AC ARC FURNACES VOLTAGE AND CURRENT HARMONICS DISTORTION. INFLUENCE OF A SVC INSTALLED

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Abstract. And AC arc furnace is an unbalanced, nonlinear and time varying load, which can cause many problems to the power system quality. Different studies on arc furnaces harmonics analysis can be found in the bibliography of the topic nevertheless it is very difficult obtain an exact model that take into account all the parameters that have influence in the process then for this reason it is necessary to take measurements in different conditions. In this paper we'll present the harmonics distortions results and conclusions about three different measurement campaigns on a iron and steel industry (SNL) with an AC arc furnace of 83 MW (170 TM) with a transformer of 120 MVA connected by a dirty line of 220 kV (55 km) with the Carregado Substation where there are another nets connected with industrial and domestic consumers.

Introduction

Harmonics, inter-harmonics, voltage flicker and unbalance are the power quality problems which are introduced to the power system as a result of nonlinear and stochastic behaviour of the arc furnace operation. The nonlinear voltage-current characteristic of the arc can cause harmonic currents which when circulating by the net can produce harmonic voltages which can affect to other users.

Different studies on arc furnaces harmonics analysis can be found in the bibliography of the topic, for example, in [1] it is presented an arc model to carry out harmonic analysis of an AC three-phase arc furnace with a single-phase circuit. This model is based on V-I characteristic of the arc and takes into account the effect of the arcs unbalance over the zero sequence harmonics.

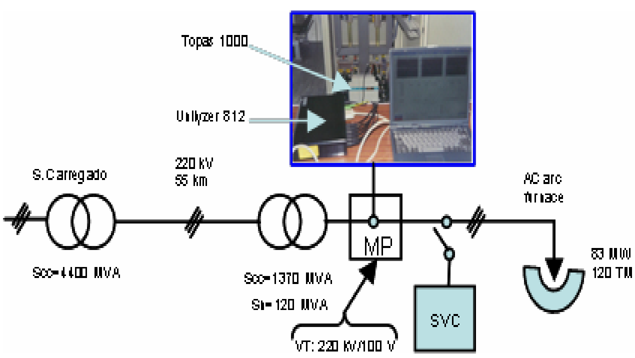
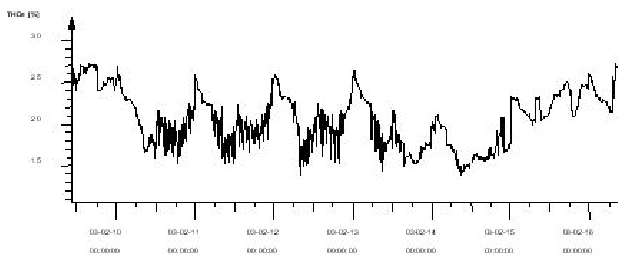


Figure 1. Electrical circuit chart of the arc furnace supply from Carregado Substation

The furnace shell is isolated and it represent a star connection of the three arcs, then if a three-phase arc furnace operation were balanced, the zero sequence components of the current wave would be null. Really, unbalance operation is the normal situation in the meltdown process and this produces zero sequence harmonics in the arc current. However, due to the influence between phases, these harmonics components do not reach the values that we would find in the current wave of a single-phase operation arc.

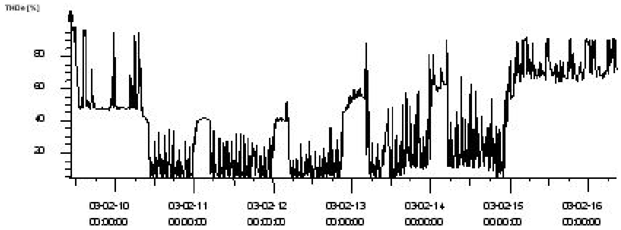
Nevertheless, take into account that the arc melting process is a stationary stochastic process it is difficult to obtain an accurate model for an arc furnace load. The factors that affect the arc furnace operation are the melting materials, the electrode position, the electrode arm control scheme, and the system voltage and impedance. For all of these reasons it is very important to take measurement.

