Energetic Analysis of the Drying Process of Current Transformers from 110 kV Ciungetu Power Station

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***Abstract* - Currently, at company Hidroserv Râmnicu Vâlcea, the drying of current transformers used in power transformer stations is done by a combination between induction and conduction heating at the frequency of 50 Hz. Obviously, this solution is outdated in terms of technology and the performed energetic analysis proves it. In order to achieve the design of a multifunction static system intended to replace the existing one, so as to respond as best as possible to the specific needs, it is necessary to analyze the drying process from energetic point of view. The knowledge of the equivalent parameters of the loads is needed too. To substantiate the feasibility of this new technical solutions, the goal of the paper is the analysis of the actual technology from energetic point of view. Considering that the current transformer of the 110 kV power station Ciungetu is the typical load, experimental determinations relating to the its drying process have been performed. Two heating coils are used, of 33 turns and 38 turns, respectively. In order to determine the associated parameters for both coils, the current and voltage across the equivalent induc tor have been recorded by using an oscilloscope Tektronix TDS3000. It is obvious, and the performed energetic analysis demonstrates this, the solution currently used is outdated in terms of technology.**

Keywords: *current transformer, electric drying, experimental recording, harmonics, numeric filtration.*

I. INTRODUCTION

In the operation of current transformers from transformer stations of hydropowers, their resistance of isulation can become lower that the limits imposed by norms. Consequently, it is necessary to dry them. The wetting of the insulation can be due to the loss of tightness between component parts and to the atmospheric moisture penetration because the insulating oil is hygroscopic.

The Norm PE116/94 for tests and measurements on electrical equipment requires that, for current transformers working at voltages in the domain 110 kV – 400 kV, the insulation resistance value to be greater than 5000 MΩ. Otherwise, their connection to the line voltage is not allowed.

The drying of the current transformers can be done through various methods: by outdoor heating, by heating with current from an independent source, by heating with short-circuit current, through ventilation, through active iron losses into the transformer. In cases where through a certain method it fails to obtain the necessary drying temperature or when heating of different parts is not uniform, two methods are combined [1], [2].

Currently, at Hidroserv Râmnicu Vâlcea, a combination of the induction heating at the industrial frequency and the conduction heating is the adopted solution to dry the current transformers used in the power transformer stations. Given the technological processes that use heating, in order to have a high degree of flexibility, it is considered that a static multifunction system is required. It could provide both DC and AC energy and, in the same time, allow the adjustment of the frequency and power level [3] - [13].

After introduction, this paper contains three background sections and ends with some conclusions.

In the following section, the structure currently used for drying by induction and conduction heating is presented and some details on the apparatus used for recording the current and voltage are given.

The next section is dedicated to the processing of the recorded data, needed for the graphical representation and harmonic analysis. Because the waveforms contain high frequency noise, their filtration is done with first order filters having the cutting frequency of 10 kHz.

Then, the electric powers in system and the total power factor are calculated by using both unfiltered and filtered waveforms. Finally, some conclusions are drawn.

II. EXPERIMENTAL SETUP

The current transformer that must be dried is covered with an insulating film of textolit, over which a coil that has shape of a truncated cone is achieved (Fig. 1). The size of the obtained coil depends on number of its turns.

The conductor used is made of flexible copper class 5 according to EN 60228, profile stranded (wire diameter of 0.51 mm), with an outer diameter of 15.8 mm. In this way, the parameters' variation depending on the frequency can be neglected.

The power supply is ensured by using the autotransformer of a source for welding capable to adjust the output voltage in large limits.

Two structures of the induction heating coil have been achieved, as follows:

1. Coil with 33 turns, when the rms values of the voltage and current are 59 V and 150 A;
2. Coil with 38 turns, when the rms values of the voltage and current are 56 V and 130 A.

In order to determine the associated parameters for both coils, the current and voltage across the equivalent induc-

Fig. 1. Detail about the drying of current transformers in actual technology.

tor have been recorded by using an oscilloscope Tektronix TDS3000. The current has been recorded by a shunt 0.5mΩ/100mV precision class 0.2% [14]. The acquisition frequency was 100 kHz.

