Power Conversion

**CASE STUDY**

# DYNAMIC REACTIVE POWER CONDITIONING SYSTEM (PCS) WITH IGBT PULSE INVERTER, ILSENBURG GROBBLECHWALZWERK

**For medium voltage power conditioning of the quatro stand in the Ilsenburg heavy plate rolling mill, GE Vernova's Power Conversion business designed and supplied a dynamic compensation system comprising of water-cooled IGBT pulse inverters.**

A power supply that runs perfectly is an essential requirement for ensuring the continuous, cost-effective operation of industrial plants with high current consumption.

This applies in particular to plants that have a low fault level in relation to the load. It is important to avoid disturbances on the public supply grid due to electrical pollution from the production process caused by instable power supply in the plant or contractual penalties incurred because power usage conditions are not met.

The new water-cooled dynamic four-quadrant PCS (power conditioning system) from Power Conversion offers seamless power supply concepts for industrial applications with high current consumption, which take into account the special requirements and the expected interactions between process and power supply.

The high quality of our solutions results from a detailed knowledge of processes in many industrial applications, the careful selection of high-quality components, and our extensive experience in the field of assembly and commissioning. Our services range from proven solutions for improving energy quality and innovative concepts for ensuring supply redundancy for important loads to careful emergency power concepts, which ensure that power is supplied in areas where a voltage failure would present a risk to personnel or to the plant. Whether a new installation or a modernisation project – the dynamic reactive power conditioning system (PCS) ensures a safe and stable power supply. Our tailored services ensure a high level of performance for your system solution throughout its entire life cycle.

Figure 1: Cubicle blocks with 4x ±1200 kvar water-cooled, modular PRO-X pulse inverters, open and closed-loop control for the 16 modular inverters and one of the four converter transformers with gas-insulated compact switchgear.

## The challenge

The time-variable, dynamic reactive power changes from thyristor-controlled drives lead to undesirable voltage changes in the incoming power supply, which may adversely affect other consumers. Although fixed compensation of the reactive power can be used to improve the average displacement factor (cos ϕ), it does not improve the voltage changes. They can only be reduced with freely adjustable, dynamic compensation.

In the past, thyristor-controlled reactor (TCR) technology was used and for more dynamic requirements, the technology of the forced commutated “Varoverter” type thyristor converter. As a promising substitute both for conventional dynamic compensation with thyristor controlled reactor and for the more dynamic, forced commutated thyristor converter, Power Conversion has successfully used standardized, self-commutated, water-cooled IGBT pulse inverters from four-quadrant drive technology to achieve the same electrical function and the same purpose more cost-effectively.

This technical solution is of particular interest because existing filter circuits and untuned capacitor banks at medium and low voltage can be used and re-used, since the new pulse inverter does not generate harmonics.

## The solution

As illustrated in Figure 2, there are two approaches for achieving the desired dynamic power range ΔQ (capacitive):

**Old approach:**

Freely adjustable line-commutated thyristor converter – by nature only inductive – with control range from

0 ... $\Delta Q_{inductive}$. Together with a parallel connected, capacitive fixed compensation of constant ΔQcapacitive, this gives a freely adjustable capacitive range of

0 ... $\Delta Q_{capacitive}$.

PCS: A freely adjustable, self-commutated pulse inverter with control range from 0 ... $½\Delta Q_{inductive}$ and 0 ... $½\Delta Q_{capacitive}$ together with a parallel connected, capacitive fixed compensation of constant $½\Delta Q_{capacitive}$ also gives a freely adjustable capacitive range of 0 ... $\Delta Q_{capacitive}$.

- PCS requires only half the installed power
- PCS enables smaller switchgear
- PCS saves space, reduced filter circuit power

It is even possible to completely omit the fixed compensation of constant $½\Delta Q_{capacitive}$.

A freely adjustable, self-commutated pulse inverter with nominal power of $\Delta Q_{capacitive}$ without parallel connected, capacitive fixed compensation also gives a freely adjustable capacitive range of 0 ... $\Delta Q_{capacitive}$.