Measurements without SVC



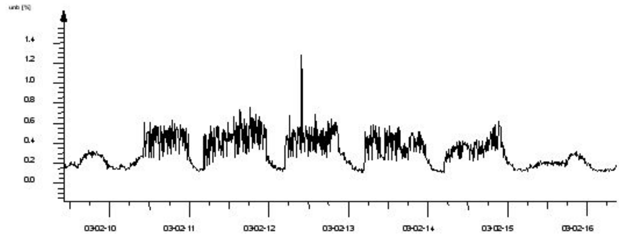
Maximum value/Minimum value of the voltage harmonic distortion Phase 1: 1,391644 % /2,728355 %

Figure 2. Total Voltage Harmonic Distortion Chart of Phase 1 without SVC and the arc furnace working at about 30 MW



Maximum value/Minimum value of the current harmonic distortion Phase 1: 4,641865 %/ 98,586993%

Figure 3. Total Current Harmonic Distortion Chart of Phase 1 without SVC and the arc furnace working at about 30 MW.



Maximum value/Minimum value of the voltage unbalance: 0,103763 % /1,275674 %

Figure 4. Chart of the unbalance with the arc furnace working at about 30 MW and without SVC.

Table 1. Summary of the minimum/maximum voltage and current harmonics values for the different phases without SVC

MINIMUM/MAXIMUM VOLTAGE THD BY PHASE AT THE CARREGADO SUBSTATION		
	Minimum	**Maximum**
PHASE 1	1,39 %	2,73 %
PHASE 2	1,19 %	2,77 %
PHASE 3	1,29 %	2,78 %
MINIMUM/MAXIMUM CURRENT THD BY PHASE AT THE PCC OF THE FACTORY		
	Minimum	**Maximum**
PHASE 1	4,64 %	98,59 %
PHASE 2	4,47 %	65,41 %
PHASE 3	4,63 %	91,75 %

Static VAR Compensator (SVC)

In its simplest form, the SVC consists of a Thyristor-Controlled Reactor (TCR) in parallel with a bank of capacitors. From an operational point of view, the SVC behaves like a shunt-connected variable reactance,, which either generates or absorbs reactive power in order to regulate the voltage magnitude at the point of connection to the inner network of the factory. It is used extensively to provide fast reactive power and voltage regulation support. The firing angle control of the thyristor enables the SVC to have almost instantaneous of response [5].

A schematic representation of the SVC used in the SNL factory is shown in Figure 5, where a three-phase, three-winding transformer is used to interface the SVC to high-voltage bus. The transformer has to identical secondary windings: one is used for delta-connected, six-pulse TCR and the other for star-connected, three-phase bank of capacitors, with its star point floating. The three transformer windings are also taken to be star-connected, with their star points floating

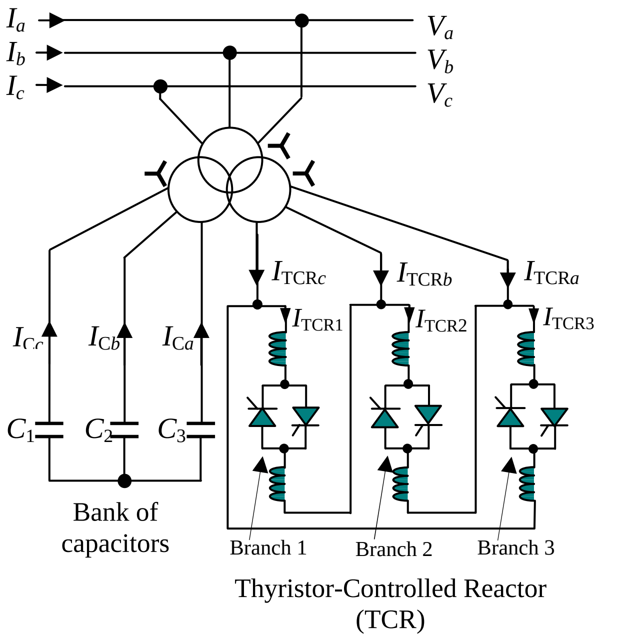
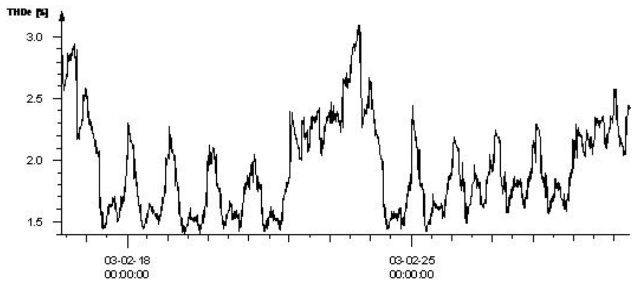


