Study regarding the non-sinusoidal regime imposed by nonlinear loads

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Abstract. Present paper represents a study concerning the variation of the phase voltages and phase currents acquired from the point of common coupling (PCC) during the functioning of an electro thermal installation with electromagnetic induction. The variation of the electrical parameters is followed on 0.02 seconds and also on 10 seconds using three methods. First method consists in modeling and simulation the electric scheme of the electro thermal installation. The second method uses a power quality analyzer and the third method is using a data acquisition system that contains an adapting interface and a data acquisition board connected to a computer. The variation of the phase voltages and phase currents and also their total harmonic distortions are presented. The electro thermal installation that is studied in this paper is a laboratory device. The technique implies reduce costs and the presented results are very useful in studying the distorting regime generated into the power network by the current harmonic sources.

1. Introduction
The presence of distorting regime into the power distribution leads to the increasing of power loss, to improper functioning of the communication systems or problems in functioning of the electronic equipment. The most unfavourable effects of the distorting regime are presented in the followings:
- overloading the capacitor banks used for power factor compensation;
- increasing the apparent power due to the distorting power;
- increasing the active power loss due to Joule – Lenz effect, determining overheating the electrical lines and the electric machines;
- improper functioning of the protection devices.

Analysing of the electrical parameters acquired during the functioning of nonlinear loads is very necessary for designing the power conditioning devices [1-2].

2. Description of the electro thermal installation
Analysing the electric parameters acquired during the functioning of nonlinear loads is very necessary for designing the power conditioning devices. A simplified scheme of the electrothermal installation is presented in Figure 1.

The electronic converter CTC 100K15 has the following characteristics [2-4]:
- supplying voltage 3 x 400 V, 50 Hz;
- rated current 27 A;
- control voltage 24V DC;
- consumed power at high frequency 15 kW;
- voltage value at medium frequency 500 V AC.

The hardening inductor is supplied from two high frequency toroidal transformers:
- T1: 660/500 V, 40 kVA, 70-100 kHz;
- T2: 150 kVA, 70-120 kHz with primary winding voltage of 500V and variable transformation ratio of 3:1, 4:1, 5:1, 6:1, 7:1, 8:1, 9:1 and 10:1. The electro thermal installation contains three coil shape inductors for hardening process.

![Electro thermal installation with electromagnetic induction](image)

**Figure 1.** Electro thermal installation with electromagnetic induction

### 3. Methods used for studying the parameters variation

#### 3.1. Modelling and simulation the electro thermal installation

In order to simulate the functioning of the electro thermal installation, PSCAD-EMTDC program was used. For simulating the power distribution a three phase voltage source was chosen: \( U_n = 6 \text{ kV}, f = 50 \text{ Hz} \). Power transformer has the following characteristics: \( U_{n1}/U_{n2} = 6/0.4 \text{ kV} \) and nominal power \( S_n = 400 \text{ kVA} \). The electric scheme presented in Figure 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 \( L = 1 \text{ mH}, C = 300 \mu \text{F} \). The inverter consists in four IGBT transistors and the model of inverter command is presented in Figure 2. High frequency transformer T1 has the following characteristics: \( U_1/U_2=0.6/0.5 \text{ kV}, f_1=100 \text{ kHz} \) and T2 has the following characteristics: \( U_1/U_2=0.5/0.1 \text{ kV}, ST_2=150 \text{ kVA}, f=100 \text{ kHz} \). Inductor is modeled using a RL series circuit \( R=0.25 \text{ } \Omega \) and \( L=1 \times 10^{-7} \text{ H} \). The phase currents that must be studied are measured using the ammeters \( I_a, I_b, I_c \) from Figure 2.

The variation of the phase currents measured at the PCC of the electro thermal installation with the power distribution is presented in Figure 3. The nominal power of the electro thermal installation is 15 kW.

