ANNALS OF THE FACULTY OF ENGINEERING HUNEDOARA
2005, Tome III, Fascicole 2

SYSTEM OF CONTROLLING THE PROCESS OF STEEL ELABORATION IN DC ELECTRIC ARC FURNACES

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ABSTRACT

The paper approaches a new domain, as, although the DC arc is by far superior to the AC arc, it is 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 highly favorable, the researches to be carried on towards developing a system of real-time control of the steel elaboration process.

KEYWORDS:
Simulation, arc furnace, melting, electric arc.

1. INTRODUCTION

An increase in the quantity of steel elaborated in electric furnaces has been noticed lately, particularly using DC arc furnaces. In spite of the well known advantages of this system [1], it is not used in Romania. The need for a high power converter complicates the feeding diagram of the furnace (non-linear charge), but allows an advanced degree of automation of the process, which leads in the long run to a much higher output of the DC furnaces. It is possible to determine the methods and control algorithms only if the work conditions of the furnaces are known and if they can be modeled and simulated.

2. TECHNOLOGICAL CONSIDERATIONS. THE DC ARC

The technology of steel elaboration in an electric arc furnace involves mainly three stages (Fig.1).

The smelting process – lasts from the moment of switching on the electric network up to the complete smelting of the material in the furnace.

The main characteristic of the smelting process is the instability of the electric arc, due to the dropping of the charge in the furnace. All along this process 60 – 80% of the energy needed by the entire preparation process is being consumed.

At the end of the smelting process the average temperature of the bath is around 1500^0C.

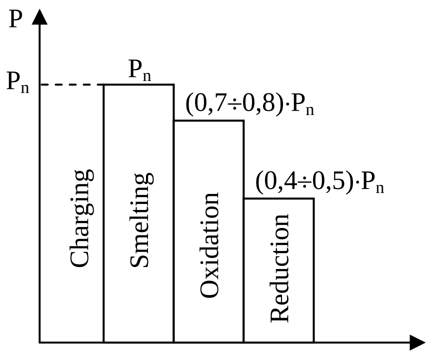


Fig.1 The stages of steel elaboration in an electric arc

The oxidation process (refining) is characterized by the fact that the electric arc is stable; the temperature of the metal 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 $(0.4\div 0.58)\cdot P_n$.

The electric arc is attached to the cathode by a relatively small area called cathode spot, the arc column reaching the metallic bath (Fig.2).

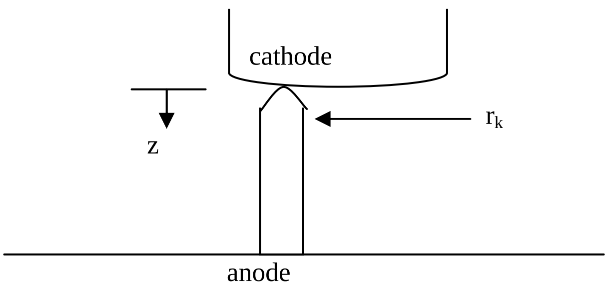


Fig.2

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 volume of the electric arc with respect to the distance z between the cathode and the metal bath. 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];

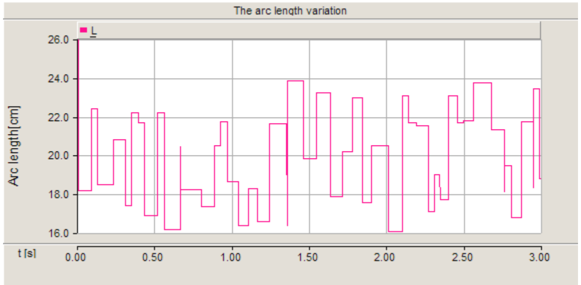
z – the axial distance between the cathode and the metal bath, [cm].

