STATCOM FOR MITIGATION OF FLICKER EMANATING FROM A LARGE EAF

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ABSTRACT

A Static compensator (STATCOM) has been installed at a green-field steel plant in Thailand for reduction of flicker emanating from the operation of an electric arc furnace. Flicker mitigation is called for due to the size of the furnace in relation to the fault level of the feeding grid, where, unless remedied, unacceptable flicker would have resulted. In the paper, the major outlines of the STATCOM are given. Performance results from field measurements are presented and discussed.

INTRODUCTION

A green field steel plant owned and operated by Siam Yamato Steel Company Ltd has been put on line in the Rayong region in Thailand. The steel making process is based on melting of steel scrap in an electric arc furnace (EAF) rated at 96 MVA and supplied by SMS Siemag, followed by refining in a ladle furnace (LF) rated at 22 MVA.

The steel plant is fed from a 115 kV power grid. The fault level varies between 1,970 MVA and 3,000 MVA, depending on grid conditions. Considering the substantial size particularly of the EAF, unless proper measures were taken, strong incandescent lamp flicker could have been expected as a result of the operation of the EAF. This would have been particularly pronounced at minimum fault level. With a STATCOM[1] (Static compensator) operated on the 22 kV EAF bus, efficient flicker mitigation was attained, and the grid code of the feeding grid is fulfilled for all operating conditions.

As a matter of fact, the flicker level at the 115 kV point of common connection (PCC) is influenced by two more steel plants situated in the same region and operated from the same grid. Consequently, the flicker measured is an aggregated value arising from the operation of all three plants.

EAF: GRID IMPACT

The electric melting process inside an EAF is erratic in its nature, from time to time resulting in an “electrical short” within the furnace’s electric circuit. As a consequence, the consumption of reactive power strongly fluctuates in a stochastic manner. The fluctuation of reactive power flowing through the circuit reactances results in voltage fluctuations, which are most clearly visualized in the flickering light of incandescent lamps serviced by the common grid. Spectral analysis confirms that lamp flicker caused by EAF action is severe around frequencies for which the human eye is particularly sensitive, i.e. below 20 cycles. Flicker is a very annoying sensation and easily becomes a source of complaints to the grid company.

BENEFITS OF THE INSTALLATION

The flicker reduction capability of a traditional SVC, based on thyristor switching technology, would have been insufficient for the purpose and a STATCOM, a device more potent for the purpose, was decided on instead.

With the STATCOM in operation, a flicker reduction factor > 5 is achieved. Furthermore, due to the active filtering capability of the STATCOM, efficient harmonic suppression has been achieved.

The installing of the STATCOM 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 PCC.
- Acceptably low amounts of harmonic distortion.
- Negative-phase sequence voltage compensation as part of the flicker compensation.
- A high and constant power factor at the feeding point of the plant, with no back-feed of reactive power into the grid.
- Keeping grid reinforcements at a minimum.

MAIN SYSTEM DESIGN

The SVC Light is based on a voltage source converter (VSC), built up of IGBT (Insulated Gate Bipolar Transistors). A single converter is utilised, thereby avoiding all paralleling of devices. The converter is directly connected to the 22 kV EAF bus, without any need for a step-down transformer or other complex magnetic interfaces. As DC link, DC capacitors are utilized. The SVC Light control scheme is based on pulse-width modulation (PWM), thereby ensuring minimum need for harmonic filtering.

Fig. 1 shows a simplified single line diagram of the SVC Light together with the furnaces and the power transformer.

The VSC is rated at ±60 Mvar. In addition, the SVC Light comprises a 2nd harmonic filter rated at 30 Mvar, a 3rd harmonic filter (28.5 Mvar) and a ripple filter (1.5 Mvar). The 22 kV bus is connected to the 115 kV grid by a 130/150 MVA power transformer.

[1] Also known as SVC Light®

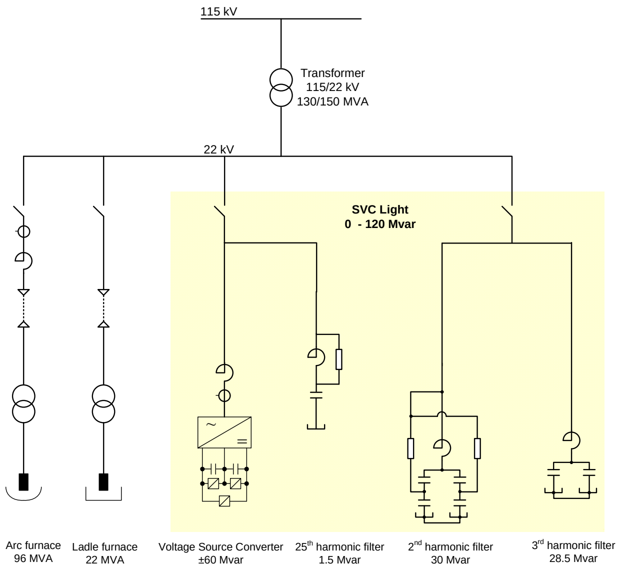

Fig. 1: Single-line diagram of SVC Light and furnaces. The yellow shaded area comprises the SVC Light.

