11th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2007, Hammamet, Tunisia, 05-09 September, 2007.

ELECTRIC ENERGY QUALITY - ANALYSIS OF CONNECTING ELECTRO-ARCHED FURNACE TO CHARGE GRID PROBLEM

M.A. Dragan V. Brajovic –
Technical College of applied studies,
Svetog Save 65, Cacak, Serbia

ABSTRACT
In this paper electro arched furnace is studied and problems of flickers and voltage and current higher harmonics are defined, with which electro-arched furnaces make bad influence on electric grid regarding electric energy quality. Problem of choosing the appropriate connection point is pointed out as well as the solutions to this problem. Measuring results of voltage and current of higher harmonics performed on high-voltage side (10kV) of an electro arched furnace is given. Previously obtained measuring results are also used for drawing certain conclusions. As in this field there is a lack of distributive regulations, these conclusions can serve as a supplement to connecting electro-arched furnaces to charge grid problem solution.
Key words: Electro arched furnace, connection point, flicker, higher harmonics, measurings.

1. INTRODUCTION
The use of a great number of non-linear consumers significantly degrades electric energy quality. Occurrence of voltage and current of higher harmonics are one of the main problems of electro power grids. Regarding technical as well as economical aspect, studying of their sources, spreading ways and negative effects is of a significant importance. [1]
Electro arched furnaces are loads with large installed powers (even over 100 MVA), uneven time diagram of usage, asymmetric electrical load and non-linear features (electrical arch as a converter of electric to thermal energy s extremely non linear). As such they are significant source of quality degradation.

2. CONNECTION POINT CHOICE
Operation of electro-arched furnace is characterised by changeable current load, which changes in scaling from zero (arch cut) to short circuit current size (direct contact of electrode with batch). Such changeable current load on impedance of grid ($\underline{Z}_m$)causes voltage fluctuation that transmits to all receivers connected in the same electrical grid point. The influence on other consumers is especially evident if electro arched furnace operates in city distributive network where there is a great number of consumers sensitive to changes in electrical energy quality. Therefore it is necessary to make a good selection of connection point to electrical power grid at the stage of projecting electro- thermal system.
This problem can be discussed through one general example of electro-arched furnace and its electrical surrounding, where two points of significance are defined: The first point on "solid" grid (constant voltage and resistant to current changes) and the second point of joint connection of electro arched furnace and other receivers from surrounding (PCC point - "Point of Common Coupling") coil impedance between these two points is $\underline{Z}_m = R_m + jX_m$, and voltage change is

$$\Delta\underline{U} = \underline{Z}_m \Delta\underline{I} = \left(R_m + jX_m\right)\Delta\underline{I} \tag{1}$$

where:

$$\Delta \underline{I} = \Delta I e^{-j\varphi} = \Delta I(\cos\varphi - j\sin\varphi) \tag{2}$$

It is thought that phase move between furnace current and voltage on collectors of joint connection (PCC point) is constant and equal to φ angle (furnace is mostly of inductive character).For higher value of φ angle we can justifiably take its real component instead of vector voltage sag, that is voltage sag:

$$\Delta U = R_e\{\Delta \underline{U}\} = R_m \Delta I \cos\varphi + X_m \Delta I \sin\varphi \tag{3}$$

Multiplzing and dividing previous formula with denominated voltage *(U)* on collectors in point PCC, we get the following:

$$\Delta U = \frac{R_m \Delta P + X_m \Delta Q}{U} \tag{4}$$

Relative voltage change in PCC point is:

$$\Delta u = \frac{\Delta U}{U} = \frac{R_m \Delta P + X_m \Delta Q}{U^2} \tag{5}$$

Active power changes (*ΔP*) are far less than reactive power changes (*ΔQ*) so that the element $R_m \Delta P$ in (5) can be neglected. So now the relative voltage change in PCC point is :

$$\Delta u \approx \frac{X_m \Delta Q}{U^2} \tag{6}$$

Short circuit grid power in PCC point is:

$$S_k = \frac{U^2}{X_m} \tag{7}$$

When the formula (7) is put in (6) we get formula for evaluating grid suitability for powering of each given electro arched furnace:

$$\Delta u(\%) = \frac{\Delta Q(S_p)}{S_k} \cdot 100 \tag{8}$$

where: $\Delta u(\%)$ is relative voltage change in PCC point, in percentage, $\Delta Q(S_p)$ is reactive furnace power change in [*MVAr*] and Sk is short circuit grid power in PCC point in [*MVA*].
The change of the furnace reactive power $\Delta Q\ (S_p)$ is calculated as

