Power quality analysis of DC arc furnace operation using the Bowman model for electric arc

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Abstract. This work is about a relatively new domain. The DC electric arc is superior to the AC electric arc and it's not used in Romania. This is why we analyzed the work functions of these furnaces by simulation and model checking of the simulation results.The conclusions are favorable, to be carried is to develop a real-time control system of steel elaboration process.

1. Introduction

An increase of steel produced quantity in electric furnaces has been noticed in the last years, mainly using DC arc furnaces. In spite of the well known advantages of this system [1], it is not used in Romania. The necessity for more powerful converters complicates the feeding diagram of the furnace, but allows an advanced degree of automation of the process, which leads in long tern to a much higher output of the DC furnaces. It is possible to determine the control algorithms only if the work conditions of the E.A. furnaces are known and can be modelled and simulated.

2. Technological considerations. The DC arc

The making of steel elaboration in an E.A. furnace involves three stages (Figure 1).

The smelting process – lasts from the moment is connected to the electric network up to the complete smelting of furnace load.

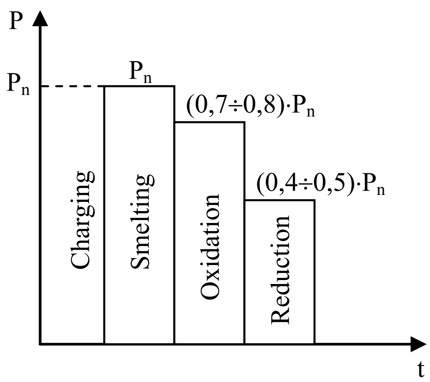

Figure 1. The stages of steel elaboration in an electric arc furnace

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The oxidation process (refining) is characterized by the fact that the electric arc is steady; the temperature of the melted steel is maintained at a value required by the chemical reactions in the process. All along this stage, the furnace works at $(0.7\div 0.8)\cdot P_n$.

The reduction process. The temperature of the bath reaches 1700^0C and the electric arc is stable, the power absorbed by the furnace being $(0,4\div 0,5)\cdot P_n$.

The electric arc is attached to the cathode by a small area named cathode spot, the arc reaching the smelted steel (Figure 2).

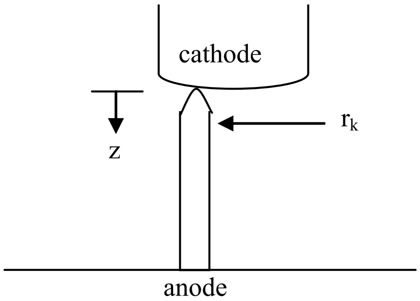

Figure 2.

The value of the current density through the cathode spot is about 3,5 KA/cm^2.

$$\frac{r_a}{r_k} = 3{,}2 - 2{,}2\cdot e^{\left(-\frac{z}{5\cdot rk}\right)} \quad (1)$$

Relation (1) describes the shape of the conducting column of the electric arc taking in account the distance z between the metal bath and the cathode. By integration we obtain the voltage of the electric arc [2]:

$$V = 2\cdot \rho_a \cdot \sqrt{\frac{L\cdot j_k}{\pi}}\cdot \int \left(\frac{r_k}{r_a}\right)^2 \cdot dZ\,; \quad Z = \frac{z}{r_k}\,; \quad (2)$$

where:
ρ_a – the passivity of the electric arc [$\Omega\cdot cm$];
j_k – the current density through the cathode spot, [KA/cm^2];
r_k – the radius of the cathode spot [cm];
r_a – the radius of the arc column [cm];
L – the length of the arc, [cm];
z – the axial distance between the cathode and the metal bath, [cm].
Calculations lead to a relation that links the voltage of the electric arc and its length to the current:

$$V_a = \frac{I\cdot \rho_a}{m\cdot \pi}\cdot \left[-\frac{1}{a^2 + a\cdot b} + \frac{1}{a^2 + a\cdot b\cdot e^{m\cdot L}} - \frac{\ln(a+b)}{a^2} + \frac{m\cdot L}{a^2} + \frac{\ln\left(a + b\cdot e^{m\cdot L}\right)}{a^2}\right], \quad (3)$$

where: $a = 3{,}2\cdot r_k$, $b = -2{,}2\cdot r_k$, $m = \frac{-1}{r_k}$, $r_k = \sqrt{\frac{I}{\pi\cdot 3500\left(A/cm^2\right)}}$.

