STATCOM FOR SAFEGUARDING OF POWER QUALITY IN FEEDING GRID IN CONJUNCTION WITH STEEL PLANT EXPANSION

R. GRÜNBAUM ?), T. GUSTAFSSON, J-P HASLER, T. LARSSON — ABB (Sweden)

M. LAHTINEN — FINGRID (Finland)

1. INTRODUCTION

A steel plant in Finland is underway to increase its capacity to produce stainless steel. A prerequisite for the expansion was to have efficient flicker mitigation and voltage control of the feeding grid.

A new melt shop with a 140 MVA +20% stainless steel Electric Arc Furnace (EAF) is part of the plant. The EAF is taking its power from a 110 kV feeding grid. Due to a modest short circuit level at the Point of Common Coupling (PCC), unless properly remedied, the EAF would become a formidable source of disturbances, which would spread over the grid to other consumers. The EAF is also a heavy consumer of reactive power, Figure 1.

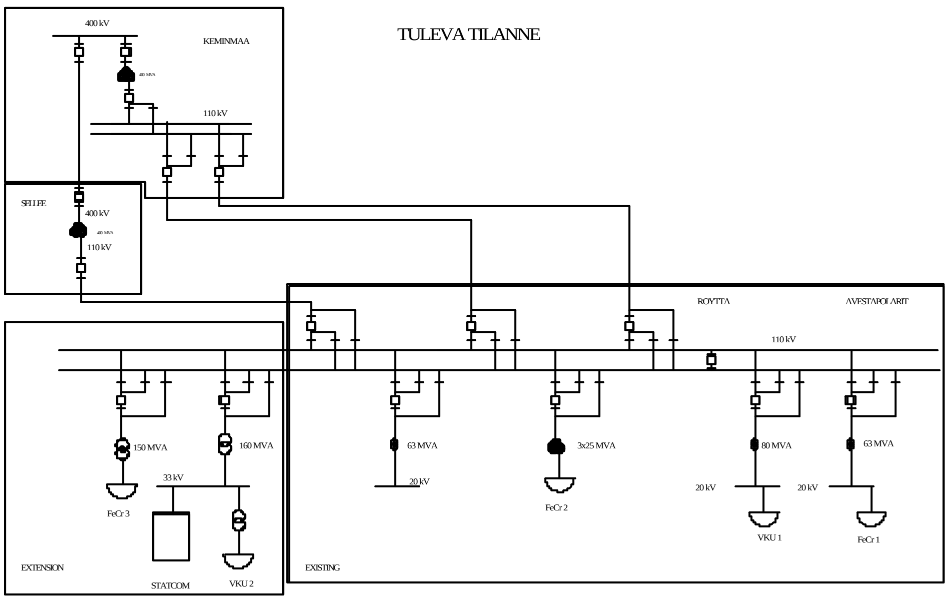

Fig. 1: Power infeed to the steel plant.

? ABB Power Technologies AB, Power Systems FACTS, SE-721 64 Vasteras, Sweden; e-mail: rolf.grunbaum@se.abb.com

The European Union has firm regulations on power quality issues such as flicker: acceptance levels, methods for measurement, and flicker meters. As a consequence, the Finnish Transmission System Operator and grid owner, Fingrid, is placing exact requirements on subscribers to power connected to its grid system, in order that proper power quality in the grid be safeguarded at all times. This fact, in the case of the steel plant, induced a need for measures to neutralize the grid polluting effects from the EAF. As an extra benefit, increased power into the EAF was achieved, enabling an improvement of process economy for the plant.

2. SVC LIGHT®

The paper will highlight and treat one particular member of the FACTS (Flexible AC Transmission Systems) family, SVC Light®, which is a STATCOM based on a three-level VSC (Voltage Source Converter) design, utilizing IGBT (Insulated Gate Bipolar Transistor) as switching element and a control concept based on PWM (Pulse-Width Modulation). The main objective for the installation of the SVC Light was to rapidly and accurately compensate the reactive power taken by the electric arc furnace in all melting phases from the AC network. Additionally the fast control system of SVC Light will improve the power quality and reduce the flicker levels generated. The SVC Light in question is rated at 33 kV, 0 to 164 Mvar (capacitive), continuously variable over the entire range, see Figure 2.

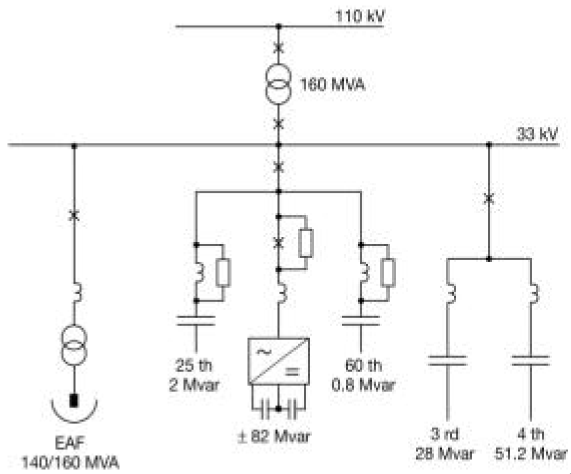

Fig. 2. Single line diagram, EAF and SVC Light®.

3. STEEL PLANT AND THE GRID OWNER´S BENEFITS

The installing of the SVC Light at the steel plant feeder has brought benefits not only to the steel plant, but also to the grid owner:
-Acceptably low flicker level at the Point of Common Coupling.
-Acceptably low amounts of harmonic distortion.
-Acceptable negative-phase sequence voltage level.
-Adequate load balancing between phases of the 110 kV grid.
-A high and constant power factor at the feeding point of the plant, with no backfeed of reactive power into the grid.
-Keeping grid reinforcements at a minimum.

Benefits to the steel plant:
-Increase of production capacity.
-Lower electricity consumption per steel weight.
-Decrease of electrode consumption.
-No reactive power fees.

4. FLICKER MITIGATION

A flicker mitigation study was performed at the design stage, evaluating the flicker reduction factor that could be expected with the SVC Light in operation. To evaluate the flicker level, the voltage variations were computed at the PCC, i.e. at the 110 kV bus. The flicker level was then estimated according to IEC 61000-4-15 recommendation (Pst). After that, field measurements were performed to validate the flicker improvement performance [1]. In Figure 3, subplot 1 shows the EAF active and reactive power, the two top curves. The bottom curve shows the reactive power taken from the grid. Subplot 2 shows a comparison between actual measured 33 kV voltage and the corresponding calculated voltage. The ignorable error is a verification of the grid impedance model. Subplot 3 shows four different Pst curves calculated during sliding 10 minute intervals. The top curve with the highest Pst levels shows the case with only EAF current and no compensation. The three bottom curves only have small deviations and show flicker curves based on the measured voltage, on the calculated voltage and on data from the standard Pst meter.

The flicker level from the simulation using EAF, VSC and filter currents gives the same flicker level as the external flicker meter and the flicker level using the measured voltage. Subplot 4, finally, shows the flicker improvement ratio calculated as the ratio between Pst values with only EAF currents and Pst values with the SVC Light in operation. The flicker improvement at the beginning of the melt-down process is ignored because it contains the time window when the EAF was not in operation and non-applicable flicker values.

Operation of the EAF with full power requires stable voltage and an efficient compensator. Operating the EAF without compensation is also possible, however, at a reduced power. During the measurement campaign measurements at reduced EAF power were performed both without and with the SVC Light in operation. Fig. 4 shows the results of the data processing. The plots are of the same type as in Figure 3.

