Corona Effect Produced by Lightning Strokes on Distribution Feeders

Zahira ANANE[1], John Armando MORALES GARCIA[2], Roberto José CABRAL[3], Abdelhafid BAYADI[1]

[1]Department of Electrical Engineering University of Setif, Algeria
[2]Carrerade Ingeniería Mecatrónica Universidad Politécnica Salesiana Cuenca,
[3]Facultad de Ingeniería Universidad Nacional de Misiones, Argentina

E-mail : zahiraelect@yahoo.fr

Abstract - Distribution feeder usually is built without shielding conductors. Hence, these elements can be greater affected by overvoltages produced by lightning strokes. These phenomena generate overvoltages that depending of its characteristic could result in the Corona effect, which retarding and decreasing the portion of the wave front above Corona inception voltage while the voltages are greater than the Corona threshold. Corona effect has usually been omitted in studies and analysis on distribution feeders. In this paper, an analysis of the influence of Corona effect on real distribution feeder is presented.Various conditions simulated with ATPDraw to study the influence of effect Corona on overvoltages due to lightning on shielding-feeders and unshielding-feeders. Simulation results demonstrate that the influence of Corona on overvoltages due to lightning strike is significant.

Keywords - Corona; Lightning; Modeling; Overhead Distribution Feeders; Overvoltage; Shielding Conductors; Simulation.

I. INTRODUCTION

Generally, severe weather conditions such as lightning and thunderstorms produce intense overvoltages that may cause serious damages to the equipment of distribution electric substations. Lightning is a dangerous natural phenomenon, which causes disturbances in our diary life, and it has a bad effect on mankind and equipment. When lightning hits either the line conductors (direct lightning strokes) or a point in the vicinity of the distribution network (indirect lightning strokes) it can produce overvoltages [1]. These overvoltages have high magnitude comparing with any voltage level of distribution network, so flashover is generated causing damage to the equipment when insufficient protection against this phenomenon is used. This directly affects on power quality and system reliability [1].

Among the effects produced by these over-voltages and has been attracting attention among researchers on the overhead transmission lines, is the Corona phenomenon or corona discharge [2-6]. When an overvoltage transient occurs on a line due to a lightning strike or switching operation, it propagates in both directions and can become harmful to line and station equipment [4].

Corona is known to have a beneficial effect since it helps in attenuating the energy contained in the travelling overvoltage. For transient analysis, corona has been interpreted as an increase in the line capacitance which can be considered as a non-linear function of the instantaneous voltage appearing on the overhead line and its rate of change [2, 7, 8].

Distribution utilities currently use LPS (Lightning Protection Systems) with great technical and economic benefits. The review of the literature will show that the studies of rays in distribution systems without shielding and with guard wire (screened) with connection to ground [9-16] are much applied. In none of the cases, the distribution systems are considered the corona effect. Therefore, this work aims to contribute to the study of the Corona effect in power distribution systems.

Many authors have studied and analyzed the propagation of waves due to the overvoltage on the distribution feeder system, and the range effect of shielding wires on the electric network in case of overvoltage [11, 12, 16, 17]. Also, in the present study, authors will study and analyze the overvoltage waves due to the lightning strike propagating along the shielding/unshielding distribution feeders by the introduction of another study, which is the corona model on the system, and to find their effect on the attenuation and distortion of the waves due to lightning strike which can disasters on the system.

The corona phenomenon begins when the voltage $v(t)$ is greater than the critical inception voltage V_i, which is given by a modified Peek's formula [18-21], by :

$$V_0 = E_0\, r_0 \left(\frac{2h - r_0}{2h}\right) \ln\left(\frac{2h - r_0}{2h}\right) \quad (1)$$

Where : h: is the height of conductor;

r_0: is the radius of conductor;

E_0: is the critical electric field on conductor surface in kV/cm, when the Corona will occur, became [18-21]:

$$E_0 = 23.8\, m \left[1 + \frac{0.67}{r_0^{0.4}}\right] \left[{}^{\mathrm{kV}}\!/_{\mathrm{m}}\right] \quad (2)$$

m: is the roughness factor (surface state of conductor).

