

Harmonic Analysis in Functioning of an Electrothermal Installation with Electromagnetic Induction

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Abstract: - Present paper studies the current harmonic spectrum generated by functioning of an electrothermal installation with electromagnetic induction. In order to analyze the electrical parameters that characterize the electrothermal installation functioning, measurement sets were accomplished using two methods. The first method consists in using a power and energy quality analyzer and the second method uses an acquisition system that contains an adapting interface and a data acquisition board connected to a computer. Paper contains also a simulation of the electrothermal installation functioning realized in PSCAD-EMTDC.

Key-Words: - nonlinear load, harmonic analysis, LabVIEW, PSCAD-EMTDC.

1 Introduction

The power quality problems are generated by many applications of static power electronic converters, fluorescent lamps, arc furnaces and so on. The frequency converters that are used in electrothermal installation sources lead to negative effects in the power distribution such as distortion of the current waveform, additional heating due to the rising of the current effective values [7], [8]. These problems can generate diminished quality in products or services, which lead to high costs for industrial and commercial activities. Nonlinear loads are responsible for the non sinusoidal regime generated into power distribution system. Analyzing the harmonic spectrum represents the first stage in designing the electronic devices that must compensate the distortion regime [15], [16], [17].

2. Description of harmonic analysis system

The electrothermal installation with electromagnetic induction that is studied in this paper is composed by an electronic converter CTC100K15 and a hardening inductor. The electric scheme of the electrothermal installation is presented in figure 1. The electrical characteristics are the followings: supplying voltage $3 \times 400\text{V}$, 50Hz , rated current 27A , control voltage 24Vdc , consumed power at high frequency 15kW . In order to study the harmonic distortion induced into the power system by the electrothermal installation, the current harmonic spectrum was analyzed using two methods [18], [19], [20], [21], [22], [23], [24], [25].

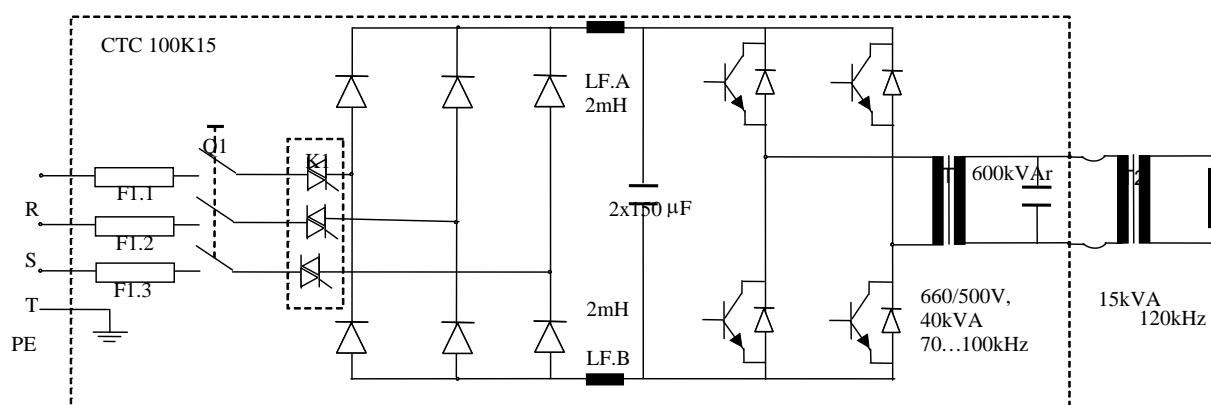


Fig.1. Hardening electrothermal installation.

2.1. Simulation using PSCAD-EMTDC

In the followings the simulation results using PSCAD-EMTDC program are presented. For simulating the power distribution a three phase voltage source was chosen: $U_n = 6kV$, $f = 50Hz$. Power transformer has the following characteristics: $U_{n1}/U_{n2} = 6 / 0,4kV$, nominal power $S_n = 400kVA$.

The electric scheme presented in Fig. 2 contains a thyristor static contactor controlled by a pulse control block. PSCAD model for static contactor command is also shown in figure 2. The alternative voltage is rectified using a diode bridge rectified and a smoothing filter with $L = 1mH$, $C = 300\mu F$.

The inverter consists in four IGBT transistors and the model of inverter command is also presented in figure 2. High frequency transformer T1 has the following characteristics: $U_1/U_2=0,6/0,5kV$, $S_{T1}=40kVA$, $f=100kHz$ and T2 has the following characteristics: $U_1/U_2=0,5/0,1kV$, $S_{T2}=150kVA$, $f=100kHz$. Inductor is modeled using a RL series circuit $R=0,25\Omega$, $L=1\cdot 10^{-7}H$. The variation of current harmonics of 5, 7, 11 and 13 rank and also the total harmonic distortion (THD)

variation are presented in figure 3. The values of these parameters are presented in table 1.

2.2. Current harmonic analysis using CA 8334B

The first method consists in using of a power and energy quality analyzer CA 8334B connected at the interface with the power distribution. Presented device is able to display in real time the electrical characteristics of the electric system that is connected to. As well, parameters in transient and permanent regime and also current and voltage harmonics can be computed [10], [11].

High frequency transformer which supplies the melting inductor, 150kVA, 70-120 kHz has the following transformation ratios: 3:1, 4:1, 5:1, 6:1, 7:1, 8:1, 9:1 and 10:1. The active power can be also adjusted.

In the followings the current harmonic spectrum for 5:1 transformation ratio are presented for the following situation: no-load operation, 4,5kW, 9kW and 15kW (figure 3).