The value of electric resistivity can be obtained experimentally and is strongly dependent on the composition of the atmosphere where the arc is.

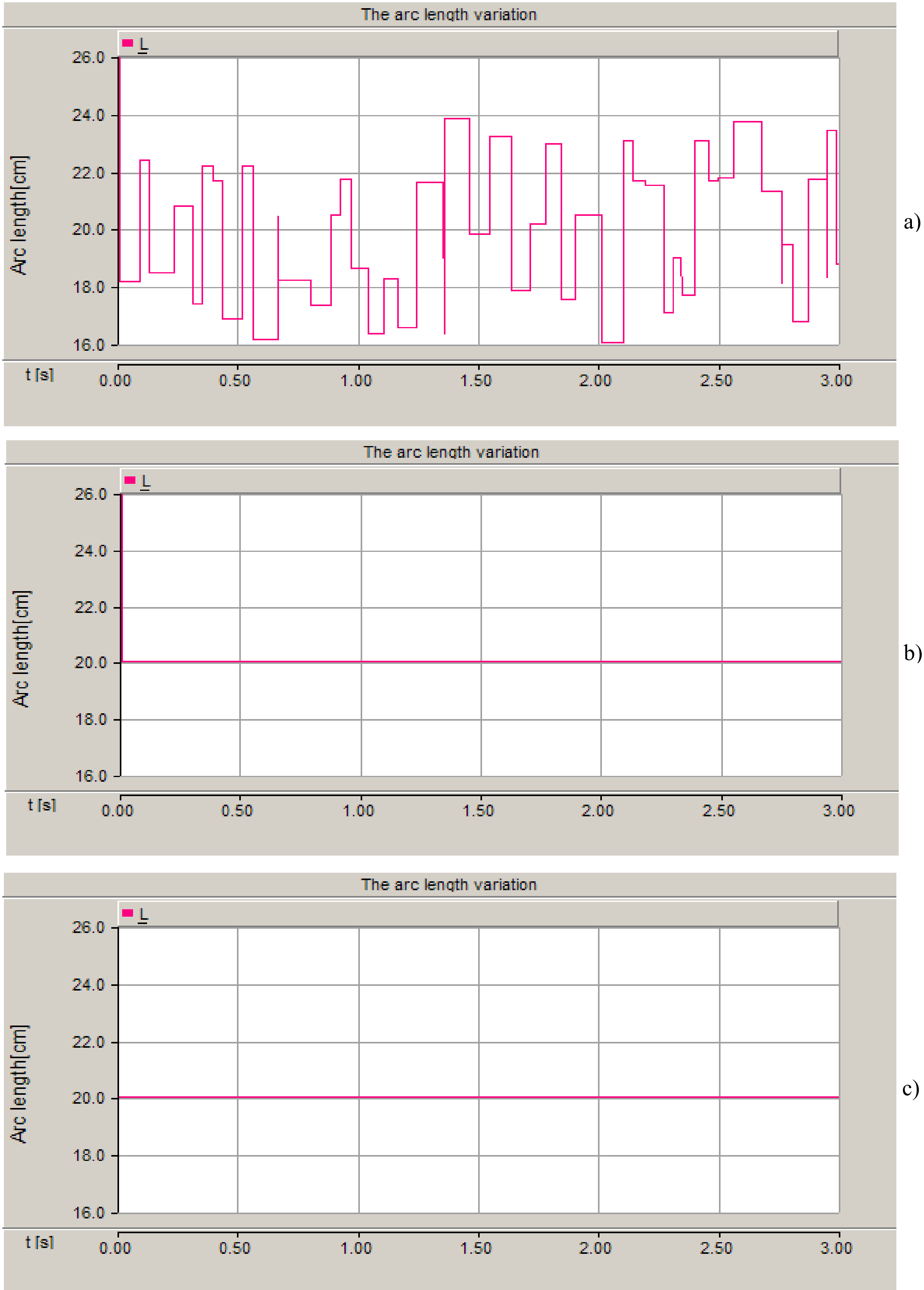

Figure 3. The variation of the electric arc length for the three stages of steel making: a) smelting; b) refining; c) reduction

