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The Lightning Power Electromagnetic Simulator for Transient Overvoltages (LIGHT-PESTO) Code: An User-Friendly Interface With the MATLAB-Simulink Environment

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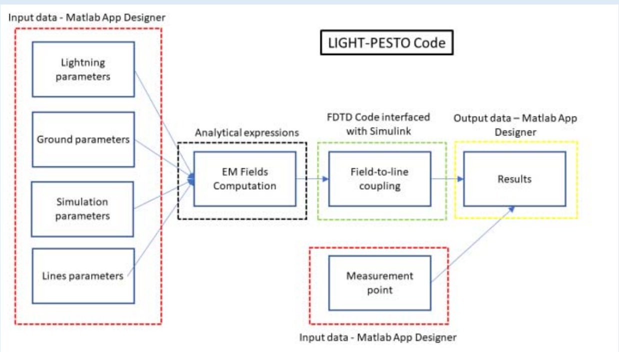
***Abstract*—The protection of power lines from lightning transients is a crucial issue that has involved the efforts of many researchers around the world. The need of relying on a precise method for the computation of the overvoltages waves travelling on the transmission lines is fundamental when the possible occurrence of flashovers has to be evaluated. The overvoltages behavior is directly related to the complexity of the power systems: as a consequence, a tool able to take into account this factor has a strong importance in the research framework. This letter presents the Lightning Power Electromagnetic Simulator for Transient Overvoltages (LIGHT-PESTO) code, which is based on an interface of a previous developed algorithm for the computation of lightning transients on a power line with the MATLAB-Simulink environment. The proposed interface allows the user to set in an easy and intuitive way the main parameters related to the lightning channel, to the overhead transmission lines, to the ground and to the surrounding power system.**

***Index Terms*—Lightning, power systems protection, numerical tools.**



Visual Summary

Take-Home Messages:
- Possibility of accounting for the complexity of a realistic distribution network
- Automatic distinguish between direct and indirect strikes
- What are the targeted EMC applications, in one sentence?
- User-friendly interface with Matlab-Simulink
- Complete description of the channel-base current
- Fast computation of lightning electromagnetic fields

I. INTRODUCTION

LIGHTNING transients can seriously affect the reliability of the transmission and distribution lines [1]. When we deal with them, two main causes of damage can be distinguished: direct lightning events (i.e., when the lightning directly hits the power system) and indirect lightning events (i.e., when the lightning hits the ground close to the power system). The first category, even if extremely dangerous, is less frequent, while the second one is much more common and represents the typical source of damage for power systems characterized by low voltage rating (such as distribution lines).

From the computational point of view, the effect of direct events can be easily computed placing a current source in parallel with the lightning channel impedance in the striking point, while the indirect ones requires the solution of the Maxwell's equations for the computation of the electromagnetic (EM) fields and the solution of the field-to-line coupling problem.

Despite the high number of possible solutions, based on analytical [2]–[6] or numerical approaches [7]–[10], if one needs to take into account the complexity of the power system, he has to rely on the numerical methods. Among them, the benchmark is represented by LIOV [7], [9], a numerical method based on the solution of the Agrawal's equations [11] through a second-order FDTD approach.

In [10], the authors proposed a numerical approach based on the Agrawal's coupling model interfaced with PSCAD-EMTDC able to: i) "*account for the complexity of a realistic distribution network*", ii) "*automatic distinguish between*

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indirect and direct strikes", iii) "*account for the power network pre-contingency conditions in a numerically efficient way*". Such approach has been validated in [12], [13].

The approach was initially based on the computation of the EM fields through the adoption of a database containing EM fields generated from a current with a specified time domain waveform with unitary peak at different distances. Such approach fails from a computational point of view when one aims at accounting for the front time effect because one database should be constructed for any considered front time value. For what concerns the Finite-Difference Time-Domain (FDTD) coupling model, the approach proposed in [10] was initially based on the update of the current at line extremities through the adoption of an extrapolation technique. According to [14], such approach can fail when the line length is comparable to the space step.

In this letter the authors present the updating of the code in [10]. The update involves: a) the implementation of analytical expressions for the lightning EM fields with any channel-base current and b) the implementation of the characteristic method for the update of the current at line extremities.

Moreover, in this letter the code is interfaced with the well-known MATLAB-Simulink environment. The interface has been developed using the MATLAB App Designer and allows the external user to easily set *i)* the lightning parameters, such as the channel-base current data, the channel height and the propagation speed, *ii)* the ground data (permittivity and conductivity) and *iii)* the power system parameters, with the possibility of considering multiple lines not only in parallel but connected through some discontinuities points.

This letter is organized as follows: Section II recalls the main assumptions and the main characteristics on which the code is based, Section III presents the graphical interface and finally Section IV is dedicated to the conclusions.

II. THE CODE

The first issue to be considered is the distinction between direct and indirect events. The code distinguishes among them according to the conventional electrogeometric model (EGM) [15]. If a direct event is detected, as previously recalled, it can be simulated basically with the injection in the striking point of a current source which can be represented by the channel-base current function in parallel with a suitable resistance accounting for the lightning channel. On the other hand, when an indirect event is detected the interaction of the lightning with the transmission line is much more complicated and is based on two separated phases: *A*) the EM fields computation and *B*) the field-to-line coupling based on the Agrawal's equations.

A. The EM Fields Computation

The field-to-line coupling equations need as input the knowledge of the radial and vertical electric field that illuminate the line.

As in [16] the computation of the EM fields are performed analytically with any channel-base current, using the TL model [17] for the return stroke channel model. Their computation requires as input the return stroke channel height, the return stroke velocity, the channel-base current waveform (including the peak value) and the characteristics of the soil (permittivity and conductivity). It is important to note that the soil dependence is taken into account with the so-called Cooray-Rubinstein approximation [18], [19].

The points at which the radial and vertical electric field must be evaluated to be inserted in the coupling equations are automatically determined from the knowledge of the line coordinates, line discretization and of the striking point. Due to the analytical solution provided the procedure is extremely fast and can be evaluated wherever the power system is placed.

B. The Field-to-Line Coupling

As proposed in [10], the field-to-line coupling is based on the second-order FDTD scheme of the Agrawal model. It receives as input the EM fields and provides as output the update of the voltages and of the currents in the internal points of the line.

Concerning the line terminations, as well as the discontinuities points, the update of the current cannot be achieved through the FDTD scheme since they represent the domain boundaries. As a consequence, differently from [10], their update is obtained through a scheme based on the characteristic method proposed in [14]. Such approach avoids numerical instability related to the possible low ratio between the space step and the line length without any reduction in the precision of the computation.

The spatial step and the time step are chosen according to the well-known Courant stability condition for second order FDTD schemes [10].

An important novelty of the proposed coupling scheme consists of the treatment of discontinuities/line terminations characterized by a very high impedance (such as the surge arresters in their first part of the $V-I$ characteristic). According to [10], if no solution is adopted, some numerical oscillations can appear. LIGHT-PESTO adopts the solution proposed in [10] where the device located at the point of interest is posed in parallel with an impedance and a current generator such that the total impedance viewed from the terminals is equivalent to the previous one, but avoiding the numerical oscillations (see [10] for details).

III. THE INTERFACE

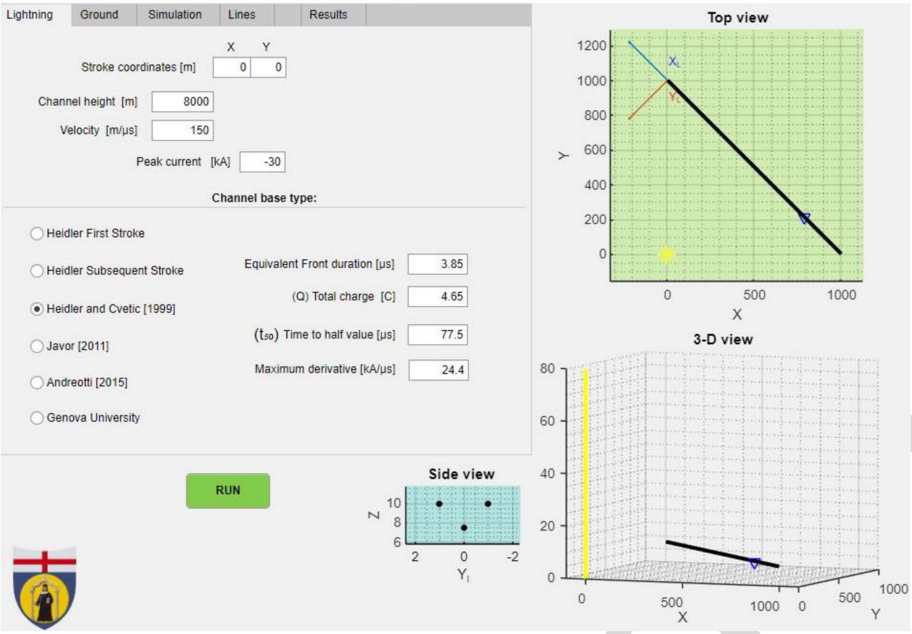
The interface with the MATLAB-Simulink environment has been obtained through the App Designer provided by Mathworks.

The graphical interface allows the user to set easily all the parameters of the lightning current, ground and lines.

Moreover, as shown in Fig. 1, the graphical interface provides the side view, the top view and the 3D view of the area where the line is located and where the stroke occurs.

A. Lightning Current Parameters

As shown in Fig. 2, the user can set the stroke coordinates, the channel height, the return stroke speed and the channel-base peak current.



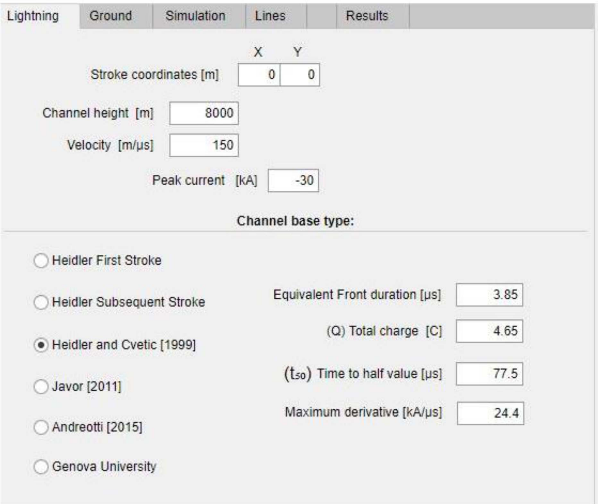
Stroke coordinates [m] X 0 Y 0
Channel height [m] 8000
Velocity [m/μs] 150
Peak current [kA] -30

Channel base type:

○ Heidler First Stroke
○ Heidler Subsequent Stroke
● Heidler and Cvetic [1999]
○ Javor [2011]
○ Andreotti [2015]
○ Genova University

Equivalent Front duration [μs] 3.85
(Q) Total charge [C] 4.65
(t_{50}) Time to half value [μs] 77.5
Maximum derivative [kA/μs] 24.4

Fig. 1. LIGHT-PESTO main view.



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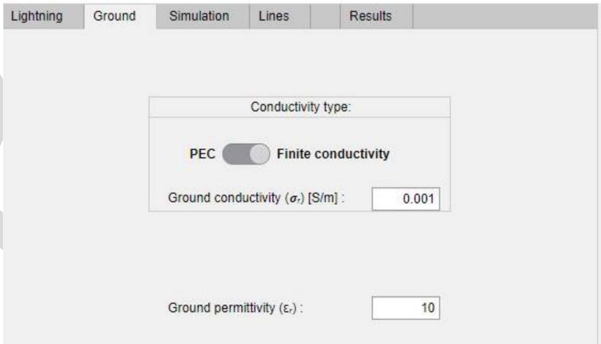
Maximum derivative [kA/μs] 24.4

Fig. 2. LIGHT-PESTO lightning parameters.

Moreover, six different channel-base models have been implemented for sake of completeness. Three of them are related to the well-known Heidler's model [20], while the other three refers to the ones proposed in [21]–[23]. Focusing on the Heidler's model, the user can set the typical first stroke waveform, the typical subsequent stroke waveform made by a sum of two Heidler's functions or a different Heidler's waveform evaluated from the main lightning parameters according to [24]. According to the corresponding papers, when we deal with the last four channel-base functions, it is possible to set the equivalent front duration ($\tau_{d30/90}$), the total charge, the time to half-value and the maximum derivative.

B. Ground Parameters

The ground can be assumed as a Perfect Electric Conductor (PEC) or it can have a finite ground conductivity and permittivity, assignable in the corresponding text boxes (Fig. 3).



Conductivity type:

PEC **Finite conductivity**

Ground conductivity (σ_r) [S/m] : 0.001

Ground permittivity (ε_r) : 10

Fig. 3. LIGHT-PESTO ground parameters.

C. Simulation Details

The duration of the simulation as well as the time step (*dt*) can be set in an independent way (Fig. 4). Consequently, the space step (*dx*) is automatically computed according to the Courant stability condition and to the characteristic method for the update of current at the line terminals [14]. The number of lines illuminated by the lightning stroke can be set in this input window.

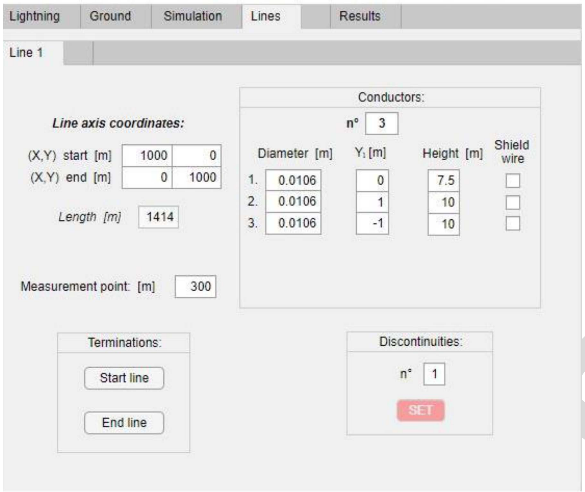
D. Lines Parameters

In this mask (Fig. 5), each line can be set independently according to its geometrical and electrical data. In particular, the user can define the coordinates of the line, the number of conductors, the diameter, the distance from the y-axis and the height. Moreover, a checkbox denotes if such conductor is a shield wire or not.

In addition to this, the user can decide where the voltage and current time-domain waveforms will be measured.

Duration (T) : [µs] 20
Time step (dt) : [ns] 10
Space step (dx) : [m] 9
Number of lines: 1

Fig. 4. LIGHT-PESTO simulation parameters.



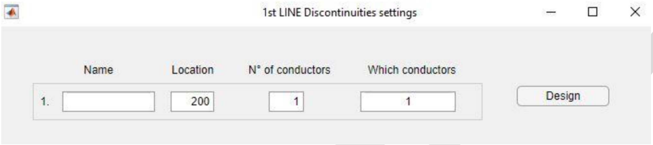
Line axis coordinates:
(X,Y) start [m] 1000 0
(X,Y) end [m] 0 1000
Length [m] 1414
Measurement point: [m] 300

Conductors:
n° 3

	Diameter [m]	Y_i [m]	Height [m]	Shield wire
1.	0.0106	0	7.5	☐
2.	0.0106	1	10	☐
3.	0.0106	-1	10	☐

Discontinuities: n° 1

Fig. 5. LIGHT-PESTO line parameters.



1st LINE Discontinuities settings

	Name	Location	N° of conductors	Which conductors
1.		200	1	1

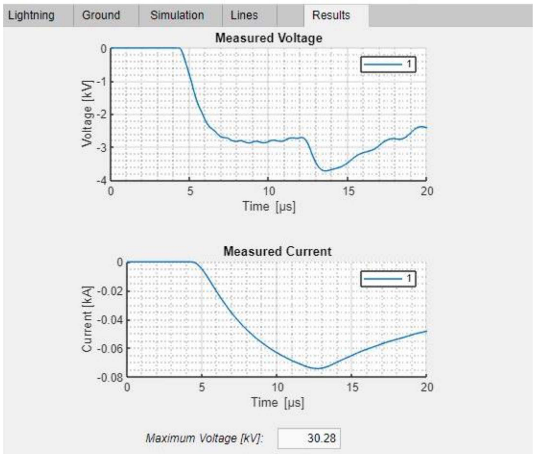
Fig. 6. LIGHT-PESTO discontinuities parameters.

The two buttons called “Start Line” and “End Line” open the Simulink interface where the user has the possibility to characterize the boundary conditions at the beginning and at the end of the line.

The possibility of considering discontinuities (Fig. 6) along the line (surge arresters, laterals, etc) is provided by inserting the desired number of them in the discontinuities mask. By opening the mask with the “Set” button, it is possible to define the location, the number of conductors and which of them are involved. As for the line terminations, in this window through the button “Design”, the user shall define the electrical circuit connected to the considered discontinuity.

E. Simulation and Results

The simulation can be easily launched by clicking on the “Run” button and the results appear in the corresponding window (Fig. 7).



Maximum Voltage [kV]: 30.28

Fig. 7. LIGHT-PESTO results.

For each line, the interface provides the voltage and the current time-domain waveforms calculated on each conductor in the desired point and the maximum voltage occurred on the line during all the simulation.

The computational time is strictly related to the hardware used for the simulations. However, on a Microsoft Windows 10 PC equipped with 16 GB of RAM and Intel Core i7-2600 CPU at 3.4 GHz, the required time to compute the effects of a single lightning stroke on the power system is about 3 seconds.

IV. CONCLUSION

This letter presents a new user-friendly interface between a numerical code and the MATLAB-Simulink environment for the computation of the lightning transients on a power system. The work focused on presenting the main characteristics and assumptions on which the numerical code is based and on the graphical interface provided to the external user, which allows him/her to easily set the lightning parameters, the ground parameters and the power system details. As a conclusion, the proposed interface can be useful when the protection of the electric infrastructures requires suitable and user-friendly instruments able to consider the complexity of the surrounding power system.

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