

About the Possibility of Power Controlling in the Three-Phase Electric Arc Furnaces Using PSCAD EMTDC Simulation Program

Manuela PANOIU¹, Caius PANOIU², Ioan SORA³, Mihaela OSACI⁴
Technical University of Timișoara, Engineering Faculty of Hunedoara,
str.Revolutiei nr. 5, cod Hunedoara, Romania

^{1,2}{m.panoiu, c.panoiu}@fih.utt.ro, ³sora@et.upt.ro, ⁴m.osaci@fih.upt.ro

Abstract—The electric arc is a nonlinear element. For this reason it must be used special techniques of modeling the electric arc that should reflect as closely as possible the behavior of the real electric arc. 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. The electric arc furnaces do not absorb sinusoidal currents and generally consume reactive power. These two phenomena produce some disturbances like the dysfunction of the equipment in the worst cases. It is perform a study of the possibilities of controlling the electric arc power, in order to obtained maximum of the active power and reducing the reactive and distorted power.

Index Terms— power control, reactive power, power system harmonics

I. THE AC ELECTRIC ARC MODELING

The AC electric arc is a nonlinear element. The variation curves of the electrical issues from the equivalent scheme of the supplying circuit are presented in figure 1. If we analyze 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 nonlinear element; 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 AC electric arc has a rectifying character.

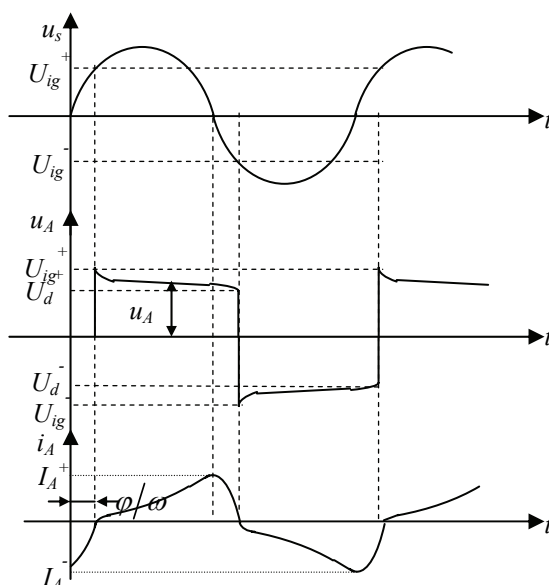


Figure 1. The variation curves of current and voltages

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The authors have analyzed the main models of electric arc from the reference literature [5] – [18] 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-furnaces. 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 [6], [9]. This 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, been composed by *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 according to [6], [8] and [11] of 200 V. Considering that the electric arc voltage has a rectangular shape, the effective value will be equal to the amplitude, according to relation:

$$U_{Aef} = U_A = 200 \text{ V} . \quad (1)$$

For this value, from relation (3) results that the minimum value of the amplitude of the phase voltage for which we have an uninterrupted current is $U_s \geq 370,37 \text{ V}$, value which corresponds to a minimal line voltage in the secondary of the medium voltage transformer of

$$U_{\min} = 453,6 \text{ V} , \quad (2)$$

which is in the range of values given by the secondary of the MT transformer.

Under these conditions, the mean value of the electric arc resistance along one phase is

$$R_A = R_{med} = \frac{3U_A^2}{P} = 4,72 \text{ m}\Omega . \quad (3)$$

One 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. There are 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. As further shown, these are not the only possibilities of controlling the electric arc power. The scheme of the electrical installation is presented in figure 2. 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. This results are present in a previous work of the authors [3]. From the studies models, it was select a model, consider the most appropriate. All simulations were carried out using the simulation program PSCAD-EMTDC.