From this figure can be observed that the distortions of the phase voltages can be neglected, but the variation of phase currents (THDI) is strongly distorted from the sinusoidal form, as in Table 1.

| Phase voltages (RMS) [V] | Phase currents (RMS) [A] | THDI [%] |
|--------------------------|--------------------------|----------|
| 233.3                    | 35                       | 78.8     |

**Table 1.** PSCAD simulation for phase voltages, phase currents and THDI
Figure 2. Electrical scheme of the electro thermal installation (PSCAD-EMTDC simulation)

Figure 3. Phase voltages phase currents and THD for phase currents obtained by simulation in PSCAD (P = 15kW)
3.2. Data acquisition using CA8334B power analyser

CA8334B is a power quality analyser which is able to acquire in real time samples of phase voltages and phase current and also computes several electric parameters [5]. In this case the analyser has been connected to the PCC of the nonlinear load with the power distribution.

In Figure 4 the variation of phase voltages, phase currents and THD for phase currents is presented in situations when the active power is: no load operation, 4.5 kW, 9 kW, 15 kW. In Table 2 the values of these electrical parameters are related. Phase currents and phase voltages are processed when the acquisition period of the power analyzer is 0.1 ms. The variation of THD for phase currents is processed with the acquisition period of 1s and the following conclusions can be generated. The variation of THD presents 3 stages.

The first stage is characterized by high values of power when the piece temperature is reaching Curie point. The duration of the first stage is depending of active power; therefore it is decreasing with the increasing of the active power. In the second stage, the piece temperature is increasing to hardening point and in the third stage the piece is extracted from the inductor.

| Absorbed power [kW] | Phase voltages (RMS) [V] | Phase currents (RMS) [A] | THDI [%] |
|---------------------|--------------------------|--------------------------|----------|
| No load             | 229.8                    | 2.8                      |          |
| 4.5                 | 228                      | 6.9                      | 130      |
| 9                   | 228.2                    | 10.3                     | 126      |
| 15                  | 229.8                    | 29.6                     | 120      |

Figure 4. Phase voltages, phase currents and THD for phase currents acquired with CA8334B
3.3. Description of data acquisition system

Data acquisition system also follows the acquisition of samples from phase voltages and phase currents at the point of common coupling. In order to accomplish the acquisition, an adapting block and a data acquisition board connected to a computer were used. The connection of data acquisition system to PCC is presented in Figure 5a.

The phase voltages and phase currents were acquired using the adapting interface which was designed in order to realize the galvanic isolation between the electro thermal installation and the data acquisition system and also to realize the compatibility of voltage levels.

The data acquisition board has the following characteristics:
- 16 analogic inputs, with 250 kS/s and 16 bit resolution;
- 2 analogic outputs, with 740 kS/s and 16 bit resolution;
- 24 TTL digital in/out;
- 1 digital trigger;
- Windows, Linux compatibility.

In order to process the acquired data, two software applications designed in LabVIEW 2011 were used: 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 electro thermal installation. The algorithm of the computing application is presented in Figure 5b.

Using appropriate subroutines, 10 analogical input channels were configured. Because the maximum sampling rate is 250 kS/s, the maximum sampling rate for a single channel is 25 kS/s.

The number of samples for a single period results from the relation:

\[ n = f_s \cdot T = 25kS/s \cdot 0.02s = 500 \text{ samples} \]

The acquisition is developed on 10 seconds interval. The number of samples acquired on each channel is 250000.

Using presented applications, 10 measurement sets were accomplished by increasing with 10% the power of electro thermal installation.

In Figure 6 the variation on 0.02 seconds and 10 seconds for phase voltages and phase currents is presented. As well, Figure 6 contains the variation on 0.02 seconds for THD for phase voltages and phase currents when the absorbed power of the power installation is 4.5 kW, 9 kW and 15 kW.

Some observations must be made. In figures that represents the variation form of the currents and voltages (on period of 0.02 seconds), phase 1 is red, phase 2 is green and phase 3 is blue.