Overhead lines are usually shielded to avoid a direct impact of lightning strokes (LS) to phase conductors, although the Corona model is used for aim of protection of unshielded lines and it is presently envisaged as a solution to eliminate the intense overvoltage on those lines.

This paper explains the phenomenon and analyses of the influence of modelling Corona effect, the grounding of the poles and of the cable's screen on the overvoltage magnitude.

The analysis is made both for direct strokes on the overhead line phase conductor and for hits on the earth wire, with and without back flashover. For the most common situation, stroke on the earth wire, it is demonstrated that the cable's ground propagation mode is dominant, reducing the impact of the reflections [12].

Therefore, it can be proposed that the modeling of Corona effect may be neglected at first and added if the overvoltage is over a defined maximum threshold or if the simulations indicate that the surge arrester's class is not suitable.

The remainder of this paper is organized as follows. Section II presents general aspects of Modeling of Corona effects on power systems. A case study is presented in section III. Section IV presents the simulations and results. Conclusions of this work are presented in section V.

II. MODELING OF CORONA EFFECT

Corona discharges often occur on high-voltage overhead lines when the electric field is strongly non-uniform, it has the aspects that have the most influence on wave propagation and distortion on overhead line.

In order to derive a model for the complicated physical processes of Corona, a number of authors [22-35] have proposed different models called analogical and numerical models to represent the physical phenomena. A number of Corona models have been developed for simulating lightning transients on transmission lines [22-35].

Corona model has been developed from macroscopical physical laws, reflecting relations between charge, electric field intensity and voltage.
The implementation of the Corona model is based on the phenomenon physical properties in the Alternative Transient Program-Electromagnetic Transients Program ATP-EMTP using MODELS interface, where this section have algebraic, differential and Boolean equations for the model are solved, and in the ATP-EMTP part it have additional network elements as the applied source.

In the analysis of lightning overvoltage, the relationship between charge and voltage, are usually employed to take account of the Corona effect on the overvoltage.

The space charge is emitted with the voltage peak in the form of a unipolar loads hull, the Corona electrode takes the value of the critical field computed by the empirical formula (2).

The charge voltage diagram of Corona is calculated by the Corona inception voltage and the charge bound on the conductor [2-3, 6-8, 24].

$$Q = 2\pi\varepsilon_0 X_c E_c \left[\frac{2h - X_c}{2h}\right] \quad (3)$$

$$V = E_0 r_0 \ln\left[\frac{X_c(2h - r_0)}{r_0(2h - X_c)}\right] + \frac{E_c X_c\,(2h - X_c)}{2h} \ln\left[\frac{2h - X_c}{X_c}\right] \quad (4)$$

Where : X_c: is the radius of the corona shell;

E_c: is the critical field of the streamers.

ATP-EMTP computes at each simulation time step the Norton equivalent of the circuit as seen from the type-94 component [36].

Thus, the outputs of the model at each time step are the conductance matrix and currents based on terminal voltage input. The User-definable Type-94 component is a special ATP interface of MODELS, utilizes the compensation method [36] used by ATP-EMTP to deal with nonlinear elements, that partly avoids the time step delay and gives direct access to the system description and nodal admittance matrix.

The interface with the circuit is a true electrical connection defined in terms of the voltages and currents of the data case.

III. CASE STUDY OF SHIELDING AND UNSHIELDING WIRES SYSTEM

Model validation is made using an 81 bus 23 kV distribution feeder data. System data can be found in [12, 15, 16].

Still, because distribution lines are usually grounded at every pole and the shielding angle is less than 45° (Fig. 1), all flashes to the distribution line are assumed to strike the guard wire [16].

