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Influencial factors in thermographic analysis in substations

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HIGHLIGHTS

- Reliability of results obtained with thermography.
- Percentage of load needed to perform thermography.
- Waiting time for thermographic inspections.
- Importance of tightening torque in generating hot spots.

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ABSTRACT

Thermography is one of the best predictive maintenance tools available due to its low cost, fast implementation and effectiveness of the results obtained. The detected hot spots enable serious incidents to be prevented, both in the facilities and equipment where they have been located. In accordance with the criticality of such points, the repair is carried out with greater or lesser urgency. However, for detection to remain reliable, the facility must meet a set of requirements that are normally assumed, otherwise hot spots cannot be detected correctly and will subsequently cause unwanted defects. This paper analyses three aspects that influence the reliability of the results obtained: the minimum percentage of load that a circuit must contain in order to be able to locate all the hot spots therein; the minimum waiting time from when an item of equipment or facility is energized until a thermographic inspection can be carried out with a complete guarantee of hot spot detection; and the influence on the generation of hot spots exerted by the tightening torque realized in the assembly process.

1. Introduction

Maintenance work in electricity companies has undergone a major evolution since its origins. Initially, only corrective maintenance was carried out: when a fault was produced, it was repaired as quickly as possible. Subsequently, preventive maintenance evolved: the existing maintenance programs were applied periodically without taking into account the particularity of each facility and with the consequent risk of introducing faults into the equipment during its manipulation. Finally, predictive maintenance can now be carried out: either without intervening in the facility whatsoever or intervening only minimally, whereby through comparison of the results obtained with the historical data of the element maintained, conclusions can be drawn regarding its state.

Predictive maintenance is the logical evolution that takes into account not only the quality of service demanded by the customer, but also the existing competition between electricity companies, and the possibility of introducing undesirable defects in facilities and equipment when maintenance is carried out. In addition, predictive maintenance gives us the information needed for intervention in the facilities only and exclusively when necessary and, from an economic point of view, this type of maintenance is the most profitable [1].

These maintenance techniques have been carried out with specific tests on various items of equipment to be maintained in the substations. Therefore, in the transformers, physical-chemical and chromatographic analyses of the oil are carried out, the dissipation factor is analysed, etc. [2]. In the circuit breakers, the displacement and speed of the poles is tested, the consumption of the coils is analysed, etc. [3,4].

However, one tool is of common application both to the variety of equipment and to the facilities, and is recognized for the benefits that it contributes: thermography [5–10]. In addition, this tool provides one of the most useful ways of carrying out maintenance due to its low cost, quick implementation, and the effectiveness of its results.

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Studies published on thermography have analysed: the factors that affect the temperature reading of thermographic cameras [11]; the equivalent modelling of certain equipment to identify internal defects through thermography [12]; and the relationship of certain parameters that characterize an item of equipment with thermography [13]. However this tool has yet to be studied from the practical point of view of the execution of the measurement process.

The main objective of thermography is to detect the hot spots of the equipment and facilities and then to proceed with their repair with the urgency associated to their criticality. This involves either programming the deenergization of the bay or carrying out work live in order not to influence the quality of the service perceived by the client.

In thermography, an experienced operator is necessary for the inspection of the installation in a fast but effective way; robots have occasionally replaced this operator [14]. In addition, it would be advisable to carry out the thermography when loads are as high as possible, although this is not always possible due to dependence on the work planning, in which case it becomes necessary to extrapolate the temperature measured for the load that is passing at that moment, to the temperature that would be obtained if the nominal current were passed through the inspected circuit.

Since thermography is carried out in each facility with the circuits in different states, a series of frequently assumed conditions are analysed in this study. However, if these conditions are not the case, the results obtained can be distorted and lead to erroneous conclusions regarding the assessment of localized hot spots. Furthermore, since in this work the field thermography operative prevails, the degree of precision of the results obtained is relegated to a secondary plane.