The new pulse inverter technology also offers the following advantages:

- Considerably higher control dynamic and regulating response
- Continued use and re-use of existing filter circuits
- Relief of harmonic currents in existing filter circuits
- No hazardous effects on personnel from magnetic or electric radiation fields
- Maintenance/repairs possible without total plant shutdown
- „N-1“ operation, continued operation if one or more parts fail
- Power and control cubicles can be arranged side by side without adverse effects
- Reduced loss on light load due to partial shutdowns
- Routine test with nominal current/nominal voltage
- Considerably shorter delivery, assembly and commissioning time
- Progressive and incremental extensions possible
- Breakdown of the central plant into distributed smaller units

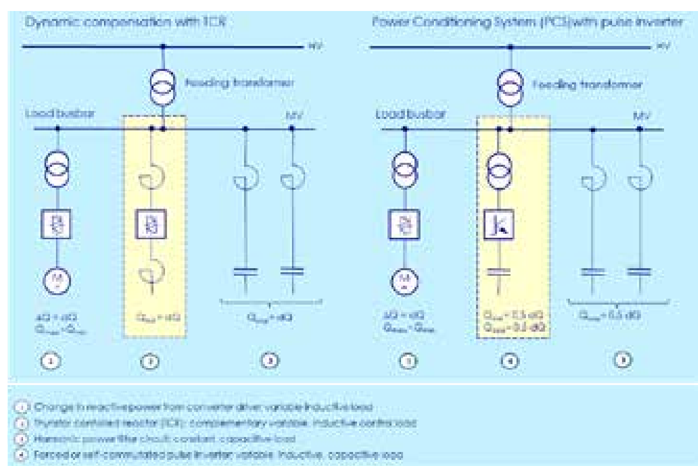


Figure 2: Comparison self-commutated pulse inverter technology PCS and conventional dynamic reactive power compensation with TCR.

**TYPICAL ROLLING SCHEDULE TWIN DRIVE QUATRO STAND**

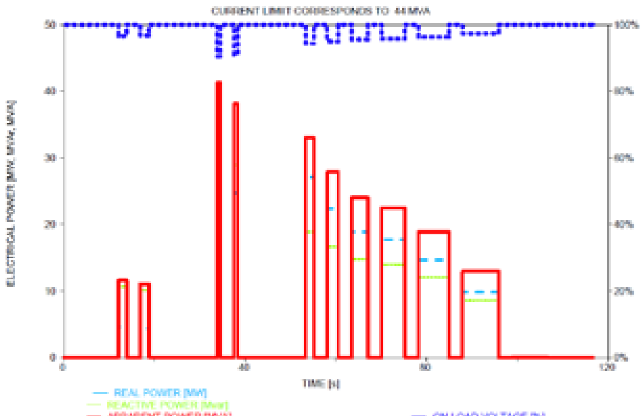


Figure 3: Typical reference load schedule of the main drive in the heavy plate rolling mill (without rolling mill base loads) real power, reactive and apparent power, calculated 15 kV voltage drop without dynamic compensation.

## Application example – Main drives in the heavy plate rolling mill

For conditioning the thyristor-controlled DC drive of the quarto stand (twin drive 2 × 6.4 MW, 246% overload, 44 MVA current limit, limited to 64% load on failure of dynamic compensation) at Ilsenburg Grobblech GmbH (see duty cycle, Figure 3), part of Salzgitter AG in Germany, Power Conversion designed, produced and supplied a modular pulse inverter system in water-cooled IGBT technology (total ±19200 kvar) for distributed installation with the following features:

- Availability 99.8%
- „n-1“ featuring
- CAN-Bus-controlled
- Water-cooled
- Digital closed-loop control VME-Bus 32-bit real-time
- Optional visualization and fault signaling via TCP connection:
  - View of each of the pulse inverters (CAN bus
  - View of protective relay (Modbus TCP, Profibus)
- Fast measured data acquisition for control responses at full power range < 20 ms
- Additional 32-bit high-speed connection to HPC of the main drive for control response ≈ 2 – 3 ms
- Special cast-resin converter transformer (optional outdoor housing)

In addition, various new system features have been implemented successfully:

- Integration of all computers and control processors in the TCP industrial point of coupling (IPC)
- Visualisation and fault signalling via TCP connection and OPC server
- Protective relay (10 items) with harmonic current measurement, integration in the closed-loop control, the visualisation and the process data acquisition „IBA-PDA“

## Design of the pulse inverter system

The PRO-X IGBT pulse inverter is in the standard 690 V range of water-cooled pulse inverters with four-quadrant drive technology (4Q) and has a modular structure. 16 units of ±1200 kvar each are divided into 4 groups of ±4800 kvar each.  The units of each group are supplied in parallel via cables. The operating voltage of 600 V is transformed via 4 special 5000 kVA cast-resin converter transformers of 15 kV.

