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Probabilistic evaluation of the substation performance under incoming lightning surges

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ABSTRACT

In the present work, a statistical method based on Monte Carlo technique for evaluating lightning performance of a complete air insulation substation (AIS) using the capability of simulation tools is presented. This technique has been coded in MATLAB and linked to EMTP/ATP program to perform the network simulations. The parallel computing feature of MATLAB is used to accelerate the solution procedure. The paper presents the modelling of the substation equipments and connected lines. In particular, a modified IEEE recommended model of the surge arrester having its parameters obtained from genetic algorithm optimisation program is used. The simulations are carried out considering several protection scenarios. It is corroborated that the installation of metal oxide surge arresters (MOSA) at line input and in the vicinity of the autotransformer gives an acceptable mean time between failures (MTBF) at different points in the substation and then provides an adequate protection. The adopted approach has permitted a more accurate prediction of the overvoltages at different points in the substation and significantly reduces the CPU run time of the overall solution process.

1. Introduction

For substation design studies, direct strokes to air insulated substations are usually ignored, since it is commonly assumed that the substation is impeccably shielded, via shield wires or lightning masts. That is to say only overvoltages caused by lightning hitting the incoming line connected to the substation have to be considered. Therefore, insulation coordination requires accurate prediction of the overvoltages at different points in the substation [1–4]. Metal oxide surge arresters are widely used as protective devices against switching and lightning overvoltages in power electrical systems. Phase to ground surge arresters are commonly installed at power transformer terminals and some protection effect for near connected equipment in a substation is supposed [5]. The installation of other additional surge arresters in a substation may be required to effectively protect all connected equipment, when a fast overvoltage enters a substation from a line. Computer simulations of electromagnetic transients in real structures of substations become step by step more precise due to the improvements of models used in simulations. Appropriate modelling of MOSA's dynamic characteristics is very important for arrester location and insulation coordination studies [6]. Several approaches have been proposed to study the overvoltages caused by lightning strokes that impact a line connected to a substation [7–9]. Regarding the random nature of the lightning phenomenon, the procedure must be statistical and generally the Monte Carlo method is used as the solution for this type of studies [10].

As stated in the standards, the lightning reliability of an overhead line is usually specified by the number of flashovers per 100 km-year [11,12]. However, the commonly used lightning reliability criterion of a substation is the MTBF. Lightning failures can be due to strokes to either a shield wire or a phase conductor. Shielding failures cannot be totally prevented, but the number of strokes to phase conductors is usually very low [11,13]. On the other hand, an accurate calculation of lightning overvoltages can be obtained by applying a time-domain technique. The number of lightning surges that arrive to a substation is a function of the number of the connected transmission lines and the lightning performance of each line. Higher number of connected lines to the substation decreases the surge crest voltage and front steepness; however, they also collect more surges.

All these aspects concur in determining how the components move among their possible states and, thus, how the system behaves. With the model, questions can be asked about the future of the system, for example in terms of its failures, maintenance and anything else that is of interest.

In this view, the Monte Carlo simulation (MCS) method is a powerful modelling tool for the analysis of complex systems, due to its capability of achieving a closer adherence to reality. It may be generally defined as a methodology for obtaining estimates of the solution of

