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Analysis of the impulse breakdown behavior of covered cables used in compact distribution lines

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ABSTRACT

This paper presents results related to the impulse breakdown behavior of XLPE- and HDPE-covered cables installed in typical compact distribution lines of Brazil. Tests with positive and negative standard lightning impulse voltages (1.2/50 μs) applied to typical single- and three-phase structures of compact distribution lines were performed. Results in terms of breakdown voltage and pinhole location are presented.

1. Introduction

Compact distribution lines have been widely adopted since the 1990s in Brazil. Fig. 1 illustrates the main components of a compact distribution line – messenger cable, polymeric spacers, polymeric pin insulators, covered cables, and metallic structures to support these elements. It is well-known that covered cables increase the basic impulse insulation level of the system compared to the use of bare conductors [1,2]. Several works have been dedicated to investigate the electrical performance of spacer-cable systems [3–5].

The withstand voltage is one of the most important parameters for the estimation of the lightning performance of distribution lines. Considering distribution lines with bare cables, the critical flashover overvoltage (CFO) corresponds to the main parameter to evaluate the impulse performance of a given insulator. It is obtained by means of the up-and-down test, which requires the successive application of standard 1.2/50 μs double exponential voltage waveforms with different amplitudes [6,7]. However, when dealing with compact distribution lines, the presence of the solid insulation layer surrounding the conductor makes the overall insulation of the structure to be non-restoring and, as a consequence, both the up-and-down method and CFO concept are no longer applicable. In this case, the impulse withstand of compact distribution lines may be described by the so-called breakdown voltage [8]. It denotes the magnitude of the impulse voltage able to produce a disruptive discharge that may lead to pinhole formation and the consequent breakdown of the covered cable [1,2]. The breakdown voltage is determined by the successive application of standard 1.2/50 μs impulse voltages with peak values increasing in steps of 10 kV from an initial value up to the occurrence of a disruption.

Previous papers were dedicated to present the influence of covered cables with crosslinked polyethylene (XLPE) on the withstand voltage level of single-phase structures. By means of experimental tests with standard lightning impulse waveforms of positive polarity, the breakdown voltages associated with the use of XLPE-covered cables were determined [2,9].

The insulation material covering the conductor is supposed to influence the disruptive process and, consequently, the withstand level. The first spacer-cable systems were constructed using cables covered with XLPE. However, this cover material has presented poor resistance to water treeing [10]. Therefore, power utilities have experimented cables covered with high-density polyethylene (HDPE) due to their better performance on medium voltage systems [11].

Although a study of the withstand voltage of different structures used in single-phase compact lines was presented in Ref. [9], such analysis was focused on the performance of XLPE-covered cables considering positive-polarity impulses only. The lack of

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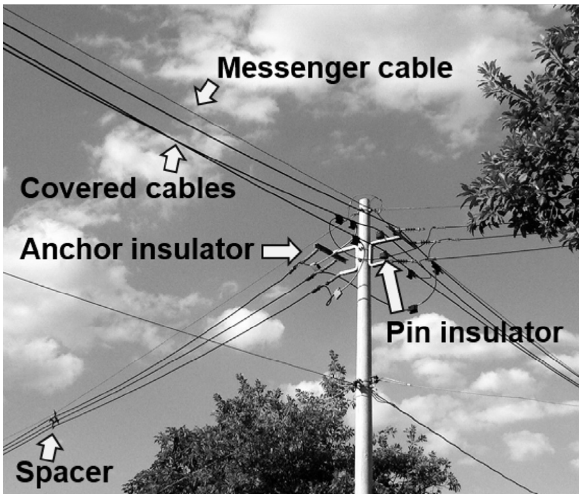


Fig. 1. Compact distribution line.

available data on the withstand level of single- and three-phase structures of compact distribution lines considering both positive and negative impulses, especially considering the use of HDPE-covered cables, has motivated this investigation. The most typical structures employed in single- and three-phase compact distribution lines in Brazil (Fig. 2) were submitted to standard lightning impulse voltages (1.2/50 μs). The obtained results describe breakdown characteristics of both XLPE- and HDPE-covered cables. Despite the fact that typical configuration of compact distribution lines presents a grounded messenger wire, it was neglected in the performed experiments since the shortest arc distance is the one between the phase conductor and the grounded structure.

