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Detection of electrical faults with infrared thermography

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Abstract

One of the problems that concern most often the electricians is how to determine the conditions or the state of operation of electrical systems quickly, without physical contact with the components and without disconnecting the network system. In other words, how to identify and locate latent defects that would cause unpredictable catastrophic failures, such as poor contact caused by corrosion and oxidation, loosening or bad crimp lugs, overloading of cables and transformers, imbalance phase loads, etc. Most electrical faults are characterized by loss of energy and overheating of the components and eventually by the emission of a quantity of infrared energy which varies with the temperature of the components, according to Plank's law. The detection of this radiation by the infrared thermography technique it is possible to inspect hundreds of points and identify the presence or absence of electrical faults.

IR thermography is a technique that converts the IR radiation into a visual image of the temperature difference shown by the surface of the components. The image obtained is a color map more or less clear showing "hot" zones and "cold" zones filmed surfaces. The inspection and comparison of the image obtained with the IR image of the reference corresponding normal operating state permit to locate the faults undetectable by the human eye. For example, a hot electrical interconnection may indicate poor contact requiring repair.

The tool used in the IR thermography is a portable camera with a pyrometric sensor capable of measuring temperatures of -40 ° C to 1500 ° C, with a resolution of about 0.1 °C. In this article, we present infrared thermography and its application for inspection and predictive / preventive maintenance of electrotechnical and electrical systems.

Keywords: Infrared, Thermography, preventive maintenance, fault diagnosis;

1. Introduction

In the electricity industry, the temperature is often considered an excellent indicator of the status or condition of operating systems because it is a very influential constraint on the reliability of the electrical components. Indeed, the life of an electrical component is significantly reduced when it is subjected to high temperature variations. To prevent failures it is often advisable to perform frequent inspections of the operating temperature of the hot spots of the electrical system, including contacts, connections and junction points. However, frequently check the temperature of dozens of points in an electrical system using temperature sensors such as thermocouples, is a difficult task, costly and can be hazardous. Now, there is the IR infrared thermography which allows the presentation in a visual form the radiant heat energy very many points on the surface of an electrical system. This technique measures the temperature of a large number of points simultaneously without physical contact and without danger. IR thermography consists in taking an infrared image of distribution of heat from the surface of a body.

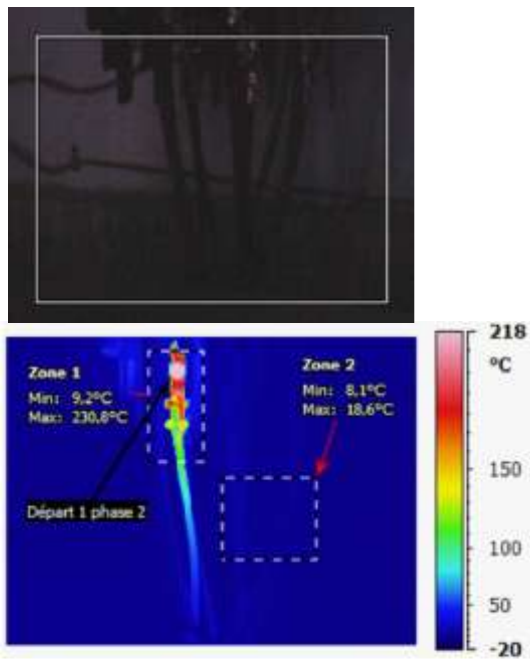

Figure 1. Thermography of depart distribution board

The points where there is a too low or too high heat emission as compared to normal conditions are source of defects in the system. However, taking an image, computer processing and interpretation of infrared images are delicate tasks as they require a good knowledge in IR material and its sources of uncertainty.

Industrial applications of infrared thermography are unlimited, in particular in electrical and mechanical domains. For example, it is effective for the inspection of transmission lines, transformers, thyristors, contactors, fuses, control equipment, motors and electric control switchboards.

In the following sections, infrared thermography technique will be described and its use as a preventive maintenance tool electrical systems.

