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Induced sheath voltage in power cables: A review

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ABSTRACT

This paper presents a review on analytical techniques used to calculate induced sheath voltage in metallic sheaths of underground cables and overhead lines. The main purpose of this paper is to re-examine the existing research with the prospect of identifying possible gaps and differences that exist in the different approaches used to calculate induced sheath voltage. The different aspects of research conducted on induced sheath voltage in cables and lines due to lightning or mutual effects have been examined. The findings indicate that when two parallel cables are fairly close together then the electromagnetic coupling effect between the adjacent cables is difficult to calculate. Therefore, this review not only describes the influence of the different arrangements of the cables but it also examines the distance between the cables to calculate their effect on the magnitude of induced sheath voltage. Comparative results of different arrangements of cables and bonding are also provided to show their effectiveness in a given scenario.

Contents

1. Introduction

This article reviews the existing literature and attempts to demonstrate different induced sheath voltage calculation methods that support different theories proposed in past. The importance of this paper lies in the fact that it re-examines the past research conducted by the relevant authorities in the field with the objective of identifying the problems in the findings of the past research. It also highlights the possible areas where further research is required.

For more than a century, overhead lines have been the most commonly used technology for transmitting electrical energy at all voltage levels. Cables are widely used for underground alternating

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current electricity distribution and progressively over longer distances. Cables have been studied for a long time, first for the transmission of signals and then for energy at industrial frequencies. Therefore, many analytical formulations have existed for almost a century though some effects like the proximity of cables have received secondary attention.

The use of underground cables has a great impact on the quality of power and has become one of the most popular topics of discussion among power engineers and researchers. Of particular relevance are the high frequency current, induced sheath voltage and voltage transients resulting from switching operations. The problems depend on several factors including: configuration of the underground cables, the characteristics of circuit breaker (CB), general network topology, as well as other external factors. To some extent, induced sheath voltage can be worse in the case of switching at the transition point of overhead to underground transmission. It is, therefore, crucial to address the impact of this switching on design requirements, not only for extra high voltage (EHV) systems but also in the case of medium transmission voltage, such as the 132 kV systems [1]. The systems just described are known to be dominant in many urban areas [2].

There are a number of dedicated models in EMTP-type suites that can be used for cable and transmission lines. The modeling choices vary from a simple PI model approach to more complex ones. Some of the models are based on theories developed by early researchers, which were established over 30 years ago [3–7]. These models are the frequency-dependent (FD) type that take into account the distributed nature and frequency-dependent characteristics of the cable (or transmission lines) parameters. In other words, they have been formulated to model transient analysis. However, these models are not general and in some situations may not be suitable for certain network configurations.

Efforts have been made in validating cable models by a detailed comparison for several cases in ATP/EMTP [8,9]. However, the approach used in [8] only gives examples of single phase energization of cables. Recently, Nichols et al. [9] carried out a practical comparison examining several frequency-dependent models such as Hermann [10] and Semlyen [3] approaches for the case of three phase energization. However these models are a bit inconsistent in their explanation of transient magnitudes because the findings are numerically unstable. Consequently, suggestions arise from previously studied models which demand further research to discover innovative cable models. Such models are currently incorporated in PSCAD/EMTDC, for instance, one of them is the Universal Line Model (ULM) [7].

The energization of an underground cable results in high frequency voltage and current. The behavior of these transients are determined by many factors. For example the transient peak magnitudes are influenced by the closing span of CB contacts and the closing angle (point-on-wave) on power frequency voltage [11]. To ensure precise and reliable results from simulation, a carefully designed model of the power system network, with the inclusion of precise frequency-dependent cable model, is indispensable. The available research shows that these assessments are predominately carried out for EHV transmission systems using the ATP/EMTP programs [12,13].

Switching transients in three phase systems can be very complex [14,15]. The research in [16] is a study on the applicability and validity of other models, namely the frequency-dependent mode (FD-Mode) and frequency-dependent phase (FD-Phase) models previously described in [17]. Still an extensive study of underground cables should be carried out with a view to provide useful information on switching overvoltage distributions based on the statistical method, as suggested by the IEC standards [18,19]. The modeling work to analyze the transient studies for underground cables can be carried out on ATP/EMTP-RV platform [20].

The fundamental theory of the voltage induced from an overhead power line was first given by Wagner in 1908 [21]. According to this theory, the charged thunderstorm cloud induced by an overhead line is at ground potential and that when the cloud is rapidly discharged by lightning, bound charge is released and this increases the roaming waves of the voltage and current. After initial development by Wagner, Adendorff (1911) presents an insightful description of the various problems created by lightning. He noted that overhead static wires solidly grounded at the poles would significantly reduce the effects due to a straight strike on the line and presented his view at that time that: “If the discharge is very heavy, usually is the case, the probabilities are that a portion of the section struck will totally disappear” [22].

A research by Wagner and McCann (1940s) explains that the induced overvoltage occurs because most of the components of the lightning discharge process, including the effects of the return stroke [23]. In response for this research, Szpor tried to calculate the induced sheath voltage on the line caused by a nearby lightning strike but he witnessed that the quasi-static nature of his solution limited the application of his results to lightning within about 100 m of the line [24].

Golde has compared frequencies of occurrence of surges caused by direct lightning strike with the frequencies generated due to induced effects for various types of overhead lines [25]. The theory in [26] has presented a model in which charge was exponentially distributed by the leader, charge neutralization by the return stroke did not take place immediately caused by the charge stored on the corona sheath; and return stroke velocity was expected to decrease exponentially with height. Lundholm [27] has established categorical expressions for induced voltage based on the model described in [23]. He derived expressions for the vector potential in terms of the assumed channel current and scalar potential in terms of the charge on the channel. However, his final results for these potentials do not satisfy the Lorentz condition.

A surprising result was discovered in [28] stating that the induced voltage on any one conductor was not influenced by the presence of other conductors in parallel or vicinity. Chowdhuri [29] disagreeing with [28] argued that the presence of other conductors influences the induced voltage on a conductor of a multi-conductor line. Chowdhuri and Gross [30] have reported that in the presence of other conductors induced voltage was greater and could be measured by considering their mutual coupling. In 1971, a theory was presented in [31] on induced voltage in overhead lines in which author agreed with [28] argued that the presence of other insulated conductors of multi conductor lines will not affect the voltage on any other conductor which challenged the research presented in [29,30]. The South African group Eriksson et al. [32,33] in the early 1980s contained duplications of typical measured overvoltage and showed comparisons with theoretically calculated wave shapes.

Hamelin et al. [34] in France derived the electric and magnetic fields produced by a vertical dipole and described line coupling sufficiently. But, they used a very basic return stroke model current with a double exponential wave shape. After this theory, Koga et al. [35] give another theory to explicate Japanese data on induced voltage. Their derivation of the horizontal electric field due to finite earth conductivity appear to be perfect. For this reason, insufficient research on lightning fields and induced voltages associated with the ground strike point, barred them from making any evaluations between theory and measurement. Horizontal field was again considered by Smith [36] and Vance [37] in which, they discussed formulations of the transmission line equations involving a horizontal electric field. Numerous groups with knowledge of coupling of incident electromagnetic fields to overhead conductors studied the effects of the Nuclear Electromagnetic Pulse (NEMP) on overhead conductors.