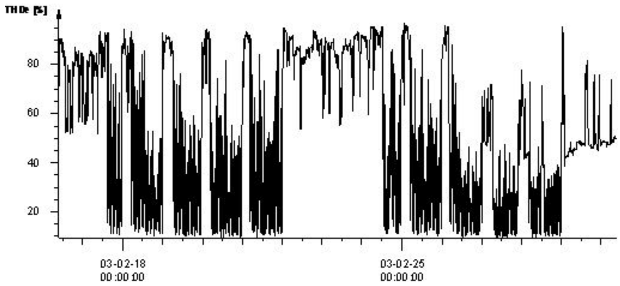
Figure 5. Representation of a three-phase static VAR compensator (SVC)

Measurements with SVC



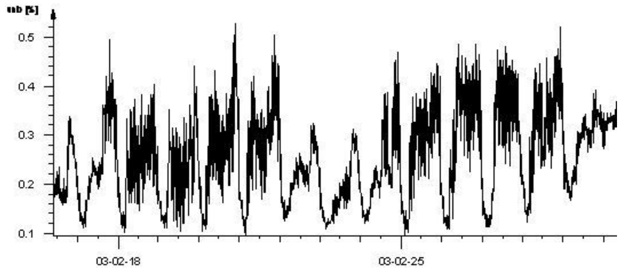
Maximum value/Minimum value of the voltage harmonic distortion Phase 1: 1,391644 % /3,0945771 %

Figure 6..Total Voltage Harmonic Distortion Chart of Phase 1 with SVC and the arc furnace working at about 30 MW



Maximum value/Minimum value of the current harmonic distortion Phase 1: 9,430219 %/ 96,728416%

Figure 7. Total Current Harmonic Distortion Chart of Phase 1 with SVC and the arc furnace working at about 30 MW.



Maximum value/Minimum value of the voltage unbalance: 0,094607 % / 0,5279703 %

Figure 8. Chart of the unbalance with the arc furnace working at about 30 MW and with SVC.

Measurements of flicker

We consider of the great importance evaluate the levels of flicker (short term and long term) at the factory without and with the SVC installed.

Table 3. Summary of the flicker Pst95% at the Measurement Point of the SNL factory and transmitted to the Carregado Substation without and with a SVC system and the arc furnace working at about 30 MW [4

SNL FLICKER MEASUREMENTS WITHOUT SVC					
FLICKER Pst95 AT THE MEASUREMENT POINT					
DATE	D 9	D 10	D 11	D 12	D 13
PHASE 1	0,125	6,031	6,313	6,031	5,938
PHASE 2	0,156	5,750	6,313	**6,375**	5,781
PHASE 3	0,125	5,688	5,625	5,688	5,188
Pst95 FLICKER TRANSMITTED TO CARREGADO SUBESTATION					
DATE	D9	D10	D11	D12	D13
PHASE 1	0,039	1,878	1,965	1,878	1,849
PHASE 2	0,049	1,775	1,965	**1,985**	1,800
PHASE 3	0,039	1,771	1,751	1,771	1,615

The unbalance is a consequence of the different distribution of voltage harmonic per phase.

Table 2. Summary of the minimum/maximum voltage and current harmonics values for the different phases with SVC

MINIMUM/MAXIMUM VOLTAGE THD AT THE CARREGADO SUBSTATION		
	Minimum	**Maximum**
PHASE 1	1,39 %	3,09 %
PHASE 2	1,22 %	3,17 %
PHASE 3	1,27 %	3,18 %
MINIMUM/MAXIMUM CURRENT THD AT THE PCC OF THE FACTORY		
	Minimum	**Maximum**
PHASE 1	9,43 %	96,73 %
PHASE 2	7,06 %	73,83 %
PHASE 3	9,66 %	86,86%

We can observe in Table 2 that with a SVC installed the Voltage Total Harmonic Distortion (THD) is practically the same (do not change) but the Current Total Harmonic Distortion increase about the double. This is a consequence of the electronic devices that constitutes the structure of the SVC.

SNL FLICKER MEASUREMENTS WITH SVC					
FLICKER Pst95 AT THE MEASUREMENT POINT					
DATE	D 16	D 17	D 18	D 19	D 20
PHASE 1	0,156	2,906	3,281	**3,313**	3,280
PHASE 2	0,156	2,844	3,281	**3,313**	3,219
PHASE 3	0,188	2,750	3,031	3,156	3,094
Pst95 FLICKER TRANSMITED TO CARREGADO SUBESTATION					
DATE	D16	D17	D18	D19	D20
PHASE 1	0,049	0,905	1,022	**1,031**	1,021
PHASE 2	0,049	0,885	1,022	**1,031**	1,002
PHASE 3	0,058	0,856	0,944	0,983	0,963

Like we can see at Table 3, the inclusion of the SVC system reduce significantly the levels of flicker [4].