2. Infrared radiation [1]

Electromagnetic radiation is the energy transfer process in the form of electromagnetic waves. These waves do not require hardware support and propagate into space. Planck, German physicist, announced that radiant energy can be emitted or absorbed in the form of quanta. The energy E contained in radiation quanta is proportional to the frequency γ of the radiation: $E = h\gamma$ where h = Planck constant. Electromagnetic radiation are also characterized by their wavelengths $\lambda = c/\gamma$ into space, $c = 3.10^8 m/s$. Electromagnetic radiation is generated by the movements of electric charges or by energy transitions between various quantum states of molecules or nucleus. On the spectrum of electromagnetic radiation, visible light can be distinguished, which covers the range of 0.4 to 0,7μm, and infrared, which is invisible to the human eye [2], extends from 0.7 to 1000μm. Infrared and its thermal properties have been evidenced by Sir William Herschel in 1800 using a thermometer placed in the solar radiation dispersed by a prism [3].

In general, all heated bodies radiate electromagnetic energy by the laws of Planck, Wien and Stefan-Boltzmann. The radiation luminance of a body is so much greater that its temperature is higher.

The field of the IR (> 0.7 μm) is arbitrarily divided by the IR detectors manufacturers in: NIR (0.7 to 1 μm), short-wave infrared (1 to 3 μm); mid-wave infrared (3 to 5 μm) and long-wave infrared (7 to 14 μm) and very long-wave infrared (14 to 30 μm) [4]. The transmission of infrared radiation is affected by absorption in the atmosphere. This absorption is related to the concentration of gases and particles which constitute the atmosphere; IR transmission depends on many factors, particularly the absorption of each gas, temperature and altitude and weather conditions. The Figure.2 [5] illustrates the rate of transmission of infrared radiation by the atmosphere clear.

The interesting IR spectral range is between 7 and 14 μm. Moreover, this broadband has encouraged the development of IR detectors based on thermal receivers as thermopile, bolometer and the pneumatic detector.

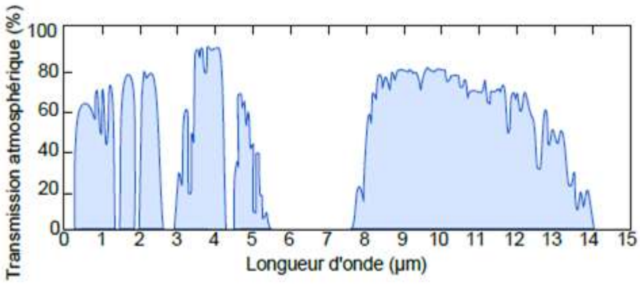

Figure 2. Transmission of IR radiation by the atmosphere

The receptors of these detectors are not selective. There are, however other types of IR detectors called quantum detectors which rely on the photo-emissive effect photoconductive or photovoltaic.

3. Thermography IR and electrical maintenance [6]

Infrared applications for the diagnosis of electrical systems, based on the detection of thermal radiation generated by its components to determine the operating conditions of the overall system, that they are normal or abnormal. Also, through to thermography it is possible to make the system images without the need to enlighten.

The military value of thermography is obvious: it allows to observe the enemy at night without sending it to radiation, easy to detect and that betray the observer. Its usefulness in industrial maintenance is even more important.

IR thermography devices employ punctual detectors or mosaic detectors which, associated with a mechanical scanning usually, provide a temperature map as a scanner as an image with a sensitivity of the order of 0.1 °C. The map points who find excessive amounts of heat are the origin of a latent defect in the system.

The employment benefits of thermography in electrical diagnosis are many, namely more efficiency, more safety, more reliability in the results, low cost and operation time.

3.1. Thermal variances in an electrical system

Thermal energy generated by an electrical component is directly proportional to the time t and the square of the current flowing through the component multiplied by the resistance ($\mathbf{W = RI^2t}$). Gradually, as the component conditions deteriorate, the resistance tends to increase and generate more heat. More the component temperature increases, resistance also augment according to the equation $\mathbf{R = R_0(1 + \alpha T)}$; where $\mathbf{R_0}$ is the resistance at 0°C, and α a coefficient to the metal; it is of the order of $\mathbf{4.10^{-3}}$ if the temperature T is given in degrees Celsius. This amplification process continues until the lowest melting point of the component is reached.

