Power quality and productivity improvement in electric arc furnace (EAF) application with 0 – 225 Mvar SVC

Abstract – This case study shows how dynamic compensation and filtering solution improves power quality and productivity in an Electrical Arc Furnace (EAF) application. With Merus™ SVC system the customer's steel plant is compliant with the grid code in terms of flicker, power factor, harmonics, unbalance, and voltage fluctuations. The improved voltage quality and excellent flicker and harmonics mitigation results in increased productivity, reduced losses and reduced wearing of the electrodes. These are achieved by improved arc stability of the EAF process. The tap-to-tap time has reduced by 9.2%. This results in annual production increase of 114 000 tonnes or 3.4 M€ per year. Additionally, the achieved energy and electrode savings are over 2.6 M€ annually.

1. Introduction

Figure 1 0 – 225 Mvar SVC system for EAF

2. Customer electrical system

Main loads at the customers steel plant are a 170-ton Electric Arc Furnace (EAF) and a Ladle Furnace (LF). The melting of the steel scrap is carried out with the EAF rated at 160 MVA and an LF rated at 33 MVA. The total production capacity of the furnaces is 1 300 000 ton/year.

The furnaces are connected to the 33kV system fed by a 400/33 kV, 170 MVA, uk 14% step-up transformer. The total maximum active power of the EAF without compensator is 117 MW. The fault level at the point of common coupling varies between 4330 and 8540 MVA.

Figure 2 Molten steel produced by the EAF

The rapid fluctuations in the reactive power drawn from the grid before the installation of the SVC were primarily caused by the EAF. The inability of the supply grid to deliver the reactive power demand in an efficient manner was resulting in high voltage fluctuations and flicker in the grid.

3. Merus™ Solution: 0 – 225 Mvar SVC system

Merus Power has comprehensive experience on dynamic reactive power and harmonic compensation systems for EAF processes and various other applications. The compensator systems, thyristor valves, control and protection system hardware and software are designed and manufactured in-house and are the IPR of Merus Power. The experience of the compensator systems and state-of-the-art control engineering guarantees excellent flicker and harmonics mitigation that results in remarkable improvement in EAF arc stability and operation.

Merus Power delivered a complete turnkey 0 – 225 Mvar (cap) Static VAR compensator (SVC) system. The SVC was connected to the 33 kV50 Hz grid frequency. Merus Power's scope of delivery included thyristor valves and reactors for Thyristor Controlled Reactors (TCR), filter capacitor banks, control and protection system (C&P), cooling system and complete engineering.

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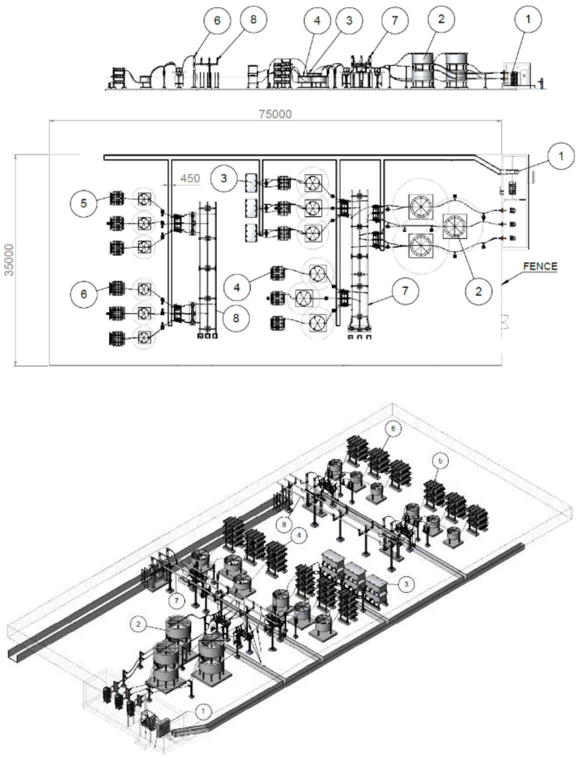

Figure 3 SVC layout. Components: 1 Thyristor valves and C&P, 2 TCR assembly, 3-6 filter capacitor banks, 7-8 busbar assembly.

