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THERMAL STRESS WIRELESS MONITORING DEVICES FOR ELECTRICAL EQUIPMENT

BY

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Abstract. The paper presents some thermal stress wireless monitoring methods for electrical equipment. Also it is presented the interpretation procedure of the thermal infrared images along with the steps needed to obtain a thermography investigation report. In addition the paper investigates how the wind affects the data obtained from the infrared thermography devices.

Key words: infrared thermography; thermal stresses; wireless monitoring.

1. Introduction

During the past years the wireless technology has developed quickly due to the large number of applications in fields like energy, agriculture, medicine, etc. In electrical engineering field the wireless monitoring of the electrical equipment provide a good image of an incipient fault (Adam & Baraboi, 2012).

Monitoring technologies can be divided in two main categories taking into account the monitoring device: with and without direct path between sensors and data acquisition unit (wireless). Thermal stress monitoring with direct path between sensors and data acquisition unit make use of the temperature transducers with contact sensors such as thermocouples, thermistors, etc. which are slowly in offering the data (Dragomir *et al*., 2013).

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Taking into account the large number of cables needed to transfer temperature data to the acquisition center, they are not a preferred choice for thermal stress monitoring. In the other hand, the wireless technologies (without direct path between sensors and data acquisition unit) are also divided in two categories as: without contact between investigated equipment and the monitoring device; with contact between sensor and the investigated equipment but without wire between sensor and monitoring device.

The paper's aim is to present the most common types of wireless devices used to monitor the thermal stresses of the electrical equipment. Also the paper present the steps needed to be followed in order to perform an infrared thermography report highlighting the influence of the wind in temperature records obtained with an infrared thermography device.

2. Thermal Stress Wireless Monitoring Devices for Electrical Equipment

One of the main advantages of the wireless monitoring consist of handiest measurement over other methods of monitoring the electrical equipment in operation, this fact leading to economical and technical benefits. Following there are presented the most common thermal stress wireless monitoring devices used for electrical equipment.

The infrared thermography (IRT) devices are those devices which utilize the thermovision method. This method relies on the fact that every object has a temperature greater than 0 Kelvin (–273.15°C) and it emits in the environment an energy in the form of infrared radiation. The greater the object temperature is, the greater will be the energy of the infrared radiation. The device which relies on this method is called infrared camera and it allows the identification and quantification of thermal stress problems via wireless measuring.

Sound acoustic waves (SAW) devices implies the use of an acoustic wave into a piezoelectric material and then this wave's energy is converted into an electrical signal which is used to calculate and display the temperature (Stevens *et al*., 2001). The wave's energy is influenced by the exposed temperature of the detection element. One of the advantages of this type of monitoring devices is the fact that the sensors do not need batteries or electric supply.

Wireless devices with GSM/GPRS data communication are intended for monitoring the high, medium and low voltage conductor's data. The sensors from high voltage conductors are independent from de electric supply point of view this being possible with the technology of converting the magnetic flux coupler into electrical energy. The data is transmitted in real time using GSM/GPRS systems.

The advantages of using thermal stress wireless monitoring devices are (Dragomir *et al*., 2014): the remote data acquisition and data transmission without using wires; the data accuracy and faster decision-making process; the operation in dangerous environments; the possibility of auto-supply; reliability, flexibility and security; monitor the electrical equipment in operation.

3. Performing an Infrared Thermography Report

In order to obtain a thermography report it is needed to process the thermal image obtained with an infrared thermography device. On the device display it will be showed the thermal map of the investigated equipment, each point being associated with a temperature (Dragomir, 2015).

During the investigation process there are taking into account the following disturbing factors:

a) reflections: in all electrical installations there are a lot of components with shiny surfaces which can generate reflections;

b) the variation of emissivity: if one electrical equipment has different emissivity zones, then the smallest emissivity needs to be considered;

c) the environment temperature;

d) the wind speed: this factor has an influence on the electrical equipment's temperature through a forced cooling effect.

In order to evaluate the overheating detected it will be utilized the temperature difference ΔT. This ΔT relies on the temperature rise which is compared with a reference temperature which can be: the temperature of a similar component which operates in the same conditions or the maximum allowable temperature indicated by the manufacturer (Infraspection, 2015).

The temperature difference ΔT on 100% load can be corrected with the relation:

$$\Delta T_{100\%} = \left(\frac{I_{\text{nom}}}{I_{\text{mas}}}\right) \Delta T, \tag{1}$$

where: n = 1.5,…,1.8; ΔT – the temperature difference for the actual load; I_{mas} – measured load current; I_{nom} – nominal load current. In relation (1) it was considered the fact that for heat transfer through conduction the temperature varies with the square load current (Joule-Lenz law) and the fact that for heat transfer through convection the radiant power depends with its own square of the square absolute temperature (Stefan-Boltzmann law) and the heat transfer through convection.

