MODELING, SIMULATING AND EXPERIMENTAL VALIDATION OF THE AC ELECTRIC ARC IN THE CIRCUIT OF THREE-PHASE ELECTRIC ARC FURNACES

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Abstract

In this paper, was performed a study regarding the modeling and simulating the electric arc in the electrical installation of the electric arc furnace. The electric arc is a nonlinear element and from this reason it give rise to negative effects on the electric power quality, especially in case of the UHP electric arc furnaces. In this paper are presented the measurement results made on the UHP electric arc furnace on an industrial plant in Romania. This measurement demonstrates the negative effects of the nonlinearity of the electric arc in the electric supply. For the purpose to make a study for improving the electric power quality it was necessary to find a model of the electric arc, model that approximate the nonlinearity of the electric arc. It was analyze by simulation several models of the electric arc. All the simulation was performed using the PSCAD EMTDC simulation program. The simulation results were compared with the measurements made on the industrial plant with a view to validate the electric arc model. Following these comparisons it was selected the most appropriate model for the real electric arc. For this purpose it was analyze several quantitative and qualitative parameters both in the real installation and in the simulating installation. It was compared the waveforms of the three phase arc currents and voltages, the electric powers in distorting work condition and the total harmonics distortions, THD, of the currents and voltages.

Keywords: electric arc modeling, simulation, PSCAD EMTDC program.

Presenting Author's biography

Manuela Pănoiu was born in 1965, graduate the Computer Science Faculty, Polytechnic University of Timisoara in 1989. She receives his PhD degree in Electrical Engineering in 2001 and is currently Assistant Professor at the Electrotechnical Department of Engineering Faculty of Hunedoara, Polytechnic University of Timisoara, Romania. His research interests focus on advanced computer programming, modeling and simulating systems, and artificial intelligence.

1 Introduction

The functional analysis of electric circuits including an AC electric arc involves the use of techniques of modeling the electric arc that should reflect as closely as possible the behavior of the real electric arc. This can be done by means of general programs for non-linear circuits, or programs that are specific for a more restricted domain. In this paper, the modeling of the functioning of the electrical installation of the electric arc furnace was done using the PSCAD-EMTDC simulation program [24]. PSCAD (Power System Computer Aided Design) is a multi-purpose graphical user interface capable of supporting a variety of power system simulation programs. This release supports only EMTDC (Electro-Magnetic Transients in DC Systems). The modeling approach adopted in the paper is graphical, as opposed to mathematical models embedded in code using a high-level computer language.

2 Characteristics of the AC electric arc

During the burning of the AC electric arc, the equivalent diagram of the supplying circuit can be represented as shown in figure 1, where r and L represent the resistance, respectively the equivalent inductance of the supplying circuit, and R_A and u_A the resistance of the electric arc, respectively the arc voltage [1].

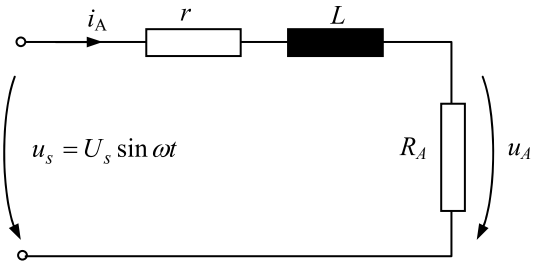

Fig. 1 The equivalent scheme of the supplying circuit of the AC electric arc.

The variation curves of the electrical issues from the equivalent scheme of the supplying circuit are presented in figure 2. Analyzing the variation curves, we obtained the following conclusions: after electric arc ignition, the arc voltage u_A is practically constant and because the current is variable, the electric arc can be considered as a non-linear receiver; the arc voltage u_A and the current i_A from the circuit are in the same phase, which means that the electric arc has a resistive character; the electric current in the circuit passes through zero twice, in each period of the alternating voltage applied, which leads to the going out and re-ignition of the arc with a frequency that is double as compared to the voltage applied; the ignition voltage U_{ig} of the electric arc is higher than the work value U_A; the AC electric arc has a rectifying character [1], [9]. That mean if there is a discharge between an electrode (usually made of graphite) and the metal to be heated up, due to the different thermal - physical properties of the two materials, (the temperature of the graphite electrode is higher than that of the material to be processed), the arc ignition voltage in the half-period where the metal represents the cathode is higher than the arc ignition voltage in the half-period when the cathode represents the graphite electrode, i.e. $U_{ig}^{+} > | U_{ig}^{-} |$. Similarly, for the drop voltage in the two half-periods, relation $U_d^{+} > | U_d^{-} |$ stands. For this reason, the amplitude of the current in the two half-periods differs, namely it is higher in the half-period when the graphite electrode is the cathode.

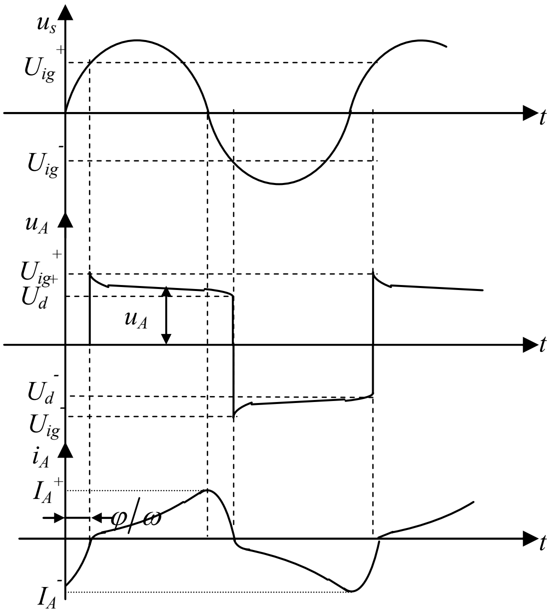

Fig. 2. The variation curves of current and voltages.