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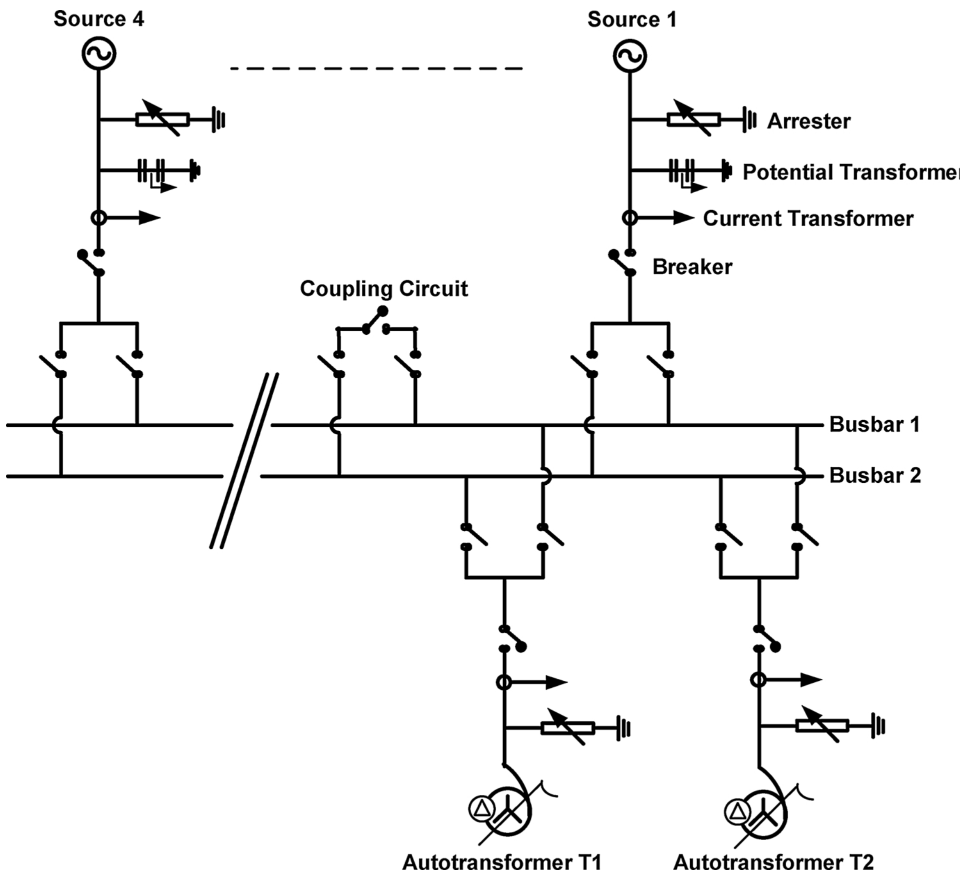

Fig. 1. One line diagram of the studied system.

mathematical problems by means of random numbers.

In the present work, a statistical method based on this technique for evaluating lightning performance of a complete three-phase operational air substation using the capability of simulation tools is presented. This technique has been coded in MATLAB and linked to EMTP/ATP program to perform the network simulations. Even it is prohibitively slow due to the high number of simulations and the complexity of the system model, it offers accurate results [14]. In order to accelerate the overall solution procedure, the parallel computing feature of MATLAB is used. On the other hand, a modified IEEE recommended model proposed in Ref. [6] is chosen. Genetic algorithm was used for the calculation of its parameters [6,15]. The model represents with good accuracy the dynamic behaviour of metal oxide arrester. The MTBF at different points in the substation is also estimated. The obtained results are presented and discussed.

2. Model of the test system

The one-line diagram of the studied system [16] is shown in Fig. 1. It is an actual 50 Hz, 400 kV air insulation substation (AIS) with a standard BIL of 1425 kV. The substation has four entrances and two autotransformers protected by surge arresters.

2.1. Stroked transmission line components

(a) The HV transmission line is represented by several blocks representing a number of spans (390 m each) with one 10 km section as line termination at the source side to avoid reflection [17]. Each span is divided into thirteen sections having 30 m in length to include the corona effect. These sections are represented using frequency-dependent distributed-parameter models. Other line components are represented as dynamic models that reproduce their behavior under the lightning stroke conditions detailed in the following sections.

(b) In this work, the towers are represented by the multistory model proposed in Ref. [18]. It is composed of three sections that represent the tower sections between cross-arms. Each section consists of a lossless line in series with a parallel R–L circuit, included for attenuation of the travelling waves. The parameters of this model are calculated using these equations [17–19]:

$$R_i = \frac{-2Z_{ti} ln\sqrt{\gamma}}{h_1 + h_2} h_i, \quad i = 1, 2 \tag{1}$$

$$R_3 = -2Z_{t3} ln\sqrt{\gamma} \tag{2}$$

$$L_i = \frac{\alpha R_i 2H}{V_t}, \quad i = 1, 3 \tag{3}$$

$$H = \sum_{i=1}^{3} h_i \tag{4}$$

where:

Z_{ti}: tower surge impedance; γ: the attenuation coefficients; V_t: surge propagation velocity; α: Damping coefficient; R: Damping resistance; L: Damping inductance; H: the tower height; h_i: height of the tower parts.

(c) It is generally agreed that the resistance of an earth electrode decreases with the applied current due to ionization of the soil.

An accurate model of the grounding impedance has to account for a decrease of the resistance value as the discharge current value increases. It is accepted that the resistance value is greater for small lightning currents, and its variation with respect the low current and low frequency values is only significant for large soil resistivity. When the soil ionization effect is incorporated, the grounding impedance model can be approximated by a nonlinear resistance [20,21] given by: