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Influence of the lightning arrester position on protection of the 220KV Overhead transmission line

***Abstract**.Overhead transmission lines are often the site of direct or indirect lightning strikes, the protection by reliable and sensitive elements to these waves is indispensable in the reversal of these lines. In this paper the protection by lightning arresters based on Zink Metal Oxide has been studied, the ATPdraw software (Alternative Transient Program) has been used to simulate the overhead transmission lines, towers , voltage sources and protection elements. A succession of three lightning strikes has been applied to the 220KV line of El Hassi line located in the north east of Algeria in the wilaya of Setif, the results have been presented and discussed.*

***Streszczenie:** Napowietrzne linie przesyłowe są często miejscem bezpośrednich lub pośrednich uderzeń piorunów, ochrona przez niezawodne i czułe na te fale elementy jest niezbędna przy odwracaniu tych linii. W niniejszej pracy badano ochronę za pomocą odgromników opartych na tlenku metalu Zink, do symulacji napowietrznych linii przesyłowych, wież, źródeł napięcia i elementów ochrony wykorzystano program ATPdraw (Alternative Transient Program). Trzykrotne uderzenie pioruna zostało zastosowane do linii 220 kV w linii El Hassi zlokalizowanej w północno-wschodniej części Algierii, w wilajacie Setif, wyniki zostały przedstawione i omówione. (**Wpływ położenia odgromnika na ochronę napowietrznej linii przesyłowej 220KV**)*

Keywords: Lightning strike, Metal oxide surge arrester, Overhead transmission line, ATPDraw software.
Słowa kluczowe: Uderzenie pioruna, ogranicznik przepięć z tlenków metali, napowietrzna linia przesyłowa, oprogramowanie ATPDraw

Introduction

In recent years the quality of energy is the great concern of consumers especially with these climatic changes that do not cease to cause damage to property and people, the number of direct or indirect lightning strikes have known a remarkable growth in recent times. A total of 2,409,799,364 atmospheric electrical discharges were recorded worldwide in 2021. This number includes cloud-to-cloud lightning and cloud-to-ground discharges, among others.

In the case of overhead transmission lines, when a lightning strike comes into contact with the line to produce dangerous surges to equipment. This is because the "induced voltages" caused by the collapse of the electrostatic field during a lightning strike in the vicinity can reach values up to 300 kV [1]. Atmospheric electrical discharges are natural phenomena in which millions of volts and thousands of amperes of current strike the stratosphere or the ground where conductive or electrical equipment is located.[2] The protection of high voltage lines is still the objective of recent research work, in reference [3] the authors presente the initiation and breakdown in biodegradable dielectric liquids at the lightning pulse voltage. Researchers In reference [4] have given an analysis of lightning surges on high voltage overhead power lines, simulation studies were performed to determine the relevant factors affecting the level of surges expected in high voltage overhead power lines. several researchers have invested in the modeling of surge arresters by different software, comparative and descriptive studies of these models have been presented. In [5] a three-dimensional finite element modeling was used to simulate the Metal Oxide arrester, ZnO, The physical parameters of an arrester that influence the leakage current under different conditions of the arrester have been identified from the model. Authors of reference [6] evaluated the effects of the half-value time of the lightning current, the phase angle of the operating voltage and the ground resistance at the frequency of the power system of the towers. in [7] the two most used surge arrester models in numerical simulations with the Alternative Transients Program, the conventional and IEEE models have been studied and simulated and compared. İn reference [8] author defines the purpose and types of surge arresters and their installation location in a high voltage network.

Simulation models

Surge arresters Models

In general, there are three models of lightning arresters most commonly used in the literature, we mention the IEEE model proposed by The IEEE WG 3.4.11 group [9] shown in figure

(1), Pinceti model has been proposed by Pinceti-Gianettoni [10] shown in figure (2) and finally Fernandez-Diaz model [11] shown in figure (3).

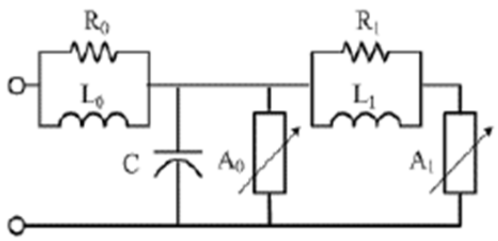

Fig. 1 IEEE Model

With: L1 =15d/n[µH], R1= 65d/n[Ω]; L0=0.2d/n[µH], R0= 100d/n[Ω]; C=100nd[pF] .
Where: d is the estimated height of the arrester in meter, n is the number of parallel columns of MO in the arrester.