The minimum thresholds of three major assumptions are therefore determined to correctly identify the hot spots: the minimum percentage of load that a circuit must contain in order to be able to locate all the hot spots therein; the minimum waiting time from when an item of equipment or facility is energized until a thermographic inspection can be carried out with complete guarantee of hot spot detection; and the influence that the tightening torque realized in the assembly exerts on the generation of hot spots.

2. Materials and methods

2.1. Thermography in substations

The environment in which the activity of electricity companies is developed has changed radically in recent years: from a regulated market composed of vertically structured companies of a monopolistic nature to companies with competing independent segments. However, transmission and distribution activities have characteristics of natural monopoly due to their increasing economies of scale since the fixed costs of investment, operation and maintenance predominate over the variable costs. Moreover, it is totally inefficient for two companies to compete in the same territory by duplicating electricity infrastructure.

In this case, market competition is replaced by state intervention through regulatory agencies that encourage companies to carry out an efficient operation, maintenance, and investment plan. As a response to this remuneration for the operation and maintenance of the facilities and the incentives for their improvement, electricity companies have had to improve their maintenance techniques and optimize their programs. Termography constitutes one of the maintenance methods that have given the best responses to this need.

Thermography measures the heat emitted by the surface of a body by means of infrared radiations. This temperature is compared with that of the surrounding surfaces and with those of the same elements of other phases. Depending on the value reached, it can be determined whether the measured point is in a functioning state, and, if is not, then the urgency of its repair to return it to its optimal working condition is indicated. However for thermographic measurements to be taken as reliable, there must be a series of circumstances regarding the condition of the installation, otherwise risks may be masked. It is precisely from these circumstances that the measurements attain reliability and this forms the focus of this paper.

Another issue to bear in mind is that the locations within a substation where there is a greater risk of presenting a hot spot tend to be: at the connection points between the conductors with the facility equipment; and at the connection points from one conductor to another. It is at these points where inspection by an experienced operator must be focused. Since these connections are made through the connectors, these elements are vital for the prevention of breakdowns. Therefore, this paper also focuses on the operating conditions of connectors which, despite their simplicity, can cause many failures in the facilities.

This paper therefore focuses on the field circumstances that enable good thermography to be performed on those elements where the most hot spots appear (the connectors) and on one of the factors that experience has shown generates the most problems: the tightening torque of the connectors. Furthermore, in the case of results from field applications, the extreme accuracy of the laboratory's own results loses importance since field conditions differ from those of the laboratory, and hence measurement precision plays only a secondary role. For this reason, no statistical study has been carried out with the results obtained, as it should have been done in case the objective of the experiment had been to demonstrate rigorously a new hypothesis. In addition, the results obtained in the tests have been increased with a safety margin to obtain the conclusions to be applied in the substations. The measurements of the tests were taken when the temperature was stabilized, which occurred at approximately two hours in all cases. The current that in each test went through the loop, and all its components, has been indicated below and the temperature measurements of the tests have been carried out with thermographic camera.

2.2. Identification of the connectors used in the study

In order to analyse the aspects that influence the attainment of the correct conclusions when the thermographic measurements are made, the connectors that produce the highest percentage of hot spots have been previously identified. Six thermographic inspections were carried out over a period of fifteen months in six substations where there was a wide range of temperatures, and the measures of the intensities that circulated around the circuits were also registered. The number of connectors registered in these substations was 21,027 with a total of 165 hot spots in the six inspections carried out (Figs. 1 and 2 show the normal and thermal images of two of these hot spots). Once the families of connectors that have the most hot spot problems had been defined, such connectors were used in laboratory tests. These connectors connected: Aluminium (Al) cable with copper (Cu) tube; Al cable with Cu flatbar; Al cable with Cu stud; and Cu tube with Cu flatbar. Both the connectors and the rest of the material used in each of the laboratory tests were new and with the characteristics indicated in each of them. When the inspections were carried out, measurements were taken of the intensities presented by the circuits, and a total of 7204 values were registered. Fig. 3 shows the percentage, compared to the total, of each step of intensities in amperes (A).