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Improving the Quality of Electric Energy to Electric Arc Furnace

This paper presents a study of power quality problems created by an electric arc furnace (EAF) with eccentric bottom tap (EBT) at power system. The analysis have been done to EAF of 100 t capacity used for steel melting. Experimental results show this EAF is substantial source of electric disturbances, such as voltage fluctuations, flicker, harmonics, and unbalance between phases. Improvement of the quality of electric energy at EAF imposes a careful technical and economical analysis. Of all possible solutions for improvement of the power quality for an EAF (passive filter, STATCOM or SVC), SVC is the ideal solution.

Keywords*: electric arc furnace, power quality, static var compensator.*

1. Introduction

A great percent of the world steel production is provided by electric arc furnaces (EAF), in consequently the energy consumption is significant.

EAF are placed among the biggest polluters of air, soil, water and electric supply grids. [1]

The furnace type EBT is a high power electric furnace in which an electric arc are primed between the electrodes. The electrical arc has a nonlinear resistance and causes a non-sinusoidal voltage-current characteristic.

The arc has a dynamic behavior throughout the melting. Due to the dynamic behavior, the arc is an important source of disturbance in the medium voltage network with a low short circuit capacity. Perturbations are random and include a wide range of frequencies, from up to several hundred Hertz. [1]

Reactive power variations are caused by the variations of currents (depending to the network short-circuit), which in turn causes voltage variations.

Voltage variation disrupts the supply network, respectively disturb the operation of other electric melting furnaces or other industrial electrical equipments fed to the network. Disturbances are transmited in the public electricity network. In contrast to other types of loads, EAF produce random flicker which cannot be easily mathematical calculated with standard curves and methods.

2. Electrical measurement and analytical determinations carried for EAF

The electrical measurements were made at EAF from the Electric Steel Shop no.2 from ArcelorMittal Steel Hunedoara. This type of furnace, with O2 and CH4 supplement and continuous operation, has a reduced energy specific consumption and high productivity. [2], [3]

In figure 1 is represented the electrical energy consumption of OE2 Power Station compared with the total electrical energy consumption of Steel Shop.

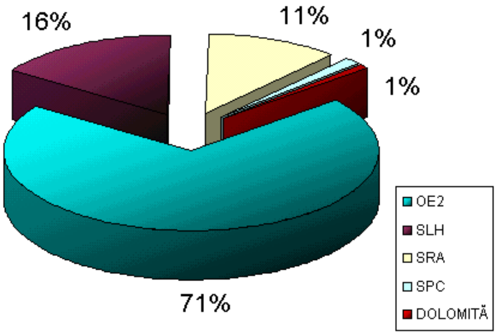

Figure 1. Electrical energy consumption of OE2 Power Station

In table 1 are represented the tehnological phases (no. charge 43.566) for electrical arc furnace.

To achieve the measurements we used an energy analyzer for three-phase, type CA 8334, from the Chauvin Arnoux company. With this tool it is possible to obtain the current image for the main characteristics of a network and monitor changes in a given period. The electric arc furnace measurements were made for the voltage of 33 kV.

Table 1.

Technology Phase	Start	End	Time
Adjust	07:00	07:04	00:04
Charge	07:04	07:08	00:04
Melting	07:08	08:23	00:15
Charge	07:23	07:27	00:04
Melting	07:27	07:32	00:05
Melting	07:34	07:47	00:13
Charge	07:47	07:50	00:03
Melting	07:50	07:58	00:08
Active Boiling	07:58	08:10	00:12
Evacuation	08:10	08:15	00:05
Total			01:13

Stationary	Type	Description	Start	End	Time
1	other	trigger electrical protection	07:32	07:34	00:02

In figure 2 is represented the OE2 Power Station that supplies electric energy to the electric arc furnace and ladle furnace.

