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Application possibilities of special lightning protection systems of overhead distribution and transmission lines

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ABSTRACT

Reduction of the overhead lines back-flashover rate (BFR) after application of special lightning protection systems is analyzed in this paper. The following lightning protection systems are considered: line arresters, underbuilt wires, additional shield wire and guy wires. Partial or combined efficiencies of mentioned lightning protection systems are analyzed. Overhead distribution (35 kV) and transmission (110 kV and 220 kV) lines BFR are estimated through the semi-statistical calculation procedure as suggested in international technical documents. System equivalent circuits in the EMTP-ATP software are created with carefully chosen models and parameters of elements. Pursuant to the estimated results, conclusions about application possibilities of different lightning protection systems are given.

1. Introduction

The fundamental task of every electric power system is to provide the consumers with quality and cheap electrical energy. To accomplish this task, many problems occurring in the operation of an electric power system must be solved. In the areas with high specific soil resistivity and high ground flash density main cause of the poor electric power quality are lightning caused trips. Selection of the optimal overhead line route in the phase of the line planning and design can have significant influence to the prospective overhead line lightning performance, especially when a line passes through regions with high ground flash density [1].

In this paper there is an analysis of application possibilities of different special lightning protection systems of distribution and transmission overhead lines from lightning surges which are the consequence of direct lightning strikes into the lines. According to [1] all lightning protection systems of overhead lines can be divided into two groups: standard and special ones. The standard lightning protection systems include: installation of shield wires [1,2], decrease of tower grounding impedance [1,3] and the selection of adequate basic lightning insulation level (BIL) [1,3]. Among the special lightning protection systems, there have been analyzed: application of line arresters, installation of additional shield wire, installation of underbuilt wires and application of guy wires on overhead line towers. Line arresters are widely used to protect both distribution and transmission lines from lightning surges [1,2,4]. The main advantages of this lightning protection system are: easy installation, reduced investment costs in relation to the couple of years ago and high protection efficiency. Line arresters can be installed at almost every overhead line because of their low weight and small dimensions. These features provide their frequent applications at overhead lines with different rated voltages and in different climate conditions. However, investment and maintenance costs of this lightning protection system depend on several aspects (line voltage level, the country of installation, accessibility of the area in which the protected line is located etc.) and in specific situations these costs can be high. In the cases when line arresters are not the optimal solution, other special lightning protection systems can be applied.

A combination of underbuilt and guy wires has been used for lightning protection of critical 220 kV overhead line in Brazil in Amazon region [5]. Line arresters are not applied because of the difficulties connected with their maintenance in this area with difficult access. Application of additional shield wires and underbuilt wires on the overhead distribution lines for reduction of the line arresters energy stress caused by winter lightning has been analyzed in [6].

In this paper a comparative analysis of different special lighting protection systems is presented. The goal is to calculate and compare their efficiencies and the application possibilities at the lines with different rated voltages. Such types of comparisons can hardly be found in the literature because most of the papers deals with individual lightning protection systems and their applications in specific situations.

2. Default calculations parameters

2.1. Input data for calculations

Efficiencies of the different special lightning protection systems of

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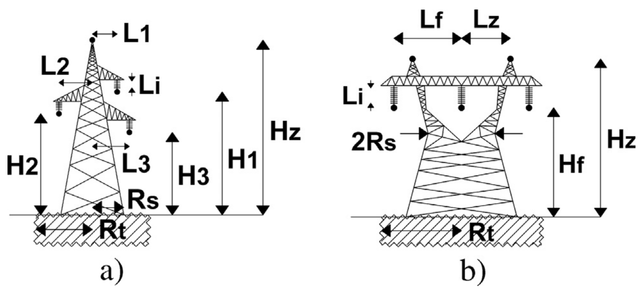

Fig. 1. Overhead lines towers configurations: (a) 35 kV, 110 kV and (b) 220 kV.

Table 1
Default input data for calculations.

