International Journal of Renewable Energy and Sustainability (RES)
Vol.2pp.7-13

Protection of Overhead Lines Coupled to a Photovoltaic Generator Against Overvoltage Induced by a Lightning Strike

Bidi Manel[#1], Latreche M^{ed} Elhadi[#2]

[#] *Electrotechnical Laboratory"LEC", Department of Electrotechnic, Faculty of Science Technology, University Mentouri of Constantine, Algeria*
[1]bidi_manel@yahoo.fr

***Abstract*— like all electrical equipment photovoltaic systems can be damaged by both direct and indirect lightning strikes and other overvoltage disturbances caused by electrical switching operations, load switching and so on.**

The purpose of this paper is to investigate the propagation of overvoltage induced by a lightning strike on an overhead line which can be coupled with a photovoltaic array.

For reasons of electromagnetic compatibility (EMC), the need for a good quality in power supply along with the widespread use of sensitive devices connected to distribution lines makes the protection against lightning induced disturbances of primary importance. In this paper we investigate the shielding effect due to the presence of other conductor in a multiconductor overhead line as well as that of the shield wire periodically grounded, and the surge arresters in order to protect an electric network coupled to a photovoltaic generator against the propagation of overvoltage induced by indirect lightning return stroke.

***Keywords*— EMC, Lightning-induced voltage, overhead lines, shielding, FDTD.**

I. INTRODUCTION

Induced overvoltage is created by either direct or indirect lightning strike hit on solar panel system. A cloud to ground lightning flash generates a transient electromagnetic field which can induce overvoltage of significant magnitudes on overhead lines situated in the adjacent. Like all electrical equipment photovoltaic systems can be damaged with both direct and indirect lightning strikes and other overvoltage disturbances caused by electrical switching operations, load switching and so on.

This paper is devoted to the study of the induced-voltages on a multiconductor line and to the influence of a shielding wire to reduce the propagation of the phenomena.

The electromagnetic field resulting from a spatial-temporal distribution of the return stroke current along the lightning channel causes induced voltage in the surrounding devices (electric power transmission lines). The calculation of these induced voltages requires the use of a suitable coupling model (coupling equations) based on the transmission lines theory applied to the problem of interaction between the lightning electromagnetic field and an overhead line.

The induced overvoltage on a conductor belong a multiconductor line is affected by the presence of others conductors, and shielding wire.

The calculation results presented in this paper were obtained by means of computer programs developed by the authors using MATLAB environment.

II. CALCULATION OF INDUCED OVERVOLTAGE

A. Coupling model between an EM field and multiconductor overhead lines

Starting from Maxwell's equations and adopting the transmission line approximation, it is possible to derive a pair of equation describing the coupling of an external electromagnetic field and multiconductor line. These equations can be written in different equivalent formulations. The formulation we adopt in this paper is the one proposed by Agrawal et al [1], which for the case of homogeneous lossless multiconductor line above a perfectly conducting ground and illuminated by an external field, is given by (see Fig. 1):

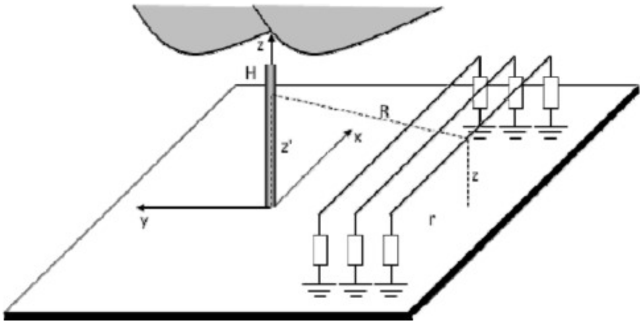

Fig.1. Geometry used to calculate the induced lightning overvoltage on a multiconductor overhead line

$$\frac{\partial}{\partial x}\left[u_i^s(x,t)\right]+\left[R'_{ij}\right]\cdot\left[i_i(x,t)\right]+\left[L'_{ij}\right]\frac{\partial}{\partial t}\left[i_i(x,t)\right]=\left[E_{xi}(x,h_i,t)\right] \quad (1)$$

$$\frac{\partial}{\partial x}\left[i_i(x,t)\right]+\left[G'_{ij}\right]\cdot\left[u_i^s(x,t)\right]+\left[C'_{ij}\right]\frac{\partial}{\partial t}\left[u_i^s(x,t)\right]=\left[0\right] \quad (2)$$