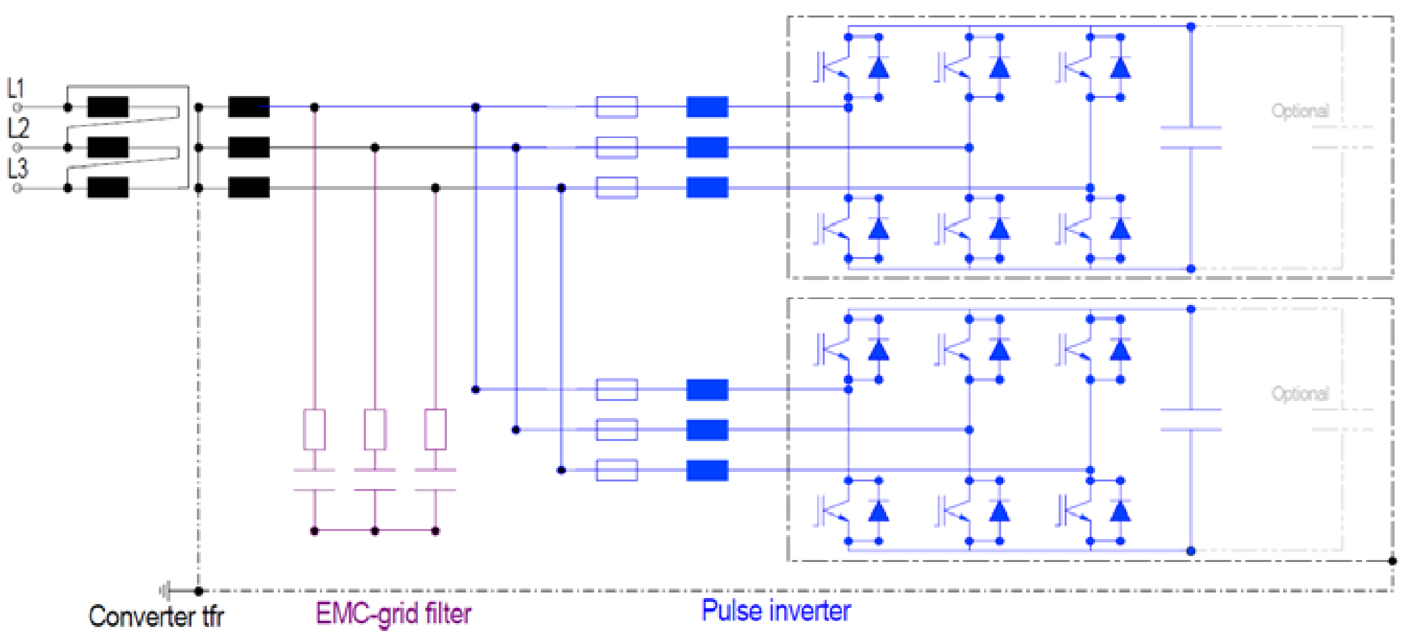


Figure 4: Simplified three-line diagram of a ±1200 kvar unit.

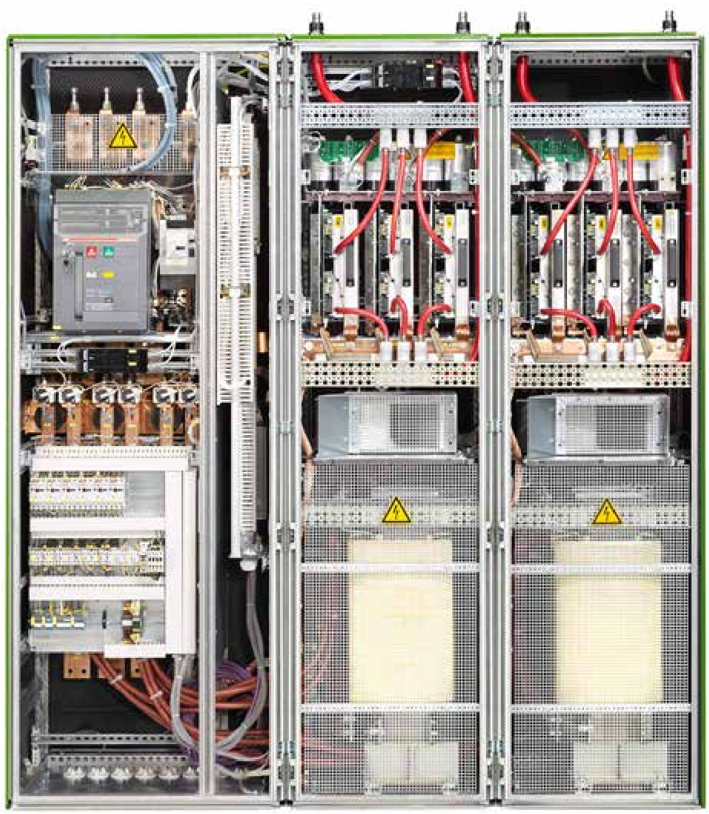

Figure 5: Water-cooled standard pulse inverter unit with busbar connection at the top/bottom for cables and expansion straps.