For the subsequent use in the calculation of the parameters, the waveforms of the two quantities have been filtered by means of first order filters having a period of 10^{-4} seconds. Thus, a significant attenuation of the high order harmonics has been achieved (Fig. 2).

It is estimated that the value of 10^4 rad/sec for the cutting pulsation represents an acceptable compromise between the mitigation of the high order harmonics and how the phases of the first 31 harmonics are affected. Thus, for a lower value of the cutting pulsation, the mitigation of the high order harmonics could be more pronounced, but the phases' changing of the first 31 harmonics would become inacceptable. Conversely, a higher value of the cutting pulsation would not mitigate sufficiently the magnitude of the high order harmonics.

III. WAVEFORMS AND HARMONIC ANALYSIS

As it can be seen in Fig. 3a), the waveform of the acquired current in the case of the coil with 33 turns contains harmonics of high frequency. Their presence is due to the induced voltages by the electromagnetic disturbances existing in the external environment.

The harmonics spectra of the raw and filtered waveforms of the current show that the harmonics up to order 31 have very little influence and the most apparent of these are of orders from 2 to 6 and 11 (Fig. 4).

Two indicators have been taken into consideration to quantify the degree of harmonic distortion, i.e. [15], [16]:

- The total harmonic distortion factor (*THD*),

$$THD = \sqrt{\left(\frac{I}{I_1}\right)^2 - 1}\,, \tag{1}$$

where I and I_1 are the global rms value of the current and the fundamental rms value, respectively;

- The partial harmonic distortion factor (*PHD*),

$$PHD = \frac{\sqrt{\sum_{k=2}^{N} I_k^2}}{I_1}\,, \tag{2}$$

where N is the order of the last harmonic taken into consideration.

It was obtained that the total harmonic distortion factor for the unfiltered wave is 6.33% and the partial harmonic distortion factor corresponding to the first 31 harmonics is 2.63%.

As regards the filtered waveform of the current, the total distortion factor is 3.8% and the partial harmonic distortion factor associated to the first 31 harmonics is 2.54%. It can be seen that the last one is slightly lower than the corresponding value related to the unfiltered wave (2.63%). It follows that the filtering process does not affect the low order harmonics, impacting on energetic quantities.

As illustrated in Fig. 5, the high frequency noises contained in the acquired waveform of the voltage are lower. The harmonic spectrum shows that the highest weight corresponds to the harmonics 2, 3, 5 and 11 (Fig. 6a).

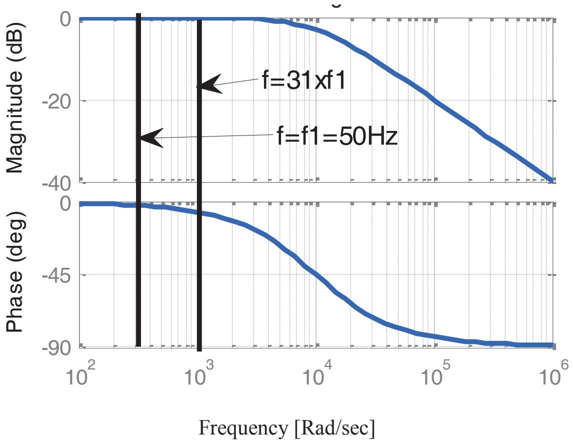

Fig. 2. Bode diagrams of the first order filter.

