The Impact of Peak Current Distribution on the Calculation of Backflashover Rate of Transmission Lines

El Impacto de la Distribución del Pico de la Corriente en el Cálculo de la Tasa de Backflashover de Líneas de Transmisión de Energia Eléctrica

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ABSTRACT

This work presents an investigation of the effect of cumulative peak current distribution on the calculation of the lightning performance of high voltage transmission lines in terms of backflashover rate. The evaluations considered the current distributions proposed by CIGRE, IEEE, and the one based on data measured at Morro do Cachimbo station, Brazil. The results obtained by the systematic application of the CIGRE methodology to calculate the backflashover rate of typical 138-kV transmission line indicated a large difference between the outages related to MCS distribution in comparison with those of CIGRE and IEEE distributions. In some cases, differences in the range of 45 to 80% are indicated, denoting the importance of an adequate definition of this parameter on calculations of the lightning performance of transmission lines.

Keywords: Backflashover, cumulative peak current distribution, lightning, lightning performance of transmission lines.

RESUMEN

Este trabajo presenta una investigación sobre el efecto de la distribución acumulada del pico de corriente en el cálculo de performance de líneas de transmisión de alta tensión frente a descargas atmosfericas. Las evaluaciones se consideran las distribuciones de CIGRE, IEEE, y la basada en los datos medidos en la estación Morro do Cachimbo, Brasil. Los resultados obtenidos por la aplicación sistemática de la metodología del CIGRE para calcular la tasa de backflashover de uma línea típica de transmisión de 138 kV indicaron una gran diferencia entre las tasas relacionadas con la distribución MCS en comparasion com aquellas de las distribuciones del CIGRE y IEEE. En algunos casos, difierencias de 45 a 80% se indican, que denota la importancia de una adecuada definición de este parámetro em el calculo del desempeño de líneas de transmisión frente a descargas atmosfericas.

Palabras clave: Backflashover, Distribución acumulada del pico de corriente, Descargas atmosféricas, desempeño de líneas de transmisión frente a descargas atmosfericas.

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Introduction

The evaluation of the lightning performance of high voltage transmission lines constitutes a relevant engineering step to provide elements needed to improve the power quality delivered to the consumers.

The calculation procedure involves several previous definitions, mainly related to the modeling of the transmission line, tower-footing grounding, lightning return stroke current, method to estimate flashover occurrence, and cumulative return-stroke current distribution.

In some evaluations, differences between the real outage rate experienced by transmission lines and the one estimated by traditional methodologies are reported. Recently, some works have been investigating the possible causes of such differences [1-4].

In this context, one important aspect that deserves to be investigated concerns the effect of the cumulative return-stroke current distribution adopted to perform the calculation of the outage rate of transmission lines.

Commonly, the cumulative return-stroke current distributions presented by CIGRE and IEEE are adopted [5-6]. Both distributions are basically related to the first return stroke current data measured by K. Berger [7] in Mount San Salvatore (MSS), Switzerland. According to Berger's measure-

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ments, the median peak current and front time (Td30) of first strokes are 31 kA and 3.83 us, respectively.

In spite of the widespread use of the aforementioned peak current distribution on lightning performance analysis of transmission lines, justified by the fact that Berger's data comprises the largest amount of data measured in instrumented towers, there is no consensus if these data also applies for regions of the world with different weather and relief characteristics, such as tropical regions.

Since 1985, the "Morro do Cachimbo" Station (MCS) has been operating in Southeastern Brazil with a 60-m-high instrumented tower, to establish references of lightning data for tropical regions [8-9]. Several papers about the data measured on the station have been published along the last years [10-13]. With the actual data of about 50 first return strokes, it is possible to establish the cumulative return-stroke current distribution of Morro do Cachimbo station to be used on the calculation of the lightning performance of transmission lines. The median peak current and front time (Td30) of first strokes measured at MCS are 45 kA and 4.83 us, respectively.

The purpose of this work is to present a preliminary contribution on the impact of distinct cumulative return-stroke current distribution on the calculation of the lightning performance of transmission lines in terms of backflashover occurrence, considering a typical 138 kV-line configuration as a case study.

In this work, the calculations were performed by means of CIGRE methodology described in [5]. Three return-stroke current distributions were adopted: CIGRE, IEEE, and MCS. The analyses will be presented in terms of different tower-footing grounding resistances, considering median current front times (Td30) of first strokes measured at Mount San Salvatore and Morro do Cachimbo stations.

MAIN ASPECTS OF CIGRE METHODOLOGY

Overview

The main aspects of CIGRE's methodology are presented in the CIGRE brochure 63 "Guide to procedures for estimating the lightning performance of transmission lines" that compiles the main aspects of CIGRE's methodology [5]. Since 2012, the CIGRE WG C4.23 is working on the revision of such document in order to incorporate the several recent advances presented in the literature concerning the calculation of the lightning performance of transmission lines.

