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Lightning protection of overhead transmission lines using external ground wires

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ABSTRACT

In this paper, a new kind of overhead transmission line (OHL) lightning protection system based on external ground wires is analyzed. Instead of a standard ground wire, two ground wires placed at the top of separate external towers located at both sides of the protected line are used. This type of protection should be applied in specific circumstances for protection of short OHL sections which are highly endangered by lightning. The distance between external protection system and OHL is calculated by using EMTP-ATP. Calculations are performed in order to avoid flashovers from the point where lightning strikes the external protection system to the protected OHL. A rolling sphere method is used to calculate the height of external ground wires above OHL phase conductors to avoid shielding failures. An experiment in a high voltage laboratory is performed to verify the dimensions of the external protection system from the aspect of shielding failures. According to the results of simulation and experiment, the optimal dimensions of the external protection system are determined.

1. Introduction

Lightning is the most frequent cause of overhead transmission line (OHL) trip outs in many countries. Although the impact of lightning overvoltages to the OHLs has been considered since the first AC transmission lines were built, it has also been frequently discussed in recently published scientific papers [1–3].

There are different methods for reduction of the OHL trip out rate caused by lightning: installation of ground wires at the OHL, reduction of the tower grounding impedance, increase of an OHL BIL (Basic Lightning Insulation Level), installation of underbuilt wires, installation of line arresters, etc. When introducing a new protection method, some investment is required and a cost-benefit analysis is a part of every such project.

The lightning performance of an OHL can be evaluated by using simple empirical formulae [4,5], specialized software [2,6] or by direct registration of OHL trip outs caused by lightning [3].

Installation of ground wires is the basic method for protection of an OHL against lightning. Back-flashovers are the most frequent kind of trip outs in the case when an OHL is equipped with ground wires. At medium voltage OHL with high tower footing impedance almost every lightning strike to the line causes a trip out. An increase of the OHL BIL decreases the probability of trip out. Reduction of the OHL tower footing impedance can be done by using bentonite [7]. Underbuilt wires, installed below the phase conductors, are also used to reduce the OHL trip out rate caused by lightning [8,9].

On the most critical sections of an OHL route, line arresters can be installed. For full reduction of OHL trip outs, surge arresters must be installed in every phase [10]. When using line arresters on medium voltage OHLs on a terrain with high specific soil resistivity, problems can occur when lightning strikes with a high current amplitude near the tower top what causes a large portion of the current to flow through the arresters. In such a situation, the energy absorbed by the arrester can exceed its capacity and the arrester can be destroyed [8,11].

In this paper, a new kind of OHL protection against lightning is analyzed. This kind of OHL protection was mentioned for the first time in [12] and its application has been suggested in [13]. Instead of a standard ground wire placed at the top of the OHL towers, an external system of ground wires for OHL protection is analyzed. This protection system is graphically presented in Fig. 1. Ground wires on external towers are installed on both sides of the protected OHL in such a way that the probability of shielding failure is negligible. In this manner lightning strikes occur only on the

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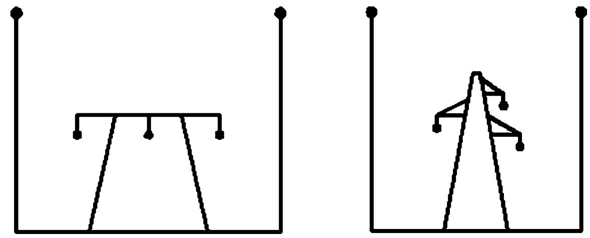

Fig. 1. External ground wire (EGW) protection system against lightning strikes for horizontal (left) and vertical (right) configuration of phase conductors.

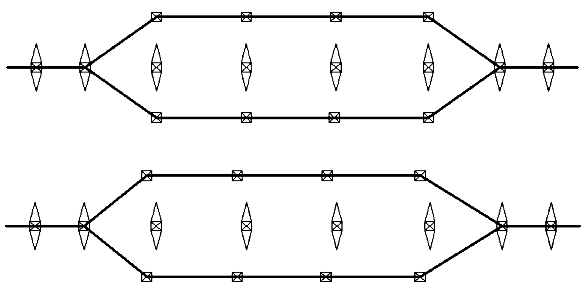

Fig. 2. EGW protection system on the most critical sections of the OHL.

external protection system and the OHL is influenced only by induced overvoltages. The influence of induced overvoltages decreases with the increase of the nominal system voltage.

