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Measurement, evaluation and proposed solution for power distribution arrangements with electrical cables in parallel

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ABSTRACT

The electrical installations to supply power for heavy loads usually are three-phase and have several cables in parallel. One reason for this choice has been the mechanical difficulties that arise when cables are too large. The shape or arrangement of cables within the conduit, beds, cable trays, or other assembly systems for cables can make each cable have a different impedance and, therefore, cause uneven distribution of the current between the cables of the same phase or circulating currents that appear in the neutral conductor. Using the Finite Element Method (FEM) or applying the solution of analytical equations, one can better understand this problem and, thus, propose solutions. This paper implements the analytical methodology, analyze it through the FEM, and take measurements in the laboratory. Thus, the method will be validated and then applied to the study of a proposed case. The purpose of this study is to present a methodology that can contribute to maximize cable ampacity and to improve the shelf life and the energy efficiency of the installation.

1. Introduction

Industries, commercial centers and large buildings have been categorized as medium or large power consumers. To meet this demand more efficiently, the utility companies suggested the installation of compact substations with demand and power factor controls and the adoption of differentiated tariff systems or new strategies to implant demand side management [1].

Despite the different industries' sectors, the electric power supply system does not differ much, regarding the basic process. In general, the feeders are installed within electric rails, conduits, cable trays or beds.

In these typical power distribution systems, when one is using a single conductor for each phase and/or neutral and the cable has a large gauge, great difficulties occur during installation, due to the mechanical properties of the cable. Large-gauge cables require very high radii of curvature and these are standardized.

With regard to the expansion of existing facilities, it is not always possible to change the infrastructure to receive these cables with greater gauges, making the installation impossible to be performed. In order to facilitate the installation, usually a single cable is replaced by several conductors in parallel, with a smaller gauge for each.

Often, the electrical designer uses the impedance shown on the cable manufacturer table. However, the impedance presented refers to the nominal frequency and does not take into account the harmonic content of the installation and the arrangement used.

With the change in impedance of the cable, due to the arrangement, the dimensions of the conductors may be erroneously performed. For example, there may be a higher dissipation by the Joule effect, compromising the efficiency and safety of the installation. It is known that the harmonic affect the power quality and increase system losses up to 20% as commented by Kalair et al. [2].

There are different analyses doing specific research in the power cable. In Napieralski et al. [3] an electrical behavior of a stranded cable is evaluate using elastic-plastic deformation through Abaqus software. A feasible method to estimate the remaining lifetime of underground power cables based in Zhurkov's life equation and thermal modeling is checked in Bicen [4] and a combined analysis method (CAM) used in EPR-insulated cables by Montanari et al. [5].

A numerical tool for a partial differential equations system solution, known as the Finite Element Method (FEM), has been used by several research groups for analysis in different engineering areas, such as structural mechanics, fluid mechanics and electromagnetism, assisting in the identification and solution of engineering problems.

The application of FEM has several uses: the evaluation of temperature rises in electrical buses [6], closing analysis of magnetic circuits [7], evaluation of the surface and contact temperature rise [8,9], contacts transformer connectors [10] electrical equipment model [11], loading limit for transformers [12], cable current analysis [13], thermal

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behavior analysis conductors in conduit [14], modelization of current sensors [15], and electrical resistance of brazed joint [16]. Some researchers have even considered the thermal behavior of conductors for high voltages [17].

Studies considering the temperature rise due to harmonic distortion [18], ampacity and temperature increase [19], temperature distribution on buried conductors [20] and current distribution in parallel wires [21] illustrate the need for a precise facilities project to maximize the lifespan of cables and minimize losses. A specific study about the adverse effect on the aging of cable insulation due to the operation of these cables near or above their thermal rating in systems with underground ducts evaluated by the Arrhenius thermal model was presented by Zarchi and Vahidi [22]. The Arrhenius thermal model is used to estimate the service lifetime of cable sheath materials designed to work in harsh operation environment, analyzing polymeric compounds materials [23]. Other equipment has been affected by harmonic distortion and different researches have been done considering these impacts, such as: lighting systems [24], transformers [25], wind power systems [26] and others.

Another tool is the solution of analytical equations, using software such as Matlab®, which is a computational tool to support engineering researchers to solve problems with various equations. Through this method, one can obtain the arrangement with the best indices, i.e., one that is more efficient and safer.