To determine these values there were conducted some experiments (Cao *et al*., 2008) which considered the measured temperature of some materials with emissivity between 0.6,…,0.95. The ambient temperature was considered 20°C, while the apparent reflected temperatures were between –25°C and +20°C.

In the case when the reference temperature is that of a similar component, the corrected temperature taking into account the current load is:

$$\Delta T_{100\%} = \frac{\left(I_{\text{nom}}/I_{\text{mas}}\right)^{1.5} + \left(I_{\text{nom}}/I_{\text{mas}}\right)^{1.8}}{2} \cdot \Delta T = C_i \Delta T, \tag{2}$$

where: C_i is the correction factor of 100 % current loading.

In Fig. 1 is illustrated how current load $Ki = (I_{mas}/I_{nom}) \times 100$, influences the value of temperature difference ΔT scanned by the infrared thermography device. As it can be seen, if the load of the current path is Ki = 100% then $\Delta T = \Delta T_{100\%}$. But for example if the current load is Ki = 30% and the value of temperature difference ΔT scanned is 5ºC, then the value of temperature difference corrected $\Delta T_{100\%}$ is close to 40ºC. That means if the current path of the equipment under investigation, will be loaded to Ki = 100% the infrared thermography device will read at the same spot a temperature close to 40ºC.

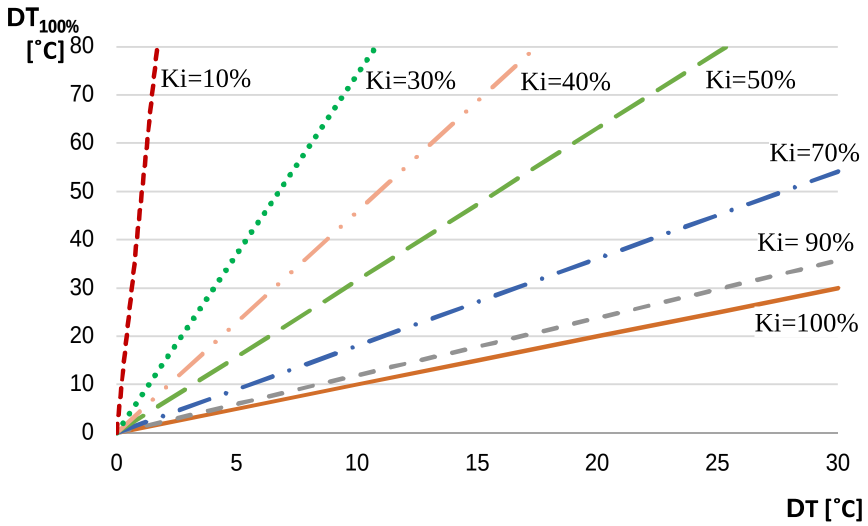

Fig. 1 – Temperature difference $\Delta T_{100\%}$ depending on the temperature difference ΔT curves for various current loads.

For outdoor substations scanning the wind is considered as a disturbing factor through the forced cooling effect introduced (Madding *et al.*, 2000). This effect will be compensated with the correction factor C_V (Lyon *et al.*, 2000).The values of C_V are indicated in Table 1. For wind speed that exceed 8 m/s it is not indicated to perform the outdoor thermography investigation.

Table 1

The values of C_V considering different values of the wind speed

Wind speed, [m/s]	≤1	2	3	4	5	6	7	8
C_V value	1	1.36	1.64	1.86	2.06	2.23	2.40	2.54

In Fig. 2 there is illustrated how the wind speed influences the value of temperature difference ΔT scanned by the infrared thermography device. As it can be observed, for the value of the wind speed 1 m/s or lower no correction will be applied and $\Delta T = \Delta T_{100\%}$. But if the wind speed value is getting higher then the wind correction factor C_V will be take in consideration as indicated in Table 1.

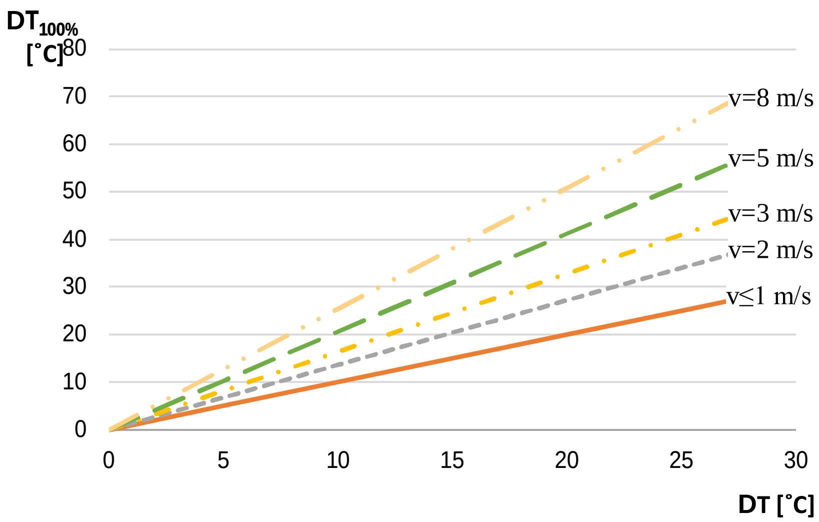

Fig. 2 – Temperature difference $\Delta T_{100\%}$ depending on the temperature difference ΔT curves for various wind speeds.