The Pst index evaluate the short term flicker and the Plt index evaluate the long term flicker.

Usually the Pst is calculated using the following equation:

$$P_{st} = \sqrt{0.0314 P_{0.1} + 0.0525 P_{1s} + 0.0657 P_{3s} + 0.28 P_{10S} + 0.08 P_{50S}} \quad (1)$$

In equation (1) the most important factor is the way used to calculate the averaged percentiles. The value of the percentil will depend excessively on the type of the classification classes in the Cumulative Probabilistic Function (CPF). It will not be the same using a linear or a logarithmic classification.

$$P_{lt} = \sqrt[3]{\sum_{i=1}^{12} \frac{P_{sti}^3}{12}} \qquad (2)$$

The long term flicker, P_{lt}, like we can see by the equation (2), is obtained by 12 values of short term flicker, P_{st}.

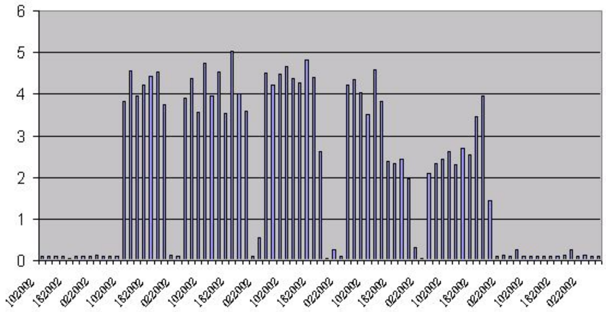


Figure 9. Bar diagram of long term flicker without SVC connected.

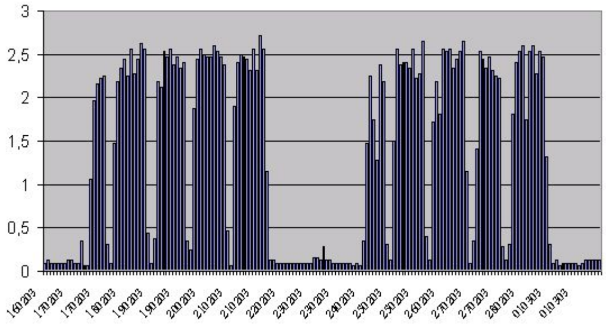


Figure 10. Bar diagram of long term flicker with SVC connected

We can see by comparing of the figures 9 and 10 that by using the SVC system the levels of long term flicker is reduce substantially

Conclusions

In normal conditions but working at about 30 MW below the nominal power (83 MW) and with SVC we can conclude briefly:

Along the measurements campaigns for the working power of the arc furnace at about 30 MW the maximum value of the total voltage harmonic distortion at the measurement point of the factory was 3,18% (about 0,99% at the Carregado Substation) and the 95% of the harmonic factor values of the most significant harmonics are within the limits of the standard EN50160. The maximum voltage harmonic factor value was 2,96% corresponding to the 5 harmonic. The corresponding value at the Carregado substation will be about 0,92%. The maximum harmonic factor value for even harmonics, corresponding to the 2 harmonic, was 0,369% (about 0,12% at the Carregado Substation) which is a very low value. In any case we must take into account that the arc furnace power is before the nominal power (about 37%).

The harmonic distortion of the current is dependent of Z(n) (inner impedance of the factory for each harmonic) and dependent of the SVC impedance, power of the load connected, amount and type of the materials, etc. This current harmonic distortion is very high and different for each phase. It is incredible but the maximum current harmonic factor value at the measurement point was 86,86% that means about 27% at the Carregado Substation.

The levels of the flicker, long term flicker and short term flicker for 95% of the measurements values (Pst95%) in the Carregado Substation are just in the limits of the EN 50160 standard . The maximum value of the Pst95% obtained at the factory measurement point was 3,313 that means 1,031 at the Carregado Substation. This value was produced the 19 of February, 2003, in phase 2 with a consumed power of 30.690 kW [4].

Time domain analysis of the arc furnaces with a three-phase circuit are quite costly concerning computation time, and those which are accomplished on a single phase circuit are not quite exact concerning harmonic content, mainly the magnitude of zero sequence components.

References

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