The TCR assembly is shown in Figure 4 and the filter capacitor banks in Figure 5.

Figure 4 TCR assembly.

Figure 5 Filter capacitor banks.

3.1 Technical specification

Table 1 Compensation system specification

Reactive power, continuous	0 - 225 Mvar (cap) at 33kV 50 Hz
PCC nominal voltage	400kV
Nominal frequency	50 Hz
Insulation level, indoor equipment	70 kV, 1 min
Insulation level, outdoor equipment	95 kV, 1 min
BIL, indoor equipment	170 kV, 1.2/50 µs
BIL, outdoor equipment	250 kV, 1.2/50 µs
Maximum short circuit current at xx kV?	31.5 kA, 1 sec
Control method	Unsymmetrical $Q_{50\ Hz}$ as per target $U_{50\ Hz}$ as per target
Outdoor ambient temperature	-15°C - +45°C
Pollution degree	2, very heavy

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3.2 Control and Protection system (C&P)

The Integrated C&P includes control and protection of the medium voltage thyristor valves, filter capacitor banks and cooling system. The entire C&P is placed in a Rittal cubicle shown in Figure 6.

Figure 6 Merus integrated C&P

The core of the control system is high performance DSP / FPGA board. This processor family is widely used in industrial, medical and military applications. The control and protection tasks have been shared between the processors so that the best features of each processor type have been utilized. The DSP has been allocated for operations such as complex floating-point calculations, thermal protection, and communications. The FPGA has been allocated for such as valve base protection, short circuit protection and over current protection. The control system incorporates Siemens S7-1500-series PLC which takes care of the pre-defined logical operations of the compensation system.

The control system contains different control methods. The open loop control method is based on reactive power measurement of the EAF and LF loads. This enables fast response to reactive power changes at loads. The target of the open loop compensation is to compensate the rapid reactive power variations caused by the loads.

The closed loop control is based on the reactive power measurement from the point of common coupling (PCC). The target of the closed loop compensation is to maintain the pre-set power factor at the PCC.

3.3 Merus™ thyristor valves for medium voltage

The thyristor valves and valve control system used in Merus™ SVC systems are designed and manufactured by Merus Power. The electrical part of the thyristor valve consists of series connected antiparallel thyristor pairs, snubber components and Thyristor Level Electronics (TLE). The structure is made simple and the number of components is minimized to improve the reliability. However, there are sophisticated features, as expected in a modern thyristor valve design. The firing commands are coming from the valve base via plastic optical fibers (POF, Versatile Link). The report signals from each thyristor level are collected and processed in the valve base units. A complete thyristor valve is shown in Figure 7.

Figure 7 Medium voltage thyristor valves

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The thyristor valves have the nominal current of 2575 A at 33 kV, 50 Hz. The valves have integrated protection and monitoring functionalities such as voltage breakover protection (VBO), Forward recovery protection (FRP), heatsink temperature monitoring (HSTM) and thyristor overshoot voltage monitoring (TOVM).

4. Grid compliance

During dimensioning stage total system and SVC performance were analysed using impedance calculations, RMS and Electro Magnetic Transient (EMT) simulations. Grid compliance was specified according to IEC 61000-3-6 (harmonics), IEC 61000-4-30 (flicker) and IEC 61000-2-12 (voltage unbalance). The achieved grid compliance is shown in the following.

4.1 Reactive power compensation and voltage flicker

The measured maximum reactive power fluctuation during EAF operation was 249 Mvar. To achieve the desired flicker reduction factor of 2.0 p.u. the size of the compensator was designed to be 225 Mvar. Based on the simulations, the expected flicker with the SVC is 0.99 p.u. at the PCC.

