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Practical methodology for modeling and simulation of a lightning protection system using metal-oxide surge arresters for distribution lines

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ABSTRACT

The application of metal-oxide surge arresters to protect distribution lines from lightning is of great interest to electric utilities seeking to improve reliability and quality of the energy supplied to consumers. However, due to the high cost of purchase and installation, technically and economically viable solutions must be found to protect these systems from lightning overvoltages. Thus, this paper describes aspects of modeling and simulating the performance of a protection system using metal-oxide surge arresters, when exposed to direct lightning. A practical methodology is developed for the specification, simulation and definition of the best sizing, location and number of surge arresters for the protection of an overhead distribution line located in a rural area. Moreover, the energy absorption for selection of surge arresters is also analyzed and the performance of different configurations of the protection system against lightning is evaluated.

1. Introduction

Lightning is one of the main factors of shutdowns in transmission and distribution lines, causing great inconvenience and generating high costs with the maintenance and replacement of damaged equipment, and with the displacement of the maintenance and repair teams. To achieve adequate operating conditions in an electric power system, and consequently a high level of power quality, it is necessary to install a lightning protection system [1–3]. In addition, current climatic changes have increased the intensity and frequency of storms, which makes research into the protection of the electric power systems even more important, particularly with respect to protection against the incidence of lightning.

Lightning protection systems are composed of surge arresters that divert atmospheric discharges to ground, at the same time limiting the voltage in the equipment for which they provide protection. This voltage-limit is the sum of the voltage discharge of the surge arresters and the induced voltage developed by the discharge current between the line and ground leads of the surge arresters [3]. Lightning protection systems can be employed in various analyses and solve different problems, such as appraisal of lightning induced voltages by direct and indirect lightning, reduction of unplanned shutdowns, and definition of the location and number of surge arresters that need to be installed to protect an electric power system. Furthermore, lightning protection systems can be used to determine the influence of the location of surge arresters in different phases of a system, the application of shield wire, the use of surge arresters with or without a spark-gap, analyzing the level of shutdowns of transmission and distribution lines and the energy absorption performance of surge arresters [2–8].

In this context, in [7] an overview is presented of the various types of lightning overvoltages that can arise in overhead power distribution networks, as well as typical voltage waveforms. The effectiveness of the most important methods for mitigating such overvoltages in medium voltage and low-voltage networks is shown and discussed. The increase of critical flashover overvoltages of the line structures, the application of line arresters, the

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Fig. 1. Distribution line located in a rural area in an open field and crossing grazing lands.

earth resistance, the use of shield wire, and the allocation of surge arresters at different intervals on the line are all evaluated.

In [9] the computation based on the lightning limiting parameters method of the surge arrester, the minimum energy absorption capacity is presented, and a process of selecting the energy absorption capacity of medium voltage surge arresters, based on the permitted failure rate, is proposed.

In [10], a lightning protection system for a transmission line is described, employing a minimum number of surge arresters, located on different towers set at varying distances between them. The dependence of these placements on the tower footing resistance was analyzed. With the implementation of these methods of analysis, the number of unplanned shutdowns was reduced and the reliability of the services provided to the consumer improved.

A useful and complete guide to the protection of power systems using surge arresters is available in [11]. This guide discusses the use of metal-oxide surge arresters to protect equipment with rated voltages above 1 kV from overvoltages. In addition, it provides information about the use of surge arresters for the protection of substations, transmission and distribution systems and large electric machines.

At this conjuncture, through the analysis of computer simulations of the performance of a rural distribution line this paper outlines the development of a methodology for the specification, simulation and definition of the best sizing, placement and number of metal-oxide surge arresters for the protection of this line. For this, the situation considered was that of direct lightning in a rural distribution line configured according to the actual parameters provided by an electric utility. This methodology also includes the analysis of energy absorption capacity in the selection of surge arresters to prevent failures due to the absorption of the energy with higher values than those specified by manufacturers in the event of direct lightning, since these flashes of lightning have a large amount of energy due to the high values of the discharge current.

Although the direct impact of lightning on distribution lines is less frequent than in transmission lines, the study of this article is justified because in the case of rural feeders that run across open pastures or field crops, as illustrated in Fig. 1, the possibility of this type of discharge is quite high when compared to its occurrence in distribution lines of urban regions.

Thus, the rest of the paper is organized as follows: the following section introduces the main issues regarding lightning overvoltages in power systems. Section 3 outlines the distribution line model selected for this research. Section 4 provides details of the metal-oxide surge arresters, their energy absorption capability, modeling, implementation, and method of simulation. The results of computer simulations are then reported in Section 5, and finally the study's findings are presented in the last section.

2. Lightning overvoltages in electric power systems

Distribution lines and transmission lines are designed to ensure an insulation level higher than their maximum instantaneous voltage in steady state value, but are often exposed to overvoltages and overcurrents that exceeds their withstand levels. These overvoltages can be either of internal origin, due to switching breaker, current harmonics and resonance phenomena, or of an external nature, resulting from lightning or the effects of electromagnetic fields. In this context, the most significant are overvoltages of atmospheric origin, which impinge directly on the electrical systems (direct lightning) or in close proximity to them (indirect lightning) and can cause overvoltages of high magnitude on the lines [2–5].

Lightning is of particular importance in overhead distribution lines where the voltages withstand levels are naturally lower, as in the case of the line analyzed in this paper, and where direct lightning strikes and overvoltages lead to dielectric failure, resulting in damage to equipment and to its components. Moreover, though direct lightning strikes on distribution lines are less frequent than indirect ones, the application and the study of methods of protection against lightning overvoltages on these lines is of great value, because open fields in rural areas allow for a wider number of dangerous events compared to an urban area. In rural areas, where buried lines are the exception, there is a predominance of overhead lines, and these are usually the highest structures in their surroundings [2]. This type of analysis is also relevant due to the severity of these overvoltages for distribution lines and the higher probability of occurrence of direct lightning on open field lines in rural areas and in less densely occupied urban areas.

Electromagnetic interactions between the conductors and structures of the overhead lines and the lightning channel is a complex point of analysis, which can cause changes in established overvoltages on the electrical system in investigations that involve the occurrence of indirect lightning. However, a direct strike on a power system causes significantly greater overvoltages than those induced by indirect lightning and electromagnetic coupling between the line and the lightning channel, causing the overvoltages to undergo minor changes due to electromagnetic coupling [2–5]. The calculation of these overvoltages induced by the electromagnetic interactions can be accomplished via the determination of the electric and magnetic potentials associated with the charges in the return stroke channel and from the currents propagated in the channel and in the structure, as shown in [12–15]. Since the present study evaluates the incidence of direct lightning and aims to present a practical methodology that is simple to apply, the influence of electromagnetic coupling in estimated overvoltages was not analyzed in this research.

3. Modeling of distribution line

To demonstrate the effectiveness and applicability of the practical methodology proposed in this paper in real electric power systems, the aim was to select and model a distribution line from an actual electric utility, the geometrical and electrical characteristics of which were available, making it as close as possible to the characteristics found in the utility's facilities.

The line parameters were taken from the data in [16,17], which show the total length to be 8.915 km, while the nominal voltage was 69 kV phase-phase and 39.8 kV phase-to-ground. Also, the Keraunic Index (I_k) of the region of the line is 60, according to the Brazilian