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ORIGINAL ARTICLES

Evaluation of V–t characteristics caused by lightning strokes at different locations along transmission lines

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Abstract Lightning stroke causes a current injection into transmission lines at the point of contact. The lightning performance can be difficult to understand without using simulation programs. PSCAD a powerful software was selected to develop the appropriate data required to investigate this phenomenon.

In this paper, two points along transmission line are selected for studying voltage–time (V–t) characteristics when any of those points is subjected to lightning strokes separately. The first assumed point is taken when lightning current is injected to the shielding wire at the top of the transmission tower, while, the other assumed point is taken when surge current is injected to the shielding wire at maximum sag location in the mid-span between two towers. The sag of transmission line has been newly developed and simulated using PSCAD.

Both transmission line containing sag as well as lightning injection current are modeled. Fast transient of flashover as well as back flashover occurrence is investigated. The results revealed that the sag of transmission line has considerable influence on flashover and induced voltages across line insulators and phase lines as well. The influence of connecting surge arrester in substations is investigated. A proper transmission line arrester (TLA) is designed in order to minimize the occurrences of overvoltages due to flashover and consequently back flashover across insulators.

1. Introduction

One of the natural sources of transient overvoltage in the power system is lightning strokes. Lightning stroke is an impulsive transient variation which is unidirectional in polarity (positive or negative). Overhead transmission line is the most part subjected to the lightning phenomena. Transmission lines are protected from the direct lightning by shield wires. The lightning current injection to shield wires or tower body will

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cause induced voltage across insulators and phase lines (Bollen et al., 2005).

In previous works, most researchers had studied several parameters that affect the lightning performance on transmission system. The common parameters of lightning are: front time, tail time, peak lightning current, tower geometry, footing resistance, corona, flashover, etc (Chowdhuri, 2001; Talib et al., 2012; Yadee and Prem, 2007).

In addition, the striking distance of lightning stroke is a very important parameter to study the performance of lightning on transmission system (Mazur and Ruhnke, 2003).

The mountainous places are mostly subjected to the lightning phenomena where the striking distances are small and the resistivity of rocky mountainous soil is very high.

This paper presents a prediction of V–t characteristics when a simulated lightning current injected at the top of transmission tower or at the maximum sag location of 500 kV overhead transmission line with and without using surge arresters. The induced voltages across insulator as well as in the phase conductors resulting from lightning strikes hitting the ground wires at sag locations are investigated. The obtained results report that the sag of transmission line has an obvious effect not only on V–t characteristics of phase conductors but also on line insulators when surge lightning hits the shielding wire. This study could be useful for predicting and improving transient overvoltage protection system.

2. Modeling of 500 kV transmission system

2.1. Tower module

Tower type and geometry used in this work is shown in Fig. 1. This type of tower can be modeled in PSCAD by representing main legs and cross arms with its equivalent surge impedances and propagation velocity. The surge impedance for each part of tower is 200 Ω and the propagation velocity is 2.5×10^8 m/s. Each part of tower is modeled as transmission line model consisting of Bergeron model and manual entry of surge impedance Z_0, propagation velocity and length (Martinez-Velasco and Castro-Aranda, 2005; Zakaria et al., 2002) as shown in Fig. 2. Line conductor radius is 15.3 mm and its assumed dc resistance is 0.0511 Ω/km, while ground conductor radius is 5.6 mm and its assumed dc resistance is 0.564 Ω/km.

2.2. Footing resistance

Generally there are two types of footing resistance models that can be used: one is simplified constant resistance model, the other model is dependent on surge current magnitude and soil ionization (Yadee and Prem, 2007; Sun and Tremouille, 2012).

In this paper, the footing resistance is kept constant and the effect of soil resistivity is considered. The footing resistance value is taken as 80 Ω.

2.3. Insulator module

The equivalent capacitance of insulator can be used to simplify the modeling of insulator in PSCAD. The insulator (cap and pin) equivalent capacitance is assumed to be 100 pF. It is assumed that the 500 kV insulator consists of 26 disks, having a total equivalent capacitance of 3.94 pF (Research center, 2008).

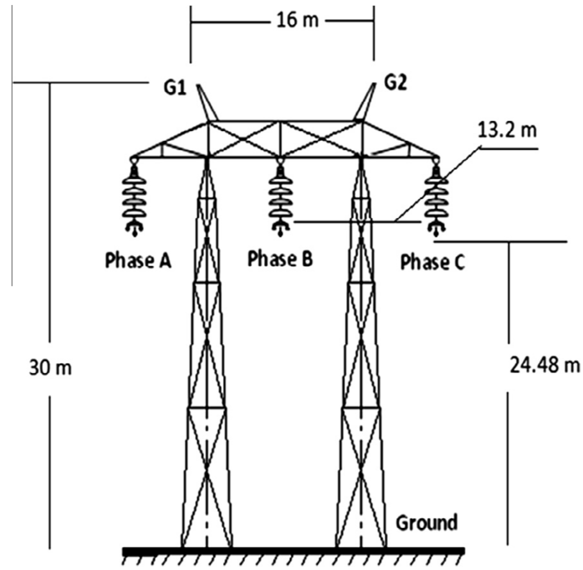

Figure 1 Typical configuration of 500 kV transmission tower.

2.4. Back flashover module

Flashover occurs due to increase in the voltage across insulators. This voltage across insulators is increased due to the injection of lightning current into the top of the tower or the shield wires. If the voltage at the top of tower exceeds the insulator withstand voltage level, then a back flashover occurs (Sun and Tremouille, 2012).

Two models are recommended by IEC 60071-4 to represent the back flashover: critical flashover voltage (CFO) model and volt-time curve flashover model. In this work the volt-time characteristic model is used as follows:

$$V_{f0} = 400l + \frac{710l}{t^{0.75}} \quad (1)$$

where V_{f0} is flashover voltage in (kV), l is the length of insulator in (m) and t is time in (μs).

The back flashover is represented by parallel switch across the insulator as shown in Fig. 3. The parallel switch is modeled and controlled by comparing the volt-time characteristics in (1) with the induced voltage across the insulator as shown in Fig. 4.

2.5. Surge arrester module

Surge arrester is a protective device used for limiting overvoltage on power system by discharging surge current to ground. IEEE had developed a model in which the non-linear V–I characteristic is represented by two sections of non-linear resistances designated by A0 and A1. These non-linear resistances are separated by an R–L filter as in Fig. 5.

For fast front surges, the impedance of the R–L filter becomes more significant (IEEE working groups, 1992).