POWER TRANSFORMER MONITORING USING A SOFTWARE APPLICATION

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REZUMAT. Identificarea transformatorului de putere necesită o monitorizare continuă a caracteristicilor sale funcționale. Având în vedere legătura dintre caracteristicile constructive şi starea fizică a transformatoarelor de putere, pe de o parte, şi parametrii lor electrici, pe de altă parte, monitorizare, chiar şi în timp cvasi- real, poate fi folositoare pentru a asigura o functionare nominală a acestor trasformatoare de putere.Lucrarea actuală prezintă o metodă originală, care poate fi folosită pentru identificare parametrilor transformatorului de putere şi o aplicație software bazat pe această metodă.

Cuvinte cheie: transformator de putere, monitorizare, aplicație software.

ABSTRACT. Identification of power transformer state requires continuous monitoring of its functional characteristics. Due to the link between constructive characteristics and physical state of the power transformer, on the one hand, and their electrical parameters, on the other hand, the parameters monitoring even in quasi-real time can be profitable to ensure the rated working time of these expensive power equipment. The current paper presents an original method that can be used for transformer identification and a software application based on this method.

Keywords: power transformer, monitoring, software application.

1. INTRODUCTION

To monitories a poly-phase transformer working in balanced load is enough to follow a single phase of the transformer. The magnetizing currents are negligible compared whit the currents for working in load, therefore at working in load the wave forms of the voltage and of the currents are considerate to be sinusoidal. The electrical transformer equations written in complex values and the transformer's phasors diagram for the figure1 are (1).

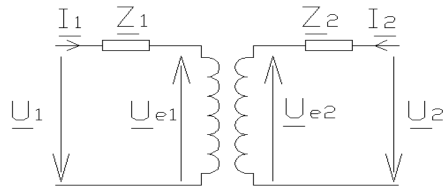

Fig. 1. Mono-phase transformer.

$$\begin{aligned}
&\underline{U_1} = \underline{Z_1}\,\underline{I_1} - \underline{U_{e1}};\\
&\underline{U_2} = -\underline{Z_2}\,\underline{I_2} + \underline{U_{e2}};\\
&\underline{U_{e1}} = -\underline{Z_{1m}}\,\underline{I_{01}};\\
&\underline{U_{e2}} = \frac{N_2}{N_1}\underline{U_{e1}};\\
&\underline{I_{01}} = \underline{I_1} + \frac{N_2}{N_1}\underline{I_2},
\end{aligned} \qquad (1)$$

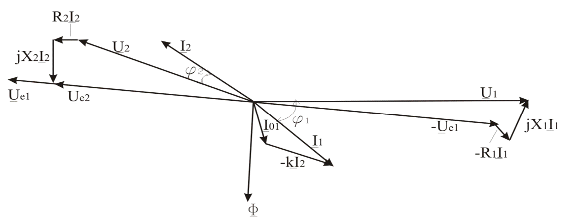

Fig. 2. Phasor diagram of mono-phase transformer.

where $\underline{U_1}$, $\underline{I_1}$, $\underline{Z_1}$ refer to voltage, current and impedance for the primary circuit of transformer and $\underline{U_2}$, $\underline{I_2}$, $\underline{Z_2}$ refer to voltage, current and impedance for secondary circuit of transformer. $\underline{U_{e1}}$, $\underline{U_{e2}}$ will be eliminated from system of equations (1) and results a system of equations only in $\underline{U_1}$, $\underline{I_1}$, $\underline{Z_1}$ and $\underline{U_2}$, $\underline{I_2}$, $\underline{Z_2}$, $\underline{Z_{1m}}$

$$\begin{cases}
K = \dfrac{N_2}{N_1};\\
(\underline{Z_1} + \underline{Z_{1m}})\underline{I_1} + K\underline{Z_{1m}}\,\underline{I_2} = \underline{U_1};\\
-k\underline{Z_{1m}}\,\underline{I_1} - (\underline{Z_2} + K^2\underline{Z_{1m}})\underline{I_2} = \underline{U_2},
\end{cases} \qquad (2)$$

where voltage $\underline{U_1}$ is considerate phase origins and can be equivalent whit U_1 and, other components of the system will be expressed in terms of real and imaginary components follow the phasor diagram of transformer from figure 2:

$$\underline{Z_1} = R_1 + jX_1,\ \underline{Z_2} = R_2 + jX_2,\ \underline{Z_{1m}} = R_{1m} + jX_{1m};$$

