EFFICIENT AND ERGONOMIC LOAD FOR DIDACTIC ELECTRICAL PANELS

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ABSTRACT

Infrared thermography allows to detect defects even incipient, reducing maintenance costs and shutdown time. To accordingly perform the infrared inspection, the operator must be capacitated and well trained. There is difficulty nowadays in teaching thermographic inspection due to the lack of didactic equipment for this purpose. For that reason, a prototype set of switchgear was developed to be used as a didactic resource for teaching-learning infrared thermography applied to the predictive maintenance of electric installation in classrooms. Typically, an association of resistors as a load is used to generate a current large enough to cause a perceptible increase in temperature at the points of failure. But this load is large and overheating, making the class uncomfortable due to heat, and electric power cost is high. The purpose of this paper is to develop a new prototype that allows the circulation of electric current large enough to cause temperature rising dissipating low power. The present prototype connects the R, S and T switchgear phases in series from the original panel and feeds it through a direct current source, keeping it without internal modifications. This source can be adjusted to fit the need of current of the system, which was decided to be 20 A. The prototype has much lower cost than traditional resistive loads, is lightweight and easy to be transported. In addition, by reducing the dissipated power, it does not generate thermal discomfort in the classroom environment and reduces the costs with electric power about 90%.

Keywords: power engineering education. switchgear. energy efficiency. predictive maintenance.

INTRODUCTION

Over the years, infrared thermography has been used in several knowledge areas, such as diagnosis of pathologies in civil constructions, patrimonial safety, human and veterinary medicines, and electrical and mechanical maintenance. It consists of temperature measurements performed at a distance with thermal imagers and subsequent analysis of the obtained thermograms (MUNIZ, 2014).

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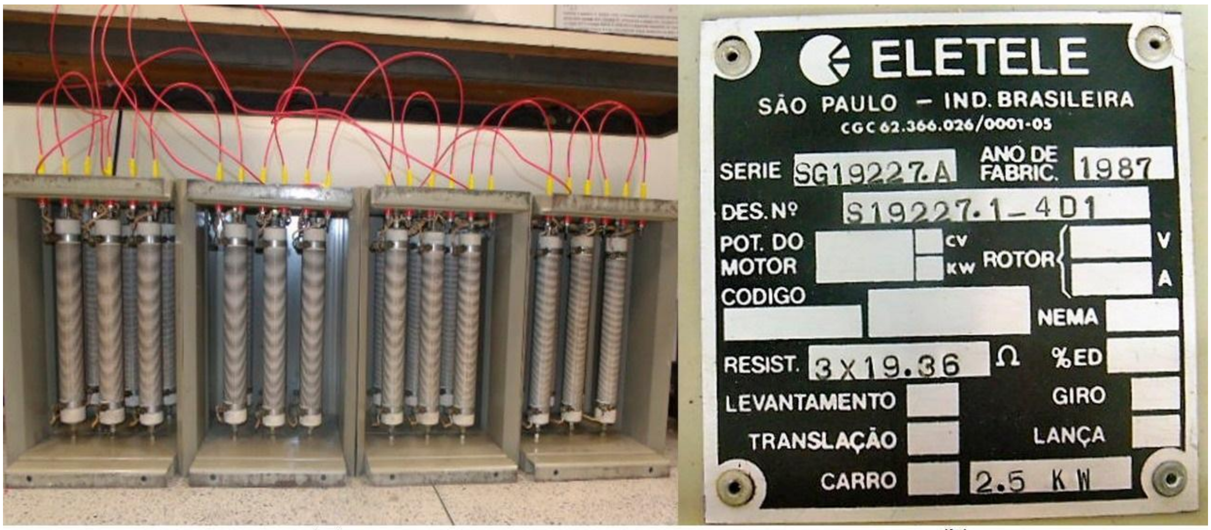
The thermography allows symptoms of failure to be detected and analyzed to correctly orientate the maintenance teams (SANTIAGO; SOLVA, 2016). It has been performed in areas where knowledge about temperature and heat patterns will provide relevant data about a system, process or structure. Thus, it is possible to detect incipient defects, reducing maintenance costs and shutdown time. Infrared thermography helps companies improve service quality, increasing end-consumer satisfaction, ensuring greater safety for employees and the population, greater productivity and improvement of maintenance routine, reduction of consumption losses, reimbursement for interruptions and reduction of maintenance and acquisition costs (SANTIAGO; SOLVA, 2016).