In figure 3 is show the dynamic characteristic of the AC electric arc, characteristic obtained according to the variation curves of $u_A(t)$ and $i_A(t)$ given in figure 2. The rectifying character of the electric arc is present because the magnitude of the ignition and drop voltage is different in the two half-periods.

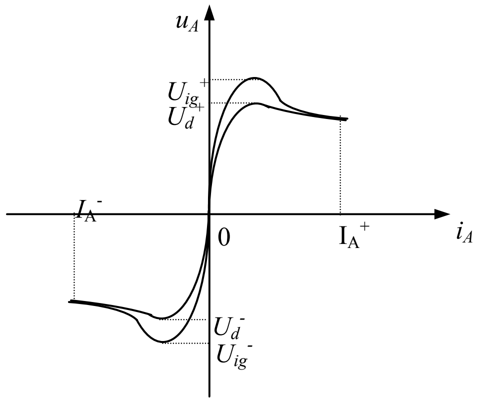

Fig. 3. The dynamic characteristic of the AC electric arc

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The burning of the electric arc can take place under the conditions of *interrupted current* or *uninterrupted current*. The burning under conditions of interrupted current leads to its unstable working and the current curve is highly distorted. For this reason it is necessary for the electric arc to burn uninterruptedly. The condition of uninterrupted burning of the arc, under the simplifying hypotheses that $U_{ig}^{+} \cong \left|U_{ig}^{-}\right| \cong U_{th}^{+} \cong \left|U_{th}^{-}\right| \cong U_A$ and the feeding voltage is sinusoidal $u_s(t) = U_s \cdot \sin \omega t$ is given by

$$U_s \cdot \sin \varphi \geq U_A \quad (1)$$

this leads to

$$\frac{U_A}{U_s} \leq \sqrt{\frac{1}{1+\frac{\pi^2}{4}}} = 0{,}54\,, \quad (2)$$

resulting that in order to have an uninterrupted current, the electrical installation must work under a natural power factor

$$\cos \varphi \leq 0{,}85\,. \quad (3)$$

3 Models of the electric arc

The models of electric arc supplied to AC voltage, given in the reference literature, can be grouped in several categories [2]-[19]. These categories of models include:

- Models using non-linear and time-variable resistances;
- Models based on empirical relations between the diameter or length of the arc, the voltage respectively the current through the arc
- Models using the current-voltage characteristic of the electric arc;
- Models using power sources meant to replace the voltage of the electric arc;
- Models using chaos theory.

The authors have analyzed the main models of electric arc from the reference literature and have come to important conclusions related to the validity of each model, the way of implementing it and the results of computer simulation of the behavior of arc-ovens. In order to be able to obtained comparative conclusions as to the performances of the models under consideration, all the models were implemented on the same electric installation, most often given in the reference literature [5], [8]. The typical installation under consideration is fed from the high voltage bars IT through a three-phase transformer 220/21 KV having the power of 95 MVA, and from the medium voltage bars MT through a three-phase transformer 21/0,4-0,9 KV having the power of 60 MVA. The electric resistance on each phase of the short network is 0,3 $m\Omega$, and the electric reactance on each phase of the short network is 3 $m\Omega$. In order to allow a comparison between the models under consideration, in all the simulations the power of the electric arc was chose 25,4 MW, consist in the power transferred to the metal bath and the power loss on the electric arc, proportional to the surface of the hysteresis curve of the current-voltage characteristic. The usual mean value of the amplitude of the electric arc voltage is 200 V. If the electric arc voltage has a rectangular shape, the effective value will be equal to the amplitude, according to relation:

$$U_{Aef} = U_A = 200\,\mathrm{V} \quad (4)$$

The mean value of the electric arc resistance along one phase is

$$R_A = R_m = \frac{3U_A^2}{P} = 4{,}72\,\mathrm{m}\Omega\,. \quad (5)$$

An important problem that has to be solved by a model is the possibility of controlling the power of the electric arc. A generally valid solution, irrespective of the model used for the electric arc, may be the modification of the effective value of the voltage supplied by the secondary of the medium voltage transformer. Relation (5) points out two possibilities of controlling the electric arc power, the modification of the amplitude of the electric arc voltage and the modification of the mean value of the equivalent resistance of the electric arc. In this way, the authors managed to perform a first checking of the implementation of the models, comparing the results they obtained, with those given in reference literature. The authors have implement 4 models of the electric arc using PSCAD EMTDC simulation program and the results of the simulation are published by the authors in a previous paper [2], [3]. These models are presented shortly in the next section.

