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Thermography in a Distribution Operator, Common Real Problems

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

Infrared thermography offers to the distribution operators the possibility to monitor their critical equipment. Early knowing the faulty or defective equipment the operators have the ability to evaluate the faults. With this knowledge, electric power distribution companies can avoid failures on their networks. In the vital areas which are installed at the High Voltage to Medium Voltage substations the interest is focusing on the equipment which is not checked by their SCADA system. In this article, the Central Greece Regional Department of the Greek distribution network operator (HEDNO S.A.) presents the most frequently reported problems during its thermographic investigations. Recommendations and interpretations, based on the experience and the database of the Central Greece department of HEDNO, are given as well.

Keywords: Nondestructive testing; infrared imaging; power distribution faults; power distribution lines.

1. INTRODUCTION

Infrared thermography is the most important non-destructive method for the distribution network operators. Any object with a temperature above zero emits infrared radiation which usually is invisible in the human eyes. This radiation can easily be detected and measured by a thermal camera which converts the invisible infrared radiation in a visible thermal image. Bad or loose

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connection in electrical equipment are not rare situation and have as results overheating which maybe lead to the disastrous failure of this part. This failure may also induces unscheduled breakdowns, fires, tragic injures or even deaths. Infrared thermography (IRT) inspection is a non contact method which is completed in a real short time and captures the thermal pattern of the investigated objects. The benefits for the electrical network companies are many and clear. The use of IRT prevents failures, reduces the unscheduled downtime and the maintenance cost, at the same time increases the reliability of the network and the life time of electrical equipment. For these reasons today the IRT as widely accepted as one of the most important monitoring tool in power networks [1-6].

The objective of the use of IRT is to obtain each company a comprehensive as well as detailed overview of its distribution system. Today power industry use the IRT in order to check a numerous part of their networks such as transformers, arresters, circuit breakers, air-breaker switches, cutout switches and fuses, insulators, etc.. For this purpose, experienced technicians inspect this equipment capturing thousand thermal images every year. This is a challenging work due to the high number of parameters needs to be considered. The results of the IRT are accurate when the load of the line is high enough because the temperature of the inspected electrical object is analogous to the square of the load. The presence of reflected radiation, wind air, intense solar radiation high humidity *can also affect the results* obtained with an infrared camera [7-8].

The primary goal of this work is to present the most common problems which faced the thermographers during the IRT inspections in their networks. In addition, the article reveals all the critical parts which must be inspected in any distribution electrical network in Medium Voltage (MV) level. It must be noticed that all the displayed examples were derived from the Central Greece department of the Hellenic Electricity Distribution Network Operator S.A. (HEDNO). Finally, the article pays attention in some very interesting special faulty cases which someone can meets in the distribution networks.

2. METHODOLOGY

2.1 Physical Basics for IRT

IRT is a technique to measures the infrared radiation which emitted by any object. This electromagnetic radiation can be described by the Plank's equation which describes the spectral emission of a blackbody. This equation can be written as:

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

where c is the speed of the electromagnetic radiation, h is Planck's constant (h = 6.63×10^{-34} J·s), k is Boltzmann's constant (k = 1.38×10^{-23} J·K^{-1}), T is the absolute temperature of the blackbody in degrees Kelvin and λ is the wavelength. The Stefan-Boltzmann law determines the relation between the radiated energy and the temperature. It can be obtained by integrating Planck's formula from λ=0 to λ=∞:

$$W_b = \sigma \cdot T^4 \quad (2)$$

where W_b is the total emitted radiation per unit area (W/m^2), σ is the Stefan-Boltzmann constant (5.67×10^{-8} W/m^{2}K^4), and T is the absolute temperature. From the equation 2 is obvious that which states that the total energy emitted by a blackbody is proportional to the fourth power of its absolute temperature. However a blackbody is an ideal object which absorbs all arriving radiation at all wavelengths and can emit more electromagnetic radiation than any other object at the same temperature; any real object characterized by its emissivity, ε:

$$E = \varepsilon \cdot \sigma \cdot T^4 \quad (3)$$

where E is the radiometric force (W/m^2), ε is the emissivity of the object (0<ε<1, ε = 1 only for a blackbody). Emissivity describes the remaining component of radiation after transmissivity (t) and reflectivity (ρ) according to the equation [9-11].

$$\varepsilon = 1 - (t+\rho) \text{ because } \varepsilon + t + \rho = 1 \quad (4)$$

2.2 Hellenic Electricity Distribution Network Operator

According to L.4001/2011 and in compliance with 2009/72/EC EU Directive relative to the electricity market organization HEDNO S.A. "is responsible for the development, operation and maintenance, under economically advantageous terms of the Hellenic Electricity Distribution Network Operator (HEDNO) so as to assure reliable, efficient and safe operation as well as its long-term capability to respond to the reasonable needs of the electricity caring for the protection of the environment and the energy efficiency. Also, it is responsible for the assurance of the users' access to HEDNO S.A. with the most economical, transparent, immediate and impartial way, to execute their activities according to Management Permit and the Management Code of HEDNO S.A." [12-13]. Table 1 shows the key figures of the electricity network.