The application of this method can be used as a setting technique to balance the current distribution in parallel cables [27], leading to the proposal of a practical and efficient solution. This project would be applied to modeling for the distribution of electric currents in cables connected in parallel, as presented by [27]. A real case is studied and the solution presented and the results would be verified with the application of FEM.

The analysis by the FEM proposed in this study allows for the viewing of magnetic flux lines, magnetic flux density, ohmic losses and energy dissipated due to the arrangement of the cables. With this study, one would be able to understand the phenomenon and compare the typical configuration of conductors to the solution suggested by [27]. The analysis using FEM to evaluate distribution of currents in parallel conductors was used by Gouramanis et al. in [28].

To accomplish these tasks based on analytical equations, simulations made through an algorithm implemented in Matlab®. In addition, a solution proposal created by a FEM software performed the simulations considering others important electrical parameters as: current distribution, field calculation and energy losses.

Finally, after the suggested method has been applied, measurements taken in the laboratory and an analysis by the FEM defines a more efficient and safe configuration for the case study.

2. Problem description

The maintenance staff of a cement plant detected that some cables were warmer than others. Measurements were conducted on-site to obtain a better understanding of the problem.

The industry focus in this study is characterized as a medium-sized cement producer with a 1.5 MVA input transformer, 13.8/0.44 kV and Δ Y-connection grounded, feeding a central distribution panel through six cables per phase/neutral of 240 mm^2, HEPR, 90° C, 0.6/1 kV and pressure connectors. The identification numbers of the 24 cables were arranged from left to right with 6 parallel cables per phase / neutral in the following sequence: Neutral, phase R, S and T (here the phases are referred as A, B and C). An illustration of the arrangement of the transformer cables' low voltage side that goes toward the panel is shown in Fig. 1.

The equipment used to perform these measurements was the energy analyzer EMBRASUL RE6081/B/M.

The obtained values (rms) of the line currents measured in each phase/neutral current are the summation of each of six wires; thus, the rated values are $I_N = 105.9$ A, $I_A = 551.2$ A, $I_B = 595.3$ A and $I_C = 586.6$ A. The distribution of the currents and the total harmonic distortion current (THD_I) measurements on the conductors are presented in Figs. 2 and 3, respectively. As can be seen in Fig. 3, the value of THD_I varies, depending on the cables in parallel connection.

Fig. 1. Arrangement of cables installed in a cement plant.

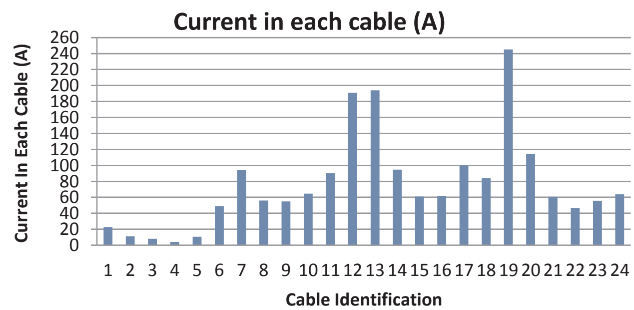

Fig. 2. Distribution of current in the cables.

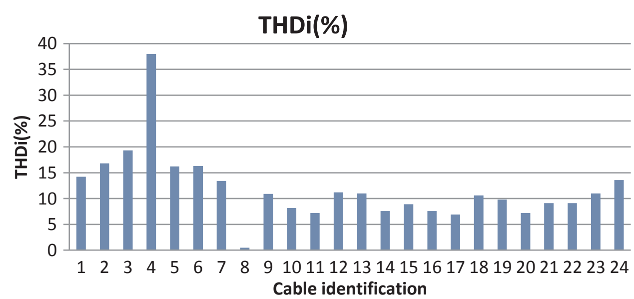

Fig. 3. Values of THD_I (%) in the conductors.

A thermograph of the cables assembled as in Fig. 1 for the measured current distribution of Fig. 2 is presented in Fig. 4. The location of the concentration of hot spots is evident and the cables with a higher current clearly present a significant increase in the temperature. For the measurements presented above this difference in the cables temperature could be superior to 12 °C.

Detailed result of the temperature distribution measured at each of the cables of the system presented in Fig. 1 is shown in Fig. 5. It should be highlighted that the cables with higher temperatures are the same cables with higher current magnitudes, as can be correlated looking the results of Figs. 2 and 5.

3. Methodology and test description

3.1. Problem modeling

The current distribution in each conductor for a system with n parallels cable per phase, was calculated analytically and by FEM, as schematized in Fig. 6. All the parallel cables of each phase are