3.1 The model based on the variation of the electric arc resistance

During the normal functioning, the resistance of the arc changes, producing voltage fluctuations at the point of common coupling (PCC). The model is based on the hypothesis that this variation can be considered as having a Gauss-type distribution, the values of the resistance for the electric arc being centered on a mean value [8]. The basic idea of this model are that for each transition through zero of the current of a phase, a new value of the electric arc resistance for that particular phase is being generated. In order to generate Gauss-distributed values for the electric arc resistance, one can use two methods. One first method is given in [8]. In this method, the resistance of the arc is given by the relation:

$$R_A = R_{med} + \sigma_R \cdot \sqrt{-2\ln(rand1)} \cdot \cos(2\pi \cdot rand2) \quad (6)$$

where *rand1* and *rand2* are two numbers with uniformly distributed along interval [0,1], automatically generated at each zero crossing of the arc current, R_m are the mean value of the electric arc resistance, and σ_R the dispersion of its values. The simulations we carried out using this model and the values given before for the parameters of the electric installation allowed us to obtain the waveforms of the electric arc current and voltage for one phase, as well as the resistance of the electric arc. A second way of obtaining Gauss-distributed values for the electric arc resistance was given in [4] and uses *the Box Mueller* transform. According to it, relation (7) gives the resistance of the electric arc:

$$R_A = R_{med} + \sigma_R \cdot \sqrt{-\ln(rand1)} \cdot \left(\cos(2\pi \cdot rand2) + \sin(2\pi \cdot rand2)\right), \qquad (7)$$

in which *rand1, rand2*, R_{med} and σ_R have the same meaning as in the previous variant.

The simulations we carried out have lead to similar results both in terms of current shape and the electric arc voltage, as resulting from the comparison of the results obtained by simulation and given in figures 4 and 5**.**

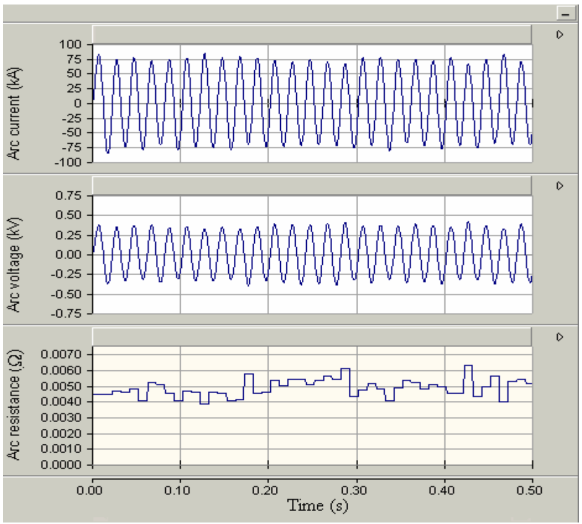

Fig. 4. The variation of the arc current, voltage and resistance according to relation (6)

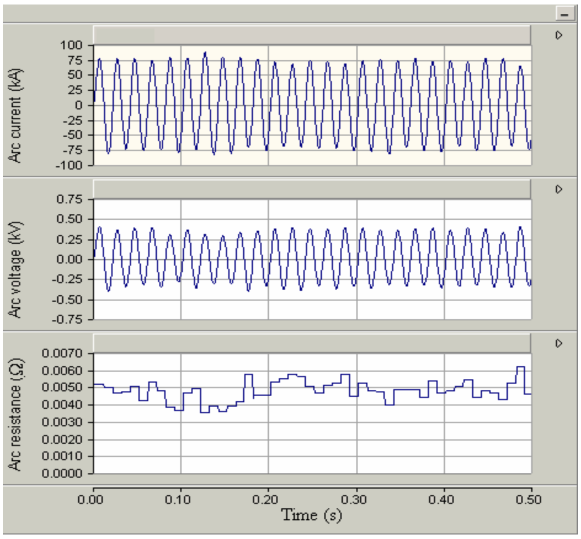

Fig. 5. The variation of the arc current, voltage and resistance according to relation (7)

We also noticed that both the current-voltage and spectral characteristics of the electric arc current and voltage obtained, but not presented in this paper are practically identical. We realized that this model can be easily implemented, but has as disadvantages the fact that the characteristic current-voltage we obtained does not reflect the real characteristic as well as the fact that in the spectrum of the current and voltage the fundamental harmonic is predominant. As a conclusion, one can say that the use of this model confers a resistive character to the electric arc and modifying the mean value of the electric arc resistance can do the control of its power.

3.2 The model based on the variation of the amplitude of the electric arc voltage

As it is known, the voltage of the electric arc mainly depends on the length of the arc. After the electric arc ignition, the electrode position control system moves them, which modifies the length of the electric arc. In this way, it can be obtain an optimal length of the electric arc, but also an optimal voltage of the arc, which leads to a stable arc. As the power of the electric arc depends on the amplitude of the arc voltage, it results that controlling the position of the electrodes lies to the control of the power of the electric arc. Because of the time limitations related to the control of electrode position with respect to the length of the electric arc, there is a fluctuation of the voltage of the electric arc. Statistic studies showed that the time distribution of the amplitude of the electric arc voltage is Gauss-type, supposing there is no mechanic resonance.