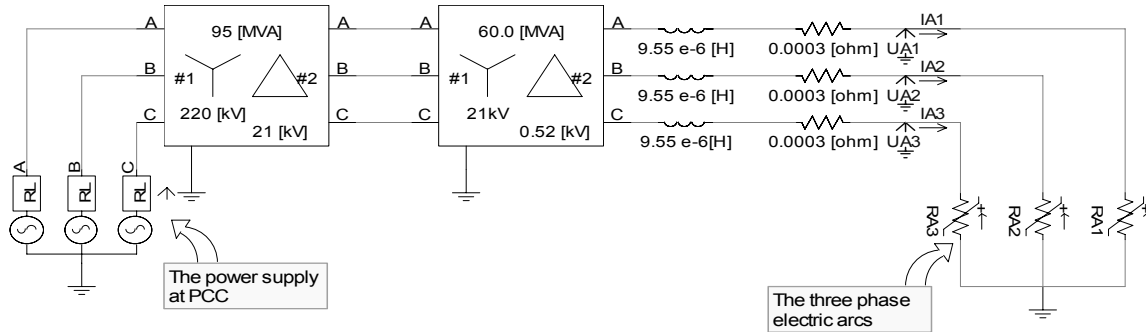


Figure 2. Circuit of the electric installation of the arc furnace used for simulation

This model, given in [2], [3] [6] and in [11], considers the characteristic current-voltage described by relation

$$U_A = U_A(I_A), U_A = U_d + \frac{C}{D + I_A} \quad (4)$$

U_A and I_A are 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

$$U_{ig} = U_d + \frac{C}{D}. \quad (5)$$

In figure 5 we gave the characteristic current-voltage obtained for the typical values given in [3], [6] and [11]: $U_{st} = 200$ V, $C_a = 190000$ W, $C_b = 39000$ W, $D_a = D_b = 5000$ A.

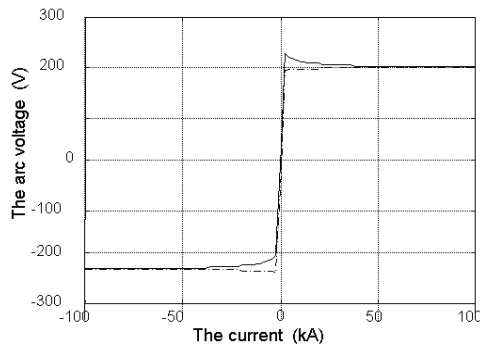


Figure 3. The voltage – current characteristic of the electric arc

As the equivalent impedance of the short network is constant, it is obvious that if we use during simulations a fix value of the drop voltage, U_d , for a certain value of the voltage in the secondary of the furnace transformer, the active power dissipated in the electric arc will be constant, its value depending on the constants in the relation (26). According to the above, the use of this model does not allow the correction 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

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I. SIMULATION RESULTS USING PSCAD EMTDC

The analysis of the results we obtained by using this electric arc model will be done in two stages:

- The determination of the model performances considering the drop voltage a constant, $U_d = 200$ V;
- The demonstration 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.

If the arc length does not change with time ($l = l_0$), the dynamic characteristic current-voltage is constant with respect to time. In order to obtain a value of the active power of the electric arc equal to the one used in the simulations we carried out with the other models of electric arc, $P = 25,4$ MW, in this case we modified the voltage of the secondary of the furnace transformer. Based on the values of the current and voltage of the electric arc, we compute its power and noticed that for a feeding voltage of

$$U_l = 520$$
 V (6)

we obtained the proposed value, $P = 25,4 \text{ MW}$. One can notice that this value of the feeding voltage is higher than the value given by relation (1), which means that, we will have an uninterrupted current for the electric arc.

The voltage in the secondary of the furnace transformer influences the shape and amplitude of the electric arc current, as resulting from figure 6. Thus, one can notice that for a value of the secondary voltage lower than the one given by relation (1) we obtain the status of uninterrupted feeding power, (figure 6.a), for the value given by relation (1) we obtain the meeting to the limit of the condition of uninterrupted work condition, (figure 6.b), while for higher values, the arc current is uninterrupted, (figures 6.c, d). For a value of the line voltage for which we have a power of the electric arc of $25,4 \text{ MW}$, given by relation (28), the simulations we carried out allowed us to obtain the wave shapes of the current and voltage of the electric arc of phase 1, given in figure 7. The shape we obtained for the electric arc voltage closely reflects the results given in the reference

literature, both for the real wave, [1], and for the one obtained by simulation [6].