$$\underline{I_1} = I_1\cos\varphi_1 - jI_1\sin\varphi_1,\ \underline{U_2} = U_2\cos\alpha + jU_2\sin\alpha$$

$$\underline{I_2} = -I_2\cos(\alpha+\varphi_2) + jI_2\sin(\alpha+\varphi_2)$$

By following the above notations replaced in relation (2) have system of equations:

$$\begin{cases} A = I_1\cos\varphi_1 - jI_1\sin\varphi_1 \\ B = -I_2\cos(\alpha+\varphi_2) + jI_2\sin(\alpha+\varphi_2) \\ T = U_2\cos\alpha + jU_2\sin\alpha \\ (R_1 + jX_1 + R_{1m} + jX_{1m})A + (R_{1m} + jX_{1m})BK = U_1 \\ -K(R_{1m} + jX_{1m})A - [R_2 + jX_2 + K^2(R_{1m} + jX_{1m})]B = T \end{cases}$$

To solve the system of equations (3) the real and imaginary components must be separated:

$$\begin{cases} I_{1a} = I_1\cos\varphi_1,\ I_{1r} = -I_1\sin\varphi_1 \\ I_{2a} = -I_2\cos(\alpha+\varphi_2),\ I_{2r} = I_2\sin(\alpha+\varphi_2) \\ U_{2a} = -U_2\cos\alpha,\ U_{2r} = U_2\sin\alpha \\ R_1I_{1a} - X_1I_{1r} + R_{1m}(I_{1a} + KI_{2a}) - X_{1m}(I_{1r} + KI_{2r}) = U_1 \\ R_1I_{1r} + X_1I_{1a} + R_{1m}(I_{1r} + KI_{2r}) + X_{1m}(I_{1a} + KI_{2a}) = 0 \\ -R_2I_{2a} + X_2I_{2r} - R_{1m}(KI_{1a} + K^2I_{2a}) + X_{1m}(KI_{1r} + K^2I_{2r}) = U_{2a} \\ -R_2I_{2r} - X_2I_{2a} - R_{1m}(KI_{1r} + K^2I_{2r}) - X_{1m}(KI_{1a} + K^2I_{2a}) = U_{2r} \end{cases}$$

This system of equations must be resolved in order to determinate electrical parameters of the electrical transformer.[1][2]

2. THE SOFTWARE APPLICATION FLOW

The application flow diagram from the figure 3 is represented for just one phase of the transformer, where we have: B[j] a vector with 7 elements. The vector B[j] contains the voltage value, the current intensity and the phase difference between those values in the transformers primary, the voltage value and the current intensity from the transformers secondary and the phase difference between those values, and it contains also the phase difference between the voltage value from the transformers primary and the voltage value from the transformers secondary.

$$B[j] = B[V_1, I_1 \cos\varphi_1, V_2, I_2, \cos\varphi_2, \cos\alpha] \qquad (2.1)$$

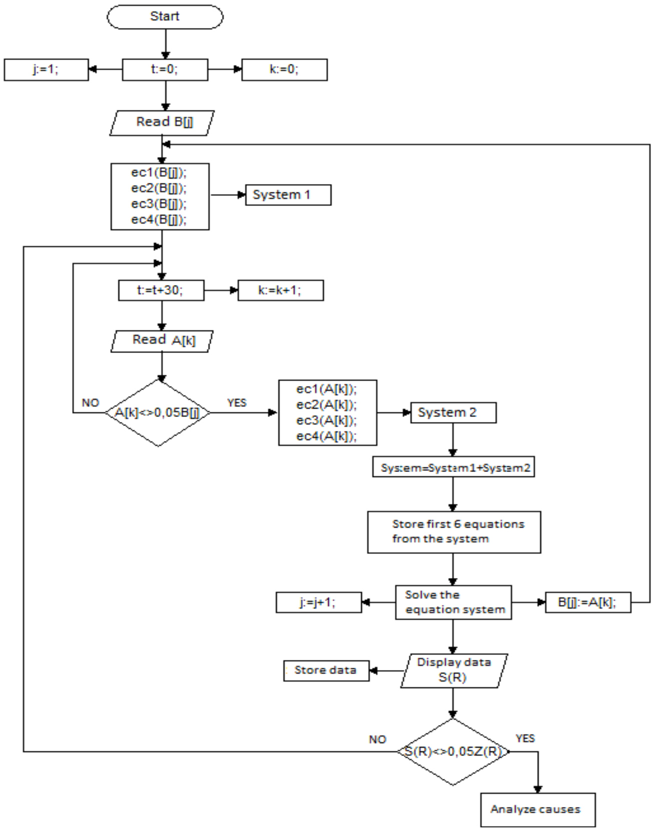

Fig. 3. The application flow diagram.