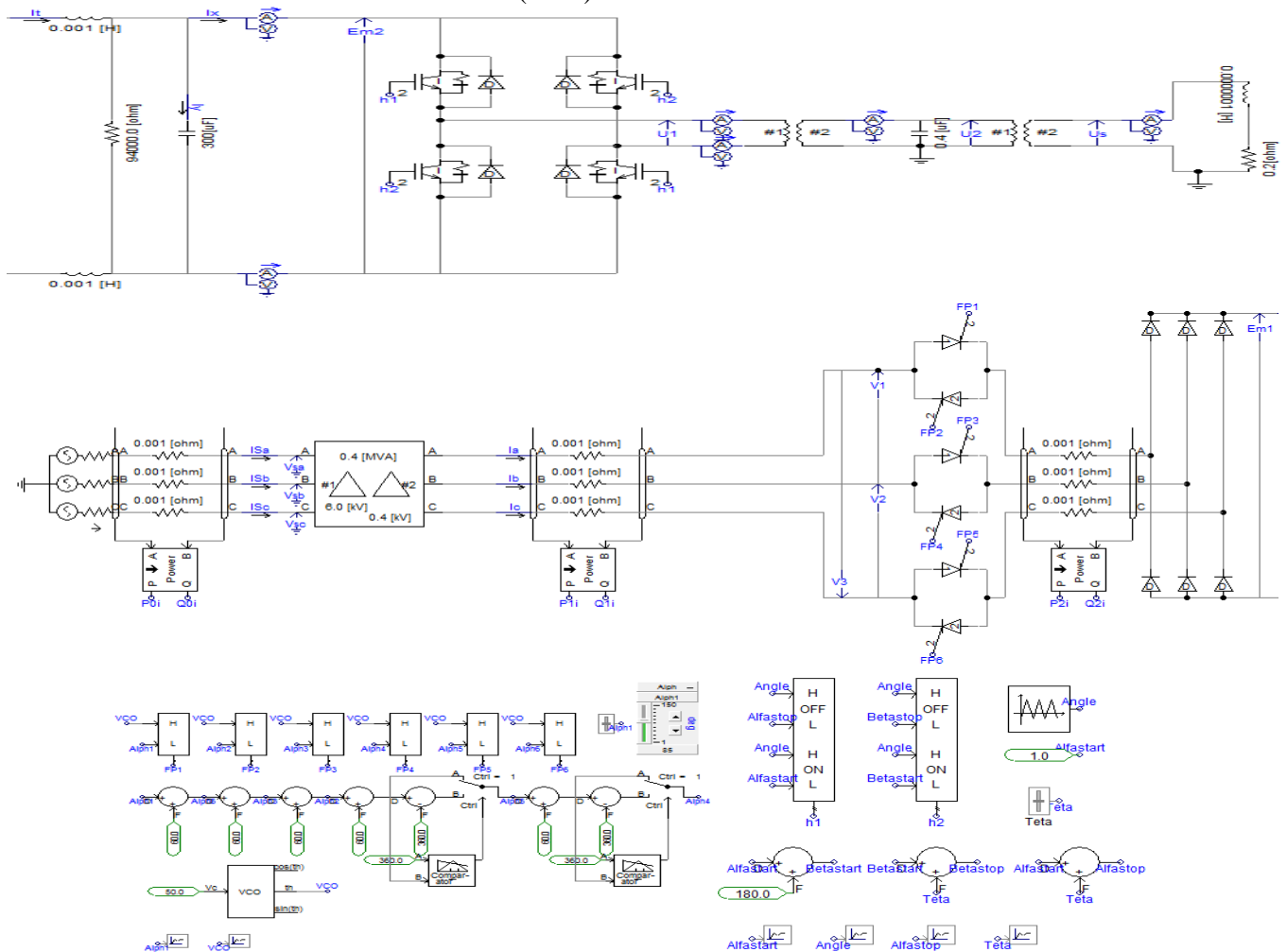


Fig. 2. Electrical scheme of the electrothermal installation (PSCAD-EMTDC simulation).