These equations will have been solved by means of the point-centered finite difference technique in time domain (FDTD).

Where:

- $[E_{xi}(x, h_i, t)]$ is the vector of the horizontal component of the incident electric field along the x axis at conductor's height h_i.
- $[0]$matrice zero.
- $[L'_{ij}]$ and $[C'_{ij}]$are respectively the inductance and the capacitance matrices per unit length of the line.
- $[i_i(x,t)]$ is the line current vector.
- $[u_i^s(x,t)]$ is the scattered voltage vector, related to the total voltage vector $[u_i(x,t)]$ by the following expression:

$$[u_i(x,t)] = [u_i^s(x,t)] + [u_i^e(x,t)] = [u_i^s(x,t)] - \left[\int_0^{h_i} E_{zi}^e(x,z,t)\,dz\right]$$

Where

$E_{zi}^e(x,z,t)$ is the exciting vertical electric field that can be considered as unvarying in the height $0 < z < hi$

$$[u_i^e(x,t)] = -\left[\int_0^{hi} E_{zi}^e(x,z,t)\,dz\right] \cong -[h_i E_z^e(x,0,t)]$$

The boundary conditions for the scattered voltage vector $[u_i^s(x,t)]$ are given by:

$$[u_i^s(0,t)] = -[Z_A][i_i(0,t)] + [h_i E_{zi}^e(0,0,t)]$$
$$[u_i^s(L,t)] = -[Z_B][i_i(L,t)] + [h_i E_{zi}^e(L,0,t)]$$

Where $[Z_A]$ and $[Z_B]$ are the matrices of the line terminations.

The equivalent circuit for infinitesimal section of a lossless line is presented in Fig. 2.

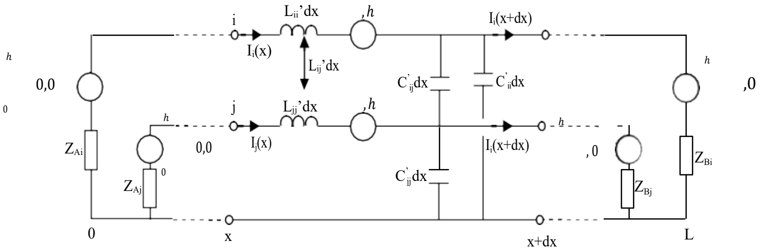

Fig.2 Equivalent circuit of Agrawal et al coupling equations for the case of a lossless multiconductor line.

III. ANALYSIS OF INDUCED OVERVOLTAGE

In the following a three-phase line is analysed. The considered geometry is represented in Fig.3. The phase conductors are located at a height of 10 m. The radius of the conductors is 9.14 mm. The ground wires are located at 3.05 m over the phase conductors and their radius is 3.96 mm. The line is 1 km long. The stroke location is at 50 m from the line centre, at the same distance from the two terminations. Each conductor is terminated on its characteristic impedance determined in absence of the other conductors. The adopted channel base current is the one represented in Fig. 4. The velocity of the return stroke is v = $1{,}3.10^8$ m/s , the channel height is 7.5 km. We note that the ground is always considered like a perfect conductor [8, 9].