Influences of the wind speed over value of temperature difference ΔT scanned by the infrared thermography device can be observed from curves of Fig. 2. As it can be seen, if the wind speed is 1 m/s or lower then $\Delta T = \Delta T_{100\%}$. But for example if the value of temperature difference ΔT scanned is 5ºC, for a wind speed of 5 m/s then the value of temperature difference corrected $\Delta T_{100\%}$ is close to 10ºC. That means the wind is cooling down the temperature difference ΔT scanned by the infrared thermography device and correction according Table 1 is necessary in order to obtain a correct value.

Temperature difference $\Delta T_{100\%}$, considering C_i and C_v is calculated as:

$$\Delta T_{100\%} = C_V \frac{\left(\frac{I_{\text{nom}}}{I_{\text{mas}}}\right)^{1.5} + \left(\frac{I_{\text{nom}}}{I_{\text{mas}}}\right)^{1.8}}{2} \cdot \Delta T = C_V C_i \Delta T \qquad (3)$$

After the infrared thermography image is captured and after considering the current load correction factor C_i and the wind correction factor C_V, the obtained values of $\Delta T_{100\%}$ can be framed into four gravity categories (ST, 2012). Taking into account these categories there can be made some recommendations as shown in Table 2.

In the thermography report there will be indicated information about: exact location of the overheating in the electrical equipment; short description of the fault; temperature: T_{def} – the temperature at the fault point, T_{ref} – the reference temperature; T_{amb} – ambient temperature, ΔT – the difference between the fault point temperature and the reference temperature; the measured load current I_{mas}; the nominal current I_{nom}; the 100% correction factor for load C_i; the wind correction factor C_V; the difference temperature $\Delta T_{100\%}$ taking into account C_i and C_V; the gravity category; recommendations regarding the intervention moment; name of the infrared and visible domain image files.

Table 2
Gravity Categories of Faults

Reference $\Delta T_{100\%}$: Similar component (ambient temperature)	Gravity category	Recommendations /observations
$\Delta T_{100\%} \leq$ 10°C	A	Keeping under observation *first overheating stage*
10°C < $\Delta T_{100\%}$ ≤ 20°C	B	Fix at first technical revision - *developed overheating*
20°C < $\Delta T_{100\%}$ ≤ 40°C	C	Urgent fix (as soon as possible but not more than a month) *acute overheating*
$\Delta T_{100\%}$ > 40°C	D	Immediate fix *very dangerous overheating*

4. Study Case - Wind Influence in Outdoor Infrared Thermography Investigation

In order to observe the wind influence on the infrared camera measurements it is analyzed the high voltage separator as in Fig. 1.

The separator under test belongs to a 400/110 kV substation and its location is in 110 kV cell of a transform unit between 110 kV bus bar and 110 kV breaker. In order to obtain better results the infrared camera was focalized on the L2 phase of the separator. Also the infrared thermography investigation device settings were adjusted in order to obtain results as accurate as possible: the emissivity was set to 0.95 (this value corresponds to steel), the distance between camera and the investigated equipment was 2 meters, the reflected temperature was 17ºC, and the ambient temperature was 16ºC.

After performing a scan with the infrared thermography investigation device, the image on the left side from Fig. 3 was captured. It can observed from this figure that the temperature of the born clip towards the 110 kV breaker (area Ar_def) is 27.2ºC while the temperature of the born clip towards the 110 kV bus bar which is used as reference (area Ar_ref) is only 23.2ºC. Thus the temperature difference ΔT results in 4ºC using the relation:

$$\Delta T = \mathrm{Ar\_def} - \mathrm{Ar\_ref} = 4\,^{\circ}\mathrm{C}. \quad (4)$$