In electrical maintenance by infrared thermography, as in any other application, the proper diagnosis depends on capacitated and well-trained technicians (ALMEIDA, 2017), i.e., the inspector must have adequate training. Currently there is great difficulty in teaching thermographic inspection due to the lack of didactic equipment for this purpose. Classroom in a real electrical installation is not recommended because of the need for defect insertion, which is not safe from operational and work safety point of view. Therefore, a prototype set of switchgear was developed, which can be used as a didactic resource for teaching-learning infrared thermography applied to the predictive maintenance in the classroom (ALMEIDA, 2017). In this educational panel, basic concepts of thermography were implemented, simulating the most common electrical defects that cause changes in the temperature pattern, which are: poor connections, open circuit, improper installation and interruption of cables in parallel (ALMEIDA, 2017; HUDA; TAIB, 2013). The electrical load was an association of four banks of three 19.36 Ω resistors, as shown in Figure 1. Almeida (2017) reports that the load used "is too large and overheating, making the class uncomfortable due to heating", and that it is necessary to use a more efficient load.

A discomfort and energy inefficiency factor for the panel with electrical load is the need for electric current that produces the didactic effects of overheating on defective elements. This electrical load, typically resistive, occupies a lot of physical space, heavy and difficult to be transported and dissipates energy in the form of heat, disturbing the thermal comfort of the classroom environment and contributing to waste of electrical energy and, consequently, financial resources.

The class with loaded didactic panel is an unusual implementation. It is verified that the didactic panels currently available for teaching and learning of Industrial Maintenance do not allow the situation above, which limits the students' analysis and learning. For example, Silva et al. (2014) developed a panel for teaching industrial maintenance applied to electrical control panels that allows students to search for defects using logic reasoning, but only with the panel without load, which makes the use of infrared thermography unfeasible.



(a) (b)

Figure 1 - (a) Resistor banks (b) Nameplate of the resistor bank (ALMEIDA, 2017).

From the exposed above, the objective of this paper is to develop a method of charging electrical didactic panels, producing the desired internal heating effects, without, however, requiring resistive load elements, which are not ergonomic, heat the classroom environment and waste electrical energy.

MATERIALS AND METHODS

The didactic panel for thermographic inspection used as the basis for the development of this paper, developed by Almeida (2017), has its electric diagram shown in Figure 2. It is a three-phase circuit, 220 V, 60 Hz, 20 A, and a star-delta motor starter. In this circuit, D1 is a bipolar thermomagnetic circuit breaker, S0 and S1 are command buttons, X is an on-delay timer. C1, C2 and C3 are contactors; L1, L2, L3, L4, L5 are lamps; XL is a fuse; SEC is a switch disconnector. A1, A2 and A3 are analog ammeters, DR is a residual differential circuit breaker and D2 is a tripolar thermomagnetic circuit breaker. The load is supplied by the force contacts of the contactor C1. Contactors C2 and C3 are responsible for connecting the star and delta loads, respectively (ALMEIDA, 2017).

The resistor bank, shown in Figure 1, was initially used as the load for the didactic panel developed by Almeida (2017). The association of resistances gives a nominal maximum current per phase of 19.68 A, sufficiently large to cause a perceptible increase in temperature at the points of failure (ALMEIDA, 2017).