A component that heater is not always linked to an intrinsic event, but it can be linked to an overcurrent caused by other system components; in the case of an overload condition or unbalance in three-phase systems.

All thermal radiation emitted by a surface are not due only to the temperature of the surface. It is therefore important to take this into consideration in the analysis and the interpretation of the IR images because the apparent radiation can be misleading and lead to erroneous conclusions about the existence or otherwise of a defect. The thermal variations of a surface can result:

- Variations in the real temperature: the temperature distribution caused by the IR energy following the surface of the component itself.
- variations in the apparent temperature: these radiations are produced by sources other than the temperature of the inspected object;

3.1.1. The real temperature

In electrical systems, the causes of temperature variations at the surface of the components and represents good indications of a fault are mainly: the increase in resistance, the load, harmonics and thermal induction. There are other causes but provide little information about the operating conditions of the system, namely mass transport (wind), thermal capacitance (solar gain) and the phase change (rain, snow ...).

3.1.2. The apparent temperature

The main causes of the apparent temperatures are: emittance, reflection, transmittance and geometric variations of the surface.

The apparent temperature is a major source of uncertainty in the results of the diagnosis by thermography. Indeed, the relationship between the real temperature and the apparent temperature is an important factor to be considered in interpreting the IR images. The problem is that this ratio varies from one point to another in random sequence. Therefore, the temperature variances indicated by the IR image is not only caused by the electrical components themselves, but also by external influences creating false defects that mask real problems.

3.2. Causes of electrical faults

3.2.1. Contact resistance

Overheating of an electrical component can be linked to several factors; the most important are the defects of contact. A contact appears when you realize a connection with low pressure parts in contact, with a malformed welding, or with materials in contact oxidized or worn, e.g. decrease the spring tension, thread wear or tightening excessive of screws of electrical appliances.

Also, the insulation degradation of the conductors in the motors raises an increase of the absorbed current. Gradually, as the component continues to deteriorate, the temperature will continue to increase until the material melting point is reached; this is the fault.

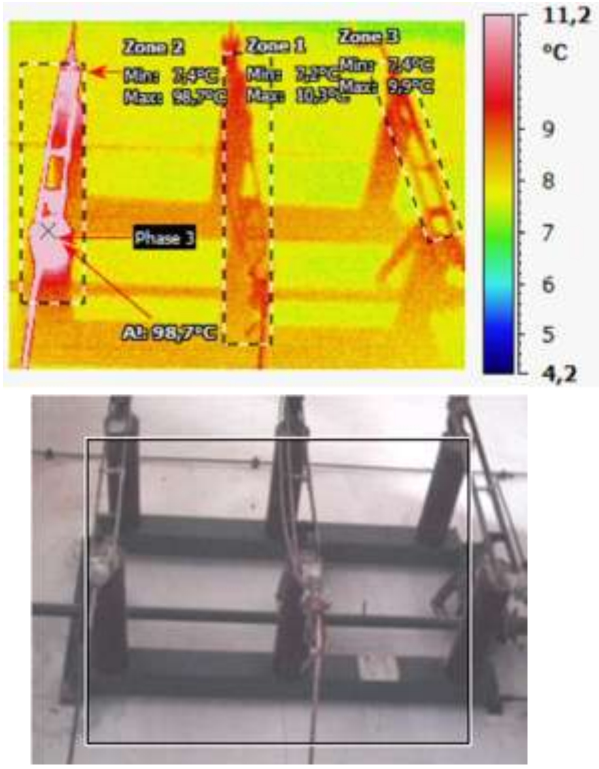

Figure 3. Thermography of disconnect switch

This type of fault can be identified because he will appear as the hottest spot in the IR image. This means that the heat generated is the largest at the point where the fault is located with a portion of thermal energy that propagates away from the defect by conduction or convection.

3.2.2. The load

Overloading also causes an increase in thermal energy. Thermographic viewpoint, a load is often considered a different type of problem with a specific thermal signature. When the load applied to an electrical component increases, the current consumption also increases which in turn causes an increase temperature of the component.