$$\Delta Q(S_p) = \Delta Q'(S_p) \cdot S_p \tag{9}$$

where: S_p is denominated power of furnace in [*MVA*] and $\Delta Q'(S_p)$ is probable change of reactive furnace load in [*MVAr*] / [*MVA*].Values for $\Delta Q'(S_p)$ are read from the diagram provided by an experiment (investigating the majority of electro arched furnaces).[3]
During the projecting stage, on the basis of the data for electro- arched furnace and according to the values of relative voltage changes which are allowed by standards, we can determine, according to the manifestation, to what extent the value of short circuit power should be so that the connection of electro- arched furnace could be adequate. According to this we determine connection point in surrounding which satisfies these terms:

$$S_k \geq \frac{\Delta Q(S_p)}{\Delta u(\%)} \cdot 100 \tag{10}$$

3. ANALYSIS OF MEASURING HIGHER HARMONICS RESULTS

Measuring was conducted on an electro-arched furnace in company "Cer" in Čačak (capacity 1.5t, power 1.2 *MVA*). Single-pole scheme of electro -arched furnace is given in Figure 1. Measurements were conducted on a high voltage side of the electro-arched furnace (10*kV*) in order to register higher harmonics of voltage and current, which are delivered to power grid by electro-arched furnace.
Measuring system for surveying higher harmonics was used in this case, accomplished at the Faculty of Technical Science - Institute for Energetic and Electronics in Novi Sad. [4] The system consists of measuring converter section, *A/D* card and portable computer (lap-top). Measuring was performed

thorough measuring converters, which are connected to secondary coils of measuring voltage and electrical transformers

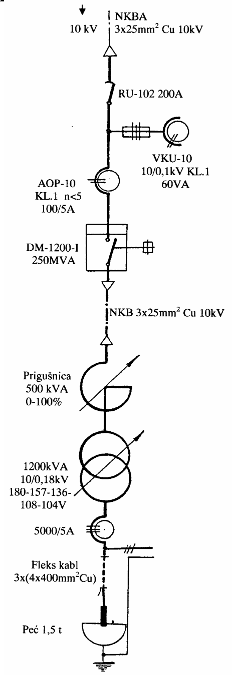

Figure 1. One pole scheme of electro-arched furnace

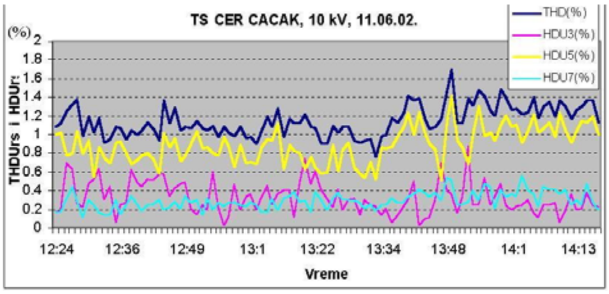

Figure 2. Diagram of voltage harmonics on 10 kV side of electro-arched furnace in factory “CER”, Cacak

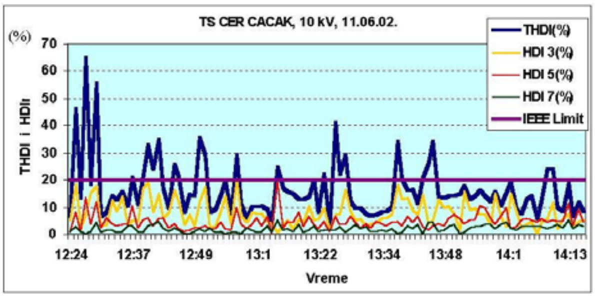

Figure 3. Diagram of current harmonics on 10 kV side of electro-arched furnace in factory “CER”, Cacak

Voltage and current harmonics were measured, that is, individual (*HD*) and total (*THD*) harmonics distortion during one cycle of batch melting.

Measuring results conducted on $10kV$ side of electro-arched furnace were analysed and presented as time-diagram of the flow of higher harmonics of voltage (Figure 2) and current (Figure 3). Standard IEEE-519 [5] was used for comparison of given results, for which limits of voltage and current are regulated:

- for voltage level: $<69kV; THDU(\%) = 5\%; HDU_n = 3{,}0\%,\ n = 3{,}5{,}7{,}...$
- for currents ratio: $I_{SC} / I_L > 1000 : THDI(\%) = 20\%; HDI_n = 15\%, n = 3-11$ and $HDI_n = 8\%, n = 13-15$

where: I_{SC} is maximum current of short circuit, I_L is maximum current of receiver. For smaller ratio I_{SC} / I_L limit level of higher harmonics is lower.

