OVERVIEW OF APPROACHES FOR ESTIMATING LIGHTNING PERFORMANCE OF POWER LINES

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Introduction. Overhead line failures are most commonly caused due to lightning strokes to either a shield wire or a phase conductor. This appears to be a significant characteristic for design and protection of power lines. The lightning performance of an overhead line is typically evaluated by the number of flashovers per 100 km per year [1]. The lightning performance of the line (lightning flashover rate) is the sum of [2]: direct strikes flashover rate; nearby strikes flashover rate; flashover rate from failures of protective equipment. The estimation of overvoltages requires knowledge on lightning discharge currents statistical distributions for all conductors of overhead line separately, both for direct and indirect strikes. The modern procedures of power lines lightning performance estimations usually include: generation of random numbers (Monte Carlo methods) to obtain input parameters of the lightning stroke and the overhead line (phase voltages) having random nature; application of an incidence model to determine the point of impact of every lightning stroke; calculation of the overvoltage generated by each stroke, depending on the point of impact; and calculation of the lightning flashover rate parameters [1, 3]. Among these are: the Lightning Flashover Rate (LFOR) of a transmission line, the Back Flashover Rate (BFOR) and the Shielding Failure Flashover Rate (SFFOR) [1]. The BFOR is the annual outage rate on a circuit or tower line length basis caused by back flashover on a transmission line and the SFFOR is calculated as the annual number of flashovers on a circuit or tower line length basis caused by shielding failures [3-5]. In addition, the SFR is the annual number of lightning events on a circuit or tower-line length basis, which bypass the overhead ground/shield wire and terminate directly on the phase conductor. This event may or may not cause flashover. There are a lot of scientific and technical publications and guides on the topic, recommendations are varied in different countries, and the issue is continuously developing [1-9]. Thus, for carrying out the discussed lightning performance of power lines (LPPL) estimation it is important to overview existing approaches.

Aim of the work. The aim of the work is to overview the existing approaches for estimating lightning performance of power lines.

Results and Discussion. The conventional existed methods for assessing lightning performance of overhead lines are based on analytical methods where the overvoltage equation calculation must be completed by means of numerical methods in which their accuracy becomes in some way questioned as the integrations are needed to solve the corresponding equations. Traditionally, the electro-geometric (EGM) model based on a strike distance has been used to determine the maximum prospective peak current magnitude I that can avoid the shielding and hit on phase conductors [4, 5]. It can be also utilized for determination of the number and position (point) of the incidents. The idea of EGM is that it considers the downward lightning leader (typically negative), while neglecting events when the upward leader (typically positive) is initiated first from the structure [1, 2, 10]. The EGM model analysis depends on lightning current parameters, and lightning and striking distance relations. The statistics of the stroke-current distribution is needed to compute the SFR. The cumulative probability of I_f to exceed I is given, or approached by Equation (1) [1, 2]:

$$P(I_f > I) = \frac{1}{1+\left(\frac{I}{I_{\text{first}}}\right)^{2.6}} \quad , \tag{1}$$

where parameter $I_{\text{first}} = 31$ kA is the median current value of first return strokes. Formula (1) is valid for currents in the interval between 2 and 200 kA [2].

The SFR is obtained by integrating the exposure width $D_c(I)$ for each current times the probability of that current on each side for all possible currents up to I_{max}, which shown by Equation (2) [4, 5]:

$$\text{SFR} = 2\, N_g\, L \int_{I=0}^{I=Imax} D_c(I)\, f_1(I) dI \quad , \tag{2}$$

where L is the line length (often considered as 100 km) and $f_1(I)$ is the density function of the lightning current amplitude distribution [1, 2, 5]. The value of I_{max} is limited by line geometry and determined from EGM model.

The striking distances r_c (to conductor) and r_g (to ground), shown in Fig. 1, are suggested by Equations (3) and (4) as [4, 5]:

$$r_c = 10 I^{0.65} \tag{3}$$

$$r_g = \begin{cases} 3.6 + 1.7 \ln(43 - y_c)]\, I^{0.65} & y_c < 40 \text{ m}; \\ 5.5 I^{0.65} & y_c \geq 40 \text{ m}, \end{cases} \tag{4}$$

where y_c is the average conductor height in meters, given by the height at the tower minus two-thirds of the midspan sag. For simplified approaches, it is often assumed $r_c = r_g = 10I^{0.65}$, which corresponds to the Rolling Sphere version of EGM model.

