Simulation Result about Harmonics Filtering using Measurement of Some Electrical Items in Electrical Installation on UHP EAF

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Abstract: - This paper present the results obtained by simulation for the functioning regime improvement of an UHP Electric Arc Furnace. Because the nonlinearity of the electric arc the EAF functioning regime are perturbed from three causes: the current harmonics, the reactive power and the unbalanced load. In this paper there are study the possibilities of harmonics filtering and compensate the reactive power. The study was made using the results of some measurements made on an EAF and using an electric arc model for simulation. The simulations are performed in PSCAD EMTDC simulation program, a program dedicated to the power system.

Key-Words: - PSCAD-EMTDC simulation program, electric arc modeling, harmonics mitigation, filtering, reactive power compensation

1 Introduction

The electric arc is a nonlinear element. For study the behavior of the systems containing an electric arc it must use techniques to model the nonlinearity of the electric arc. Because the electric arc's nonlinearity, this is a massive generator of harmonic currents and reactive power in electrical power system. The EAF are also a reactive power source because the electric arc is also a reactive load. The electric arc furnace is also and unbalance load [19]. For improving the functioning regime of the electric arc furnace it can be used harmonic filters and a reactive power compensation installation. The effect of these installations was analyzed using simulation program PSCAD/EMTDC [20]. 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).

For simulation it was use an electric arc model, depending on the nonlinearity of the electric arc. The modeling approach adopted in the paper is graphical, as opposed to mathematical models embedded in code using a high-level computer language. The well-developed graphic facilities available in an industry standard power system package, namely PSCAD-EMTDC, are used to conduct all aspects of model implementation and to carry out extensive simulation studies.

2 The measurements made on electrical installation of an UHP EAF

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.

The methods of measuring the electric values are using numerical systems, based on data acquisition systems. It's been used a computer system with an ADA3100 data acquisition board. The electric scheme for the measurement is show in fig. 1.

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.

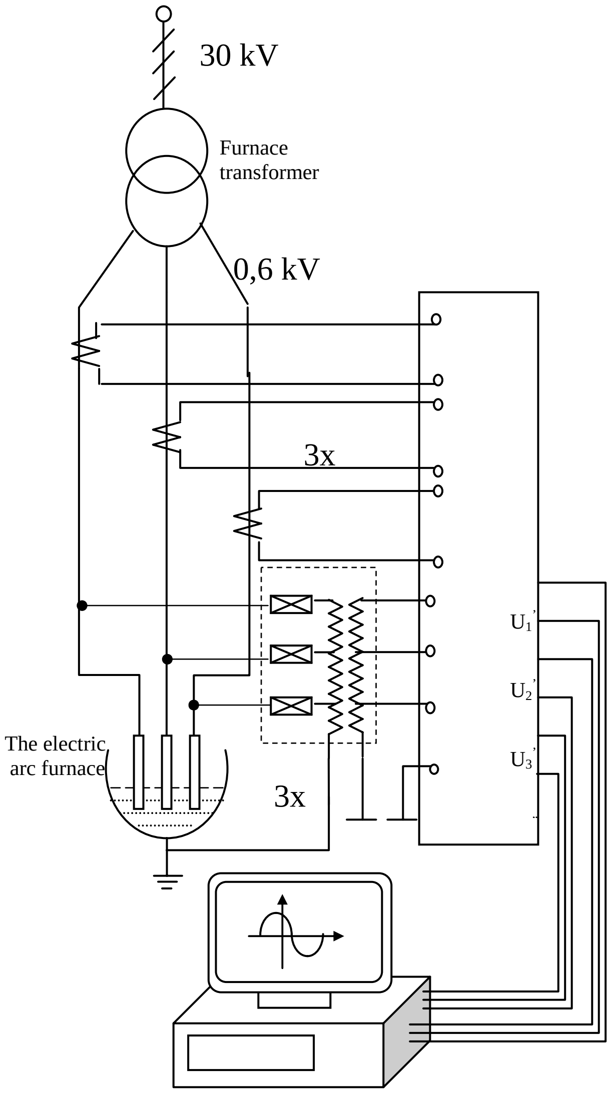

Fig. 1. The measure scheme

As regards to the waveforms of the currents and voltages on the low voltage supply line, presented in fig. 2, 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 power's variation on the entire melting process are show in figure 4 (active power), figure 5 (reactive power) and in figure 6 (distorted power).

3. The Electric Arc Model

In [1], [3], [4], [11], [12], [13] and [14] was present some models for the electric arc. From these models in this paper was choose the model based on the empirical relation between the arc current, arc voltage and arc length. This model are considered by the authors the most appropriate model for describe the electric arc behavior. This model, given in [3], [4], [11] and in [12], considers the characteristic current-voltage described by relation

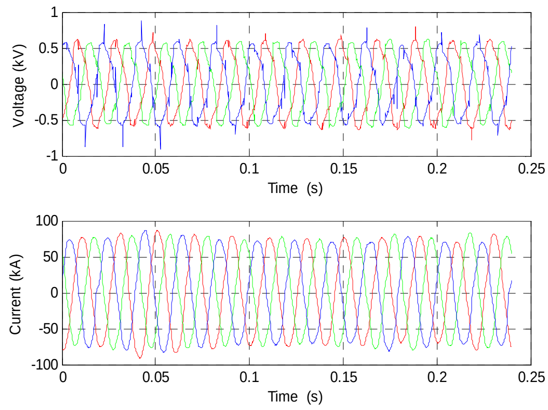

Fig. 2. The variation of measured voltages and currents for the three phases

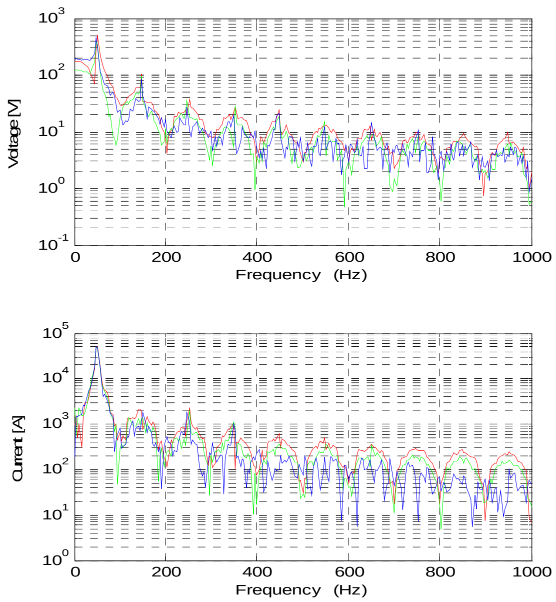

Fig. 3. The spectral characteristic for measured currents and voltages

$$U_A = U_{th} + \frac{C}{D + I_A}. \qquad (1)$$

In this relation U_A and I_A are the arc voltage and arc current, and Ud are the threshold voltage. The C and D constants determine the difference between the current increasing part and current decreasing part of the current–voltage characteristic (C_a, D_a irrespective C_b, D_b). The typical values ([3], [4], [11], [12]) are: U_d = *200 V*, C_a = *190000 W*, C_b = *39000 W*, D_a = D_b = *5000 A*. Because the real values of the model parameters depend on the voltage arc variations, the dynamic arc voltage–current characteristic must be an arc length function, given by relation ([3], [4]):

$$U_A = k \cdot U_{A0}(I_A). \qquad (2)$$

In (2) U_{A0} are the value of the arc voltage for a reference arc length l_0 and k is the ratio between the threshold voltage value for arc length l, $U_{th}(l)$ and the threshold voltage value for arc length l_0, $U_{th}(l_0)$.

The dynamic model for electric arc presumes that the relation between the threshold voltage value and the arc length can be expressed by:

$$U_{th} = A + Bl \ . \qquad (3)$$

In (3) A is a constant equal with the sum of cathode and anodic threshold voltages ($A \cong 40V$) and B represent the threshold voltage on the unit length, having usual values of $10V/cm$ ([3], [4], [11]). The dependency of k by the electric arc length is:

$$k(l) = \frac{A + B \cdot l}{A + B \cdot l_0} \ . \qquad (4)$$

Using this model, the correction of the electric arc power can be done within loose limits by modifying the threshold voltage, which corresponds in practice to the modification of the distance between the electrodes and the metal bath.

The simulation of the EAF installation was performed by using the dedicated simulation program PSCAD – EMTDC. This program is dedicated to the power systems simulation ([20]). PSCAD (Power Systems CAD) is a powerful and flexible graphical user interface to the EMTDC solution engine. PSCAD enables the user to

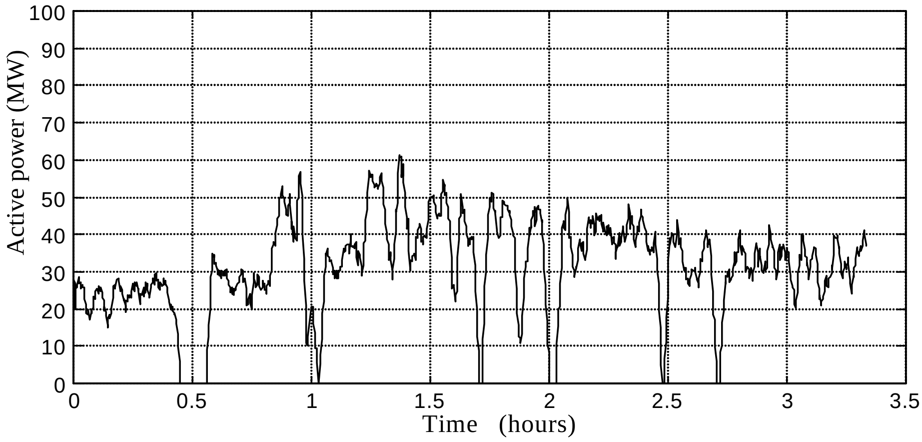

Fig. 4. The variation of the active power on entire melting process.