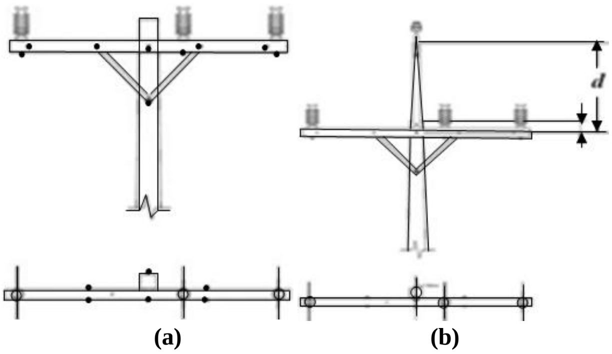

Fig. 1. Types of pole structures : (a) unshielded, (b) shielded with wire-guard (d = 1 m) [12, 15].

Figure 2 illustrates grounding system types considered in this work. Grounding rods are steel-copper type 19 mm (3/4 inch) in diameter and length of 2.4 m (8 feet). Conductors used in the interconnection of grounding and descent wires of shielded structures (Franklin captor or wire guard) are 2AWG copper.

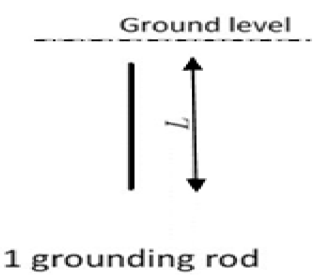

Fig. 2. Grounding topologies considered [12, 15].

In the present work, the model of Corona effect is developed to aim of analyzing the influence of Corona due to overvoltages on the real distribution feeder (Fig. 3), where lightning stroke currents are represented by means of the Heidler model [25] for an impulse of 1.2/50µs and current intensity equal to 6000 A.

The chosen line is the JMarti type, who's the conductor characteristics are provided in Table 1.

Table 1. Line conductor characteristics.

	Type	Diameter (cm)	Resistance (Ω/km)
Phase conductors	JMarti	1.83	0.16925
Shieldwires		1.011	0.53615

The equivalent distribution system-shielding presence of corona model is presented in Figure 3, by two slices, where corona is the dynamic corona model described is implemented in a new model, developed using MODELS simulation language Type-94 within the ATP-EMTP package [36].

The Type-94 component is seen by EMTP as an electrical black box connected to the circuit, and it illustrates how to add new electrical components to ATP using external subroutines through the non-delayed interface between Models and ATP by the nonlinear components Type-94.

In the Norton type component, the corona capacitance is similar to a true non-linear component, with the same restrictions. The input to the model from the circuit is its Norton equivalent (resistance matrix and current vector) for the voltage time step.

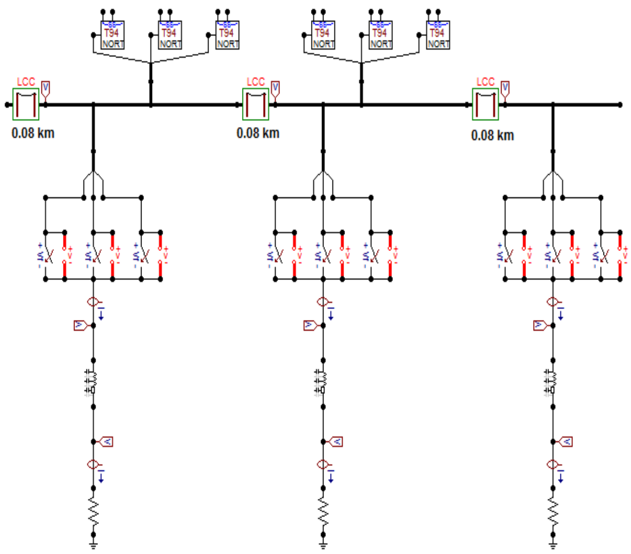

Fig. 3. Two slices of Equivalent distribution system - Shielded feeders with Corona effect model in ATP-Draw.

IV. SIMULATION AND RESULTS

The simulation was performed according to the two case studies for a real distribution feeder, of seven poles, considered with and without presence of Corona model protection component (wire-guard), where the lightning hits on one phase of line at a distance of 3240 m from source, and has the magnitude of 6 kA for the impulse of 1.2/50µs.

The results of this simulation are shown in Figure 4 to Figure 6, where the results are found in different points of measurement from the impact point of lightning strike.