As a result of the simulation, we obtained the current-voltage characteristic presented in figure 8. One can notice that *this characteristic shows a (low) hysteresis phenomenon*, unlike the theoretical characteristic given in figure 5, which corresponds to the real process [1]. Because the surface of the hysteresis curve represents a measure of the power loss, it results that the simulations may lead to conclusions related to the power loss on the electric arc.

One can also notice that there is an asymmetry of the characteristic caused by the different values chosen for constants C_a and C_b from relation (26). Because D_a has been chosen to be equal to D_b the gradients in the growing or decreasing zones are equal too. It results that this model offers the advantage of allowing the simulation of the rectifying character of the electric arc.

Using a program implemented on Matlab we obtained the spectral analysis of the arc current and voltage, using the

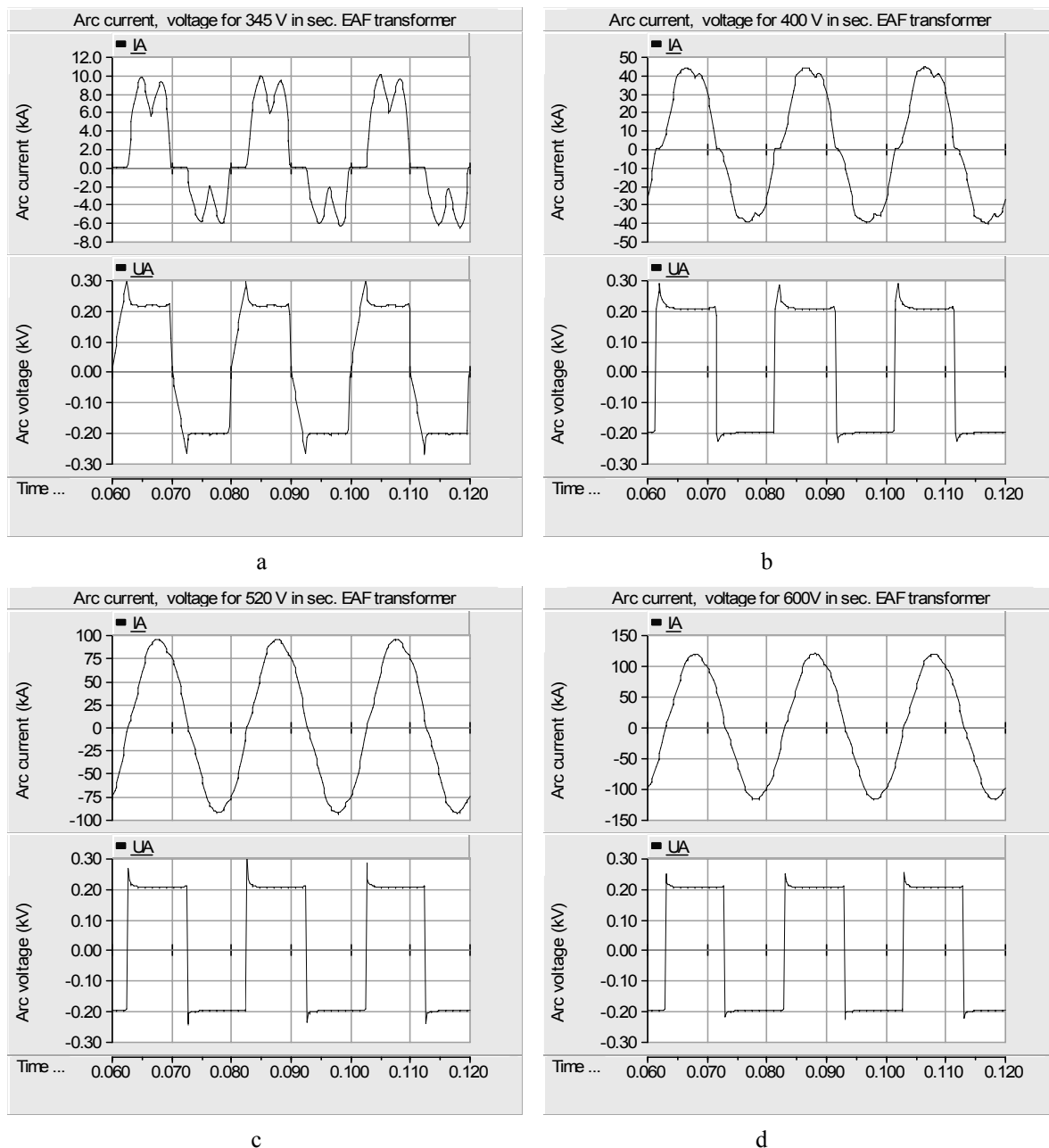


Figure 4. The variation of the arc current and voltage for various values of the voltage given by the secondary of the furnace transformer a) 345V; b) 400 V; c) 520 V; d) 600V.

Fourier transform, the frequency spectrum under consideration ranging within $0 - 1000$ Hz, the sampling frequency being 5 KHz. Because the Fourier transform was computed in 2500 points, it results that the resolution in frequency analyze of the experiment was 2 Hz. The advantages of using the spectral characteristics consist in the fact that for a given signal we could also determine the amplitudes of the components of a frequency that is different from a multiple of the fundamental frequency and we thereby brought into relief the inter-harmonics. This is particularly useful as in reality the electric arc is a powerful