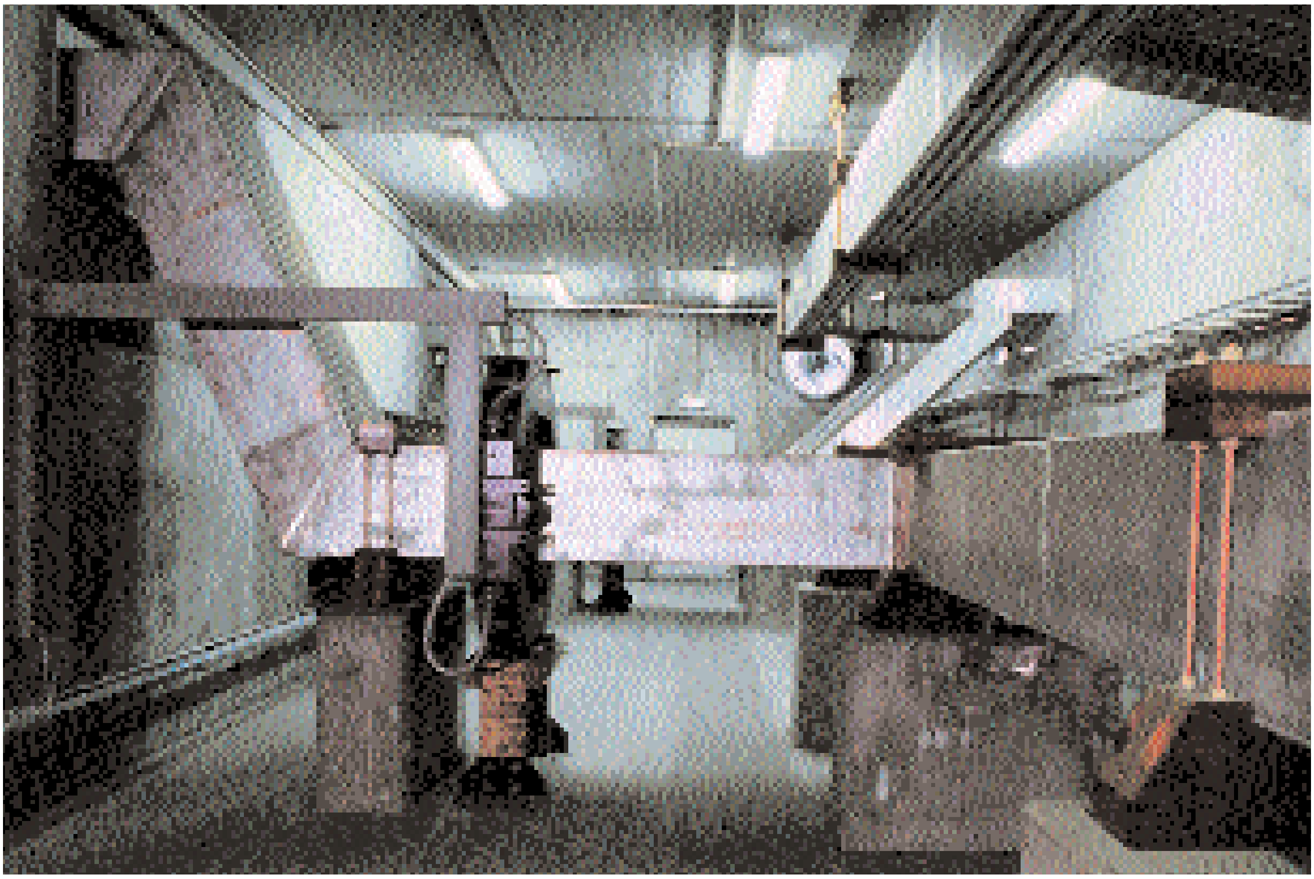


Active power P and reactive power Q at 220 kV during initial start-up of potline 3, with 130 kA and 65 MVAr compensation. Transformer off-load tap changes caused the 'steps' in the reactive power plot. The measurements covered a period of 80 days. **5**

Active power
Reactive power
U DC voltage

Measurement of the total DC

Between the rectifier sections and the pot room is a collector busbar room for the



Collector DC busbars with precision current transformer for tracking the potline's total current **6**

precision current transformer 6 that tracks the potline's total current. The 160 pots are connected in series with the main busbar, which is fed from the collector busbar.

Fitted to each minus pole collector busbar is a DC current measurement head, the output of which is routed to a summation device for both collector busbars. This highly accurate DC current signal is transmitted to the PSR programmable high-speed controller [1], which is also from ABB, in the master panel in the control room. The PSR generates a reference current for the individual rectifier section controllers, which use it to run up and hold the potline current at its setpoint value. If special measures are not taken, the strong magnetic fields caused by the high currents in the plant would falsify the results of the current measurements. Attention was given to this during the design phase, as a result of which there are no interference fields around the measuring heads.

Measuring heads with a traceable calibration facility are employed. The installed supervisory control and data acquisition (SCADA) system, which monitors the measurement results, allows the measurement error to be compensated on the basis of the calibration certificates. The total current measurement accuracy is estimated to be at least 0.1%. An important electrolysis characteristic, the current efficiency, is calculated by means of the Faraday law, using the integrated current (kAh) and the weighed production output as basis. The electrolysis MWh – a key figure for the energy management of a smelter – is also calculated using these measurements.

Control system

An I&C system provides the overall control, measurement and protection functions for the AC and DC power supply systems of potline 3. The system operates on three levels:

Level 1

Local control panel with an integrated programmable high-speed controller and operator interface for each individual rectifier section.

Level 2

Joint control of the sections is carried out at the master control panel in the control room 7 of the main substation.

Level 3

Remote control via the keyboard and mouse of the man-machine interface

(S.P.I.D.E.R MicroSCADA [2], an ABB system). Manual back-up control is provided by the master control panel.

Local control

Each rectifier section is connected to one local control panel, for which different operating modes can be selected. This panel contains measurement, control and protection units. If the joint control system fails, the rectifier sections can be operated either automatically or manually from these panels. The local control and protection equipment is based on the PSR controller.

The PSR was chosen because of several key benefits it offers:

- Very high processing speed
- Simple, user-friendly programming, based on a graphic function block language
- Fast switchover to other parts of the user-program
- System-integrated function blocks for converter or rectifier applications
- High reliability
- Fault diagnostics for all modules

Communication between the local control panels, the master PSR, the man-machine interface (MMI) and the switchgear control units takes place over fiber optic cables, thus effectively avoiding any potential electrical interference.

Master control panel

The master control panel (MCP) consists of a mimic diagram **7** showing all the breaker and disconnector positions in the 220-kV and the 33-kV switchbays, plus the most important measured data from the plant. It gives the operator a good overview of the statuses of the AC and DC power supply systems while also acting as back-up to the MMI.

The main features of the MCP are the potline master control functions and display of the main potline data, including:

- Total DC current
- DC voltage
- DC power
- Potline current setpoint
- Total harmonic distortion

Supervisory level

Aluminium producers require very accurate and highly reliable overall current control. The current control system delivered by ABB is built around the PSR high-speed controller. The setpoint for the potline can come from either the master panel, SCADA system, electrolysis foremen's room or the host computer.

