Power Conversion

CASE STUDY

PCS DYNAMIC REACTIVE POWER CONDITIONER WITH FOUR-QUADRANT IGBT PULSE INVERTER

A secure power supply is an important base for the continuous economic operation of industrial plants with high power consumption. It is necessary to avoid power system pollution disrupting the public supply network and prevent an erratic power supply in the factory itself or peak value loads causing disruptions to in-house production.

Secure power supply with high power consumption

The PCS (power conditioning system), a dynamic four-quadrant power conditioner, provides universal power supply concepts for industrial applications with high power consumption, which take into account special requirements and the interaction to be expected between the process and the power supply. Our range of services runs from tried and tested solutions to improve the power quality, to innovative concepts to ensure supply redundancy for important consumers.

Whether a new installation or a modernization project – the PCS dynamic reactive power conditioner provides a secure and stable power supply. Our perfectly coordinated services ensure that your system solution performs well throughout the entire life cycle.

In R&D, manufacturing as well as after-sales, top priority was given to service, quality and reliability.

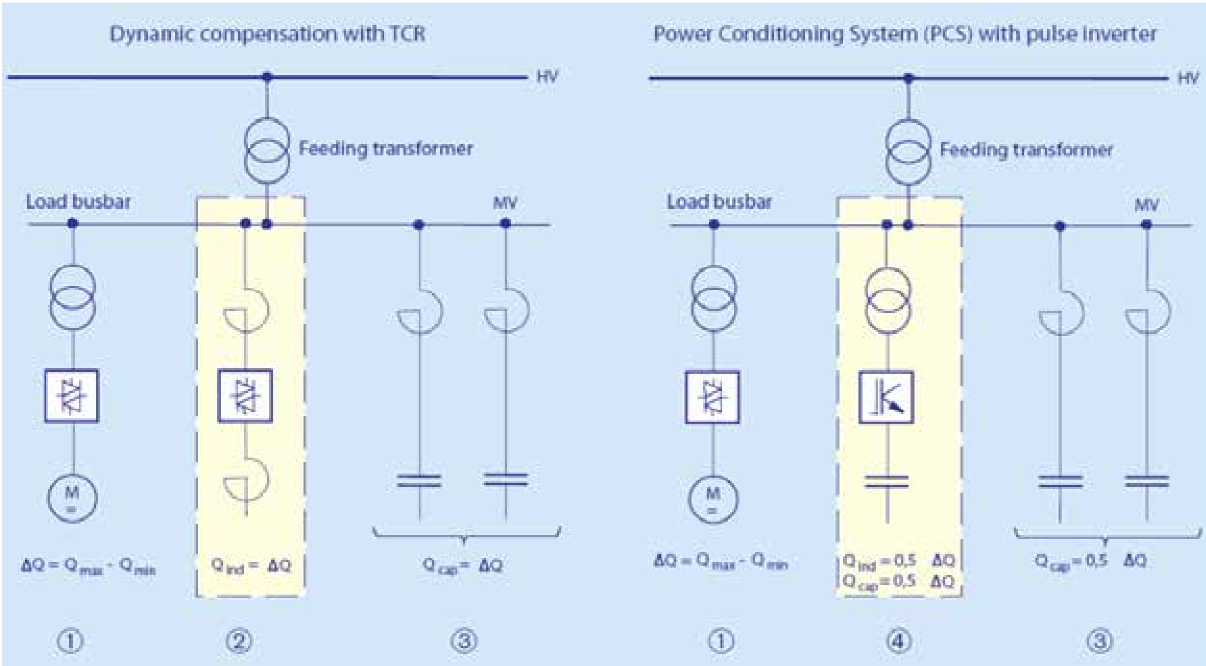
The challenge

The dynamic reactive power changes of large thyristor-controlled drives lead to voltage changes in the incoming supply that can be undesirable or adversely affect other loads. Although fixed compensation of the reactive power can improve the average power factor (cos ϕ), it cannot improve voltage variations. These can only be reduced with steplessly variable, dynamic compensation.

In the past, thyristor-controlled reactor (TCR) techniques were used for this. Our company has developed a promising substitute for conventional, dynamic compensation with thyristor-controlled reactor, the Power Conditioning System (PCS), based on standardized IGBT pulse inverters from four-quadrant drive technology.

This technical solution is particularly interesting because existing harmonic filter circuits and untuned capacitor banks on medium and low voltage can continue to be used and re-used, as the new pulse inverter does not generate harmonics.