Since the self-commutated pulse inverters can be operated both capacitively and inductively, a dynamic control range of 9600 kvar per group can be achieved.

The 16 units of the four groups result in a total control range of 38,400 kvar. As shown by the three-line diagram inFigure 4, each pulse inverter unit is an independent converter system and has its own circuit breakers, LCL grid filter, fuse switch-disconnector, power reactor and IGBT modules with ignition amplifiers and DC link capacitor (new feature: film instead of electrolytic capacitors), pre-loading and control and ignition electronics (Figure 5). All pulse inverter functions are distributed for each power unit.

The 16 IGBT pulse inverter units are controlled individually and practically simultaneously with setpoints from a higher-level closed-loop control. The closed-loop control unit consists of a fast digital closed-loop control system in 32-bit realtime, which derives the setpoints from the measured actual values of the fast measured value acquisition (Figure 6) and simultaneously executes all control, monitoring and visualisation tasks.

The determined setpoints are transmitted individually to the 16 pulse inverters via a CAN bus system. All open-loop control and monitoring signals and the dynamic setpoint transmission are transmitted via the bus (CAN-open), and its time slots are so short that there is no instability for the individual pulse inverter systems.

A PI-controller reduces the reactive power in the supply practically to zero or another desired value. Without precontrol and disturbance variable compensation, and using only this controller, a control response of 50 ms can be achieved for the entire control range.

To accelerate the control response to less than 25 ms, the current of the main drive must be measured directly and compensated in terms of control technology as the setting path.

Special feature: Another proactive controller can calculate the reactive power in advance using the setpoint of the motor current and the armature voltage of the thyristor-controlled main drives. It improves the control in total response to ≈ 2-3 ms.

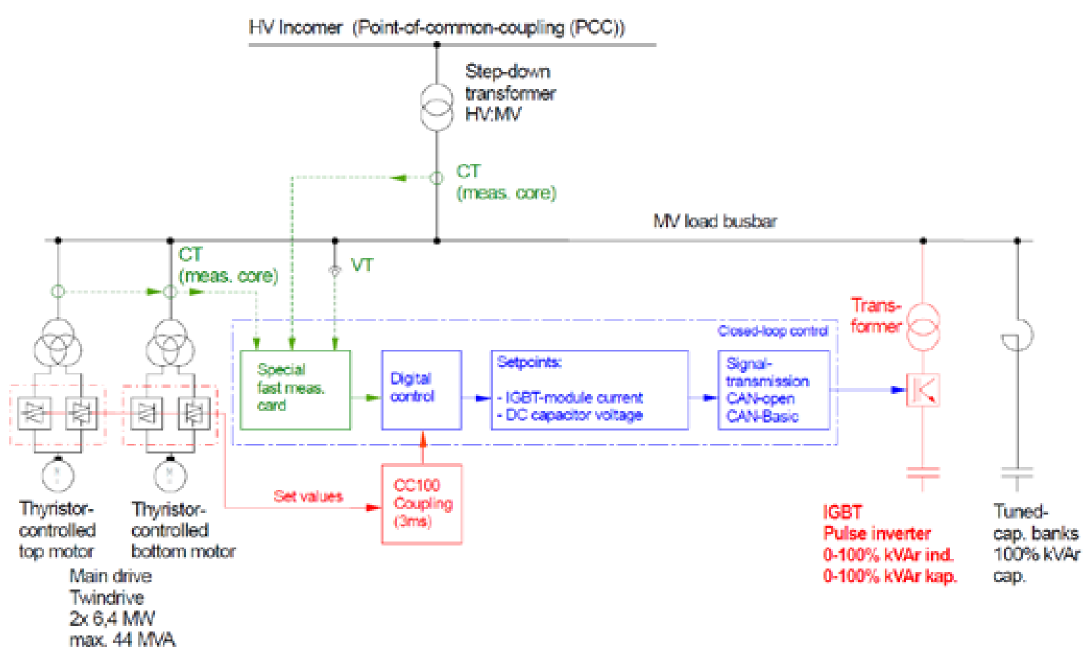


Figure 6: Simplified control diagram for the power conditioning system (PCS).

