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Dynamic Simulation of Lightning Strikes on Transmission Lines Based on ATP-Matlab

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ABSTRACT
The principal function of an Electric Power System is to supply energy power, maintaining acceptable service conditions. Where, the insulation coordination and protection relays play a crucial role. However, it is clear that lightning strokes on transmission lines can affect the performance of protection devices and insulator strings. In this context, in order to analyze and study the lightning strikes performance, it is necessary to develop simulations of that phenomenon on transmission lines.
In this paper a new methodology to develop dynamic simulations of lightning strikes along transmission lines is proposed. The dynamic representation of atmospheric discharges is developed in MATLAB, employing ATP-based files that correspond to the Electric Power System as database for classification schemes. Thereby, the lightning impact point is moved along the transmission line with an interval ΔL until its terminal is reached. For each step ΔL, various simulation cases considering different flash peak current magnitudes, polarities, front times and others characteristics of lightning strikes are developed. Thus, flashes which hit towers, live wires and ground wires are considered. This algorithm can be widely applied to other overhead lines especially for the robustness offered by the interfaces MATLAB-ATP.

1. Introduction

Investigations on the lightning performance on Electric Power Systems have demonstrated that this phenomenon is an imperative factor for the insulation design of Electric Power Systems (EPS) [1]. Transmission lines (TLs) are one of the major targets of lightning [2-4]. Thus, when ever this phenomenon hits transmission lines, towers, ground wires or any other crucial component, it causes overvoltages, which can produce a failure in the affected insulator. This failure is produced if the overvoltages magnitude is higher than Basic Insulator Level (BIL) [1].
Lightning strikes affect considerably the overhead lines performance. Still, due to their unpredictable behavior and considering their increasing intensity and frequency worldwide caused by global warming [5], they gain more significance and become a focus of scientific research. In this context, the development of alternatives methods for lightning strikes simulation can help to facilitate the analysis and study of these phenomena and their impact on electric systems like insulator coordination (sensitivity studies), relays devices and other [6-8]. Therefore, the analysis and study of atmospheric discharges and their characteristic parameters, which can produce flashovers across insulator strings is imperative. As the lighting strike can hit at any points along the line, its total length needs to be considered.
Simulation of lightning strokes on transmission lines using the Monte-Carlo model has been an important tool for many years [9-10]. In this paper, the benefits of both ATP for transients' simulation [11] and MATLAB for signal processing and analysis to realize the simulation of lightning strikes on transmission lines, are used.
As stated previously, the lightning strike study is crucial for the performance of both transmission and distribution lines. Therefore, databases are required as storage of lightning strikes' signals simulated along overhead lines that can be analyzed for flashover verification.
Extensive studies presented in [12-16] prove the proposed methodology's performance and demonstrate its use for numerous applications such as transmission line faults indication and lighting strike classification.
As regards the format of this research, it is organized as follows: Section II present the benefits of lightning strike big data and the algorithm developed corresponding to the lightning strikes simulation. Section III presents the methodology application. Finally section IV presents the main conclusions on this work.

2. Lightning simulation algorithms

2.1 Benefit of databases for lightning strike analysis

In general, lightning strikes on overhead lines produce overvoltages, which can be either higher or smaller than voltages that can withstand the insulator string (BIL). Their scale depends on the lightning strikes parameters and the flash impact point on the transmission line [17].
In order to develop studies and analysis of lightning focused on sensitive analysis, protection relays and other relevant aspects of the EPS, extensive databases are required to create training and testing sessions. For instance, in order to develop novel methodologies for lightning transmission lines

protection relays, it is necessary to obtain transient signals produced by lightning and recovered by the relay placed at one transmission line terminal. Fig. 1 shows this issue.

Conclusively, different lightning stroke databases must be simulated for the training process, which allow the patterns extraction-classification corresponding to lightning with and without fault. Furthermore, new lightning stroke databases are necessary to test the classification algorithm. These new signals must be simulated varying their features, especially the impact point along transmission lines.

2.2 Lightning simulation

The simulation of lightning strikes is realized through an interface Matlab-ATP. This interface is a program developed in Matlab that manipulates an ATP file, named as "ATP base case", to generate different cases of lightning strokes over a TL in the same EPS scenario. Figure 2 shows their flowchart that displays the scheme for the creation of databases. This algorithm has two principal processes, the first is related to the fixed data included before the simulations, and the second is related to the variables that go changing during the simulations.