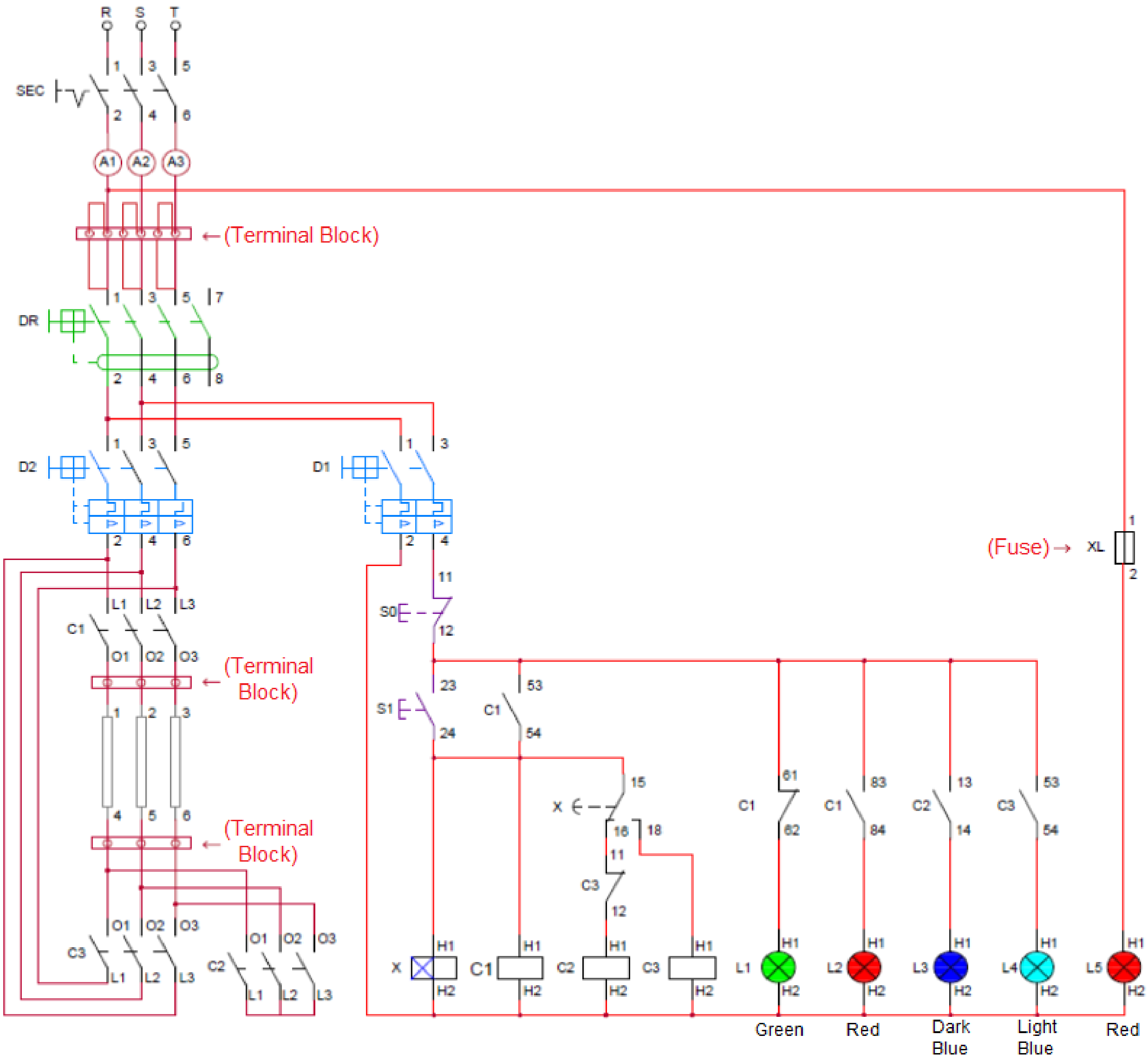


Figure 2 - Original operation of the electric command circuit (ALMEIDA, 2017).

The didactic defects purposely inserted in the original and conventional panel are open circuit, interruption of cables in parallel, improper installation and poor connections, (ALMEIDA, 2017). They are detailed below:

- open circuit: the lack of current flow causes an open circuit conductor to present a cooler thermal pattern when compared to an adjacent conductor under load (JADIN; TAIB, 2012).
- interruption of cables in parallel: parallel conductors of the same phase can produce an unexpected thermal profile. If there is poor contact in one of the cables or the conductor is disconnected, the current will be significantly higher in cables with good connections and less in cables with defective connections. Therefore, there may be a greater energy dissipation in the good connections than in the bad connections (MENDES et al., 2016).
- improper installation: the electrical current carrying capacities of electrical cables and other

devices are directly related to the thermal conditions of conductor dissipation and to the operating conditions. During prolonged periods in normal operation, the current carried by any conductor must be such that the maximum continuous service temperature of the cable is not exceeded (ABNT NBR 5410, 2004). If the conductor is undersized or the installation conditions (grouping factor, installation location, protection, voltage drop, atmospheric temperature, etc.) are inadequate, it will overheat, leading cable insulation to a risky situation and increasing Joule effect (ALMEIDA, 2017).