A balanced load of a three phase system should result in a uniform temperature distribution on the three phases. And an anomaly is identified as the temperature of an entire component or conductor is too high or too low. A balance condition is identified by the phases that do not observe even temperatures.

An unbalanced or overloaded component may generally be identified because the temperature remains relatively constant along the conductor or component as the size and mass of the object are fixed.

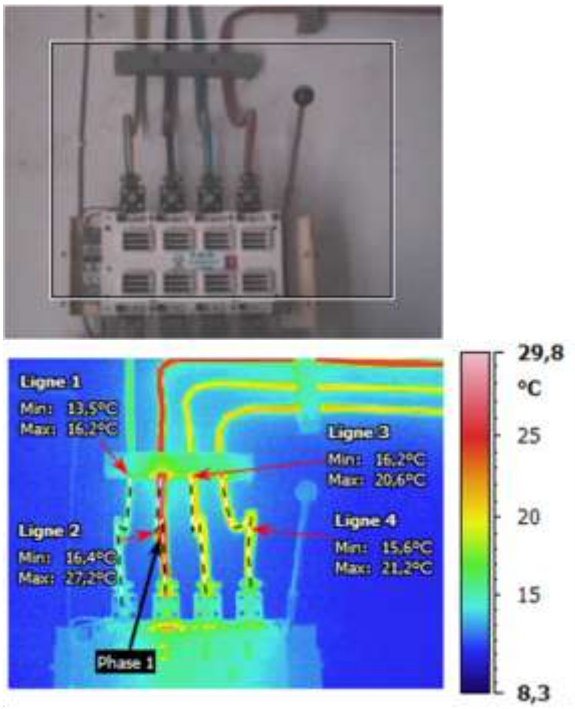

Figure 4. Thermography of an imbalance of the load

3.2.3. *Harmonic*

Harmonics are currents and voltages whose frequency is a multiple of fundamental frequency 50 Hz of the electric network. Presumably the risk harmonics are odd harmonics. These odd harmonics are superimposed on the fundamental harmonic and generate overvoltage, overcurrent and possible overheating.

Thus, the odd harmonics can cause significant heating and even cause melting of the conductors, connections, contact surfaces, and power outlets. Other equipments affected by the harmonics are transformers, motors, telecommunications equipment, electrical panels, breakers, disconnectors and busbars

3.2.4. *The heat-induced*

The induced heat is the heat generation in a material or a surface by the induced currents or by the inductive magnetic field created by an external source. This phenomenon occurs in the media located in a strong electromagnetic field, as is the case of HV equipment, Transmitters, and thermal induction equipment. The magnetic induction and also relates ferrous ferromagnetic material placed in a changing magnetic field.

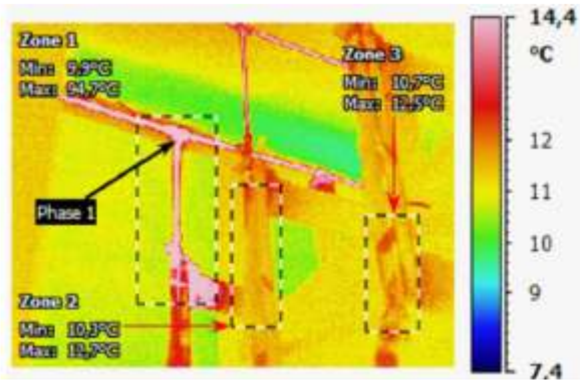

Figure 5. Thermography of a defect busbars

The induced currents or faucault currents summed of losses due to the hysteresis cycle causes heating of the magnetic material.