An external ground wire (EGW) protection system configuration for the most vulnerable sections of an OHL is shown in Fig. 2 (top). When the distance between the external tower and OHL tower footings is short, there is a possibility for their interaction when lightning strikes the external protection system. In this case, the distance of the groundings can be increased by repositioning the external towers along the span, Fig. 2 (bottom).

2. Dimensioning of the external protection system

There are two scenarios in which a trip out on an OHL protected by an external protection system can occur:

a) Shielding failure of the external protection system and direct strike to the OHL tower or phase conductor, marked with (a) in Fig. 3.
b) Flashover from the point of lightning strike on external protection system to the OHL phase conductor, marked with (b) in Fig. 3.

The three dimensions from Fig. 3, D, L and H, must be correctly calculated to avoid these scenarios:

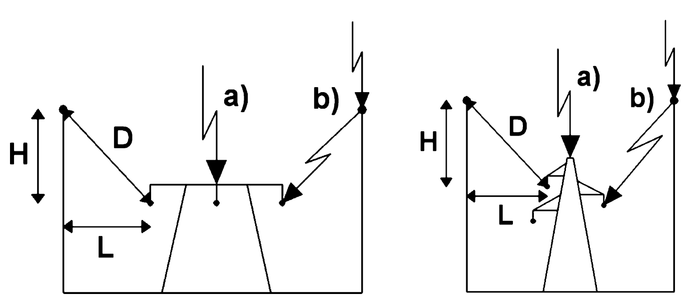

Fig. 3. Scenarios in which trip out of an OHL protected by external protection system can occur for horizontal (left) and vertical (right) configuration of phase conductors.

Table 1
Default parameters values for calculations.

Element	Value	Element	Value
External tower height	45 m	Tower surge impedance [4]	150 Ω
Equivalent radius of the tower footing	5 m	Ground wire surge impedance	550 Ω

D – the distance between EGW and OHL phase conductor [m]. This must be determined to minimize the probability of a flashover from an EGW to a phase conductor when lightning strikes an EGW.
L – the distance between external tower and OHL phase conductor [m]. This must be determined to minimize the probability of a flashover from an external tower to the OHL phase conductor when lightning strikes the top of the tower.
H – the height of EGW above OHL phase conductors [m]. This must be determined to minimize the probability of the external protection system shielding failure.

2.1. Determination of the distance between EGW and OHL phase conductor – D

The EGWs can be placed as close as possible to the protected OHL to ensure a low probability of shielding failure. The minimum distance is determined so that there is a low probability of a flashover from the point of lightning strike at EGW to a protected OHL. The distance D is modeled as an air gap with a Leader Progression Model (LPM) flashover characteristic (1) [14–17] and this model is implemented in the EMTP-ATP program [6]:

$$v = 170 \cdot d \cdot \left[\frac{u(t)}{d-l} - E_0\right] \cdot e^{(0.0015 \cdot (u(t)/d))} \quad (1)$$

where d is the air gap distance [m], $u(t)$ is the instantaneous overvoltage value [kV], l is the leader length [m], E_0 is the critical leader inception gradient [kV/m], the value around 545 [kV/m] should be used [16].

In practical calculations a corona inception time in the LPM can be neglected [14,15], while the streamers propagation time is completed when the applied voltage reaches a value of E_0 [15]. The leader velocity should be modeled by Eq. (1).

In Table 1, the default parameters values of the network elements used in all calculations in this paper are presented. Models of elements applied in simulations are used from the international technical documents [4,14,15] and in accordance with conclusions presented in [17].

A lightning current waveshape 5.63/77.5 μs/μs has been used in all calculations corresponding to the negative lightning strikes [14,18]. A lightning strike is represented as a non-ideal current source consisting of an ideal current source with double ramp waveshape [15] parallel to the lightning channel surge impedance which is assumed to be 1000 Ω [17]. Although there are some more accurate models of the lightning current waveshape, as Cigre source [14] or Heidler source [19], sensitivity analysis shows that, in the case when LPM model of air breakdown is used, the application of advanced lightning current models has small influence to the estimated results [17].

The tower footing impedance is calculated by using the equation for semi-spherical configuration. The ionization effect in the soil around a tower footing is modeled according to [14]. The impulse model of the tower footing impedance decreases the maximum overvoltages, so that more critical results are obtained by neglecting the frequency dependence of soil parameters [20].

The maximum overvoltages on the external protection system appear in the case when lightning strikes the middle of the EGW span and this case is analyzed when calculating the distance D. It is