A[k] is a vector with 7 elements which contains all the read values starting with position 2, the equations ec1, ec2, ec3 and ec4 are the equations from the block diagram of the method proposed in the paper at chapter 1. K stores the number of readings done, and "j"is the number of equation systems obtained. S[R] is a solution vector which contains the solutions obtained out of the equations system. The S[R] vector contains the following values: the resistance and the reactance from the transformers primary, the resistance and the reactance from the transformers secondary and the mutual resistance and reactance of the transformer.

$$S(R) = S[R_1, X_1, R_2, X_2, R_m, X_m] \qquad (2.2)$$

The vector Z[R] contains the initial values, those which were obtained during the transformers design. The time period between two consecutive readings is represented in the flow diagram with "t" (the time frame between two consecutive readings is 30 milliseconds). What is important for this method is the fact that during the measurements the temperature inside the transformers windings must be constant. The proposed method, and the software application takes into account a measurement error of 5%.

The software application reads the data from an acquisition board USB 6621. The acquisition board transmits the signals collected from the current transducer and from the voltage transducer to the software application, which based on those information is capable to represent the wave forms for the current and for the voltage.[2][3]

3. HARDWARE EQUIPMENTS

In order to determine the electrical parameters of power transformer it is necessary to perform some measurements on the transformer operating in a sinusoidal steady state. The measurements were performed using two measuring kits, one for transformers primary and one for transformers secondary. For data acquisition it was used a system of voltage transducers and current transducers connected to a acquisition board use to make the connection between the transducers and the computer used to run the software application.The mounting diagram to determine the electrical parameters using a software application is shown in figure 4.

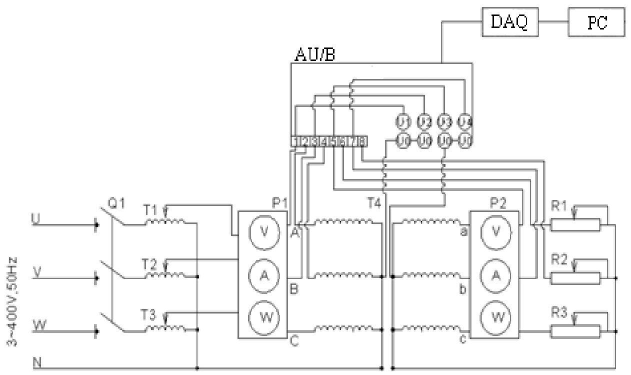

Fig. 4. Experimental model.

In figure 4 we denote by T1, T2, T3 the auto transformers are used with a single-phase voltage adjustable from 0 to 240V, the switch Q1 is used to power up the three autotransformers which supply each phase of the three phase transformer T4. P1, P2 are measurement kits that are installed for a high precision measurement. AU / B represent the transducers system for the electrical and non-electrical values. The three resistors R1, R2, R3 used to load the transformer have an adjustable resistance up to 440 Ω.

The analog signals are acquired by the acquisition board from the voltage transducers and from the current transducers LV 25P respectively LA55-P/SP1. In order to perform the necessary measurements at optimal parameters the transducers used are based on Hall elements.

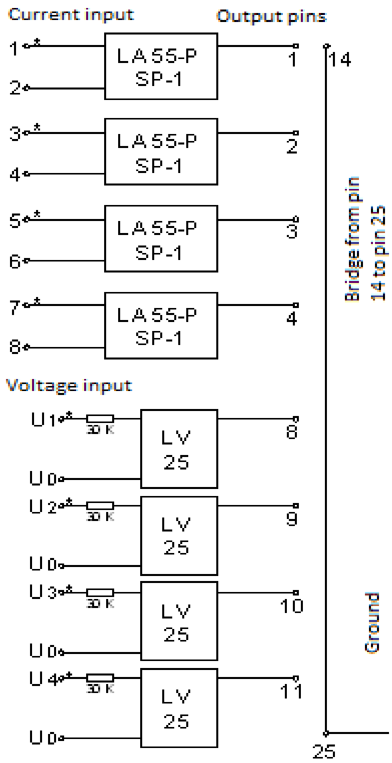

Fig. 5. Outputs of the acquisition board.

