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ELECTROMAGNETIC POLLUTION PRODUCED BY THE INDUSTRIAL FREQUENCY CRUCIBLE INDUCTION FURNACES IN THE POWER SUPPLY NETWORK

Angela IAGĂR[1], Ioan ŞORA[2], Caius PĂNOIU[1], Cristian ABRUDEAN[1]

[1]"POLITEHNICA" UNIVERSITY OF TIMIŞOARA,
FACULTY OF ENGINEERING HUNEDOARA
[2]"POLITEHNICA" UNIVERSITY OF TIMIŞOARA,
ELECTRO-TECHNICAL AND ELECTRO-ENERGETICAL FACULTY TIMIŞOARA,
MEMBER OF THE ROMANIAN ACADEMY OF TECHNICAL SCIENCE

ABSTRACT:

This work presents the influence that the crucible induction furnaces of industrial frequency has upon the power supply network.

The measurements taken inside the electric circuit of a crucible induction furnace of industrial frequency, with 12,5 t capacity of cast-iron, have emphasized the presence of some electromagnetic disturbances as non-symmetry and harmonics in the currents absorbed from the network and harmonics in the current through the inductor. Further to the harmonic analysis of the signals acquired in the furnace installation, have been proposed some optimization methods for its operation, in such way to comply with the European norms of electromagnetic compatibility.

KEYWORDS:
induction furnace, electromagnetic disturbances, electromagnetic compatibility

1. INTRODUCTION

The induction furnaces supplied at industrial frequency are of high capacity and their functioning could produce disturbances on the power supply network.

It's been studied a crucible induction furnace of industrial frequency, having 12,5 t capacity of cast-iron, supplied from the three-phase mean voltage network (6 kV) through a transformer in Δ/Y connection, with step-variable voltage. Load balancing of the three-phase network phases is currently achieved by a Steinmetz connection, and the compensation of the reactive power is achieved by means of some step-switching capacitor batteries.

The measurements have been made both in the secondary and the primary of the furnace's supply transformer, using a signal acquisition and processing system, composed by an IBM-PC computer endowed with an ADA-3100 data acquisition board and an adapting block for measuring of high currents and voltages.

2. WAVEFORMS OF THE SIGNALS ACQUIRED IN THE ELECTRIC INSTALLATION OF THE ANALYZED FURNACE

During the experiments was aimed the way in which the installation's energetical parameters are influenced by the furnace charge (in the initial state - „cold" state, the charge is non-linear from magnetic viewpoint, and for temperatures higher than Curie temperature, the cast iron becomes non-magnetic), by its supply voltage and by the symmetrization and power factor compensation installations.

In this respect, the most significant moments during the induction melting process of the cast-iron charge were classified as follows:

- „cold" state of the charge - *after 5 minutes* from the beginning of the heating process;
- intermediary regime (the furnace charge being partially melted) - *after 4 hours and 38 minutes* from the beginning of the heating process;
- the end of the melting process (the furnace charge being totally melted) - *after 7 ½ hours* from the beginning of the heating process.

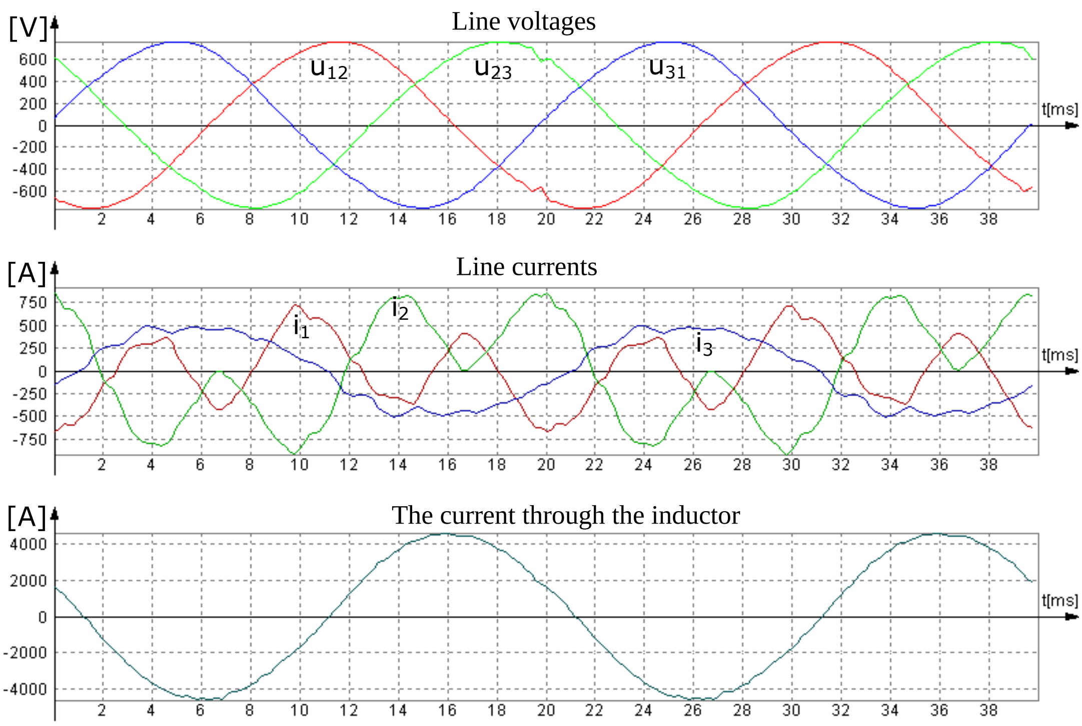

Fig. 1 Signals acquired on the low voltage line, in the transformer's secondary, *after 5 minutes* from the beginning of the cast-iron's heating process.

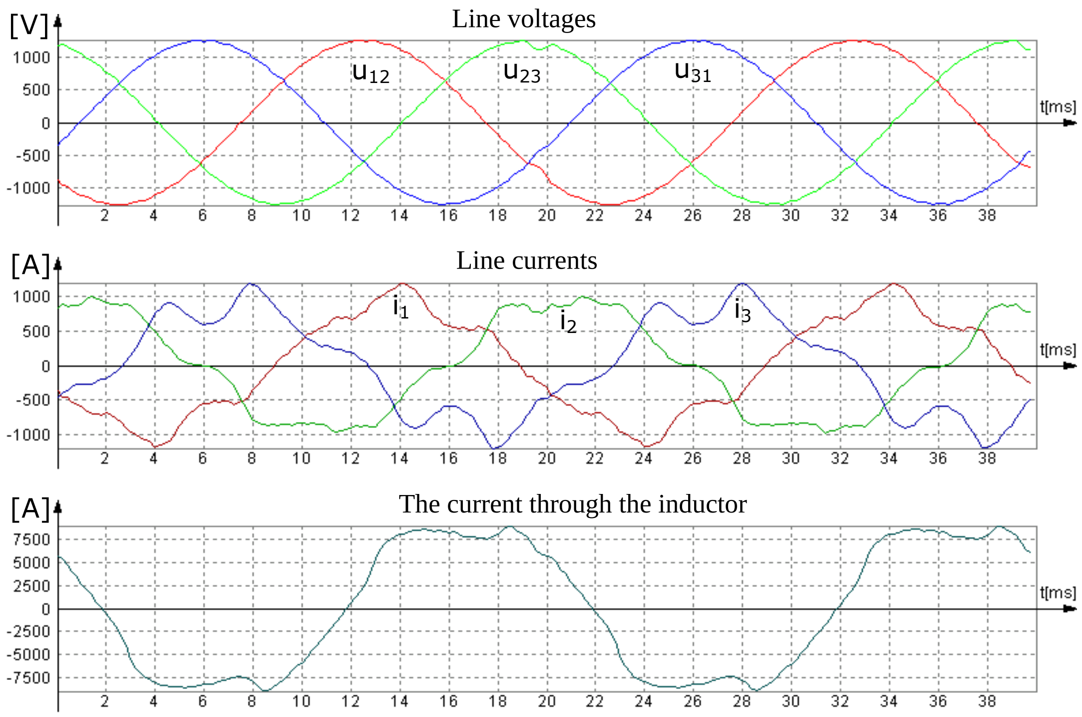

Fig. 2 Signals acquired on the low voltage line *after 4 hours and 38 min.* from the beginning of the cast-iron's heating process.

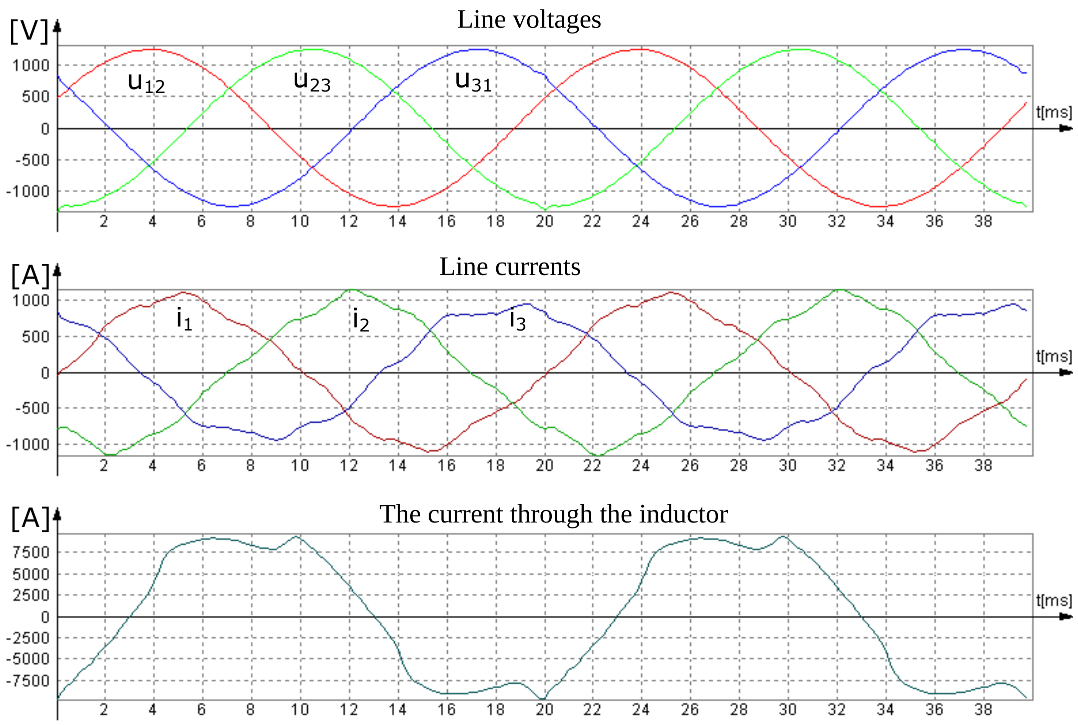

Fig. 3 Signals acquired on the low voltage line *at the end* of the cast-iron's heating process.

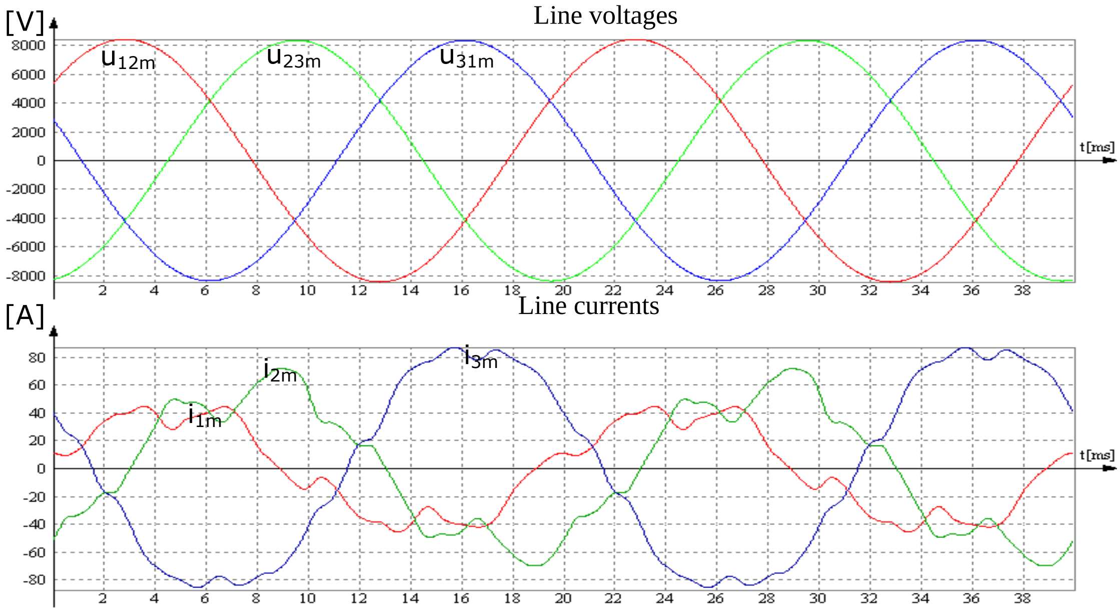

Fig. 4 Signals acquired on the mean voltage line, in the transformer's primary, *after 5 minutes* from the beginning of the cast-iron's heating process.

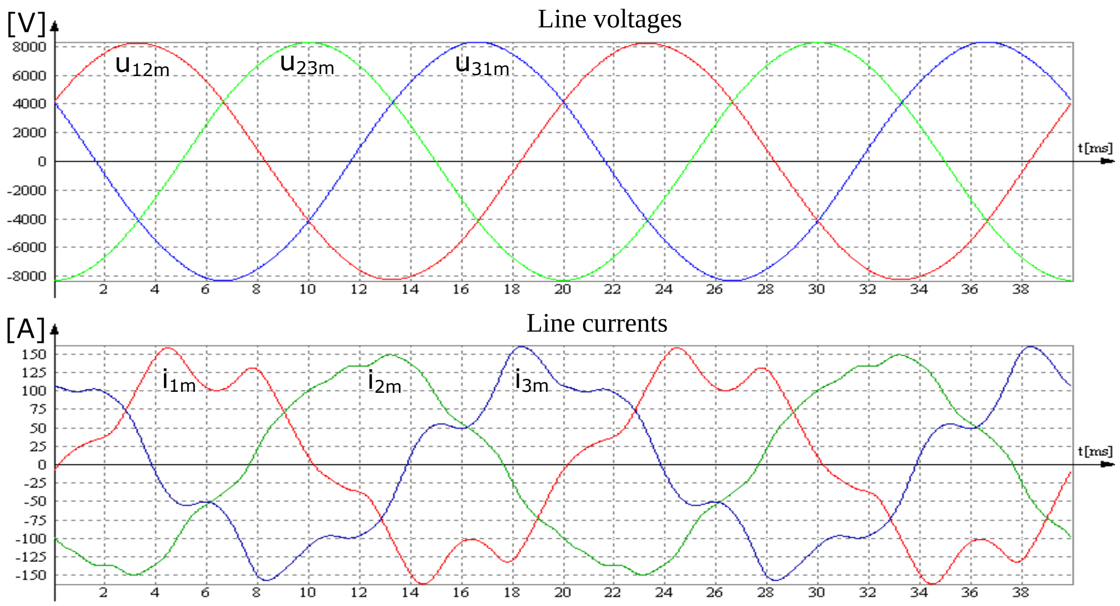

Fig. 5 Signals acquired on the mean voltage line *after 4 hours and 38 min.* from the beginning of the cast-iron's heating process.

Following the experiments it's been noticed the existence of some electromagnetic disturbances in the currents absorbed from the network (both on the low voltage line and on the mean voltage line) and in the current through the inductor, in all the analyzed situations, but not in the line voltages.

The strongest disturbances of the line currents were recorded at the beginning of the inductive heating process, in the „cold" state of the charge, and at the end of the melting process the disturbances of the line currents were minimum.

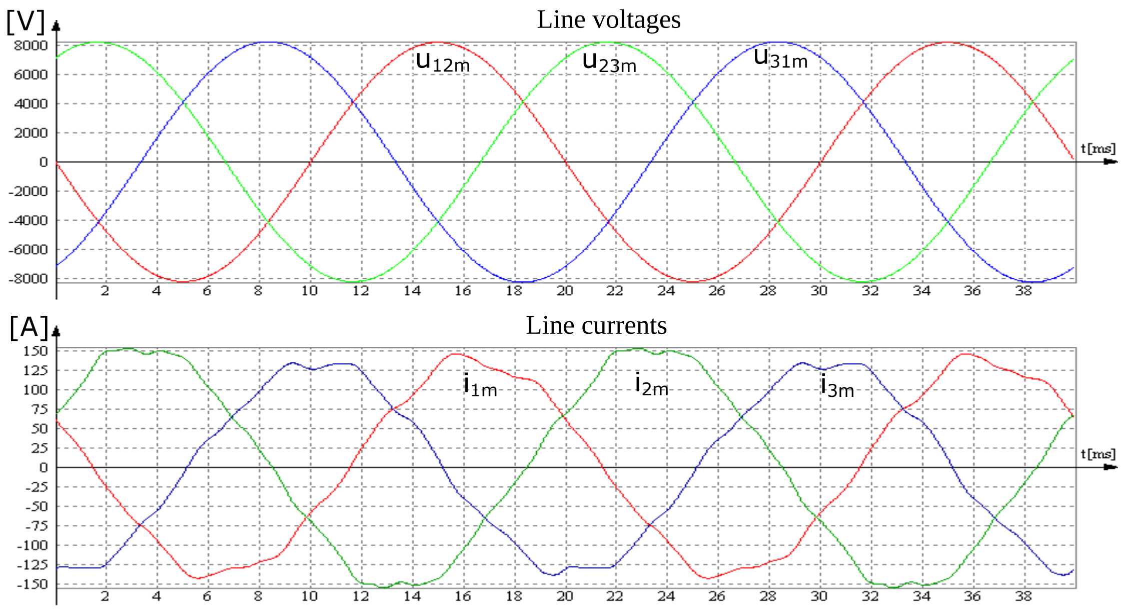

Fig. 6 Signals acquired on the mean voltage line *at the end* of the cast-iron's melting process.