From these two Figure 4 and Figure 5 with and without presence of shielding wire, the most affected part in this case is the tail magnitude where its time of takedown is very fast in Figure 4 than presented in Figure 5 (for all measurement points : from P0 to P7 as shown in Table 2).

With presence of shielding wire the magnitude of overvoltages are greater in case where lightning hits on the phase A than that presented in Figure 6.

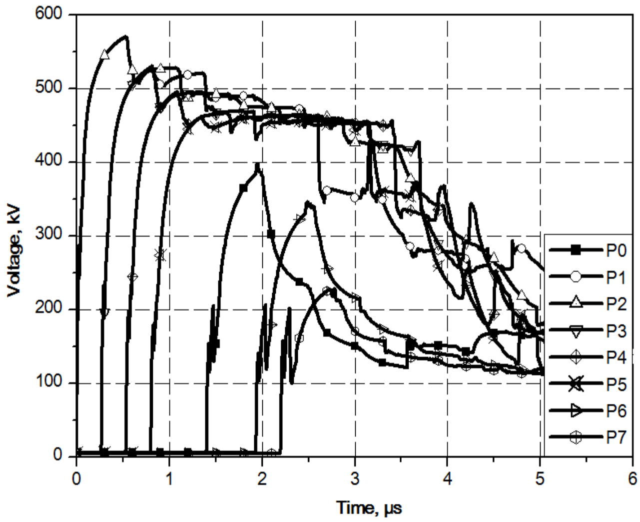

Fig. 4. Voltages at points of measurement for the system shielded with grounding wire.

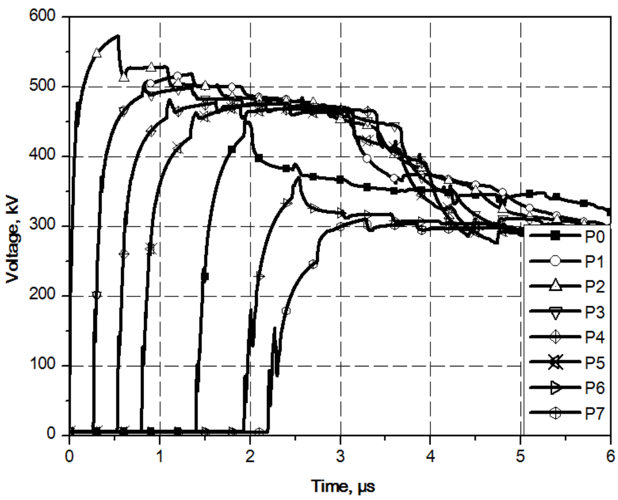

Fig. 5. Voltages at points of measurement for the system unshielded, LS hits on phase A.

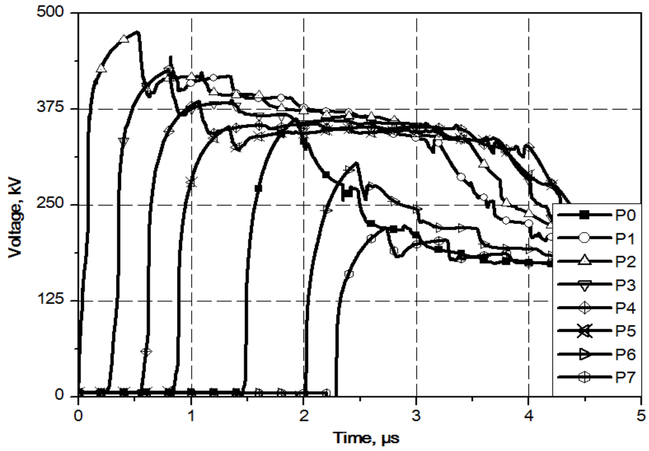

Fig. 6. Voltages at points of measurement for the system shielded with grounding wire, LS hits on shielding wire.

