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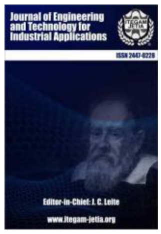

RESEARCH ARTICLE OPEN ACCESS

SIMULATION AND ANALYSIS OF LIGHTNING STRIKES IN ELECTRICAL SYSTEMS BY MATLAB/SIMULINK AND ATP/EMTP

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ABSTRACT

Lightning is a major disruptive phenomenon in the operation of all electrical installations. Lightning has always been a cause of disruption in the use of electricity. However, it is important to note the fairly recent and growing requirement for the quality of electrical systems (reliability, availability, continuity of service, etc.) as well as the constant concern to minimize the costs of using and producing electricity. This leads us to see that lightning becomes a hard point in improving all these factors. In this article, we present the ATP software that we will use in the simulation. After that, we discussed the description of lightning strikes and how to protect facilities from them. The next important step, which represents the novelty of this work, was to create a lightning strike model using the MATLAB/SIMULINK program, based on the mathematical equation of a lightning strike.
After that, by using the model created, we simulated a lightning strike that attacked two different nodes of an electrical network, generators, and nine nodes, using the two-simulation software's ATP/EMTP and MATLAB/SIMULINK to study the effect of the lightning strike on the voltages and currents of our network system. At the end of the work, we compared the results obtained by the two-simulation software, ATP/EMTP and MATLAB/SIMULINK, and we discussed and explained the results obtained by the two software.

I. INTRODUCTION

Lightning-induced overvoltage in electrical power net-works is one of the main causes of problems with the quality of power supplied to consumers and with electromagnetic compatibility [1],[2]. In recent years, due to the growing demand for better quality electrical power and the widespread use of sensitive electronic devices connected to distribution lines, protection against lightning-induced disturbances has become of paramount importance.

Therefore, the accurate assessment of lightning-induced over-voltages has become essential for the effective protection of electrical and electronic systems [2]. Thus, the idea of having tools that simplify the study, the analysis, and the simulation has been perceived for a long time, and computer software specialized in the study of the transitory regimes of electrical systems appeared to be used by electricity companies and by research centres specializing in the field of electrical networks [3],[4].

A simulator can therefore be developed to simulate not a single particular physical phenomenon but to study a vast quantity of phenomena that can be very different from each other [5],[6].

Lightning is a lightning bolt that falls to the ground. It is a frequent phenomenon that behaves like a perfect genera-tor of electric current. To protect yourself in 95% of cases, the current that should be taken into account is 100 kA with a very short rise time. In addition to the conduction phenomenon, the ionized channel of lightning behaves like a long wire that radiates an electromagnetic field. This field induces voltages in large ground loops, which are counted in kilovolts. These surges can destroy interface components. Lightning is therefore not a phenomenon to be feared only during a "hit on goal"; the effect induced by the field matters.

In this work, a lightning strike model will be created un-der the MATLAB/SIMULINK environment for use in simulation tests with an IEEE 9 node power grid.

In this article, we simulate a lightning strike that attacks two different nodes in an electrical network with three generators and nine nodes. The lightning strike was created with the MATLAB/SIMULINK software, and the lightning strike exists in the ATP library with the ATP software to have their impact on the voltages and currents of this network [7].

II. PRESENTATION OF SOFTWARE'S

II.1 ALTERNATIVE TRANSIENT PROGRAM (ATP)

ATP is a universal program system for digital simulation of transient phenomena [8],[9] of electromagnetic as well as electromechanical nature. With this digital program, com-plex networks and control systems of arbitrary structure can be simulated.

ATP has extensive modelling capabilities and additional important features besides the computation of transients. It has been continuously developed through international contributions over the past 20 years [10],[11].

The ATP program can model almost anything that exists in the network. However, users can still create the various elements themselves thanks to additional modules and pro-grams such as for example, TACS (Transient Analysis of Control Systems) or MODELS (simulation language), which allow the modelling of control systems or non-linear characteristics [12].

III. LIGHTNING STRIKE THEORY

III.1 DEFINITIONS

Lightning is a manifestation of electricity of atmospheric origin, comprising an electric discharge accompanied by a bright light (lightning) and a violent detonation (thunder). Lightning is a set of luminous manifestations caused by discharges of atmospheric origin [13],[14].

Fundamental thunderstorms are, for the meteorologist, linked to cumulonimbus clouds. The stormy mechanism consists of a succession of very rapid lifts, causing the formation of cumulonimbus clouds and determining two series of parallel but distinct effects; Electrical phenomena include lightning, which does not always exist, and electromagnetic disturbances, which always exist. Mechanical and rainfall phenomena include gusts of wind and showers.

III.2 CLASSIFICATION OF LIGHTNING STRIKES

The asperities of the ground or structures create a "point effect", which greatly amplifies the local electric field. This increase in the electric field results in a "Corona" effect - local ionization of the air. An ionized air channel linking the cloud to the ground allows the flow of the lightning strike. There are four characteristic types of lightning strikes: negative, positive, descending and ascending. In France, 90% of lightning strikes are descending negative. The amplitude of the current can be very strong, varying from 2000 to 200000 amperes [15].

III.3 PRIMARY PROTECTIONS

Their purpose is to protect installations against direct lightning strikes. These protections make it possible to capture and route the lightning current to the ground. The principle is based on a protection zone determined by a structure higher than the others. It is the same for any peak effect caused by a pole a building, or a very tall metallic structure.

