The high-voltage substation configuration influence on the estimated lightning performance

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Contents The substation configuration has a great influence on the lightning overvoltages caused by backflashes at the lines connected in front of the substations. In most of the analyses the critical substation configuration is assumed with only one connected line. In the paper the influence of the substation configuration the line performance is analyzed. The mean time between power transformer insulation failures is computed taking into account the monthly distribution of the lightning activities and also the monthly probability distribution of certain substation configurations. The method is illustrated by a 400 kV substation example.

Der Einfluß der Schaltung auf die Blitzstoßkennlinien von Hochspannungs-Schaltanlagen


1 Introduction

Different methodologies for the transmission line and the high-voltage substation lightning performance estimation have been developed in the last 50 years. Some of the methods are based on a transient process simulation with a certain lightning current magnitude and rate of rise [1, 2]. On the other hand there are the lightning performance studies where the lightning discharge is treated as a probabilistic phenomenon represented by the lightning current magnitude and rate of rise frequency distribution. The risk of insulation failures is most frequently computed by means of the Monte-Carlo method [2, 3] or by the method of limiting parameters [4-6].

The high-voltage substation lightning performance can be estimated by applying a statistical procedure giving the insulation failure risk of the substation components represented by the number of insulation failures in a given period. The inverse value of the insulation failure risk is the Mean Time Between Failure (MTBF).

The criterion for the statistical insulation coordination procedure consists of the comparison of the calculated insulation failure risk or MTBF with admissible values. The definition of the admissible failure risk or MTBF is an important question affecting directly the cost-efficiency and technical feasibility of insulation coordination [7]. The adopted admissible MTBF value ranges between 400 and 1000 years [2, 4, 8]. Owing to such MTBF selection, the failure due to lightning overvoltages will have minor effect on the total mean outage rate during the substation's life.

The substation configuration is a parameter having influence on the magnitude of the lightning overvoltages. National regulations recommend the calculation of the lightning overvoltages for the most critical configuration (one with a minimum number of lines) connected. However, configuration changes are frequent during a year and in the paper a statistical procedure allowing the analysis of their influence on the MTBF is presented. In [2, 3, 7, 9-11] the dependence of the open air and gas insulated substation (GIS) components risk of failure on the high voltage substation configuration has been investigated. In [2] it is concluded that the most critical substation configuration with minimum connected lines has greater influence on the risk of the insulation failure than all other more frequent configurations. The number and the place of positioning the surge arresters, capacitances of equipment, as well as the tower-footing resistance have greatest influence on the MTBF [11].

The number of lightning discharges to the line impinging the high-voltage substation is the parameter affecting substantially the MTBF. It depends on the line geometry and keraunic level. In most of the lightning performance studies the annual number of discharges to the 100 km long line \( n_{\text{year},100\text{ km}} \) is applied.

In this paper the monthly distribution of the number of the discharges to the line is used in the lightning performance sensitivity analyses. The proposed approach to the high-voltage substation lightning performance estimation...
due to the backflash process on the connected lines provides more realistic results of the estimated risk of insulation failures.

The number of connected lines to the substation is a random parameter with great influence on the power transformer insulation risk of failure. Due to this reason the substation configuration's frequency distribution is included in the lightning performance estimation procedure. The improved methodology of the lightning performance estimation can contribute to a more economical substation design.

2 The statistical approach to the lightning performance estimation

2.1 Method of limiting parameters

The probabilistic method of limiting parameters described in [5] is used for estimating the risk of insulation failures at a certain point of the substation. This method is based on the computation of the critical value of the lightning current magnitude which, if applied to a certain point in front of the substation, causes greater overvoltage than the basic insulation level (BIL) at the inspected part of the insulation in the substation. The computation is repeated for various lightning current rates of rise to obtain the relation between the current rate of rise and the critical current magnitude causing the insulation failure. In Fig. 1 the curve of limiting current magnitude and steepness is shown. All lightning parameters in the zone D above the curve of limiting parameters cause the insulation failure. The risk of the insulation failure can be computed following

\[ P_i = \int_D f(I, S) dI dS, \] (1)

where \( f(I, S) \) is the joint frequency distribution of the lightning current magnitude and the wave rate of rise [12] and \( D \) is the failure zone above the curve of limiting parameters.

In the statistical estimation method of the substation lightning performance due to direct strikes to the line earth wire or the tower and back-flashover is front of the substation, the place of the discharge is varied along the first few spans, as shown in Fig. 2 [6]. Instead of a continuous variation of the discharge point along the span only a few (usually 5) equidistant discharge point at every span are analyzed. The mean value of the probability of the overvoltages occurrence exceeding the BIL of the equipment in the substation due to a strike somewhere on the analyzed span can be computed by means of the trapezoidal rule in the following form:

\[ \bar{P} = \frac{0.5 K_i P_1 + P_2 + \ldots + P_{n-1} + 0.5 K_n P_n}{n - 1}, \] (2)

where \( n \) is the number of equidistant discharges points; \( P_i(i = 1, n) \) is the probability of the lightning overvoltages occurrence exceeding the BIL of the equipment in the substation if the lightning hits the top of tower 1 or \( n \) in Fig. 2, causing back-flashover; \( P_i(i = 2, 3, \ldots, n - 1) \) is the probability of the overvoltages occurrence exceeding BIL of the equipment in the substation if the lightning hits certain points \( (2, 3, \ldots, n - 1) \) at the span, causing back-flash on the nearest tower; \( K_i \) is the coefficient of correction of the discharge probability to the top of the tower, which is presumed to be 1.3. In this way it is supposed that the probability of discharge to the top of the tower is 30% greater than to the certain point of the span.

The risk of occurrence of lightning overvoltages exceeding the BIL of the equipment in the substation can be computed following

\[ R = \sum_{j=1}^{m} \bar{P}_j d_j n_{1\text{year}, 100 \text{ km}}, \] (3)

where \( m \) is the number of observed spans (usually \( m = 2 \)); \( \bar{P}_j \) is the mean probability of the overvoltages occurrences exceeding BIL of the analyzed equipment in the substation if the discharge hits the \( j \)-th span; \( d_j \) is the length of the \( j \)-th span; \( n_{1\text{year}, 100 \text{ km}} \) is the annual number of lightning flashes to the line per 100 km, which can be calculated according to [13] in the following way:

\[ n_{1\text{year}, 100 \text{ km}} = 0.1 N_g (b + 28 h_{cw}^{0.6}), \] (4)

where \( N_g \) is the annual ground discharge density per km²; \( b \) is the effective line width (m); \( h_{cw} \) is the mean height of the earth wire (m).

The annual ground discharge density dependence on the keraunic level, based on the data for the observed local