Parameter	Value 35 kV	110 kV	220 kV
Tower height (Hz) [m]	15	25	30
Conductor height (H1-H2-H3, Hf) [m]	13–11.5–9.5	20–18–16	23.5
Underbuilt and guy wire hanging point [m]	6.4	12	15
Guy wire length [m]	10	17	21
Conductor sag [m]	3.5	8	11
Sag of wires[a] [m]	2.5	6	8
Tower base radius (Rs) [m]	0.8	2	4
Tower footing radius (Rt) [m]	2	4	8
Insulator strings clearance (Li) [m]	0.44	0.96	1.65
Line BIL	200 kV	550 kV	950 kV
Conductor to tower axis distance [m]	(L1–L2–L3) 1–1.2–1.5	(L1–L2–L3) 2.7–3.1–3.5	(Lf–Lz) 9.5–7.7
Distances between two underbuilt wires and two shield wires [m]	2 and 2	3 and 3	8 and 15.4
Radii of conductor and wires[a] [mm]	6.8 and 3	8.6 and 4.75	15.3 and 5.5
DC resistance of conductor and wires[a] [Ω/km]	0.306 and 5.5	0.194 and 3.55	0.059 and 2.79
Span length [m]	180	250	300
Tower surge impedance [Ω]	195	173	123
Matching lines lengths	6 km		

[a] Shield and underbuilt wires.

overhead distribution (35 kV) and transmission (110 kV and 220 kV) lines are estimated through the numerical calculations performed by using EMTP-ATP software [7]. Default overhead lines towers configurations applied in calculations are presented in Fig. 1. Default input parameters for calculations are presented in Table 1.

Non-linear *U-I* curves of line arresters (LA) provided by manufacturer and obtained with 8/20 μs/μs impulse currents are presented in Table 2. Shaded fields in Table 2 are estimated by linear extrapolation of the data provided by the manufacturer. It is assumed that 35 kV network has an insulated neutral point (that is common practice in many countries). Because of that, line arresters with higher rated voltage and higher residual voltage characteristics are selected, resulting in the reduction of arresters efficiency. At the 110 kV and 220 kV overhead line rated voltages of arresters are used to be one step higher than the rated voltages of the station arresters for the same voltage level [2].

2.2. Models of elements applied in the equivalent circuit creation

This section provides a brief description of the models of elements applied in the equivalent circuit creation. All adopted models of elements and they parameters are used from international technical documents [2,8–11] and in accordance with conclusions presented in [12]. In this way, the accuracy and reliability of the obtained results are

Table 2
Non-linear *U-I* curves of line arresters provided by manufacturer and obtained with 8/20 μs/μs impulse currents.

Current	35 kV line Residual voltage	Current	110 kV line Residual voltage	220 kV line Residual voltage
0.1 mA	105.4 kV	0.1 mA	248 kV	420 kV
1 kA	109.7 kV	5 kA	264 kV	443 kV
2.5 kA	116.1 kV	10 kA	280 kV	466 kV
5 kA	121.8 kV	20 kA	314 kV	512 kV
10 kA	129.0 kV	40 kA	359 kV	573 kV
20 kA	147.1 kV			

provided. More details about the influence of different models of elements on the estimated lightning performance of overhead transmission lines can be found in [12].

(a) Lightning strike model

Lighting strike is represented as a real current source. Lightning current waveshape is modeled by using double ramp function, as suggested in [8,11], and with parameters for the front and tail of the wave equal to 5.6/77 μs/μs respectively [4,10,13]. Lightning channel surge impedance is modeled with constant value of 1000 Ω [12,14].

(b) Overhead line model

Overhead lines (phase conductors, shield wires and underbuilt wires) are modeled by using JMarti frequency dependent model [11,15]. Parameters of the model are calculated at the frequency of 500 kHz and with skin effect considered in calculations [11].

(c) Overhead line tower model

Overhead line tower is modeled as an equivalent line with surge impedance and propagation velocity of 0.85 light speed [9,12]. Towers surge impedances are calculated by using Eqs. (1) and (2) for towers with vertical (Fig. 1(a)) and horizontal (Fig. 1(b)) arrangement of phase conductors respectively.

$$Z_{t,V} = 30\cdot\ln\left(\frac{2(h^2+r^2)}{r^2}\right) \tag{1}$$

$$Z_{t,H} = 60\cdot\left(\ln\left(\sqrt{2}\,\frac{2h}{r}\right)-1\right) \tag{2}$$

where h is tower height [m] and r is tower leg equivalent radius [m].

(d) Overhead line tower grounding system model

Overhead line tower grounding system is assumed to be semi-spherical and it is modeled by using ionization model, Eq. (3), [10–12].

$$R = \begin{cases} R_0, & I \leqslant I_g \\ \dfrac{R_0}{\sqrt{1+\frac{I}{I_g}}}, & I > I_g \end{cases} \tag{3}$$