Some data like frequency, line parameters or overhead line length must be taken from the EPS model simulated in ATP. These parameters are added in the Matlab program and considered as constant data. In Fig. 2 the line length is fixed as fixed data. After the data are fixed, the program initiates by using the *simulation* function, however simulation variables must be initialized [12].

In order to start the automatics simulations, a *base case* must be considered. The *base case* is an.*atp file* which is builded according to the desired EPS scenario, on which the simulations are done.

Automatic simulations, varying parameters inside of the simulation are developed through closed loops. In this paper are used two variables to be modified, corresponding to the flash peak current magnitude and the point of impact of lightning along the TL. However, other characteristic features of a lightning strike could be considered as variables [12].

As regards the simulations on the TL, two subroutines called *generate_line* and *write_lib* are used. The first generates models of sections of lines to be used by the ATP with a specific length. A variable L_F is used to define the point of impact of the lightning over the TL. This variable is measure from one side of the line and its value is moving with a predefined step ΔL to reach the other side of the line [12]. In this context, the lightning hits along the TL point L_F, which is done by modifying the length of the section A and F of Fig. 1 by the program.

As stated previously, the first subroutine is related to the TL length. Instead, the second subroutine is related to write to disk the variables of TL sections in a.lib format as required by ATP.

After the base case is done and ready to be simulated, it is necessary to save to disk the changes in a specific.*atp* file which name is related with the values of the variables.

The interface between Matlab and ATP is developed through the command *dos*, thus by using this command the *name_case.atp* is run. Finally, in order to use the simulations, these are saved as files.*mat* through the routine Pl42mat. Finally, in order to check the correct simulations, an output variable called *verify* is used, which records all data needed by the user for the examination [12].

Fig. 2 shows the simulation algorithm flowchart. From this Fig. it is possible to see that before starting the simulations, some features must be incorporated, some of them are obtained through a first ATP run and others are fixed by the user. Furthermore, the simulation program is designed avoiding mal-operations if the initial length is greater that total length.

3. Proposed methodology application

3.1 Lightning stroke simulation along the transmission line

The simulation program developed in this research was employed for generate different database make up by transient signals simulated on EPS. In [13-16] were presented applications of the simulation methodology oriented to faults classification and lightning classification. In this research in order to show the potential of the simulation methodology, the EPS used consist of 6 buses, 5 single transmission lines, 2 transformers and 6 generators. The transmission line used in this work is denoted as M-N, which is simulated with the frequency dependent model [18]. These databases were generated for two purposes:

First: To analyze and study the insulator string performance due to lightning strikes, and thus easily determine on which insulator string the flashover is produced.

Second: To propose a novel methodology for lightning stroke protection relays, the methodology uses voltage signals produced by lightning strokes on transmission lines, registered by the protection relay in one transmission line end. The aim is correctly classify if the lightning produce or does not produce fault. Thus, protection relays only to send the trip order when a lightning stroke produces a fault, to avoiding unnecessary interruptions. However, in this paper the methodology is used for the first case.

As regards the insulator performance, several studies have been published regarding the modeling of components in power system transient analysis **Error! Reference source not found.**. Based on the previous, the transmission line is modeled using un-transposed distributed parameter line models corresponding to shield wires and live wires with two spans at each side of the point of impact. See Fig. 1.

On the other hand, Fig. 1 shows the transmission line divided in six sections denoted by A, B, C, D, E and F, where B=C=D=E= 0.5 km=distance among towers. A and F are the distances which are varied though the simulation program. Table 1 presents the stretches lengths distributed along the transmission line.

As can be observed the transmission line was divided in six sections, where the points denoted as IP_1 and IP_2 represent the impact point of lightning on phase conductor directly and on the transmission tower displayed in. See Fig. 3.a and Fig. 3.b.

By running the simulation case, the program creates six.*lib* files corresponding to the six sections of Fig. 1 for a specific lightning impact point on the TL.