Figure 1: Row of four ± 812.5 kvar cubicles based on MD2000 pulse inverters installed close to 20 kV switchgear and closed loop control



1. Change in reactive power from converter drive; variable inductive load
2. Thyristr-controlled reactor (TCR); complementary variable, inductive control load
3. Harmonics power filter circuit; constant, capacitive load
4. Forced or self-commutated pulse inverter; variable, inductive, capacitive load

Figure 2: Comparison of TCR and PCS

The solution

There are two approaches for achieving the desired dynamic power range ΔQ (capacitive):

1. Conventional approach
An steplessly variable line-commutated thyristor converter, that by its nature can only be inductive, with a control range of $0\text{-}\Delta Q_{inductive}$ produces, together with a capacitive fixed compensation of a constant $\Delta Q_{capacitive}$ connected in parallel, provides a steplessly variable capacitive range of $0\text{-}\Delta Q_{capacitive}$.

2. Approach with PCS
A steplessly variable, self-commutated pulse inverter with a control range of $0\text{-}½\Delta Q_{inductive}$ and $0\text{-}½\Delta Q_{capacitive}$ together with a capacitive fixed compensation of a constant $½\Delta Q_{capacitive}$ also provides a steplessly variable capacitive range of $0\text{-}\Delta Q_{capacitive}$.

These two approaches are compared in diagram form in Figure 2.

When using the PCS, the same result is achieved more economically using the same electrical function:

- The PCS only needs half the installed power level
- The PCS needs less switchgear
- The PCS saves space, requires less filter circuit power

It is even possible to dispense with the fixed compensation of a constant $½\Delta Q_{capacitive}$: a steplessly variable, self-commutated pulse inverter with a rated power of $\Delta Q_{capacitive}$ without capacitive fixed compensation connected in parallel, also produces a steplessly variable capacitive range of $0\text{-}\Delta Q_{capacitive}$.

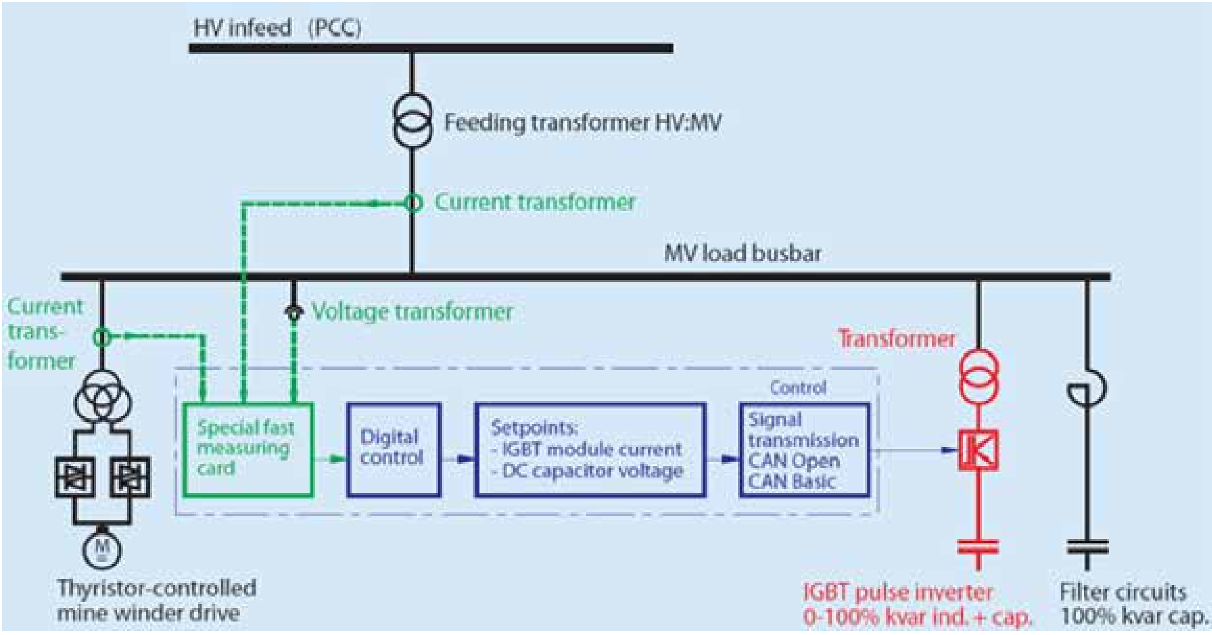


Figure 3: Simplified control diagram for the reactive power conditioner

The new technical solution also promises additional benefits in the form of:

- Far better dynamic control response
- “N-1“ operation, continued operation when one or more of the individual units fail
- Continued use and re-use of existing filter circuits
- Reducing the load of harmonic currents in existing filter circuits
- No unhealthy effects from magnetic or electrical radiation fields
- Power and control cubicles can be side by side without effecting each other
- Minimal loss during light load from partial shut-downs
- Short delivery, assembly and commissioning times
- Modular structure for stage-by-stage and step-by-step expansion
- Division of central systems into localized, smaller units.

Technical features

- „n-1“ capability
- CAN-bus-driven
- VME-bus 32-bit real-time digital control
- Optional visualisation and fault reporting via TCP coupling:
  - observation of each pulse inverter (CAN bus)
  - observation of the protective relay (Modbus TCP, Profibus)
- Special cast resin converter transformer in optional outdoor housing
- Fast measured-value acquisition for dynamic control response of < 25 ms over a full power range
- Optional teleservice and VPN links

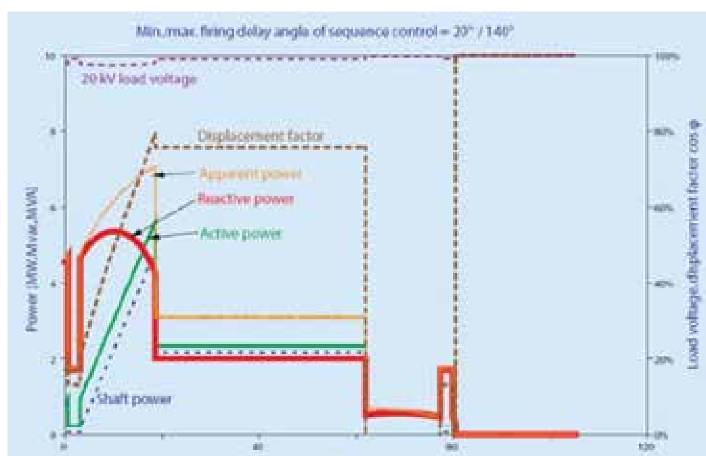


Figure 4: Mine winder load duty cycle of the sequentially controlled mine winder(with-out mine base load): shaft power and active power, reactive power and apparent power, cos ϕ

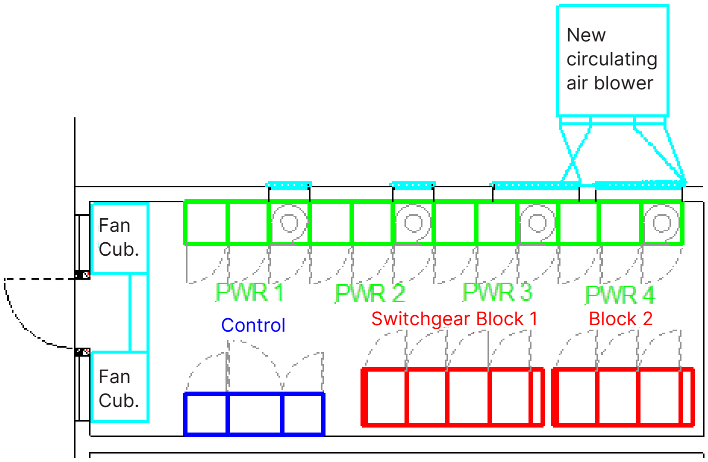


Figure 5: Arrangement indoor layout

The four IGBT pulse inverter units are triggered individually and virtually simultaneously by setpoints from a common, higher-level control system. The control unit comprises a fast 32-bit realtime digital control system, which derives the setpoints from the measured actual values using fast measured-value acquisition (Figure 3) and which simultaneously runs all the control, monitoring and visualisation tasks.

The determined setpoints are transmitted individually by means of a CAN-bus-system to the four pulse inverters.

The MD2000 has two buses: one for all the control and monitoring signals(CAN-open) and a second, faster one (Basic-CAN) exclusively for dynamic setpoint transmission.

PCS in use with a mine winder

For a thyristor-operated mine winder (Figure 4), a PCS with ± 3250 kvar for localized installation was supplied.