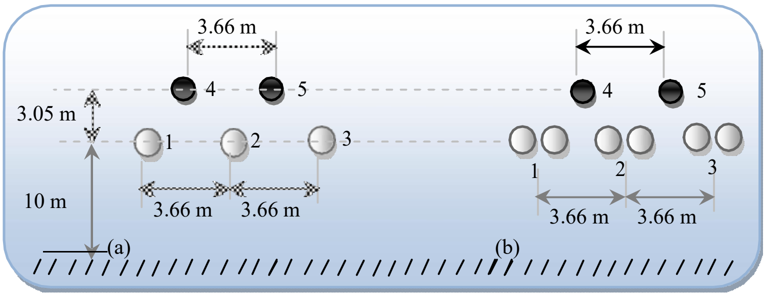

Fig. 3 Power line configurations for the analysis (4, and 5 ground wire), a) 1 conductor in each phase, b) 2 conductors in each phase

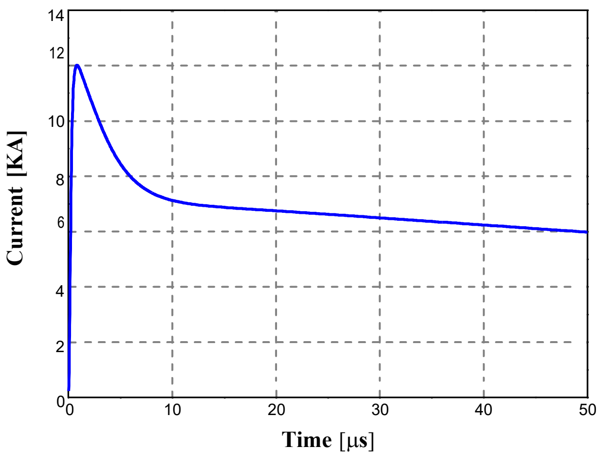

Fig. 4 Typical lightning current over 50 µs

A. *Multiconductor line without a shielding cable*

Fig. 5 shows induced-voltages calculated at the line extremities, for the horizontally-configured line, the highest reduction occurs for the middle one (conductor 2 in Fig. 3). We also note that the induced-voltage in conductor 1 and 3 are superposed. The shielding effect due to the presence of other conductors is much more important and remarkable when each phase is fractionated in two conductors which is shown in Figure 5-b.

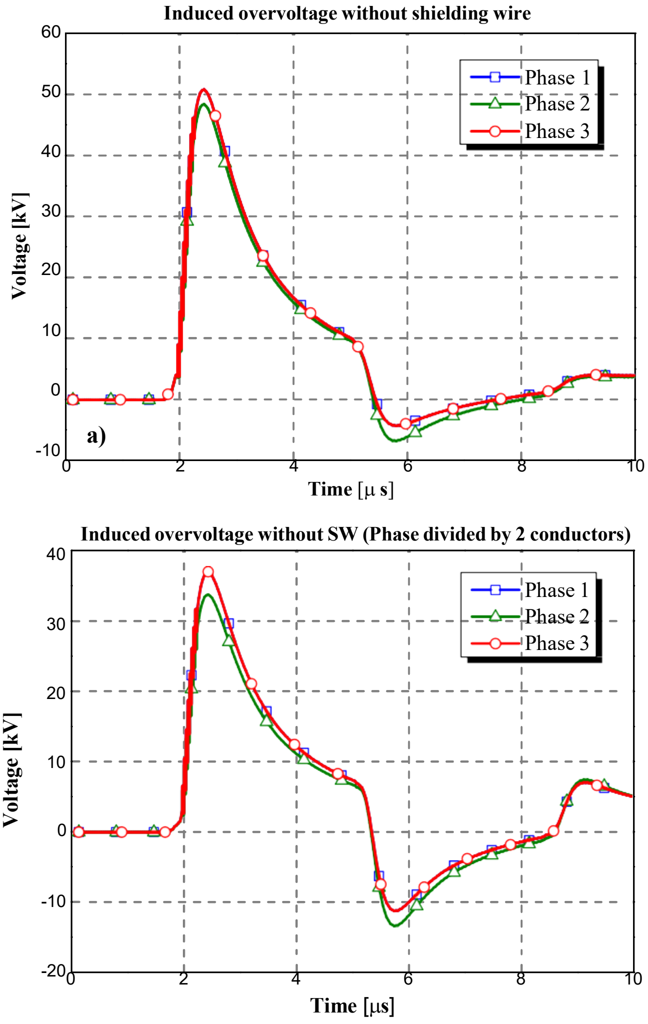

Fig. 5 Induced-voltage on horizontal multiconductor overhead line without shielding wire, a) the three phase conductors, b) each phase divided by 2 conductors