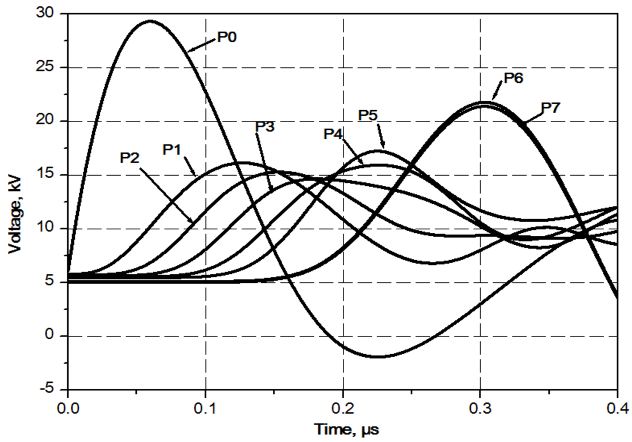

Fig. 7. Voltages at points of measurement for the unshielding system, LS hits on phase A at P0.

If the lightning stroke hits a phase conductor, the lightning current and voltage surges will flow through the conductor in two directions from the point of impact. When the stroke hits a phase conductor the overvoltage caused is much greater than the overvoltage that the same stroke would cause if the point of impact was the tower or the shield wire as show in Figure 4 and Figure 6. This is the reason why a good lightning shielding is of paramount importance in the design of overhead distribution feeders [10].

Table 2. Impact points of lightning stroke.

Points of measurement	Distances from source (km)
P0	3.08
P1	3.42
P2	3.5
P3	3.58
P4	3.66
P5	3.74
P6	4.08
P7	4.16

The increasing values of overvoltage obtained in this part, are very dangerous and cause a serious damage to the equipment of the distribution substations. Whereas the including of the Corona model, by using of type-94 component, in the present simulation is very interesting (section II).

The results illustrated in Figure 8 to Figure 11 shown that the greater impulse magnitude is obtained on the point measurement in which the lightning strike hits the phase conductor (point of impact). The dynamic Corona model adjusts the voltage level in the rest of the network from the point impact of the lightning stroke to the level of the applied voltage by attenuation and distortion of the overvoltage waves, where this adjustment is observed on the maximum values found by the present simulation, as shown in Figure 8 to Figure 11.

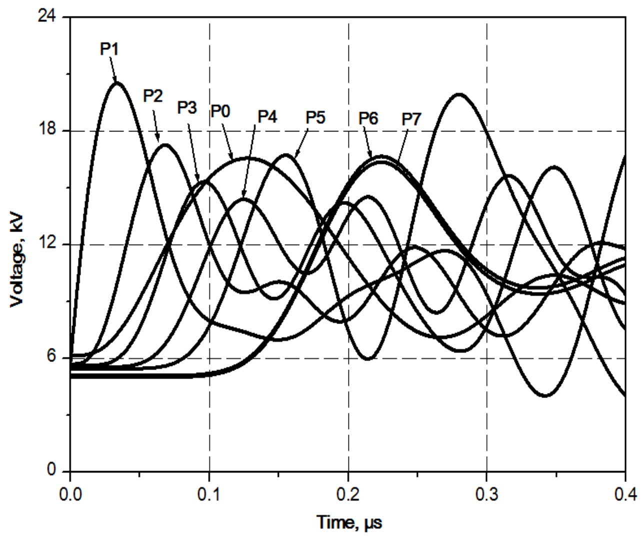

Fig. 8. Voltages at points of measurement for the unshielding system, LS hits on phase A at P1.

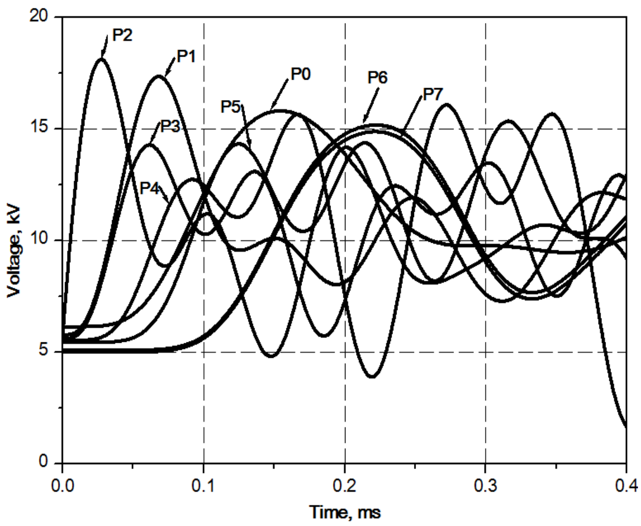

Fig. 9. Voltages at points of measurement for the unshielding system, LS hits on phase A at P2.