- poor connections: this defect is associated to the reduction of the area of conduction of current flow in the electrical connections (SCHUÍNA; MUNIZ; QUEMELLI, 2016). In electrical installation where there is poor connection the heat generated is higher (DIB; DJERMANE, 2016).

Once electrical current circulation in the didactic panel for heating generation is desired, a new prototype that would impose the circulation of electrical current in its three phases, giving up the voltage level of 220 V, has been developed. This would maintain the internal heating by Joule effect through the electric current but would reduce power dissipation by reducing the voltage level.

Another premise adopted was the internal nonintervention in the original didactic panel, so that it could be used both in the traditional way, feeding resistive loads, and by the proposed method, through forced circulation of electric current.

To adapt it to the new project, shown in this paper, and for heating purposes, the R, S and T phases were later connected in series from the panel, subjecting the system to 20 A and maintaining it without internal modifications. Its power, previously made directly by the power grid, was carried out by a direct current source, which can be found in laboratories and is portable, lightweight and easy to use. Thus, in the new project, an external female socket was decided to be used and, when connected to the male socket from the original didactic panel, automatically links its three phases in series, and provides two terminals that can be powered by the external current source, commonly available in didactic laboratories. The diagram in Figure 3 shows this circuit.

The user of the project must connect the male socket from the control panel to the female socket from the proposed prototype, as shown in Figure 3a and Figure 4a. One must also connect the properly identified prototype cables to the panel output terminals, which would feed the physical load, Figure 4b, and connect the proposed prototype to the current source, Figure 4c. Finally, as shown in Figure 2, when the direct starting of the panel is performed, the command button S1 must be pressed to allow the circulation of the current to the panel output terminals 1, 2 and 3.

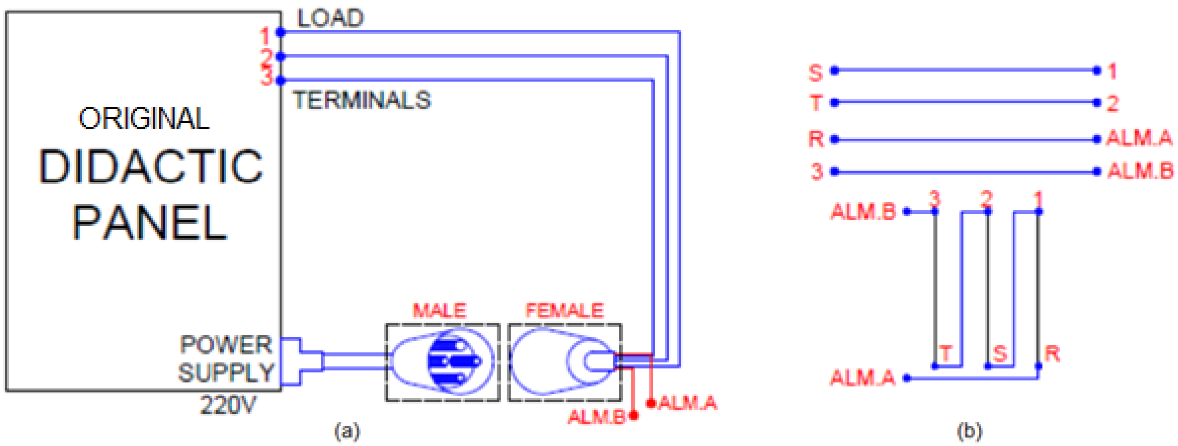


Figure 3 - (a) Diagram showing the connection procedure between the prototype and the panel (b) Diagram showing the electric links between the panel output and the prototype.