The calculation of the lightning performance of high-voltage transmission lines by means of CIGRE methodology assumes analytical formulations to describe the transient behaviour of the resulting overvoltage due to direct lightning strikes to the line, including the voltage reflection on tower-footing grounding. The calculations assume linearly rising wavefront for representing the lightning return stroke current.

Based on the resulting overvoltage, the critical current able to cause backflashover is determined. The estimation of the line lightning outage rate is obtained by means of the probability of current to exceed such critical current, using a cumulative distribution function of first return stroke current.

Surge impedances are used to represent the transmission line tower and the overhead line conductors. Tower-footing grounding is modeled by a resistance whose value equals the one obtained by measurements using low frequency, low amplitude current. The soil ionization effect may be represented by means of Weck's formula [5].

CIGRE's methodology adopts the concept of a non-standard critical flashover overvoltage (CFO_{NS}) that depends on the line CFO, the nominal voltage of the line, tower-footing grounding resistance and the span length between adjacent towers. If the peak overvoltage exceeds the CFO_{NS}, a backflashover is considered.

The backflashover rate (BFR) is calculated by multiplying the probability of a current to exceed the critical current, the rate of strokes hitting the line (NL) and the 0.6 factor.

CUMULATIVE RETURN STROKE CURRENT DISTRIBUTION

CIGRE's cumulative current distribution is based on the integration of the probability density function indicated in [5]. On the other hand, the IEEE cumulative current distribution is reproduced by a simplified equation [14]. Figure 1 illustrates both current distributions. As can be noted, in the 20-60 kA range, both distributions are very similar. In the large current region and for currents below 20 kA, IEEE presents a large probability of occurrence. For the sake of comparison, the MCS current distribution is also included in this figure.

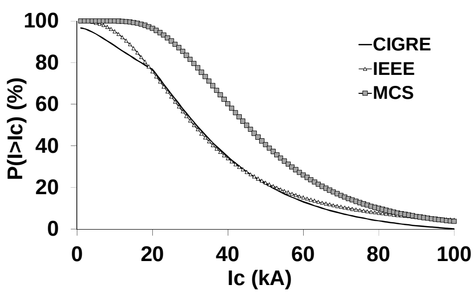

Figure 1. CIGRE, IEEE and MCS cumulative first stroke current distribution.

DEVELOPMENTS

The analyses performed in this work considered lightning striking the top of the 30-m-high 138 kV single-circuit transmission line tower illustrated in Figure 2. The simulations assumed a 400-m long span and a 650-kV line CFO.

Two Td30 front time were assumed in simulations: 3.83 μs and 4.83 μs, corresponding to the median current parameters measured at Mount San Salvatore [15] and Morro do Cachimbo [8] stations, respectively.

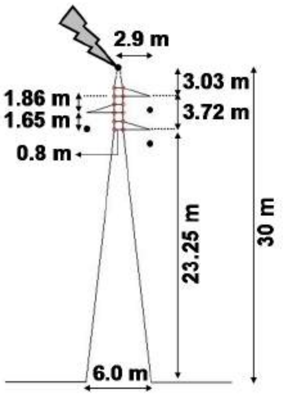

Figure 2. Geometry of the simulated 138-kV transmission line tower.

RESULTS AND ANALYSIS

The performed analyses are divided in two groups: first, results of the impact of the cumulative first stroke current distribution on the backflashover probability of occurrence are presented for 3 values of tower-footing grounding resistance Rg (10, 20, 40 Ω). Following, a case study assuming a lognormal distribution of the tower-footing resistance along the line is developed.

Tables 1 and 2 present the peak overvoltages calculated by CIGRE methodology across the lower insulator string for tower-footing grounding resistance varying from 10 to 40 Ω, for median current parameters of MSS and MCS, respectively. Previous simulations indicated this insulator string as the critical one in terms of the larger overvoltage.

Table 1. Peak overvoltages across lower insulator string. MSS median current parameters: Ip = 31 kA, Td30=3.83 μs.

Rg (Ω)	Vp (kV)	Variation (%)
10	308.9	-
20	516.5	+67.2
40	875.7	+183.5

Table 2. Peak overvoltages across lower insulator string. MCS median current parameters: Ip = 45 kA, Td30=4.83 μs.

Rg (Ω)	Vp (kV)	Variation (%)
10	423.8	-
20	718.2	+69.5
40	1213.5	+186.3

The results show the larger overvoltages related to the MCS current parameter, mainly due to its larger peak current.