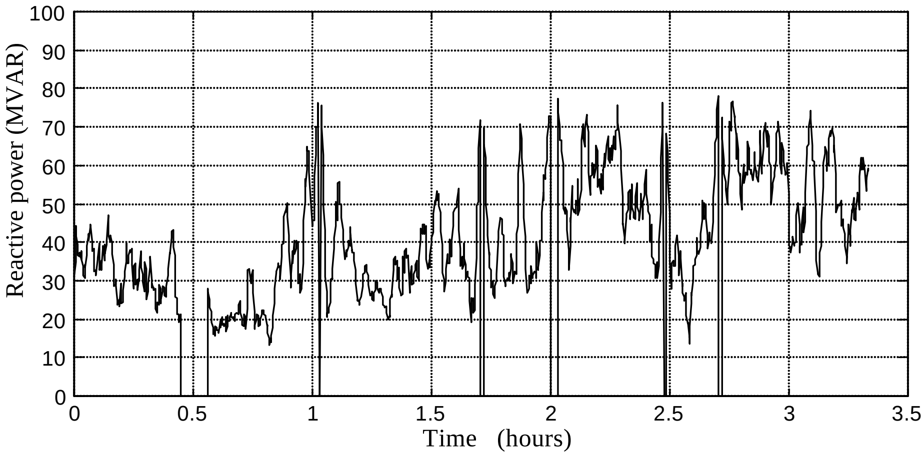

Fig. 5. The variation of the reactive power on entire melting process.

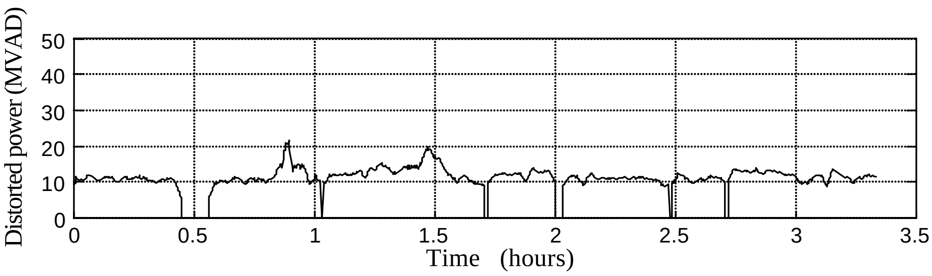

Fig. 6. The variation of the distorted power on entire melting process

schematically construct a circuit, run a simulation, analyze the results, and manage the data in a completely integrated, graphical environment.

The PSCAD electrical scheme of the EAF is show in figure 7. The parameters of the electrical installation of the EAF were determined based on the real installation on an industrial plant ([2]). The relation (5) and (6) show the values of the short network's parameters.

The total resistances, on each phase are:

$$R_{r1} = 0{,}6908\, m\Omega,\quad R_{r2} = 0{,}3640\, m\Omega,\quad R_{r3} = 0{,}0372\, m\Omega, \tag{5}$$

And the total inductivities:

$$L_{r1} = L_{r3} = 9{,}5422\, \mu H,\quad L_{r2} = 8{,}9416\, \mu H. \tag{6}$$

Because the impedances of medium voltage supplying 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/0,6k; Δ/Y.

Following the measurements made on the EAF's real installation, was observed that its operation is featured by the presence of an unbalanced 3-phase regime regardless the technological step, both on the low voltage supply line and the medium voltage one ([1], [2]).

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 Da and Db 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 simulations for these constants were taken the values from literature, $C_a = 190000$ 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 [2], [3], [5], [10].

As regards the drop 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. The detailed results for model validation was present in [14].

4. The results for the reactive power compensation and harmonics filters design

Based on the model present in the previous section, it was design a simulation scheme for the entire electrical installation of the EAF. The simulation scheme is show in figure 7. The simulations are validating by some experimental measurement made on the electrical installation of an UHP EAF on an industrial plant in Romania. It results also from the simulation and from experimental measurement that the functioning regime are unbalanced, affected by the reactive power and by the current harmonics.

The values for characterize this functioning regime are show in table 1 and they are result from [2].