generator of both harmonics and inter-harmonics. Because several quality indices of the electric power are determined according to the harmonics of the current and voltage signals, one can consider that for one time window, the spectrum of the signals we are interested in, contain only the harmonics of the fundamental. In this case, the energy of the inter-harmonics is distributed to the nearest harmonics, the spectrum of the signals containing only the harmonics of the fundamental. This representation can be obtained computing the Fourier transform in 100 points, the frequency range thus obtained being of 50 Hz.

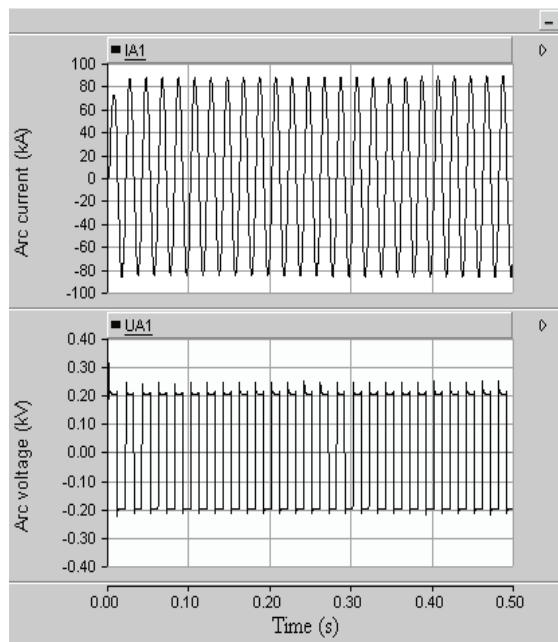


Figure 5. The variation of the arc current, voltage and resistance, according to relations (26), (27) and $U_f = 520$ V.

In figure 9 is present the spectral characteristic and the amplitudes of the harmonics of the arc current and voltage, obtained by simulation. One can notice that both in the spectrum of the current and in that of the electric arc voltage, the odd harmonics prevail. This is due to the fact that during the simulations we chose equal values for both half-periods of the drop voltage, $U_d^+ = U_d^- = 200$ V. Because the values of the ignition voltages on both half-periods are different, both in the voltage and current spectrum, one can notice the presence of even order harmonics (particularly the second and the fourth, but having much lower amplitudes). In the current spectrum one can notice that, the fundamental let aside, *higher amplitude characterizes harmonics 5 and 7 while harmonics 11 and 13 have lower amplitude*. Also, with respect to the amplitude of the fundamental, the electric arc voltage harmonics have a much higher amplitude than

the current, which also results from the wave forms given in figure 7.