- There are three main types of primary protection [16],[17].
- The lightning rod, which is the oldest and best-known protection.
- Stretched wires.
- The mesh cage, or Faraday cage

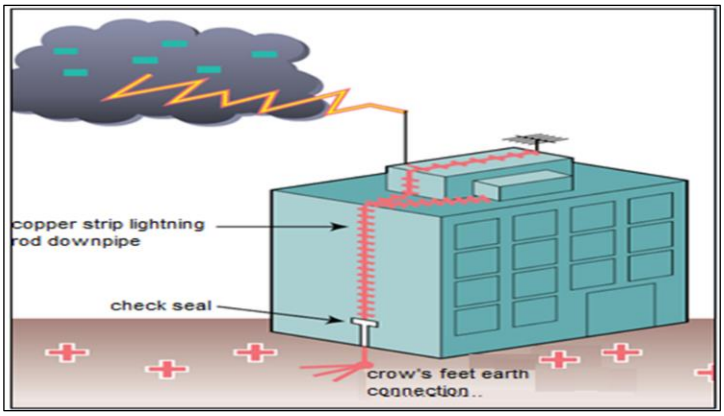

Figure 1: Principle of the rod lightning rod.
Source: Authors, (2024).

III.3.1 THE TAUT THREADS

These are cables stretched above the work to be protect-ed. They are used for special works include rocket launch pads, military applications and above all ground wires above high voltage lines [18].

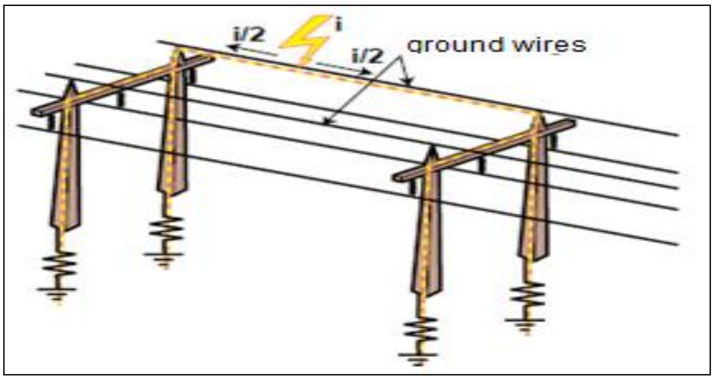

Figure 2: Ground Wires.
Source: Authors, (2024).

III.3.2 The Mesh Cage (Faraday Cage)

This principle is used for very sensitive buildings housing computer equipment or the manufacture of integrated circuits. It consists of multiplying the descent strips outside the building in a symmetrical manner. Horizontal links are added if the building is tall; for example, every two floors (Figure 3). The down conductors are earthed by the crow's feet. The result is to obtain meshes of 15 x 15 m or 10 x 10m.

The effect results in a better bedded equipotential of the building and the division of the lightning currents, thus strongly reducing the electromagnetic fields and inductions [19],[20].

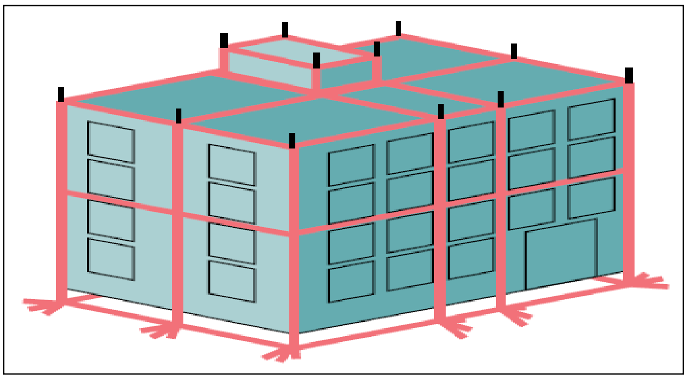

Figure 3: Principle of a mesh cage (Faraday cage).
Source: Authors, (2024).

III.4 SECONDARY PROTECTIONS

The protection of electrical loads against overvoltages of atmospheric origin most commonly used is protection by lightning arresters [21],[22]. The arrester is generally placed between a conductor and the ground, and sometimes between active conductors. The two cases are represented in Figure 4. Under normal tension, the surge arrester behaves practically like an infinite resistance, and the current that crosses it is null or negligible (leakage current). On the other hand, on the appearance of an overvoltage, as soon as the voltage at the terminals of the surge arrester exceeds a certain limit, the surge arrester becomes conductive, letting a current flow, which limits the voltage at its terminals and thus protects the installation and receivers. For each use case, the arrester is chosen mainly according to the following parameters:

- The overvoltage permitted by the devices to be protected.
- The intensity of the current that the surge arrester will have to withstand for the duration of the overvoltage.

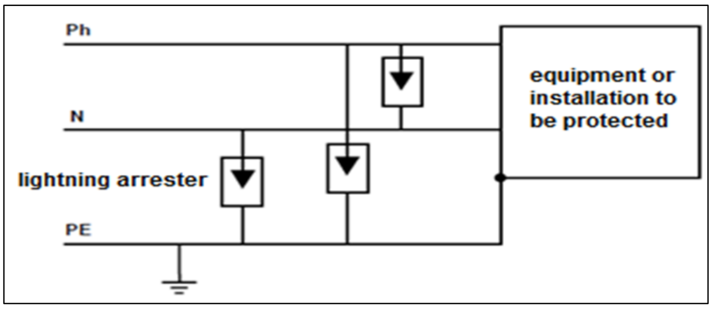

Figure 4: Use of Lightning Arresters.
Source: Authors, (2024).