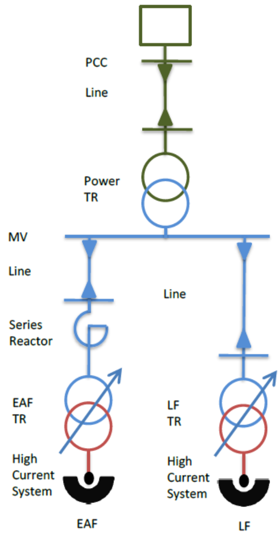

Figure 8 Simplified system schematics

The average power factor of the EAF and the LF was 0.78 p.u. The needed long-term reactive power capacity was dimensioned to be 75.9 Mvar to maintain power factor 0.98 p.u.

4.2 Harmonics

Harmonic current content of the steel plant is generated by electrical arc furnace (EAF), ladle furnace (LF) and thyristor-controlled reactors (TCRs). The generated harmonic current flow through the system impedances is causing harmonic voltages at respective harmonic frequencies. To mitigate the harmonics, filter capacitor banks tuned at 2nd, 3rd, 4th and 5th harmonic frequency were dimensioned and installed. The harmonic mitigation results are shown in Figure 9. Also, the system impedance was calculated as shown in Figure 10.

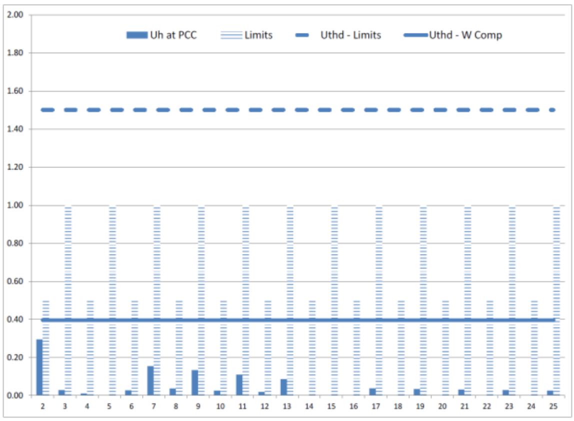

Figure 9 Harmonic voltage distortion at 400 kV PCC, fault level 6600 MVA, Uthd 0.40%.

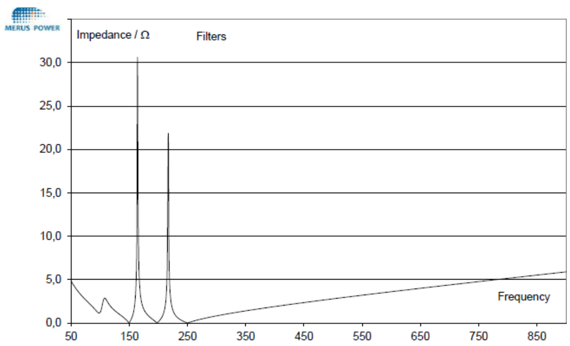

Figure 10 System impedance with filter capacitor banks.

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4.3 Power quality and compliance

The power quality parameters and grid code compliance with and without the SVC system is shown in Table 2.

Table 2 Power quality and compliance at 400 kV busbar

Parameter	Limit	Without SVC	With SVC
Voltage fluctuations	≤ 1%	5.6	0.9
Flicker at PCC, Pst	≤ 1 p.u.	2.0	0.99
Voltage unbalance	≤ 1 %	2.24	0.87
Power factor, cosphi	≥ 0.98 p.u.	0.78	0.98
Harmonic voltage distortion, Uthd	≤ 1.5 %	2.4	0.40

5. Productivity increase

EAF process has the nature of a constant impedance process. This means that the active power flowing into the melting process is dependent on the square of the voltage. For constant impedance loads:

$$P = P_0 \frac{U^2}{U_0^2}$$

where P is the active power of the process when voltage is U calculated based on reference power P_0 and reference voltage U_0. Voltages with and without the SVC during the EAF operation are shown in Figure 11.

