# Lightning induced voltage on telephone cables and power systems

A. S. Ahmad, T. Aka-Ngnui

**Abstract-- Several times, the lightning damaged the electronics components of a real station of communication. Consequently, this work relates to a study on the interaction of lightning with the lightning protective system, telephone cables, and power system in order to analyze lightning induced voltages. A topology of a communication station is described and the structural lightning protection, telecommunication station, earthing network, power system is well realized. The cable parameters are calculated and it is represented as transmission line model TLM. The others system elements are modeled by equivalent circuits. The global model is introduced in EMTP (ElectroMagnetic Transient Program) allowing to study various configurations of telephone cable and power systems. Discussions of results and comparisons with other methods are presented. The results show the influence of topology configuration (power system/telecommunication sites), on induced overvoltages and confirm, for the case studied, which is a factor important.**

**Keywords: telephone cable, lightning protection system, modeling, transient analysis, lightning induced voltages, cable parameters, EMTP, overvoltages.**

## I. INTRODUCTION

THE most important reason of the overvoltage in communication system are caused by lightning. These overvoltages cause a dangerous disturbance which sometimes may destroy the system if it is not protected enough, When the lightning strikes, an over voltage are induced on the conductor. This induced voltage depends on many factors: The distance between the strike location, cable type, the material of the shield, its thickness and insulation. In addition the amplitude of the lightning current itself which enters the cable [1].

Many papers studied the characteristic of induced voltages and currents on transmission lines and communication systems [2-3]. Time-domain finite differences concept is used in order to estimate the induced voltages caused by electromagnetic pulse or electrostatic discharge for time in order of nano-seconds [4]. Analysis of the effects caused by a direct lightning stroke on the protection system of an industrial building presented by a method based on a circuit approach [5]. Different approach in the modeling of the low voltage cables are made using Finite Element Method for calculating of the cable parameters [6]. Hybrid methods based on analytical and numerical methods are developed to find models for close conductors [7-8]. These methods take into account the skin and proximity effects in a frequency range about 0 Hz, 10 MHz for a cable system.

The evaluation and analysis of the calculation of lightning induced voltages on complex distribution systems requires accurate models. Moreover, the availability of model parameters and their implementation into software must be able to calculate lightning–induced electromagnetic transients in distribution systems [9]. In some special studies, special programs and models are used just for these cases [10-11].

When a lightning strikes directly the cable, a current with high amplitude can be injected in the cable. The current source generates a solenoid field and is associated to the longitudinal current that flows along the element. The effect of such source is to establish a voltage drop along the own element and to contribute to the voltage drop along all other elements (induced voltage drop), [12]. The problem has been discussed in this paper is intended to this type of current; because a single equivalent cable is studied and the remote points around it are not taken into account. The employed methodology to represent the problem achieved through these steps: a topology of a communication station is. Fundamental ideas to develop the methods employed were exposed. The problems concerning the calculation of the cable's parameters (R, L, and C) are studied, using an equivalent system. And an equivalent distributed constant line model of a transmission tower is used. The global system model is introduced in EMTP (ElectroMagnetic Transient Program) [13] allowing studying various configurations of telephone cables and power systems.

Various scenarios of simulation were investigated (a direct strike to the overhead line MV or telephone cable …) in order to quantify the problem. Discussions of results and conclusions are presented.

## II. SYSTEM MODELING

A diagram of the real system is shown in Fig. 1. This installation is constituted by these parts:

1- The overhead line MV, Medium Voltage,

2- Metallic tower,

3- Power transformer MV/LV,

4- Earthing system for tower and transformer,

5- Output of telephone cables (connection box); from this part the telephone cables, number 9, were connected to arrive to consumers,

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6- Communication system building,
7- Lightning protection system,
8- Building earthing system,
9- Telephone cables.

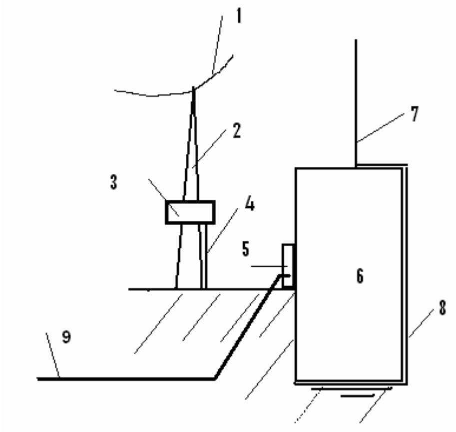


Fig. 1. Diagram showing the real system elements.