At higher transmission line voltages, a shielding failure with a low current may not necessarily cause a flashover. The minimum or critical current I_C required for flashover can be evaluated by Equation (5) [2, 4, 5]:

$$I_c = \frac{2\text{CFO}}{Z_{\text{surge}}} \quad , \tag{5}$$

where CFO is the Critical Flashover Voltage (the peak value of the impulse wave which, under specified conditions, causes flashover through the surrounding medium on 50% of the applications [2]) and Z_{surge} is the conductor surge impedance under corona [2].

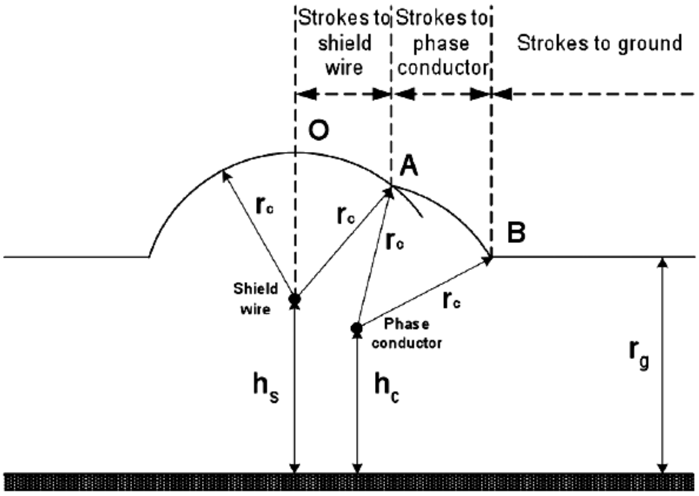

Figure 1 – Application of EGM model [1]

Equation (6) represents the number of shielding failures at the line having length L per unit time (typically on year) that results in flashovers (SFFOR) [4, 5]:

$$\text{SFFOR} = 2\, N_{\text{g}}\, L \int_{I=Ic}^{I=Imax} D_c(I)\, f_1(I) dI \ . \tag{6}$$

The EGM model assumes that the downward leader channel is approaching the ground and that the flash will strike the tower if its prospective ground termination point lies within the attractive radius r_{c}, as shown in Fig. 1 [1]. The attractive radius depends on several factors, such as: charge of the leader, its distance from the structure, type of structure (vertical mast or horizontal conductor), structure height, nature of the terrain (flat or hilly), and ambient ground field due to cloud charges [2].

When lightning hits an overhead phase-conductor, the current large magnitude and its high-frequency nature are causing voltage surges propagating in both directions from the point of strike. Since transmission lines are usually shielded by several wires, lightning overvoltage can be caused by strikes to either a shielded wire or a phase conductor. This type of strike produces a flashover if the back flash overvoltage exceeds the insulator strength. Overvoltages caused by a shielding failure, are more dangerous, while their frequency is low due to shielding provided by sky wires [2, 4, 5]. Direct lightning strikes to power distribution lines cause insulation flashover in the great majority. However, experience and observations show that many of the lightning-related outages of low-insulation lines are due to lightning that hits the ground in proximity of the line [2, 6]. The induced overvoltages are not much considered for transmission lines as compared to distribution lines due to large voltage insulation levels and heights of the towers.

Some of the recent models such as upward connecting leader, leader progressive model, leader inception and propagation model are based on simulations of upward connecting leader development. According to leader progressive model (LPM) [7], the flashover mechanism comprises of three stages: corona inception, streamer propagation and leader propagation. The total flashover time is the addition of the corona inception time, the streamer propagation time and the leader propagation time [7]. The snapped data of natural lightning discharge exposes that the lightning leader has a noticeable effect of branching and tortuosity, which can be defined by fractal mathematics [9]. Hence the fractal approach model can be used in analyzing the progression patterns of leaders.

A self-consistent leader inception and propagation model (SLIM) also can be applied to study lightning attachment to grounded structures, which include conductors and towers of power transmission and distribution lines [7, 8]. In the model, the corona inception is estimated by using the well-known streamer inception criterion; however the total charge in second or successive corona burst decides the changeover from streamer to leader [8]. SLIM, which is based on the physics of the conversion of streamer to leader, dynamically evaluates the inception of upward positive leaders considering the time variation in the electric field produced by the stepped downward leaders and the space charge associated with streamers and aborted leaders produced before the stable leader inception takes place [8].

The estimation of lightning performance parameters for the given power line is carried out by a stepwise procedure which is considering the available data and approach of study. This stepwise procedure can be represented in a flow chart, as shown in Fig. 2.