IV. LIGHTNING MODEL

The lightning strike is represented by the following mathematical equation [23],[24].

$$f(t) = Amplitude(e^{At} - e^{Bt}) \quad (1)$$

So that each of the amplitude, A and B, are represented in the following Table 1.

Table 1: Lightning Parameters.

Lightning Parameters	
Constant	Value
A	-9500
B	-600000
Amplitude	34000
Tstart	0.00
Tstop	0.0006

Source: Authors, (2024).

If we click on the lightning strikes block, illustrated in Figure 5, we obtain the following figure:

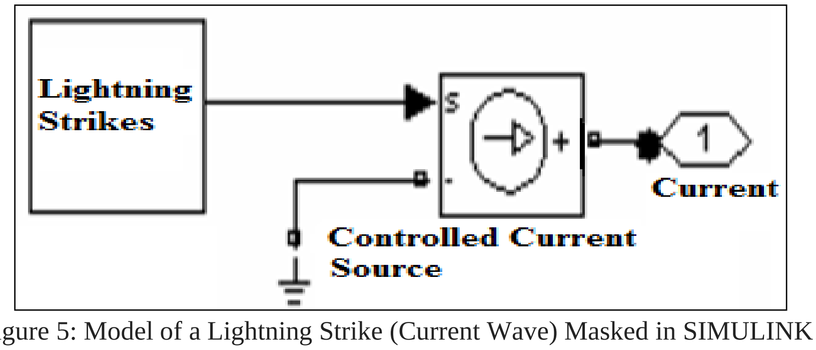

Figure 5: Model of a Lightning Strike (Current Wave) Masked in SIMULINK.
Source: Authors, (2024).

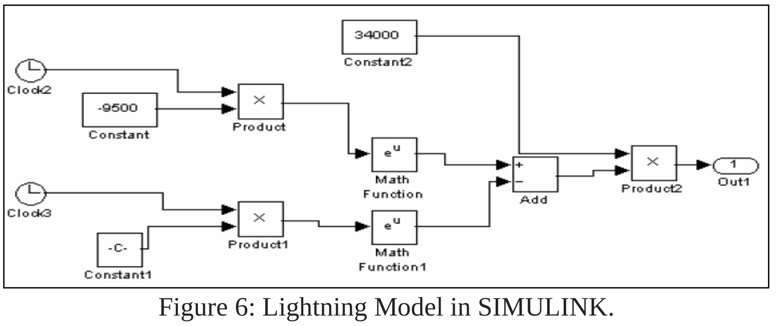

Figure 6: Lightning Model in SIMULINK.
Source: Authors, (2024).

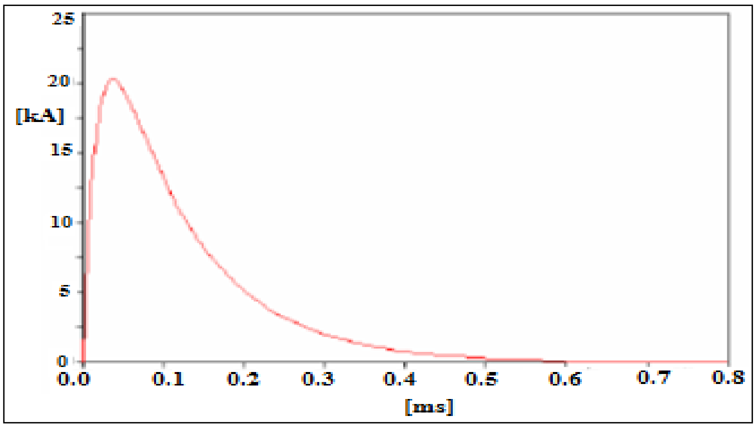

Figure 7: Lightning Strike Wave Current 20KA 0.6ms.
Source: Authors, (2024).

V. TEST NETWORK

A 9-bus 3-machine system [25], includes three generators and three large equivalent loads connected in a meshed transmission network through transmission Lines, as shown in Figure 8.

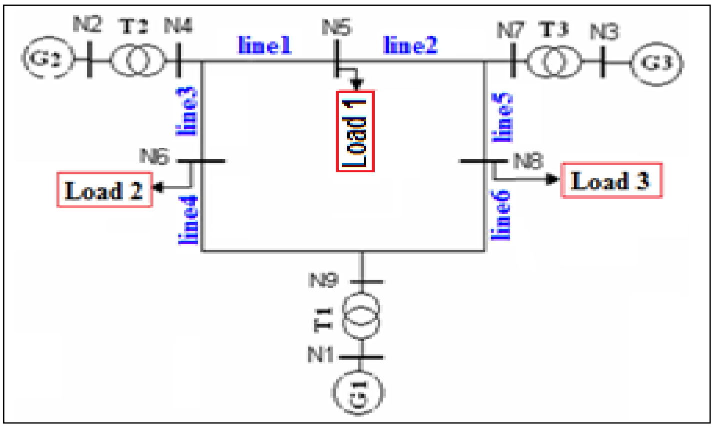

Figure 8: Synoptic Diagram of the WSCC Network (3G, 9N).
Source: Authors, (2024).