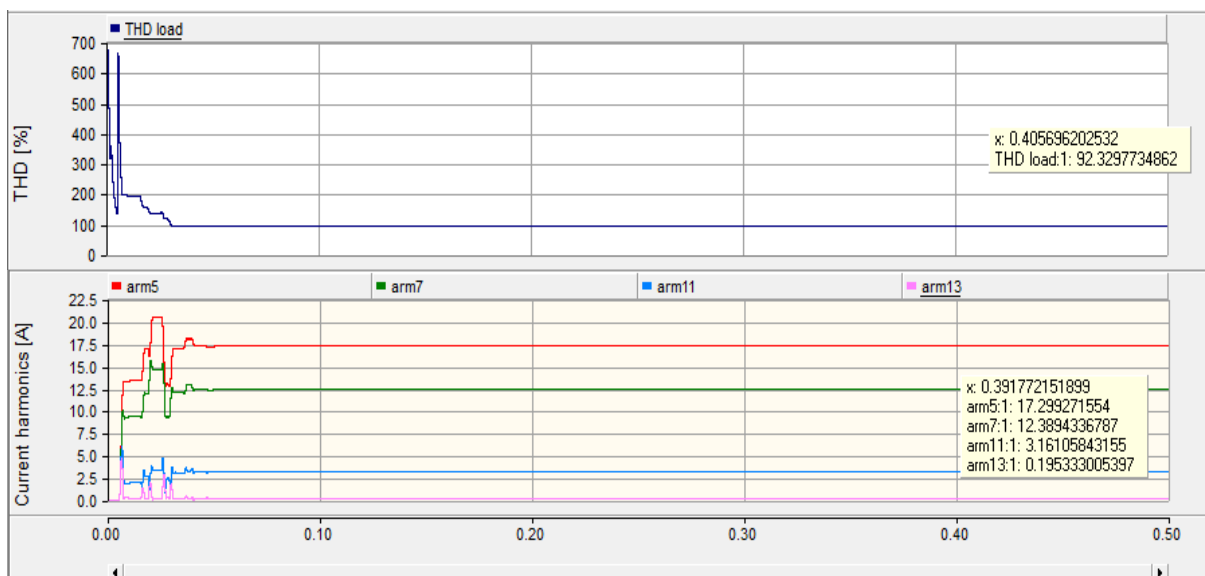


Fig. 3. Variation of current harmonics of 5, 7, 11 and 13 rank and THD (PSCAD simulation, P = 15kW).

Table 1. Values of current harmonics of 5, 7, 11 and 13 rank and THD.

Current harmonics and THD				
I_{arm5} [A]	I_{arm7} [A]	I_{arm11} [A]	I_{arm13} [A]	THD [%]
17,29	12,38	3,16	0,19	92,32

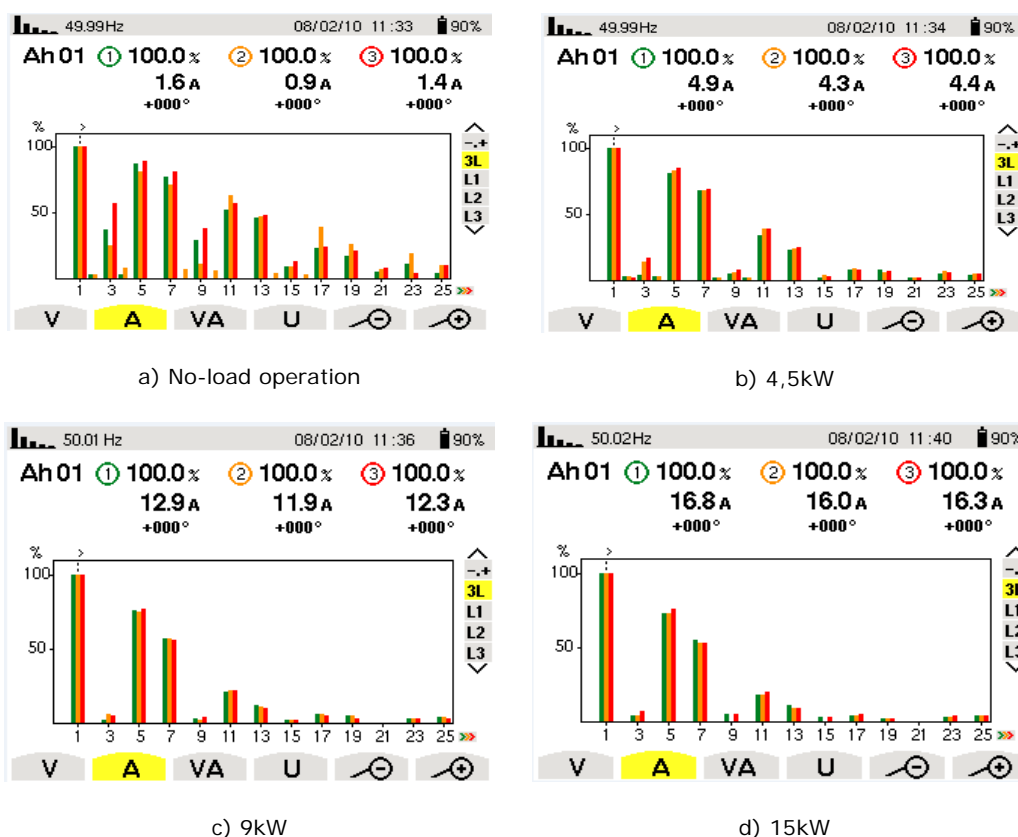


Fig. 3. Current harmonic spectrum acquired with CA 8334B: a) No-load operation; b) P = 4,5kW; c) P = 9kW; d) P = 15kW, transformation ratio 5:1.

In table 2 the effective values of the current harmonics are presented (maximum rank is $k = 25$). The even rank harmonics and the multiple of 3 rank harmonics can be neglected. The effective value of the total current is given by the relation:

$$I_{total} = \sqrt{\sum_{k=1}^{25} I_k^2} \quad [\text{A}] \quad (1)$$

The harmonic distortion of the current curves THD_I is calculated with the following relation:

$$\text{THD}_I = \sqrt{\sum_{k=2}^{25} \frac{I_k}{I_1}}^2 \cdot 100 \quad [\%] \quad (2)$$

where $k = 25$ and represents the current harmonic rank [12], [13], [14].

2.3. Current harmonic analysis using the acquisition system

Harmonic spectrum analyzing was also accomplished using an acquisition system that contains an adapting interface and a data acquisition board connected to a computer [2], [3], [4]. The acquisition of voltage and current signals was made at the interface of the electrothermal installation with the power distribution.

The phase voltage $u_R(t)$, $u_S(t)$, $u_T(t)$, and phase

currents $i_R(t)$, $i_S(t)$, $i_T(t)$ were acquired using the adapting interface which was designed in order to realise the galvanic isolation between the electrothermal installation and the acquisition system and also to accomplish the compatibility of voltage levels.

The data acquisition board has the following characteristics:

- 16 analogic inputs, 250ks/s, 16 bit resolution;
- 2 analogic outputs, 740ks/s, 16 bit resolution;
- 24 TTL digital in/out;
- 1 digital trigger;
- Windows 2000 (NT, XP), Linux compatibility.

The connection of the acquisition system is described in figure 4. In order to process the acquired data, two soft applications designed in LabVIEW 2011 were prepared: *acquisition application* and *computing application*. Using the *acquisition application*, the voltage and current samples are transformed into numeric data and stored into text documents.

This information is loaded by the *computing application* which is able to compute the most important electrical parameters that characterize the functioning of the electrothermal installation. In figure 5 the algorithm of the *computing application* is presented.

Table 2. Current harmonics (effective values) acquired with CA 8334B.

Rank	Current harmonics							
	No-load operation		P = 4.5kW		P = 9kW		P = 15kW	
	[%]	[A]	[%]	[A]	[%]	[A]	[%]	[A]
1	100	1.6	100	4.9	100	12.9	100	16.8
3	34	0.54	6	0.294	3.5	0.451	5	0.84
5	80	1.28	88.5	4.336	85.5	11.029	78	13.104
7	70.5	1.12	62	3.038	59.5	7.675	58.5	9.828
9	27	0.43	5	0.245	2.5	0.327	5	0.84
11	44.5	0.71	41.5	2.033	26.6	3.43	22.5	3.78
13	42.5	0.68	25	1.22	15	1.935	17.5	2.94
15	6.5	0.104	2.5	0.122	4	0.516	4	0.672
17	19.5	0.312	11.5	0.563	6	0.774	5	0.84
19	15.5	0.248	12	0.589	6	0.774	2.5	0.42
21	4	0.064	4	0.196	0	0	0	0
23	8	0.128	7.5	0.367	4	0.516	2.5	0.42
25	2.5	0.04	7.5	0.367	3.5	0.451	5	0.84
I_{total} [A]	2.667		7.669		19.098		24.022	
THD_I [%]	133.381		120.397		109.16		102.211	

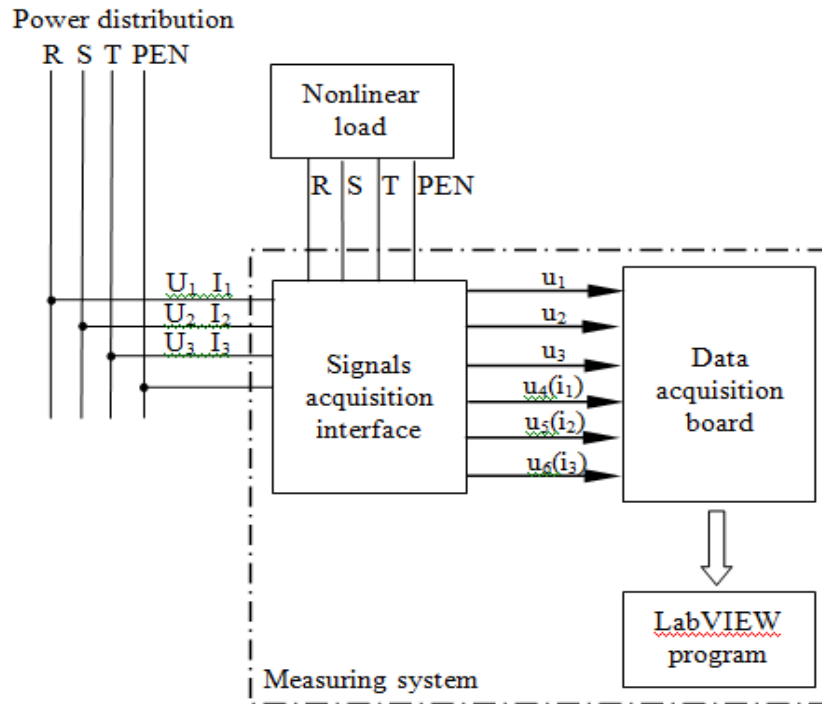


Fig. 4. Acquisition system connection.

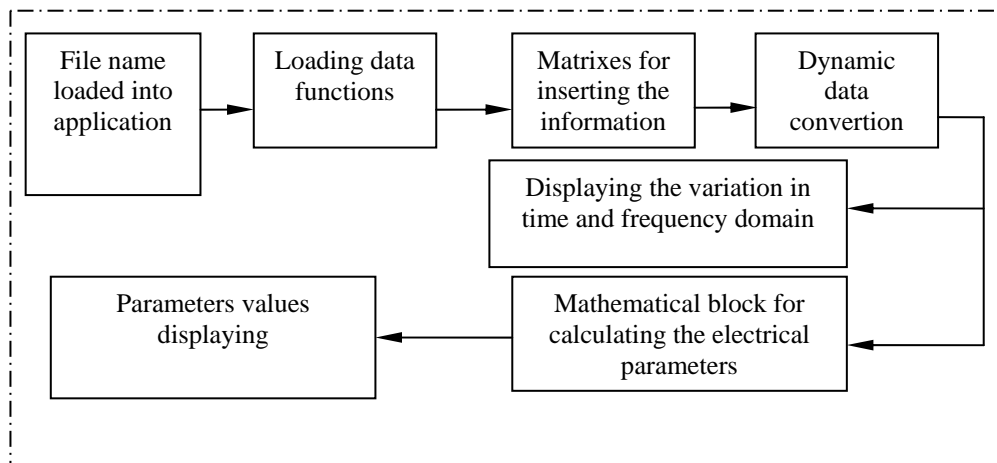


Fig. 5. Computing application block scheme.

In the followings the mathematical relation for computing the electrical parameters are presented.

The active power of i phase is computed with the relation:

$$P(i) = \sum_{k=1}^{50} U_{efk}(i) \cdot I_{efk}(i) \cdot \cos \Phi(i) \quad (3)$$

The reactive power of i phase is computed with the relation:

$$Q(i) = \sum_{k=1}^{50} U_{efk}(i) \cdot I_{efk}(i) \cdot \sin \Phi(i) \quad (4)$$

In relations (12) and (13). k represents the harmonic rank.

The harmonic voltage on i phase is computed as in the relation:

$$U_{thd}(i) = \frac{\sqrt{\sum_{n=2}^{50} U_{harm}(i,n)^2}}{U_{harm}(i,1)} \quad (5)$$

The harmonic current on i phase is computed as in the relation:

$$I_{thd}(i) = \frac{\sqrt{\sum_{n=2}^{50} I_{harm}(i,n)^2}}{I_{harm}(i,1)} \quad (6)$$

where N is the number of samples / period and i is the phase.

The total values of the active and reactive powers are computed as in the following relations:

$$P = \sum_{i=1}^3 P_i \cdot Q = \sum_{i=1}^3 Q_i \quad (7)$$

The total apparent power is computed as:

$$S = 3 \cdot U_{ef} \cdot I_{ef} \quad (8)$$

The distorted power is computed as in the relation:

$$D = \sqrt{S^2 - P^2 - Q^2} \quad (9)$$

The total values of the harmonic voltages and currents are computed as in the followings:

$$U_{thd} = \sqrt{\frac{U_{thd(1)}^2 + U_{thd(2)}^2 + U_{thd(3)}^2}{3}} \quad (10)$$

$$I_{thd} = \sqrt{\frac{I_{thd(1)}^2 + I_{thd(2)}^2 + I_{thd(3)}^2}{3}} \quad (11)$$

In figure 6 the 3phase measuring system subroutine is represented.

In figure 7 the scheme of measuring on each phase is depicted and the subroutine that computes the currents and voltage spectrum is presented in the figure 8. The front panel of the application is presented in figure 9.

In figure 10 is presented the voltage and current harmonic spectrum that were recorded in the following conditions: active power adjusted at 4.5kW, 9kW and 15kW with transformation ratio 5:1. Table 3 synthesizes the current harmonic amplitudes that were generated with the acquisition system and table 4 shows the total harmonic distortion for the current curves computed by the acquisition system.

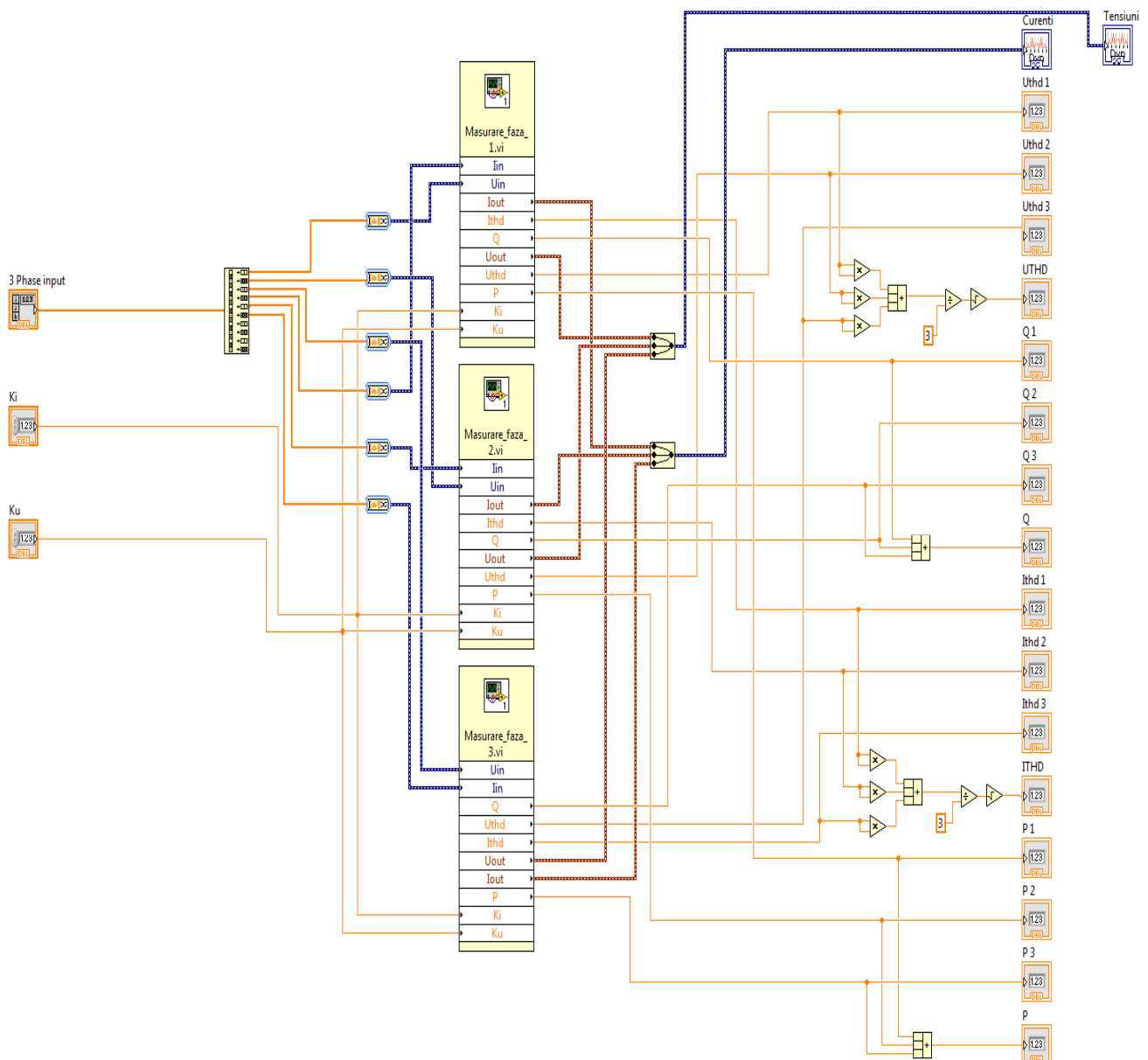


Fig. 6. 3phase measuring system subroutine.

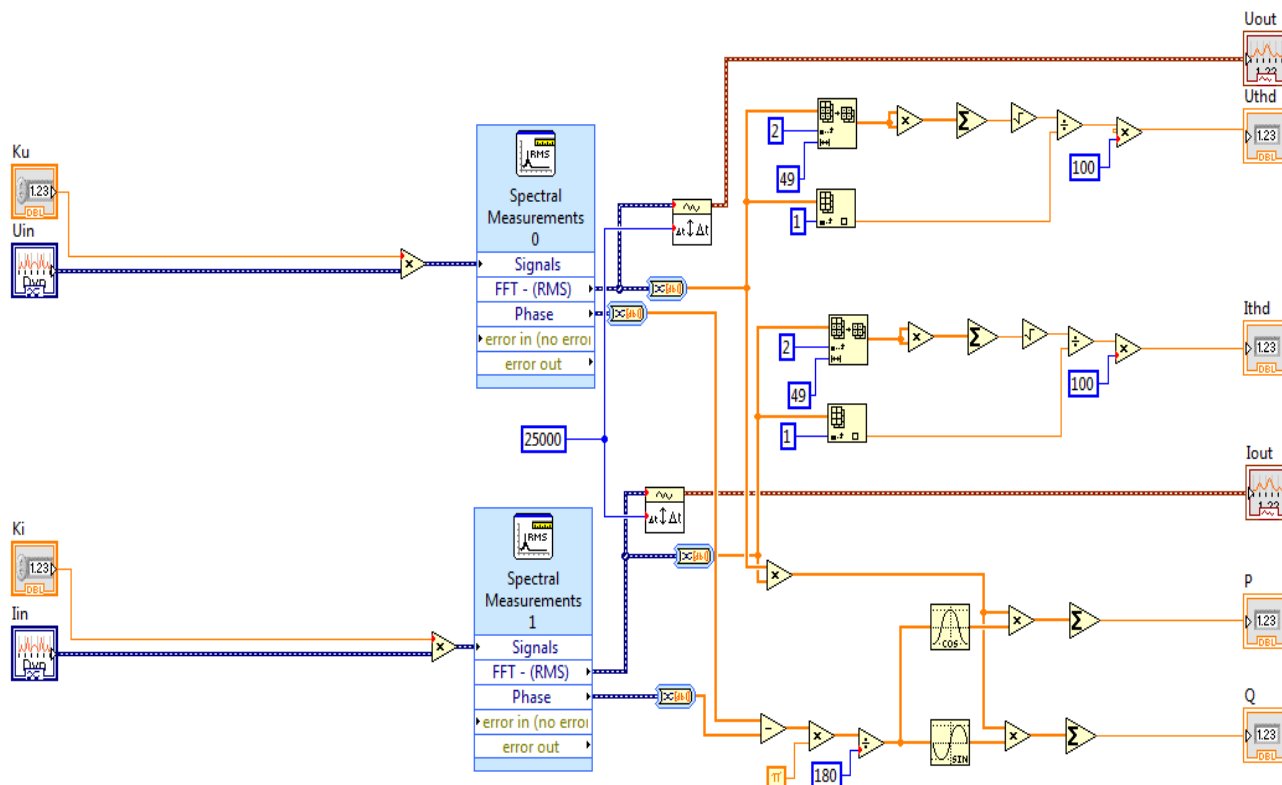


Fig. 7. LabVIEW code for measuring the electrical parameters on each phase.