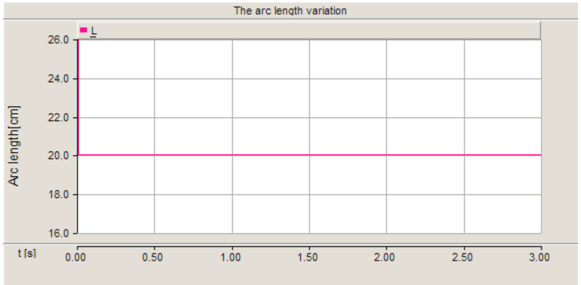
Calculations lead to a relation connecting the voltage of the electric arc and its length to the current:

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

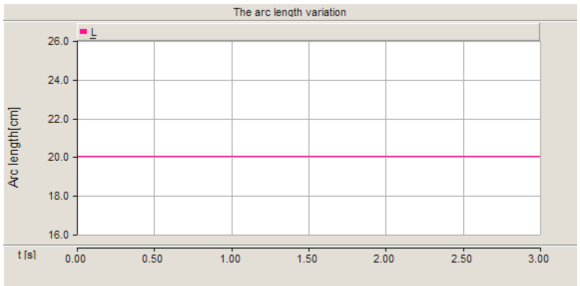
where: $a = 3{,}2 \cdot r_k$, $b = -2{,}2 \cdot r_k$, $m = \frac{-1}{r_k}$, $r_k = \sqrt{\frac{I}{\pi \cdot 3500\left(A/cm^2\right)}}$.

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





a) b)



c)

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

Figure 3 shows the variation shapes of the electric arc length in the stages of smelting, refining and reduction. The average length of the electric arc is l = 20 cm [3]. During the process of smelting the arc length and implicitly its resistance vary randomly with a frequency ranging between 0 ÷ 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 4.1 has been used. Fig.4 shows the simulation diagram that was created.

The electric arc furnace belongs to the 1st 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.