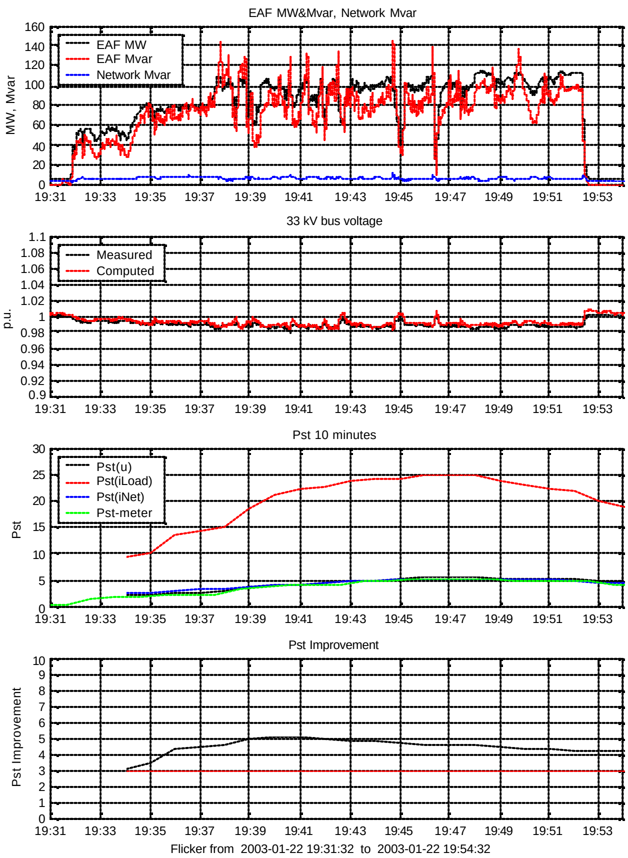

Fig. 3. Flicker with full EAF power and with SVC Light in operation.
subplot 1: EAF power and grid reactive power.
subplot 2: Voltage profile; measured (black) and simulated (red).
subplot 3: Sliding Pst 10-minute values from measured voltage (black),
from simulation with EAF current only (red),
simulated with EAF+VSC+Filter currents (blue) and
from external flicker meter (green).
subplot 4: Simulated flicker improvement ratio, sliding 10 minute average.

Two melts with the same EAF transformer tap changer patterns are shown. At approximately 14:40, the SVC Light was put on line. Subplot 2 showing the 33 kV bus RMS voltage clearly indicates the difference. The large voltage peaks during the melting without the SVC Light are due to load rejection. The voltage is then controlled with the 110/33 kV transformer tap changer and finally reaches the set point. The voltage set point was chosen below unity to reduce the voltage amplitudes after load rejection.

4.1 Flicker improvement ratio

The flicker improvement ratio is calculated during a time window were the EAF is in operation. When the EAF is out of operation the flicker improvement will be unity in case of no background flicker and below unity to zero if there is disturbing background flicker existing.

The flicker improvement ratio was calculated using a time window beginning 10 minute after EAF melting start and ending at the end of the same heat. The 10 minute delay corresponds to the 10-minute time window used by the flicker meter to exclude the period the EAF was not in operation. The method was applied to the data in Figure 3 with full EAF power. This time window includes two EAF transformer energizations and includes the time window with the highest flicker level recorded during the measurements. The result was a flicker improvement ratio of 4.6 times for full EAF power.

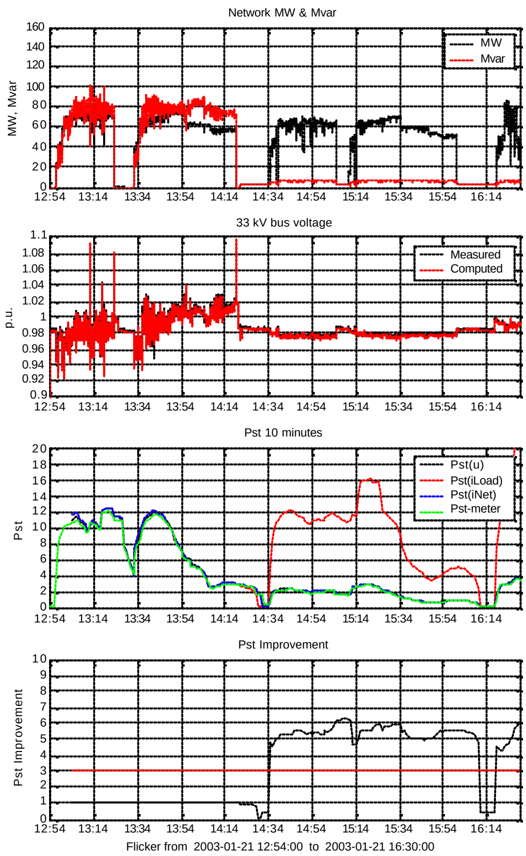

Fig. 4. Flicker without and with the SVC Light, reduced EAF power.
Subplots as in Fig. 3.

On the other hand, the flicker improvement ratio in Figure 4 with lower power in the EAF is between 5 and 6 times. If higher flicker improvement is desired, it is hence essential to choose an adequate rating of the SVC Light. Reference [2] gives more guidance in this respect.

5. SOME SALIENT DEVELOPMENT FEATURES

5.1 Voltage Source Converter

SVC Light is built up around a three-level VSC. In the converter, there are four IGBT valves and two diode valves in each phase leg. The valves are built up by stacked devices with interposing coolers and an external pressure applied to each stack (Figure 5).

