

Research Article

The Temperature Measurement in a Three-Phase Power Transformer under Different ConditionsK. Karakoulidis^{1,*} J. G. Fantidis^{1,2} and V. Kontakos²¹Department of Electrical Engineering, Technological Education Institute of Eastern Macedonia and Thrace, Saint Loucas, Kavala, Greece²MSc in Innovation in Technology & Entrepreneurship, Technological Education Institute of Eastern Macedonia and Thrace, Saint Loucas, Kavala, Greece

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Abstract

Infrared thermography is a powerful non contact method with the ability to fast inspection of abnormal situations in many electrical systems and equipments. With the aim of a high resolution thermal camera a laboratory power transformer was checked under different scenarios. These scenarios include thermal measurements for 58%, 87% and 116% of rated load conditions, problems in primary or secondary phases and an asymmetric charge. The thermographic system illustrate fast and reliable the changes in the windings of the power transformer.

Keywords: Thermography; Power transformer; temperature measurement;

1. Introduction

Power transformers is one of the most important and expensive elements in power generation and transmission systems. Considering the importance of the power transformers in the electric system their correct functioning or maintenance is vital to system operation. Commonly reasons for failure include external factors such as lightning strikes, short circuits, system overload, and internal factors such as insulation deterioration, winding failure, and overheating. For these reasons fault diagnosis power transformers is necessary. Even though a number of industrial methods exist (Visual Inspection, Insulation Resistance Test, Transformer Turns Ratio Test, Dissolved Gas Analysis, Magnetic Balance Test, Tan Delta Test, Transformer Oil Break Down Test, thermography) both for on-line and off-line monitoring of transformers, most of them are costly and complex [1-3].

Infrared thermography is a non-destructive and visualizing technique which commonly used in preventive maintenance for the advantage of carrying out rapid, precise, and broad area inspections. They can identify heat patterns or temperature changes in materials and structures. With thermography technique, defective parts can be identified through simple observation without disrupting the transformer's operation. According to Mady and Attia [4] the primary reasons for transformer overheating includes excessive transformer loading, excess current in the neutral of the transformer, high harmonic content in the power

supply and continued overvoltage for a long period of time. The major goal of this work is to study the thermal behavior of a transformer under different operations conditions. All the measurements realized at the Kavala Institute of Technology in the electrical machine laboratory [5-6].

2. Background of infrared thermography physics

The principle of infrared thermography is based on the fact that any object that has a temperature above absolute zero (-273.15 °C) radiates energy at a wavelength corresponding to its surface temperature. In physics, a blackbody is defined as an object which absorbs all radiation that falls on it at any wavelength. Infrared thermography is the science of transforming infrared measurements to construct a radiometric image. In physics, a blackbody is defined as an object which absorbs all incident radiations it receives whatever the wavelength and re-emits all these absorbed radiations.

Electromagnetic radiation emitted from a blackbody ($W_{\lambda b}$) can be calculated using Planck's law, as in Equation (1), where c is the speed of light, h is the Planck's constant, k is Boltzmann's constant, T is absolute temperature of the blackbody in Kelvin and λ is wavelength.

$$W_{\lambda b} = \frac{2\pi hc^3}{\lambda^5 (e^{hc/\lambda kT} - 1)} 10^{-6} [\text{watt} / \text{m}^2 \mu\text{m}] \quad (1)$$

By integrating Planck's formula from $\lambda = 0$ to $\lambda = \infty$ it allows calculating the total amount of radiation (W_b) emitted by the blackbody at a certain temperature T (in every direction and over all wavelength)

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$$W_b = \sigma \cdot T^4 \tag{2}$$

which states that the total emissive power of a blackbody is proportional to the fourth power of its absolute temperature while σ is the Stefan-Boltzmann constant, equals to $5.6704 \cdot 10^{-8}$ (W/m²K⁴).

A more general case is of a non-blackbody emitters for which the emissivity is constant regardless wavelength are called grey bodies. In this case the total amount of radiation emitted by the grey body characterized by its emissivity, ϵ and can be calculated using the Stefan-Boltzmann law:

$$E = \epsilon \cdot \sigma \cdot T^4 \tag{3}$$

where E is the electromagnetic radiation (W/m²), ϵ is the object surface emissivity after transmissivity (t) and reflectivity (ρ) are taken into account [7-9].

$$\epsilon = 1 - (t+\rho) \tag{4}$$

3. Case study

The Jenoptik VarioCAM[®] 7800 thermographic system was used for the purposes of this work. It is a high-resolution, portable, digital color infrared and visual camera with a noncooled Focal Plane Array microbolometer which is used as an infrared radiation sensor. The thermographic system during the measurement has a standard 30mm lens with minimum focus 0.3m IFOV 0.8 mrad and FOV (30×23)° and communicates with the PC via FireWire (IEEE 1394) which are later processed in the suitable analysing software IRBIS[®] 3 professional. Table 1 shows the main specifications of the thermographic system Vario CAM[®] 7800 [10-11].

Table 1. Technical characteristics of the VarioCAM[®] 7800 thermographic system.

Parameter	Value
Spectral range	7.5 – 14 μm
Resolution	640 × 480 pixels (resolution enhancement onto 1280 × 960 pixels)
Temperature measuring range	-40 – 1200 °C
Temperature resolution at 30°C	Better than 0.08 K
Measurement accuracy	± 1.5 K (0 – 100 °C), ± 2% (< 0 and >100) °C
Emissivity	Adjustable from 0.1 to 1, in increments of 0.01
Spatial resolution/IFOV	0.8 mrad
Field of view/FOV	30° (H) ×23° (V)

In this article a 3-phase, 2 kVA transformer (Terco MV 1972) with E- type core was used (Figure 1). Table-2 provides the specifications of the transformer. The necessary load was supplied by the Terco MV 1100 load resistor which contains three ganged resistors with continuous spindle

regulation. The current in the resistor is limited by tubular wire fuses in each phase. Last but not least the Terco MV 1300 power pack, which is suitable for laboratory experiments, was used as power supply unit. All outputs are fused by MCB's and have load switches. The Power Pack has also Earth Leakages Circuit Breaker (ELCB). The technical specifications both for load and power supply unit are also presented in Table 2 while the Figure 1 is a picture of the experimental test bed [12].

Table 2. Specifications of the used electrical equipment

MV 1100 Load Resistor	
Type	3-phase 3.3 kW, continuously adjustable
Star connection	400/230 V 0,8 - 5 A
Star connection	230/133 V 0.5-5 A
Delta connection	400/230 V 2.4-8.7 A
Delta connection	230/133 V 1.03 - 8.07 A
DC parallel connection	220 V 2,3 έως 15 A
Overload capacity, brief duration	approx. 20%.
Dimensions	630 x 250 x 890 mm
Weight	46 kg
MV 1972 Transformer 3-phase	
Power rating:	2 kVA
Primary voltage:	400 V ± 5% or 230 V ± 5% per phase
Secondary voltage	2 x 66,5 V ± 5% per phase 2,5 kV
Efficiency	92%
Dimensions	350x 165x260 mm
Weight	30kg
Terco MV 1300 power supply unit	
Type	MV 1300-405 Supply voltage 380-400 / 220-230 V 50 / 60 Hz 3-ph.
Output voltage	DC fixed 220 V 3.5 A DC variable 0-220V 16A AC fixed 230/133V 10A 3-ph AC variable 3 x 0-230V, 10A 3- ph
Standard	AC fixed 230V 10A
Dimensions	660x435x790 mm
Weight	103 Kg

4 Results and discussion

In order to study the thermal behavior of transformer the Terco MV 1972 was tested under different operations conditions. In the first scenario the transformer was operated at 58% load for two hours. Figure 2 illustrates the relevant results. It is clear from the measurements that for 58% load the temperature increases slowly during the first 90 minutes and is nearly steady after this time. For 58% of rated load

conditions the maximum temperature in the transformer remained in low levels reaching up to approximately 43°C. Figure 3 illustrates the real thermal images for 58% load after 30, 60, 90 and 120 minutes of continues operation.