In the example described here, the setpoints from the HPC closed-loop control of the main drives were transmitted to the HPC closed-loop control of the PCS via a fast, digital CC100 connection in a 5 ms cycle (Figure 6); a stringent advantage for the 15 kV dynamic voltage quality of the relatively weak power supply company's power supply at the end of a 110 kV overhead line with a short-circuit rating of only 900 MVA.

## Method of operation of the pulse inverter

The semiconductors, which can be switched on and off in a pulse width cycle, switch the voltage of the DC capacitor onto the three-phase AC side. The PWM (pulse width modulation) is modulated. The width of the individual pulses is selected such way that the resulting voltage on the three-phase AC side has a time-variable, sinusoidal voltage form with a power frequency of 50 Hz. The momentary value of the clocked pulse voltage is either zero or equal to that of the DC capacitor. It therefore has one of two values. As a result, this type of converter is called a „2-level" inverter. The clock frequency is 3 kHz (60th harmonic), the vector frequency is double this value (6 kHz).

The pulse inverter can therefore be operated in time slots of 660 µs (< 1 ms) in freely dynamic inductive operation (lagging, underexcited) or capacitive operation (leading, overexcited). Capacitive or overexcited operation is not possible with a conventional line-commutated, i.e. underexcited, converter.

For capacitive nominal operation, Figure 7.1 illustrates the voltage clocking, which is modulated over the time so that the associated average values of the individual pulse voltage widths form a sinusoidal voltage curve.

Figure 7.2 illustrates the curve of the 15 kV single-phase voltage and the leading pulse inverter current without the effect of the LCL filter (the illustrated calculations do not include the grid filter). A corresponding curve can be illustrated for inductive nominal operation.

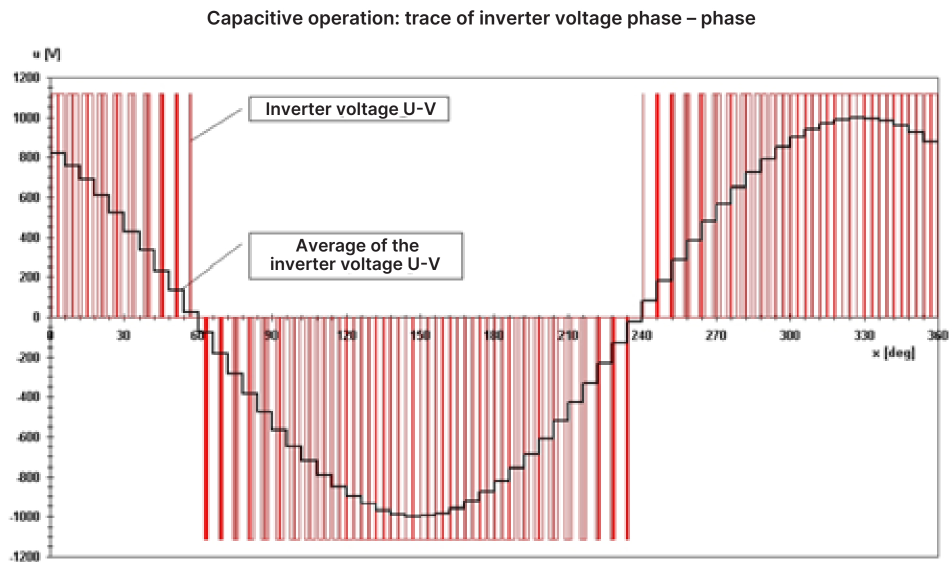


Figure 7.1: Capacitive operation: pulse width modulation of the DC capacitor voltage for an overexcited, sinussoidal voltage curve.