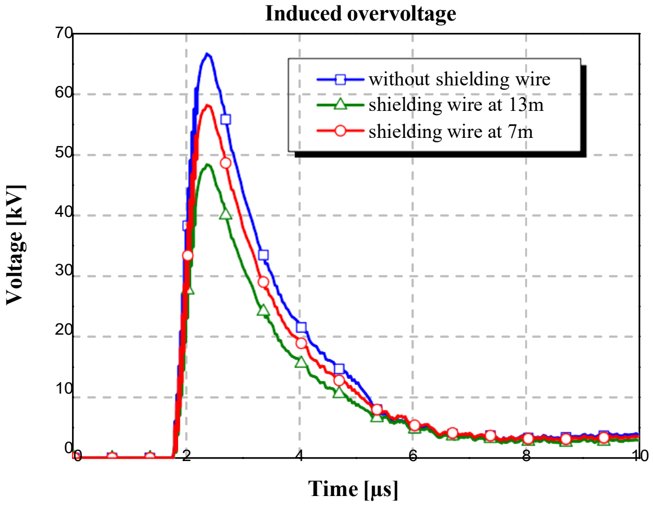

Fig. 6 Induced-voltage on a single conductor with and without a shielding wire

B. *Influence of the shielding wire*

To illustrate the reducing effect of a shielding conductor, we have considered both a single-wire configuration and the same three-phase configurations examined previously with the presence of the shielding wire grounded at line extremities (conductor 4 and 5 in Fig. 3).

For the configuration with a 1 km single-conductor, the shielding wire was placed successively above and under a single phase-conductor at two different heights, namely 7 or 13 m (the single-wire height is 10 m).

Figure 6 shows the induced-voltage at line terminations of a single phase conductor with and without the presence of the shielding wire. It can be seen that the shielding wire is more efficient in mitigating the induced-voltage when it is placed above the phase conductor.

Figure 7 shows the effect of the ground wires on the induced-voltage on the three conductors. It can be seen that the peak value of the induced-voltage is significantly reduced. The induced current in the shielding wire is represented in figure 8.