In terms of number of consumers served, HEDNO S.A. with 7.5 million consumers is the fifth largest Distribution Company in EU. HEDNO S.A. manages 125.160 km of Low Voltage Network (LV), 111.130 km of Medium Voltage Network (MV) and 945 km High Voltage Network (HV) with 161.180 substations of MV/LV and 225 HV/MV substations. Must be notice that HEDNO S.A. is the only distribution operator in Europe which, based on the institutional powers conferred to it, ensures proper operation and management of the Electrical Systems (a total of 32) operating on the InterConnected Islands. It is a difficult and much complex project, because there are too many islands with different features (size, population, distance from mainland, isolated electrical system without possibility for energy exchange and very different energy demand between winter and summer).

The fault diagnosis which usually uses from the distribution operators based on the NETA's (inter-National Electrical Testing Association) standards Delta T criteria as shown in Table 2 [14]. For critical components such as the High Voltage to Medium Voltage (HV/MV) substations, thermographers of the distribution network have gained the know-how to identify how tight rein is necessary to the system and equipment of each substation. In the case of fault evaluation the Fig. 1 shows the parameters which are considered by a thermographer in order to evaluate the IRT results.

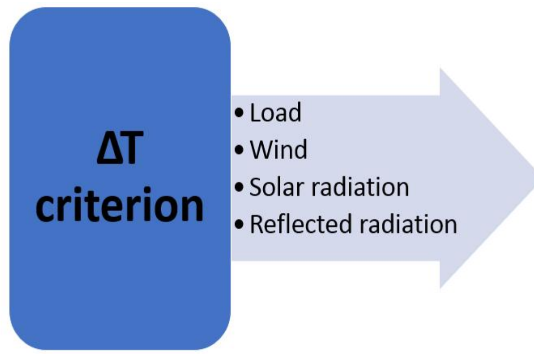


Fig. 1. The parameters which are considered by a thermographer in HEDNO

Table 1. Key figures of the Greek electricity network (at the end of 2015)

11.130 km of Medium Voltage Network (MV)
125.160 km of Low Voltage Network (LV)
161.180 Substations of MV/LV
945 km High Voltage Network (HV)
225 HV/MV Substations
7.438.455 Customers (11.444 MV & 7.427.011 LV)
43.237 GWH Customers' consumptions (10.973 in MV & 32.264 in LV)

Table 2. NETA Maintenance Testing Specifications for electrical equipment

Priority	Temperature difference (ΔT) based on comparisons between similar components under similar loading	Temperature difference (ΔT) based upon comparisons between component and ambient air temperatures	Recommended action
4	1ºC –3ºC	1ºC –10ºC	Non-Defective equipment
3	4ºC –15ºC	11ºC – 20ºC	Probable defective equipment, investigate further
2	-------------------	21ºC – 40ºC	Minor defect, repair at next opportunity
1	> 15ºC	> 40ºC	Defective equipment repair instantly

3. RESULTS AND DISCUSSION

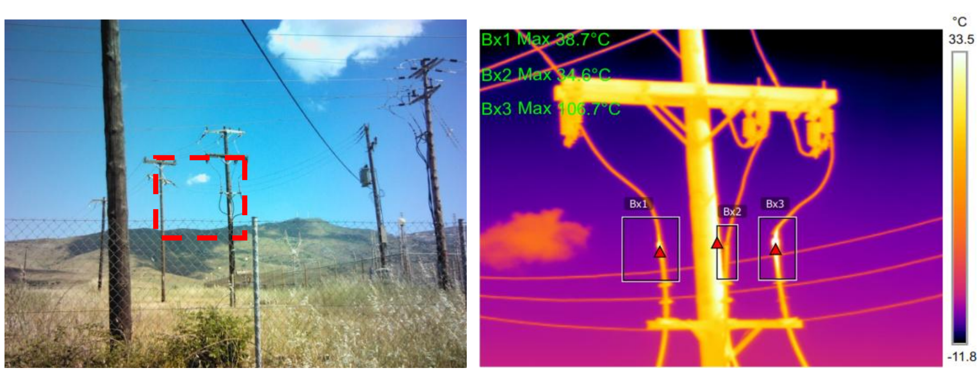
The IRT inspection procedure in the field based on the general rule that, usually in the distribution operator networks, owing to the presence of a three-phase current, there is the same electrical equipment three times. This equipment operates simultaneously in similar conditions. The direct comparison of these objects helps a lot the fault evaluation via the ΔT criterion. One of the most typical failures in the electrical networks has as reason the presence of some bad or loose connections. (Fig. 2a and b) is a representative example of this category. The loose connection has as a result excess heat (caused by increased resistance) and the priority of the fault is 1. All the presented examples based on the use of the Flir T 640 thermal camera which is the most common thermographic system in the HEDNO S.A.