### A. Lightning stroke model

The required test pulses can be obtained by applying two double exponential pulse voltages, through the equation:

$$f(t) = A(e^{-at} - e^{-bt}) \qquad (1)$$

Here are the characteristics:

- The time to half value *T(1/2) = 50 µsec.*
- The time to crest of the pulse, *Tcr = 1.2 µsec.*
- The crest amplitude = *A = 10 kA.*
- $a = -1400$ and $b = -4.85\ 10^6$

Consequently, the represented lightning pulse is shown in Fig. 2.

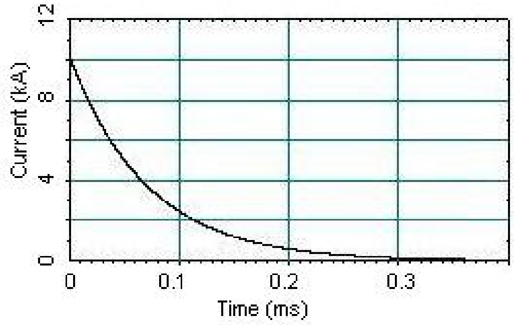


Fig. 2. Lightning stroke modeling.

### B. Communication cable modeling

The telephone cable consists of fine conductors close to each other: there will be many difficulties to simulate it (in the modeling), including the electromagnetic interference (coupling ) and mutual inductance and capacitance calculating between those conductors, as well as the geometric difficulties to determine the cable characteristics (R,L,C). Various types of cables of communication used in our system and we describe the one of them. The required test cable of copper conductors contains three sets; each one include 50 conductors with fine diameter (0.5mm), as shown in Fig. 3, and consequently, the skin and proximity effects can be ignored, so it is possible to simulate the cable as coaxial one as illustrated in Fig. 3, [6].

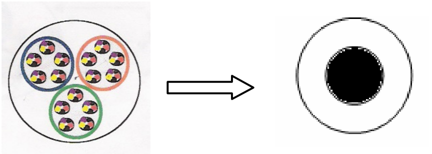


Fig. 3. Configuration of the conductors.

When the lightning strikes the cable that will lead to short the cable conductors with each other, which means it can be considered as if they are in a parallel configuration and the equivalent resistance can be defined as: $R=R_1/n$ where:

- $R_1$ is the resistance of single conductor,
- n is the number of the conductors.

It is important to mention that this kind of approaches allowed in such researches of direct lightning stroke [6-7]. The represented cable is an aerial one of 10 Km length and 5 m height; the above-mentioned approaches lead to the characteristics of the equivalent cable capacitance [10]:

$$C = 2\pi\varepsilon / (Ln(4h/2r)) \qquad (2)$$

where: $\varepsilon$: is the absolute permittivity.
$h$: is the cable height.
$2r$: is the conductor's diameter.

The self-inductance can be calculated using classical formulas [6]. The cable parameters are calculated and it is represented as transmission line model TLM in EMTP model. For this model parameters are as follow:

$$C = 0.0066\,\mu F/km,\quad L = 0.05\,mH/km,\quad R = 1.208\,\Omega/km$$

### C. Tower modeling

The surge impedance of an electrical tower is expressed by the function of it dimension and geometry. An equivalent constant line model of a transmission tower is developed is using the approach proposed in [14]. The surge of various sizes of vertical cylinder can be expressed by the following empirical equation:

$$Z = 60\left(\ln\frac{2\sqrt{2}h}{r} - 2\right) \qquad (3)$$

where r and h are the cylinder radius and height, respectively.

### D. Global system model

An EMTP model of the system was developed including the models cited above and the following models of the rest of the elements of the system:

- Transmission line MV model using the transmission line model in the EMTP [14].
- Medium to low voltage transformer model using a simplified model of the secondary of the transformer taking into account the capacitance and inductive effect inside the transformer and the resistance on the winding [15].
- Lightning rod and down conductor model using the model developed in [16] constituted by an

inductance L in series with a resistance R. The values of R and L are 5 mΩ and 15 µH, respectively.

- Ground rods, represented by a lumped–circuit model which R, L and C are calculated [17-18].

## III. RESULTS AND DISCUSSIONS

Many computational problems can be appears including the computation parameters (delta, maximum time…) and entering the cable's and lightning's parameters. Let us consider two cases;

- The first one a study shows the direct strokes on telephone cables.
- The second one represents direct lightning strokes on power system (tower and MV lines).