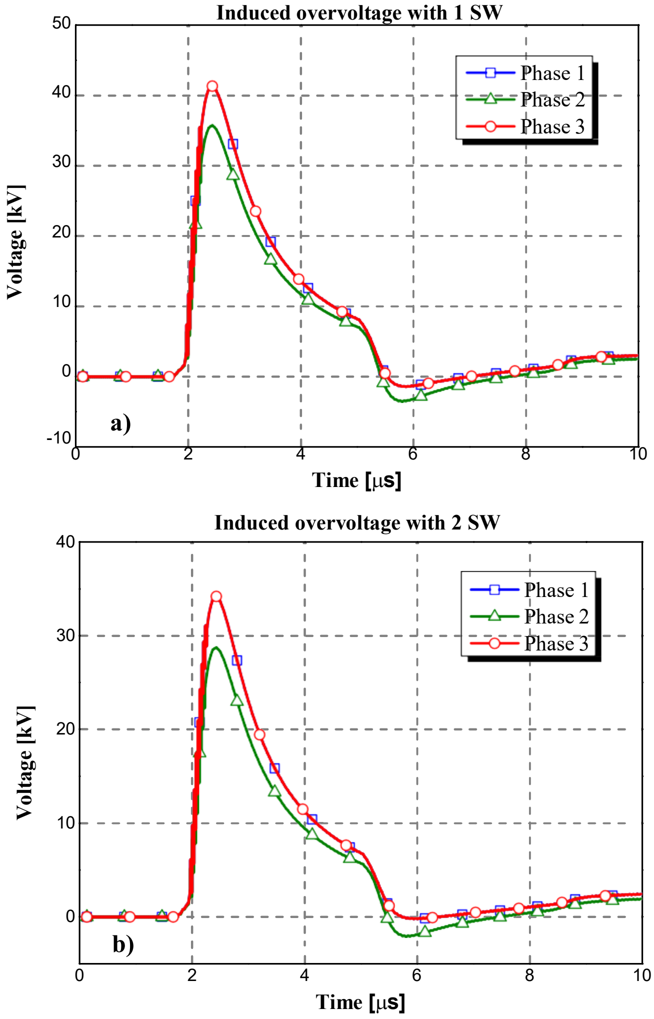

Fig. 7 Induced-voltage on the three line conductors of a multiconductor overhead line with, a) 1 shielding wire, b) 2 shielding wire

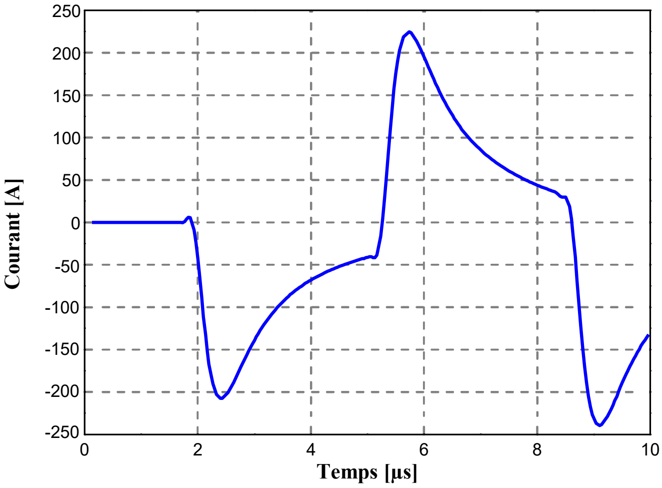

Fig. 8 Induced-current in the end of the shielding wire (Conductor 4 for the horizontal configuration).

C. Three-phase line without ground wires and with surge arresters

Besides, the line has been analysed when terminated on non-linear loads: each conductor, in this case, is terminated at both ends on its characteristic impedance R_L in parallel to a Zn-O surge-arrester, inserted to "protect" the load R_L (Fig. 9).

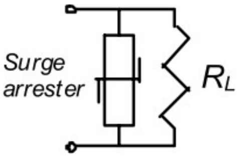

Fig.9 Non-linear load terminating the phase-conductors

The Zn-O surge-arrester has been modelled by $i=k(v/v_{ref})^n$,with k = 2,5 kA , n= 24 and v_{ref}= 40 kV (Fig.10).

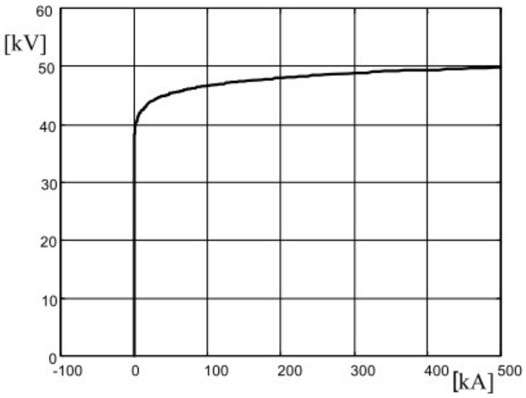

Fig.10 Characteristic of the Zn-O surge arrester [12]

The nonlinear surge-arresters play a significant role in limiting the induced overvoltages. This is well remarked in Figure. 11.