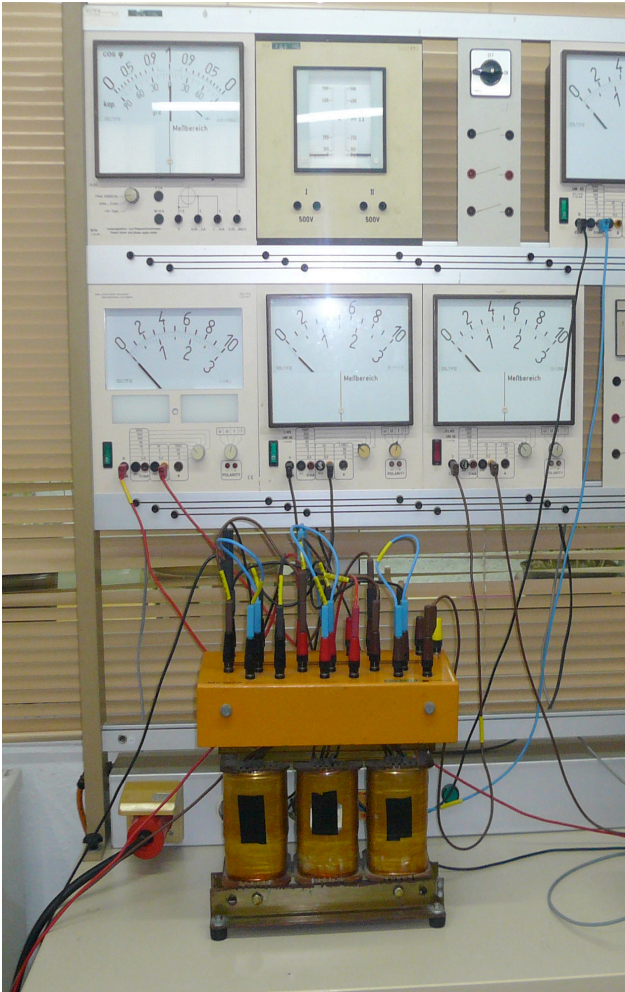


Fig. 1. Experimental bench.

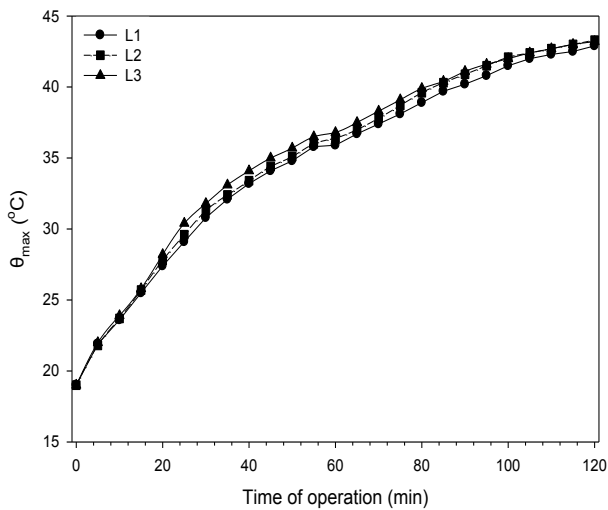


Fig. 2. The measured temperatures in the 3 phases for 58% of rated load conditions.