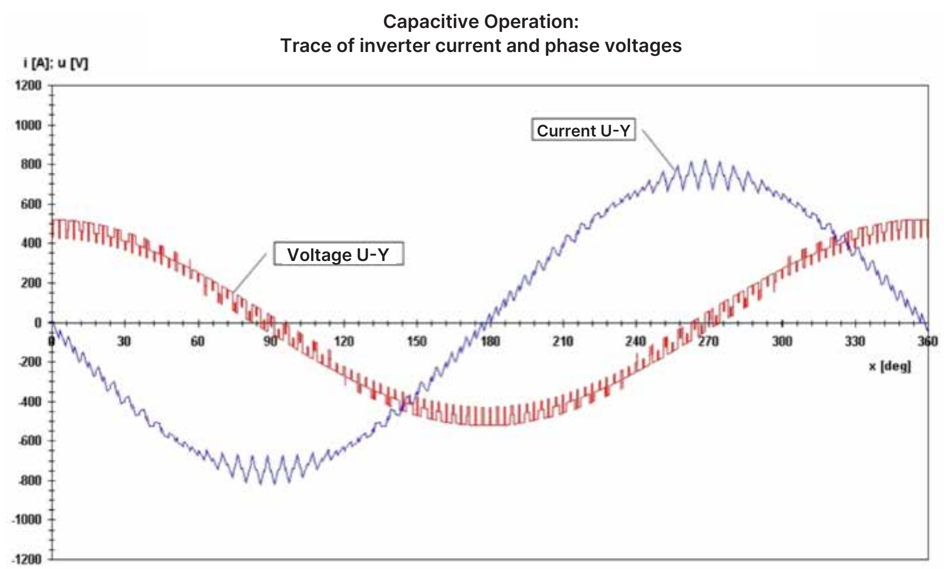


Figure 7.2: Capacitive operation: Pulse inverter current leading the single-phase voltage. The 15 kV voltage is illustrated without the effect of the LCL filter.

## Generation of harmonics

Low-frequency harmonic currents, which are familiar from conventional converter drives, are not generated by this IGBT pulse inverter.

During the design of the pulse inverter, it was assumed that, in future, limit values in the 2 – 9 kHz frequency range will be specified by the IEC:

- Industrial mains supply: Distortion (THD) < 3.0%
- Public mains supply: Distortion (THD) < 1.5%

These limit values are met using a standard LCL grid filter (Figure 4). In special cases (such as this application), this standard filter can be extended or replaced by a specially configured solution.

## Installation and time-critical conversion time

The short delivery time of five months and the overall very short completion period of just six months to handover, as well as the extremely short assembly and commissioning time of just four weeks during the annual shutdown, created particular challenges in terms of planning, design, and installation. Since other modernisation work was also carried out by the customer during the same annual shutdown, various site activities – such as processing, material loading and commissioning – overlapped and had to be carefully coordinated in terms of processing, delivery dates and safety. The customer implemented an external safety coordinator for this task. There were no accidents despite the considerable potential risks. The design solution for installation was only possible with help and close cooperation from the customer as well as systematic planning for the integration of various systems. The designs and conversions that were concluded with mutual understanding by the customer were part of the scope of supply for Ilsenburg Grobblech GmbH.

Power Conversion created the required design drawings for the converter, transformer, closed-loop control and cooling system installation and for the arrangement of air conditioning components, which were refined by the customer's construction department and a commissioned civil engineering company to create a construction project that could be implemented in the time frame. Preliminary conversion work and preparations for the implementation of the time-critical project during the 2006 annual shutdown were carried out by the customer during continued production. The statics of the distribution station were reinforced with a steel frame, which was positioned in the building wall behind the existing live transformers – because the transformers of the old system that operated until the annual shutdown were essential for uninterrupted production.

The new converter system could then be installed before the start of the annual shutdown in the existing open transformer cell above the live transformers of the old system, on a specially positioned intermediate ceiling made of steel.

This was designed so that there was no risk of thermomagnetic side effects (Figure 8). In the short project time, it was impossible to obtain official approval for a magnetic field-resistant reinforcement made from glass fibre reinforced plastic (GRP). After the start of the annual shutdown, the old transformers were removed, and the remaining new steel construction was put in place and completed within a week and the new transformers installed. Once other assembly work was complete, the transformer cells were externally sealed using a steel wall. In this way, the previous outdoor cells were converted to 2 two-story air-conditioned indoor cells. The customer's existing air conditioning systems were adapted and re-used.