Voltage transducer LV 25-P. LV 25-P is a voltage transducer with galvanic separation between the primary circuit (the power circuit used for measurements) and the secondary circuit (electronic circuit used for processing the signal generated by transducer). The main parameters of this type of transducer are presented in figure 6 and in figure 7. To measure voltage, an external resistorR1 is expected to be traveled by a current proportional to the measured voltage.

Current transducer LA 55-P/SP1. LA 55-P/SP1 is a current transducer with galvanic separation between the primary circuit (the power circuit used for measurements) and the secondary circuit (electronic circuit used for processing the signal generated by transducer). The main parameters of this type of transducer are presented in figure 8 and in figure 9.

A general structure of transducer blocks with the outputs for the acquisition board is shown in figure 5

ELECTRICAL DATA	Nominal current I_N		10 mA	
	Measurement domain		0 for ± 14 mA	
	Measurement resistance R_M		R_{Mmin}	R_{Mmax}
	Power supply ±12V	± 10 mA max	30 Ω	190 Ω
		± 14 mA max	30 Ω	100 Ω
	Power supply ±15V	± 10 mA max	100 Ω	350 Ω
		±14 mA max	100 Ω	190 Ω
	Output nominal current		25 mA	
	Precision	for 25°C & ±15V	± 0,8% for I_N	
		for 25°C & ±12÷15V	± 0,9% for I_N	
GENERAL DATA, PRECISION, DYNAMIC PERFORMANCES	Offset current	for 25 °C	max. ± 0,15 mA	
		after overload of $3I_N$	max. ± 0,3 mA	
	Linearity		better than 0,2 %	
	Response time		40ns for R_1 = 25kΩ (depends on time constant of the circuit L/R)	
	Operating temperature		(0 ÷ 70) °C	
	Storing temperature		(-25 ÷ +85) °C	
	Primary internal resistance		250Ω (la 70 °C)	
	Secondary internal resistance		110Ω (la 70 °C)	
	Connection with the primary circuit		2 pins with square section with a width of 0,635mm	
	Connection with the secondary circuit		3 pins with diameter of 1mm	
	Polarity marking		When applying a positive voltage on terminal + HT a positive current is obtained on terminal M	

Fig. 6. Voltage transducer LV 25-P characteristics.

Voltage input pin	Output pin BL 25	INPUT VOLTAGE [VOLTS]							
		25	50	100	150	200	250	270	
U1	8	0,309	0,615	1,238	1,856	2,483	3,100	3,350	OUTPUT VOLTAGE [VOLTS]
U2	9	0,308	0,612	1,231	1,852	2,470	3,100	3,350	
U3	10	0,308	0,614	1,233	1,854	2,475	3,101	3,350	
U4	11	0,307	0,610	1,235	1,855	2,480	3,098	3,350	
U5	12	0,304	0,615	1,235	1,856	2,490	3,102	3,355	[VOLTS] =

Fig. 7. Input/output voltages for the voltage transducer.

DATE ELECTRICE	Nominal current		50 A rms			
	Measurement domain		0 for ± 70 A			
	Measurement resistance R_M		+70 °C		+85 °C	
			R_{Mmin}	R_{Mmax}	R_{Mmin}	R_{Mmax}
	Power supply ±12V	± 50 A max	0 Ω	215 Ω	0 Ω	210 Ω
		± 100 A max	0 Ω	35 Ω	0 Ω	30 Ω
	Power supply ±15V	± 50 mA max	0 Ω	335 Ω	70 Ω	330 Ω
		±100 mA max	0 Ω	95 Ω	70 Ω	90 Ω
	Output nominal current		25 mA			
	Precision	for 25°C & ±15V	± 0,65% at I_N			
		for 25°C & ±12÷15V	± 0,9% at I_N			
DATE GENERALE, PRECIZIE, PERFORMANȚE DINAMICE	Offset current	for 25 °C	max. ± 0,1 mA			
		after overload $3I_N$	max. ± 0,15 mA			
	Linearity		better than 0,15 %			
	Response time		< 500 ns			
	Banda		0 - 200 kHz			
	Operating temperature		(-25 ÷ +85) °C			
	Storing temperature		(-40 ÷ +90) °C			
	Current consumption		10 mA (±15V) + output current			
	Primary internal resistance		80Ω (at 70 °C), 85Ω (at 80 °C)			
	Connection with the primary circuit		orifice from 12,7 x 7 mm			
	Connection with the secondary circuit		3 pins 0,6 x 0,56			
	Polarity marking		When applying a current in the direction of the arrow a positive current is obtained on terminal M			

