Power variation during the functioning of nonlinear load

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Abstract. Present paper studies the variation of active, reactive, distorted and apparent powers measured during the functioning of an electro thermal installation with electromagnetic induction. In order to analyze these electrical parameters, measurement sets were accomplished using two methods. The first method is based on using a power quality analyzer and the second method consists in using a data acquisition system that contains an adapting interface and a data acquisition board connected to a computer.

1. Introduction
Distorted regime intensification into the power system implies important repercussions on the electrical parameters that characterize the functioning of the electric equipment that must work in sinusoidal regime. Some equipment is sensitive to voltage or current variation distortion and others are sensitive to the presence of some particular harmonic.

Circulation of the harmonic currents determines additional loss into the power network, increasing in this way the technological consumption. This fact leads to reducing the performances of the electrical machines, overvoltage, or electromagnetic interferences over telecommunication network. Analysing of the electrical parameters acquired during the functioning of nonlinear loads is very necessary for designing the power conditioning devices [1-3].

2. Description of electrical power analysis system
The electro thermal installation with electromagnetic induction that is studied in this paper is composed by an electronic converter CTC100K15 and a hardening inductor. The electrical characteristics are the followings: supplying voltage 3 x 400 V, frequency of the supplying voltage 50 Hz, rated current 27 A, control voltage 24 Vdc, consumed power at high frequency 15 kW, voltage at medium frequency 500 Vac. In order to study the variation of electrical powers, two methods were accomplished.

2.1. Electrical power analysis using CA 8334B
The first method consists in using of a power quality analyzer CA8334B connected to the point of common coupling on 0.4 kV. The analyzer is able to display in real time the electrical characteristics of the electric installation that is connected to. As well, parameters in transient and permanent regime and also current and voltage harmonics can be computed.

In Figure 1 the variation of active and reactive power is represented. As well, the variations of the total harmonic distortion of the phase voltage and phase currents are presented. The sampling period of the acquisition of active and reactive power is 1 second and the acquisition duration is 67 seconds.
The measurements were accomplished on the maximum power level. THD is computed using Fast Fourier Transformer of phase voltages and phase currents samples. In Figure 1, W represents the active power, VAR represents the reactive power, Athd and Vthd represent the total harmonic distortion of the phase currents and phase voltages. Studying the Figure 1, it can be noticed that in the hardening process of a steel piece, the variation of the active and reactive powers 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, i.e. it is decreasing with the increasing of the active power. In the second stage the piece temperature is increasing to hardening point, active and reactive powers being approximately constant and in the third stage the piece is extracted from the inductor and the powers is decreasing to zero.

\[ P = 4.5\text{kW} \]
\[ P = 15\text{kW} \]

**Figure 1.** Variation of active and reactive powers and THD for the phase voltages and currents (acquisition with CA8334B)
The same stages are also presented in variation of the total harmonic distortion of the phase currents where can be observed that THD is decreasing when the installation is in load operation. This can be explained by the increasing of the fundamental component in load operation.

A very important notice is referring to powers measurement possibility of CA8334B analyser. This analyzer indicates apparent power \( S \), active power \( P \) and reactive power \( Q \). This means that in situation in which the distorted power \( D \) is significant, when the analyser indicates a reactive power \( Q \), this \( Q \) means \( \sqrt{Q^2 + D^2} \). This fact leads to the wrong conclusion about the real value of the measured reactive power in situations in which the distorted power is significant irrespective to reactive power. The measurement results which are obtained using CA8334B analyser are presented in Table 1. These measurements results were made when the electro thermal installation works on 4.5 kW and 15 kW.

| Phase | L_1 [V] | L_2 [V] | L_3 [V] | L_1 [A] | L_2 [A] | L_3 [A] |
|-------|---------|---------|---------|---------|---------|---------|
| 4.5 kW| 395.5   | 398.6   | 397     | 399.2   | 402.3   | 400.7   |
| 15 kW |         |         |         |         |         |         |
| U_{\text{phase}} [V] | 228.4 | 229.7 | 229.7 | 230 | 231.8 | 231.8 |
| THD_{\text{phase}} [%] | 4.3 | 4.2 | 4.2 | 3.9 | 3.9 | 3.9 |
| I_{\text{phase}} [A] | 7.7 | 6.6 | 6.8 | 31.1 | 31.1 | 31.1 |
| \( \sqrt{Q^2 + D^2} \) | 3625.52 | 15210 |
| PF (cos\( \phi \)) [-] | 0.67 | 0.66 | 0.65 | 0.7 | 0.7 | 0.7 |

From Table 1 it can be observed that the phase currents and phase voltages are balanced and also it can be concluded that the power supplying system is balanced. Another conclusion is referring that when the active power is on the maximum level, the analyser indications referring to the reactive power are almost the same.

2.2. Electrical power analysis using the data acquisition system

Electrical power analyzing was also accomplished using a data acquisition system that contains an adapting interface and a data acquisition board connected to a computer [4-6]. The acquisition of voltage and current signals was made at the point of common coupling. 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 realize the galvanic isolation between the electro thermal installation and the data acquisition system and also to realize the compatibility of voltage levels.

In order to process the acquired data, two soft 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. 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:

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

\((1)\)
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 2 the LabVIEW code of the computing application is presented. In Figure 3 the LabVIEW code for computing the electrical parameters and in figure 4 the front panel of the application is presented.