### A. *Direct Lightning stroke on telephone cables*

If lightning surges appear in the telephone cable, we search for the wave-shapes, and the variation of overvoltages magnitudes at the connection box, at point N, Fig. 4. In order to study the influence of each parameter, this parameter changes into a determined domain while other parameters stay constants. The telephone cables characteristics (length, height) depend of localization of the customers. Fig. 4 shows that the system have connection nodes of cables, number 10 in the Fig. 4 and the most part of telephone cable is placed on wood tower.

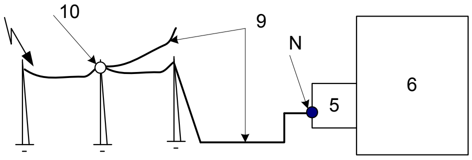


Fig. 4. The telephone cable system

The simulation is achieved by using EMTP. In order to evaluate the transient overvoltages, the equivalent circuit of the test status is shown in Fig. 5. A current source presents the direct lightning stroke, the transmission line model presents the telephone cable and the resistance presents the load of the communication system. In this part, effects of the communication system parameters on lightning distribution are analyzed.

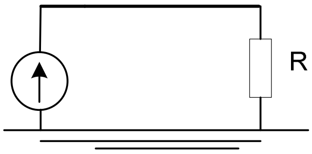


Fig. 5. The equivalent circuit of the telephone cable system.

Influence of cable height: to study the influence of this parameter on lightning induced overvoltages, three line heights are simulated: 1, 5 and 10 m with 10 km of length and 20 Ω of load. A simple review of the (2) shows that the capacitance varies due to height changes. The obtained results in Fig. 6 show a maximum voltage is almost equal to 4 kV. When the height increase, the capacitance decreases so the resistance (1/cω) increases; which means a decrease in the wave attenuation and a larger voltage reaches the end of the cable. This analyze agree with those obtained by other researches [10-11]. However, in our case, the results do not show changes in induced overvoltages and we think that resistances of earthing system have a great influence in the results.

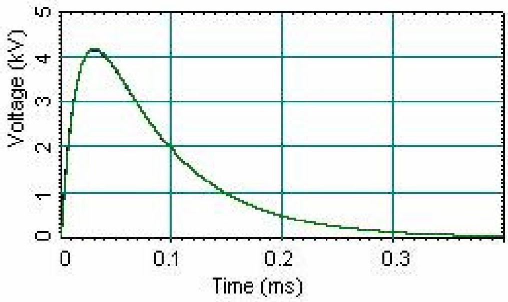


Fig. 6. Cable height influence.

Influence of cable length: To study the influence of the cable length; three lengths: 1, 5, 10 km are involved with 5 m of height and 20 Ω of load. The influence of the cable length on the induced voltage value is shown in Fig. 7 for the previous values of the cable length. The magnitudes of overvoltages are great between 4 kV to 8.5 kV.

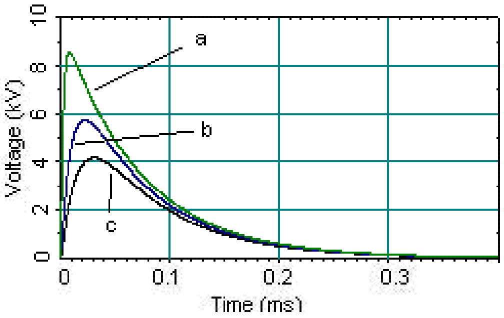


Fig. 7. The influence of cable length: a-1 km, b-5 km, c- 10 km.

The results shown in Fig.7 illustrate the drop of induced voltage as the cable becomes longer and longer; in addition a slower attenuation is noticed in this case. The obtained results have a large agreement with the search [11].

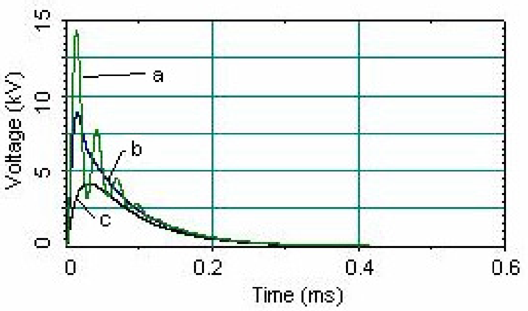


Fig. 8. The influence of the load: a- 500 Ω, b- 100 Ω, c-20 Ω.