Considering the cumulative distribution of first-stroke peak currents of CIGRE, IEEE, and MCS, the percentages of currents expected to overpass the value required to flashover were determined. These results are equivalent to backflashover frequency of occurrence per strike to the tower for each assumed tower-footing grounding resistance. Tables 3 and 4 show the probability of backflashover occurrence assuming current front time of 3.83 and 4.83 μs, respectively.

Table 3. Probability of backflashover occurrence. Td30=3.83 μs.

Rg (Ω)	% I > Ic			Difference MCS x CIGRE (%)	Difference MCS x IEEE (%)
	CIGRE	IEEE	MCS		
10	9.51	12.24	19.56	105.6	59.7
20	33.25	32.62	58.17	74.9	78.3
40	62.88	61.59	89.06	41.6	44.6

Table 4. Probability of backflashover occurrence. Td30=4.83 μs.

Rg (Ω)	% I > Ic			Difference MCS x CIGRE (%)	Difference MCS x IEEE (%)
	CIGRE	IEEE	MCS		
10	7.66	10.75	16.28	112.6	51.4
20	30.62	30.22	54.41	77.7	80.0
40	60.04	58.70	87.00	44.9	48.2

For the simulated current front time, the results indicate very similar probability of backflashover occurrence estimated assuming CIGRE and IEEE peak current distributions, except for the very low grounding resistance case (10 Ω). However, the comparison assuming the MCS current distribution shows large difference on the resulting probability of backflashover occurrence. In all cases, the use of the MCS current distribution leads to a larger expectation of backflashover occurrence. Moreover, such difference is even more relevant for decreasing values of tower-footing grounding resistance when comparing CIGRE and MCS current distributions.

Taking as reference the results related to the 3.83-μs current front time (MSS median current front time), for 20-Ω-tower-footing resistance, the outage rate estimated assuming MCS current distribution is about 75% and 78% larger in relation to those associated to CIGRE and IEEE distributions, respectively. Such increase would represent an estimation of 9 outages/100 km/year assuming MCS current distribution against about 5 outages for CIGRE and IEEE distributions.

The analysis considering the simulation of the 4.83-μs current front time (MCS median current front time) indicates a difference even larger in comparison to the results provided by CIGRE and IEEE current distributions. The difference varies from 78% to 45% and from 80% to 48% in the 20-to-

40-Ω-tower-footing resistance range, in relation to CIGRE and IEEE distributions, respectively.

Case study: lognormal distribution of tower-footing grounding resistance

The analysis in this section considers the tower-footing grounding resistances with median value of 20 Ω and standard deviation of 1. A number of 30 strikes to the 138-kV line per 100 km per year (N_L) was assumed. The obtained results in terms of the resulting outages for 3.83 µs and 4.83 µs current front time as function of the assumed cumulative peak current distribution are shown in Table 5.

Table 5. Outage rate as function of the cumulative peak current distribution for Td30 of 3.83 and 4.83 µs.

Front time (µs)	Outages/100 km/year		
	CIGRE	IEEE	MCS
3.83	6.5	6.7	9.7
4.83	6.1	6.3	9.2

The obtained results confirm the trend shown in Tables 3 and 4: the MCS peak current distribution is responsible for larger outage rates. For this specific case study, the resulting outage rates are about 50% and 45% larger than those associated with CIGRE and IEEE current distributions.

This difference has an important impact on the proposals of protective practices dedicated to improve the lightning performance of transmission lines.

Conclusions

This work presented a preliminary investigation of the impact of distinct peak current distributions on the calculation of the lightning performance of transmission lines in terms of backfashover rate. The evaluations considered a typical configuration of a 138-kV transmission line. Systematic simulations using the CIGRE's methodology were developed considering three cumulative peak current distributions: CIGRE, IEEE, and the one derived from the Morro do Cachimbo station (MCS) data.

The results indicated very similar outage rates calculated assuming CIGRE and IEEE current distributions. On the other hand, the use of MCS current distributions leaded to much larger expectation of backflashover occurrence. The analysis assuming a lognormal distribution of the tower-footing grounding resistance with median value of 20 Ω and standard deviation of 1 showed outage rates about 50% and 45% larger than the ones estimated assuming CIGRE and IEEE current distributions, respectively.

The obtained results show more research is needed on this topic aiming a complete definition of the causes of differences on evaluated outage rates of transmission lines. The use of more elaborated methodologies of analysis, including the realistic representation of the lightning current waveform is important in order to extent the range of application of the obtained results. Furthermore, it is important to clarify the limit of application of global data and regional data of lightning peak current distributions in evaluations of the lightning performance of transmission lines since such definition directly affects the estimated line outage rate. All these aspects are under investigation by the authors of this work.

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