Power Conversion

CASE STUDY

230 MVAR DYNAMIC COMPENSATION WITH TCR FOR ELECTRIC STEEL PLANT, LECHSTAHLWERKE

GE Vernova's Power Conversion business has designed and supplied a 230 Mvar dynamic compensation system for Lechstahlwerke electric steel plant's two electric arc furnaces along with their two ladle furnaces.

At its Berlin site, Power Conversion designed a 230 Mvar dynamic compensation system for the two 75 MVA and 82 MVA electric arc furnaces and their two-ladle furnaces belonging to the 20 kV 180 MVA electric steel plant at Lechstahlwerke (LSW), Meitingen, Germany. A further complication was that these run off what is, in relative terms, the extremely weak 110 kV power supply belonging to Lechenergiewerke (LEW), with a short-circuit rating of between 885 and 1210 MVA.

Power Conversion delivered the project in six months. The project was undertaken as part of a consortium with the Augsburg subsidiary of AREVA, with Power Conversion retaining responsibility for and management of the technical side of the project. All the necessary dimensioning and calculations were carried out by Power Conversion, including those relating to the items to be supplied by its consortium partner.

This dynamic compensation must be the largest in Germany and Europe, in terms both of its power and of the nominal power of the thyristor controller, which surely has a performance class that few manufacturers involved in converter technology can manage.

The main aim of the project was to improve 20 kV voltage stability and to reduce 20 kV voltage fluctuations from 30% to below 5%, in order to thereby significantly increase steel production from the electric arc furnaces. At the same time, the average 20 kV load voltage was increased from 20 kV to 21.5 kV.

Power Conversion also manufactured the converter of the 250 Mvar TCR and its digital closed-loop control. The entire system consisting of 72.5 kV SF6 outdoor switchgear, 230 Mvar filter circuits with installed power of 341 Mvar, a sheet steel container of laminate design, a cooling and recirculation cooling system for the converter, as well as the 20 kV control system, was designed and configured at Power Conversion.

The fears of the local power supply company that the 32-year-old 110 kV/20 kV transformers might sustain damage as a result of overvoltage were taken very seriously. Various measures to protect the transformers were agreed with the power supply company, and these were then configured, implemented and tested prior to connecting the dynamic compensation.

The following demands were made of the voltage quality in the 20 kV industrial point of coupling (IPC), having a short circuit rating of only 611 MVA:

- Absolute voltage changes of less than 5% (±2.5%)
- Average load voltage on 20 kV of 21.5 kV
- Individual harmonic currents below the limit values of EN 61000-2-2

The outdoor switchgear of the 67m long and 31m
wide dynamic compensation looking from East to West.

The noise-insulated TCR reactors are clearly visible, as well as the container for the converter and closed-loop control, and the 33 kV aluminium tubing busbar.

The filter circuits of the dynamic compensation are designed for the 2nd, 3rd, 4th and 5th harmonic and due to their size, also filter out the harmonic currents of the 7th to 13th harmonics to a significant degree.

Switching of the compensation involved the use of four SF6 circuit breakers in their outdoor version. These circuit breakers with a rated voltage of 72.5 kV ensure that the higher recovery voltages generated when switching off 100 Hz filter circuits do not result in damage to switches or compensation, or in damage to the upstream 20 kV indoor switchgear of the steel plant operator. In addition, these outdoor circuit breakers can safely channel the transient current into the filter circuits when the power is connected. Numerous calculations and simulations were performed in order to obtain project approval of the manufacturer of these circuit breakers.

Design approach

Bidders initially submitted a compensation rating of 135 Mvar. Power Conversion pointed out, however, that with this rating it would be physically impossible to meet the concomitant requirement of a maximum 5% of voltage changes on the weak IPC, and that 180 Mvar on 20 kV would be required for this.

Since the steel plant operator also planned to increase the 20 kV voltage from 20 kV to a maximum of 21.5 kV +5% in order to also increase furnace output, the compensation rating had to be increased quadratically to 230 Mvar to match.

To determine the number of filter circuits, calculations were performed with a view to, on the one hand, obtaining the smallest possible number of filter circuits, and on the other, not exceeding the limit values for harmonics, as well as being able to switch the filter circuits safely off and on, and without risk of damage, which was a lot more important in this case. These mutually conflicting objectives could only be reduced to a common denominator by using four filter circuits for the 2nd, 3rd, 4th and 5th harmonic.

Anti-noise enclosures of the self-cooling TCR reactors; on the right, sheet steel container of laminate design; in the foreground, the glycol water/air heat exchanger of the thyristor controller.

One phase of the capacitor bank of the 100 Hz filter circuit with twin bridge com – parison protection, anti-noise enclosures of the self-cooling TCR reactors, and the laminate sheet steel container for the converter and closed-loop control.

Rating of the components of the filter circuits was selected in such a way that processes that were also neglected elsewhere, such as the frequent start-up of the furnace transformers, which generated harmonics, were dealt with.

The 20 kV filter circuits can be used at any time on 21.5 kV +5%, without limitations in terms of the service life of the capacitors, and without using up the IEC 871 10% hidden reserve. This therefore resulted in the capacitor banks requiring installed power of 341 Mvar, i.e. 1½ times the nominal compensation rating of 230 Mvar on 21.5 kV +5%.

The solid approach used in the design has proved itself, since transient situations can arise, particularly in the weak 20 kV IPC or if there is outage or shutdown of a power supply company transformer, but these have no dama-ging effects on the filter circuits.

What was important for the steel plant was a reduction in noise levels, and it was a requirement that the noise out-put of each of the TCR reactors should be reduced from 110 dB (A) per phase to 96 dB (A), something that was only possible by enclosing the reactors. The sound insulation involved represented a significant percentage cost of the project budget.

Two phase racks of the 250 Mvar thyristor converter connected in series in the sheet steel container

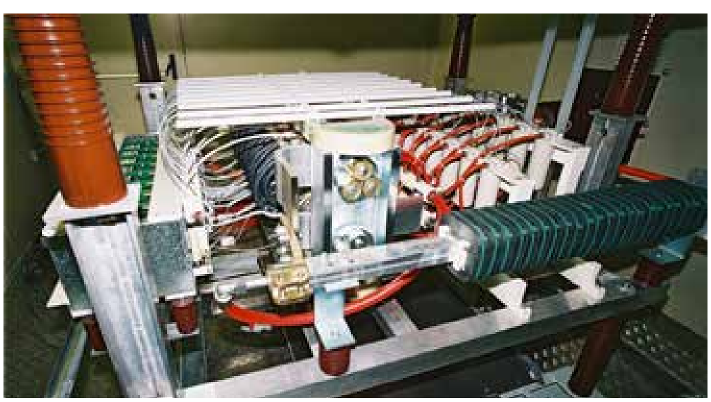
Thyristor controller – core component no. 1 of the dynamic compensation

The thyristor controller always loads the mains supply with reactive power to obtain precise push-pull vis-à-vis the electric furnaces. This results in the reactive power output that is removed from the mains supply (the sum of the reactive power outputs of the furnace and of the thyristor controller) remaining equal in terms of the control speed of the TCR, and only results in relatively low reactive power output fluctuations in the incoming mains supply, resulting in stable mains voltage. The following is an approximation for the fluctuation, ΔU, of the latter: $\Delta U \approx \Delta Q/Sk$, where ΔQ is the re-active power output, and Sk the effective short-circuit rating at the IPC.

Arranged in a twin column, the anti-parallel disc thyristors of the delta-connected thyristor controller are connected directly without transformers to 23 kV via a re-actor. 16 thyristors, connected in series, with a nominal voltage of 5200 V each, provide the relevant operating and surge voltage stability. There are two thyristor racks connected in series.

Each thyristor rack is equipped with saturable ferrite core reactors, and, if the thyristors do not all ignite at once, these protect the last thyristor ignited from fatal overvoltages. In addition, this saturable reactor limits the rate of current rise on ignition. RC attenuation on each thyristor pair limits overvoltages at the thyristor to an acceptable level in the event of current extinction.

The ignition signals for the semiconductors are determined by the closed-loop control and transmitted to the thyristor via synthetic optical fibres. Since no ignition energy can be transmitted via the fibre optics, this is tapped from the RC attenuation. This important task is performed for each thyristor position by the thyristor section electronics (TSE), and their control in the control cubicle ensures that the thyristor is still shut down safely in the event of a disabled signal logic failure (e.g. if the supply voltage is down), even when running automatically. Breakdowns due to thyristors not being shut down, as have already occurred with other manufacturers, are prevented with our thyristor controller.



Valve platform with water-cooled thyristor twin column, water-cooled RCattenuation and water-cooled ferrite core reactors

Twin column with water-cooled 100 mm disc thyristors. In the foreground are the thyristor section electronics for control and monitoring via synthetic optical fibres.

BOD (break-over diode) modules are fitted on these TSEs, and these provide emergency ignition of the thyristors if there is hazardous overvoltage in the 23 kV mains supply, thereby removing the overvoltage from the thyristor. The converter is water-cooled, i.e. the thyristors are clamped in place between water-fed cooling boxes. The attenuation resistors are also water-cooled.

A treated water-cooling system (360 kW) with deionised water supplies the thyristor rack with the right amount of water at the required pressure. In order that excessive temperature differences between the ambient air and the live thyristors cannot lead to hazardous condensation, the treated water temperature is regulated to within around 3°C of the ambient temperature. Converter losses to the cooling water are released via a treated water/glycol water heat exchanger and led off at that point via a glycol water/ air heat exchanger into the surrounding area.

With this thyristor controller from **Power Conversion**, converter losses account for only 0.16% of the nominal power of the dynamic compensation.

Particular attention was given to the power supply connection of the converter for a rated current of 4000 A. Expansion straps and self-locking nuts provide a solid power supply connection. The 4000 A insulating bushings (36 kV series) lead the thyristor current into the outdoor switchgear.

Digital closed-loop control – core component no. 2 of the dynamic compensation

The digital closed-loop control, which has been tried and tested in numerous dynamic compensations, was again successfully used here, with numerous minor modernisations. As before, however, due to the particular requirements for speed, the measured value acquisition of the control variables and the control and monitoring of the thyristors are better and more cost-effectively implemented in analog technology rather than fast-moving digital technology. An industrial PC with colour flat screen for error display, visualisation, remote control and parameterisation of the digital closed-loop control is housed in a 600 series cubicle section. A Profibus connection to the customer was implemented with the CANopen bus we use as standard.

The closed-loop control is based ona three-phase design and is equally suitable for unbalanced loads, such as electric arc furnaces, and balanced loads, such as rolling mill drives. It balances the mains voltage by means of contra-directional unbalanced control of the thyristor-controlled reactor (TCR). Via its control structure, the closed-loop control converts the measured actual values into the setpoints for thyristor control. There is three-phase measurement of the furnace currents that are to be compensated: those of the two electric arc furnaces, the currents to the three 20 kV steel plant supply lines, and the 20 kV voltages.

Cooling system of the converter in the sheet steel container.
Control valve in the glycol water circuit for continuous adjustment of treated water temperature as a function of ambient temperature. Twin pumps. In the background is the closed-loop control of the dynamic compensation.

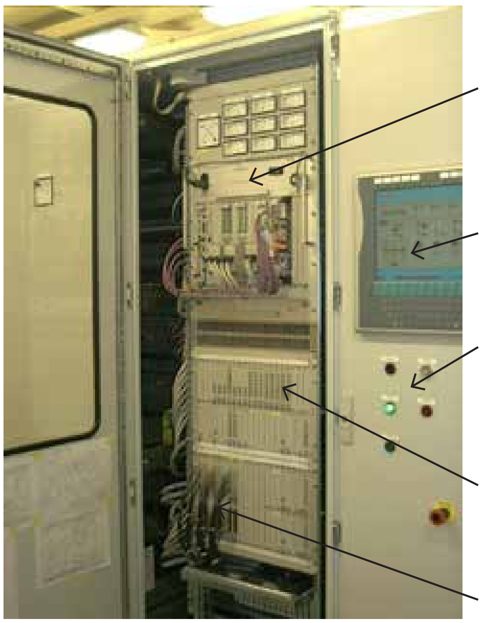
Power supply connection for 4000 A from the insulating bushing to the thyristor rack

The measured real-time values for closed-loop control are processed in a fast processor, as are the control tasks, regulation of the treated water´-cooling system and its recirculation cooling system, as well as the error display and visualization. The connections to the peripheral systems are transmitted by means of binary and analog signals. Remote field bus technology is used throughout.

The UPS-supported closed-loop control consists of the system HPC (high-performance controller), Logidyn D2, and is freely programmable via the LogiCad tool. If parameterisation is required in day-to-day operation, LogiCad is not, however, necessarily required; such settings can be made using LogiView during operation.