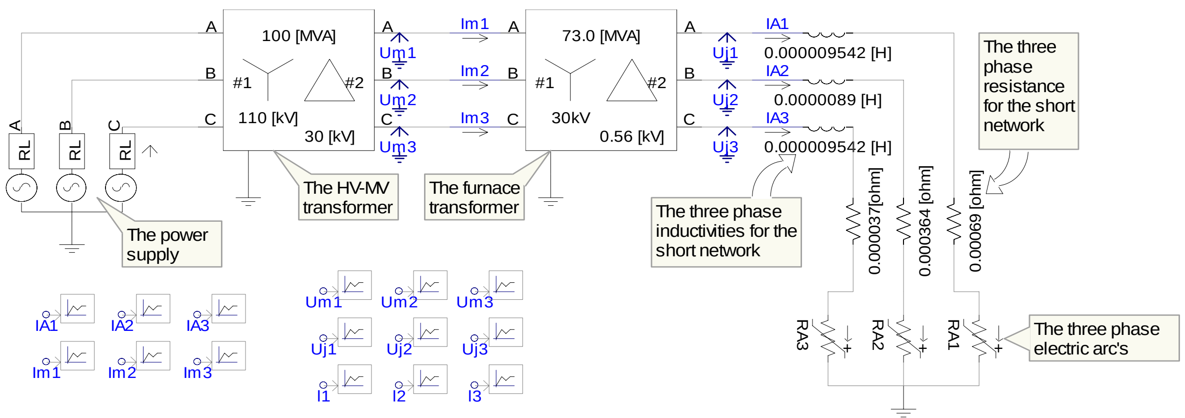

Fig. 7. The simulation circuit for the electrical installation of the EAF

Table 1

	The powers				The power factor, k_p	Thdi (%)	Thdu (%)
	S *(MVA)*	P *(MW)*	Q *(MVAR)*	D *(MVAD)*			
Measure values	72,25	48,63	52,43	10,29	0,546	16,83	7,3
Simulating values	73,51	47,36	55,97	5,35	0,644	8,44	3,17

To determine the values of the elements of the harmonic filters and reactive power compensation installation the authors used the measurement results realized to the real installation on the 100 tones electric arc furnace. To determine the values of the elements of the harmonic filters and reactive power compensation installation was used the measurement results realized to the real installation on the 100 tones electric arc furnace. In fig. 8 are show the way of connecting the harmonics filters and the power compensation installation.

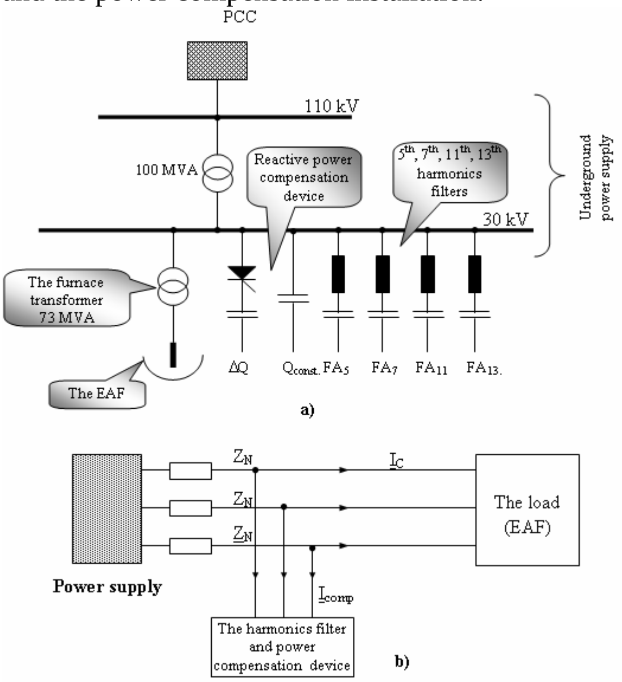

Fig. 8. a) The way of connecting the harmonics filters and the power compensation installation; b) The equivalent electric circuit on the power supplying line.

The design of the dynamic reactive power compensation is made for the maximum voltage value of the transformer ([5], [9]). The reactive power compensation depends of the 2 parts:

$$Q_{comp} = Q_{const} + \Delta Q \qquad (7)$$

In order to obtained the power factor:

$$\cos \varphi_{\max} = 0{,}95 \qquad (8)$$

Result the value for the reactive power compensation installation:

$$Q_{comp} = 84{,}2\,\text{MVAR} \qquad (9)$$

The variable component ΔQ, it was choice following ([5])

$$\Delta Q = 58{,}4\,\text{MVAR} \qquad (10)$$

$$Q_{const} = Q_{comp} - \Delta Q = 25{,}8\,\text{MVAR} \qquad (11)$$

The commutation steps design result,

$$(\Delta Q)_{step} = \Delta u_{admis} \cdot S_{sc}. \qquad (12)$$

The steps number results from the relation (7):

$$n = \frac{\Delta Q}{\Delta u_{admis} \cdot S_{sc}} = 13{,}27\,, \qquad (13)$$

and was choice 14 steps:

$$\Delta Q_{step} = 4{,}17\,\text{MVAR}\,, \qquad (14)$$

For determine the values of the filters capacitors it is necessary to know the values of the k^{th} order harmonics currents, because, following the recommendation ([5], [9])) a capacitor with a certain nominal voltage U_{n50}, corresponding to the fundamental with the frequency of 50 Hz and a certain nominal current I_{n50} can functioning in a long time distorted regime characterized by $U_{ef} = 1{,}1 \cdot U_{n50}$ and $I_{ef} = 1{,}3 \cdot I_{n50}$, which mean a overloading by 43%. For this reason it is important to determine the nominal value for the k – harmonic. Taking into account of the measurements on the 30kV supplying line feed, the nominal currents for the filters design are:

- the nominal current for the 5th harmonics: $I_n^5 = 100A$;
- the nominal current for the 7th harmonics:: $I_n^7 = 50A$;
- the nominal current for the 11th harmonics:: $I_n^{11} = 25A$;
- the nominal current for the 13th harmonics: $I_n^{13} = 25A$.