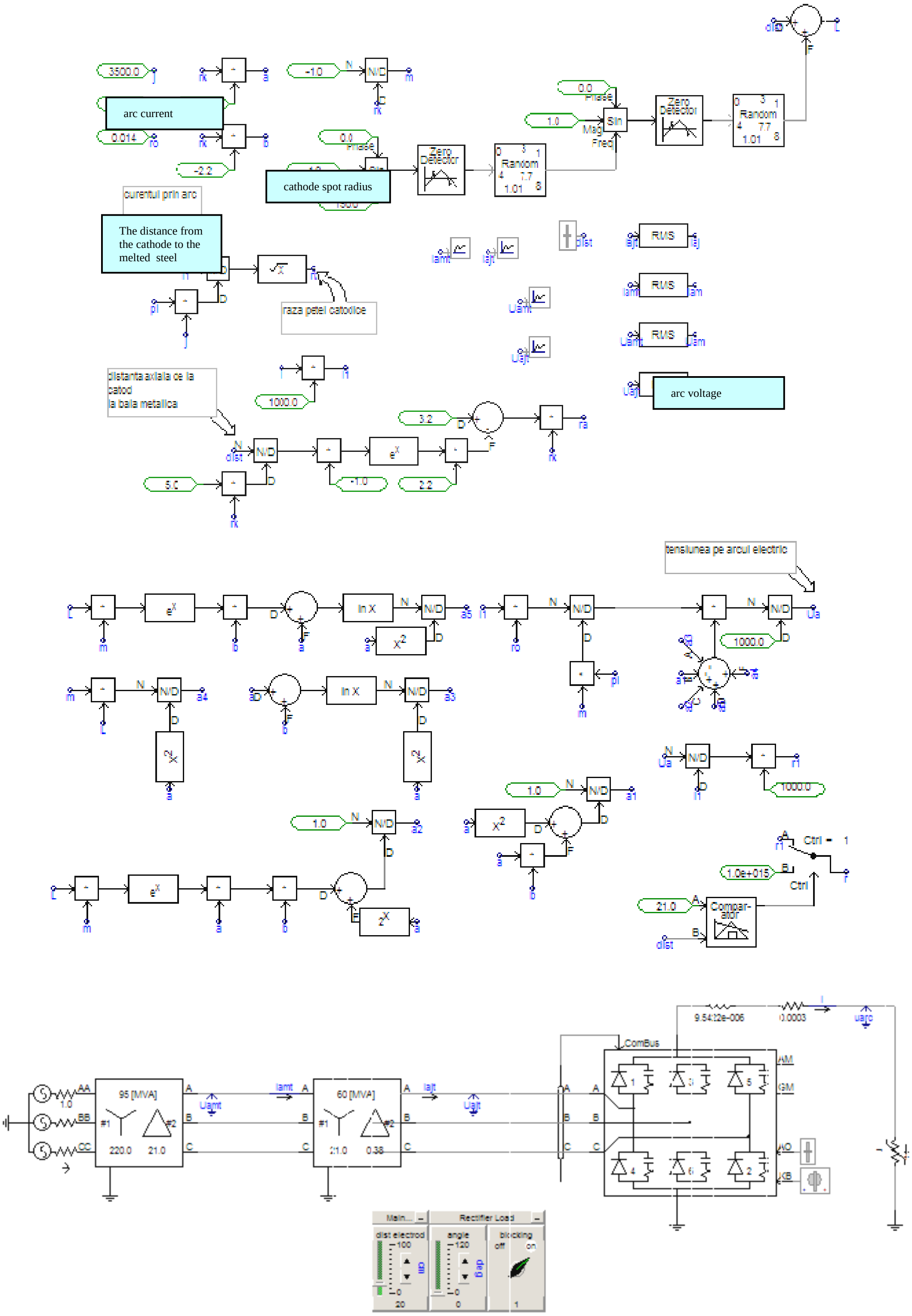
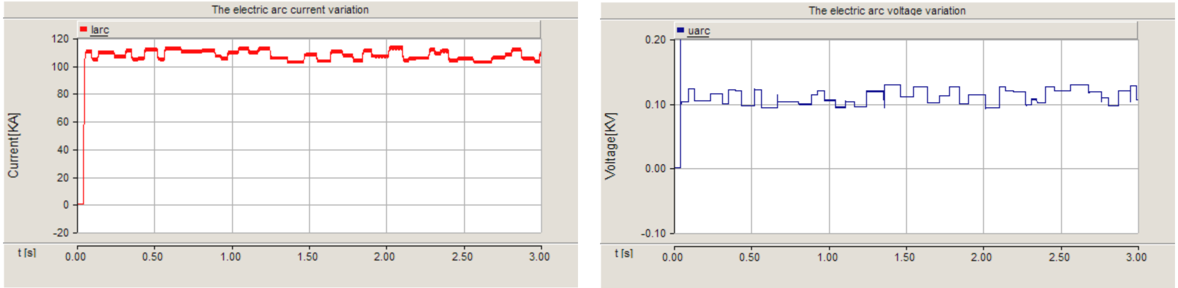
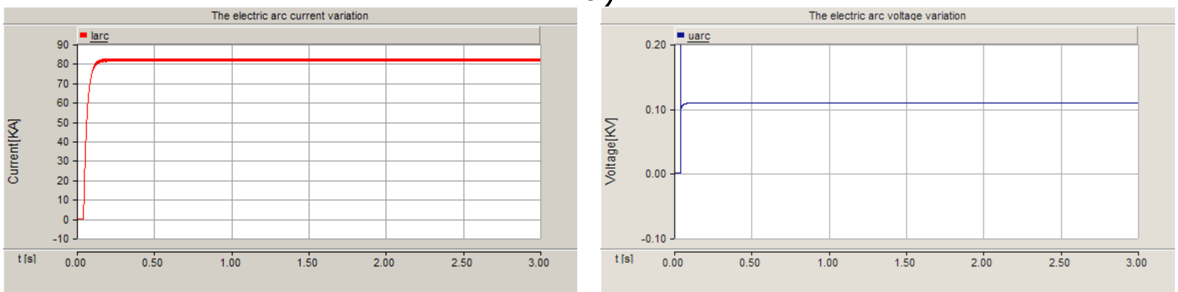