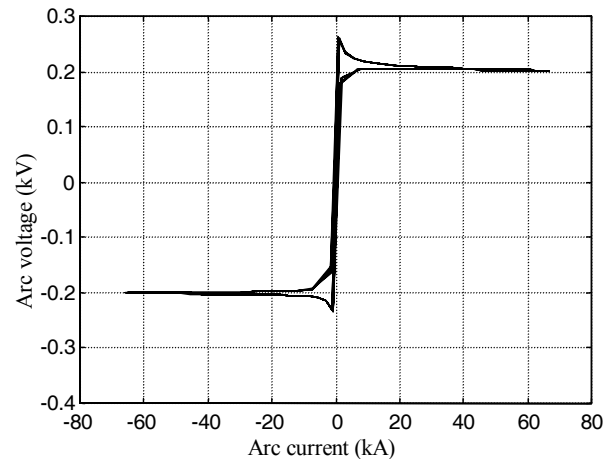


Figure 6. The characteristic current-voltage of the electric arc for phase 1, obtained by simulation.

Using the values of the voltages and currents obtained during simulations we calculated: the apparent power, the active power, the reactive power, the deforming power as well as the power factors under deforming work conditions, the results we obtained being given in Table 1.

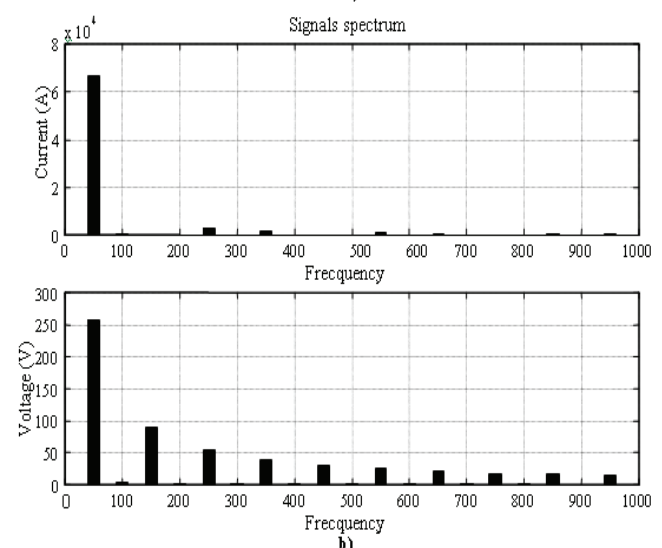
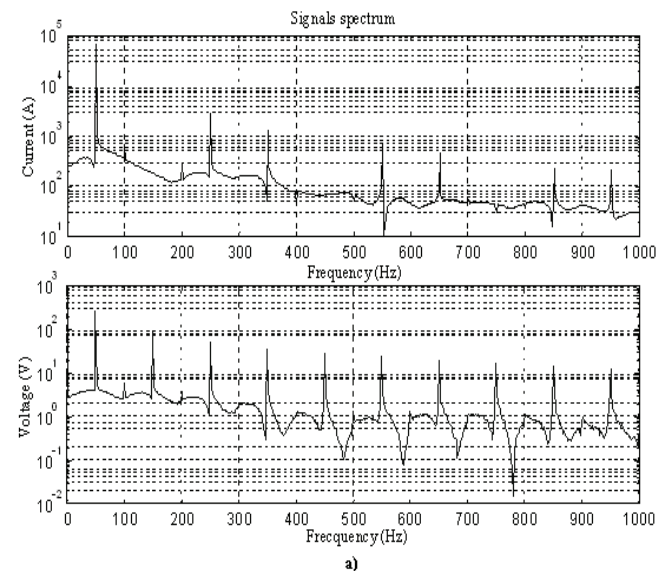


Figure 7. a) The spectral characteristic of the arc current and voltage; b) The amplitude of the harmonics of the arc current and voltage