In addition, various system innovations are being introduced:

- New protective relay with measurement of harmonic current (together < 100 ms),
- Filter circuit capacitor overvoltage protection integrated in the digital control
- Visualisation and fault reporting via TCP coupling

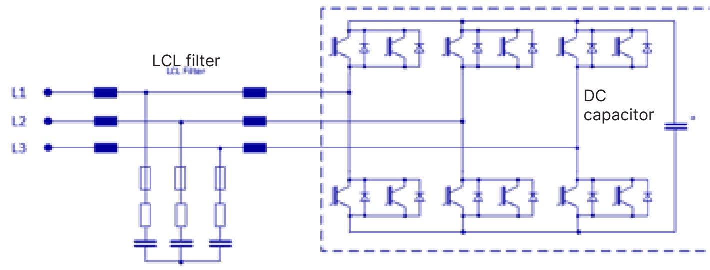


Figure 6: Simplified three-line diagram of an 812.5 kvar unit

Design of the pulse inverter system

The PCS with ±3250 kvar is based on the modular IGBT pulse inverter MD2000.

Four units of 812.5 kvar each, are supplied in parallel via cables. The operating voltage of 600 V is transformed for the pulse inverters istransformed by a special 3500 kVA castresin power converter transformer(Figure 12) from 20 kV. As the self-commutated pulse inverter can be run both capacitively and inductively, a dynamic control range of 6500 kvar is achieved.

Each pulse inverter unit can be interpreted as an independent power converter system (Figures 6 and 7).This has its own power contactor, LCL mains filter, separate fuse switch-disconnector, separate line decoupling reactor and IGBT modules with amplifier boards as well as a DC link capacitor, preloading and control and ignition electronics. All the pulse inverter functions areperformed locally for each power unit.

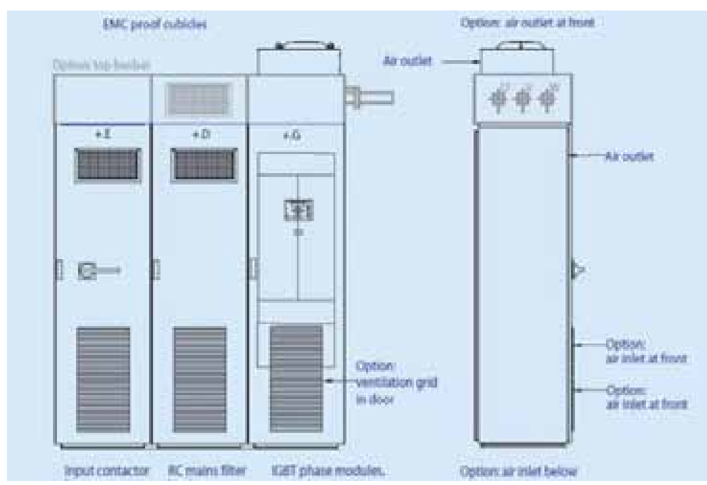


Figure 7: Standard pulse inverter unit with optional top busbar to connect the converter transformer above

Figure 8: Standard unit of a 812,5 kvarpower conditioning system withoutfan

This rules out any instability of the individual pulse inverter systems.

A PI-controller reduces the reactive power in the incoming supply to virtually zero. With just this controller, dynamic control response of 50 ms can be achieved over the full control range. To accelerate the dynamic control response to less than 25 ms, the mine winder current is measured directly here and is applied in terms of control technology as an actuating circuit.

A further proactive control setting can calculate the reactive power in advance from the setpoint value of the motor current and the control voltage of thyristor-operated mine winder. This reduces the dynamic control response to virtually zero.

How the pulse inverter works

The semiconductors connected and disconnected in pulse width cycles switch the voltage of the DC capacitor to the three-phase power system side. The pulse width is modulated (pulse width modulation, PWM). The width of the individual pulses is selected in such a way that the resulting voltage on the three-phase side assumes a dynamic, sinusoidal voltage waveform with a line frequency of 50 Hz. The instantaneous value of the switched mode pulse voltage is either zero or the same as that of the DC capacitor. So, it has one of two values. Which is why this power converter is called a “2-Level” inverter. The clock frequency is 3 kHz (60th harmonic), the vector frequency, at 6 kHz, is twice this.

In this way, continuously dynamic operation of the pulse inverter can be inductive (lagging, underexcited) or capacitive (leading, overexcited). Capacitive or overexcited operation is not possible with a conventional, line-commutated, that is to say underexcited converter.

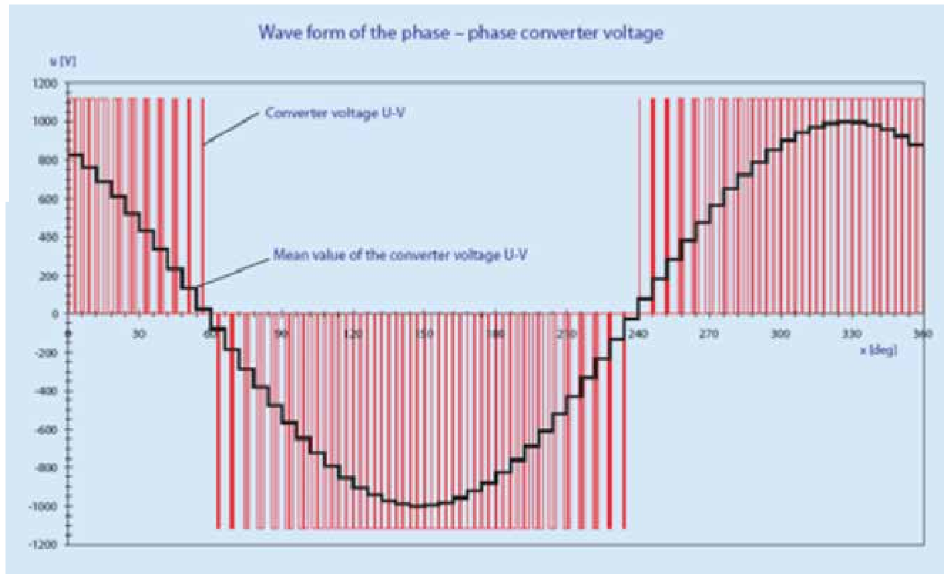


Figure 9.1: Capacitive operation: pulse width modulation of the DC capacitor voltage for an overexcited, sinusoidal voltage curve

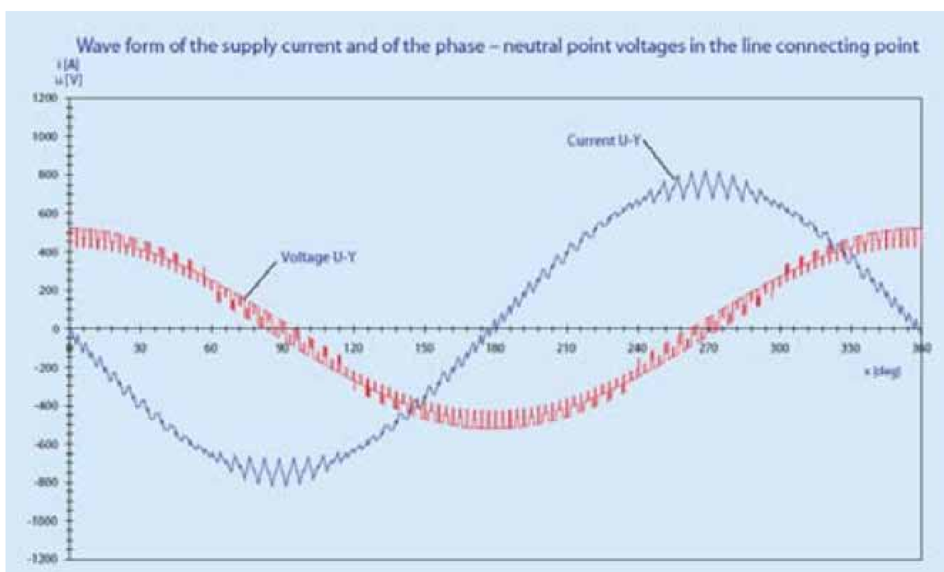


Figure 9.2: Capacitive operation: pulse inverter current of the phase-to-earth 20 kVvoltage, leading. Note: The 20 kV voltage is shown without the effect of the LCL filter

For capacitive operation at normal rating, Figure 9.1 shows the voltage synchronization, modulated over time in such a way that the associated mean values of the individual pulse voltage widths form a sinusoidal voltage curve.

Figure 9.2 shows the curve for the 20 kV phase-to-earth voltage and the capacitive pulse inverter current without the LCL filter method of operation (the calculations shown here do not includethis filter). It is possible to show this accordingly for inductive operation at a normal rating.

Generation of harmonics

Low-frequency harmonic currents, familiar from conventional converter drives, are not generated by these IGBT pulse inverters.

When designing the pulse inverters, it was assumed that in future the IEC would stipulate limit values in the frequency range 2-9 kHz:

- Industrial power system: distortion THD < 3,0%
- Public power system: distortion THD < 1,5%

These limit values are achieved using a standard LCL grid filter (Figure 6). In special cases, this standard filter can be supplemented or replaced by a specially configured one.

Operating characteristics, project-specific

As the supplying 20-kV voltage must not exceed 20 kV + 10% (=22 kV) and as at full capacitive operation the 20 kV voltage is raised by approx. 2.5%, the control starts to reduce the supplied capacitive pulse inverter current in an indirect proportion, as from a voltage of´21.5 kV (= 20 kV + 7.5%).

The same applies the other way round for inductive operation (Figure 10).

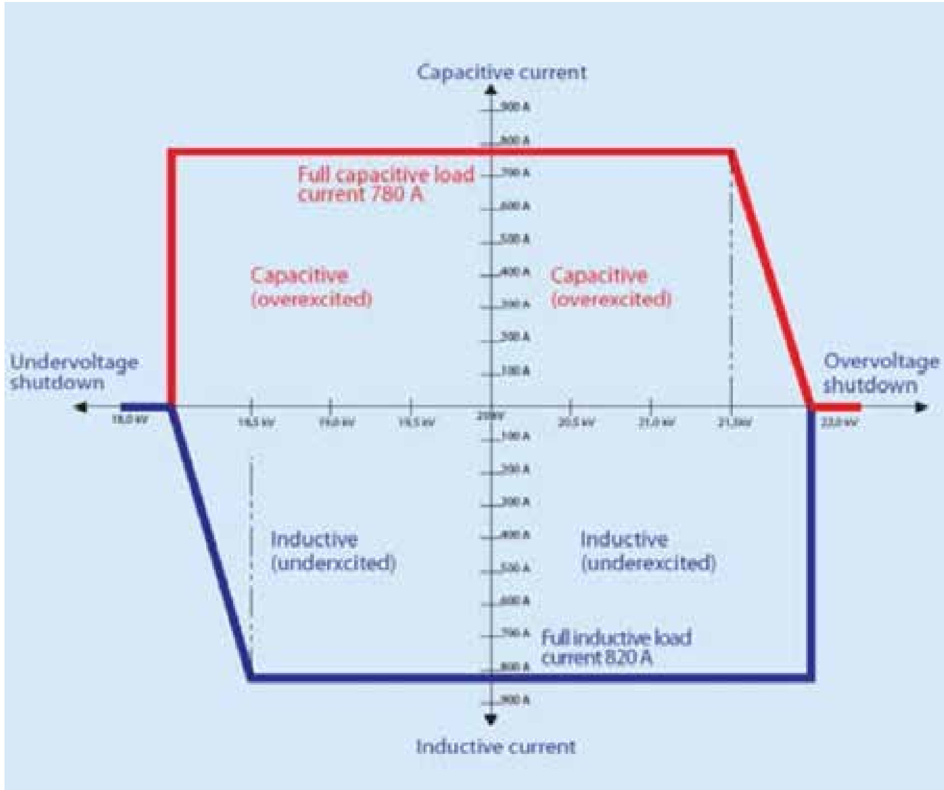


Figure 10: Operating characteristics of the pulse inverter module current for each 812.5-kvar unit