The values for the nominal currents are greater than the recorded values by measure because, in practice, it was observed some cases of filters deterioration which was rigorous dimension based on the load harmonics generator [6], [16]. This fact is based on the harmonics circulation of provenance on the far distorted loads [10] [15].

The method used allows the design of the filters based on the conditions regarding the voltage and

the thermal properties of the capacitors [5].
The first condition is:

$$U_{C50} + U_{Ck} \le U_{adm}\,, \qquad (15)$$

Where U_{C50} are the fundamental voltage, U_{Ck} are the kth harmonic voltage and U_{adm} are the admissible voltage for the choose capacitor.
This can be writing as:

$$\frac{k^2}{k^2-1}U_f + \frac{I_n^k}{k\omega C} \le U_{adm}\,, \qquad (16)$$

where U_f is the phase voltage. Result the first condition for the filters capacity based on the limitation of the voltage filter:

$$C_u \ge \frac{I_n^k}{k\omega\left(U_{adm} - \frac{k^2}{k^2-1}U_f\right)} \qquad (17)$$

The second condition imposes that the filter's power to be smaller than the admissible power, so:

$$P_{C50} + P_{Ck} \le P_{adm}\,, \qquad (18)$$

Where P_{C50} are the fundamental active power, P_{ck} are the kth harmonics power and P_{adm} are the admissible power on the choose capacitor. This relation can be writing

$$\omega \cdot C \cdot U_{C50}^2 \cdot tg\delta + \frac{I_n^k}{k\omega C}\cdot tg\delta \le \omega \cdot C \cdot U_{adm}^2 \cdot tg\delta\,, \qquad (19)$$

where $tg\delta$ are tangent for the dielectrically losses angle of the choose capacitor. From this relation result the second condition for the capacity of the filter:

$$C_t \ge \frac{I_n^k}{\omega\sqrt{k\left(U_{adm}^2 - \left(\frac{k^2}{k^2-1}\right)^2 \cdot U_f^2\right)}}\,. \qquad (20)$$

Choosing filter's capacity can be made so that the both relations (17) and (18) to be right.
The filter's inductivity for the kth harmonic can be made using the relation:

$$L = \frac{1}{k^2\omega^2 C}\,. \qquad (21)$$

The filter's performances can be calculated using the values of the filter's components. So, the current corresponding to the 50 Hz frequency is

$$I_{50} = \frac{U_f}{\frac{1}{\omega C} - \omega L} = \frac{k^2}{k^2-1}\cdot \omega C U_f\,, \qquad (22)$$

and the total current for the filter:

$$I_F^k = \sqrt{(I_{50})^2 + \left(I_n^k\right)^2}\,. \qquad (23)$$

If Q_0 is the reactive admissible power for one capacity, U_0 the admissible voltage for one side and n the numbers of the parallel connected capacitors, the admissible current are:

$$I_{adm} = n \cdot \frac{Q_0}{U_0}\,. \qquad (24)$$

The validation of the filter design from the point of view of the current are made using the relation:

$$\frac{I_F^k}{I_{adm}} \le 1{,}3\,. \qquad (25)$$

The capacity voltage of the filter are obtained using the relation:

$$U_C = \frac{k^2}{k^2-1}\cdot U_f + \frac{I_n^k}{k\omega C} \qquad (26)$$

whom can be verified the cndition

$$\frac{U_C}{U_0} \le 1{,}1\,. \qquad (27)$$

The 50 Hz reactive power are compose from the capacitive and inductive reactive power. The capacitive reactive power are:

$$Q_{C50} = 3\cdot X_{C50}\cdot I_{50}^2 = 3\cdot\frac{U_f^2}{X_{C50}}\cdot\left(\frac{k^2}{k^2-1}\right)^2\,, \qquad (28)$$

and the inductive reactive power

$$Q_{L50} = 3\cdot X_{L50}\cdot I_{50}^2 = 3\cdot\frac{U_f^2}{X_{L50}}\cdot\left(\frac{k^2}{k^2-1}\right)^2\cdot\frac{1}{k^2}\,. \qquad (29)$$

Because on 50 Hz frequency the filter's impedances have capacitive character, result that the total reactive power absorbed by them are:

$$Q_{Filtru} = Q_{C50} - Q_{L50} = 3\cdot\frac{U^2}{X_{C50}}\cdot\frac{k^2}{k^2-1}\,. \qquad (30)$$

An unrestrictive condition that appear in the filters design are that the characteristics impedances for the filters must be equals. That can be writing:

$$Z_c^5 = Z_c^7 = Z_c^{11} = Z_c^{13}\,, \qquad (31)$$

or

$$\frac{L^5}{C^5} = \frac{L^7}{C^7} = \frac{L^{11}}{C^{11}} = \frac{L^{13}}{C^{13}}\,. \qquad (32)$$