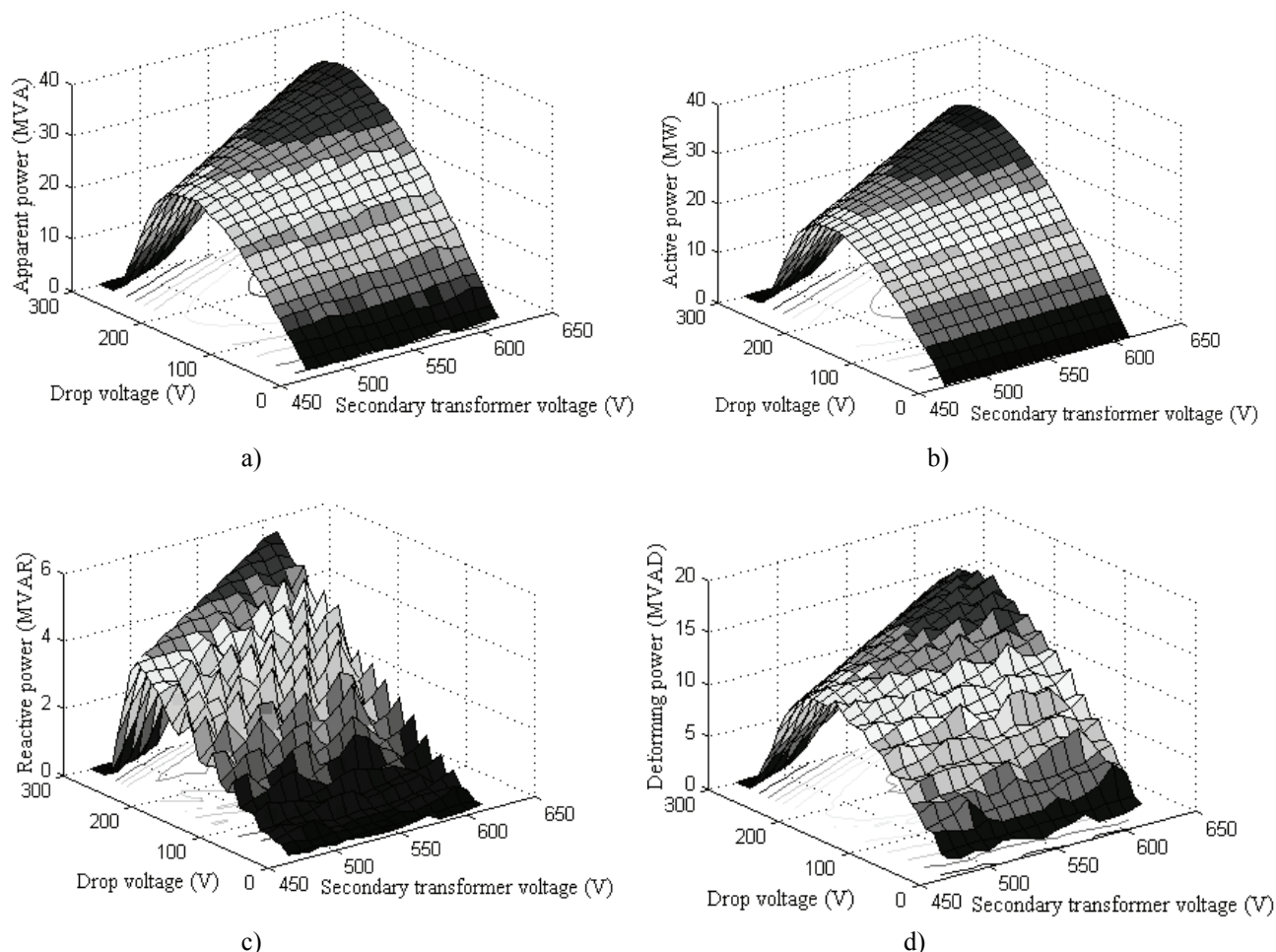


Figure 8. The power variation with the drop voltage for different values for the secondary voltage transformer. a) apparent power; b) active power; c) reactive power; d) deforming power;