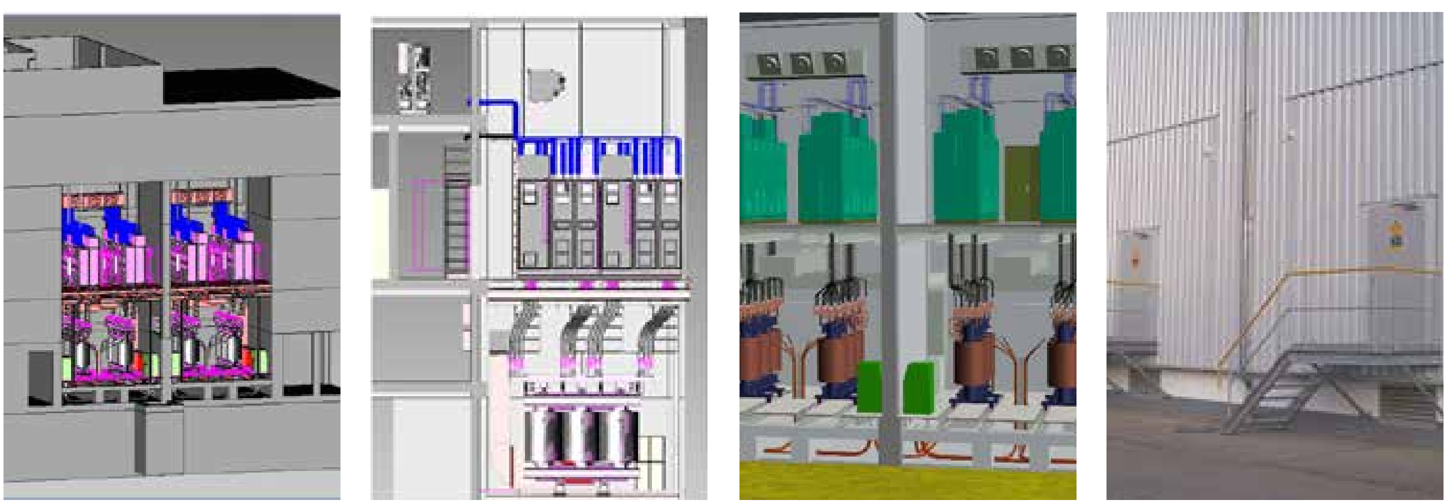

Figure 8: Installation in the distribution station in existing transformer cell on inserted steel ceiling, converted to air-conditioned indoor cell and sealed externally to absorb sound, declared as an electrical operating room. Closed-loop control installed in passageway, water-cooling system in false floor above.

## Commissioning, test operation, and acceptance

The system was configured, supplied, assembled, commissioned, and handed over in just six months. Deadlines agreed informally and those subject to penalties were all met.

Following production acceptance, the closed-loop control was continuously improved during operation, and weaknesses were analysed and removed until stable operation was ensured.

In particular, the high dynamic requirements of the powerful main drive on the weak power supply placed new demands on the control optimisation process.

The closed-loop control in this system differs from other previously implemented dynamic compensation systems above all in terms of its complexity. In addition, the full use of the modularity options offered by the converter system led to a considerably more complex control than usual.

In particular, the control compatibility with the existing 110 kV tap changer and the strongly fluctuating 110 kV voltage of the weak power supply, independent of the rolling mill, required special and system-specific control topologies.

The IGBT pulse inverter with digital setpoint transmission proved to be clearly more dynamic than a thyristor-controlled reactor with analog control voltage. Measurements of the magnetic and electric fields in the rooms next to the converter system showed conformance with UVV BGV B11. Noise emissions were also within the permitted values.The requested and agreed availability of 99.8% could be achieved safely.

## Training for operating personnel on-site and at the plant

At the Berlin factory, the operating personnel were trained in how to use the digital closed-loop control system. As well as providing the necessary basic knowledge, the training course also covered working with the LogiCad graphical user interface.In addition, the on-site training included system operation, troubleshooting, error removal, acknowledgement and the use of the 5 safety rules with concrete reference to system-specific features.

## Other project-specific option

As well as the design of separate, gas-insulated 15 kV compact switchgear, the necessary short-circuit and selectivity records, protective relay settings and tests, the available filter circuits and other outgoing circuits from the compensation were fitted with new protective relays, which were also integrated in the open and closed-loop control and the visualization.

Due to the separate compact switchgear, maintenance can be carried out at one part of the pulse inverter system during shifts with no rolling or during annual revision downtime, without having to shut down the entire system.

Furthermore, operational losses can be reduced through specific partial operation of the modular converter system. The existing 120 mm² 15 kV power cable, which was not short-circuit proof, was replaced by 150 mm² XLPE cable.

## Option: teleservice and internet VPN connection

Teleservice and VPN connection will become increasingly popular in future and our new PCS is already designed with this in mind.The digital closed-loop control enables not only a view of the current closed-loop control parameters and signals and the actual values and setpoints, but also of the bus-controlled pulse inverters and the protective relays in the various switchgear.

This means that it is possible to dial into the digital closed-loop control online from the service center in Berlin.

The service center can therefore read error logs from the closed-loop control, the protective relays and the pulse inverters. This means that parameters can be modified much faster and more cost-effectively than by servicing work. In many cases, there is then no need for a service engineer to travel to the site, and even if this is required, the engineer can be better prepared.