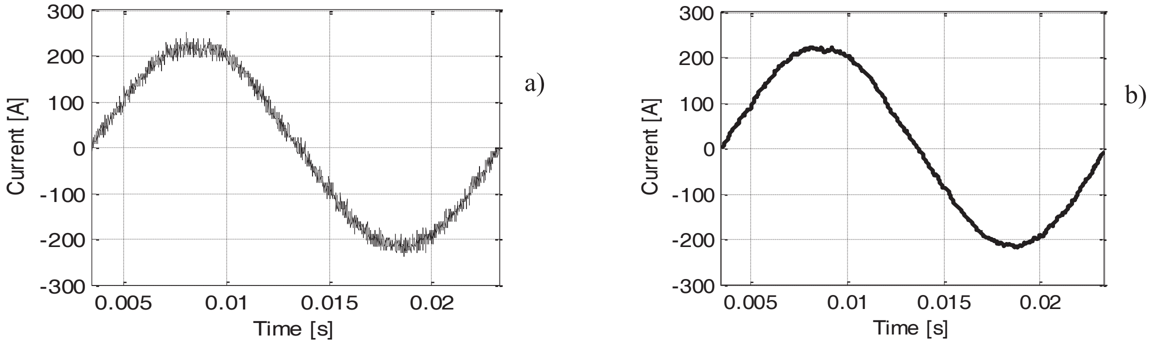

Fig. 3. The waveform of current for the coil with 33 turns: a) recorded; b) filtered.

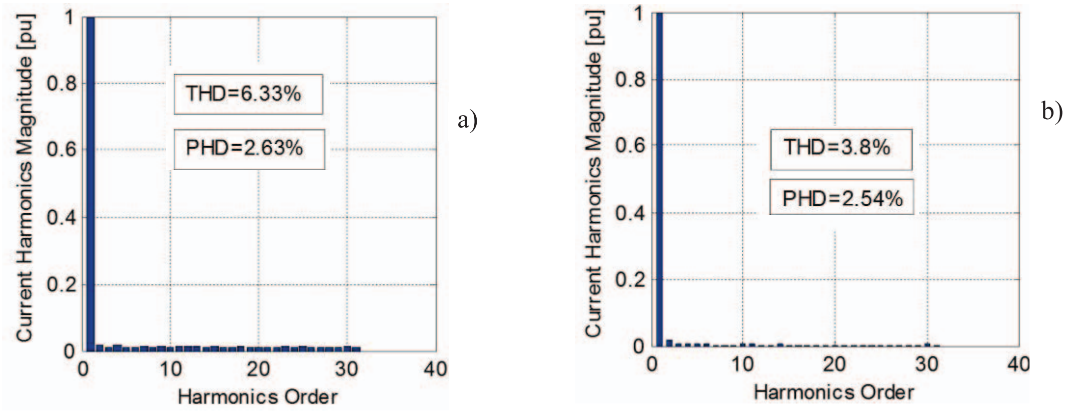

Fig. 4. Harmonic spectra of the current (p.u.) for the coil with 33 turns: a) for the acquired wave; b) for the filtered wave.

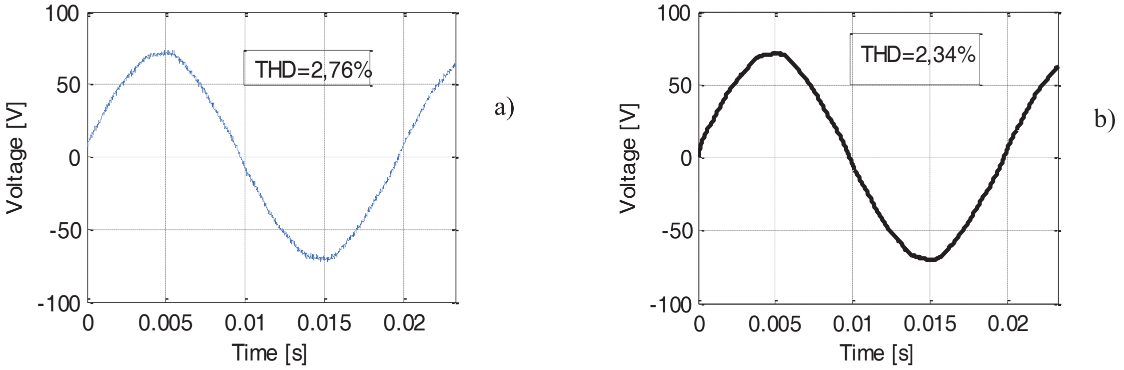

Fig. 5. The waveform of voltage for the coil with 33 turns: a) recorded; b) filtered.