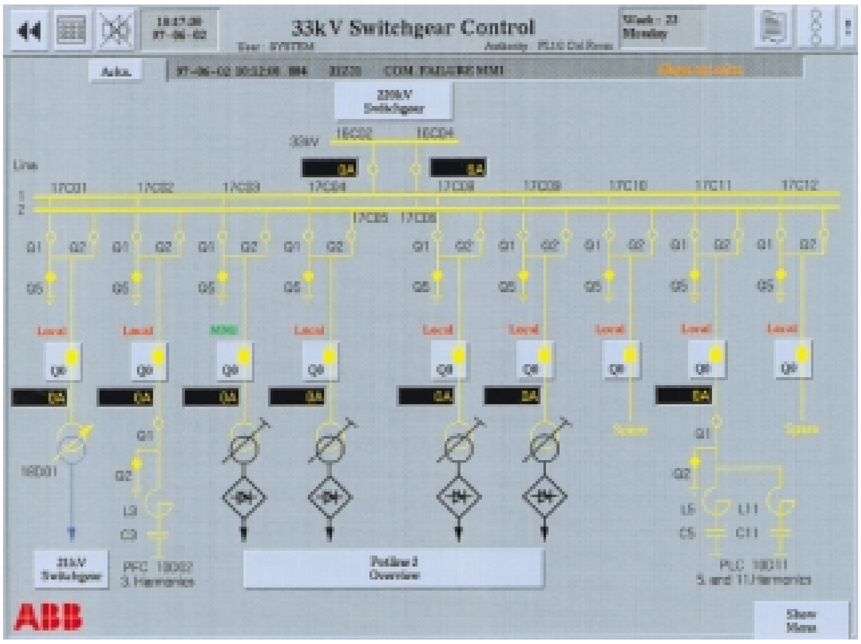
The current value setpoint for all three potlines in ISAL's smelter can also come directly from the master SCADA system of the main power supply (MPS), or indirectly, as a calculated value, when the ISAL MPS is set to a power curtailment mode. The necessary command can be transmitted directly to the main power supply's master PLC in the control room from the National Dispatch Centre, via the NPC control station in Straumsvik. The signals from the instruments are communicated to the Master PSR and processed with very high accuracy, ensuring an overall control accuracy of 0.2 %.

By constantly monitoring the signals from the DC current measuring heads and comparing them with the AC current transformers in the rectifier transformers and the 33-kV feeder values, it is possible to automatically switch to the AC back-up current measuring system without interruption should one of the DC measuring heads fail.

SCADA system

The SCADA system provides the man-machine interface and displays all the operating states of the four rectifiers, the high-voltage and medium-voltage switchbays, and the supervisory level control system. Approximately 20 process schematics and overlays give detailed information about the various parts of the plant. In addition to digital signals (eg, circuit-breaker positions and pump operating modes), the SCADA system displays all the main load values, such

Control room with mimic diagram. In the foreground are the MMI monitors. **7**



Aluminium producers require very accurate, reliable overall current control. Some 20 process schematics and overlays give detailed information about the various parts of the plant. This screenshot shows the 33-kV distribution level with DC power supply and harmonic filter feeders. **8**

as currents, voltages and power on the AC and DC sides of the main power supply **8**.

In this context, the electrolysis data (V, kA, MW) transmitted to the SCADA from the master PSR, are of the highest importance. If the main measurement system should fail, the PSR will automatically switch to the back-up measuring system.

The operator's work includes actuating the circuit-breakers and the DC isolators, adjusting the overall current setting (or current) for each individual rectifier, and choosing the operating mode. The SCADA system provides extensive event recording facilities. Warnings, alarms, trips, events such as breaker operations etc, are recorded by the PSR systems with a time resolution of 1 ms and transmitted together with a precision clock time stamp to the SCADA system.

Early completion yielded ‘bonuses’

This project, in which the ISAL potline 3 was ‘powered up’ in just 18 months, benefited strongly from the close cooperation between ISAL, ALESA and ABB. Delivery dates and installation deadlines were met. Constant project monitoring ensured that technical milestones were reached. Moreover, early commissioning represented ‘bonus’ revenues and a faster return on ISAL’s investment. An additional ‘bonus’ was the fact that the DC power supply losses are about 250 kW lower than originally calculated and guaranteed. Yet, the most important benefit will be the competitive success of ISAL. Given the energy-intensive characteristics of aluminium smelting, the value of ABB’s electric power engineering and the efficiency of its components and systems will ultimately be determined in the marketplace.

Final performance tests conducted during acceptance in October, 1997, confirmed that all the electrical systems were operating within the specifications of the contract. This, completion of the ABB package on time and speeding up of other critical work by the IPM Team, enabled some 14,000 extra tonnes of aluminium to be produced, exemplifying the value added by advanced, proven technologies, experience and professional project management.

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