By using the base models simulated in ATP, two base cases corresponding to lightning on phase conductors and on transmission tower are created. Thus, on these cases the

lightning impulse is inserting using the models shown in Fig. 3. On this context, the ATP generates the ATP codes, which are varied by Matlab Program.
As stated previously, the lightning presents an unpredictable behavior. Thus, it is necessary to simulate the lightning impact point along the transmission line total length. In this way, the sections B, C, D and E are fixed values, and the sections A and F are adjusted consecutively keeping constant the total length.
For example, in Fig. 2 the total transmission line length (L), initial lightning stroke distance (L_0) measured from a transmission line end, the length variation along the line (Δ_L) are initialized. Hence, the variable initialized L_F and the closed loop *for* displaces the lightning from L_F to L. By moving the lightning impact point from one end to another, it analyses the total length. The impact point is varied injecting the lightning impulse to the nodes IP_1 and IP_2 to a distance L_F.

3.1.1 Requirements for the lightning simulations

In the previous section, the methodology to make the dynamics simulations is presented. However, in order to analyze and study transmission lines performance against atmospheric discharges, different parts of an overhead transmission line such as wires shield wires and phase conductors, towers, grounding, insulator strings and others have to be simulated. Accordingly, a summary of guidelines used in this research not only for the transmission lines representation in lightning studies but also for the representation of different lightning flash features are presented as follows [19-21]:

- ✓ The most important factor in lightning surge simulations is related to their magnitude. However, it has been accepted that when a lightning hits a transmission line, it injects current into the power system. On this context, the lightning is represented by an impulsive current source named Heidler [22].
- ✓ As regards the transmission tower, there are two possibilities to simulate this element, the first consists of using inductances-resistances, and the second consists of using distributed parameters impedances, the last one considerers voltage reflections from adjacent towers and from cross arms, thus, in this research the tower is represented as a lossless distribute-parameter transmission line, characterized by their impedance and travel time. The applied tower model used is presented in Fig. 4. On the other hand, using the ATP the tower equivalent circuit consisting of main legs and cross-arms can be simulated as it is presented in Fig. 5.
- ✓ Insulators are simulated by a voltage-dependant flashover switch and based on the voltage-time characteristic. The dielectric strength of an insulator string as a function of time to flashover for a lightning impulse voltage wave is:

$$V_f = 400 * Li + \frac{710 * Li}{t^{0.75}} \qquad (4)$$

where:
V_f = flashover voltage in kV
t = time to flashover in µs
Li = length of the insulator string in meters

- ✓ The flashover mechanism corresponding to insulators is simulated through the volt-time curve, which in this paper is implemented using MODELS language [23]. Fig. 6 shows their code.

Table 1 Stretches lengths.

Line section	Length (km)
A	L-4B-L_F
B	0.5
C	0.5
D	0.5
E	0.5
F	L_F
L= transmission line total length	
L_F= initial length	

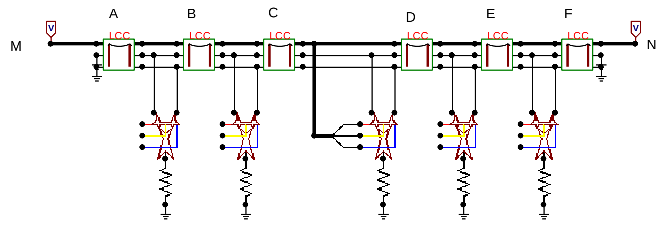

Figure 1 Lightning recovered by relays.