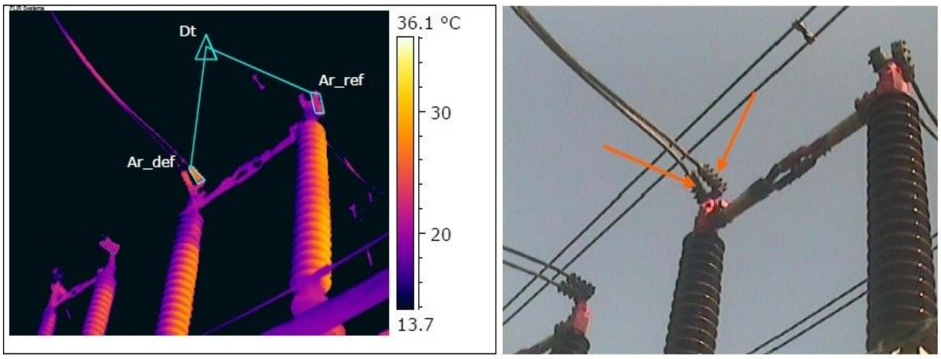

Fig. 3 – Infrared and visible spectrums of a 110 kV high voltage separator.

Taking into account that the load of installation was Ki = 30%, it is necessary to adjust the temperature difference ΔT value with correction factor of 100% current loading, which in this case is C_i = 2.33. Therefor it can be calculated the corrected value considering the load calculated with relation (2):

$$\Delta T_{100\%} = C_i \Delta T = 9.3\,°\text{C}. \tag{5}$$

If the thermal image is adjusted only with C_i then the identified fault area will be framed on A gravity group with the recommendation to be keep under observation.

But for this case scenario the wind speed measured with an anemometer was 7.5 m/s. Then taking into account also the wind correction factor C_V, relation (3), the corrected value of the difference temperature will result in 22.8ºC, (see Fig. 4):

$$\Delta T_{100\%} = C_v C_i \Delta T = 22.8\,°\text{C}. \tag{6}$$

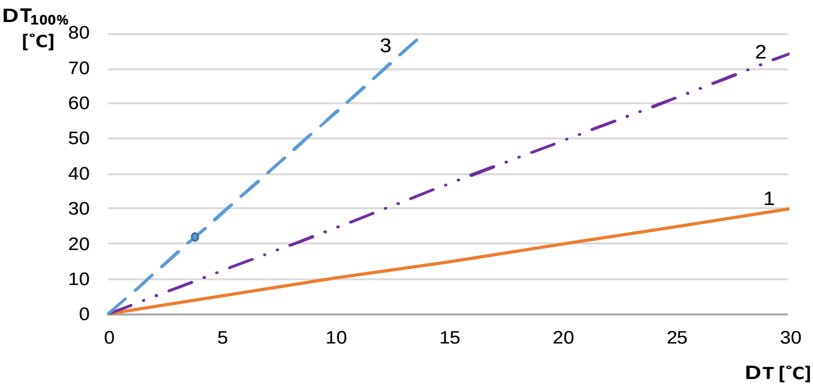

Fig. 4 –Temperature difference $\Delta T_{100\%}$ depending on the temperature difference ΔT for: 1 – no correction applied to value recorded; 2 – correction applied only for factor C_i of current load Ki = 30 %; 3 – correction factor C_V of wind speed v = 7.5 m/s and correction factor C_i of current load Ki = 30%.

If the thermal image is adjusted also with C_V then the identified fault area will be framed on C gravity group with the recommendation to be urgent fix (as soon as possible but no more than a month).

For this particularly case, when the wind speed was 7.5 m/s the correction factor's value is C_V = 2.47 and the current load, at time of measurement, was 30% with correction factor C_i = 2.33. It can be observed from the dot symbolized on Fig. 4, the temperature difference $\Delta T_{100\%}$ considering both factors C_i and C_V has a value up to five times higher than the value of temperature difference ΔT measured with no corrections.

5. Conclusions

Proper use of thermal stress wireless monitoring devices for electrical equipment requires a full understanding of the electrical system and its features. Therefore, in order to monitor the wear level of the electrical equipment is required to choose the correct wireless monitoring device.

In order to obtain values more closely to real values, for thermal stress monitoring with infrared thermography investigation devices, it is necessary to adjust the settings of the device and to define the correct parameters of the investigation scenario. The measured value must be corrected in terms of electrical load and in terms of the wind influence for outdoor measurements.

In case of thermographic measurement, if it is not considered the wind influence then the gravity classification of the area identified as being overheated can be wrong. Forced cooling caused by the wind, for outdoor operation of electrical equipment can mask their overheating and thus to risk of failure is greater.

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DISPOZITIVE FĂRĂ FIR DE MONITORIZARE A SOLICITĂRILOR TERMICE ALE ECHIPAMENTELOR ELECTRICE

(Rezumat)

Se prezintă metode de monitorizare fără fir a solicitărilor termice ale echipamentelor electrice, de asemenea se prezintă modul de interpretare a imaginilor termice in infraroşu împreună cu etapele ce trebuie urmate in vederea întocmirii unui raport de investigare termografica. Lucrarea abordează si modul in care vântul influențează valorile prelevate de dispozitivele de investigare termografica in infraroşu.