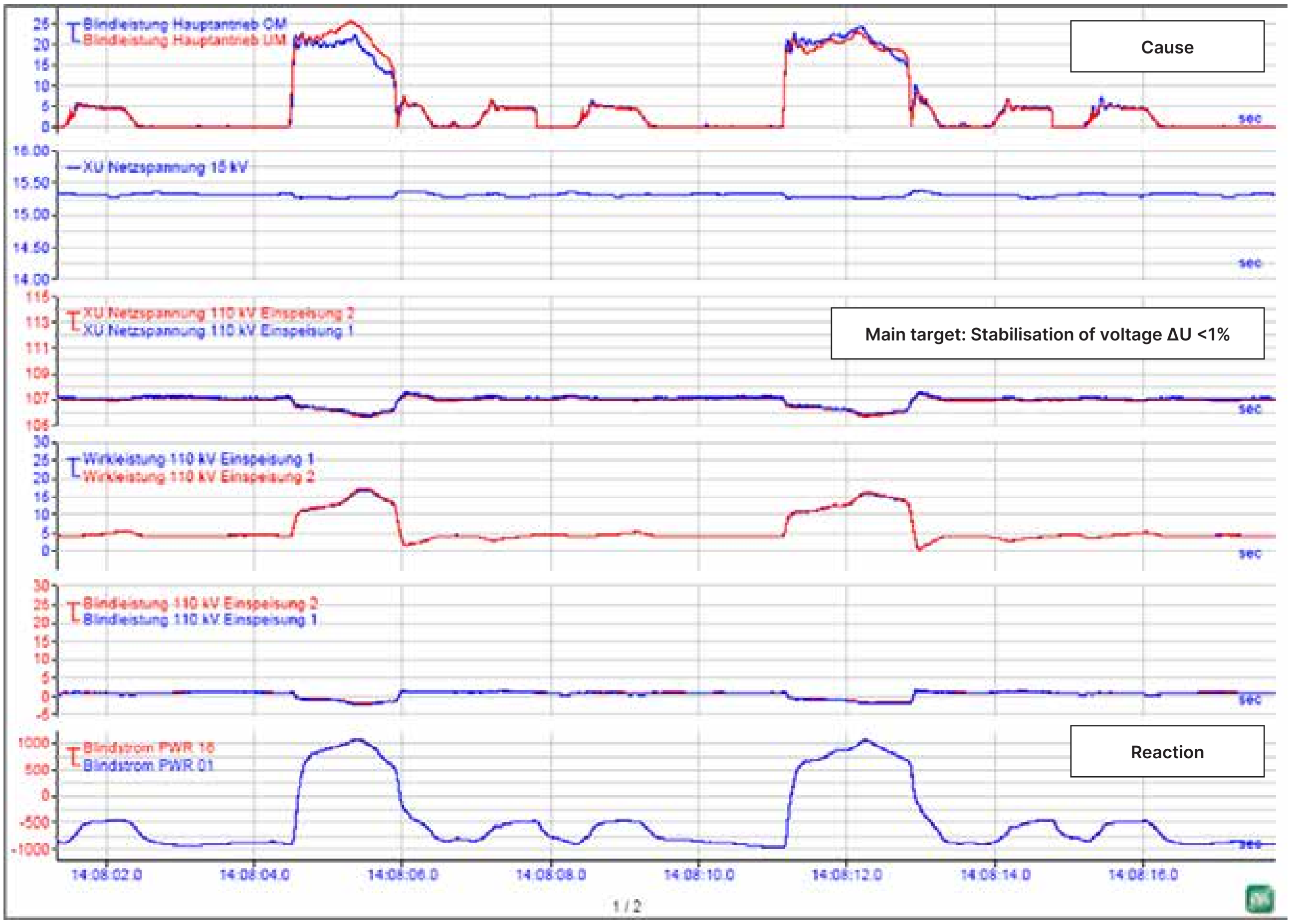


Figure 9: Measured traces (5 ms sampling) of the operation of the dynamic compensation on the rolling passes of the main drive. Curve for 15 kV and 110 kV voltages, real power, reactive power of the 110 kV supply.

## Outlook – reasons to choose PCS

- Increased productivity – due to perfect power supply quality
- Higher product quality – by improving the power supply quality
- Better integration in existing operating structures

## More Safety, More Stability

PCS not only reduces undesirable power pollution directly at the medium voltage busbar of the plant supply, but also helps to save energy costs through modularity.

Power Conversion‘s experience with industrial processes enables us to reliably estimate potential disturbance in specified mains configurations.

We always remained focused on our main aim: a system application with the best possible price/performance ratio.

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