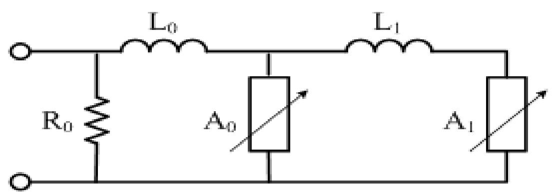

Fig 2. Pinceti Model

$$(1)\quad L_1 = \frac{1}{4}\,\frac{U_{r1/T2} - U_{r8/T2}}{U_{r8/T2}}\,U_r \quad [\mu H]$$

$$(2)\quad L_0 = \frac{1}{12}\,\frac{U_{r1/T2} - U_{r8/T2}}{U_{r8/T2}}\,U_r \quad [\mu H]$$

Ur is the rated voltage, $U_{r1/T2}$ is the residual voltage at 10 kA, fast front current surge ($1/T_2$ μs), $U_{r8/20}$ is the residual voltage at 10 kA, current surge with 8/20 μs shape, R_0 = 1 MΩ is introduced to avoid numerical instabilities.

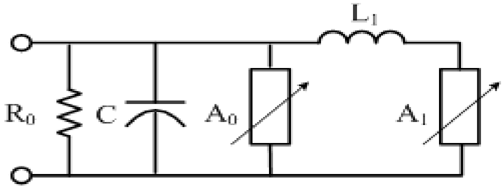

Fig 3. Fernandez-Diaz model

$$(3)\quad L_1 = \frac{2}{5}\,\frac{U_{r1/T2} - U_{ss}}{U_{r8/T2}}\,U_r \quad [\mu H]$$

$$(4)\quad C = \frac{1}{55}\,\frac{U_{r1/T2} - U_{ss}}{U_{r8/T2}}\,U_r \quad [pF]$$

Ur is the rated voltage, $U_{r8/20}$ is the residual voltage at 10 kA, current surge with 8/20 μs shape in kV, Uss is the residual voltage at 500 A, current surge switching 60/2000 μs, or 30/70 μs in kV, R0 = 1 MΩ.

Lightning Source model

Lightning is a very strong electrical stress that can reach 200 kA in a few microseconds and has extremely high frequencies [12]. The lightning-strike concept is represented by a current source with parallel resistance in the EMTP/ATP software. Lightning-path impedance is the parallel resistance. The Heidler current model was utilized in this study, and it takes into account four features of lightning current amounts at the striking point.

The EMTP/ATP software has a very rich library, it gives the possibility to introduce the characteristic values of lightning such as the rise time, the peak of the lightning current, the fall time and the pulse duration [13-14]. It is represented by a current source in parallel with a resistor representing the lightning channel (about 400 Ω) or even a voltage source, both types of sources having an exponential shape. In this study, the lightning strike is represented by a voltage source of exponential form based on the Heidler model. It is represented in figure 4 [15].

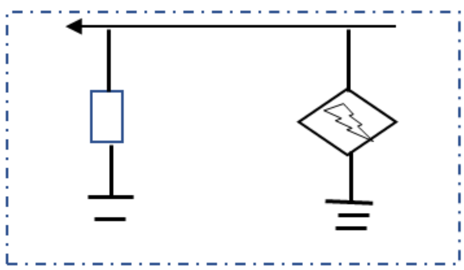

Fig 4. Heidler type Model

Surge arrester model in ATPDraw software

The surge arrester used is a metal oxide surge arrester (MOSA) . It is a type of resistor with non-linear voltage-ampere characteristics, with resistance characteristics. These surge arresters have high resistance, which means that they allow a small amount of current to flow through them when the voltage applied across them is below the threshold voltage. When the voltage applied across them is lower than the threshold voltage, and when the voltage is increased, they allow a high current to flow through them. They have a very low resistance, which reduces the voltage in the circuit and protects them. This ensures that there is not much voltage fluctuation in the main circuit. [16]

Metal Oxide surge arrester MOSA is modeled by MOV-Type 92 component [17-18]. the ATPDraw model is given on figure 5.