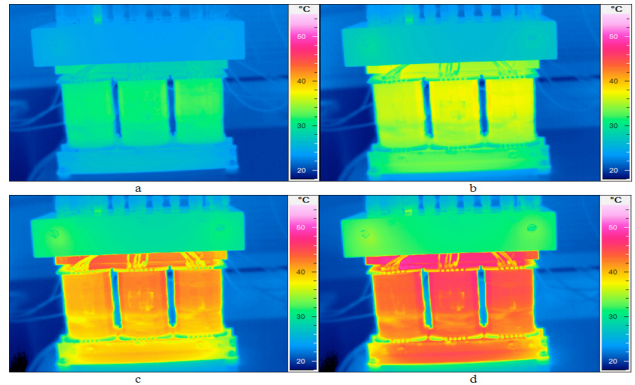


Fig. 3 Thermal images of the transformer after a. 30 minutes, b. 60 minutes, c. 90 minutes and d. 120 minutes of operation for 58% load.

In the second scenario the rated transformer load was 87% and the relative results are shown in Figure 4. As expected the temperature rise faster and after 2 hours is above than 60°C. In this case the temperature rises rapidly in the first 40 minutes, with slower speed for the next 60 minutes and is almost fixed after 100 minutes continuous operation. The relatively thermographs after 30, 60, 90 and 120 minutes are given in Figure 5. The third scenario includes the case in which the transformer operates in overload conditions (116% of rated load). As a sequel to this event there is a steep increment in temperature during the first 60 minutes, with lower rates for the next 35 minutes and almost stops to increase after 95 minutes of continuous operations. The maximum temperature is nearly 89.5°C (see Figure 6). Figure 7 provides the thermal images with steps every 30 minutes for total 2 hours operation.

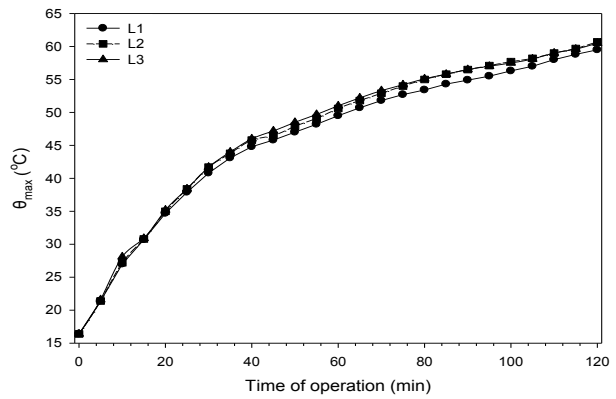


Fig. 4 The measured temperatures in the 3 phases for 87% of rated load conditions.

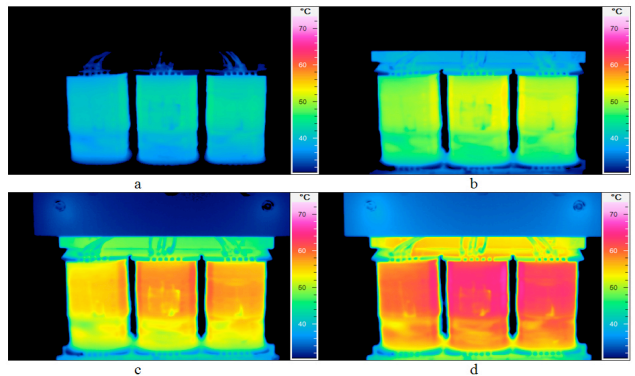


Fig. 5 Thermal images of the transformer after a. 30 minutes, b. 60 minutes, c. 90 minutes and d. 120 minutes of operation for 87% load.