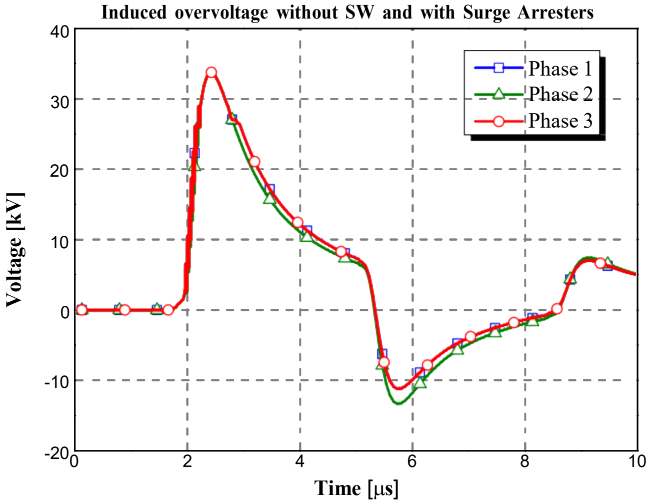

Fig. 11 Induced overvoltage on three line conductor terminated on non-linear loads

IV. SURGE PROTECTION OF SYSTEMS

The photovoltaic system coupled with an overhead network is schematized in figure. 12

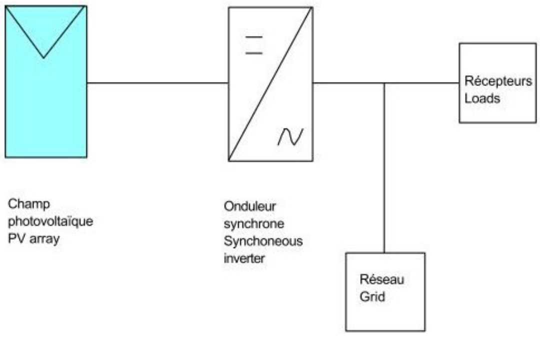

Fig. 12 PV array coupled with overhead network

The protection of photovoltaic systems coupled to the overhead electrical networks is performed primarily by limiting induced voltage by the indirect effect of a lightning strike on overhead lines (working section III).

The principle of the protection of the photovoltaic system side is carried out as follows [13]:

- Interconnection of the masses by bare copper cable between the PV array and inverter.
- Grounding of the masses.
- Floating photovoltaic generator.
- Connection PV array / inverter with reinforced protection.
- Insulation monitoring device generally integrated in the inverter.