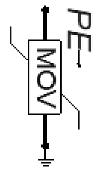

Fig 5. Surge arrester model in ATPdraw software.

Simulation models of different components of the transmission line

The line comprises the following elements: towers, earthing resistance, insulators, sections of the overhead line, ground wire and the lightning current channel.

The characteristic Tower overvoltage impedance is given by:

$$(5)\quad Z_T = 60\left[ln\left(\sqrt{2}\,\frac{2h}{r_x}\right) - 1\right]$$

rx: Tower base radius [m].

h: Tower height [m].

The tower earthing system can be modeled as a non-linear resistance, the CIGRE [19] model is used, which is modeled as a non-linear resistance of Type-91 in EMTP / ATP :

$$(6)\quad R_T(\mathrm{I}) = \frac{\mathrm{R_0}}{\sqrt{1+\frac{\mathrm{I}}{\mathrm{Ig}}}}$$

R_0= Tower footing resistance at low current and low

R_T = Tower footing resistance [Ω].

Ig = the limiting current to initiate sufficient soil ionization [A]

I = the lightning current through the footing impedance [A].

The limiting current is a function of soil ionization is given by:

$$(7)\quad \mathrm{Ig} = \frac{1}{2\pi}\,\frac{\mathrm{E_0 \rho}}{\mathrm{R_0^2}}$$

$\rho\ [\Omega.\mathrm{m}]$ is the soil resistivity;

$\mathrm{E_0}\left[\frac{\mathrm{kV}}{\mathrm{m}}\right]$: is the soil critical electric field intensity (approximately 300 kV/m.

For the isolator, the CIGRE [20] model was used and modeled by a capacitance connected in parallel with a model which represents the overflow mechanism of the insulator. The latter is represented by a switch controlled through models, by the implementation of the equations.

$$(8)\quad dL/dt = k_3 V[V/(D-L) - E_0]$$

Where:

Ʋ=dL/dt : is the speed of the arc (m / s)

k_3 : is a constante, ($m^2\ kV^2\ s^{-1}$)

V (kV) : is the instantaneous voltage across the insolator or the gap.

D (m): is the length of the insulator or the length of the gap.

L(m) : is the length of the arc, L≥D

E_0 (kV / m) is the strength of the critical electric field.

Power system description

The electrical network chosen for this study is a high voltage network El Hassi located in the north-east of Algeria in the wilaya of Setif with a voltage of 220 KV, the line is divided into a number of identical sections as shown in figure 6.

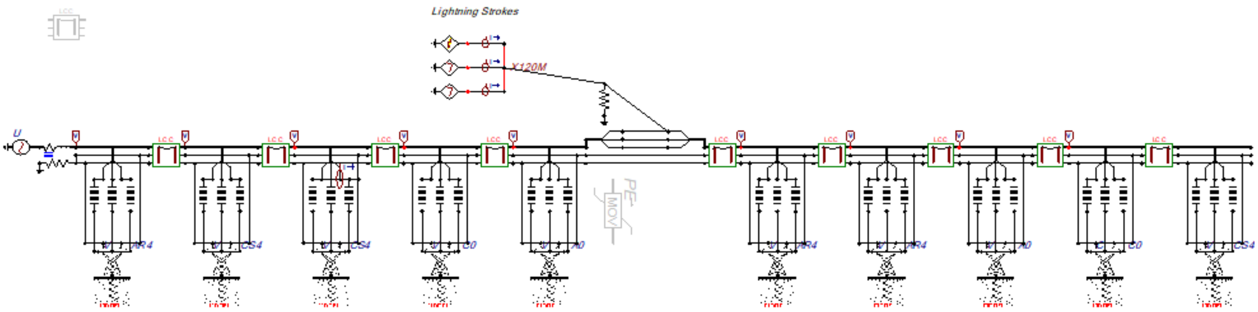

Fig 6. ATPDraw circuit of Power system

In this study we have simulated a length of portion equal to 2.4 km, divided into eight spans. Each span has a length of 300 m which is close to the average value of the spans of this line of OAT-El Hassi in Setif, supplied with 220 kV.