In the following section are present the 5th harmonic filter design.
Using the relation (17) and (20) result the conditions:

$$C_u \ge 21{,}52\,\mu F\,, \qquad (33.a)$$

$$C_t \ge 13{,}24\,\mu F\,. \qquad (33.b)$$

For the purpose to respect simultaneous both (27) conditions, the filters capacity value are choose:

$$C = 16\cdot 1{,}44\mu F = 23{,}04\mu F\,, \qquad (34)$$

Result that the filter needed using 48 equivalent

capacitors connected in parallel therefore 96 capacitors for the choose type.
Based on the choose filter's capacitor value, from the relation (15) result the filter's inductivity value

$$L = 17{,}59 mH \quad . \tag{35}$$

The validation of the filter design regarding current value is made using relations (22) – (25). It will be obtained

$$I_{50} = 130 A,\quad I_F^5 = 164 A,\quad I_{adm} = 152{,}2 A, \tag{36}$$

being accomplish also the condition impose by the relation (25)

$$\frac{I_F^5}{I_{adm}} = 1{,}07 \le 1{,}3 \tag{37}$$

Using (26) are obtained the voltage value of the filter capacity

$$U_C = 20804 V \ , \tag{38}$$

value that satisfied the relation (27)

$$\frac{U_C}{U_0} = 0{,}99 \le 1{,}1 . \tag{39}$$

The absorbed reactive power on the 5th harmonic filter is obtained from (30) and result:

$$Q_{Filter}^5 = 6{,}785 MVAR \ , \tag{40}$$

the installed power being:

$$Q_{Installed}^5 = 9{,}6 MVAR . \tag{41}$$

In the same way was design also the 7th, 11th and 13th harmonics filters. The results are in table 2.

Table 2.

Parameters \ Harm order	5th	7th	11th	13th
C_u [μF]	21,52	6,85	2,04	1,71
C_t [μF]	13,24	5,31	2,057	1,88
C [μF]	23,04	8,64	5,76	5,76
Number of capacitors parallel connected	16	6	4	4
L [mH]	17,59	23,93	14,54	10,41
I_{50} [A]	130	48	31,6	31,5
I_F^K [A]	164	69,31	40,29	40,21
I_{adm} [A]	152,32	57,12	38,08	38,08
$\frac{I_F^K}{I_{adm}}$	1,07 <1,3	1,21	1,058	1,055
U_C [V]	20804	20312	18720	18485
$\frac{U_C}{U_0}$	0,99 <1,1	0,967	0,890	0,880
$Q^{(k)}$ [KVAR]	6785	2494	1628	1624
$Q_{installed}$ [KVAR]	9600	3600	2400	2400

Constructively the capacitors are connected in double star as follow:

- 16 equivalent capacitors (two capacitors serial connected) to the 5th harmonic filters, parallel connected, resulting on each phase 32 capacitors like in fig. 15;
- 6 equivalent capacitors to the 7th harmonic filters, parallel connected, resulting on each phase 12 capacitors like in fig. 16;
- 4 equivalent capacitors to the 5th and 7th harmonic filters, parallel connected, resulting on each phase 8 capacitors.

The sum of powers absorbed by the filters is:

$$Q_F = Q_F^5 + Q_F^7 + Q_F^{11} + Q_F^{13} = 12{,}53 MVAR . \tag{42}$$

5. The simulation results

In fig 9 are show the PSCAD EMTDC simulation scheme for the EAF with the harmonics filters, the reactive power compensation and the load balancing component. In this scheme the user can simulate the unbalancing load by selecting different length for the electric arc. Because the capacity value necessary to achieve such a battery is 14,4 μF , in order to simulate the introduction of a number of n steps, the value of the selected capacity in the fix capacitor battery's diagram is given by the relation (43).

$$C = 47{,}52 + n \cdot 14{,}4 \quad (\mu F) \tag{43}$$

The values for powers, power factors and distortions obtained for each of the 14 steps were written in table 3 for the primary furnace transformer.

Table 3

Compensation step	S (MVA)	P (MW)	Q (MVAR)	D (MVAD)	Kp	ρ	σ	Thdi (%)	Thdu (%)
Without comp	73,51	47,36	55,97	5,35	0,64	1,18	0,073	4,44	3,17
Q1	56,74	47,58	30,57	4,63	0,83	0,64	0,082	3,77	2,34
1.	54,67	47,57	26,53	4,64	0,87	0,55	0,085	3,94	2,16
2.	52,91	47,65	22,55	4,61	0,90	0,47	0,087	4,12	2,06
3.	51,46	47,75	18,61	4,61	0,92	0,39	0,090	4,21	1,94
4.	50,08	47,71	14,53	4,59	0,95	0,30	0,092	4,36	1,83
5.	49,17	47,80	10,55	4,61	0,97	0,22	0,094	4,45	1,67
6.	48,49	47,83	6,51	4,58	0,98	0,13	0,095	4,48	1,58
7.	48,16	47,87	2,53	4,61	0,99	0,05	0,096	4,51	1,52
8.	48,17	47,92	-1,55	4,62	0,99	-0,03	0,096	4,56	1,48
9.	48,47	47,92	-5,61	4,61	0,98	-0,11	0,096	4,54	1,54
10.	49,18	48,00	-9,65	4,65	0,97	-0,20	0,095	4,49	1,67
11.	50,18	48,06	-13,7	4,68	0,95	-0,28	0,094	4,37	1,71
12.	51,45	48,06	-17,7	4,71	0,93	-0,36	0,092	4,26	1,79
13.	53,00	48,05	-21,8	4,72	0,90	-0,45	0,089	4,14	1,85
14.	54,85	48,10	-25,9	4,70	0,87	-0,53	0,086	4,03	1,92

