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Shielding failure analysis of a hybrid transmission line with AC and DC systems on the same tower

Pawel Malicki*, Simon Papenheim, Mustafa Kizilcay

University of Siegen, Chair of Electrical Power Systems, Siegen, Germany

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ABSTRACT

Hybrid AC/DC transmission lines have different systems on the same tower and combine HVDC transmission over long distances with common HVAC transmission. Evaluation of the risk of lightning stroke outage of high power transmission lines is very important because lightning strokes cause mainly outages. The present paper illustrates how to combine efficiently different methods to support insulation coordination studies. Maximum lightning current amplitude that does not cause flashover across insulator string is estimated in response to first and subsequent lightning strokes with three different flashover models using several electrogeometric models and simulations in EMTP-ATP. Characteristic quantities like Shielding Failure Rate (SFR) and Shielding Failure Flashover Rate (*SFFOR*) are calculated for different shielding configurations.

1. Introduction

The interest in lightning research has increased in last years. The reasons are of different origin. Firstly, more field measurements of lightning strokes like in Switzerland, Italy, South Africa and Japan are available nowadays. Nevertheless the use of the global distributions for negative first strokes is recommended according to Ref. [1]. The global distributions of lightning peak currents for negative first strokes based on a mix of direct measurements and indirect measurements. New design of power transmission towers is another factor that makes lightning studies essential. Lightning performance of overhead line towers [2] and hybrid HVAC/HVDC [3] lines has to be estimated before they will be erected. Particularly the hybrid line with AC and DC systems offers an efficient alternative to increase transmission capacity using the same tower [4]. The importance of insulation coordination studies of a hybrid line was noted in Ref. [3].

Conversion of one 380-kV AC system into new HVDC system along an existing line route on the same tower will be taken into consideration (see Fig. 1). Available conductors, shield wires and insulator strings of AC lines will be adapted to a HVDC system.

Evaluation of the risk of lightning stroke outage of transmission lines is very important. The outages that are caused by lightning strokes have two origins. Lightning strokes that are intercepted by shield wires can cause backflashover across insulator strings. Due to shielding failure a lightning stroke may hit a phase conductor and can cause a flashover across an insulator.

Shielding failures that are estimated by electrogeometric models are investigated. This study which is an extension of Ref. [5] aims to estimate maximum shielding current and lightning outage rates for a HVDC/HVAC hybrid line. The transients program EMTP-ATP [6] is well suited to analyze lightning surge phenomenon on overhead lines.

2. Lightning occurrence

2.1. Types of lightning discharges

About three-quarters of lightning flashes do not hit the ground. These are termed cloud flashes. Lightning discharges between cloud and earth are termed cloud-to-ground discharges. About 90% of global cloud-to-ground lightning are downward negative lightning flashes and remaining 10% of global cloud-to-ground lightning are downward positive lightning flashes according to Ref. [1]. Thus only negative downward lightning is considered in this study. Downward flashes exhibit downward branching, while upward flashes are branched upward.

* Corresponding author.
E-mail address: pawel.malicki@uni-siegen.de (P. Malicki).

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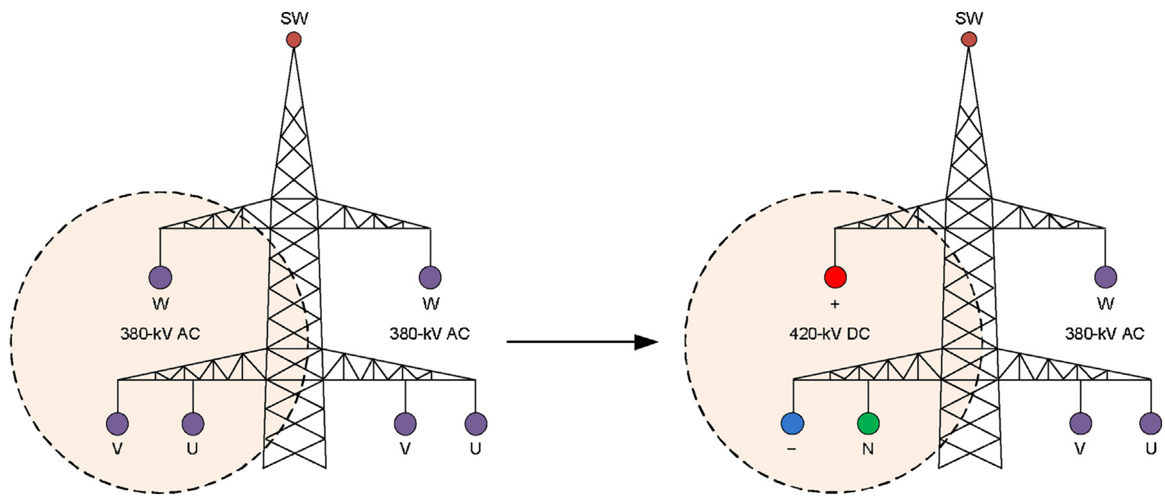

Fig. 1. Tower layout before and after conversion into a hybrid HVAC/HVDC tower.