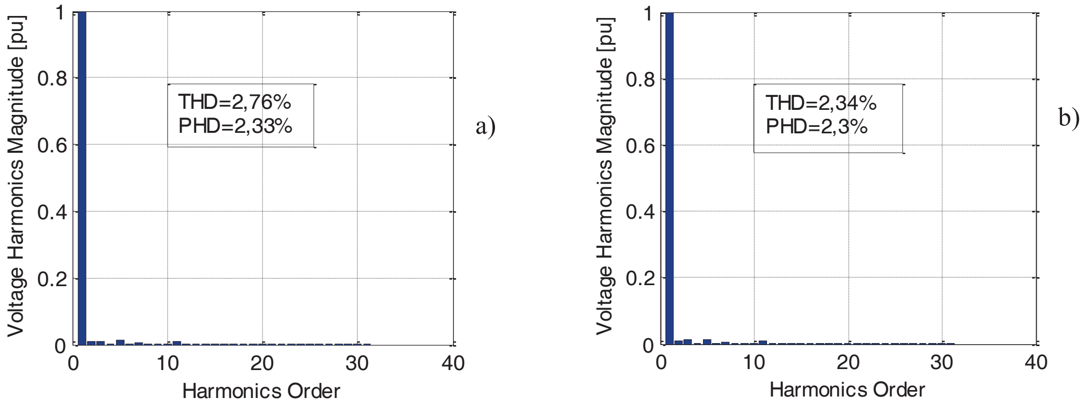

Fig. 6. Harmonic spectra of the voltage (p.u.) for the coil with 33 turns: a) acquired wave; b) filtered wave.

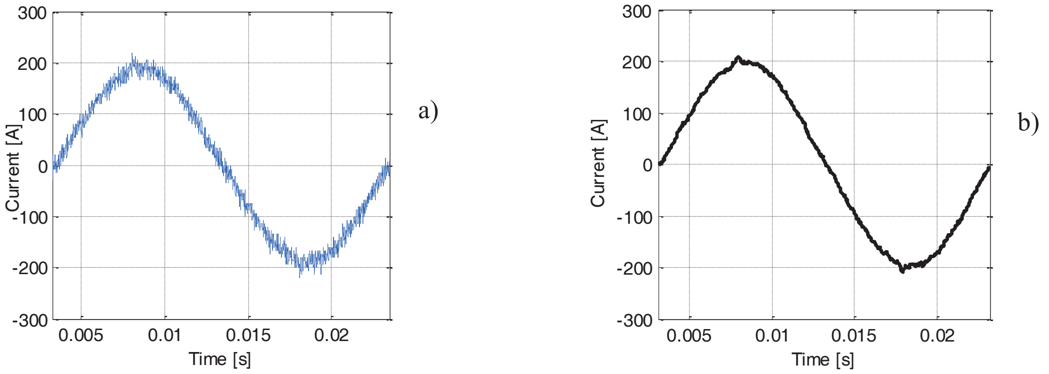

Fig. 7. The waveform of current for the coil with 38 turns: a) recorded; b) filtered.

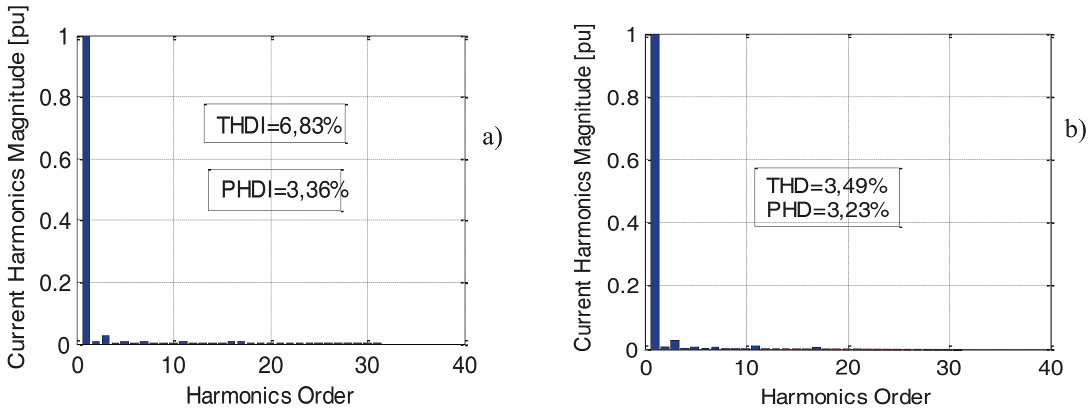

Fig. 8. Harmonic spectra of the current (p.u.) for the coil with 38 turns: a) acquired wave; b) filtered wave.