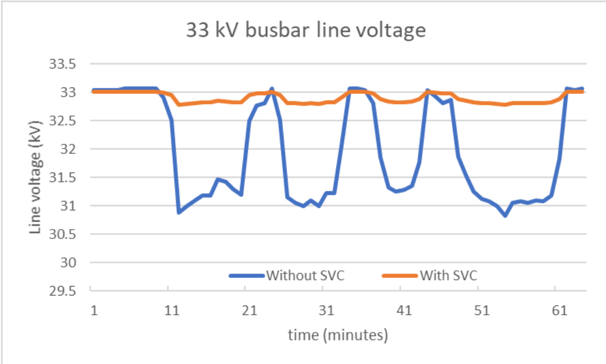

Figure 11 Medium voltage busbar voltage with and without SVC while EAF is operating.

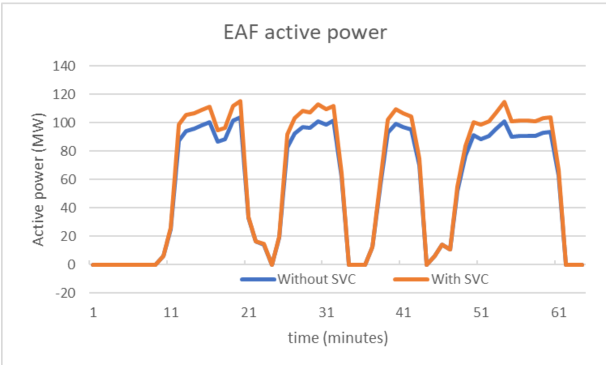

Figure 12 EAF active power with and without SVC

With the dynamic reactive power compensation, the tap-to-tap time has reduced by 9.2 %. The reduced tap-to-tap time influences the productivity. In this case, the 9.2% reduction in the tap-to-tap times results in 114 000 ton increase in production capacity per year. In addition, the reduced tap-to-tap time and more stable arc process causes energy and electrode savings. The energy savings are caused by the reduced radiation losses per melt because of shorter tap-to-tap time and reduced transformer losses because the power factor is improved. The graphite electrode consumption can be split into two parts: side oxidation and tip consumption. The side oxidation depends mainly on the tap-to-tap time while the tip consumption is related to electrode current. The reduced tap-to-tap time thus reduces the side oxidation, and thus the specific electrode consumption. The effect of the tap-to-tap time reduction on savings and payback calculations is shown in Table 3.

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Table 3 Payback calculation

EAF CAPACITY INCREASE		
Units	1	units
Capacity	170	ton per unit
Operation days	310	per anno
Tap to tap without compensation	58	min
Charges per day	24.8	
Tap to tap with SVC	52.7	min
Charges per day	27.0	
Capacity increase	114486	ton per anno
Profit	30	€ / ton
Profit due productivity increase	**3 434 586**	€ per anno
ENERGY SAVINGS		
Energy	94350	kWh / charge
Energy cost	0.08	€ / kWh
Tap to tap time reduction	9.2	%
Radiation losses, on average over tap to tap time	20	%
Profit due radiation loss decrease	**1 162 452**	€ per anno
Power transformer loss decrease	21.1	kW
Profit due Power transformer loss decrease	**12 531**	€ per anno
ELECTRODE SAVINGS		
Electrode consumption decrease	0.18	kg / ton
Electrode cost, on average for 2019	10	€ / kg
Profit due electrode savings	**2 561 220**	€ per anno
DYNAMIC COMPENSATION SYSTEM LOSSES		
Active power losses over tap to tap	0.8	%
M2000 - compensation system nominal power	225	Mvar
Loss due the compensation system operation	**-1 071 360**	€ per anno
TOTAL PROFIT	**6 099 429**	€ per anno

6. Conclusion

The installed SVC system for EAF application ensures the grid code compliance. The improved voltage quality also improves the productivity of the EAF process. The tap-to-tap time has reduced by 9.2%. This results in annual production increase of 155,000 tonnes of molten steel. Also, energy and graphite electrode savings are achieved. The total production increase is around 3.4 M€ and savings due to better operation is over 2.6 M€ per year.

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