Comparing measuring results with given limits, we can see that *THDU*(%) is kept within bounds (< 5%), although there are significant deformations concerning wave shapes of current, meaning that *THDI* (%) > 20% as well as the fact that 3rd and 4th current harmonics dominate. In this early stage (melting stage) extremely high exceeds are present for the reason that during this period short circuits are very common, which means direct contacts of electrode and metal.

Re-adding of the batch was conducted in the middle of the cycle, which manifested in repeated increase of *THDI* (%) but in smaller amount than at the beginning of the cycle, because the furnace is heated in presence of thermal inertia. Statistic analysis of gained results for voltage harmonics is shown in figure 4 and figure 5 shows current harmonics. Given diagrams also show the level of harmonic which is not exceeded in 95% of time.

Figures 3 and 5 depict certain differences between levels of *THDI* and individual harmonic, specially when maximum values are concerned. This implies greater spectrum than expected (only odd harmonics). Figure 6 shows a complete spectrum of current wave shapes as well as levels of limits. We can also see the presence of even harmonics, as well as high levels of zero and other harmonics in the beginning of the spectrum.

According to the drawn measuring results we can conclude that current distortion is present, but it doesn't cause any serious deforming of voltage. The reason for this is a good choice of connection point on " solid" grid, that is on TS 35/ 10 kV " Kazanica", meaning high value of short circuit power.

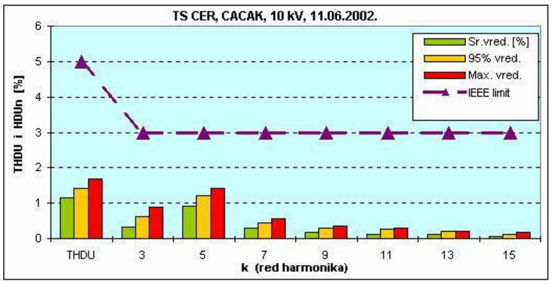

Figure 4. Statistic analysis of measuring results of higher harmonics voltage

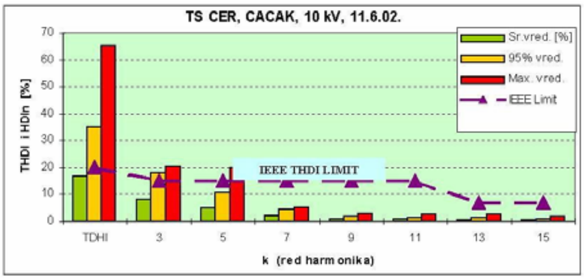

Figure 5. Statistic analysis of measuring results of higher harmonics current - statistical spectrum of limit values – IEEE 519

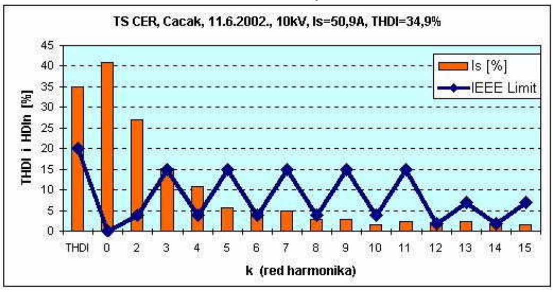

Figure 6. Spectrum and IEEE limit

4. CONCLUSION

Serious issues, which electro arched furnace transfers to electrical grid in a form of degradation of electrical energy, point out necessity of the right selection of connection point.

At the projecting stage, through the power of short circuit, it is possible to determine if there is an appropriate connection point in electro arched furnaces surroundings. It is also essential to conduct evaluation of connection point from the aspect of flicker, in order to reduce influence on other receivers in a joint connection point.

Connecting electro arched furnace in company " CER" to " solid" grid, that is to TS 35/10 kV " Kazanica" represents a good solution and the result is that distortion of voltage is kept within the bounds, apart from evident distortion of current. If there isn't possibility of connecting to " solid" grid, it is necessary to limit higher harmonics within the bounds regulated by rules. One of the ways of solving the problem is projecting and installing filters of higher harmonics.

5. REFERENCES

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