The text is organized as follows. Section 2 describes the breakdown mechanism of covered cables. Section 3 presents the experimental tests. Section 4 presents the obtained results, followed by conclusions in Section 5.

2. Breakdown mechanism of covered cables

The cable characteristics have a direct influence on the surge response of the insulation. In a conventional configuration using bare cables, the surrounding air has an important role as insulating medium. Breakdown takes place when the voltage gradient overcomes the dielectric strength of air. Due to the process of collisional ionization [12], electrons might be multiplied in an exponential manner leading to a disruptive discharge [13]. Since air is a self-restoring insulation, its insulating properties are completely recovered after the flashover [14].

On the other hand, the breakdown mechanism in a compact configuration with covered cables comprises a different set of events. When a covered cable is subjected to impulse voltages, air ionization is usually observed around the insulator/tie region. Due to the discharge in air, it is noted a charge deposition on the outer surface of the insulating layer. The polarity of this charge is opposite to the polarity of the impinging voltage [1,15]. The charge deposition precedes the breakdown of the covering insulation [1,15–17].

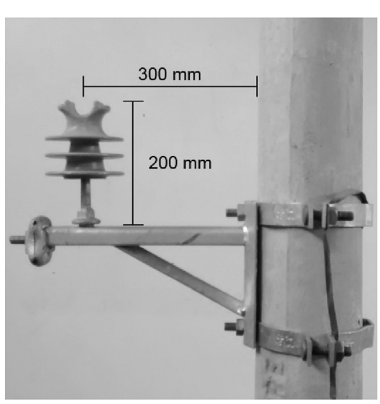
The accumulated surface charge modifies the electric field in the region around the insulation. The degree of influence depends on the amount of deposited charge [17]. If the resulting electric field magnitude exceeds the dielectric strength of air, a partial disruptive discharge takes place. It differs from the partial discharges that affect polymeric insulation generally due to the presence of voids inside the dielectric material. In this work, the term partial disruptive discharge refers to a luminous arc in the air between the outer surface of the insulating layer and the grounded part of the insulator. As a result, a drop of several kV in the voltage waveform across the insulator is observed [1,8].

Due to the presence of a solid insulating layer, the electrical stress might produce permanent loss of dielectric strength [14]. In the most severe case, disruptive discharges may lead to the formation of a pinhole on the covering of the power cable [18]. As a result, a highly luminous breakdown arc is established between the pinhole and the grounded structure [1,19].

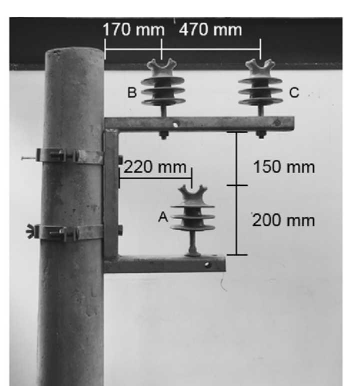
3. Experimental tests

Laboratory tests with standard lightning impulse voltages (1.2/50 μs) [7] were performed to evaluate the impulse behavior of typical structures used in compact distribution lines in Brazil (Fig. 2). The single-phase structure, named CM2, is composed of a metallic L-type support arm, metallic belts, and a 15-kV class pin-type polymeric insulator. The three-phase structure, named CE2, is formed by a metallic C-type support arm, metallic belts, and three 15-kV class pin-type polymeric insulators. Both structures are mounted on concrete poles and all metallic structures are grounded.

Two types of 15-kV cables were tested: an XLPE- and an HDPE-covered conductor (Fig. 3). The XLPE cover has a thickness of 3 mm, and a semiconductive layer is not used. The thickness of the HDPE cover equals 4 mm and the cable has an inner semiconductive layer. In both cables, the conductor has seven aluminum strands. Its cross



(a) Single-phase structure – CM2.



(b) Three-phase structure – CE2.

Fig. 2. Tested structures.