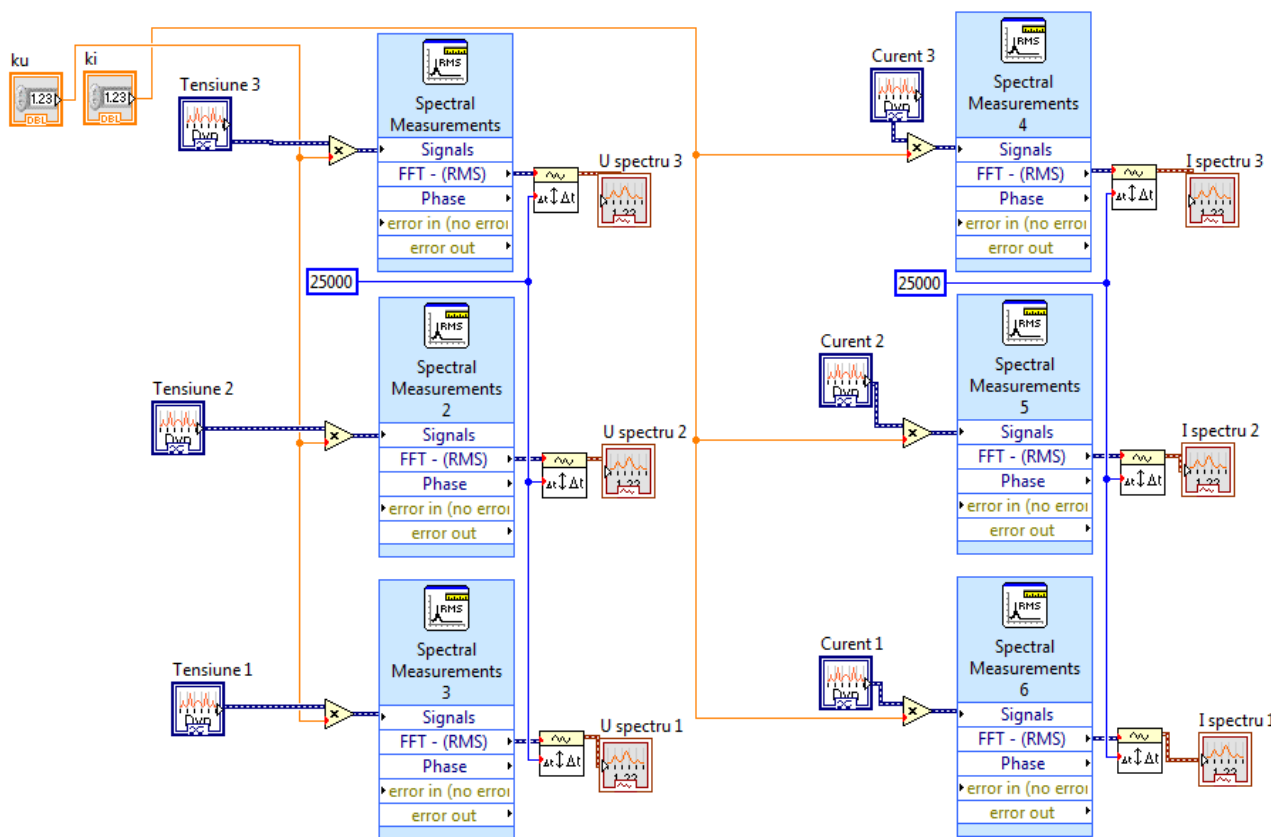


Fig. 8. LabVIEW code for computing the current and voltage spectrum.

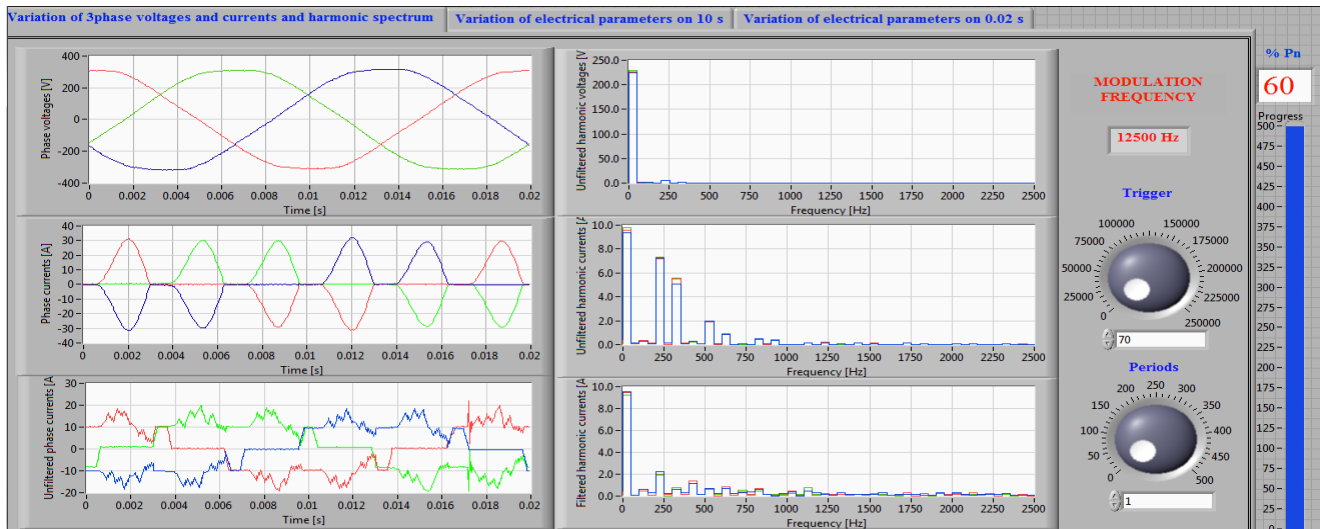


Fig. 9. Front panel of the application.