2.2. Ground flash density

In the present study the ground flash density N_g (strikes/km^2/year) has been taken from records of lightning locating system BLIDS [7] in Germany and is 4 strikes/km^2/year. This lightning locating system is based on the time-of-arrival method (TOA). TOA uses measurements of the electromagnetic field at several stations. A lightning stroke generates an electromagnetic field which propagates with the speed of light. Comparisons of the differences in the arrival time of two or more stations define the source location. Therefore stations must be precisely synchronized. Other lightning locating systems work with magnetic direction-finders (MDF) or with the combination of TOA and MDF [8]. If no measurements of the ground flash density N_g are available, this parameter can be roughly estimated from the annual number of thunderstorm days, also called the keraunic level.

2.3. Lightning analysis

The functionality of shield wire can be estimated with Shielding Failure Rate (*SFR*). *SFR* is number of lightning strokes (strikes/100 km/year) that can directly terminate on the phase conductor. In other words it indicates malfunctions of shield wire.

$$SFR = 2N_g L \int_{3kA}^{I_{max}} D_C(I) f(I)\, dI \quad (1)$$

where: N_g is ground flash density (strikes/km^2/year) according to Ref. [7], L is line length (km), I_{max} is the maximum current, that can be estimated by the electrogeometric model, $D_C(I)$ is shielding failure width and $f(I)$ is the probability density function of the lightning crest distribution.

Not all of these lightning strikes to phase conductor would result in flashover across insulators on a cross-arm. The number of lightning strokes to phase conductor that cause flashover across insulator is called Shielding Failure Flashover Rate (flashovers/100 km/year) and can be calculated with Eq. (2).

$$SFFOR = 2N_g L \int_{I_C}^{I_{max}} D_C(I) f(I)\, dI \quad (2)$$

where all quantities are described above except I_C, which is critical shielding current (kA).

Table 1
Different probability density functions.

Probability density function *f(I)* [1]			
Author	Location	Median (kA)	σ_{Igl}
Berger	Switzerland	30	0.265
Takami	Japan	29	0.28
Visacro	Brazil	45	0.2
Global	7 countries	31	0.21

where: σ_{Igl} is standard deviation of probability density function

Lightning current parameters and probability density function of the current crest distribution are based on the distribution according to Ref. [9]. In Table 1 different probability density functions for negative first strokes according to Ref. [1] are presented.

The choice of the probability density function *f(I)* has significant influence on *SFR* and *SFFOR*. The global distribution of first negative strokes recommended in Ref. [1], is considered in this investigation.

3. Lightning attachment model

The maximum shielding current I_{max} can be estimated by means of different lightning attachment models like electrogeometric, Erikssonís, generic and statistical model according to Ref. [10]. In this work maximum shielding current I_{max} was estimated on the basis of the electrogeometric model (EGM), assuming vertical downward channels, for different transmission line tower geometry. Conductor sag of 9 m is taken into account by calculating an equivalent average height h_{eq} of the conductors as follows:

$$h_{eq} = \frac{2}{3} \cdot h_{mid} + h_{tower} \quad (3)$$

Where h_{mid} is the height at the mid of line span and h_{tower} is the height of the conductor at the transmission tower.

General concept of electrogeometric model was presented in Ref. [11]. In Fig. 2 radii r_c are drawn from shield wire and phase conductor for increasing lightning currents. Additionally a horizontal line with distance r_g is drawn from earth surface. Those radii are striking distances for a vertically moving lightning stroke and are dependent on the stroke current crest value. The intersections are marked A, B and C. The distances D_C and D_G are the exposure distance for the phase conductors and shield wires.

For increasing lightning currents the distance D_C decreases until a point is reached at which D_C becomes zero. This point is defined by the current I_{max}. According to the lightning attachment models only

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