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Research Paper

Thermographic analysis of parallelly cables: A method to avoid misdiagnosis

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HIGHLIGHTS

- A method that conduces to more assertive diagnosis in parallelly conductors.
- In some cases, the colder connection may be the defective connection.
- Paper gives a model to estimate temperatures and currents in parallelly conductors.
- The experimental evaluation led to estimations with acceptable errors.

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ABSTRACT

Thermography infrared technique is quite used in predictive maintenance. Thermographic analysis consists in associating regions with high surface temperatures to defects and failures. However, for some situation, such as parallelly conductors of the same phase, the warmer connection may be in accordance, and the colder one may be defective. If there is a "poor contact" failure in one lead, electrical current can be significantly higher in the cable with lower contact resistance and, consequently, lower intensity on the cable where the connections have higher resistance. This paper develops an analysis method that conduces to more assertive diagnosis regarding the identification of the faulty connection of parallelly conductors in low voltage electrical installations, non-invasively and under operation.

1. Introduction

Predictive maintenance is a technique based on monitoring and periodic analysis of some parameters of equipment in operation, enabling fault identification in an early stage. Thus, corrective interventions happen in a planned way, accurate and only when needed, maximizing the operational availability of monitored equipment [1].

Measuring of infrared radiation emitted by bodies highlights in predictive maintenance. This technique, known as thermography, is used for various purposes where the temperature is a symptom of a phenomenon to be evaluated, particularly: analysis of electrical equipment, corrosion analysis, welds in construction coatings, electronics, and mechanical equipment, among others [1–7].

These are some of the installations and electrical equipments that present temperature rise as a characteristic symptom [1,8–11]:

- Terminals wrongly set up;
- Disconnectors' contacts in disagreement;
- Corrosion;
- Overload;
- Load imbalance;
- Poor connections;
- Thermally aged conductors (and their insulation);
- High-resistance electrical joints in electrical connectors;
- Loosening splices;
- Dirt;
- Contamination.

Specifically in electrical installations, thermography diagnosis non-accordance based on the detection of points at high temperatures, fleeing parameters outlined by the manufacturers and international organizations [1]. In general, the rise in temperature of the analyzed surface is associated to equipment failure severity [1,2,5,10,12]. Fig. 1 illustrates problems in disconnect switch in a three-phase system of 220 V. Although the electric current is balanced in three phases, the central phase is about 15 °C above the left phase and 27 °C above the right phase.

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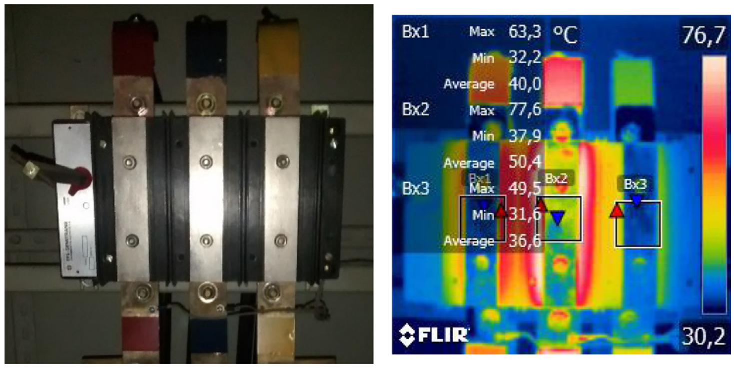

Electric currents:
Phase 1: 200 A
Phase 2: 201 A
Phase 3: 193 A

(a) (b) (c)

Fig. 1. Disconnect switch in a three-phase system of 220 V: (a) real picture; (b) infrared thermogram; and (c) electric current values in the 3 phases. Credit images: Ifes.

Another method of analysis of thermograms in electrical equipments consists of assessing the differences in surface temperatures of the inspected equipment, or evaluate the difference between lower and higher temperatures [11]. Even temperatures whose values are not considered excessive can be identified as hot spots, leading to identifying early defects. This approach has been highly efficient and standardized, also allowing training artificial neural networks for automatic diagnosis of electrical installations [13].

However, high temperature cannot be associated to failure under some circumstances. For example, parallelly cables of the same phase can occasionally result in an unexpected fault profile, different from usual patterns. If there is any failure of poor contact type, electric current can have significantly higher intensity in the cable whose connections are good and less intense in cables of poor connections [14]. This eventually may result in higher power dissipation in the good connection and lower power dissipation in the faulty connection. Exemplifying this situation, Fig. 2 shows the thermogram of a three-phase system with two conductors per phase in which trivial diagnostic method would indicate that the warmer connection (110.9 °C) would be defective. Actually, in this context, this connection could be in accordance. The colder connection (85.9 °C), apparently healthy, could be the non-compliant, conducting lower electrical current.

Misdiagnosis may suggest corrective actions in healthy conductors and connections, keeping defective parts without intervention [15]. Thus, it is noticed the need for more robust testing methods and diagnostics through thermography concerning parallelly cables of the same phase.

This paper then develops a mathematical model to estimate temperatures and currents in parallelly conductors of the same phase, in low voltage electrical installations, that leads to a more assertive analysis compared to the currently methods available.

Fig. 2. Parallelly cables thermogram in a three-phase installation. Courtesy of ArcelorMittal Tubarão.

2. Methodology

Whereas an electrical installation with parallelly conductors may have non-trivial behavior, i.e., the most heated cable can be not the defective one [14], such situation was modeled as shown in Fig. 3.

Where:

V_0: AC power supply, V;
R_{POOR}: non-accordance connection electrical resistance, Ω;
R_{GOOD}: in-accordance connection electrical resistance, Ω;
R_{CABLE}: line resistance (the cable), Ω;
R_{LOAD}: load resistance, Ω.

In this model, load power cables are modeled as resistors, once the inductive effects can be neglected at low voltage in a steady state [16]. The equations of electric currents on each parallelly cable are obtained through the concept of current divider.[1]

Equations of temperatures on the connections are obtained from a model that correlates the temperature rise and the power dissipated in the connection itself. The independent variable in both cases is the electrical resistance of the faulty connection, here referred as "poor contact resistance". The dependent variables are the currents in each parallelly branch and the temperatures in each parallelly connection. The currents equations for good connection and poor connection are presented in Eqs. (1) and (2).

$$I_G(pu) = \frac{R_{POOR} + R_{LOAD}}{R_{POOR} + R_{GOOD} + (2 \cdot R_{LOAD})} \tag{1}$$

$$I_P(pu) = \frac{R_{GOOD} + R_{LOAD}}{R_{POOR} + R_{GOOD} + (2 \cdot R_{LOAD})} \tag{2}$$

where $I_G(pu)$, electric current in good contact, per unit[2]; $I_P(pu)$, electric current in poor contact, per unit.

From the electrical currents in the good and the poor contact, one can get the power dissipated in each connection through Eq. (3).

$$P = R \cdot I^2 \tag{3}$$

[1] Current divider is a technique of analysis of linear electric circuits. It allows to determine the current passing in each branch of a circuit, as a fraction of the total passing current [17].

[2] Per unit (pu): a system that allows express quantities as percentage of a defined base unit quantity. Per unit system is widely used in power systems field [18].