In Figure 5 the displaying parameters subroutine is depicted.

In Figures 6, 7 and 8 the variation of active, reactive, distorted and apparent powers and THD for phase currents and phase voltages when the electro thermal installation is functioning at 4.5 kW, 9 kW and 15 kW is presented.

The acquisition is developed on 10 seconds. Figures 6, 7 and 8 contain also the variation of phase voltage and currents on 0.02 seconds (power network period).

Some observations must be made. In figures that represent 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.

In Figures 6, 7, 8, on 3 phase powers menu are represented the electric powers of the electro thermal installation: apparent power S (black), active power P (red), reactive power Q (green) and distorted power D (blue). For the other menus with variation on 10s, the variation for all three phases (black), phase 1 (red), phase 2 (green) and phase 3 (blue) is represented.

By analysing variations from Figures 6, 7, 8, observations concerning the measurements using data acquisition system can be made. Studying the variation on 0.02 seconds, can be observed that the phase currents are deeply distorted and the variation of phase voltage is almost sinusoidal.

The same conclusion can be made from the variation of THD of the phase currents (85% before reaching the Curie point and 110% after that) and phase voltages (2% before reaching the Curie point and 3% after that). Studying the power variation, can be concluded that the distorted power is significant, 12 kVAd, comparing with the reactive power of 2 kVAR.

However, the resulting component from the composition of distorted and reactive powers, \( \sqrt{Q^2 + D^2} \), is comparable with the component measured with CA8334B analyser.

A very important conclusion is that a data acquisition system makes possible to measure the distorted power and CA8334B is not able to realize the distorted power acquisition.

In table 2 is synthesized the variation of the studied parameters increasing the power of the installation with 10%, using data acquisition system.

3. Conclusions

This paper proposes two different and accessible methods for following the time variation of the most important electric parameters that characterize the functioning of an electro thermal installation with electromagnetic induction.

The main conclusion is based on important possibility offered by data acquisition system. Using the samples acquired from phase voltages and phase currents, the present system is able to compute correctly the values of reactive and distorted powers. This opportunity leads to correct designing of the harmonic filters and the reactive power compensation system as well. On the other hand, the power quality analyser CA8334B offers correct information about the variation of apparent and active powers, THD for phase voltages and phase currents, even it is not able to separate the reactive from distorted powers.

From the powers variation can be observed that the distorted power is very significant comparing to the reactive power, so another conclusion is that the current harmonic spectrum contains harmonics with high amplitudes. Therefore, an important necessity is the power quality improvement at the point of common coupling using harmonic compensation devices. Analysing the information from Table 2, is observed a decreasing of THD for phase voltages (low values 2-3%) with the increasing the installation power.
Figure 2. Computing application LabVIEW source code
Figure 3. LabVIEW code for computing the electrical parameter

Figure 4. Front panel of the application
Figure 5. Displaying parameters subroutine

Figure 6. Variation of active, reactive, distorted and apparent powers, THD for phase voltages and currents, P = 4.5 kW
Figure 7. Variation of active, reactive, distorted and apparent powers, THD for phase voltages and currents, P = 9 kW

Figure 8. Variation of active, reactive, distorted and apparent powers, THD for phase voltages and currents, P = 15 kW
Table 2. Variation of electrical parameters using data acquisition system

| Installation power [kW] | Phase voltage [V] | Phase current [A] | Active power [W] | Reactive power [Var] | Distorted power [VAd] | Apparent power [VA] | THD voltages [%] | THD currents [%] |
|-------------------------|-------------------|-------------------|------------------|----------------------|-----------------------|---------------------|----------------|-----------------|
| 1.5                     | 226.5             | 3.5               | 1300             | 180                  | 1750                  | 2187                | 2.95           | 140             |
| 3                       | 227               | 6                 | 2700             | 300                  | 3100                  | 4122                | 2.8            | 120             |
| 4.5                     | 226.5             | 10                | 4700             | 500                  | 4800                  | 6737                | 2.65           | 105             |
| 6                       | 226.6             | 10.5              | 4800             | 500                  | 4900                  | 6878                | 2.7            | 105             |
| 7.5                     | 226.5             | 11                | 5500             | 750                  | 5300                  | 7675                | 2.65           | 100             |
| 9                       | 226.5             | 13                | 6200             | 800                  | 6000                  | 8665                | 2.5            | 98              |
| 10.5                    | 226.3             | 15.5              | 7500             | 1000                 | 7000                  | 10308               | 2.4            | 95              |
| 12                      | 227               | 19                | 9500             | 1500                 | 8500                  | 12835               | 2.35           | 92              |
| 13.5                    | 227               | 24                | 11500            | 1700                 | 10000                 | 15334               | 2.1            | 90              |
| 15                      | 226.5             | 27                | 14000            | 2000                 | 12000                 | 18547               | 2              | 85              |

As well, THD for phase currents has a slow decreasing, but maintaining high values (85-140%).

Comparing the results obtained by both methods can be concluded that during the acquisition, the effective values of phase voltages are constant. The current values and the power factor are increasing with the increasing of the absorbed power of the installation. The total harmonic distortion of the voltage waveform is situated below standard limits (8%). The variation of phase current acquired at the point of common coupling is deeply distorted from sinusoidal shape, so THD can reach 140%. Following the results, the distortion of the current variation falls below the standard limits and the current harmonics must be compensated using appropriate devices [7-9].

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