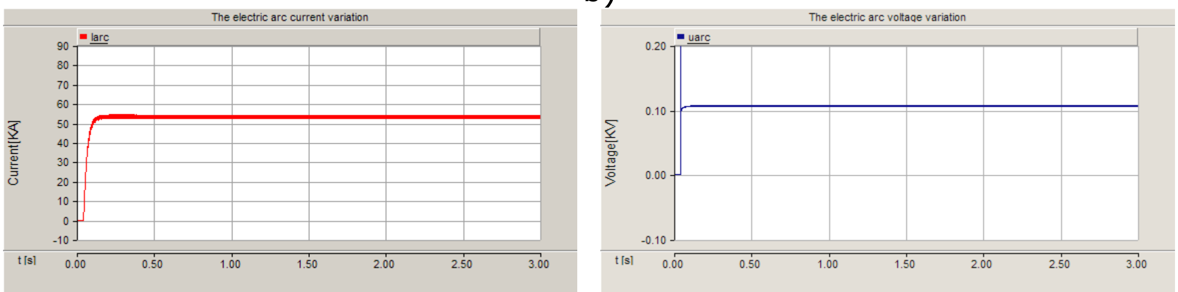
Fig.4 The simulation diagram



a)



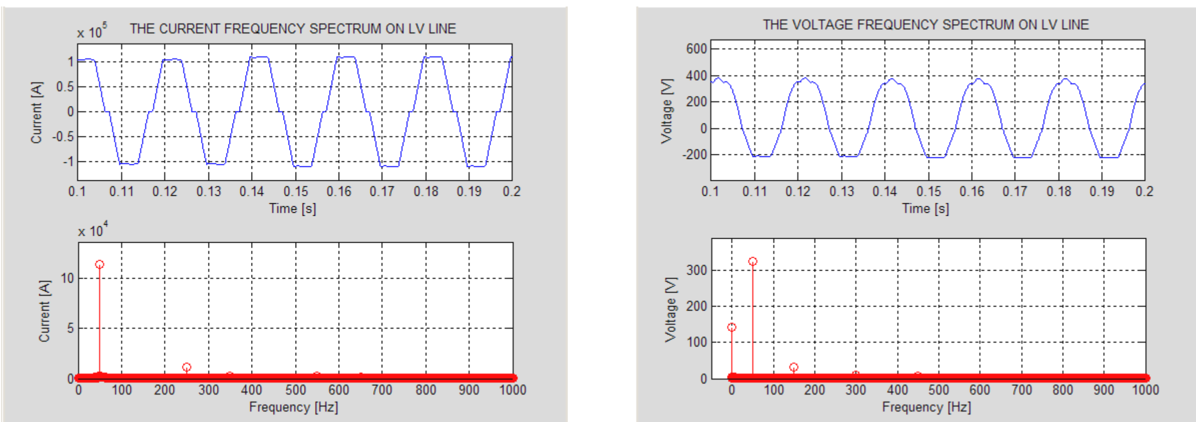
b)



c)

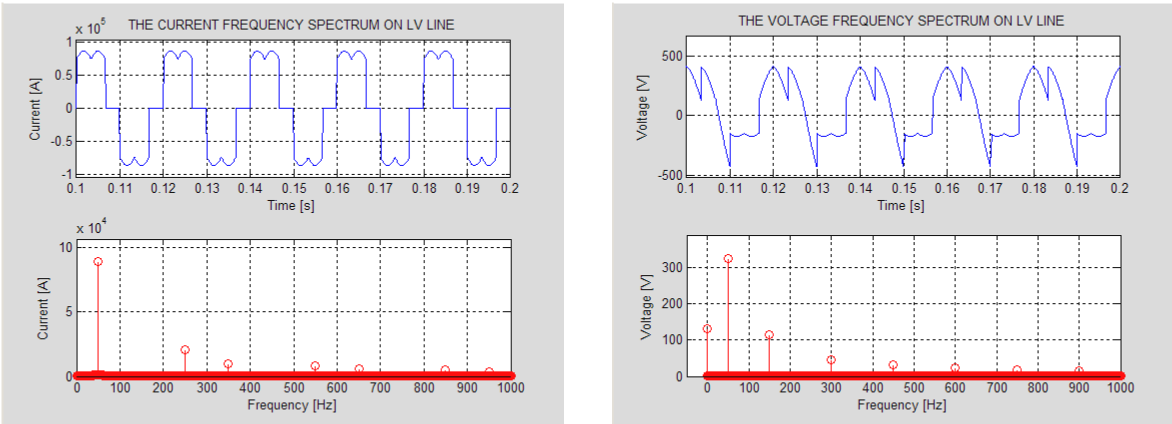
Fig.5 The variation of the current and voltage of the electric arc during the stages of: a) smelting; b) refining; c) reduction