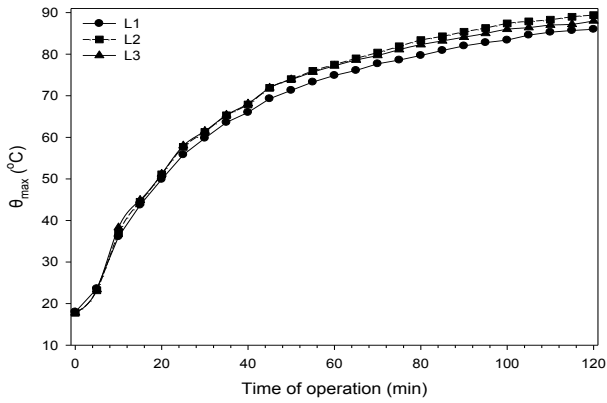


Fig. 6 The measured temperatures in the 3 phases for 116% of rated load conditions.

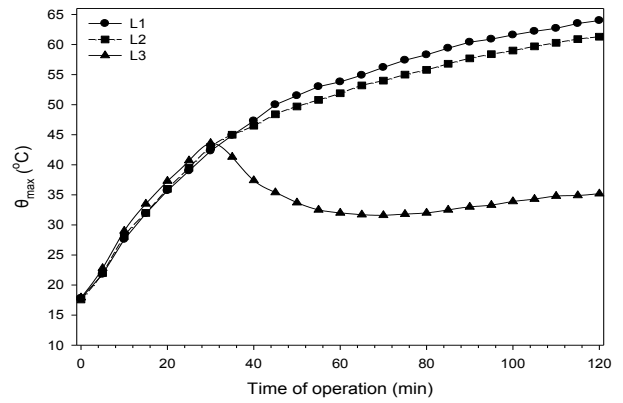


Fig. 9 The measured temperatures with break circuit in the L3 phase on the primary.

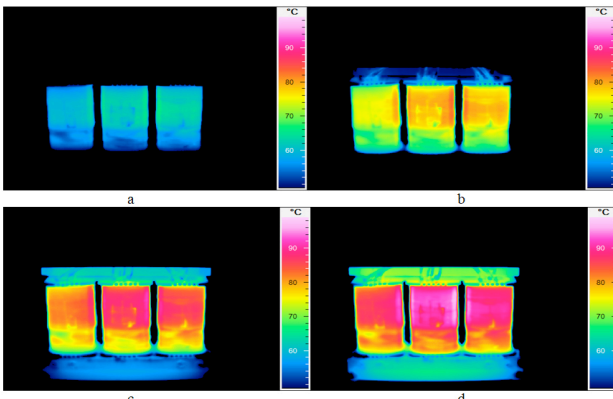


Fig. 7 Thermographs of the transformer after a. 30 minutes, b. 60 minutes, c. 90 minutes and d. 120 minutes for overload (116%) conditions.

The next testing setups comprise theoretical problems in the primary or secondary windings. Specifically for 87% of rated load conditions after 30 minutes normal operation we cutoff the transformer in L1 phase of the primary windings. Immediately the temperature in the other two phases (L2 and L3) drops down while the temperature in the L1 increases normally. Figure 8 shows the related results. In the next step after again 30 minutes normal operation we cutoff the L3 in the secondary winding. The results were plotted in the Figure 9 and are obvious that the "problem" transpires very quickly.

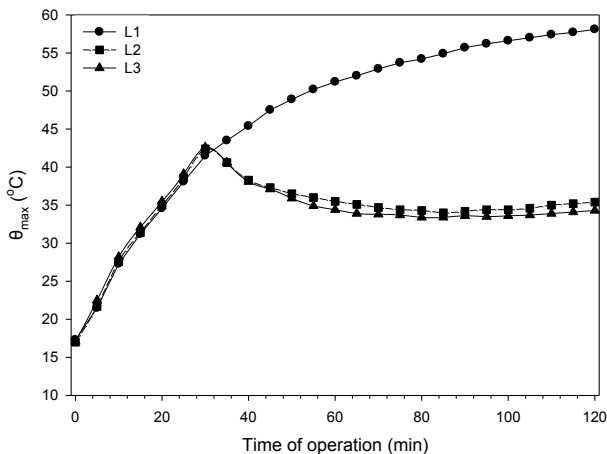


Fig. 8 The measured temperatures with break circuit in the L1 phase on the primary.