The model based on the variation of the voltage amplitude of the electric arc given in [8] considers that this variation has a Gauss-type variation, the values of voltage amplitude of the electric arc being also centered on a mean value. The basic idea of this model consists in the fact that at each passage through zero of the electric arc voltage value, a new value for the amplitude of the electric arc voltage is being generated for the respective phase. As for the previous model, the generation of values with Gauss-type distribution, using evenly distributed values can be done by means of the two methods given hereinafter.

a) The first means of variation of the voltage amplitude of the electric arc, given in [8], implies the generation of a new value for the voltage amplitude of the electric arc, according to relation

$$U_A = U_{med} + \sigma_U \cdot \sqrt{-2\ln(rand1)} \cdot \cos(2\pi \cdot rand2), \qquad (8)$$

where *rand1,rand2* represent two numbers with even distribution along the interval [0,1], U_{med} represents the mean value of the voltage amplitude of the electric arc and σ_U the dispersion of its values.

b) The second means of obtaining a Gauss-type noise with a null mean, given in [4] uses *the Box Mueller transformation.* According to it, the relation (9) gives the voltage amplitude of the arc

$$U_A = U_{med} + \sigma_U \cdot \sqrt{-\ln(rand1)} \cdot \left(\cos(2\pi \cdot rand2) + \sin(2\pi \cdot rand2)\right), \qquad (9)$$

where *rand1, rand2*, U_{med} and σ_U have the same significance as in the previous variant.
The simulations we carried out, given in figures 6 and 7, have led to similar results, both in terms of current and electric arc voltage shape, as well as in terms of the current-voltage characteristic, and the spectral characteristic of the electric arc current and voltage.

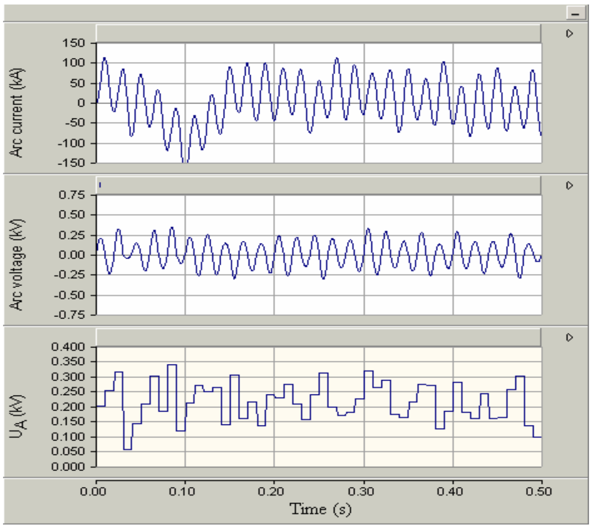

Fig. 6. The variation of the arc current, voltage and resistance according to relation (8)

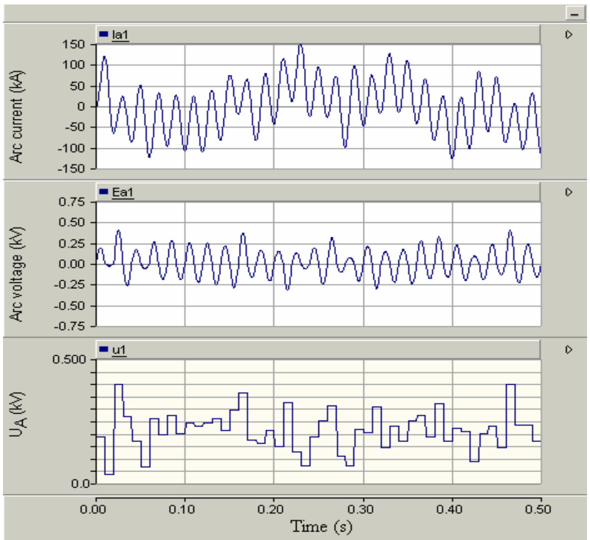

Fig. 7. The variation of the arc current, voltage and resistance according to relation (9).

As a result of the simulations we carried out, we came to the result that in this model too we find the advantage that it is easy to implement, the correction of the electric arc power being done by modifying the mean value of the electric arc voltage amplitude, but it has the disadvantage of giving a current-voltage characteristic that does not emulate the real characteristic, as well as the fact that in the spectrum of the current and voltage the fundamental harmonic is dominant, as its amplitude is much higher than that of all the other harmonics.

3.3 The model based on the use of the electric arc current-voltage characteristic

This model of the AC electric arc, given in [4], is based on linear approximation of the real characteristic current-voltage, typical for the electric arc. Also, the particularity of this simulation technique consists in the fact that the parameters of the model depend on the power of the charge and therefore the model parameters depend on the work conditions.
As the model uses the power absorbed by the electric arc furnace as an input, it results that the model allows the modification of the characteristic current-voltage, so that the power absorbed can be the one we want to be used by the charge circuit. The principle according to which the model under consideration takes into account the active power absorbed by the circuit is based on the fact that the area of the current-voltage characteristic represents the active power absorbed. In figure 8 is presented the typical dynamic characteristic and the linearized approximation of the current-voltage characteristic of the AC electric arc.