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



THD = 10,137% Y_d = 11590,749 A THD = 40,9757% Y_d = 145,2917 V

Fig.6 The voltage and current frequency spectrum during the smelting stage on the JT line



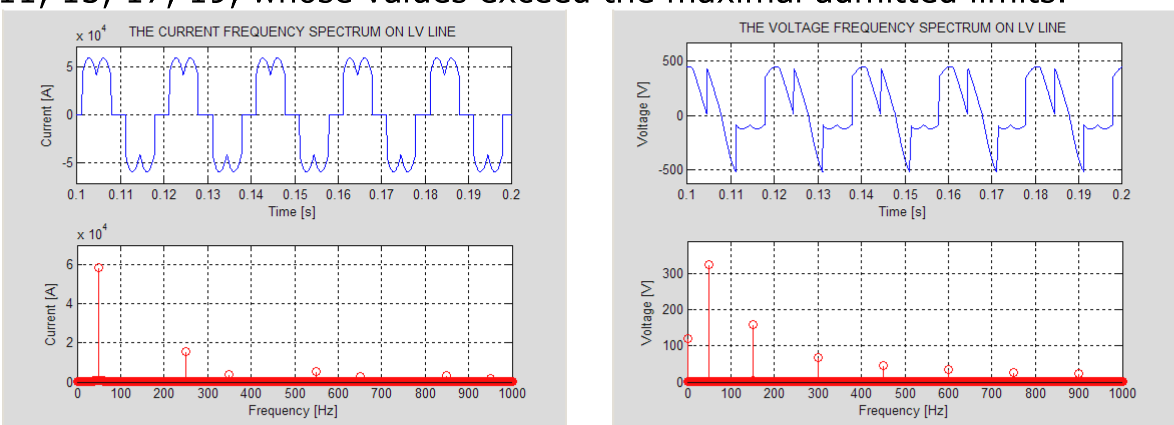
THD = 28,0481% Y_d = 25951,4773 A THD = 49,9998% Y_d = 186,5558 V

Fig.7 The voltage and current frequency spectrum
during the refining stage on the JT 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 of harmonics 3, 9, 15 and 18 in the voltage spectrum exceed the limit levels of compatibility. In the current spectrum on the JT line, harmonic 5 with a content related to the fundamental of 9,6248% exceeds the maximal admitted value.

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 JT line contains harmonics 0, 3, 6, 9, 12, 15 and 18 (Fig.7), all of which exceed the limit compatibility levels.

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



THD = 29,0364% Y_d = 17669,3544 A THD = 56,6584% Y_d = 223,1912 V

Fig.8 The voltage and current frequency spectrum
during the reduction stage on the JT line

During the reduction stage, in order to have a power $P = (0.4 \div 0.5) \cdot P_n$, the converter has to work at a command angle of $\alpha = 80^0$. Because of the fact that the command angle has a high value, the pollution with higher order harmonics of the feeding network is maximal. The voltage frequency spectrum on the JT line (Fig.8) reveals the fact that this is greatly deformed, as it 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 JT line the harmonics of ranks 5, 7, 11, 13, 17, 19 are prevailing, their values exceeding the standardized maximal limits.