Influence of the load: In order to analyze load impedance influence, impedance is varied as the following values: 20, 100, 500 Ω with 5 m of height and 10 km of length. Fig. 8 denotes the lightning induced overvoltage at each mentioned value and we have also great values of overvoltages (from 4 kV to 14 kV). According to Fig. 8, it is clear that as the impedance increase as the induced voltage increases, and this agree with Ohm law R=V/I (when R increases V increases too).

Results analysis: The load is the most effective parameter on the induced voltage and it must be considered carefully in such kind of studying. It is clear that the effect of height can be ignored. Results concerning the effect of the cable length confirm the necessity of existence of lightning earthing system along the telephone cable and especially for those are short.

### B. *Direct Lightning stroke on power system*

We have two cases:

- Case a: the lightning strikes directly on the MV overhead lines and flows via earthing system.
- Case b: the lightning strikes directly on the tower directly and then the wave is propagated in the tower and tower footing ground system.

We will try to estimate the transient voltages at point N, Fig. 4, (output connection of telephone cables). It noted that the distance between the foot of the tower and point N of the communication station building is of the order of 5 meters. We have adopts a standard value for the resistivity of the ground for our calculations (100 Ω.m). It be noted that during the rain and the storms the part besieged between point N and the tower, Fig. 1, is often immersed by water. We show here some examples in order to demonstrate great values of overvoltages induced in point N. Fig. 9 shows that the value of the overvoltages beside the box, point N, in the case of a dry ground. In fact, the distance of the earth is short (5 m) and that have probably a great influence of the obtained results. Fig 10 shows overvoltages during the winter by holding account that the resistivity of the ground became 20% of its value in the dry earth case. We continue to analyze the work specially this part by other ways (measurements, methods) in order to more simulate the wave propagation in the earth. The real telephone system was damaged more than one time in the case humid earth.

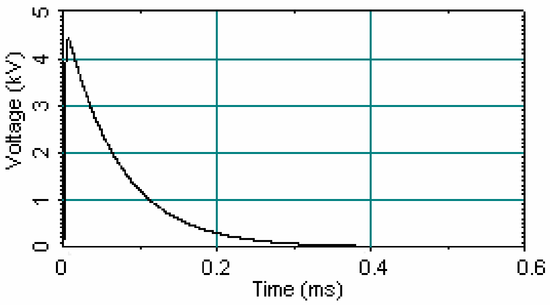


Fig. 9. Induced overvoltages, case dry earth.

It well clearly, from two schemas that there is a great chance that the transient wave penetrates in the communication system has through the connection of telephone cables by induction or by the earthing system directly (tower, earth, earthing system of building). Theses overvoltages, upper 4.5 kV, present a real danger for electronic equipments of communication system. We carried out several simulations for various equivalent circuits for the studied system and the results confirm the possibility of existence of voltages raised in point N and these voltages take the form of lightning wave with reduced values.

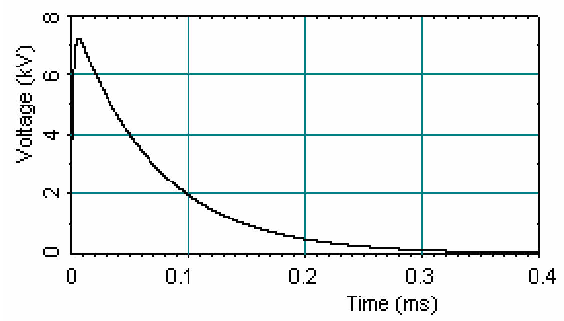


Fig. 10. Induced overvoltages, case humid earth.

One notes that the arrival of a voltage of a value 50 V can cause damages in the telephone system (in our case), if protection does not work. The latter point is very important; by what in certain cases the lightning wave is faster than the protection apparatus. That already arrived more than one time and caused some damages. The results suggest the change of lieu of the electric tower with the power transformer.

## IV. CONCLUSIONS

The effects of direct lightning strikes on the incoming power line and communication cables at the communication site equipments for a real configuration are analyzed and determined. Each element of the system is modeled by an equivalent model. The global system model is introduced in EMTP allowing studying various configurations. By using the approach proposed, the wave-shape of the induced voltage and the variation of its magnitudes can be studied.

Results confirm the necessity of existence of lightning earthing system along the telephone cable and especially for those are short. The results show the influence of earthing resistances and topology configuration (power system/telecommunication sites) on induced overvoltages and confirm, for the case studied, which is a factor important. Consequently, the change of lieu of the electric tower with the power transformer is suggested.