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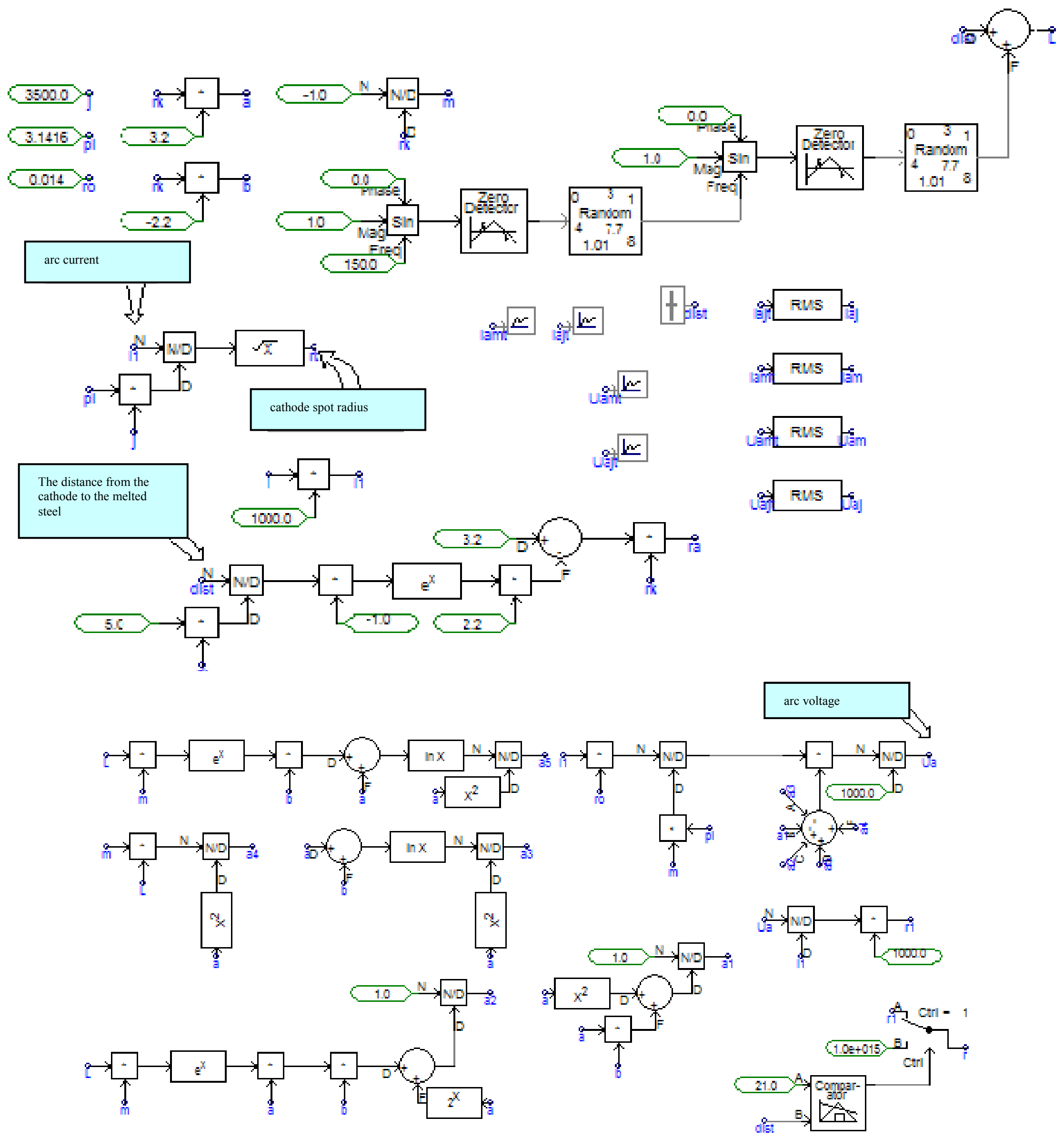
Figure 3 shows the variation of the electric arc length in the phases of smelting, refining and reduction. The average length of the electric arc is l = 20 cm [3]. During the smelting process, the arc length and its resistance vary randomly with a frequency in between 0 and 15 Hz [3].

3. Modeling and simulation of the processes in the DC arc furnace

In order to model and simulate the process of steel elaboration in the DC arc furnace, the utility program PSCAD – EMTDC 4.2 has been used. Figure 4 shows the simulation diagram that was created.