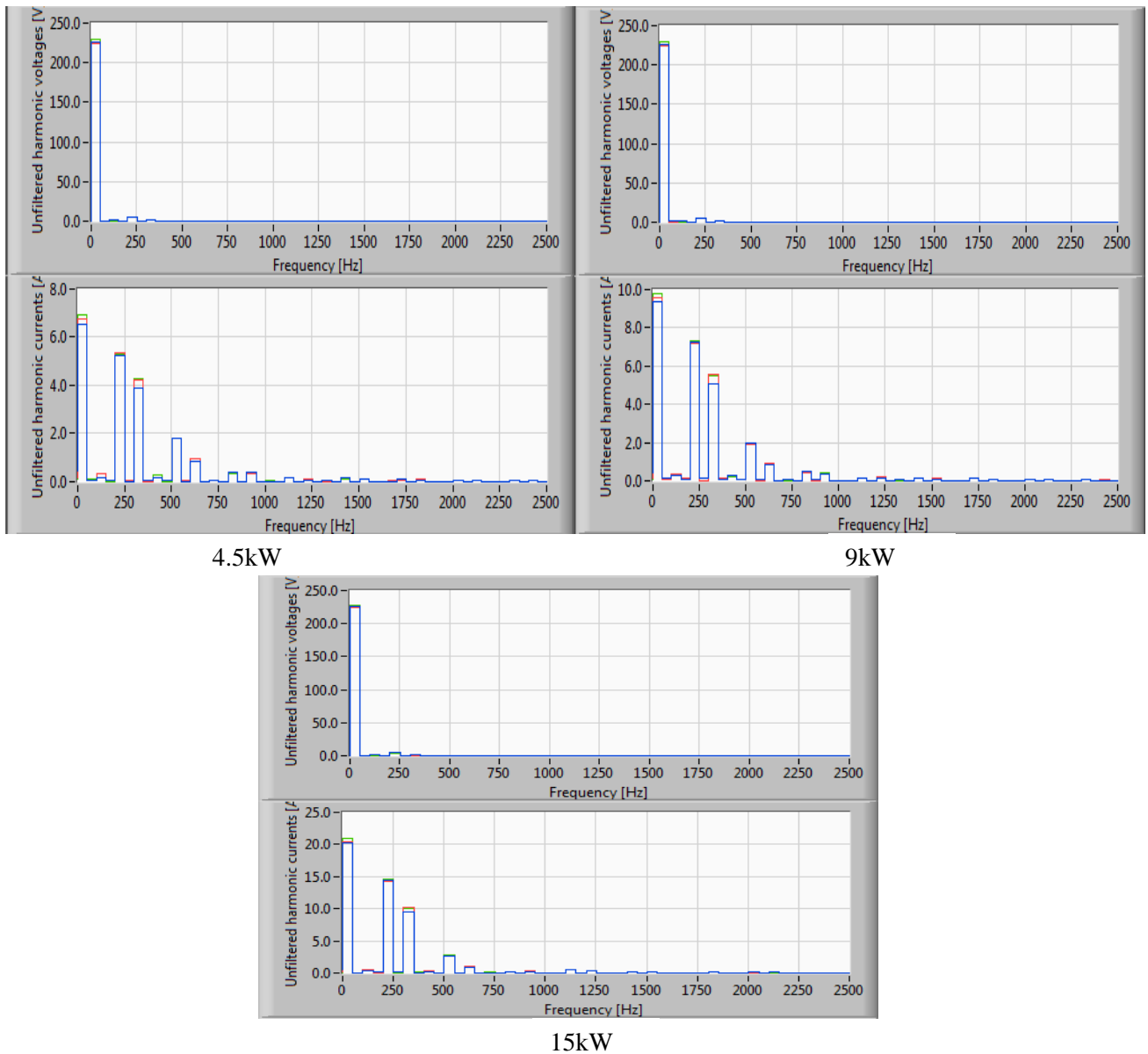


Fig. 10. Current and voltage harmonic spectrum generated with the acquisition system.

Table 3. Current harmonic amplitudes generated with the acquisition system.

Active power [kW]	Harmonic currents [A]										
	Rank										
	1	3	5	7	9	11	13	15	17	19	21
4.5	5	0.4	4	3.1	0.1	1.5	0.8	0.1	0.3	-	-
9	14	-	10	7	-	2	1	-	-	-	-
15	20	-	15	10	-	3	2	-	-	-	-

Table 4. Total harmonic distortion for the current curves generated with the acquisition system.

Computed parameter	Active power of the installation [kW]		
	4.5 (30% P _n)	9 (60% P _n)	15 (100% P _n)
THD for currents [%]	105.14	88.41	89.88

3. Conclusions

Harmonic analyzing is very necessary for designing the electronic devices which must compensate the distorted regime introduced into the power system by the nonlinear loads. This paper proposes three different and accessible methods for following the variation in time and frequency domain of the most important electric parameters that characterize the functioning of an electrothermal installation with electromagnetic induction.

Using PSCAD-EMTDC simulations of the electric equipments functioning can be accomplished. So, the command and control elements for the electrothermal installation were modeled. The PSCAD EMTDC is able to display the variation of the 5th, 7th, 11th and 13th current harmonics.

Acquisition with CA8334B power analyzer represents a very practical method for studying in real time of the electrical parameters variation. As well, this method generates the variation of current and voltage harmonics when the electrothermal installation is functioning at 4.5kW, 9kW and 15kW. From Table 2 can be concluded that the total harmonic distortion for phase currents reaches high values that step over 133%.

Data acquisition system which is described in the third method presents the advantage of permanent improvement concerning the soft applications that compute in real time the electrical parameters. The present method follows the variation of the phase current spectrum when the electrothermal installation is functioning at 4.5kW, 9kW and 15kW.

Modeling and simulation are essential tools in many areas of science and engineering, for example in Netlogo language [9].

Using both data acquisition methods, the variation of the current harmonics are displayed.

The nonlinear load described in this paper represents a current harmonics source. Following the results, the distortion of the current curves falls below the standard limits and the current harmonics must be compensated using appropriate devices [1], [5], [6].

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