Table1. Electrical faults and their potential effects:

Equipment:	Faults:	Potential effects:
Distribution post of electrical energy, capacitors, spark gaps; conductors or wires junction; Disconnector	Contact weak / poor / worn; Badly made connection or junction; Bad switch connection; spark gaps defective; Overheating, Overload; Broken strands wires	Overheated; Arc striking; Fire; Burning device; Cable break; Fall of airline line, capacitor inoperative losing the protection against transient overvoltage; Losses of electrical energy (cost) Replacement Parts (cost); Security problems.
Various electrical equipments; Switches.: loads Station; motors control post of	Worn or weak connection; Bad contact; Unbalanced load; Overload. Overheated.	Arc striking; Short Circuit; burning, fire. Repair or replacement of the control post (high cost) Loss of energy (cost) Security problem.
Transformers;	Weak or deteriorated connection; through transformer overheating; Low contact (tap changer); Overload; Unbalanced three-phase load; Clogged or restricted cooling tube. Fluid level.	Arc striking; Short Circuit; burning, fire. Rewind (expensive) replacement (more expensive) Loss of energy (cost)
Motors and Generators;	Overheat bearings; unbalanced load; open-circuit or shorted turns; heating brushes; rings and switches: overload / overheating; ventilation or cooling blocked.	Defective bearings causing damage to the steel core or windings; Brooms defective → damage rings or switches → damage to the windings. Damage to the driven load. Rewinding motor (cost) Replacement Parts (cost) Security problems.

This process creates a true change in temperature on the surface. When warming concerns Steel or aluminum busbar bolts, it is often difficult to know a priori that it is a default component or a variation of emissivity.

3.3. Effects of electrical faults [6]

The following table presents some electrical devices that can be inspected using the IR thermography technique. Table 1 also indicates in columns 2 and 3, the most common electrical faults and their potential effects.

The application of thermography is also useful for the precise localization of drawing of electric cables heat and of any defects, monitoring power installations "sensitive" to which an operation stop for verification is not feasible, and even the detection Fluid leaks in underground pipes or exposed, and the detection of insulation defects, etc.

4. Instruments IR thermography

IR cameras the most common and most precise are two types: mechanical scanning cameras on a single receiver and pyroelectric vidicon camera [7].

4.1. mechanical scanning cameras

This type of camera is constituted by a movable flat mirror associated with another fixed parabolic mirror, allows, by an appropriate two-dimensional scanning to combine all the points of a landscape with a single receiver.

These cameras are the most popular to date; they may scan 200 lines of 200 points in 30 seconds, with a thermal resolution of 0.1 °K to about 300 °K temperature objects.

4.2. Pyroelectric vidicons cameras (pyricons)

The pyricons are newer IR cameras that compete with mechanical scanning cameras. Their principle is to project a thermal image on a pyroelectric target. There is obtained a relief of related electrical charges that can be read with a beam of electrons as in an ordinary vidicon. After digital video signal processing, we come to a resolution in temperature of 0.5 °K on an object at 300 ° K. The frequency reached 15 images per second. Thus, images are obtained whose quality of 250 lines approaches the visible television commercial.

In trade, many IR camera models are offered by manufacturers FLIR SYSTEMS and AGEMA. Two models are cited as an example: the IR camera around to 2 to 5 µm, make AGEMA Thermovision 470, and IR camera using 7.5 to 13 µm, make FLIR SYSTEMS THERMACAM PM 595

With these cameras IR thermal scenes from -40 °C to 1500 °C can be thermography with a temperature resolution of up to tenths of a degree and a spatial resolution of less than 2 cm to 10 meters.

5. CONCLUSION

IR thermography is an effective tool for predictive and preventive maintenance of electrical failures. It measures, without physical contact and safe, component temperature from thermal radiation emitted. The result is a visual image which shows the "hot" areas and "cold" zones characterizing the importance of thermal stress and the presence or absence of latent faults in power systems. Factors causing warming components are mainly the contact resistance, the load, harmonics and thermal induction.

However, the use of thermography requires special precautions and rigorous knowledge to avoid IR image interpretation errors that may be distorted by the effects of emissivity, reflection, transmittance and geometrical variations in the surface.

The benefits of IR thermography are many, including:

- Fault location quickly without interruption of service or production
- Reduction of unplanned outages and costs caused by the unavailability of equipment
- Extension the lifetime of the of the equipment by the identification of defects before the occurrence of catastrophic failure
- Equipment check for problems before the warranty expires
- Confirmation that appropriate repairs are made correctly
- Acquisition of Spare Parts can be done before the failure, and downtime is kept to a minimum
- Security inspection of systems at risk,
- Locating areas of energy loss in generation systems, transmission and distribution of electrical energy.

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