The electric arc furnace belongs to the 1[st] category of elements generating deforming work conditions [4]. It happens so on the one hand because of the non-linear character of the charge, respectively of the electric arc resistance, and on the other hand because of the controlled converter.



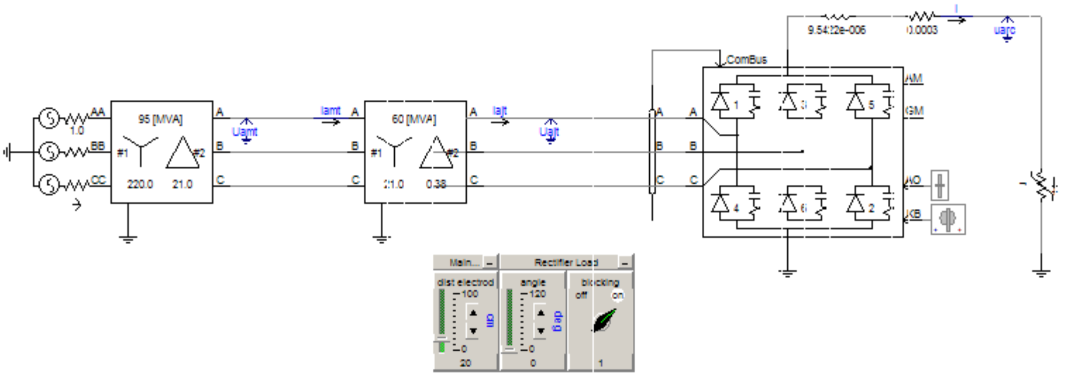
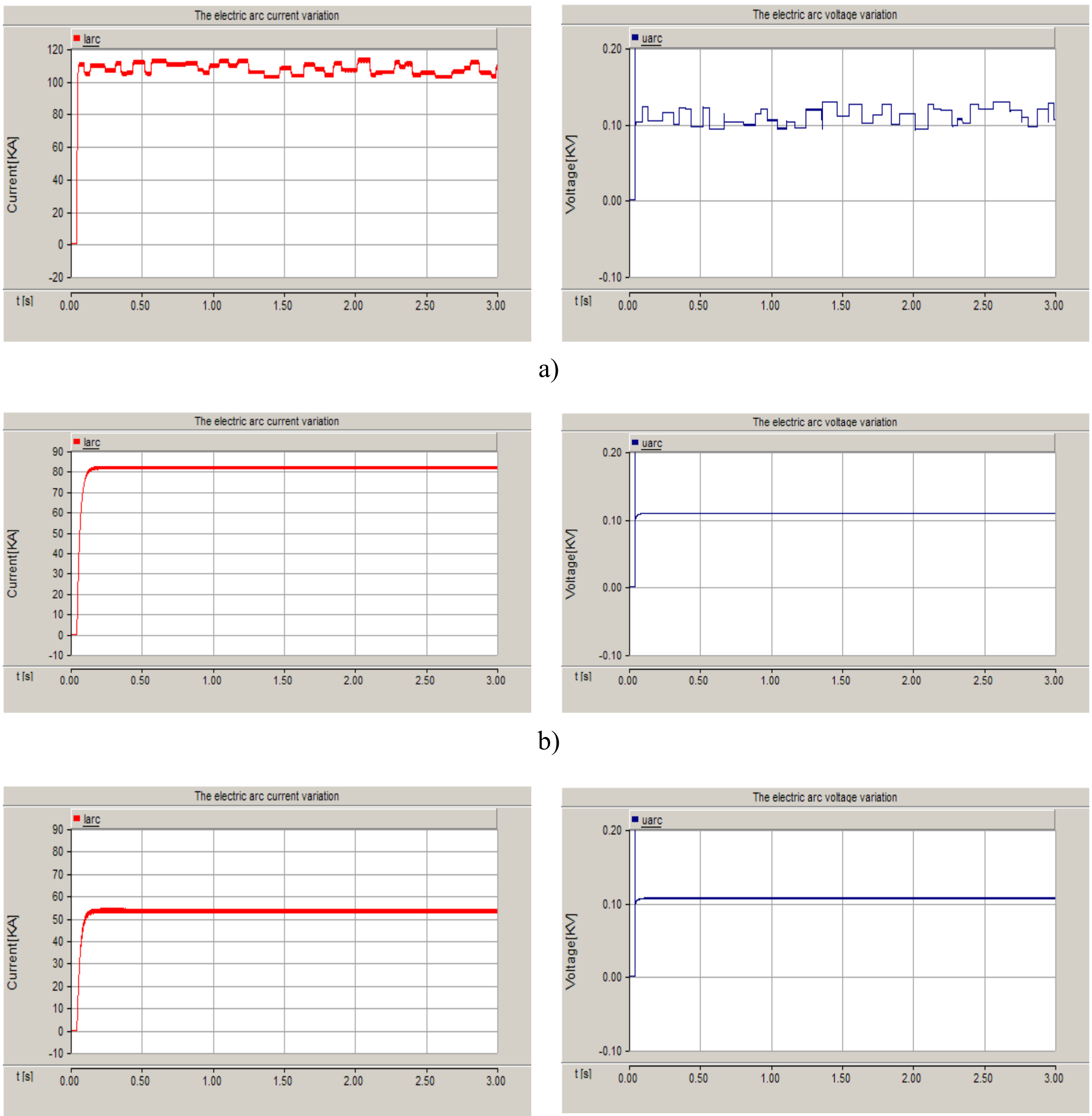