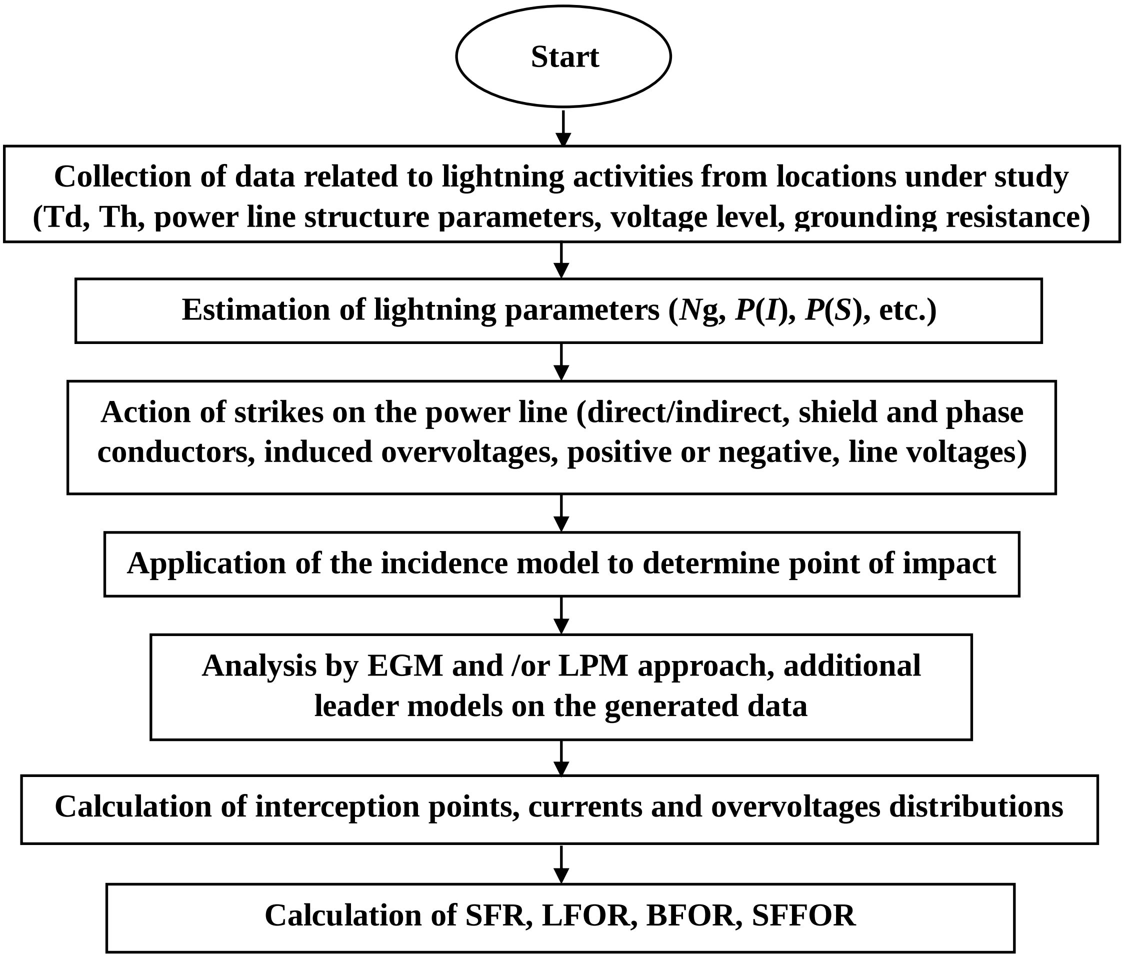

Figure 2 – Flow diagram for lightning performance of power lines estimation based on [3-5, 7-9] and authors’ view

Conclusion. The lightning performance of power lines (LPPL) estimation procedure is based on the selected interception model (EGM, LPM and other), available lightning characteristics, the transmission line structure and voltage levels, type of overvoltages and other characteristics under study.

For this procedure, various traditional and recent models are utilized, which consider both the deterministic and stochastic features of downward and upward lightning leader. The new methods for simulation of lightning interception (like LPM, fractal models) and for LPPL estimations are utilizing more physics and statistics approaches, and hopefully will result in more accurate results. These to be validated by field studies supported by novel instrumentations.

Of course, as it was previously, of great importance is obtaining of reliable statistical data on lightning characteristics at the region of studied power line trace.

Future authors' efforts will be focused on obtaining not only the positions and number of strikes to the line, and SFR, LFOR, BFR, SFFOR parameters, but also the statistical distributions of lightning current values and related overvoltages parameters at the overhead wires and different phase conductors.

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