Fig. 8. Current transducer LA55P/SP1 [127] characteristics

INPUT CURRENT	OUTPUT PIN BL 25	INPUT CURRENT [AMPERS]							
		1	2,5	5	7,5	10	12,5	15	
1-2	1	0,250	0,626	1,249	1,870	2,503	3,100	3,760	OUTPUT VOLTAGE [VOLTS]~
3-4	2	0,251	0,626	1,250	1,870	2,500	3,104	3,760	
5-6	3	0,250	0,627	1,250	1,870	2,500	3,098	3,760	
7-8	4	0,251	0,625	1,248	1,872	2,500	3,097	3,760	
9		1	2	4	6	8	10	12	[VOLTS] =
10	5	0,412	0,811	1,600	2,400	3,196	4,000	4,800	

Fig. 9. Input/output currents for the current transducer.

4. THE SOFTWARE APPLICATION PANELS

The front panel of the software application is presented in figure 10.

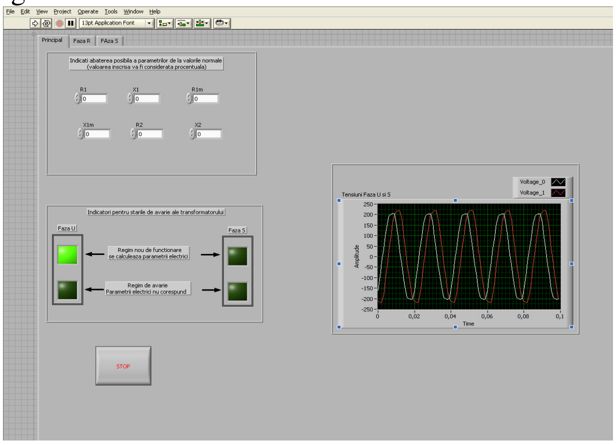

Fig. 10 Front panel.

The first block, of the front panel, positioned at the top left, alows the user to set the accepted difference between the calculated values and the measured ones, this values are expressed in percentage (figure 11).

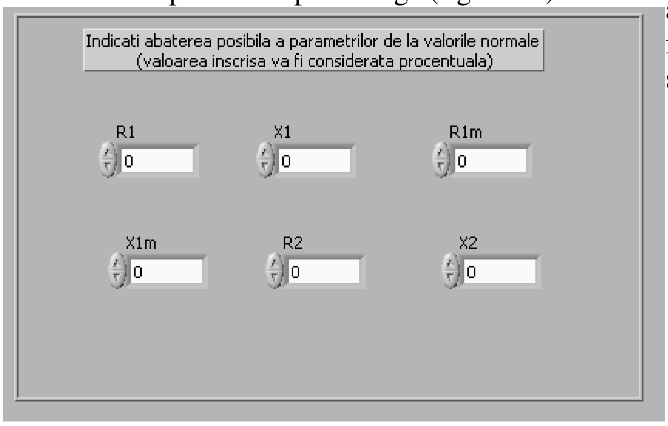

Fig. 11 Accepted error input.

The block from the bottom left is used to show status of the transformer.

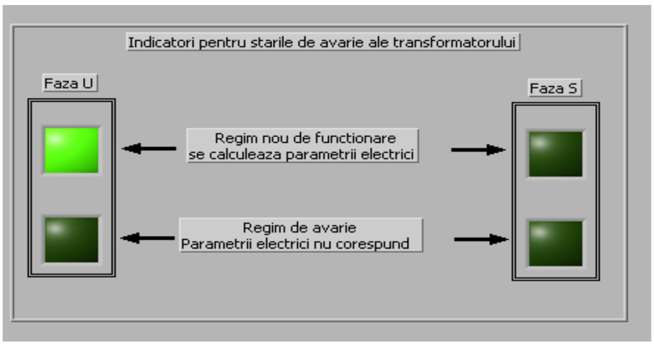

Fig. 12 Damage indicators.