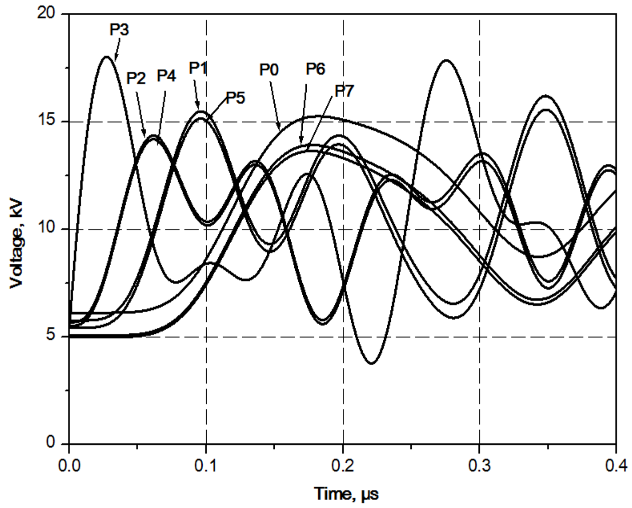

Fig. 10. Voltages at points of measurement for the unshielding system, LS hits on phase A at P3.

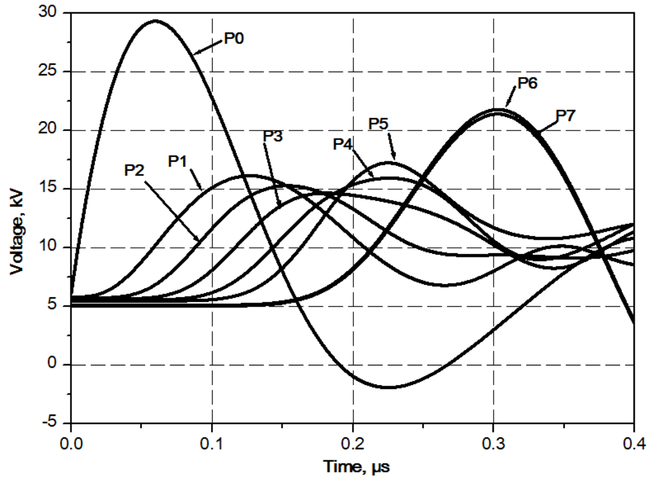

Fig. 11. Voltages at points of measurement for the unshielding system, LS hits phase A at P4.

V. CONCLUSION

In this paper, 23 kV distribution feeders and its related lightning parameters are simulated with ATPDraw. Various conditions simulated to study the influence of effect Corona on overvoltages due to lightning on shielding-feeders and unshielding-feeders. The Corona effect is implemented in the ATP-EMTP through MODELS. Simulation results demonstrate that the influence of corona on overvoltages due to lightning strike is significant. Therefore, Corona model must be considered in lightning on distribution feeders studies, and to increase the accuracy of the simulation, it is recommended to consider the corona effect in simulations.

Modeling of a Corona effect is an important topic in the engineering research. Corona on overhead distribution feeders plays an important role in determining the magnitude and waveshape of overvoltages.

The paper describes a mathematical Corona model implemented in the EMTP with aid of the Models and type 94 component features in this program, where the good results are given for this modeling. The overhead line models are also modeled and interfaced with a general purpose Electro-Magnetic Transient Program (EMTP) with real parameters, the present Corona model of type 94 is implemented on the overhead distribution feeders, and good results of attenuation on the wave propagation are given.

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