Simulation results

The lightning flash is implemented in ATP-Draw using three shunt connected ideal current sources, In the simulation, we studied the impact of a series of three lightning strikes of 12KA, 10KA and 6KA in succession on the 220KV transmission line in two study cases:

- *First case*: Without Surge arrester.
- *Second case*: with Surge arrester

Lightning-surge current was injected into conductor phase of the fourth tower (middle tower), The voltage patterns due to the direct lightning strike on conductor phase are recorded throughout the distance from the network at each section of (300 m). the authors have chosen to record the simulation results at 05 calculation points (300m, 600m, 900m, 1200m and 1500m) to the right of the lightning strike point as shown in the figure (6). The simulation time is 0s to $5E^{-5}$s.

Table 1 Lightning stroke Parameters

Amplitude	Tstart (s)	Tstop (s)
12 KA	1.6 E^{-5}	1.65 E^{-5}
10 KA	3 E^{-5}	3.1 E^{-5}
6 KA	4.75 E^{-5}	4.8 E^{-5}

The evolution of lightning strikes in time is given on figure (7).

The analysis of the curve in figure 8 shows that the impact is destructive for the cases without lightning arresters. this voltage value is very sufficient to guarantee a failure of the insulation of the line structures and damage to the connected equipment. The maximum voltages recorded, caused only by the first lightning strike, can reach 2MV, while the induced voltages of the two lightning strikes are 700KV and 400KV, successively.

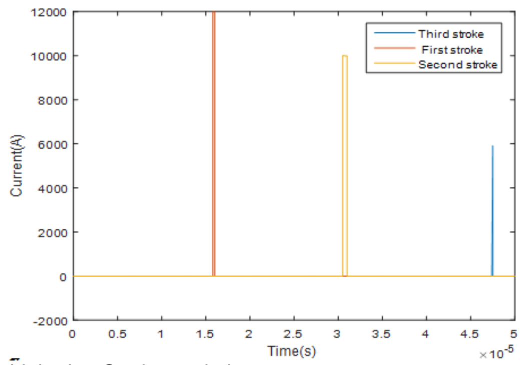

Fig 7. Lightning Stroke evolution

First Case: Without Surge arrester

Figure 9 shows the voltage variation of the different calculation points over the simulation time range of 0s - $5E^{-5}$ s.

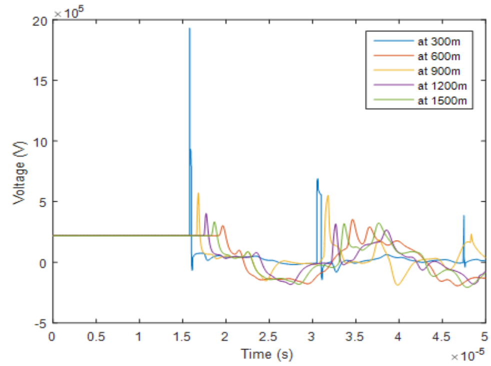

Fig 8. Amplitudes of induced voltage

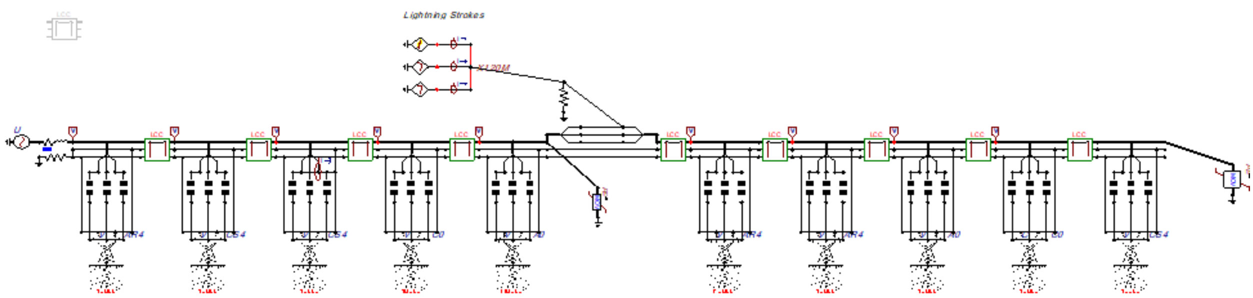

Fig 9. ATPDraw Power system circuit with Surge arrester model

Second Case: With Surge arrester

The Installation of transmission line surge arresters is one of the solutions found to improve the lightning performance of overhead transmission lines [21]. In this case of study, we have chosen to make three cases of configuration:

- The first one: we place a lightning arrester near the lightning strike impact point.
- The second one: we place a lightning arrester at the end of the line.
- The third one: surge protectors placed simultaneously in both positions (Figure 9).