In LogiCad, online connections to the realtime machine can be established and, e.g. signal flows and signal states tracked on the display during commis-sioning. Parameters can also be set and changed. Changes to the control structure during commissioning are performed locally via LogiCad, and then translated into machine code via the system compiler and loaded into the Logidyn processor.

Once the closed loop-control has processed the measured values and control variables, control is determined. The thyristors are ignited via synthetic optical fibres. The feedback signal from the thyristors is also sent via optical fibers. The feedback signals are monitored, and the converter can still be operated safely with two thyristors down per phase.



Closed-loop control, open-loop control and protection cubicles of the dynamic compensation

Installation

Whereas the thyristor racks, the closed-loop control and the cooling system are housed in a sheet steel container of laminate design, the noise-insulated TCR reactors, the filter circuits, and the inco-ming circuit breakers are designed as uncovered outdoor switchgear. Insulation coordination for the dynamic compensa-tion components was not dimensioned for a 24 kV pulse level of 125 kV, but for one of 170 kV (36 kV series). Conductor bars are not present, since the 110 kV aerial lines crossing the plant ensure adequate lightning protection. Current transport is by means of aluminum tubing.

The foundations of the TCR reactors were not executed in steel, but by using glass fibre reinforced (GRP) reinforcements so as to completely prevent thermomagnetic effects.

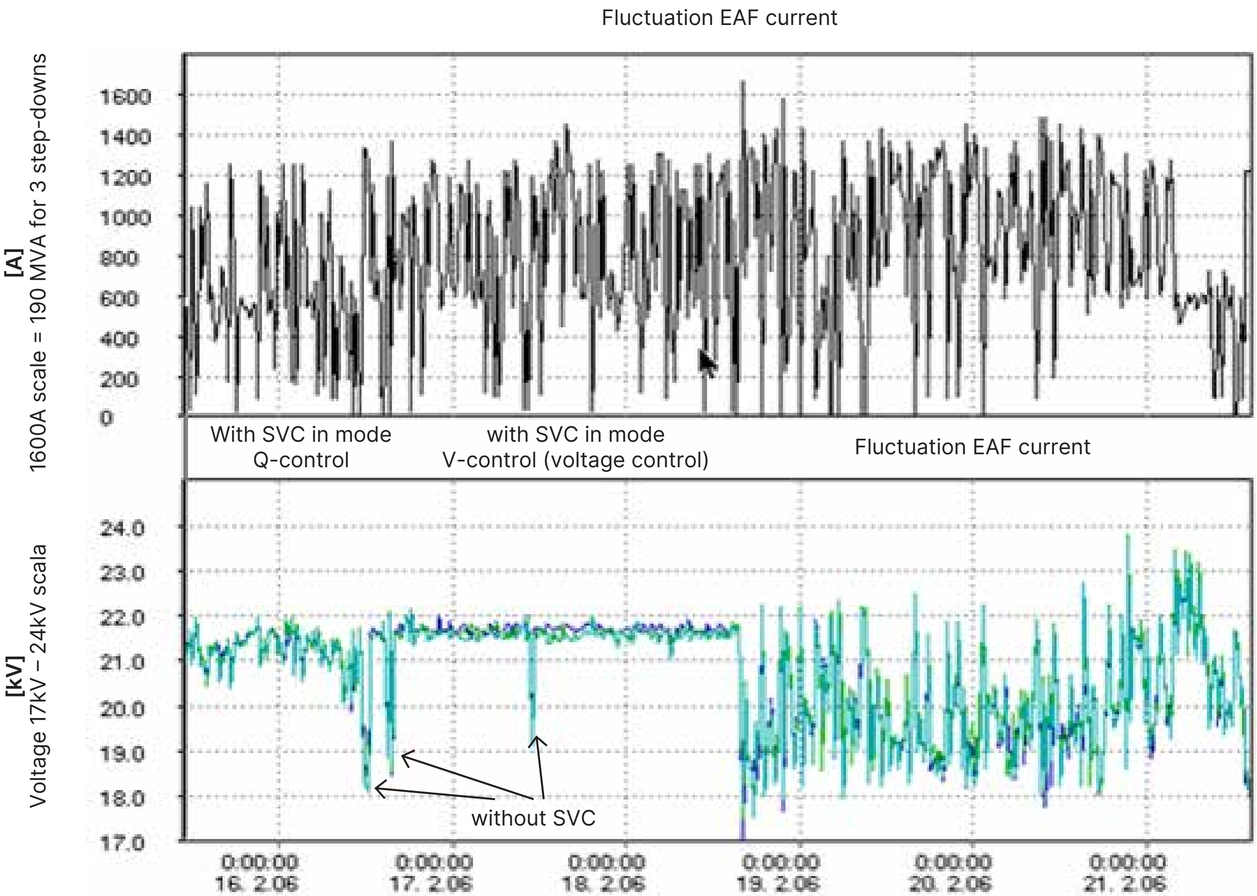
Foundations of the TCR reactors with GRP reinforcement