## V. REFERENCES

[1] M. Master, M. Uman, W. Beasley, and M. Darveniza, "Lightning induced voltages on power lines: experiment", *IEEE Trans. on Power Apparatus and Systems,* vol. PAS-103, no.9, pp. 2519-2563, Sept. 1984.

[2] P. Anzanel and P. Kouteynikoff, "Induced voltages in a telecommunication circuit encased inside an earth wire struck by lightning", *E.D.F. Bulletin de la Direction des Etudes et Recherches - Série B, Réseaux Matériels Electriques,* n° 1, pp. 59-74, 1982.

[3] A. Zeddam and P. Degauque, "Signaux induits par la foudre sur les lignes de télécommunications", *R.G.E.*, n° 3, pp. 52-58, mars 1989.

[4] E. S. M. Mok and G. I. Costache, "Skin-Effect Considerations on Transient Response of a Transmission Line Excited by an

Electromagnetic Pulse", *IEEE Trans. on Electromagnetic Compatibility,* vol. 34, no. 3, pp. 320-329, August 1992.

[5] S. Cristina and A. Orlandi, "Calculation of the induced effects due to a lightning stroke", *IEE Proceedings-B,* vol. 139, no. 4, pp. 374-380, July 1992.

[6] M. Puharic, A. Ahmad, and Ph. Auriol, "Modelling and simulation of low voltage power cable", *in Proc. 1992 of the Eleventh IASTED International Conference, Modelling, Identification and Control,* Innsbruck, Austria , pp. 443-446.

[7] A. Ahmad, M. Kane and Ph. Auriol, "High Frequency equivalent models for multiconductor transmission lines", *in Proc. EMC'94 ROMA, International Symposium on Electromagnetic Compatibility*, September 13-16, 1994.

[8] M. Kane, A. Ahmad, and Ph. Auriol, "Multiwire Shielded Cable Parameter Computation", *IEEE Transactions on Magnetics,* vol. 31, no.3, May 1995, pp. 1646-1649.

[9] E. Petrache, F. Rachidi, A. Borghetti, J.A. Gutierrez, C.A. Nucci, and M. Paolon, "Software tools for the calculation of lightning induced voltages on complex distribution systems", *in Proc. ICLP 2002, International Conference on Lightning Protection*, Cracow, Poland, 2-6 September, pp. 202-207.

[10] A. Ahmad, A. Al Ali, and K. Aboud, "Effect communication system parameter on lightning distribution", *in Proc.1999 Krajowe Sympozjum Telekomunika,* 8-10 Wrzesnia 1999r, Poland.

[11] F. H. Silveira, S. Visacro, A. R. De Conti, A. Soares, M.A.O. Schroder, and M. H. M. Vale, "The influence of transmission line configuration on the amplitude of lightning induced overvoltages", *in Proc. ICLP 2002, International Conference on Lightning Protection,* Cracow, Poland, 2-6 September, pp. 198-201.

[12] S.F. Visacro, A. J. Soares and M.A.O Schroeder, "An interactive computational code for simulatin of transient behavior of electric system components for lightning currents", *in Proc. ICLP 2002, International Conference on Lightning Protection,* Cracow, Poland, 2-6 September.

[13] H. W. Dommel, *EMTP, Theory Book*, Bonneville, USA, 1986.

[14] T. Hara and O. Yamamoto, "Modelling tower for lightning surge analysis", *IEE Proc. Gener. – Transm. – Distrib.,* vol. 143, no. 3, pp. 283-289, May 1996.

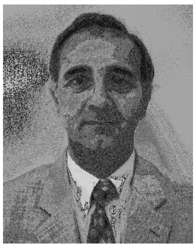
[15] A. Rakotomalala, Ph. Auriol, and A. Rousseau, "*Lightninig distribution through earthing systems*", *in Proc. IEEE 1994 International Symposium on Electromagnetic compatibility,* Chicago, August 22-26, USA, pp.419-423.

[16] M. Aguet and M. Ianoz, *Haute Tension, Traite d' Electricité* , vol. xxii, ed. Dunod, 1987.

[17] S. Wojtas and A. Rousseau, "Impulse and high frequency tests of lightning earthing", *in Proc. ICLP 2004 International Conference on Lightning Protection,* Avignon, France , 13-16 September.

[18] M. Puharic, "Modélisation en regime transitoire HF des lignes d'énergie BT: Application au couplage avec la foudre", *PhD Thesis Ecole Centrale de Lyon*, France, 1992.

## VI. BIOGRAPHIES



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