3. HARMONIC ANALYSIS OF THE SIGNALS ACQUIRED IN THE ELECTRIC INSTALLATION OF THE ANALYZED FURNACE

Deformation of a non-sinusoidal signal $y(t)=Y_0+\sqrt{2}\sum_{k\neq 0}^{\infty}Y_k\sin(k\omega t+\varphi_k)$ could be quantified through the following quantities [1-7]:

- harmonic content:

$$\gamma_k=\frac{Y_k}{Y_1}\cdot 100\ [\%]\,, \tag{1}$$

where Y_1 is the rms value of fundamental component and Y_k is the rms value of k order harmonic.

- total harmonic distorsion:

$$THD=\frac{\sqrt{\sum_{k=2}^{40}Y_k^2}}{Y_1}\,, \tag{2}$$

defined as the ratio between the harmonic's rms value and the fundamental's rms value.

- total harmonic distorsion pondered:

$$THD_p=\frac{\sqrt{\sum_{k=2}^{40}k\cdot Y_k^2}}{Y_1}\,, \tag{3}$$

introduced to ensure that by increasing of harmonic order k, the harmonics decrease.

In order to assess the electromagnetic pollution introduced by the analyzed induction furnace in the power supply network, it's been achieved a C++ program, which determines the harmonic spectra of the signals acquired in the furnace installation (using the Fourier discrete transformation), the harmonics content and the values of the distorsion coefficients.

Fig. 7-12 present the harmonic spectra of the signals acquired on the low voltage line and on the mean voltage line, correlated with the oscillograms from Fig. 1-6.

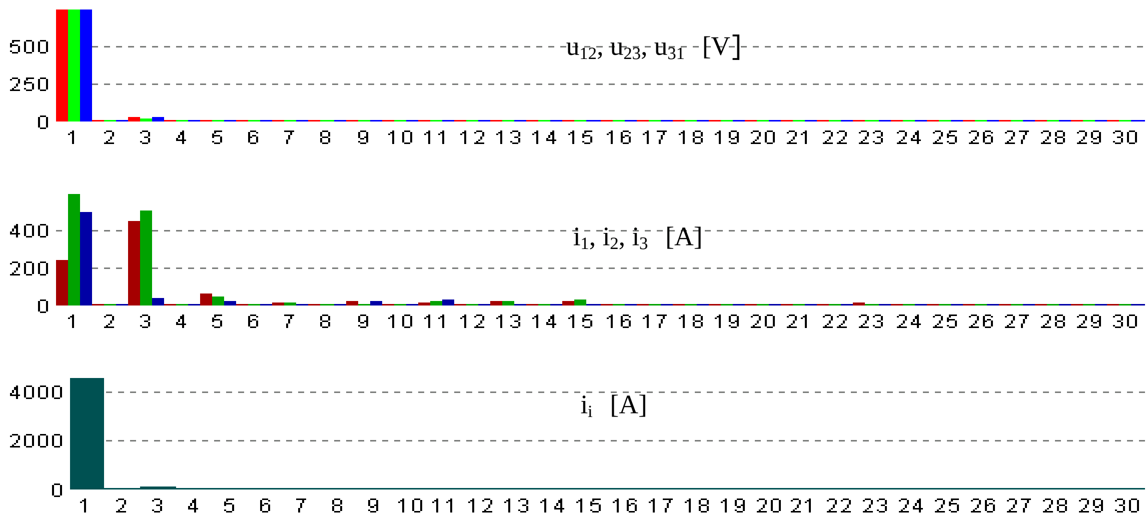

Fig. 7 The harmonic spectra of the signals acquired on the low voltage line *after 5 minutes* from the beginning of the heating process.

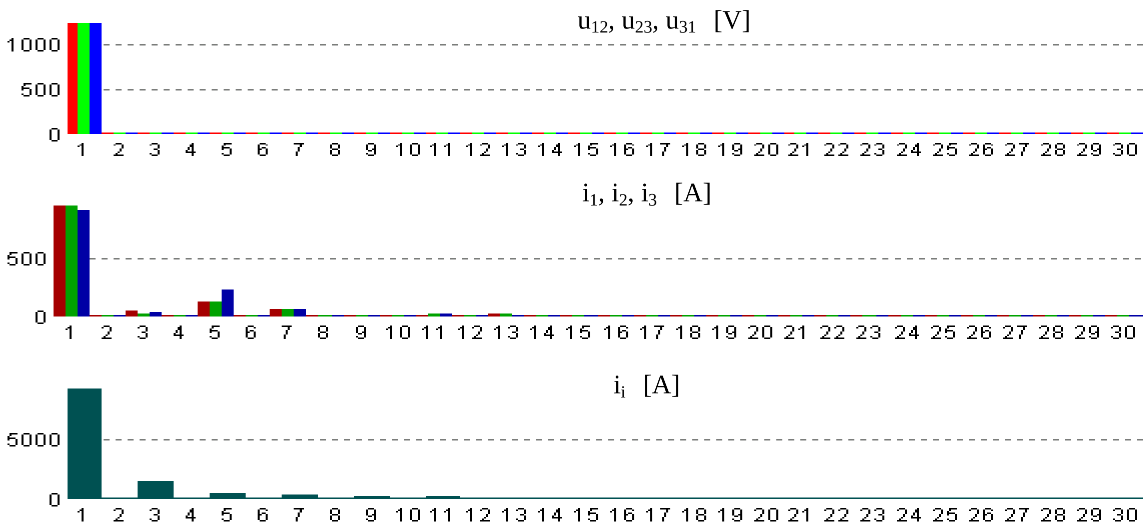

Fig. 8 The harmonic spectra of the signals acquired on the low voltage line *after 4 hours and 38 min.* from the beginning of the heating process.

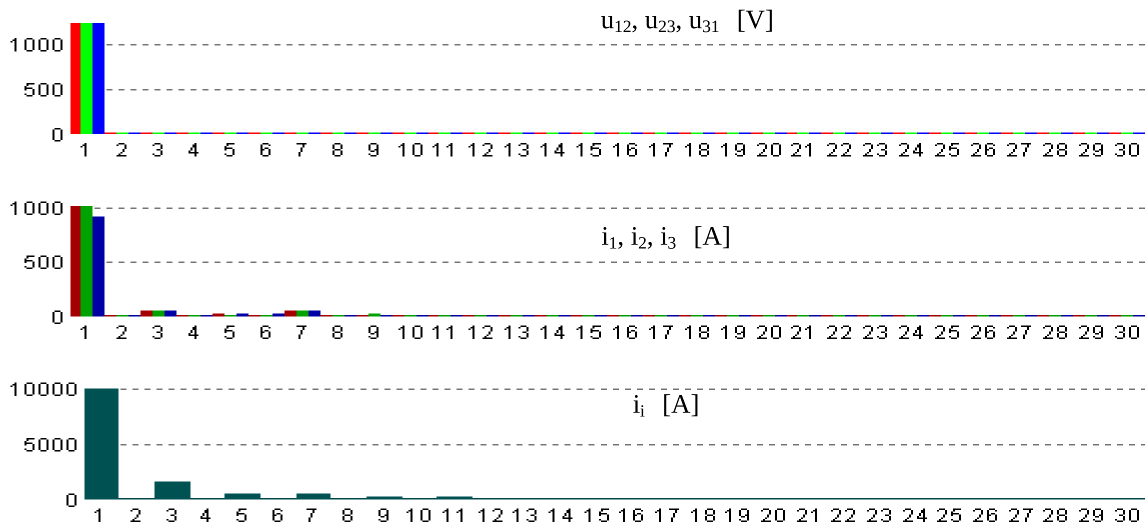

Fig. 9 The harmonic spectra of the signals acquired on the low voltage line *at the end* of the cast-iron's melting process.

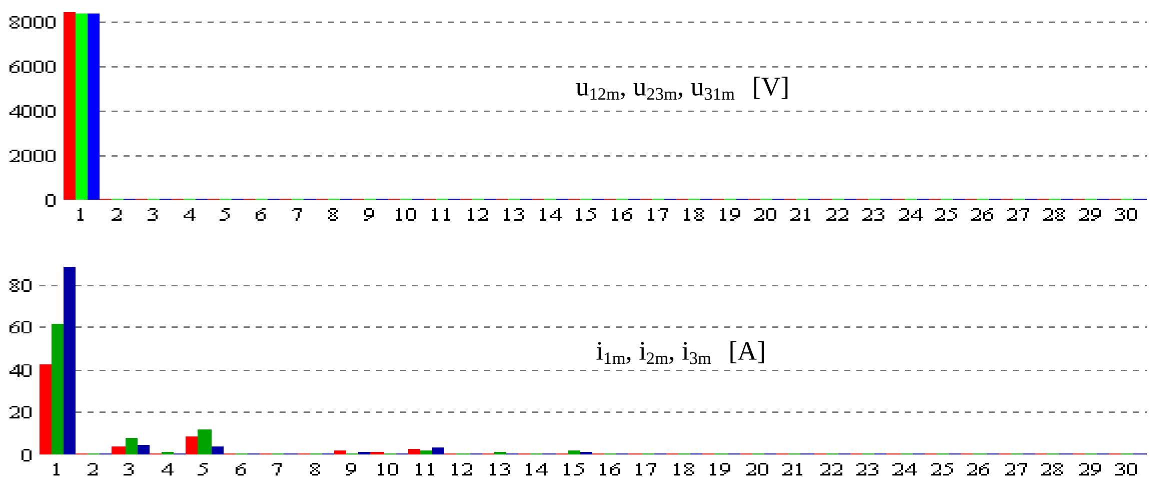

Fig. 10 The harmonic spectra of the signals acquired on the mean voltage line *after 5 minutes* from the beginning of the heating process.

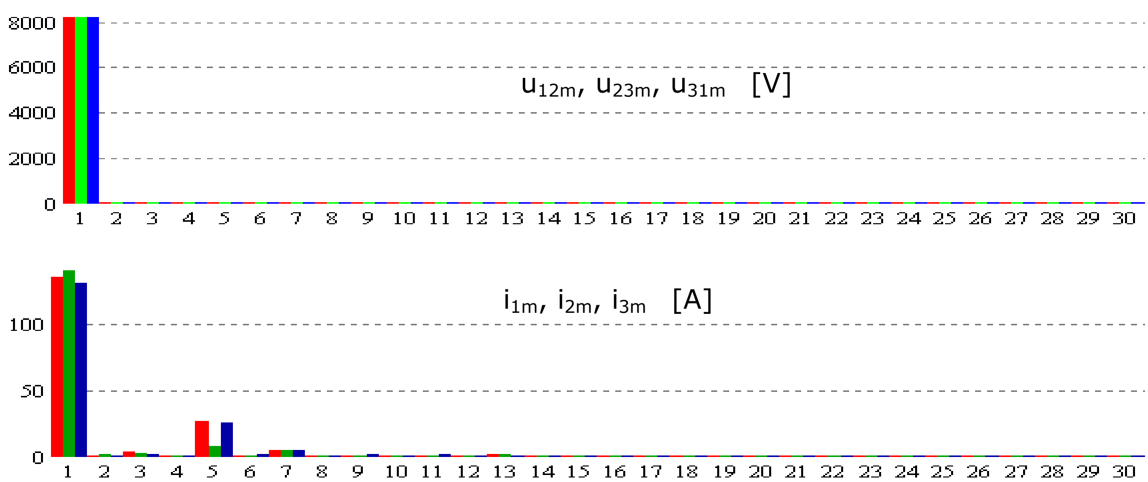

Fig. 11 The harmonic spectra of the signals acquired on the mean voltage line *after 4 hours and 38 min.* from the beginning of the heating.

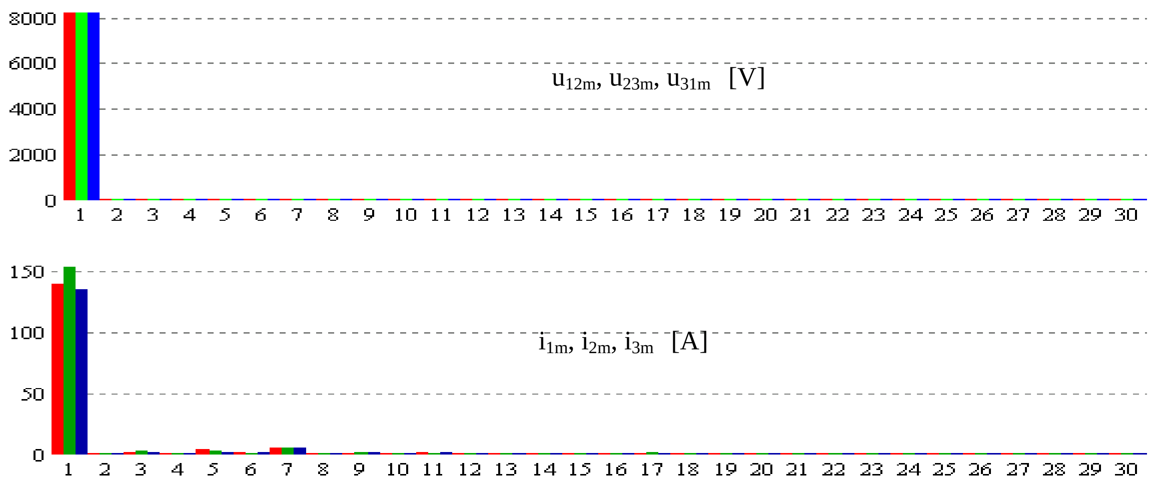

Fig. 12 The harmonic spectra of the signals acquired on the mean voltage line *at the end* of the cast-iron's melting process.