In the last experiment the transformer supplied with unbalanced load in every phase. L1 has 116% of rated load, L2 has 87% of rated load and L3 has 58% of rated load. The real thermal images after 0, 30, 60, 90 and 120 minutes of operation are shown in Figure 10 while the Figure 11 illustrates the results. The difference in temperature between the phases is noticeable instantly. After 1 hour operation L1, L2, and L3 have temperature approximately equal to 70, 53 and 41°C correspondingly while after 2 hours the relevant values are 83, 64, and 51°C. Common deduction in all cases is the ability of the thermal camera to detect very fast the changes on the operation conditions.

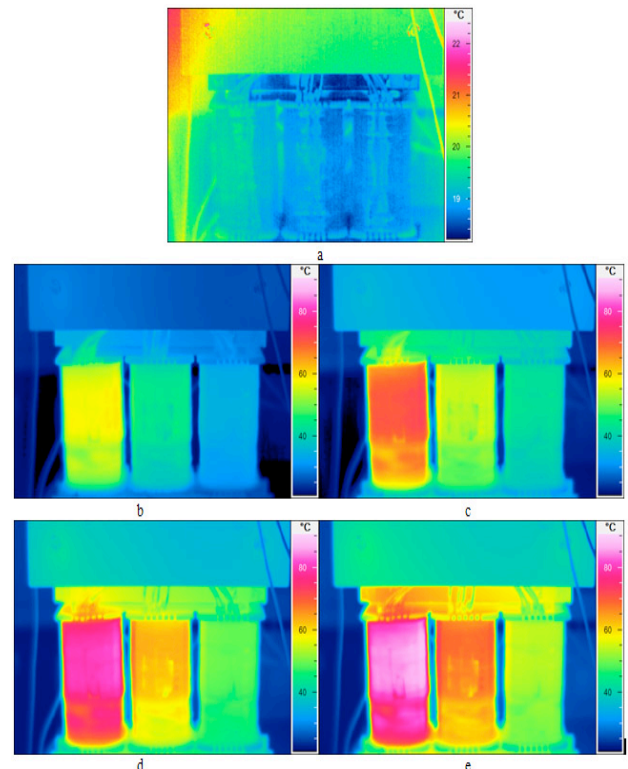


Fig. 10 The real thermographs in the 3 phases for asymmetric load a. at the begin of the experiment and after b. 30 minutes, c. 60 minutes, d. 90 minutes and e. 120 minutes after continues operation.

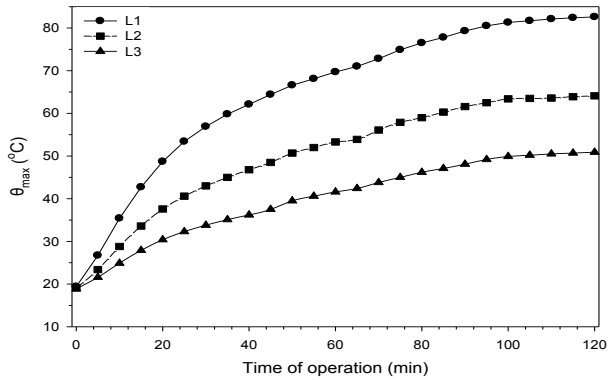


Fig. 11 The measured temperatures in the 3 phases for asymmetric charge (L1 116%, L2 87%, L3 58%).

5. Conclusions

Power transformers play a vital role in every electric system. Owing to this fact a numerous diagnosis methods have been developed. Infrared thermography is a helpful non-destructive method for the conditioned monitoring and diagnosis of transformers. In this work a small power transformer tested under different scenarios with the aid of a portable and high-resolution infrared thermographic system. In any case the system is suitable to detect rapidly the problems on the transformer operation.

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