Commissioning and operational experience

The interval between run-offs for the electric arc furnaces was significantly reduced from approximately 37 minutes to around 31 minutes. The measurements performed as part of commissioning on 20 kV confirmed the calculations of the design phase. The required limit values for voltage changes (ΔU ≤ 5%) and har-monic voltages were met. The overvoltage that posed a risk to the 32-year-old supply transformers of the power supply company did not occur in connection with closed or open-loop control.

Apart from component damage in terms of a power capacitor, an unbalanced cur-rent transformer and screw connections coming loose in the TCR 6000 A range, there were no incidents. The reasons for the screw connections coming loose were investigated and countermeasures introduced; some of the screw connections had to be renewed. There were sporadic occurrences of „phantom signals" relating to thyri-stor failure, and a faulty PCB in the root electronics was identified and replaced. After that the system ran without fault and with excellent availability.

One striking result worthy of note is that the voltage changes on the 20 kV IPC are reduced to one tenth by dynamic compensation. Without it, during smelting the voltage changes due to the steel plant are approximately 30%, whereas with it they are only around 3%.



[A]: steel plant current and [kV]: voltage changes, with/without dynamic compensation in standard reactive power control and in improved voltage control (1 second intervals measured according to IEC 1000-4-7)

Basic technical specifications of the dynamic compensation (SVC, Static VAR Compensator)

Dynamic compensation:

Nominal voltage:	20 kV to 21.5 kV ±5%, 50 Hz, 3 AC
Nominal operating voltage:	21.5 kV +5% = 22.575 kV
Nominal operating range:	0 to 230 Mvar capacitive on 22.575 kV
TCR operating range:	0 to 230 Mvar inductive on 22.575 kV
Filter circuits (FC) compensation rating:	230 Mvar capacitive on 22.575 kV
Filter circuits (FC) installed power:	341 Mvar capacitive
Filter circuits:	2nd, 3rd, 4th, 5th harmonic

Thyristor-controlled reactor and water-cooled three-phase AC power controller:

Converter designation:	2 x Semivar W10052/4000/13,8
Converter rating:	250 Mvar on 22.575 kV
Nominal power:	0 – 230 Mvar/0 – 3400 A (Δ)/0 – 5890 A (Y)
Number of 100 mm thyristors in series:	16 items per phase (2 redundant)
Thyristor type:	Infineon Eupec T2851N5200
TCR power reactors:	2 × 8.25 mH per phase (Δ)

Cooling system of the water-cooled converter:

Type:	Treated water/glycol water/air
Nominal power:	360 kW
Treated water intake/outlet temperature:	47°C/65°C
Treated water mass flow rate:	16.2 m^3/h
Glycol intermediate circuit:	30% glycol, 70% treated water
Number of pumps:	2 of each (1 redundant)
Nominal ambient temperature:	40°C (outdoor)
Heat exchanger:	8 fans, Lwp≤ 88 dB (A)

Closed and open-loop control:

High-performance controller:	Digital, 32-bit realtime
Processors:	1 x Binary
Inputs/outputs:	208/48 items
AD/DA converter:	8/24 items
Control for thyristor ignition:	Optical, synthetic optical fibre
“Fast“/“slow“ digital controllers:	3/10 ms clocking
Maximum physical delay time:	10 ms (½ mains period of 50 Hz)

Circuit breakers:

Circuit breaker type:	Areva GL309 (SF6)
Rated voltage:	72,5 kV
Nominal current/short-circuit current:	3150 A, 40kA/3s

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