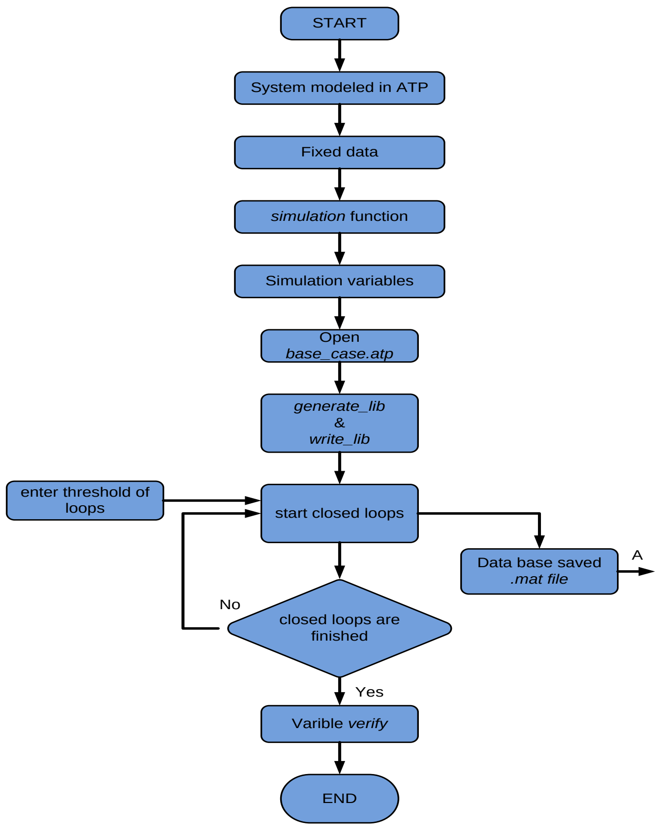

Figure 2 Simulation algorithm flowchart.

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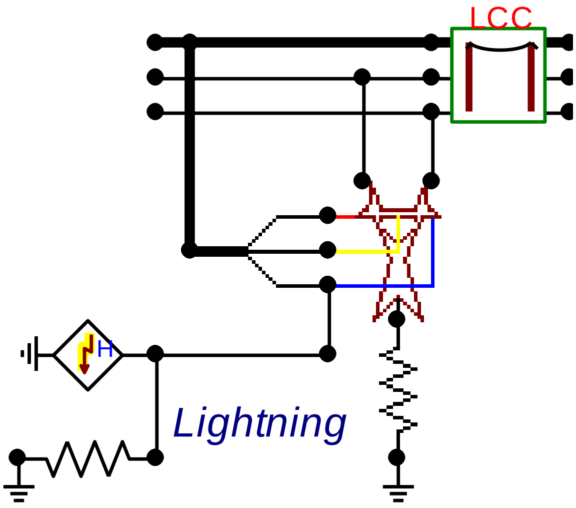
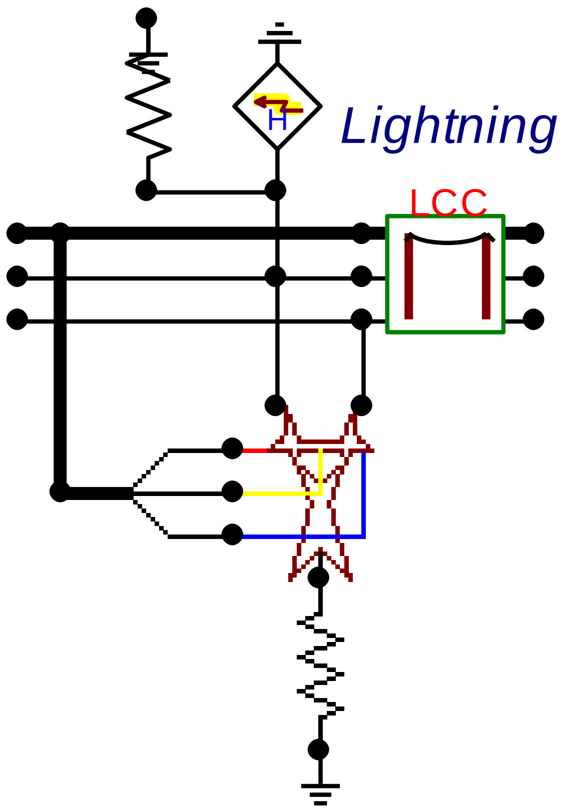


(a) IP_1



(b) IP_2

Figure 3 Impact points.