VI. APPLICATIONS EXAMPLES

VI.1 EXAMPLE 1: SIMULATION OF LIGHTNING STRIKE AT NODE 4

VI.1.1 With Atp

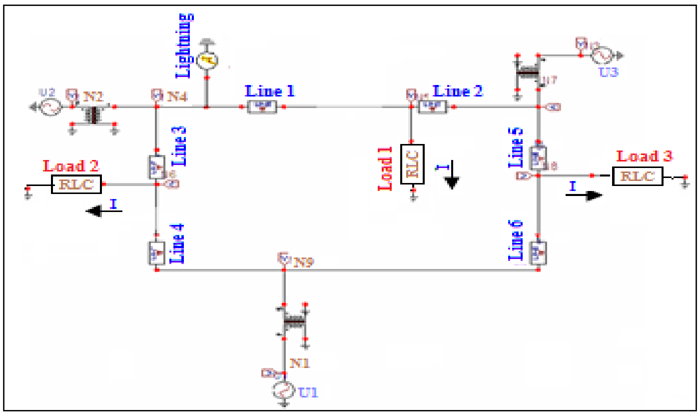

Figure 9: Simulation of lightning strike at node 4 with ATP.
Source: Authors, (2024).

VI.1.2 With Matlab/Simulink

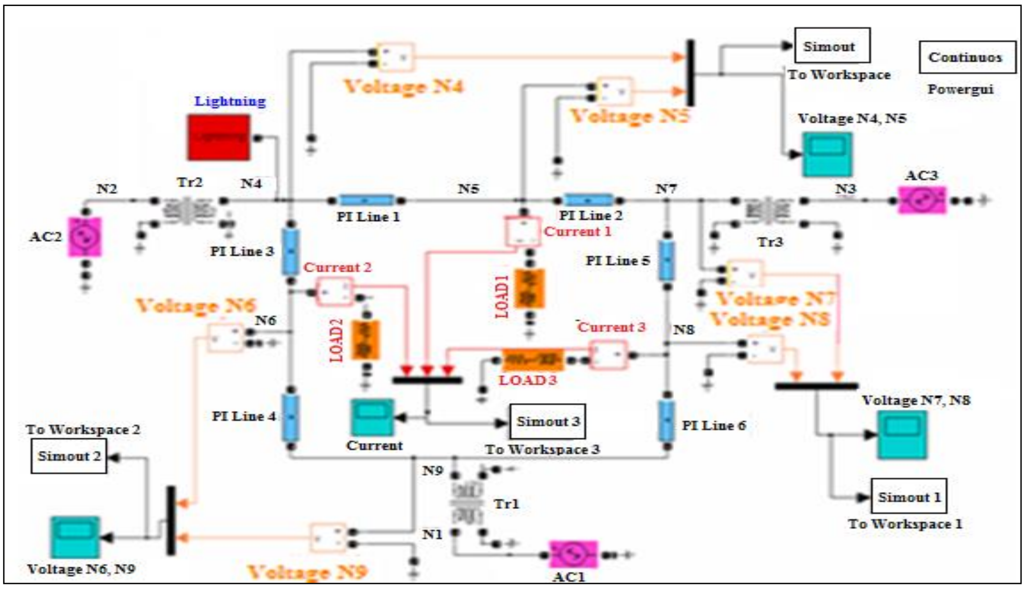

Figure 10: Simulation of lightning strike at node 4 with SIMULINK.
Source: Authors, (2024).

VI.2 EXAMPLE 2: Simulation of Lightning Strike at Node 5

VI.2.1 With Atp

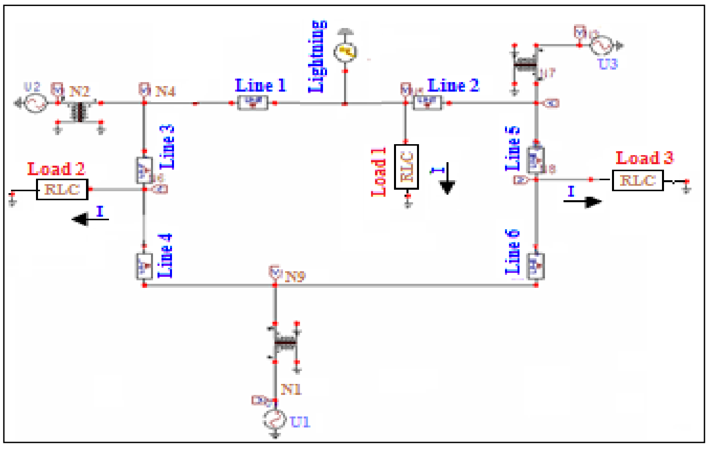

Figure 11: Simulation of lightning strike at node 5 with ATP.
Source: Authors, (2024).