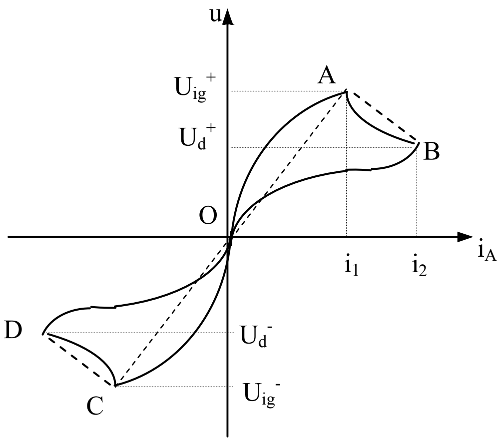

Fig. 8. The real and linearized characteristic of the electric arc

The leveled approximation of the current-voltage characteristic can be defined in the first quadrant by the equation:

$$u = \begin{cases} i \cdot R_1 & 0 \le i \le i_1 \\ i \cdot R_2 + U_{ig} \cdot \left(1 - \frac{R_2}{R_1}\right) & i_1 < i \le i_2 \end{cases} , \quad (10)$$

where $i_1 = \frac{U_{ig}}{R_1}$, (11.a)

$$i_2 = \frac{U_{ig}}{R_2} - U_d \cdot \left(\frac{1}{R_2} - \frac{1}{R_1}\right). \quad (11.b)$$

Values i_1 respectively i_2 correspond to the ignition voltage, U_{ig}, respectively the drop voltage, U_d, of the electric arc and R_1 and R_2 represent the slopes of segments OA respectively AB.
In view of using the equation (10) for the negative half period of the feeding voltage too, it can be rewritten taking into consideration the fact that the values of currents i_1 respectively i_2 are negative. As the power

absorbed by the electric arc is equal to the area included under the current-voltage characteristic, the resistance of the arc along the segment OA can be calculated according to the relation

$$R_1 = \frac{U_{ig}^2}{\left(P + \frac{U_{ig}^2}{R_2} - \frac{U_d^2}{R_2}\right)} \quad (12)$$

where P represents the power dissipated within the electric arc.

The simulation of the rectifying character of the electric arc using this model can be done by choosing different values for the ignition, respectively drop voltage, along the two half-periods. Under these circumstances, in order that the power dissipated on the electric arc be the same for the two half-periods, it is important that parameter R_1 be calculated for each half-period. In the simulations carried out by means of this model we used for the ignition, respectively cut-off voltage values that were equal for both half-periods, $U_{ig}^+ = \left|U_{ig}^-\right| = 240$ V and $U_d^+ = \left|U_d^-\right| = 200$ V.

The value of parameter R_2 was chosen according to the data given in reference literature $R_2 = -0{,}0007272$; it is negative as segment *AB* has a negative gradient [4]. The value of parameter R_1 is to be calculated according to relation (12), the power dissipated by the electric arc being $P = 25{,}4$ MW.

After having carried out the simulations given in figure 9 the authors came to the conclusion that this arc model, based on a linear characteristic of the electric arc is characterized by:

- The obtained current-voltage characteristic is a replica of the shape given in figure 3.
- The characteristic of the electric arc, through parameters R_1 and R_2 depends on the power dissipated in the electric arc. It results that this model allows the simulation of the functioning of the furnace electric installation within a wide range of dissipated powers, the correction of the electric arc power being done according to relation (12).
- Within the current range, one can notice the presence of harmonics of 5^{th},7^{th},11^{th} and 13^{th} order, which corresponds to reality [2], [6], and [14].

As to the distortions of the current and voltage curves, the authors noticed the following:

- The voltage curve is most distorted on the low voltage line and least distorted on the high voltage line;
- The current distortion is lower than that of the voltage on the low voltage feed, both from the standpoint of the total harmonic distortion and from the pondered one;
- On the medium and high voltage feed, the voltage curve is less distorted than that of the current.

From the standpoint of the powers and power factors under non-sinusoidal work conditions, on each of the three feeding lines obtained by means of this model of the electric arc the authors noticed that:

- The active power obtained on the three feeding lines has approximate the same values, the highest value being touched on the high voltage line and the lowest on the low voltage line;
- The low value of reactive power on the electric arc, as compared to the one obtained on the low voltage line suggests the fact that this model allows the simulation of a highly resistive character of the electric arc. This difference can be explained by the fact that the reactance value on each phase of the low voltage line ($3\ m\Omega$) is comparable to the value of the total resistance on each phase ($5{,}02\ m\Omega$). On the medium and high voltage lines we can obtain higher values of the reactive value, because of the furnace transformer, which shows the necessity of using a compensation system for the reactive power;
- The deforming effect is most significant on the low voltage line, which can be proved by the much higher value of the deforming factor.

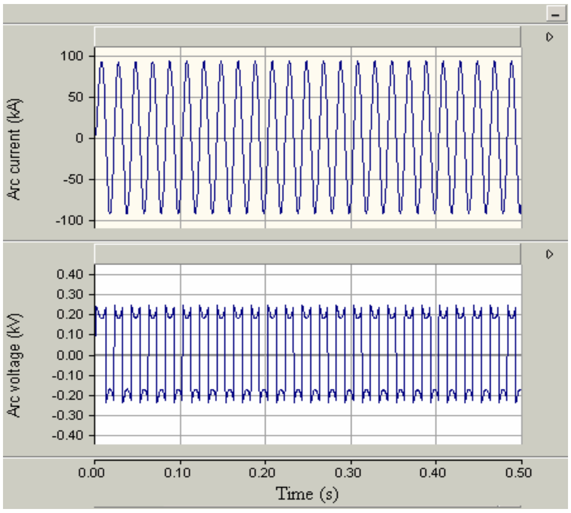

Fig. 9. The variation of arc current and voltage according to relations (10) and (11).