The VSC together with the harmonic filters give the SVC Light a total operating range from zero to 120 Mvar capacitive reactive power.
The footprint of an SVC Light is small compared to traditional SVCs based on thyristor technology, mostly due to the symmetrical reactive power range of the VSC that makes it possible to reduce the harmonic filter sizes.

Voltage Source Converter

The VSC is based on IGBTs that enable high-frequency current switching. The IGBTs therefore give possibilities to control the current much faster than conventional thyristor based compensators. The IGBT valves are configured as a three-level Neutral Point Clamped (NPC) converter, illustrated in Fig. 2.

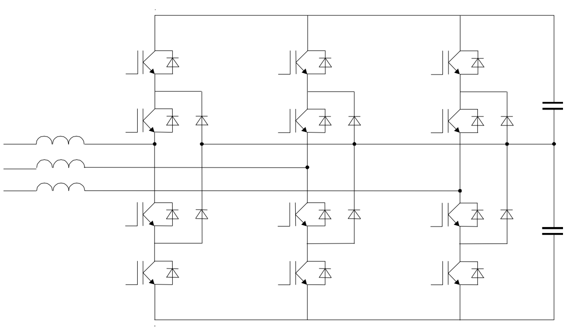

Fig. 2: Configuration of a three-phase Neutral Point Clamped (NPC) converter.

Each phase of the converter has six valves; four IGBT valves with anti-parallel diodes, and two diode valves. All three phases are connected to a common bank of DC capacitors. With this valve configuration, the voltage on the output terminal towards the reactors can achieve three levels; +DC, zero or –DC. The valve current is smoothed by the phase reactors connecting the IGBT valves to the compensator bus.
The switching of the IGBT valves is controlled by the Valve Control Unit (VCU), which is part of the SVC Light control system. As the required valve current is determined by the control system, the VCU enables the correct switching of the valves. The VCU communicates with each IGBT using optical fibres, one fibre for sending switching orders to the IGBT and another fibre for receiving data concerning the IGBT voltages during the switching sequence. The Gate Unit (GU) located next to each IGBT in the valve receives the switching order and controls the voltage of the IGBT gate. The energy needed for turning on and off the IGBT is sourced by the voltage that rises across each level every time the IGBT turns off. The information sent back to the VCU makes it possible for the operator to observe the status of all IGBTs in the converter.

CONTROL SYSTEM

The SVC Light is controlled by a redundant MACH 2 control system. MACH 2 is a very advanced micro-processor based control system used for SVC (Static var compensator), SVC Light, series capacitors and HVDC (High voltage direct current) systems in a vast number of installations throughout the world. The MACH 2 system has integrated Transient Fault Recorders (TFR), event database and possibilities for remote control of the SVC Light. The MACH 2 system I/O interface is used for analogue data acquisition of the bus voltages and branch currents in the system, as well as digital inputs and outputs for control of circuit breakers and disconnectors.

Flicker Compensation

The main purpose of the SVC Light control system is to reduce the flicker generated by the arc furnace and the ladle furnace. The flicker compensation is an open-loop control, where the SVC Light current order is determined based on the measured furnace currents. A regulator block diagram is shown in Fig. 3.
It is mainly the arc furnace that generates flicker, requiring accurate measurements of the individual phase currents. A current measuring device with frequency range from DC up to 50 kHz is used both in the electric arc furnace feeder as well as in the converter valve phase currents. Regular current transformers are used for the ladle furnace and harmonic filter currents where the frequency response is less critical.
Besides the flicker control, SVC Light comprises Negative Phase Sequence Control that compensates for unbalance between the phases. The flicker and negative phase sequence control are time critical applications located in a separate DSP (Digital signal processor) in the MACH 2 system. The measured load currents, I_{Load}, in

the arc furnace and the ladle furnace are used as input to the flicker and negative sequence control function. The VSC current, I_{VSC}, required to compensate the load currents is calculated by the flicker and negative phase sequence control functions.