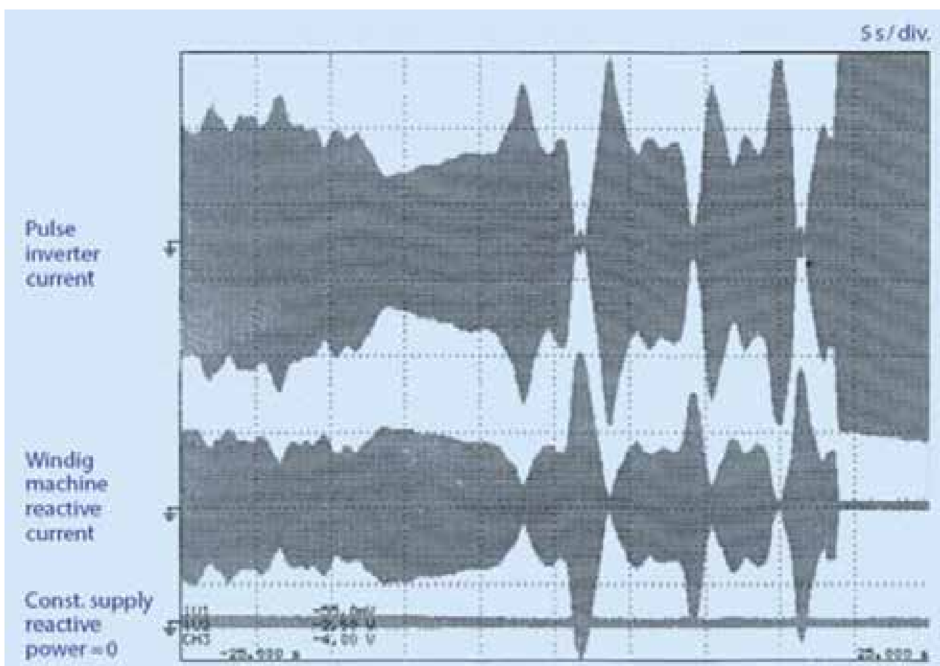


Figure 11: Oscillogram of the dynamic reactive current of the thyristor-controlled mine winder and of the dynamically compensating pulse inverter current and of the incoming supply reactive power current compensated to virtually zero

Commissioning

Taking into account the particular project-specific features, commissioning took some than five weeks to complete. TÜV inspection and acceptance from the technical inspectorate, involving four weeks of fault-free test operation and delivery of spare parts, followed immediately afterwards.

A performance test demonstrates the warranted properties:

- Dynamic control response below 25 ms (0-6500 kvar)
- Thermal stability at full cap./ind. Load (± 3250 kvar)
- Dynamic compensation of the mine winder without delay (Figure 11)
- Adequate peak compensation power during heavy load material winding
- Man winding without filter circuits, THD <2%
- Trouble-free transitions to “n-1“ operation, “n-2 “ operation and “n-3“ operation
- Pulse inverter current without harmonics
- Measurable harmonic load reduction in the existing filter circuits
- Immune to interference even with voltage distortion >12% (emergency material winding without filter circuits)

Training operating personnel on site and at the factory

At the Berlin factory, operating personnelwere trained to handle the digital controlsystem. As well as the requisite basic knowledge, training also includes working with the graphical user interface, LogiCad.

On site, training comprises operating thesystem, troubleshooting, fault elimination, acknowledgement and applying the five safety rules, with actual reference tothe special features specific to the system.

Other project-specific options

In addition to a separate, gas-insulated (GIS) 20 kV switchgear delivery, the required short-circuit and selectivity verifications, protective relay adjustments and tests, all components thatcontinue to be used and that arereusable were serviced and repairedindoors and out. This separate switch-gear saves energy loss, which pays offthis acquisition quickly.

Figure 12: Cast resin transformer in outdoor housing, outdoor harmonic filters

Totally new documentation was drawn up. All the 20 kV power cables were replaced and the cable route lining was restored. Assembly in accordance with state-of-the-art installation technique, taking into consideration the special requirements of the mining company, rounded off this turnkey project.

Option: teleservice and internet VPN link

Teleservice and VPN links (virtual private network) will come into their own in the future and our forward-looking, new PCS is already designed for this.

The digital control makes it possible to observe not only current control parameters and signals, actual values and setpoints, but also the bus-driven pulse inverters and the protective relays in the switchgear.

This makes it possible to log into the digital control by modem via a telephone line or an Internet connection from the Service Centre at the Berlin facility.In this way, fault reports from the control system, the protective relayand the pulse inverter can be read fromthe service support point. Changes toparameters can also be made in this way, which is faster and more economicalthan field service.

With this option, it is unnecessary, in many cases to call out a service engineer and even if this is still necessary, they can then be better prepared.

Good reasons for PCS

- Higher productivity – thanks to a perfect power supply
- Improved product quality – due to improving the power quality
- Better integration into existing operating structures

Greater certainty, greater stability

The PCS not only reduces undesirable grid pollution directly at the medium voltage busbar of the factory incoming power supply, its modular construction also helps to save energy costs. The experience with industrial processes allows us to reliably estimate potential faults in given reticulation configurations.

The PCS offers an innovative solution geared to your requirements. This holds true for hoisting engines in the mining industry, for wind energy plants as well as for power supply in steel plants.

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