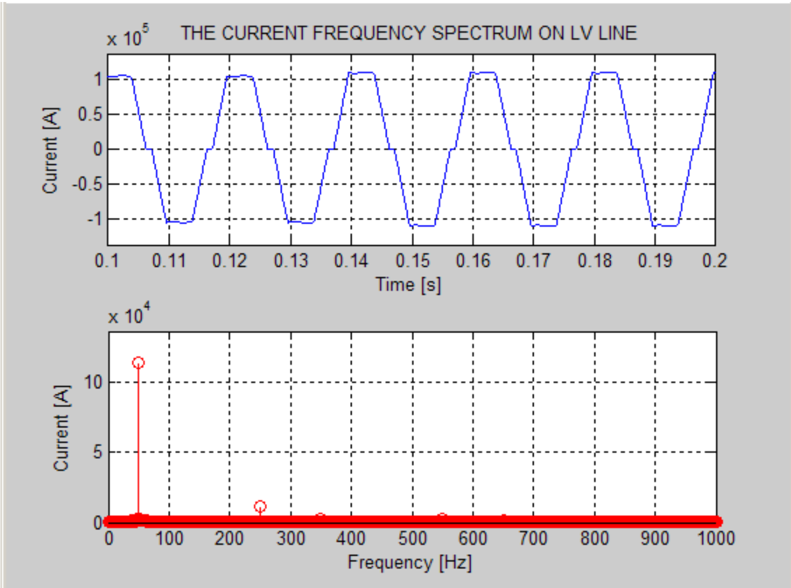
Figure 4. The simulation diagram



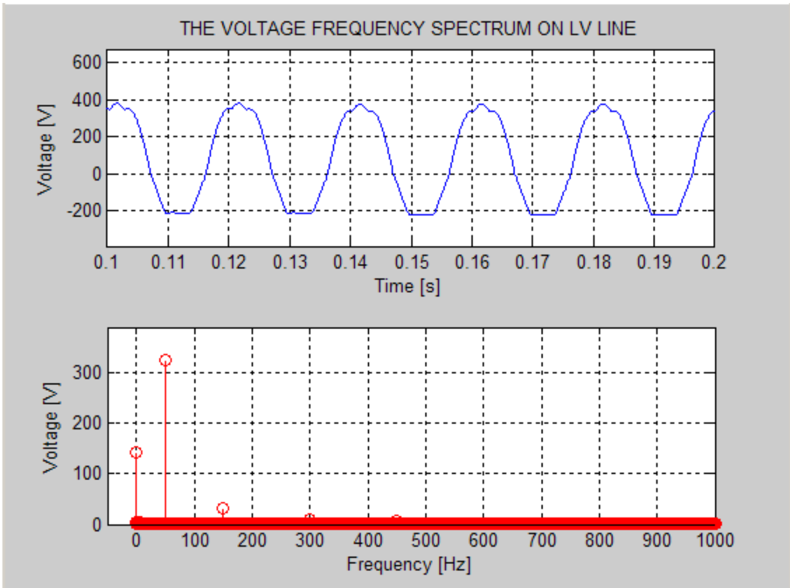
c)