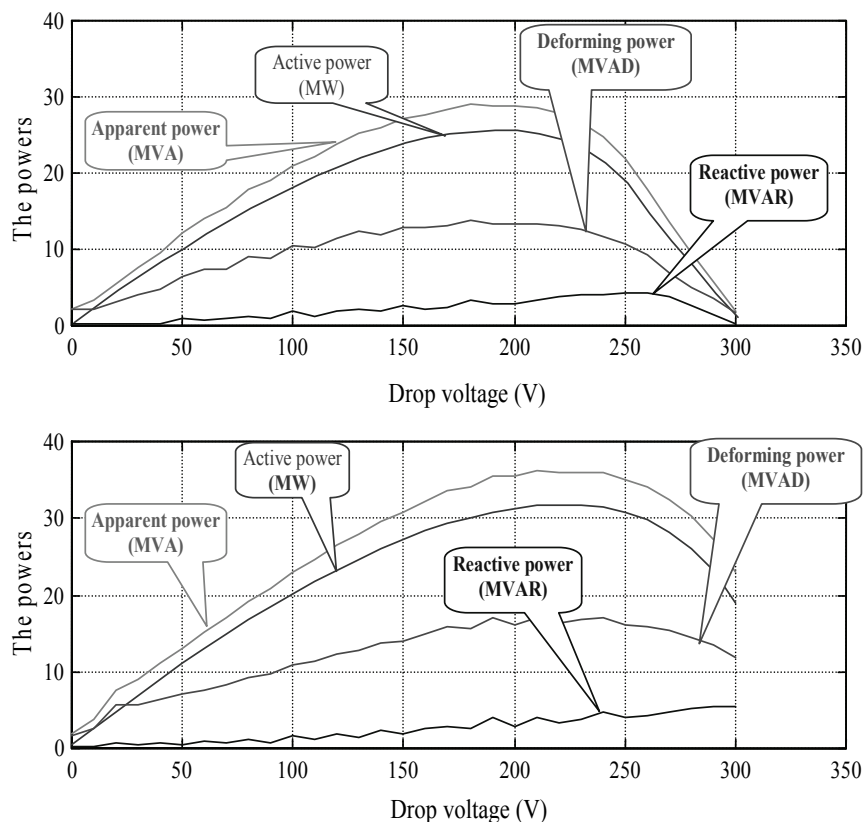


Figure 9. The power variation for: a) $U_1=520$ V; b) $U_1=610$ V

As a result of the analysis, we found that:

- The active power obtained on the three feeding lines has approximately the same values, irrespective of the modeling type, the highest value being reached on the high voltage line and the lowest, on the low voltage line;

- The lowest value of the reactive power is obtained on the electric arc, which leads to the idea that the model enables us to obtain a highly resistive character of the electric arc. On the medium and high voltage feeding lines we obtained much higher values for the reactive power, which shows the need for a compensation system for the reactive power;

- The deforming effect is highest on the low voltage feeding line. In the case of using the random variation of the electric arc length, the deforming power has highest values on all the feeding lines, which is reflected in the high values of the deforming factor.

According to the conclusions given in this paragraph, after the analysis we carried out by simulating the functioning of the electric arc furnace electric installation we found that this model is good as it gives the possibility of replicating the real situation, both from the standpoint of the wave shapes and of the characteristics current – voltage and frequency, and from the point of view of the powers dissipated on the feeding lines model.

The model presented in this section was validated experimentally by comparison with the results of the measurements made at an industrial plant [4].

II. CONTROLLING OF THE ELECTRIC ARC POWER

One of the important requirements that a model should meet is the possibility to adjust a certain by variation of one or more parameters [7,12]. In case of electric arc's modeling, the model should offer, beside the fulfillment of other requirements regarding the current-voltage characteristic, wave shapes and harmonics' specter of currents and voltages, also the possibility of electric arc's power control. In case of the analyze model, from the relations (25), (26) and (27), is found that for higher values of the extinction voltage are obtained smaller values of the arc's current and reciprocally. This suggests that there is an intermediary value of the extinction voltage for which the electric arc's power is maxim. It's obvious that this variation form of the electric arc's power is similar regardless the value of the supply voltage from the transformer's secondary.

III. CONCLUSION

Based on the studies present in this paper the authors can propose a complex installation for power quality improvement. This installation must contained a reactive power compensation system and harmonics filter on 5, 7, 11 and 13 harmonics current.

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