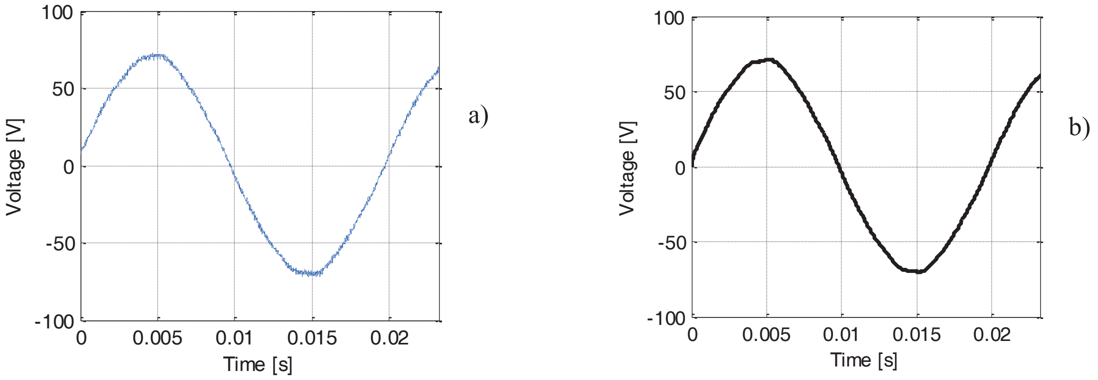

Fig. 9. The waveform of voltage for the coil with 38 turns: a) recorded; b) filtered.

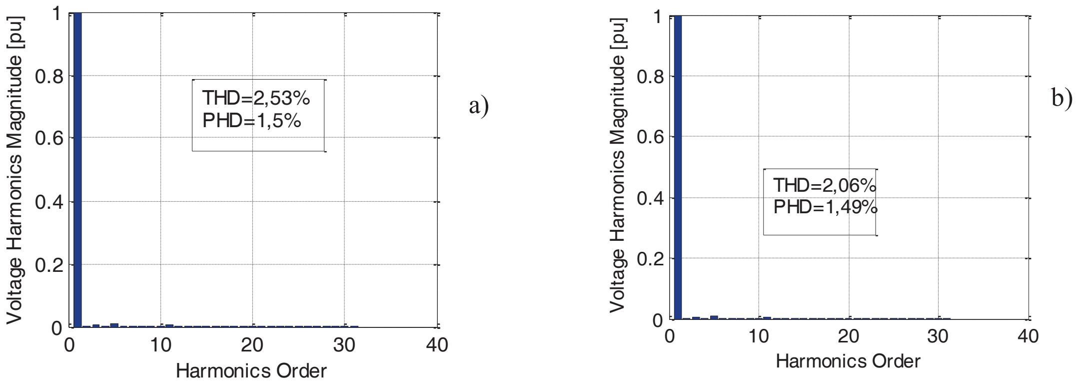

Fig. 10. Harmonic spectra of the voltage (p.u.) for the coil with 38 turns: a) acquired wave; b) filtered wave.

The total harmonic distortion factor of the unfiltered and filtered waves of voltage is 2.76 % and 2.34 % respectively. The partial distortion factors by considering only the first 31 harmonics have the values 2.33 % for the raw wave and 2.3 % for the filtered wave.

As it can be seen from Fig. 4b) and Fig. 6b), the weight of harmonic of order 31 is 0.12 % for voltage and 0.15 % for current. This aspect and the very close values of the partial harmonic distortion factors show that the consideration of the first 31 harmonics is enough.

In the case of the 38 turns coil, the phenomena are similar in terms of quality aspects (Fig. 7-Fig. 10). There are, however, few quantitative differences, as follows:

- The total harmonic distortion of the current is 6.83 % for the acquired wave and 3.49 % after filtration;
- The partial harmonic distortion of the current is 3.36 % for acquired wave and 3.23 % for after filtration;
- The total harmonic distortion of the voltage is lower, respectively it is 2.53 % for the unfiltered wave and 2.06% for the filtered wave;
- The partial harmonic distortion of the voltage is lower, that is 1.5% for unfiltered wave and 1.49% for filtered wave;
- The weight of the harmonic voltage of order 31 is about 0.066 %;
- The weight of the harmonic current of order 31 is about 0.35 %.