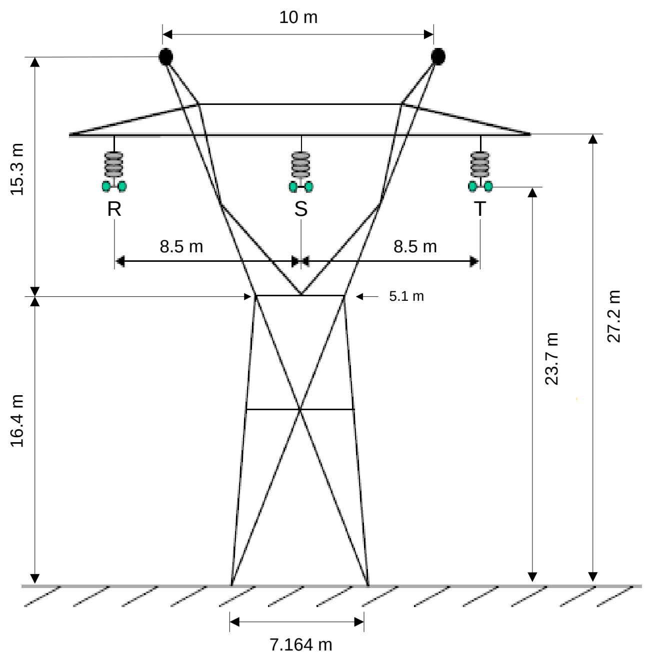


Figure 4 Transmission tower.

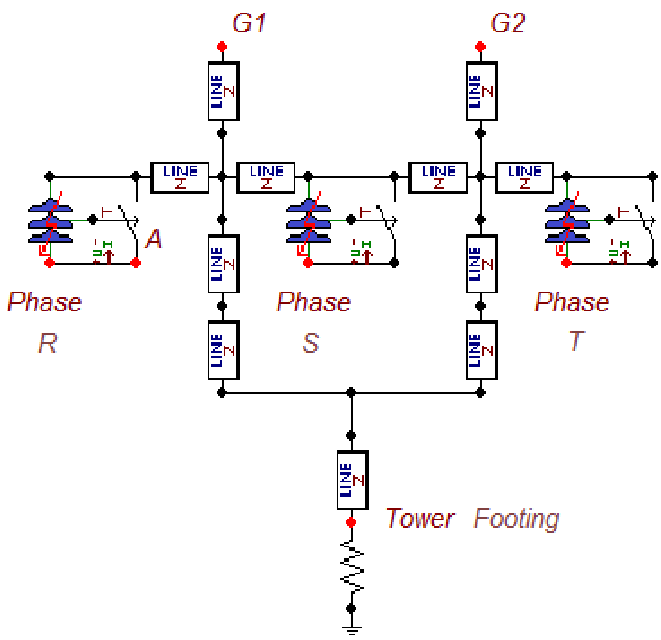


Figure 5 ATP model of transmission line tower.

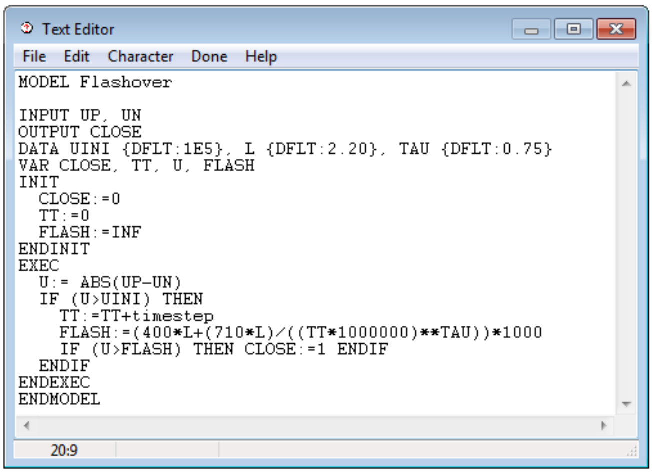


Figure 6 MODEL code.

4. Conclusions and contributions

Lightning studies and analyzes on EPS performance, especially on Transmission Lines are crucial for safe and reliable power supply. In this paper a novel methodology for simulation of lightning strikes is presented. The methodology uses an interface between MATLAB-ATP.

Large databases are necessary both for protection relays and for other topics as insulator coordination, thus the work developed in this paper is a useful tool for the lightning strike simulation on TLs. Their performance was tested varying the lightning impact point. Thus, data bases considering the transmission line total length are built.

As the main contribution of this work, it is related to the building databases for specific conditions, reducing the operation time that some cases can be unnecessary. Only adjusting specific features in the *input data*, systematic simulations can be automatically developed.

Due to the potential of the simulation methodology, this work can be employed to analyze other elements, where specific conditions must be considered.

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