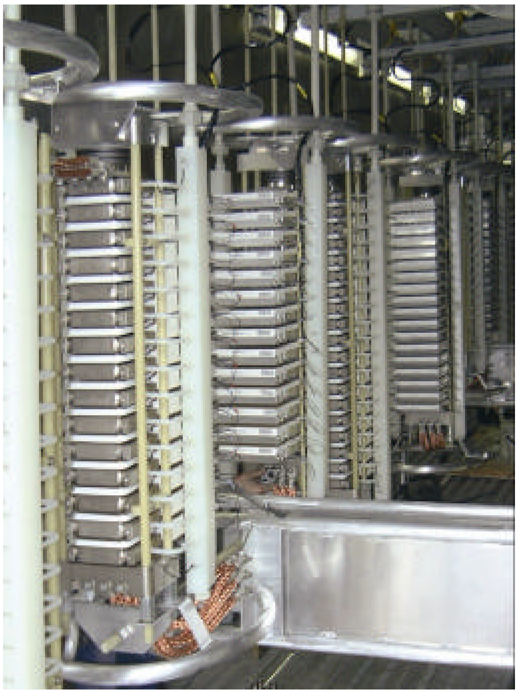

Fig. 5. SVC Light valve assembly.

One side of the VSC is connected to a capacitor bank, which acts as a DC voltage source. The converter produces a variable AC voltage at its output by connecting the positive pole, the neutral, or the negative pole of the capacitor bank directly to any of the converter outputs.

By utilizing PWM, an AC current of nearly sinusoidal shape is produced, requiring only very limited harmonic filtering. This contributes to the compactness of the design, as well as robustness from a harmonic interaction point of view.

5.1.1 Valve voltage

The valve voltage rating has undergone considerable development since the first installation of SVC Light. Thus, in the first SVC Light, in operation in 1999, the VSC was connected directly to a bus voltage of 10.5 kV. The next development stage enabled the direct connection of the VSC to 20 kV (in operation in 2000). And now, since 2002, a VSC directly connected to a bus voltage of 33 kV is in commercial operation. In neither of the cases has there been a need for a large and complicated intermediate transformer.

5.2 Dry type capacitors

The DC link is built up from a novel design of compact, high voltage, dry type capacitors. By use of metallized film, insulated by means of polymers instead of impregnated materials, the capacitors get a dry design, making them environmentally very friendly. In manufacturing, they require neither impregnating fluids nor the use of paint solvents. They have high energy density, which together with their cylindrical shape enables very compact build-up of the DC capacitor bank.

Figure 6 shows an internal view of a valve hall. The DC capacitors as well as the DC bus bar are found closest to the camera.

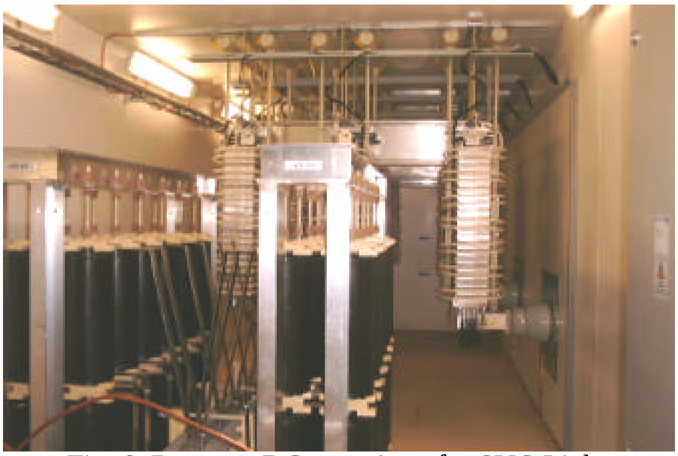

Fig. 6: Dry type DC capacitors for SVC Light.

5.3 Control algorithm

To mitigate flicker efficiently, the SVC Light control algorithm calculates setpoints for the phase currents to be produced by the SVC Light. In this process, the EAF currents as well as the bus voltages are used. There is a need for very fast control action, in the order of 1 ms [1].

It must be emphasized that the arc furnace load is very rapidly changing even within the cycle and may furthermore also be very unsymmetrical. PWM based STATCOM is the only device capable of coping with the demand to compensate the unsymmetrical, distorted reactive currents inside the cycle. Traditional SVC can basically compensate only the 50 Hz reactive power component. Symmetrical currents will minimize additional heating in generators and other loads. The compensation of asymmetry, however, gives benefits from the arc furnace point of view, as well. This performance can be illustrated by Figure 7:

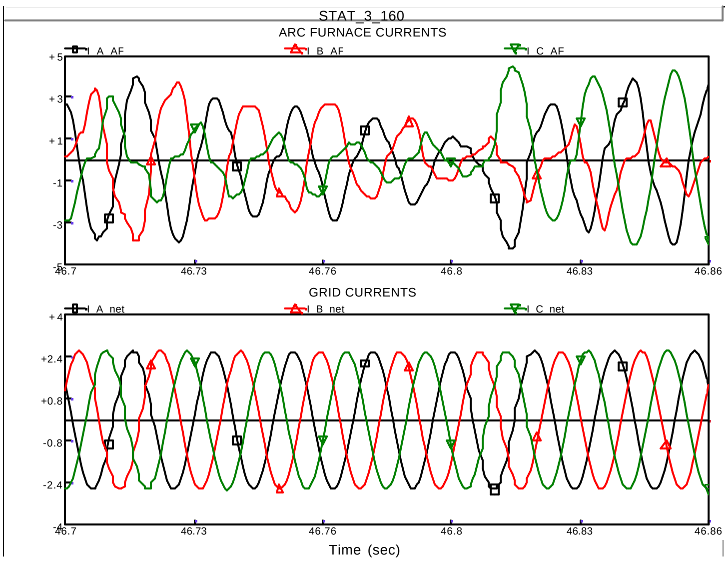

Fig. 7: Arc furnace currents: upper curves, and currents to the grid with STATCOM in operation: bottom curves.

5.4 Control and Protection Scheme

To fulfill the requirements of the plant on control and protection, a fully computerized control and protection system named MACH2 has been developed. It is using state of the art computers, micro controllers and digital signal processors. High performance industrial standard buses and fibre optic communication links are utilized.

The development in the field of electronics is very fast. The best way to make sure that designs can follow and benefit from this development is to build all systems based on open interfaces. The MACH2 platform is built around an industrial PC, running Windows NT, equipped with high performance add-in boards. It also includes a whole family of I/O circuit boards for sampling and signal conditioning.

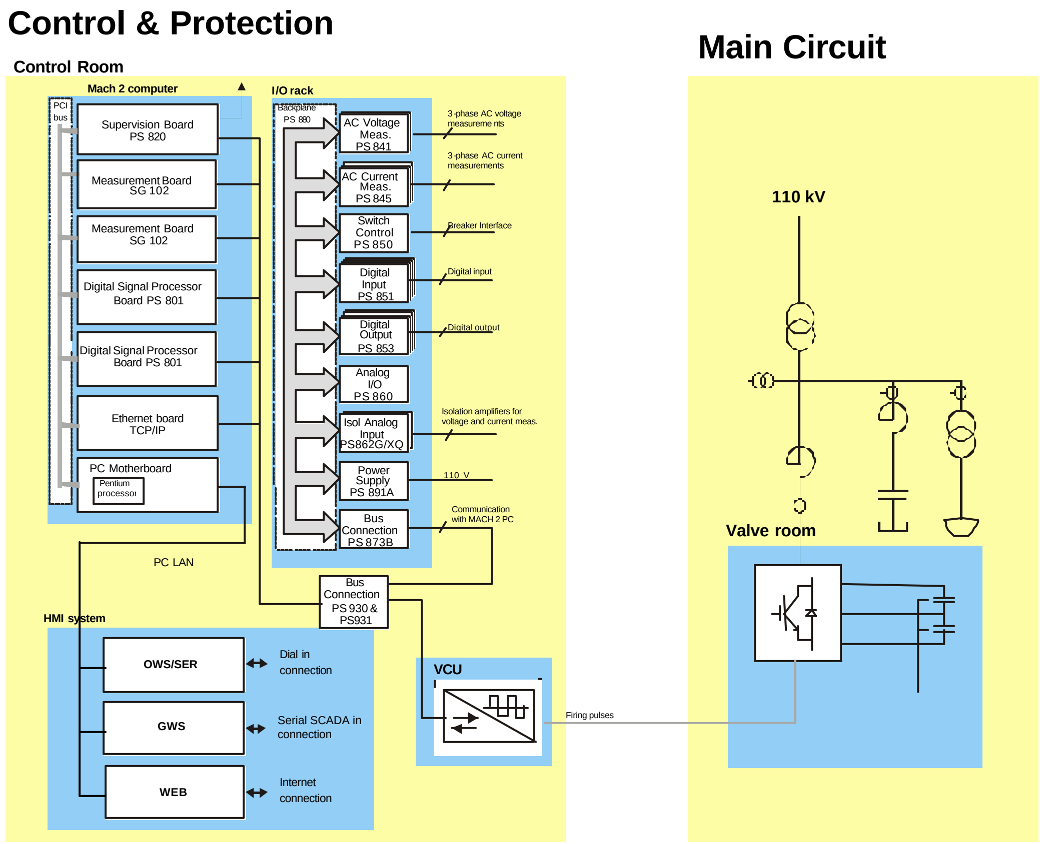

Fig. 8: Control and Protection System.