Another critical object is the connection point between underground and aerial cables. Fig. 3a shows the visual image of the first pole outside of the HV/MV substation. With the help of the IRT the thermographer has found the problematic point (Fig. 3b). General the first pole outside of the HV/MV substations is critical equipment and checked with the thermal camera at least every three months.

In case of a 3-pole sectionalizer the connection between bushing and conductors maybe presents a problem. These problems can cause enough heat to destroy the internal parts of the electrical equipment (Fig. 4a and 4b). In the a-phase has found a problem with the connection at the top of the bushing; as a result, this termination is showing excessive heat compared to the other two phases. The fault has priority 1. Another point which usually checks an experienced is the closure of a 3-phase knife switch. In (Fig. 5a and b) the B-phase knife switch blade is overheating at the hinged joint and this cause overheat at the whole blade. The thermal image shows a fault with priority 3.

(a) (b)

Fig. 2. (a) The visual photo of the loose connection and (b) the thermal photo which reveals the fault



(a) (b)

Fig. 3. (a) The visual photo of the fault connection between underground and aerial lines (b) the fault in the same point with the help of the thermal photo

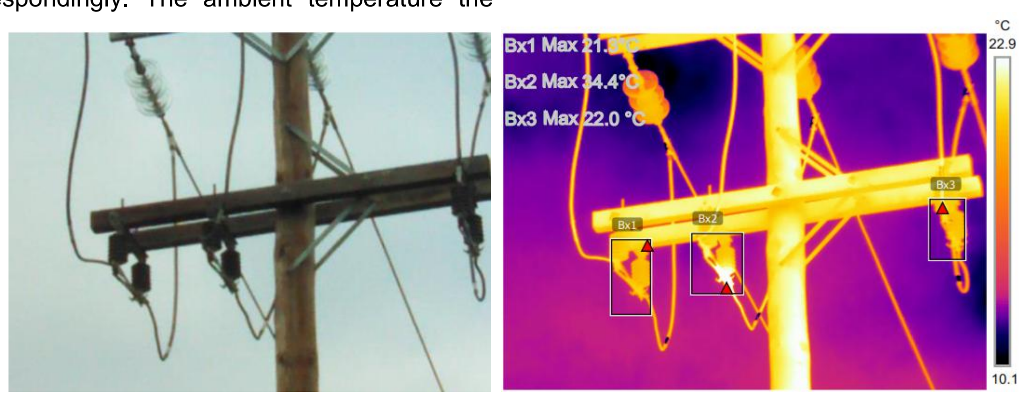
(a) **(b)**

Fig. 4. (a) The visual photo of a disconnector and (b) the thermal photo of the same disconnector reveals the most common problem, a fault with the connection at the top of the bushing

It must be say that owing to the strict maintenance program in the HV/MV substations in these areas the faults are rare. With thermal cameras distribution operators try to locate the faults in equipment which are not monitored by their SCADA system. For the power transformers which are the heart of each HV/MV substation the critical parts are four, bushings heads, surge protection, tap changer tanks and the cooling systems though, the last two seldom present problems. By scheduled cleaning the bushings, preventing looseness in connections and taking frequently a thermal image is possible to avoid the catastrophic failures in power transformers.