It must be mentioned that the measurements for the two coils were performed on different days. Accordingly, the supply conditions were not identical. Even the frequency of the supply voltage was different, namely 50.5 Hz in the case of coil with 33 turns and 50 Hz in the case of coil with 38 turns.

IV. ENERGETIC ANALYSIS

In order to perform the energetic analysis, the active power (P), the apparent power (S) and the global power factor (PF) have been calculated. The following expressions have been implemented by modeling under MATLAB/Simulink software:

- for the active power,

$$P = \int_{t-T}^{t} u \cdot i \cdot d\tau \; ; \tag{3}$$

- for the apparent power,

$$S = U \cdot I \; ; \tag{4}$$

- for the global power factor, which is a synthetic indicator on powers,

$$PF = \frac{P}{S} \; . \tag{5}$$

The rms values values of the voltage and current (U and I), which intervene in (4), have been implemented through their definitions [16]:

$$U = \sqrt{\int_{t-T}^{t} u^2 d\tau} \; ; \tag{6}$$

$$I = \sqrt{\int_{t-T}^{t} i^2 d\tau} \; . \tag{7}$$

The power that could be compensated (P_C) has been calculated too,

$$P_C = \sqrt{S^2 - P^2} \; , \tag{8}$$

and its weight in the active power (W_{CP}) and apparent power (W_{CS}) are expressed as:

$$W_{CP} = \frac{P_C}{P} \; ; \tag{9}$$

$$W_{CS} = \frac{P_C}{S} \; . \tag{10}$$

It must be noted that the power that could be compensated to reach the unity power factor contains both the reactive power and the distortion power [16].

In the same time, the undimensional indicators WCP and WCS are a measure of additional expenses because of unussed power.

The numerical results given in Table I show that the energetic performances are weak.

Thus, low values are obtained the the global power factor (about 38 % for the coil with 33 turns and about 45 % in the case of the coil with 38 turns).

If it is obvious that the drying process by heating the current transformer is more effective if the coil covers better the transformer's height and the number of turns of the coil is higher. This second aspect is confirmed by the results shown in Table 1.

TABLE I.
THE NUMERICAL RESULTS OF ENERGY PARAMETERS

Coil	33 turns		38 turns	
	Filtered wave	Unfiltered wave	Filtered wave	Unfiltered wave
Frequency	50.5 Hz		50 Hz	
U [V]	49.41	49.43	49.41	49.44
I [A]	153.5	153.8	138.3	138.6
P [W]	2885	2887	3091	3093
S [VA]	7583	7601	6832	6851
PF	0.3816	0.3798	0.4595	0.4515
P_C[VA]	7013	7031	6093	6113
W_{CP} [%]	243.08	243.55	197.11	197.64
W_{CS} [%]	92.48	92.51	89.18	89.23

The need to search for new sources and technologies based on the heating process, dedicated to the drying of the current transformers and other components of the hydropower plants, is better illustrated by the high values of indicators W_{CP} and W_{CS}.

Thus, the power that could be compensated represents about 90 % of the apparent power and 200 % of the active power.

V. CONCLUSIONS

1. The detailed energetic analysis of the drying process by heating of a current transformer from a power station in a hydropower plant shows that the existing technology and equipment are "energy-intensive".

2. The data obtained through this analysis can be used to calculate the equivalent parameters of the system, which are required in identification and the design of new equipment with better energy performance.

3. The power that could be compensated, with favorable consequences on the supply system, is about 2 ÷ 2.5 times higher than the active power.

4. A simple solution to compensate this useless power is to use a compensation capacitor connected in parallel with the inductor.

5. It is estimated that a complete way to improve the energetic performances requires supplying from a static system based on a resonant voltage inverter.

6. A multifunction static system able to provide both AC and DC voltage, continuously adjustable in large limits, may be obtained by supplying the voltage source inverter from either a fully controlled rectifier or a half controlled rectifier.

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