Included in the system is also a Human Machine Interface (HMI). This serves as the interface between the operator and the control system. The HMI communicates with the control system via the LAN. The system can be controlled from several different locations, locally in the control room or connect a remote OWS using a RAS connection[1].

The system also includes a Gateway Station (GWS) and a web interface (FACTS Online). The GWS enables remote control and supervision of the station. The web interface makes it possible to access the system via the Internet allowing for remote supervision of the station. This interface is also capable of notifying service personnel via SMS and e-mail in case of a fault generated by the system.

The principles for signal flow in the control and protection system are shown in Figure 8.

5.5 Web Interface

The hardware realization of the Web Interface for a FACTS system comprises a web server, a software or hardware firewall and the necessary connections to the FACTS internal LAN and ISP (Internet Service Provider) connection, Figure 9. The Web Server contains several web pages that present dynamic data from the FACTS installation, such as indications for breakers, disconnectors, analog values, etc. as well as several lists.

Data for the indications are acquisitioned via Java applets (communicating via a TCP/IP based protocol e.g. NetDDE, SuiteLink) from the MACH2 Control Computer. The lists are retrieved from the MS SQL Server via JDBC (Java Database Connectivity). The Notification Engine is a SQL application that monitors events coming from the control system and sends e-mail notifications via an external mail server.

[1] OWS = Operator Work Station; SER = Sequence of Event Recorder; LAN = Local Area Network; RAS = Remote Access Service.

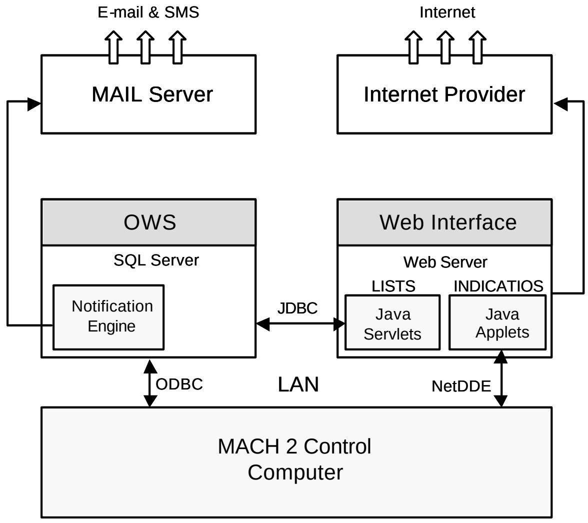

Fig. 9: Web Interface: Web Based Support system for FACTS.[2]

6. CONCLUSIONS

A large EAF for stainless steel has been installed in northern Finland. Studies performed before the installation indicated a requirement for flicker mitigation. The chosen solution was based on SVC Light, an IGBT based STATCOM concept. The usefulness of this solution has been demonstrated in field measurements, showing a flicker improvement ratio of 4.6 times. Furthermore, it has been shown that it should be possible to reach a flicker improvement ratio between 5 and 6 times if the SVC Light rating could be chosen freely. The SVC Light has shown outstanding performance in respect of safeguarding the power quality in the feeding grid in conjunction with the steel mill expansion.

As a typical illustration of the dynamic development within IGBT based STATCOM technology in recent years, a factor three increase in voltage rating of the STATCOM has been highlighted in the paper. The increased voltage rating has been achieved without any complicated or large intermediate transformer. Also a novelty, dry-type, compact DC capacitors have replaced traditional DC capacitors for use in the DC link. And finally, Web Based Support has been introduced in the Human Machine Interface, as an Internet based communication facility.

7. REFERENCES

[1] R. Grünbaum et al, “STATCOM, a prerequisite for a melt shop expansion – performance experiences”, [IEEE Bologna Power Tech 2003, Bologna]

[2] CIGRE WG 14.19, “STATCOM for Arc Furnace and Flicker Compensation”, [Brochure No. 237, Paris 2004]

[3] M. Lahtinen, “New method for flicker performance evaluation of arc furnace compensator”, [Report 36-205, CIGRE Session 2002]

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[2] SMS = Short Message System; SQL = Structured Query Language; ODBC = Object DataBase Connectivity; TCP/IP = Transmission Control Protocol/Internet Protocol; NetDDE = Network Dynamic Data Exchange; Java applets/servlets = Internet programming modules