For the other variations on 10 seconds, the colour signification is: black for all three phases, red for phase 1, green for phase 2 and blue for phase 3.

In Table 3 are synthesized the electrical parameters obtained by accomplishing 10 measurement sets using data acquisition system.

Studying the variation from Figure 6, it can be concluded that the total harmonic distortion for the phase currents reaches high values, comparable with the others obtained with the previous methods. These values are decreasing with the increasing of the absorbed power.

The total harmonic distortion for phase voltages is approximately constant during the variation of the absorbed power of the installation.

4. Conclusions

The electro thermal installation that is described in this paper represents a laboratory device. The electromagnetic pollution generated by its functioning deserves high importance. In order to study the variation of the electrical parameters at the point of common coupling with the power distribution during the functioning of the electro thermal installation, three methods were accomplished.
### Table 3. Electrical parameters obtained with data acquisition system

| Absorbed power [kW] | Phase voltages (RMS) [V] | Phase currents (RMS) [A] | THD voltages [%] | THD currents [%] |
|---------------------|--------------------------|--------------------------|------------------|------------------|
| 1.5                 | 226.5                    | 3.5                      | 2.95             | 140              |
| 3                   | 227                      | 6                        | 2.8              | 120              |
| 4.5                 | 226.5                    | 10                       | 2.65             | 105              |
| 6                   | 226.6                    | 10.5                     | 2.7              | 105              |
| 7.5                 | 226.5                    | 11                       | 2.65             | 100              |
| 9                   | 226.5                    | 13                       | 2.5              | 98               |
| 10.5                | 226.3                    | 15.5                     | 2.4              | 95               |
| 12                  | 227                      | 19                       | 2.35             | 92               |
| 13.5                | 227                      | 24                       | 2.1              | 90               |
| 15                  | 226.5                    | 27                       | 2                | 85               |

**Figure 5.** a) Connection of data acquisition system at PCC, b) Computing application block scheme

Using PSCAD-EMTDC, simulations of the electric equipment’s functioning can be accomplished. So, the command and control elements for the electro thermal installation were modelled. As can be seen from Figure 3, the variation of phase voltages, phase currents and THD for phase currents are presented. The voltage system is balanced and symmetrical. The phase voltages present a neglected distortion from the sinusoidal form, so the Figure 3 presents only the variation of the total harmonic distortion for the phase currents. By simulation the functioning of the electro thermal installation when the absorbed power is 15 kW, the THD for phase currents are 87.7 %, falling below standard limits of 8 %.

Acquisition with CA8334B power analyser represents a very practical method for studying in real time of the electrical parameters variation. From Figure 4 results a sinusoidal variation for phase voltages.
Figure 6. Phase voltages, phase currents and THD for phase voltages and phase currents acquired with data acquisition system
The phase currents are deeply distorted and this fact demonstrates that the electro thermal installation represents a current harmonic source. The RMS value of the phase currents is increasing with the increasing of the absorbed power. At 15 kW, RMS value of the phase currents is 29.6 A. The total harmonic distortion for phase currents exceeds 120%. These values fall below standard limits of 8%.

Data acquisition system which is described in the third method presents the advantage of permanently improvement concerning the soft applications that compute in real time the electrical parameters. The application displays the variation on 0.02 seconds and 10 seconds of the phase voltages, phase currents and THD for phase voltages and phase currents. Studying Figure 6, can be concluded that the voltages are balanced and symmetrical (the same conclusion from the second method) and THD for phase voltages are approximately constant and can be neglected. By studying Figure 6, we can observe that the variation on 10 seconds presents the same three stages described in the second method. Studying Table 3, the RMS values of the phase currents are increasing (3.5 – 27 A) and the THD for phase currents are decreasing (140 – 85 A) with the increasing of the absorbed power. Even in this situation, the values of THD for phase currents fall below standard limits. The most important conclusion is that the current harmonics must be compensated using appropriate devices [6-10].

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