VI.2.2 With Matlab/Simulink

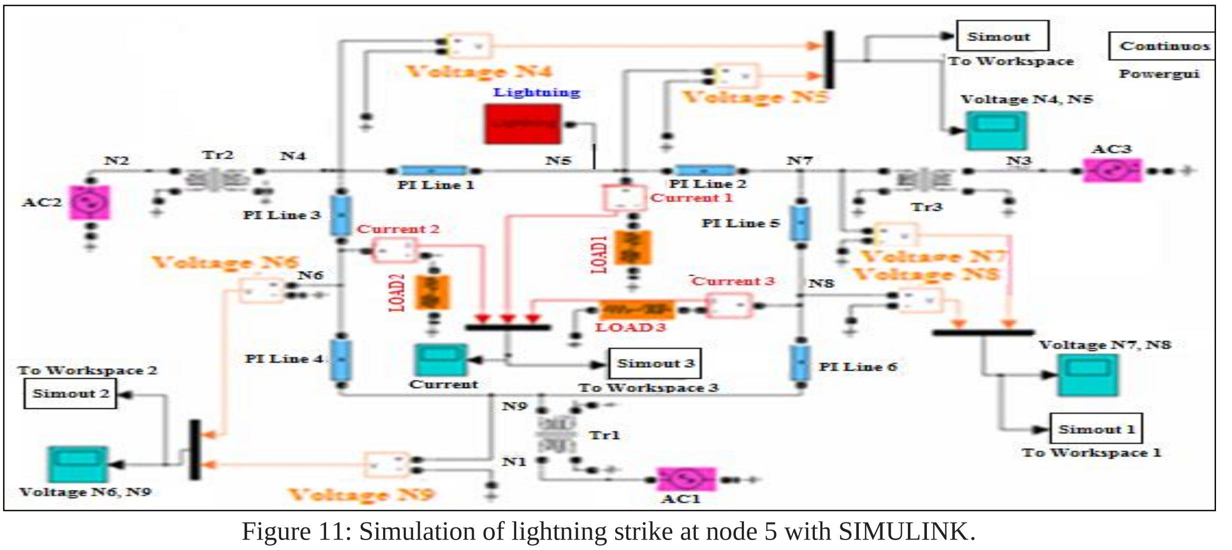

Figure 11: Simulation of lightning strike at node 5 with SIMULINK.
Source: Authors, (2024).

VII. SIMULATION RESULTS

VII.1. EXAMPLE 1

VII.1.1. With Atp

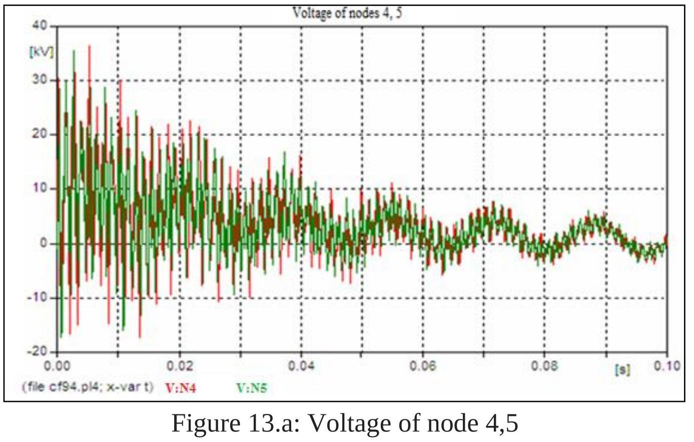

Figure 13.a: Voltage of node 4,5

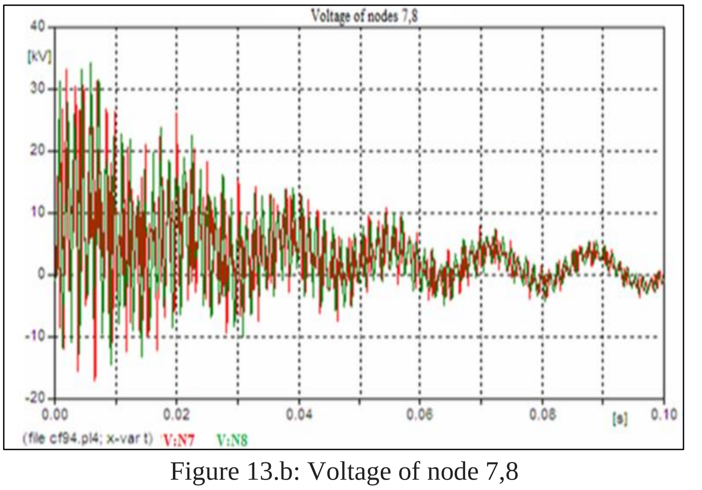

Figure 13.b: Voltage of node 7,8

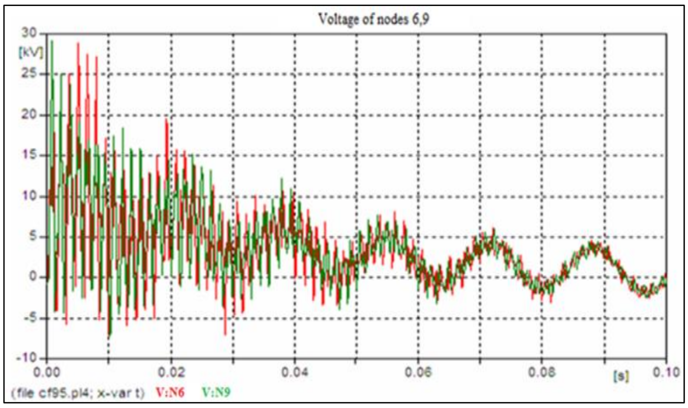

Figure 13.c: Voltage of node 6,9
Figure 13: (a, b, c) Voltage Curve of Example 1
Source: Authors, (2024).

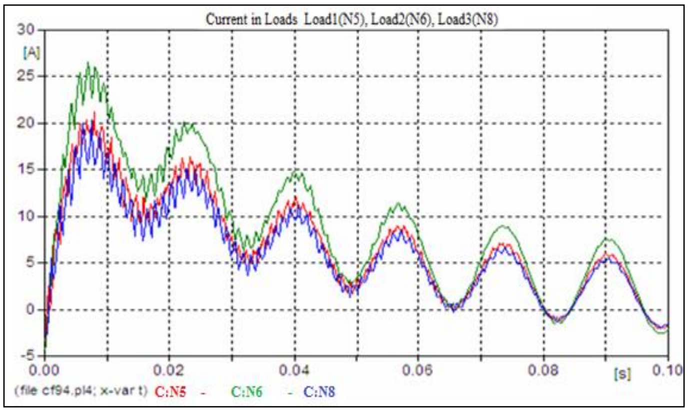

Figure 14: Current Curve of Example 1
Source: Authors, (2024).