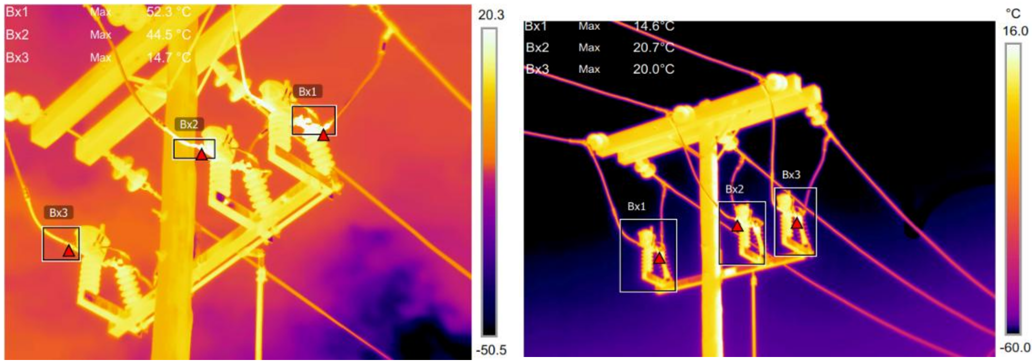
Except of these common problems, a thermographer in a live network meets and some with lower frequency. (Fig. 6a and b) shows a 3-phase switch load in which the three connections at the top of the bushings have maximum temperature 17ºC, 44ºC and 53ºC correspondingly. The ambient temperature the same time was about 15ºC so a thermographer of the HEDNO S.A. believe that there is problem both in B and C phase at once. After linemen repair the connections, it was revealed not only that the thermographer had right but also that there was a small imbalance of the load between phase A and phase B and C. From this example infers that sometimes the combination of two thermal images, before and after the repairing damage, it is possible to give valuable extra information.

However, usually the interpretation of fault is not so evident. Then the experience and the perceptivity of a thermographer are crucial. In (Fig. 7a and b) there are 6 points with measured temperatures from 20ºC up to 47ºC. The thermographer compares the input and the output in each phase and successfully detects the faults in the input of A-phase and in the output of C-phase.



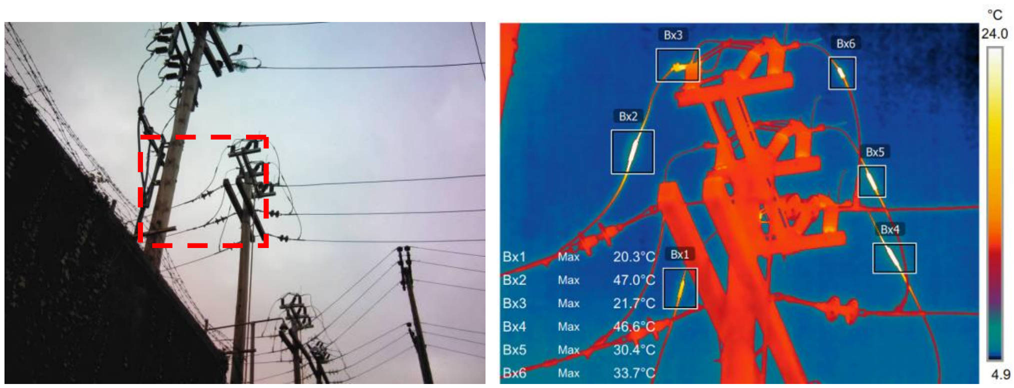
(a) **(b)**

Fig. 5. a) The visual photo of a 3-phase knife switch shows and b) the thermal photo which reveals a fault with priority 3



(a) **(b)**

Fig. 6. (a) the thermal photo of a 3-phase switch load reveals problems in B and C phase and (b) after repairing the fault the thermal photo shows a small imbalance of the load in A, B, C phases



(a) **(b)**

Fig. 7. (a) A visual image of a 3-phase disconnector and (b) the thermal photo shows problems faults in the input of A-phase and in the output of C-phase

The next object of Central Greece Regional Department is the creation of an analytical database with a correlation between the frequency of faults and the inspected equipment. The expectation of this database is not only to collect the necessary info by the operation of each part but also to evaluate each thermal image with the intention to improve the effectiveness of their thermographers. Another attempt will be to start to inspect systematically the MV/LV power transformers. Due to the fact that is considerably more than these of HV/MV in the first stage only these which has installed in big cities will be inspected systematically. Last but not least today the HEDNO S.A. work in two important fields for more accurate results i) in the development of semi-empirically correction factors in order to evaluate the influence of many environmental and physical factors ii) in the creation on an automated intelligent system which will use neural networks.

4. CONCLUSIONS

The article presents real examples of the most common problems which are possible to find an experienced thermographer during the inspections in a distribution network. The investigations of these parts are necessary in order to avoid the failure of the distributions networks. In this list belong the connections at the top of the bushings, the connections between aerials and undergrounds cables and the hinged joint of the knife in the disconnectors. In the case of HV/MV power transformers except of the bushings heads generally the other critical parts rarely present faults. The combination of three actions namely clearance of the bushing, prevent looseness in connection and frequent thermal imaging inspections helps to identify the faults before a breakdown occurs. Also, some other problems which occur in Greek networks are also presented. The exhibition of these faults accompanied with useful tips which can have considerable importance with intention to identify the problems and prevent the outages.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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