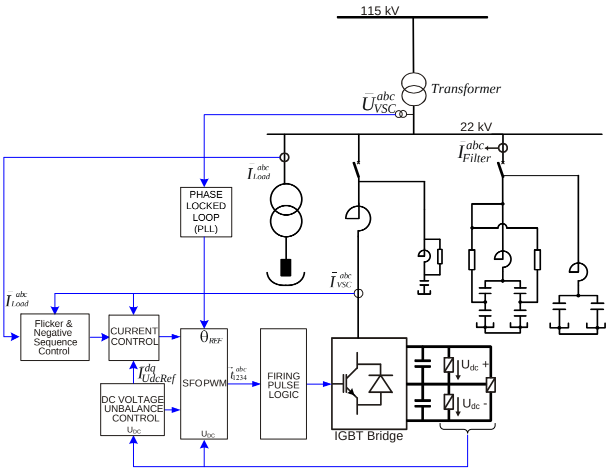

Fig. 3: Simplified block diagram of the SVC Light open-loop control.

The DC voltages, U_{dc}, of the converter valve are continuously measured and regulated by the DC voltage unbalance control, to ensure that the DC voltages are symmetrical regardless of the asymmetry that can occur in the load currents. The DC voltage control operates continuously to maintain stable and symmetrical DC voltages, in addition to the flicker and negative phase sequence control. The output from both the DC voltage control and the flicker control is used for determining the current required by the VSC converter. Based on the measured converter currents, I_{VSC}, the current control function can limit the current order to protect the IGBTs from over-current or over-heating.

The VSC converter uses an SFOPWM (Switching Frequency Optimum Pulse Width Modulation) switching pattern, whose switching times are determined based on the current order input. The switching times are synchronized with the bus voltage through a phase locked loop (PLL). Finally, the SFOPWM switching times are converted to fire pulses in an optical interface, the Valve Control Unit, in the MACH 2.

Active filtering

Besides the flicker compensation algorithms, SVC Light also enables active filtering of harmonics in the load current. The ability to reduce the harmonics by active filtering depends of the energy stored in the DC capacitors, which is limited by the voltage and the capacitor bank size.

For this particular application, the converter is optimized for damping of harmonics between the 2^{nd} and the 9^{th} harmonic. The upper plot of Fig. 4 shows the harmonic current spectrum of the EAF. The current spectrum corresponds to the output of the measuring instrument defined by the IEC Standard [1] obtained by Discrete Fourier Transform (DFT) of the current using a 200 ms time window. The DFT provides individual magnitudes of the current, i.e. the value of each frequency component calculated. The frequency step is 5 Hz. The EAF harmonic spectrum at Siam Yamato Steel (SYS) is a typical EAF spectrum containing inter-harmonics having amplitudes decaying with frequency and odd harmonics due to the non-linearity of the arc resistance. DC component and even harmonics are also present mainly due to transformer inrush current during energization. The lower plot of Fig. 4 shows the harmonic spectrum of the current injected into the feeding network. All harmonics from the 2^{nd} harmonic up to the 9^{th} harmonic are damped by means of the SVC Light.

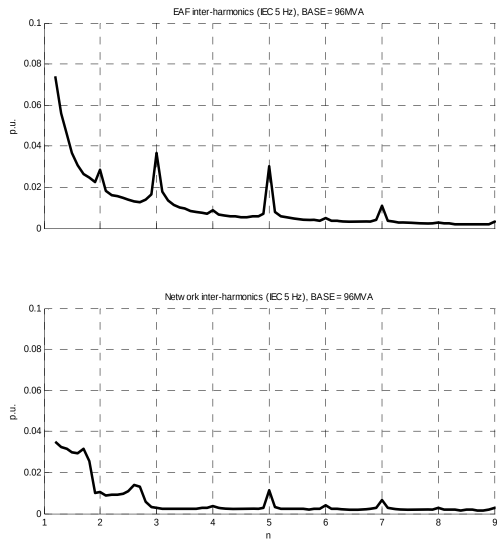

Fig. 4: Load current (upper plot) and feeding network current (lower plot).

SVC LIGHT PERFORMANCE

With a fault level of only 1,970 MVA, flicker compensation requirements can be a challenge. The performance requirements were stated as follows:

Flicker: Maximum compensated P_{st} (95%): ≤1.0
Maximum compensated P_{lt} (95%): ≤0.8
Total Harmonic Distortion (THD): ≤1.5%
Power Factor: ≥0.95

Field Measurements

The flicker level at the PCC is measured with SYS in operation, and with SYS off line. Fig. 5 shows the active power of the EAF (upper plot) and the measured short time flicker level Pst (red line) and long time Plt (blue line). The figure shows that operation of SYS has very limited influence on the flicker level at the PCC, i.e. the SVC Light operates in a very disturbed power system.

According to [2], the resulting flicker caused by independent sources can be estimated by summing up the cubic contribution of each individual source. Due to the very high level of background flicker, the method presented in the IEC standard cannot be directly used as it would lead to a large error. Under such a condition, an indirect method to evaluate the flicker contribution from SYS at the PCC based on current is used instead [3]. Operation of the EAF without compensation was not possible due to the strong flicker it would have caused.