3.4 The model based on the relations between the length of the arc, the voltage and current in the arc

This model, given in [5] and in [10], considers the characteristic current-voltage described by relation

$$U_A = U_A(I_A), \quad (13)$$

that can also be written as

$$U_A = U_d + \frac{C}{D + I_A}. \quad (14)$$

In relation (14), U_A and I_A represent the voltage and current of the electric arc, U_d is the drop voltage towards which the voltage tends as the current increases. Constants C and D determine the difference between the sectors of the characteristic where the current increases or decreases (C_a and D_a, respectively C_b and D_b). The value of the ignition voltage is obtained for $I_A=0$ and is given by relation

$$U_{ig} = U_d + \frac{C}{D}. \quad (15)$$

The typical values given in [3], [5] and [10]: U_{st} = 200 V, C_a = 190000 W, C_b = 39000 W, D_a = D_b = 5000 A.

According to the above, the use of this model does not allow the control of the active power of the electric arc, but the authors will demonstrate that the correction of the electric arc power can be done within loose limits using this model by modifying the drop voltage, which corresponds in practice to the modification of the distance between the electrodes and the metal bath. The analysis of the results we obtained by using this electric arc model was done in two stages: the determination of the model performances considering the cut-off voltage a constant, U_d = 200 V; the demonstration of the fact that one can correct the power of the electric arc by modifying the value of the drop voltage. According to the time variation of the length of the electric arc, the dynamic characteristic current-voltage can be a constant or a variable with respect to time, which has an impact upon the model to be chosen. In [2] [3] was give the detailed result from the analyze of this model (the waveforms, voltage – current characteristic, the spectral characteristic of the arc current and voltage).

From the obtained results, in fig. 10 are show the variation shapes of the electric arc current and voltage obtained by using PSCAD EMTDC simulation program.

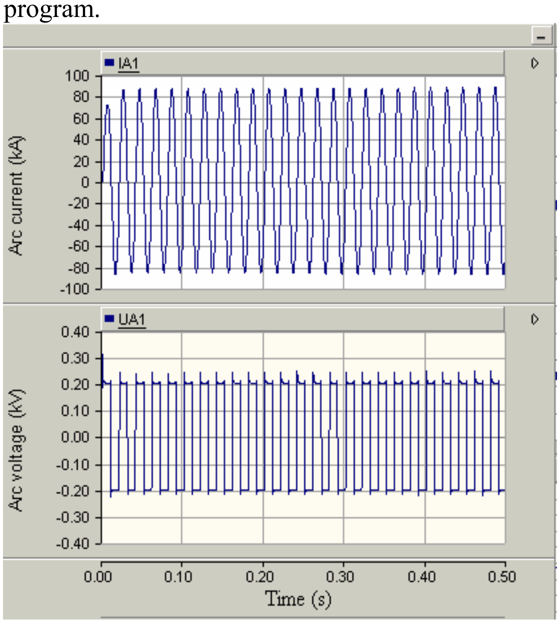

Fig. 10. The variation of the arc current and voltage.

This model are consider by authors the best model of the electric arc because their advantages: the possibility of obtaining the shapes of the real electric arc voltage and current curves and the characteristic current – voltage of the real electric arc; while the current frequency characteristic does not include harmonics of an multiple of 3 order, the voltage wave contains these harmonics on the low voltage line, as well as on the medium voltage one (but dimmed), like in real processes.

4 The experimental validation of the arc model

For the purpose of experimental validation of the arc model present in section 3.4, the authors was performed some measurement on an industrial plant. This model is considered by the authors the most appropriate model. The experiments were developed in the Electric Steel Plant No.2, S.C. Mittal Steel S.A. Hunedoara. Here is an UHP electric arc furnace with 100 tones capacity. The electric scheme for the measurement is show in fig. 11.

4.1 The measurements on the low voltage line

The measurements were made at a 3-phase power supply installation of a 3-phase EAF of 100t, to which were not connected the filters for the current harmonics, neither the load balancing device nor reactive power compensation.