4. THE CONTROL OF THE STEEL ELABORATION PROCESS

The process of charge elaboration in the DC electric arc furnace implies the regulation of the power dissipated in the smelting, which, on principle, can be achieved by two basic procedures:

- the modification, by means of the controlled converter, of the electric arc feeding voltage;
- the modification of the electric arc length.

A very important characteristic is that the higher the command angle of the converter, the higher the electromagnetic pollution.

As in the case of the AC arc furnace, in order to dim out the negative effects upon the feeding network, the installation includes an automatic filter for the harmonics, which improves the power factor. Although the charge is a one-phase type, the converter makes it unnecessary to have a device of charge balancing.

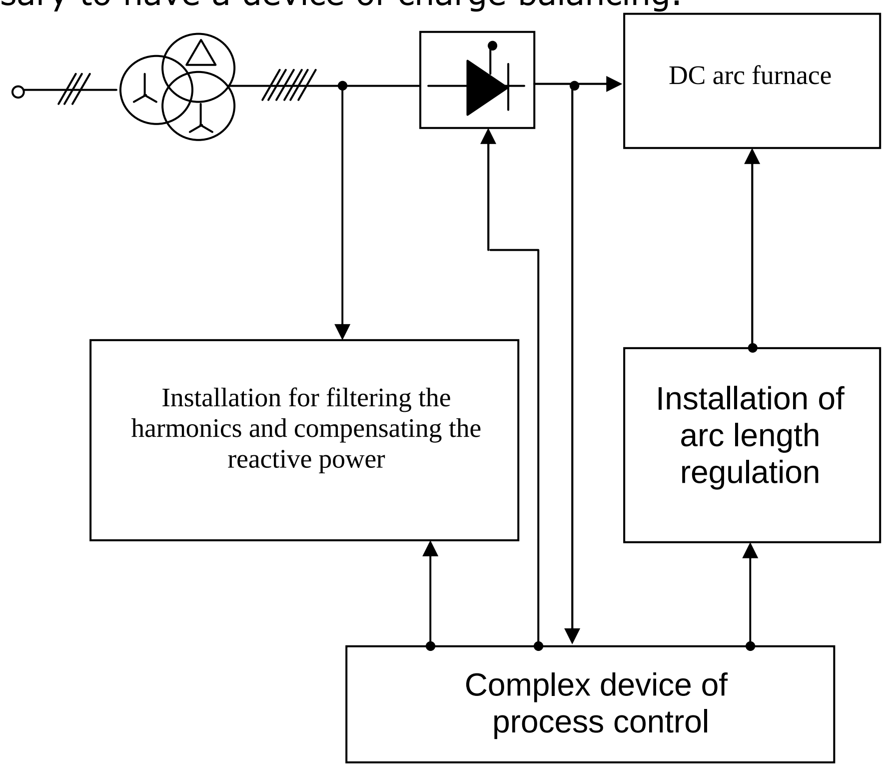


Fig.9

The previous modeling has lead to the conclusion that the power discharged by the DC arc is a monotonously increasing function of the switch off voltage, which, in its turn, linearly depends on the arc length. We suggested an iterative algorithm for the regulation of the arc length, according to the desired power. If, for iteration n, the arc length is l(n) and power P(n), the arc length for iteration n+1will be given by the relation:

$$l(n+1) = l(n) + \alpha \cdot e(n), \quad (4)$$

where:

$$e(n) = P_0 - P_n, \quad (5)$$

represents the error which the desired power Po is obtained for, at iteration n, and α represents an adaptation factor. This algorithm is known as LMS, or the algorithm of the stochastic gradient which, due to its simplicity, is largely used in actual systems.

Taking into consideration that a correction of the power dissipated by the arc can be made by modifying its feeding voltage, we suggest the following strategy:

- for errors under 20%, the power shall be corrected by modifying the command angle of the converter;
- for errors above 20%, a first correction shall be done by modifying the arc length, after which the voltage shall be corrected.

We elaborated all the algorithms for the correction of power, as well as of controlling the process of filtering the harmonics and compensation of the power factor.

6. CONCLUSIONS

The paper analyzes by simulation the performances of the system of steel smelting 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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