Figure 5. The variation of the voltage and current of the electric arc in the phases of:
a) smelting; b) refining; c) reduction

The harmonic analysis has been done by means of a program designed by the authors under Matlab. After the analysis on the low voltage line for the smelting stage, we obtained the spectra of the current and voltage (Figure 6)



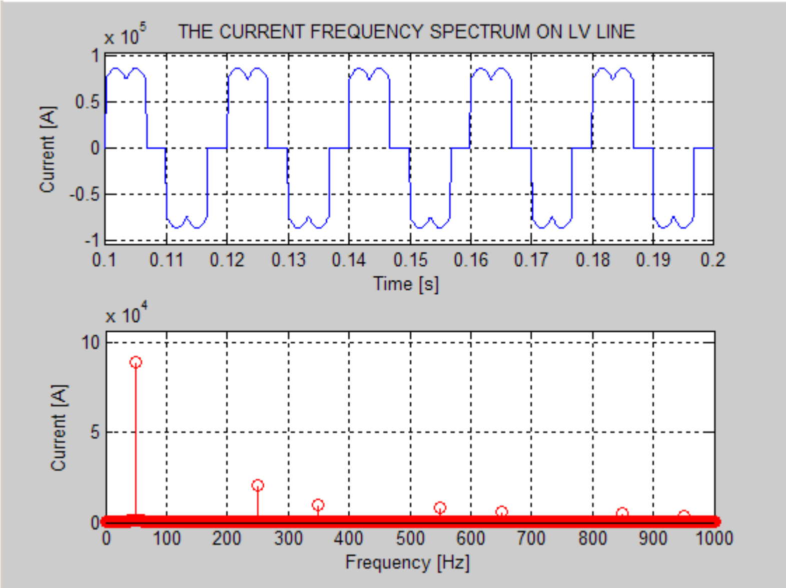
THD = 10,137% Y_d = 11590,749 A



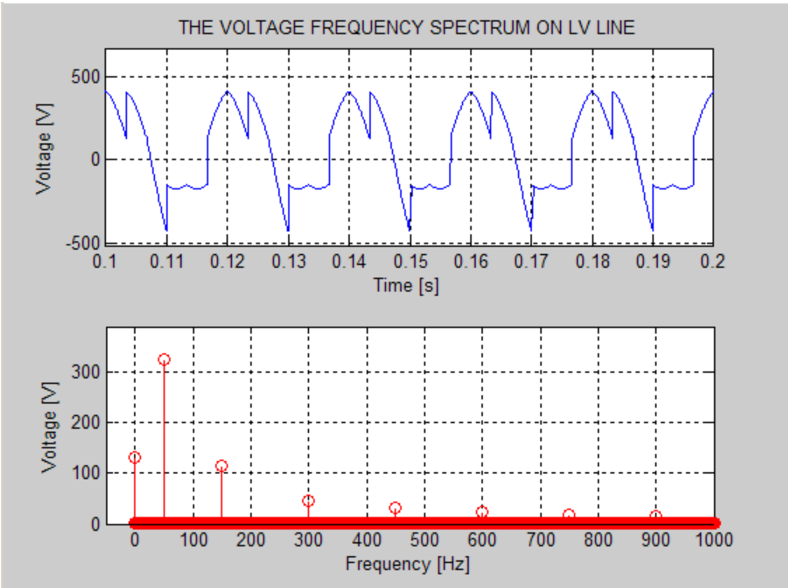
THD = 40,9757% Y_d = 145,2917 V

Figure 6. The voltage and current frequency spectrum during the smelting stage on the low voltage line

According to the CEI recommendations with respect to the 2nd class installations of electromagnetic media, included in the PE143/94 norms [4], the harmonics content of the fundamental, the harmonics 3, 9, 15 and 18 in the voltage spectrum are much larger then the limit levels of compatibility. In the current spectrum on the low voltage line, harmonic 5 with a content related to the fundamental of 9,6248% exceeds the maximal admitted value.