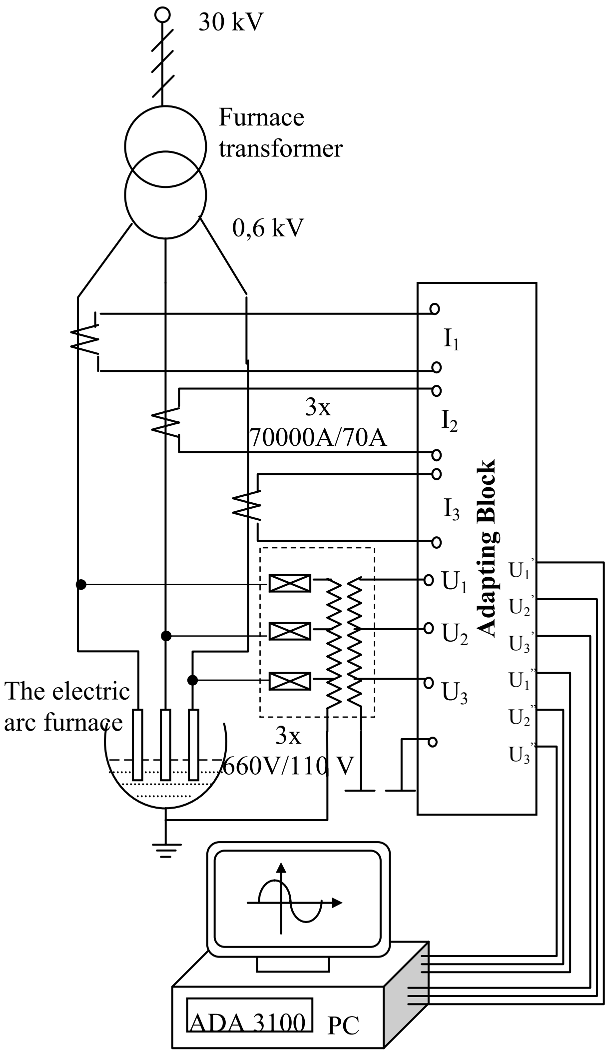

Fig. 11. The measure scheme

The modern methods of measuring the electric values are using numerical systems, based on data acquisition systems, and method presented in this paper are using such a system. It's been used a computer system with an ADA3100 data acquisition board.

The acquisition board allows the simultaneous acquisition of 3 currents and 3 voltages, for the low or medium voltage lines of the transformer which supplies the furnace. The data acquisition on the 6 channels was made as follows: during 250 ms have been acquired simultaneously the data on the 6 channels, the selected acquisition frequency being of 5 KHz. In this way, have been acquired the signals during 12,5 periods. This fact allowed that in case the frequency of the supply voltage is different of 50 Hz, the data should contain a number of 12 full periods, selectable by program; the data acquisition process was restarted, during 250 ms, at an interval of 9,75 seconds, interval during which were saved in memory the previously acquired data. In this way, results that have been acquired, on the entire duration of the heat, data in time windows of 250 ms length, the interval between two consecutive data windows being of 10 seconds.

As regards to the waveforms of the currents and voltages on the low voltage supply line, presented in fig. 12, is found a strong distortion of these. Also, one can notice that because the amplitudes of the currents and voltages on the 3 phases are unequal, results that the load is also unbalanced.

The spectral characteristics of the current and voltage were achieved by using a Matlab program by processing the data acquired by using the Fourier rapid transform, and are show in fig. 13.

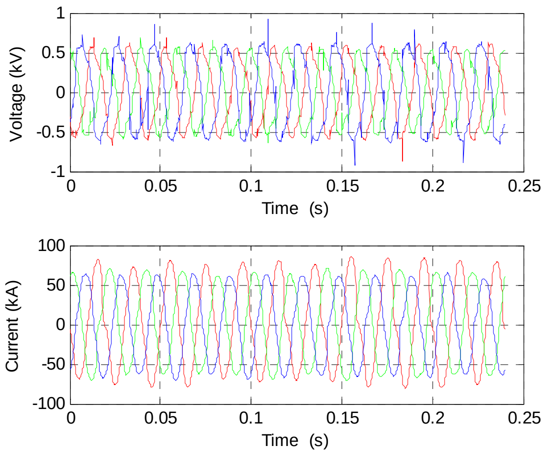

Fig. 12. The variation of measured voltages and currents for the three phases

For the comparison of the simulation results and the performed measurement it was made a simulation of the entire electric installation of the UHP electric arc furnace. For the simulation scheme it was consider the all the electric parameter of the real installation. Thus, the length of the section where the short network conductors are situated in the same plan is $l = 10\,\text{m}$, and the distance between the short network's conductors

$$d_{12} = d_{23} = d_1 = 1\,\text{m}, \quad d_{13} = d_{12} + d_{23} = 2\,\text{m}. \tag{16}$$

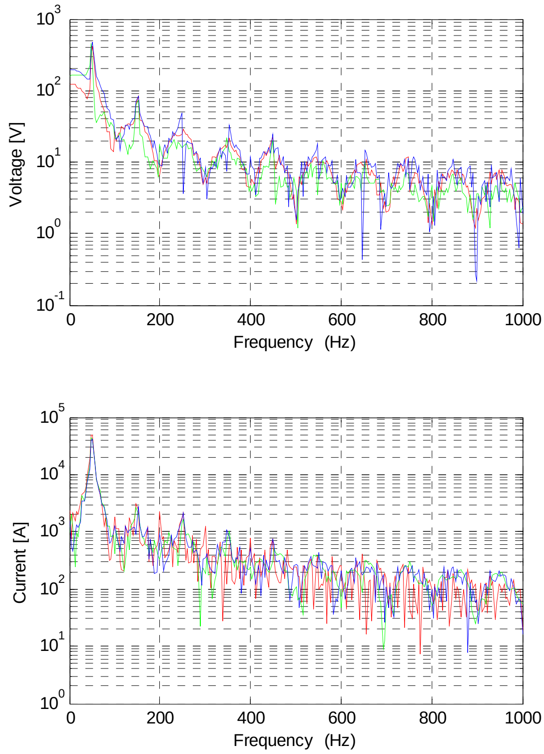

Fig. 13. The spectral characteristic of currents and voltages for measured data

With these values, the mutual inductivities between the phase conductors in the zone where these are in the same plan are

$$M_{12} = M_{23} = 4{,}1865\,\mu\text{H}, \quad M_{13} = 2{,}9853\,\mu\text{H}. \tag{17}$$