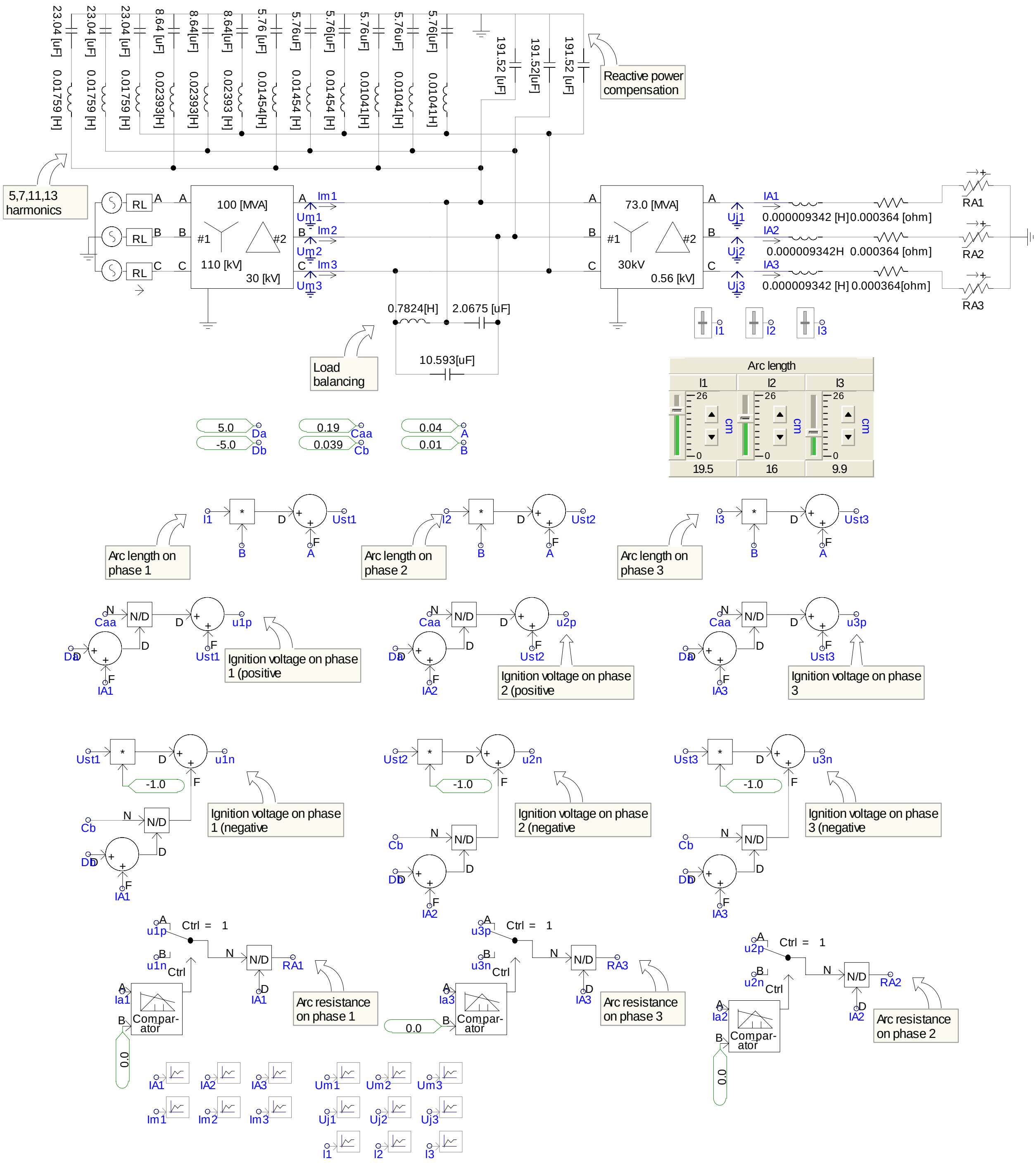

Fig. 9 The PSCAD simulation scheme for the EAF with the harmonics filters, the reactive power compensation and the load balancing component

In fig. 10 are show the signal spectrum obtain by simulation without filters and reactive power compensation and in fig. 11 are show the signal spectrums obtain by simulation with filters and reactive power compensation.

Analyzing these results, we notice that:

The effect of using the reactive power compensation installation is negligible on the secondary furnace transformer. One can observe that the reactive power keeps high values, regardless the compensation step, fact which reflects also in keeping of a small value, even decreasing, of the power factor.

Since the distorted power keeps high values regardless the compensation step, it results that on the secondary voltage transformer the harmonic filters don’t have a significant effect.