THD = 28,0481% Y_d = 25951,4773 A



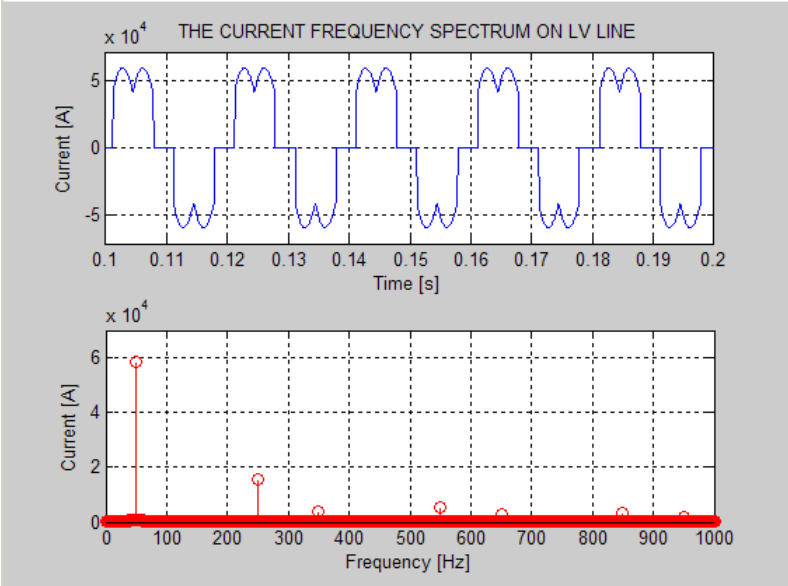
THD = 49,9998% Y_d = 186,5558 V

Figure 7. The voltage and current frequency spectrum during the refining stage on the low voltage line

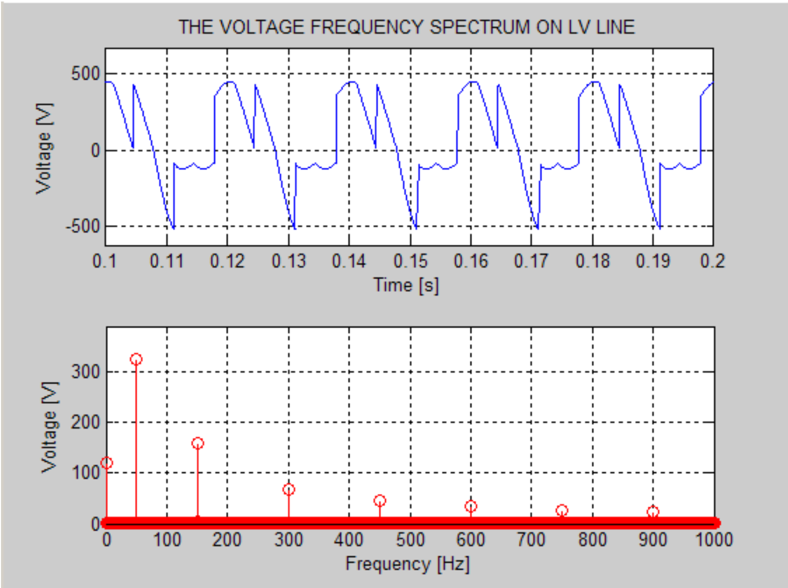
Power reduction during the refining stage can be done by controlling the converter at an angle of $\alpha = 60{,}34^0$. During this stage, the voltage frequency spectrum on the low voltage line contains harmonics 0, 3, 6, 9, 12, 15 and 18 (Figure 7), all of which exceed the limit compatibility levels.

The current frequency spectrum on the low voltage line includes harmonics 5, 7, 11, 13, 17, 19, whose values exceed the maximal admitted limits.

During the reduction stage, in order to have a power P = (0,4÷ 0.5)·P_n, the converter has to work at a command angle of α = 80^0. The high value of the command angle, leads to higher levels of harmonic pollution in the feeding network.



THD = 29,0364% Y_d = 17669,3544 A



THD = 56,6584% Y_d = 223,1912 V

Figure 8. The voltage and current frequency spectrum during the reduction stage on the low voltage line

The voltage frequency spectrum on the low voltage line (Figure 8.) reveals that this is greatly polluted with harmonics and includes harmonics of 0, 3, 6, 9, 12, and 18 ranks, all of which exceed the limit values admitted. In the current spectrum on the low voltage low voltage line the harmonics of ranks 5, 7, 11, 13, 17, 19 are prevailing, their values exceeding the standardized maximal limits.

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4. Conclusions

This work analyzes the performances of the smelting process in DC arc furnaces and suggests a system of controlling this process, meant to point out to the advantages of this method, minimizing its disadvantages.

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