Figure (10),(11) and(12) show amplitudes of induced voltage across conductors in different calculation points over the simulation time range of 0s - 5E^{-5} s,

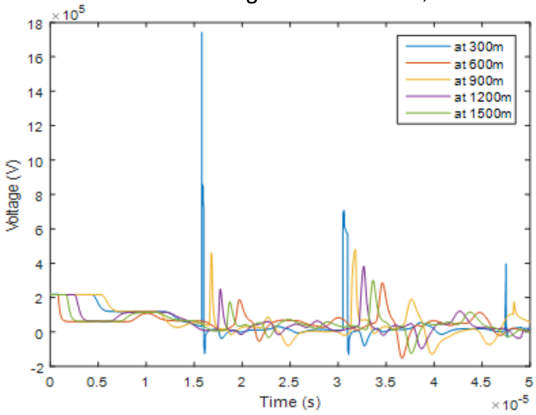

Fig 10. Amplitudes of induced voltage – surge arrester near lightning strike impact point-

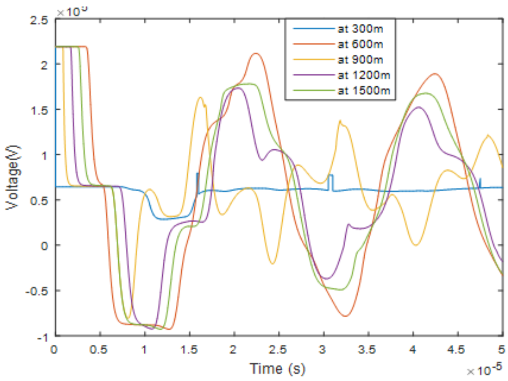

Fig 11. Amplitudes of induced voltage – surge arrester at the and of line-

In this study and according to the results obtained in figures (10), (11) and (12), it is concluded that the insertion of lightning arresters in the power system is very beneficial and useful, and moreover the location of these protection devices on the lines is very significant from the point of view of reducing the induced and transited voltage along the line.

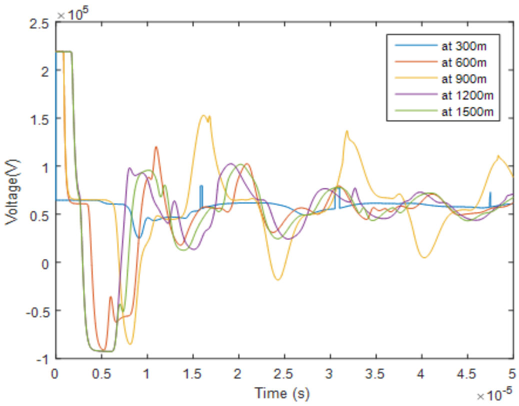

Fig 12. Lightning arresters placed at the same time

Figure 10, shows that the voltages induced by lightning strikes on the line with a lightning arrester placed near the point of impact can reach 220 KV with a deformed lightning shape.

This value is of the order of 1,7 MV in the case of a lightning arrester placed at the end of the line at a distance of 1,5 Km from the impact point.

The results give a clear vision of the capacity of the lightning arresters to immediately reduce the impact of lightning stroke on the population and the electrical network. Figure (12) shows strongly reduced voltage peaks in the situation of placing both arresters at the same time, we notice that the waveforms of the reduced voltages are also improved.

Conclusion

In this study, the effects of a lightning strike are simulated and analyzed by ATP-Draw. A series of several lightning strikes were successfully simulated in ATP-Draw software, using models implemented in the software of various devices in the power system such as lines, towers, sources, insulators and lightning arrestors. Lightning has been used to study the impact of such transient phenomena in electrical systems.

The IEEE model of zinc oxide metal surge protector (MOSA) is widely used by researchers due to its simplicity, reliability and accuracy in terms of order of magnitude and recorded waveforms.

In this article, we have simulated the impact of lightning strike on the electrical network without and with lightning arrester, we have proved the effectiveness of adding such device in the electrical networks to avoid the damage caused by the failures in the constructive elements of the whole power system.

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