On the primary voltage transformer is found that the reactive power compensation installation allows, depending on the compensation step, to offer an adjustment of the reactive power within +30,57 MVAR ÷ -25,93 MVAR. This makes that, for a certain step, the reactive power value to be the closest to zero.
One can observe that the variation of the reactive power between two subsequent steps is of $\Delta Q_{step,sim}$=4,04 MVAR, lower than the designed one, ΔQ_{step}=4,17 MVAR , given by the relation (14) due to the fact that the selected value for capacity on one phase of a compensation step is lower than the one resulted by calculation.
The reactive power's value compensated by the fix batteries (difference between the reactive power values from the first two lines of table 3 is $Q_{const,sim}$=25,4 MVAR, closed to the one resulted by designing Q_{const}=25,8 MVAR, given by the relation (7).
The value of the total compensated reactive power (difference between the reactive power values from the first and last line of table 3) is $Q_{comp,sim}$=81,9 MVAR, and the one resulted by designing Q_{comp}=82,4 MVAR, given by the sum of the relations (7) and (9).
One can also observe that, practically, in the moment when the reactive power is null, the active power is approximately equal with the apparent one, fact which leads to obtaining of some maximum values of the power factor. The maximum values for the total harmonic distortions are obtained for power factor values close to 1.
Also, the obtained values are close to the measured values on the medium voltage supply line.

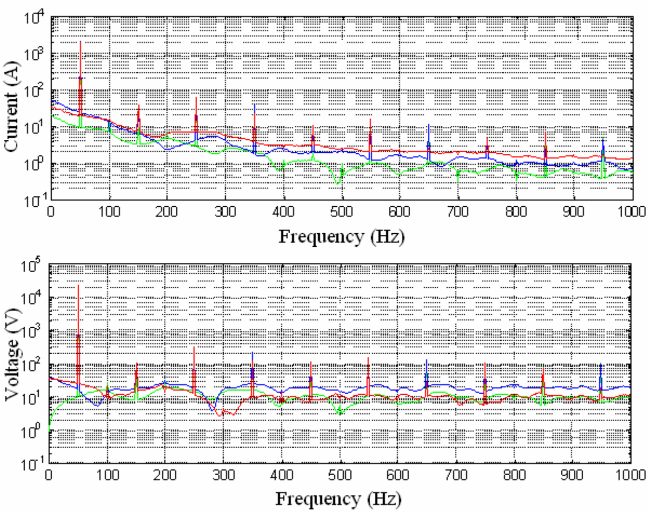

Fig. 10. The signal spectrum obtain by simulation without filters and reactive power compensation

6 Conclusion

From all previously presented, resulted that the simulations concerning the operation of the reactive power's compensation installation confirm the expecting conclusions, that the installation allowing obtaining a power factor very close to 1.
Analysis of the effects of using filters on the harmonics 5, 7, 11 and 13 can be made comparing the current and voltage harmonics' spectral characteristics on the voltage supplying line, obtained for the electric installation's operation without filters (fig. 10) and the ones obtained when the filters are used on the optimal compensation step, the 8th from table 2, presented in fig. 11. One can observe that, in case of using harmonic filters, the harmonics' amplitude for which were placed the filters is greatly reduced, against the situation when these were not used. However, as expected, the deforming power can not be cancelled because, in the current's and voltage's specters, besides the harmonic of rank 5, 7, 11 and 13 for which were designed the filters, there are on one side also other harmonics of which effect was not cancelled but also a series of inter-harmonics which, together, contribute at generating of a distorted power.
In conclusion, it was proven by simulation that the values obtained for the parameters of the reactive power's compensation installation, as well as of filters' for the harmonics of rank 5, 7, 11 and 13 allow a significant improvement of qualitative use indicators of the electric power at the electric arc furnace, both from power factor's viewpoint, of powers in deforming regime, as well as of the current's and voltage's total and partially balanced harmonic distortion.

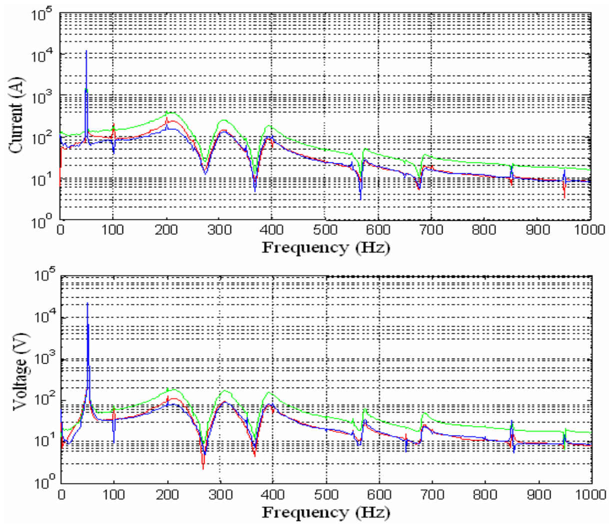

Fig. 11. The signal spectrum obtain by simulation after currents filtering and reactive power compensation

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