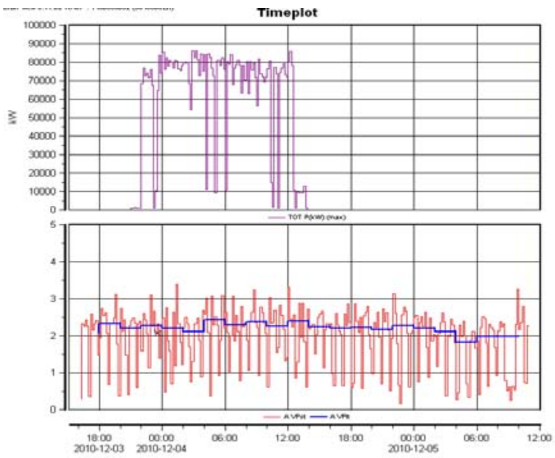

Fig. 5: SYS active power in MW (top graph) and flicker at 115 kV PCC (bottom graph). Pst in red and Plt in blue.

The total harmonic distortion (THD) and telephone interference factor (TIF) are shown in Fig. 6, middle plot and bottom plot respectively. The upper plot indicates the SYS EAF power. The SYS contribution to the THD and TIF, thanks to the SVC Light, is unnoticeable.

Power Factor

The power factor of the EAF only is in the range of 0.75 to 0.8. With the fast flicker and reactive power compensation provided by SVC Light, the power factor at the 115 kV bus is controlled to cos φ = 1.000 during the entire measuring period. Fig. 7 shows the large variation in power factor of the EAF, with an average of cos φ = 0.77, as well as the compensated power factor.

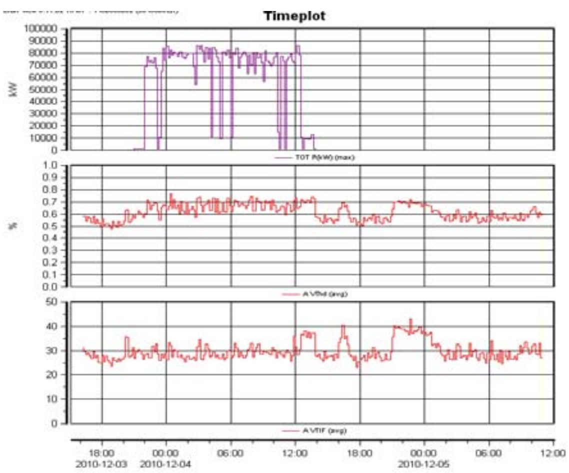

Fig. 6: SYS active power (upper plot), THD (middle plot) and TIF (bottom plot).

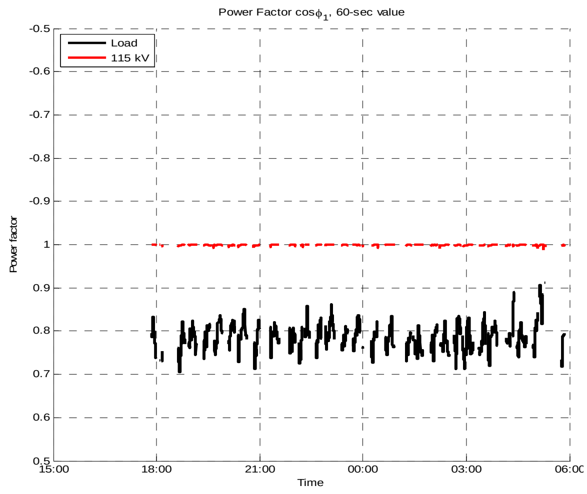

Fig. 7: Power factor of the arc furnace (black), as well as at the 115 kV bus with compensation by the SVC Light (red).

CONCLUSIONS

A STATCOM rated at 22 kV, 0-120 Mvar has been commissioned in a green-field steel plant in Thailand. The purpose of the STATCOM (also known as SVC Light®) is to mitigate flicker emanating from the operation of an electric arc furnace rated at 96 MVA.
The steel plant is fed from a 115 kV grid. The fault level varies between 1,970 MVA and 3,000 MVA, depending on grid conditions.
The following conclusions can be made:
- Due to the substantial size of the EAF, without the STATCOM, strong incandescent lamp flicker could have been expected as a result of the operation of the EAF.
- The flicker demands at the 115 kV point of common coupling have been met, with a flicker reduction factor at the point of common coupling better than five.
- Requirements on harmonic limitation and power factor correction in the feeding grid have been fulfilled, as well.

REFERENCES

[1] IEC 61000-4-7, Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto

[2] IEC 61000-3-7, Electromagnetic compatibility (EMC) – Part 3-7: Limits – Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems

[3] M. Lahtinen, "New method for flicker performance evaluation of arc furnace compensator", *Cigré 36-205*, Paris, 2002.