The boolean indicators from the front panel are used to identify different states of the transformer. Because the monitoring process was performed for two experimental phases of the transformer, the indicators are for the phase R and for the phase S of the transformer. The green light color indicates the occurrence of the event marked in its right side. In order to see what happens on one of the phases, the mouse pointer can be used to choose one of the phases in the front panel as it is shown in figure 13.

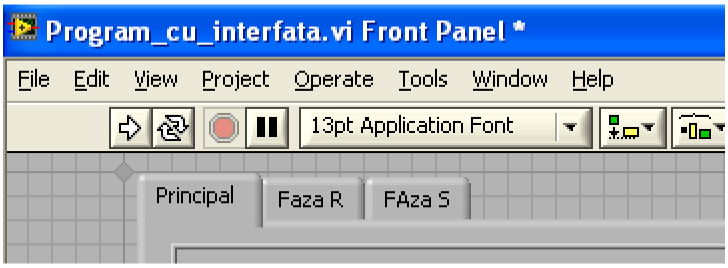

Fig. 13 Phase selector.

When the user chooses to see the events from a particular phase, the application will display the voltage and current values from the transformers primary and from transformers secondary. The used will be able to see the numerical values and also as wave forms.

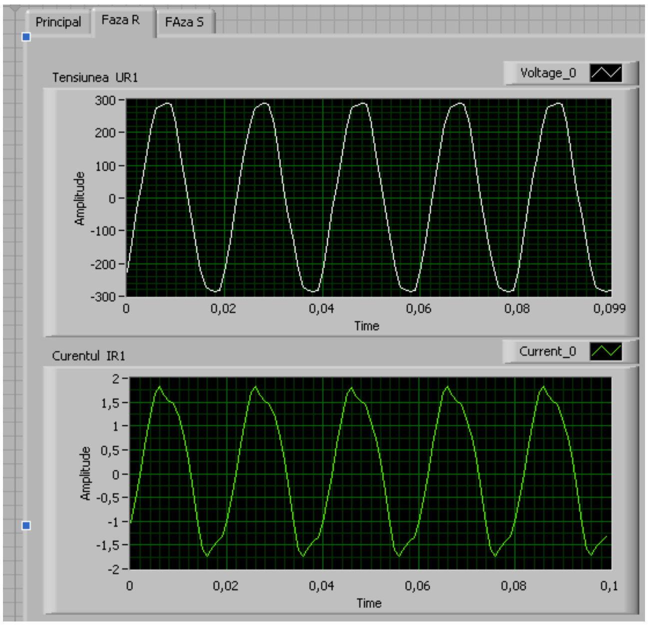

Fig. 14 The voltage and current waveform display.

Nr citiri	Frecventa	UR1	IR1	UR2	IR2	UR1faza	IR1faza	UR2faza	IR2faza
0	50,0056	216,011	1,32108	216,422	1,13234	0	4,77492	179,734	179,602
1	50,0097	218,057	1,23110	217,399	1,03428	0	4,33533	179,699	179,747
2	50,0042	213,747	1,29994	214,475	1,09799	0	4,47491	179,67	179,296
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Fig. 15 Voltage and current values display.

As it is shown in fig 15 the software application displays the voltage values and current values form the transformers primary and from the transformers secondary and also the phase differences between those electrical values. In the figure 16 is shown the transformers parameters calculated by the application according to the proposed method from this paper.

R1	X1	Rm	Xm	R2	X2
3,72708	478,146	225,108	310,214	4,41415	481,109
3,75149	478,987	225,927	311,221	4,45771	481,934
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0

Fig. 16 Transformer parameters display.

CONCLUSIONS

✓ The method proposed in this paper is an original one and it bring a new way of handling the problem related with the power transformers monitoring process. The proposed monitoring method together with the hardware equipments available on the market will make a complex system capable to provide precise information regarding the state of the transformer which is under the monitoring process.

✓ The proposed method was tested on a laboratory power transformer. The monitoring was performed on two phases of the transformer. Since the transformer was operating under a sinusoidal and symmetrical regime it was not necessary to monitories all the three phases of the transformer.

✓ In order to obtain the electrical parameters of the transformer, using the method proposed by the paper, it is enough to know the transformers voltages and currents values. The other values needed to obtain the transformer parameters will be obtained inside the software application trough mathematical operations.

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