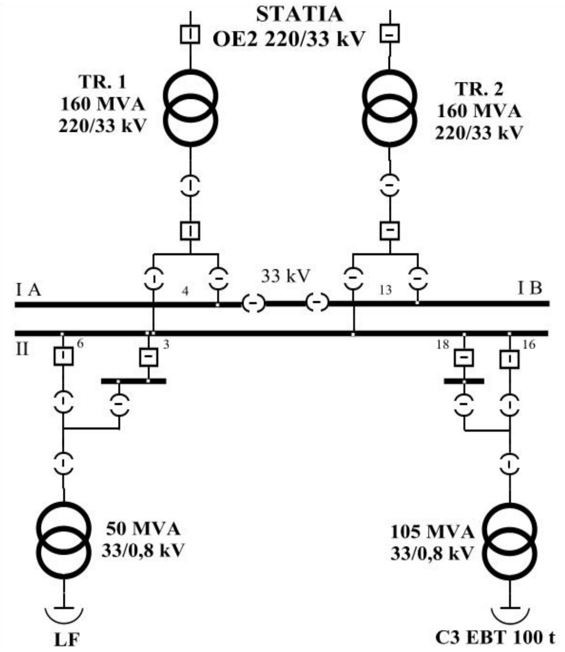

Figure 2. OE2 Power Station 220/33 kV

The results of measurements at 33 kV voltage level for the maximum recorded electrical parameters (active power, reactive and apparent power) are at 07:52:24:

- nominal voltage for phase R: U_{nR} = 26.16 kV;
- nominal voltage for phase S: U_{nS} = 27.30 kV;
- nominal voltage for phase R: U_{nT} = 28.53 kV;
- apparent power: S = 109.66 MVA;
- active power: P = 66.92 MW;
- reactive power: Q = 86.29 MVAR;
- deforming power: D = 10.05 MVAD.

It is determines the instantaneous power factor:

$$\cos\varphi = K = \frac{P}{S} = \frac{P}{\sqrt{(P^2 + Q^2 + D^2)}}, \tag{1}$$

result $\cos\varphi$ = 0.61.

First it is calculated the apparent power for $\cos\varphi$ = 0,92:

$$S_{92} = \frac{P}{\cos\varphi_{92}}, \tag{2}$$

result S_{92} = 72.74 MVA.

Second it is calculated the reactive power for $\cos\varphi$ = 0.92:

$$Q_{92} = S_{92} \cdot \sin(\varphi_{92}), \tag{3}$$

result Q_{92} = 28.51 MVAR.

Reactive power needed to be compensated for $\cos\varphi$ = 0.92:

$$Q' = Q_{\max} - Q_{92}, \tag{4}$$

result Q' = 57.58 MVAR.

In practice, it is calculate the average power factor in a time:

$$\cos\varphi = \frac{W_a}{\sqrt{({W_a}^2 + {W_r}^2)}}, \tag{5}$$

where: $W_a = \int_0^t P * dt$ is reactive power [Wh], (6)

and: $W_r = \int_0^t Q * dt$ is reactive power [VARh]. (7)

After the measurements performed at OE2 Power Station 220/33 kV for 24 hours, result the medium power factor $\cos \varphi_{med} = 0.72$.

Electrical measurements performed at 33 kV voltage level and the analytical procedure revealed that the resultant load is a resistive-inductive character pronounced.

The power factor and hourly energy: active, reactive and apparent varies widely during the melting on the electric arc furnace. The company who has electric arc furnace pays penalties for power factor less than 0.92.

The total harmonic distortion for current and voltage were determined with the CA 8334.

The total harmonic distortion for current: [1]

$$I_{THD} = \sqrt{\sum_{k=2}^{40} \left(\frac{I_k}{I_1} \right)} \cdot 100 \quad [\%], \tag{8}$$

where $I1$ is the RMS value for current.

The total harmonic distortion for voltage: [1]

$$U_{THD} = \sqrt{\sum_{k=2}^{40} \left(\frac{U_k}{U_1} \right)} \cdot 100 \quad [\%], \tag{9}$$

where $U1$ is the RMS value for voltage.

In table 2 is represented the total harmonic distortion for electrical arc furnace (time 07:15).

Table 2.

Harmonics order	1	3	5	7	9	11	13	15	17
I_{THD} [%]	100	17.4	7.7	4.8	3.5	3.9	3.5	3.5	3.5

In figure 3 is represented the instant image from CA 8334 with total harmonics distortions for current.

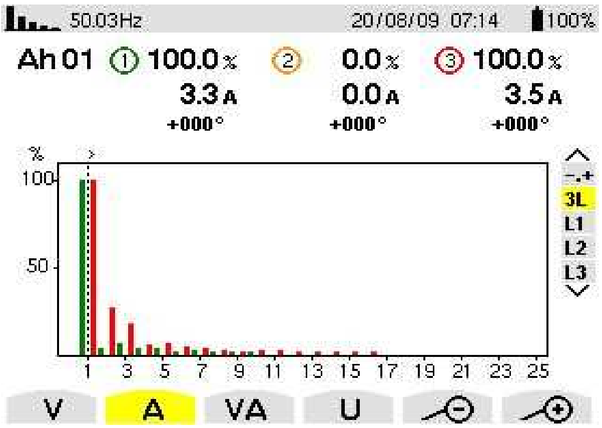

Figure 3. Instant image from CA 8334

In table 3 are represente three necessary types of harmonic filters for level three, five and seven.