Table 1. Distorsion coefficients for the signals acquired on the low voltage line

Heating moment	THD, THDp	u_{12}	u_{23}	u_{31}	i_1	i_2	i_3	i_i
„Cold" State	THD [%]	3,52	3,01	3,02	193,2	84,65	11,40	2,44
	THDp [%]	8,55	7,84	5,59	342,20	149,50	30,30	7,46
Intermediary regime	THD [%]	1,70	2,40	1,35	15,48	14,55	26,25	17,19
	THDp [%]	6,20	8,15	5,06	37,69	35,72	60,23	33,04
End of melting process	THD [%]	0,51	1,21	0,87	7,24	7,56	8,40	16,87
	THDp [%]	2,01	5,46	3,66	16,83	17,65	20,04	32,57

Table 2. Distorsion coefficients for the signals acquired on the mean voltage line

Heating moment	THD, THDp	u_{12m}	u_{23m}	u_{31m}	i_{1m}	i_{2m}	i_{3m}
„Cold" State	THD [%]	0,274	0,235	0,105	22,84	22,93	7,84
	THDp [%]	0,605	0,522	0,294	52,98	49,87	18,48
Intermediary regime	THD [%]	0,389	0,352	0,641	20,15	7,188	20,05
	THDp [%]	0,883	0,811	1,443	45,34	17,1	45,31
End of melting process	THD [%]	0,148	0,14	0,155	5,32	4,34	5,21
	THDp [%]	0,376	0,375	0,397	13,33	11,39	13,75

Analysing the results from the induction furnace installation's measurements, the following are to be ascertained:

- <u>*on the low voltage supply line*</u>:
  - ❖ in case of *line currents*, *at the beginning* of the cast-iron's heating process, the 3rd, 5th, 7th, 9th, 11th, 13th and 15th harmonics order exceed the compatibility limit levels (4% for $k<11$ and 2% for $11<k<17$, k being the harmonic order [6, 7]), *in intermediary regime*, the 3rd, 5th, 7th harmonics order do not lies within the limits

permitted by norms, and *at the end* of the heating process the 3rd and 7th harmonics order exceed the limits permitted by norms;

- *the distorsion coefficients* of the *line currents exceed the limits permitted* by norms in all the analyzed situations;
- in case of the *current through the inductor*, the levels of the 3rd, 5th, 11th harmonics order do not lies within the limits permitted by norms *in intermediary regime*, and *at the end* of the heating process the levels of the 3rd, 5th, 7th, 11th harmonics order do not lies within the limits permitted by norms;
- *the distorsion of the current through the inductor* is *over the limit permitted* by norms;
- *the line voltages* have *a small distorsion*, being respected the compatibility limit values for the harmonics level, and the *THD* values are within the limits prescribed by norms in all the analyzed situations.

- *on the mean voltage supply line*:
  - *at the beginning* of the cast-iron's heating process, the levels of the 3rd, 5th, 11th, 15th harmonics order from *the line currents* do not lies within the limits permitted by norms;
  - *in intermediary regime* (after 4 hours and 38 min. from the beginning of the cast-iron's heating process), the level of the 5th harmonic order from *the line currents* does not lies within the limits permitted by norms;
  - *at the end* of the cast iron's melting process, the level of the 7th harmonic order from *the line currents* does not lies within the limits permitted by norms;
  - *the distorsion coefficients* of the *line currents exceed the limits permitted* by norms in all the analyzed situations;
  - *the line volatges* have *a small distorsion*, being respected the compatibility limit values for the harmonics level, and the *THD* values are within the limits prescribed by norms in all the analyzed situations.

It is ascertained a much more reduced proportion of the 3-multiple order harmonics in the currents absorbed from the mean voltage network, compared with the proportion of the 3-multiple order harmonics in the line currents from the low voltage line, due to the Δ/Y (Dy-11) connection of the transformer which supplies the analyzed induction furnace.

4. CONCLUSIONS

From the measurements results analysis on the low- and mean-voltage lines it's been found that the operation of the analyzed induction furnace determines electromagnetic disturbances as non-symmetry and harmonics.

In order to eliminate the non-symmetry, it is suggested to add a balanced system in the connection point of the furnace to the network, that should contain only circuit reactive elements [1].

Because the proportions of the 3rd, 5th, 7th, 11th and 15th harmonics order in the currents absorbed from the mean voltage network by the installation of the analyzed induction furnace exceed the limits imposed by the norms, it is necessary to introduce harmonic filters in the transformer's primary through which is made the supply from the mean voltage network.

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