VII.1.2. With Matlab

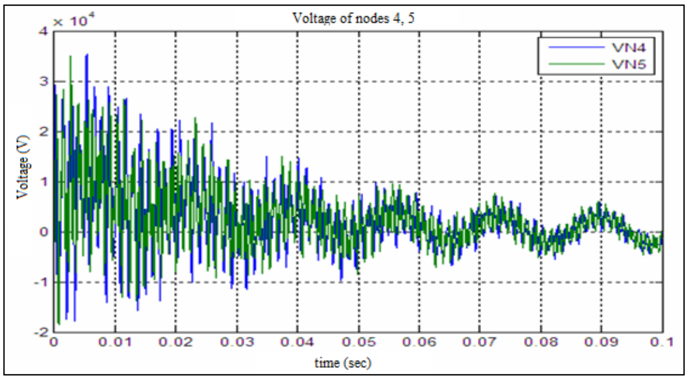

Figure 15.a: Voltage of node 4,5

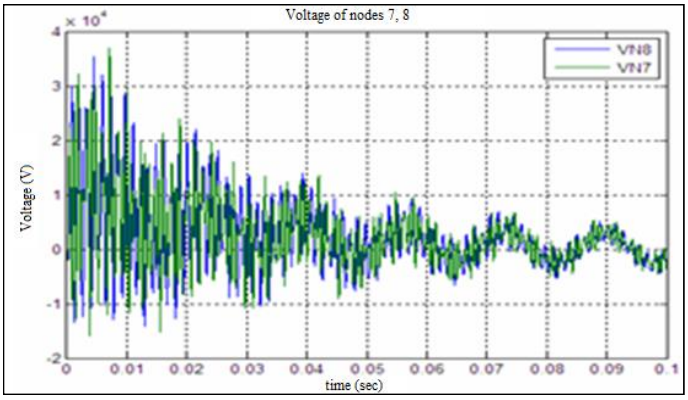

Figure 15.b: Voltage of node 7,8

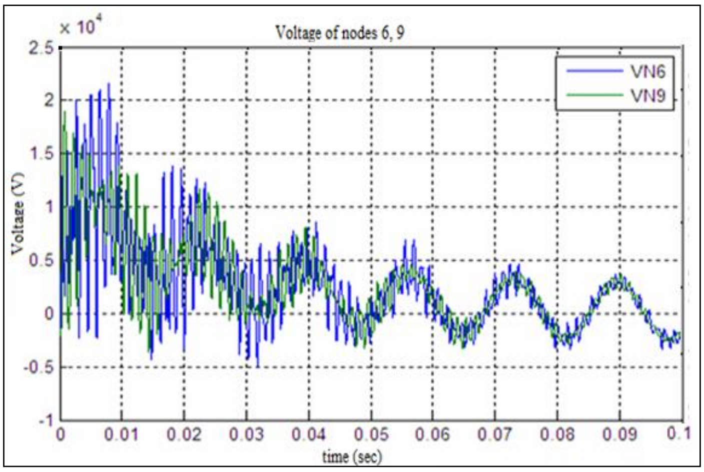

Figure 15.c: Voltage of node 6,9
Figure 15: (a, b, c) Voltage Curve of Example 1
Source: Authors, (2024).

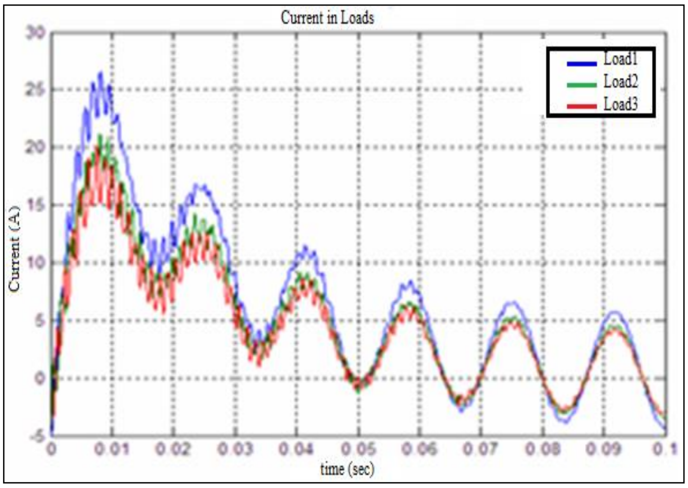

Figure 16: Current Curve of Example 1
Source: Authors, (2024).

VII.1.3. Interpretation

For example, 1, a lightning strike hits node 4 of the 9N-3G network. The voltages of nodes 4 and 5, VN4, VN5 then reach peaks between -20kV and 40kV, before decreasing at the end of the cycle to around 3.5kV. The voltages VN7, VN8 of nodes 7 and 8 respectively reach -20kV and 40kV at the start of the fault then oscillate to reach 3.5kV at the end of the cycle. At nodes 6 and 9 have voltages VN6, VN9, for their part, reach peaks of - 5kV and 25kV to stabilize around 2 kV at the end of the cycle.

We noticed that the voltage peaks did not reach very large values compared to the previous example because the reactance's of the lines in this example have slightly smaller values.

The currents of loads 1 and 3 show peaks that reach 20A, then decrease and stabilize towards the end of the second cycle around their initial values.

The current of load 2 has a peak that reaches 25A, then decreases and stabilizes towards the end of the second cycle around its initial value. We notice that the load current increases in this example by 5 and 6 times the nominal value due to the lightning strike, and it takes a time of 0.16sec (10 periods) to return to its normal value.

We note in this example that the results obtained under ATP software are quite similar to the results obtained under MATLAB/SIMULINK.

VII.2. Example 2

VII.2.1. With Atp

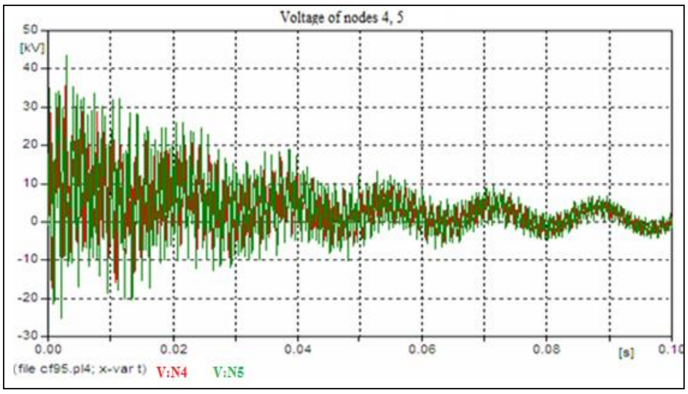

Figure 17.a: Voltage of node 4,5

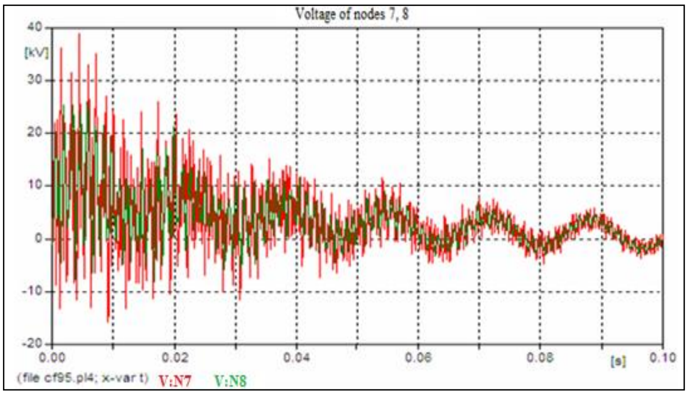

Figure 17.b: Voltage of node 7,8

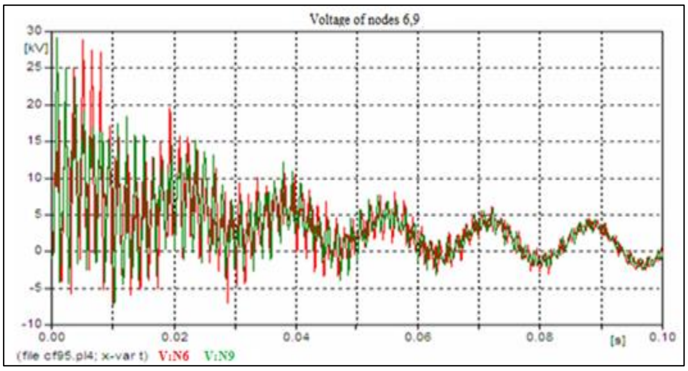

Figure 17.c: Voltage of node 6,9
Figure 17: (a, b, c) Voltage Curve of Example 2
Source: Authors, (2024).

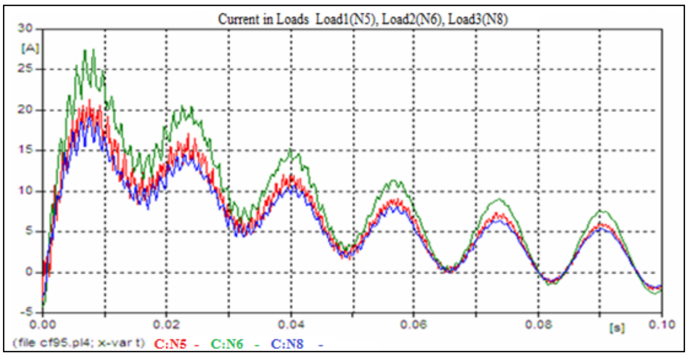

Figure 18: Current Curve of Example 2
Source: Authors, (2024).

VII.2.2. With Matlab

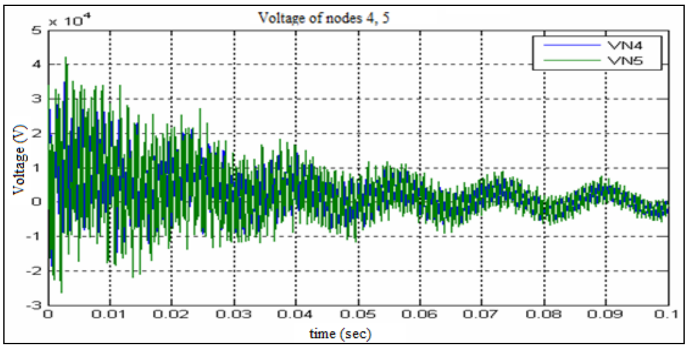

Figure 19.a: Voltage of node 4,5

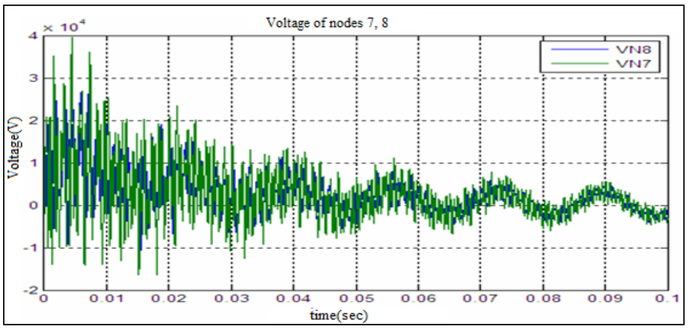

Figure 19.b: Voltage of node 7,8

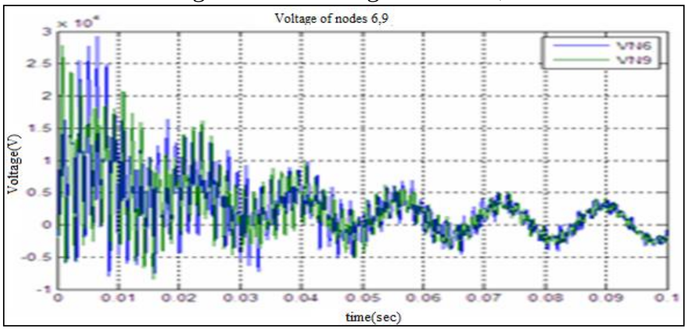

Figure 19.c: Voltage of node 6,9
Figure 19: (a, b, c) Voltage Curve of Example 2
Source: Authors, (2024).

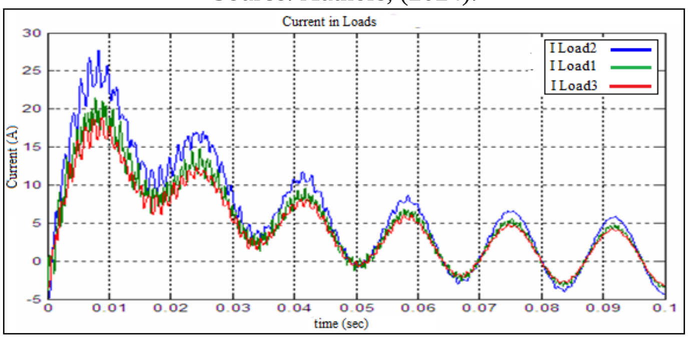

Figure 20: Current Curve of Example 2
Source: Authors, (2024).

VII.2.3. Interpretation

For example, 2, a lightning strike hits node 5 of the 9N-3G network. The voltages of nodes 4 and 5, VN4, VN5then reach peaks between -30kV and 50kV, before decreasing at the end of the cycle to around 4kV. The voltages VN7, VN8 of nodes 7 and 8 respectively reach -20kV and 40kV at the start of the fault, then oscillate to reach 3.5kV at the end of the cycle. At nodes 6 and 9 have voltages VN6, VN9, for their part, reach peaks of -10kV and 30kV to stabilize around 2.5kV at the end of the cycle.

We notice that the voltage peaks did not reach very large values compared to the previous example because the reactance of the lines in this example have slightly smaller values.

The currents of load 1 and load 3 show peaks that reach 20A, then decrease and stabilize towards the end of the second cycle around their initial values. The current of load 2 has a peak that reaches 25A, then decreases and stabilizes towards the end of the second cycle around its initial value.

We notice that the load current increases in this example by 5 and 6 times the nominal value due to the lightning strike, and it takes a time of 0.16sec (10 periods) to return to its normal value. We note in this example that the results obtained under ATP software are quite similar to the results obtained under MATLAB/SIMULINK.

VIII. INTERPRETATION

This work focused on the use of MATLAB/ SIMULINK and ATP software for the simulation of lightning strikes in electrical networks, the impact of lightning strikes on the behaviour of an electrical network, and on the other hand, a comparison between the results obtained from the two simulation Programs, MATLAB/SIMULINK and ATP.

In this work, a lightning strike model will be created in the MATLAB/SIMULINK environment for use in simulation tests with an IEEE 9-bus power grid.

Our work consisted in simulating lightning faults at different points of the IEEE 9bus network by using ATP/EMTP and MATLAB/SIMULINK simulation software to study and analyse the results and curves obtained by each simulation program so that they could be interpreted and compared.

I note that whatever the point of the lightning strike in the electrical network, the voltages and currents are severely affected and reach significant values, up to ten times the real value of the voltage or the intensity of the electric cur-rent.

We can say that the lightning strike is a very severe short-circuit; therefore, it is necessary to protect the electrical networks as much as possible from these lightning strikes.

The results obtained by the MATLAB/SIMULINK pro-gram were thus tested on the same examples and gave complete satisfaction for the simulations carried out by the ATP software, which confirms the relevance of the work.

IX. AUTHOR'S CONTRIBUTION

Conceptualization: Mohamed. Elbar, Aissa Souli, Abdelkader Beladel and Mohamed Khaleel.
Methodology: Mohamed. Elbar, Aissa Souli, Abdelkader Beladel and Mohamed Khaleel.
Investigation: Mohamed. Elbar, Aissa Souli, Abdelkader Beladel and Mohamed Khaleel.
Discussion of results: Mohamed. Elbar, Aissa Souli, Abdelkader Beladel and Mohamed Khaleel.
Writing – Original Draft: Mohamed. Elbar, Aissa Souli, Abdelkader Beladel and Mohamed Khaleel.
Writing – Review and Editing: Mohamed. Elbar, Aissa Souli, Abdelkader Beladel and Mohamed Khaleel.
Resources: Mohamed. Elbar, Aissa souli.
Supervision: Mohamed. Elbar, Aissa Souli, Abdelkader Beladel and Mohamed Khaleel.
Approval of the final Mohamed. Elbar, Aissa Souli, Abdelkader Beladel and Mohamed Khaleel.

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