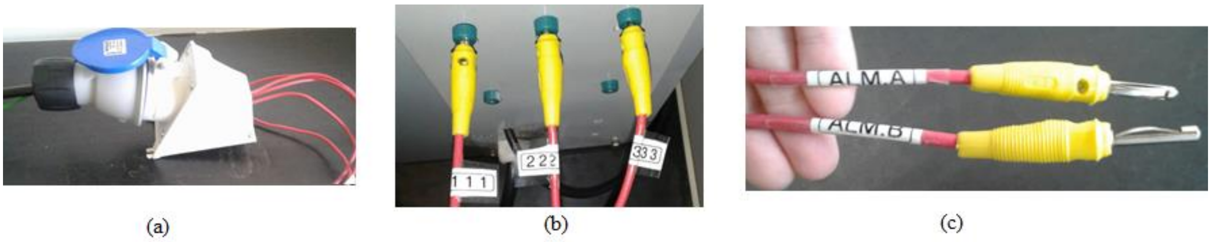


Figure 4 - (a) Educational panel male socket connected to the prototype. (b) Prototype connected to educational panel output. (c) Prototype terminals to be connected to the current source.

This procedure makes it possible to perform the activity without needing to manipulate the electrical components, and the connections between the terminals can easily be performed by the student or teacher, reducing accident risks. The thermographic inspection of the didactic panel working through the method proposed in this paper produced the same results obtained when fed with a three-phase voltage source of 220 V and load of 19.68 A.

Unlike Almeida (2017), the panel will not maintain its normal operation with the methodology proposed in this article and its control circuit will not be energized, as well as other parts of the circuit. In this case, the panel will only operate in triangle mode, and not in star mode operation and, because of that, the thermographic study performed with the proposed methodology provided the same results with the conventional methodology regarding the use of three-phase voltage and resistive load.

RESULTS AND DISCUSSION

The panel operating by the traditional method, with the resistive load used in the panel, is powered by a 220 V three-phase source, conducting 20 A, which would lead to dissipation of approximately 7,620 W in the load. Internally, the insertion of defects generated a resistance about 1.7 Ω, which generates about 680 W. Thus, according to Equation 1, the total power dissipated for panel operation would be about 8,300 W.

$$P_i = \sqrt{3}V_L I_L + RI^2 = \sqrt{3}(220)(20) + 1.7(20^2) \cong 8{,}300W \quad (1)$$

Where V_L is the panel supply voltage, I_L is the current flowing through the panel and R is the internal resistance in the panel due to the defects inserted.

With the proposed prototype, the external load is eliminated, leaving only the internal power dissipation to the panel. Thus, the total power dissipated is restricted to 680 W.

The materials needed to assemble the proposed prototype require about US$ 70, and are:

- one three-phase female 2P + T, 20 A connector;
- cables and connection terminals;
- a buck converter of 20 A.

The buck converter was used as an element for the construction of the direct current source since, even if it is adjusted by voltage, and not current, it can define the maximum current to which the system will be subjected, besides maintaining it constant.

The bank of resistors for physical load demands approximately US$ 700 to be assembled, and is composed of:

- 12 19.36 Ω / 833.33 W resistors;
- 4 metal boxes;
- cables and connection terminals.

From the above, it is noted that the proposed prototype represents about 10% of the cost of the resistor bank.

Another advantage of the proposed prototype concerns energy consumption. Considering the cost of US$ 0.14/kWh and 8 hours of class per month, classes with a resistor bank would imply approximately US$ 9.30 per month in electricity, as indicated by Equation 2. The classes with the proposed prototype, under the same conditions, would cost approximately US$ 0.76, according to Equation 3.

$$8{,}300kW.\frac{8h}{month}.\frac{US\$0.14}{kWh} = \frac{US\$9.30}{month} \quad (2)$$

$$0.680kW.\frac{8h}{month}.\frac{US\$0.14}{kWh} = \frac{US\$0.76}{month} \quad (3)$$

CONCLUSIONS

Practical classes in electrical maintenance uncommonly reproduce real thermal effects in laboratory environments. Until then this effect was reproduced through the feeding of resistive loads, implying a waste of financial resources in electrical energy dissipation, thermal discomfort in the labor environment and ergonomic problems in the handling of equipment.

The prototype proposed in this paper imposes current circulation in the didactic panel without the need of power supply at nominal voltage, reducing drastically the electric power consumed. The prototype has a much lower cost than traditional resistive loads, of the order of 10%, is lightweight and easy to be transported, and it does not require internal changes in the didactic panel used in class. In addition, by reducing the power dissipated, it does not generate thermal discomfort in the classroom environment and, for the hypothetical case studied, reduces the costs with electric power in the order of 90%.

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