Induced Voltages and Power Losses in Single-Conductor Armored Cables

Y. Du, X. H. Wang, and Z. H. Yuan

***Abstract*—Single-conductor armored cables are often used to carry high currents in buildings. This paper presents an experimental investigation into both induced voltages and cable resistances associated with the installation of these cables within the buildings. Both induced armor voltages and cable resistances under different installation practices were measured at both power frequency and its harmonic frequencies. The impact of cable formation, bonding arrangement, and cable supporting method on these issues was addressed and illustrated experimentally via 185-mm^2 (365-kcmil) single-conductor armored copper stranded cables. The standing voltage is generally small for the armored cables used in the buildings. The power losses increase significantly when the cable armor is bonded at two cable ends, particularly in the case of rich harmonic currents in the cables. Recommendations are finally provided for the installation of single-conductor armored cables in buildings.**

***Index Terms*—Cable, induced voltage, metallic tray, power loss.**

I. INTRODUCTION

SINGLE-CONDUCTOR cables are frequently used in buildings for high-current distribution due to their large current-carrying capacity and easy installation. These cables are armored with a concentric layer of aluminum wires for mechanical protection and fault current return as well. When ac current flows through cable conductors, induced voltages are generated on cable armor. Although cable oversheath (jackets) permits a high standing voltage on the armor, excessive voltage is generally not allowed. For example, the practice in the U.S. appears that a steady-state sheath/armor voltage of 65–90 V is permitted [1], while in the U.K., the 25-V level is used for the cables installed in buildings to prevent corrosion as a consequence of electrolysis and other factors [2].

The armor of single-conductor cables may be bonded and grounded at their two ends to eliminate the induced voltage on the armor. Different bonding arrangements were introduced and illustrated in [1]. Some other publications [2]–[5] also presented the application and selection of bonding arrangements and the calculation of induced voltages and currents and of power losses in the cables at power frequency. In these cases, the single-conductor armored cables were laid either in free air or underground.

Armor bonding provided at two cable ends is the simplest solution to the problem of induced voltages and is highly recommended in [2] for the cables used in buildings. However, circulating currents are induced in the armor by the ac current flowing in the cable conductors. The induced current on the armored single-core cables is not negligible. It generates additional power losses in the cables and reduces the current-carrying capacity of the cables. It was estimated in [5] that the ampacity of three single-conductor 500-kcmil cables at power frequency was reduced by approximately 20% by the armor current when they are laid parallel on 8-in centers with 20 spiral copper armor wires. In Hong Kong, the Code of Practice for Energy Efficiency of Electrical Installations [6] sets out the minimum requirements on power losses of electrical installations in buildings (e.g., less than 1.5% of power delivered in a rising main circuit). Therefore, it is necessary to have a critical review of both induced voltages and cable resistances of the single-conductor armored cables under different installation practices.

This paper presents an experimental investigation into both induced voltages and cable resistances associated with the installation of low-voltage single-conductor armored cables within buildings. Both induced voltages and cable resistances were measured in the laboratory at power frequency as well as its harmonic frequencies. The single-conductor cables were laid either in free air or on perforated metallic tray. These issues, which have not been addressed in literature significantly before, are discussed extensively in this paper. Typical installation practices of the single-conductor armored cables adopted in buildings were considered in the experiment and are presented in Section II. It is followed by the description of measurement setup in the laboratory. Both induced voltages and cable resistances of the sample cables under different installation practices are presented at the order of up to 11. The impact of cable installations on induced voltages and cable resistances is addressed. Finally, recommendations are provided for the installation of single-conductor armored cables in buildings.

II. CABLE INSTALLATION

XLPE-insulated cables with stranded copper conductors to BS/IEC standards are widely used for low-voltage high-current

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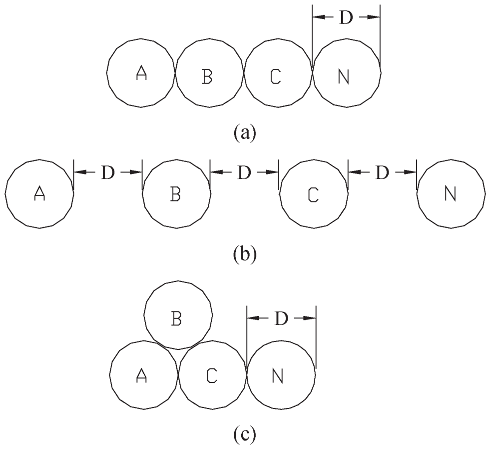

Fig. 1. Cable formation for a three-phase four-wire distribution system. (a) FT. (b) FS. (c) TF.

distribution in local buildings. The stranded conductor in the single-conductor cables is covered by an insulation material. In ac circuits, in order to reduce magnetic losses, single-conductor cables are normally protected by the armor made of a concentric layer of aluminum wires. This armor is considered as an exposed conductive part in the cabling system and has to be connected to earth at the supply end as required by the local code [7].

As the TN-C-S grounding system is adopted in local buildings [7], a separate circuit protective (grounding) conductor is provided to run in parallel with the power cables and is connected to the ground in the buildings. The standing voltage in buildings therefore refers to the induced voltage on cable armor with respect to the adjacent circuit protective conductor (e.g., a single-conductor cable or copper tape). The single-conductor armored cables are normally deployed on metallic tray (e.g., galvanized iron tray) or directly mounted on wall, floor, or ceiling in free air. When the metallic tray is used in the cable installation, the standing voltage is the induced armor voltage with respect to the metallic tray as the metallic tray normally serves as a protective conductor [7].

The power distribution system in buildings is a three-phase four-wire system. With the considerations of space or heat dissipation, three types of cable formation are applied in the installation of single-conductor armored cables. These are flat and touching (FT), flat and spaced (FS), and triangular or trefoil (TF) configurations, as shown in Fig. 1. In the FS configuration, the cables are separated with one cable diameter to improve the heat dissipation process. However, this formation could increase induced voltages and power losses.

For the cables with metallic armor, a bonding arrangement should be adopted in the cable installation. Generally, solid bonding, which bonds the armor of the cables at both ends, as shown in Fig. 2, is required to diminish the voltage induced along the cable armor. Special bonding arrangements, such as single-point bonding or cross-bonding, are used in view of economics or minimizing the heat generation by induced current. Single-point bonding means that the armor of cables in the same circuit is connected and grounded at one end only. Cross-bonding consists in sectionalizing the armor into minor sections and cross-connecting them to neutralize the total induced voltage in three consecutive sections. Both solid bonding and single-point bonding are normally for the short-length cables used in buildings and are addressed in the following sections.

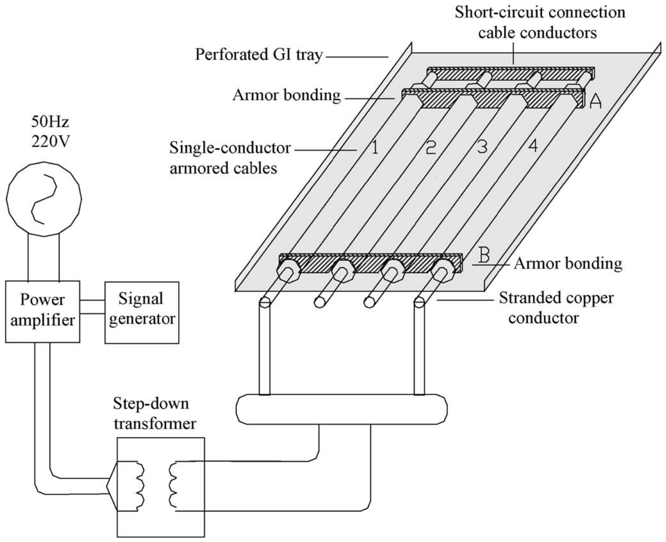

Fig. 2. Experimental setup for measuring induced voltages and cable resistances.

III. EXPERIMENTAL SETUP

Shown in Fig. 2 is an experimental setup for the measurement of both induced voltage and cable resistance with the single-phase current injection. The cables under test were four low-voltage single-conductor armored cables to BS6724 [8]. These cables have a conductor size of 185 mm^2 (365 kcmil) and a length of 10 m. In the experiment, the cables run in parallel in free air or on perforated galvanized-iron (GI) tray. They were arranged in the cable formation according to Fig. 1, i.e., FT, FS, or TF configuration. The single-conductor armored cables were connected together at one end with a copper bar and connected to a current source at the other end. The armor of these cables was bonded either at one cable end (point A) or at two cable ends (points A and B), depending whether the single-bonding or solid-bonding system is employed. When the cables were installed on the GI tray, the cable armor was bonded to the tray at point A, as shown in Fig. 2.

The current injected into the cables was generated from a harmonic current source. It was made of a harmonic signal generator, a power amplifier, and a step-down transformer, as shown in Fig. 2. In the measurement, the current in the cables was either an ac component at 50 Hz or its harmonic component at the order of up to 11. The magnitude of the injected current was determined by the output of the power amplifier, which remained unchanged in the measurement of induced voltage or cable resistance at all orders. The injected current therefore decayed with the inverse of harmonic order. The output voltage from the power amplifier was selected in such a way that the fundamental current was approximately equal to 50% of the cable current-carrying capacity.