Table 3.

Harmonics order	Frequency	Reactive power
[-]	[Hz]	MVAR
3	150	30
5	250	25
7	350	10

The ideal solution to improvement of power quality is SVC for electric arc furnace is SVC.

3. Dynamic reactive power compensation and attenuation for harmonic distortions at OE2 Power Station 220/33 kV

A Static VAR Compensator (or SVC) is an electrical device for providing fast-acting reactive power on high-voltage electricity transmission networks. The SVC generates reactive power witch compensates the variations of reactive power and stabilizes the power factor. [3], [4].

A rapidly operating Static VAR Compensator (SVC) can continuously provide the reactive power required to control dynamic voltage swings under various system conditions and thereby improve the power system transmission and distribution performance. In addition, an SVC can mitigate active power oscillations through voltage amplitude modulation.

In figure 4 is represented the schematic diagram for SVC.

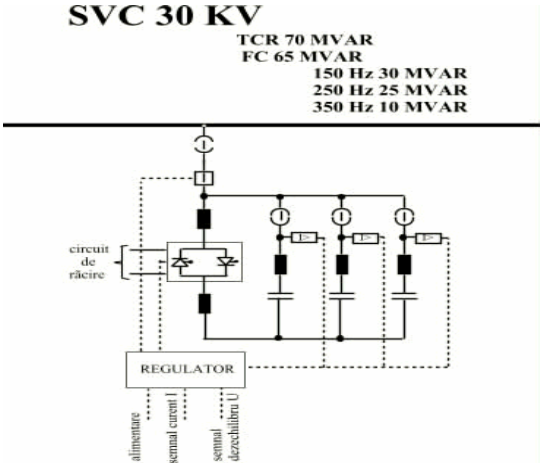

Figure 4. Schematic diagram for SVC

The operating principle of SVC's is based on the following equality:

$$Q_{load} + Q_{TCR} - Q_{FC} = 0 \tag{8}$$

where:

- Q_{load} is the reactive power absorbed by the electric arc furnace [MVAR];
- Q_{TCR} is the reactive power thyristor controlled reactor [MVAR];
- Q_{FC} is the reactive power harmonic filters [MVAR].

In other words, the sum of the existing reactive network node where the SVC has to be fitted to be zero, a condition perfectly feasible if used thyristor to control inductors.

SVC's are built up to 200 MVAR power thyristors and the ordered coil can be mounted directly to the 33 kV voltage levels.

The SVC filter circuit's component is designed to filter harmonics. The carefully adjusting the resonant frequency filter circuits reduce I_{THD} and U_{THD}. For 50 Hz the filters act as a capacitor that compensates the reactive powe

Reactance of the magnetic core has a number of advantages over other magnetic cores of the impedance in the air, such as:

- does not radiate a magnetic field outside the yoke;
- has reduced dimension;
- has low power loss;
- is resistant to corrosion;
- not maintenance required even in polluted environments.

The parameters for SVC's sizing are considered the following:

- S = 80 MVA;
- $\cos \varphi$ = 0.94;
- Q = 65 MVAR.

Fluctuations in voltage coming from the system can not be compensated with SVC's.

5. Conclusions

The benefits of an SVC can be seen within a steel plant as a stable power factor in spite of varying loads at the plant, and externally when the disturbances do not affect the supplying grid.

Proposed technical solution to implementation of SVC has the following advantages:

- reduces the voltage fluctuations;
- reduce the flicker phenomenon;
- reduce the weight of harmonics;
- is fast reactive power compensation;
- reduce power losses;
- reduces the reactive power bill;
- lower maintenance costs;

- improves the voltage local by local reactive power production leading to increased efficiency;
- increased load capacity active power energy plants;
- not required operating personnel;
- specific cost is lower than the value of synchronous compensators with the capacitor (compared in the EUR/kVAR);
- ensure continuous power factor adjustment to achieve optimal compensation;
- can be located outdoors;
- have a long service life;
- does not introduce harmonics in the network;
- the investment pays for itself in short period (one year and three months).

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