The values of the total resistances, on each phase

$$R_{r1} = 0{,}6908\,m\Omega, \quad R_{r2} = 0{,}3640\,m\Omega, \quad R_{r3} = 0{,}0372\,m\Omega, \tag{18}$$

as well as of the total inductivities

$$L_{r1} = L_{r3} = 9{,}5422\,\mu H, \quad L_{r2} = 8{,}9416\,\mu H. \tag{19}$$

Because the impedances of medium voltage supply line are small compared with the ones from the low voltage line, these were included in the EAF's transformer parameters. The values of the main parameters of the EAF's transformer are 73 MVA; 30KV/0,6kΔ/Y; Transformer's parameters LV - MV was identified based on the catalog data from the Medium Voltage Transformer Station: 100MVA; 110kV/30kV; Δ/Y. High voltage supply line's parameters used in case of simulations: the voltage from the high voltage line is of 110 kV, the high voltage supply line is considered symmetrical and the short-circuit power of the high voltage line is of 1100 MVA**.**

The selection of the values of the model's parameters was made in such way that the waveforms of the currents and voltages obtained following the simulation to correspond to the ones obtained following the measurements made on the real installation. In this purpose was analyzed the influence of each parameter which comes in the relation (14), finding the following:

The constants D_a and D_b have a small influence on the values of the amplitudes of the measured values as well as of the waveforms, finding that the values comprised between *2000 A* and *50000 A* do not modify the amplitude of the currents and voltages with more than *2%*, for the same values of the other parameters. From this reason, in the performed simulations the values of these constants were the ones mentioned in literature, $D_a = D_b = 5000\ A$ [2],[3],[5],[10].

The influence of constants C_a and C_b on the ignition voltage values is small.

In the performed simulations for these constants were taken the values from literature [2], [3], [5], [10], Ca = *190000 W,* respectively $C_b = 39000\ W$. In this way, for the same value of the extinction voltage the values of the ignition voltage on the two semi-alternances are different.

As regards the extinction voltage value used during the simulations, was found that this influences both the waveforms and the values of currents and voltages obtained by simulation. Was admitted $U_{th} = 200\ V$.

Based on these conclusions, combined with a great number of simulations, resulted that the value of the extinction voltage that allow the best reproduction of the results obtained following the measurements in the reduction phase is $U_{th} = 200\ V$**.**

4.2 The simulation results of the real installation

Following the measurements made on the EAF's real installation, was observed that its operation is featured by the presence of an unbalanced three-phase regime. The unbalance of the three – phase regime is due to the unequal values of total impedances of short network phases and due to unequal values of the electric arcs' lengths on the three phases. Analyzing the values obtained by simulation, presented in fig. 14, compared with the measured ones on the low level voltage line (substation transformer), is found that there is a good correspondence for the waveforms of the currents and voltages on the low level line feed. For a quantitative comparison it was calculate the main quality power indicators: *the active power, the reactive power* and *the total harmonic distortion for current and voltage*, specific to the non-sinusoidal, periodical work conditions, presented in table 1.

Tab. 1 The power quality factors (the active and reactive powers ad the total harmonic distortions)

	Measure values	Simulating values
P (MW)	48,63	47,36
Q (MVAR)	52,43	55,97
THDI (%)	10,83	8,44
THDU (%)	17,3	15,17

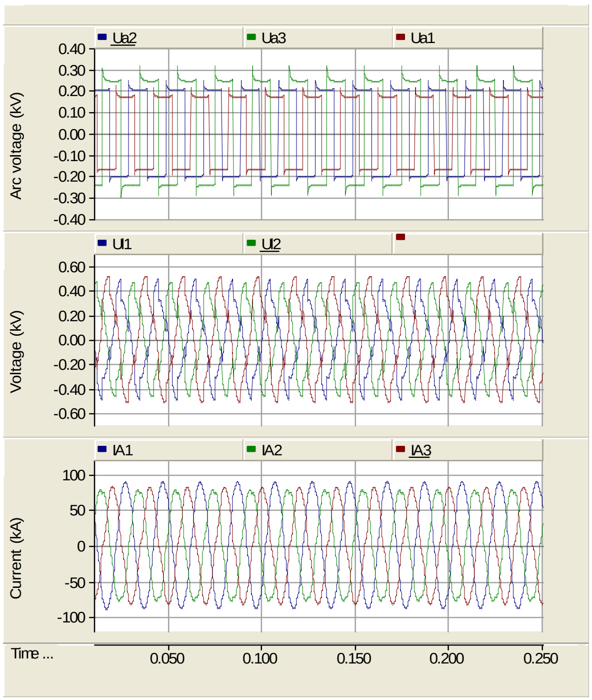

Fig. 14. The simulation result

5 Conclusion

By analyzing the 4 models it was possible to select one of them, consider by the authors the most appropriate for real electric arc simulations. Using this model a simulation for the electric arc installation on an industrial plant was done. It was made both qualitative and quantitative comparisons for the electrical parameters between the simulation results and the performed measurement. Following these comparisons it was observe that the model correspond with the real electric arc because permit the distorted work conditions simulating, the unbalanced load simulating and the presence of the reactive power simulating. Thus the model will be use for design of an complex installation for reactive power compensation, load balance and harmonics filters.

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