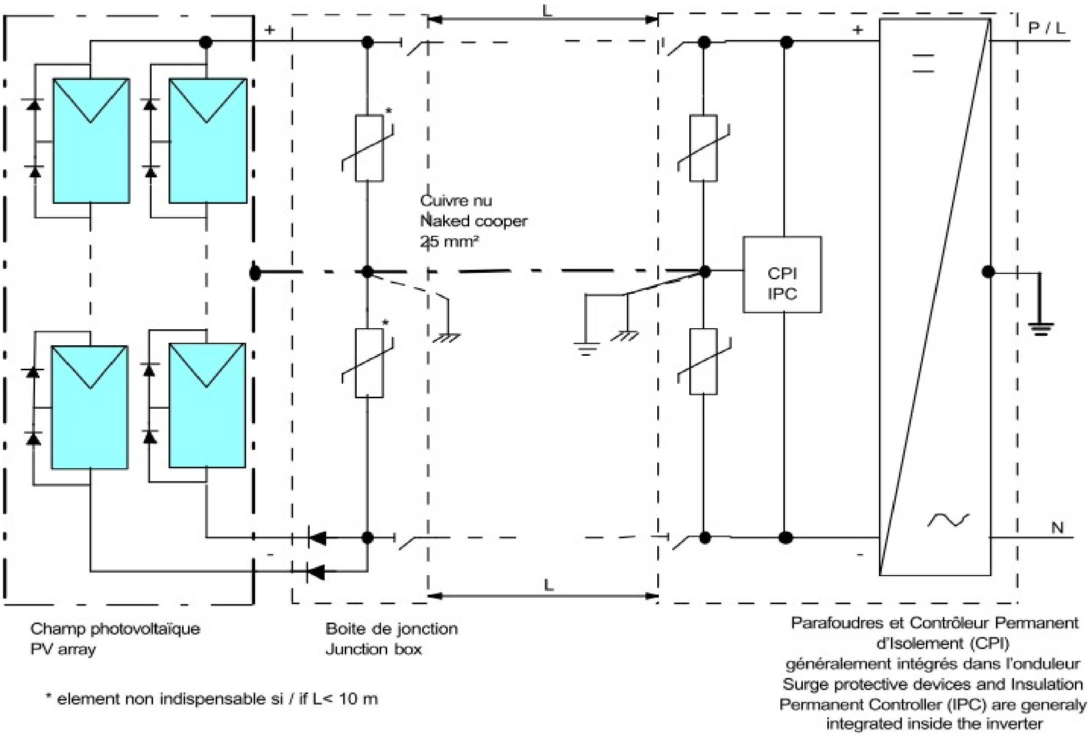

Fig. 13 protection of the photovoltaic system side [13]

- Surge arresters on DC Circuit:
  - ➢ Bipolar in junction (varistor characteristics of zinc oxide) with integrated thermal disconnection.
  - ➢ Bipolar inverter input.
- Surge arresters on alternative circuit:
  - ➢ TT modular type for high flow capacity of distributor network.

V. CONCLUSIONS

The knowledge of induced voltage will aid the designer for the appropriate design of solar power system as well as its set up in a proper way. In our study, we have observed the effect of indirect lightning strike on an overhead lines witch coupled with a solar power system.

Lightning induced-voltages on multiconductor lines are computed using MTL model for the return stroke field calculation and the Agrawal et al. coupling model for field-to-transmission line coupling calculations.

Voltages induced on 1 km long three phase power lines by a subsequent return stroke with a striking point close to the line equidistant to the line terminations have been calculated in order to assess the shielding effect of a multiconductor and the ground wire. It has been shown that:

- The induced overvoltage on a phase of a multiconductor line is affected by the presence of other conductor. For the examined cases, the induced-voltages on each of the line conductors are generally 15 to 25% lower than those corresponding to a single phase placed at the same height.
- The presence of the shielding wire allows to reduce the peak value of the induced-voltage about 40% (horizontal with two shielding conductors).
- The presence of non-linear loads (Surge arresters) at the termination of the line plays a significant role in limiting the induced overvoltages.

REFERENCES

[1] Agrawal.A.K, H.J.Price, S.H.Gurbaxani, Transient Response of Multiconductors Transmission Lines Excited by Nonuniform ectromagnetic Field, IEEE Transaction on ElectroMagnetic Compatibility (EMC), Vol. 22, N° 2 1980

[2] Diendorfer.G, and M.A.Uman "An Improved Return Stroke Model with Specified Channel Base Current", Journal of Geophysical Research, Vol 95 (D9), pp. 13621-13644, 1990.

[3] Borghetti.A, C.A.Nucci, M.Paolone, E.Petrache, and F.Rachidi "Lightning Induced Voltages on Complex Distribution Systems: Models Advanced Software Tools and Experimental Validation, Journal of Electrostatics, Vol. 60(2-4), pp. 163-174, 2004.

[4] Heidalen.H.K "Calculation of Lightning Induced Overvoltages in Low Voltages Systems", PhD Thesis, Norwegian University of Science and Technology, 1997.

[5] Ishii.M, K.Michishita, Y.Hongo, and S.Oguma "Lightning Induced Voltages on An Overhead Wire Dependent on Ground Conductivity, IEEE Transaction on Power Delivery, Vol. 9, No. 1, pp. 109-118, 1994.

[6] Master.M.J, M.A.Uman "Lightning Induced Voltages on Power Line: Theory", IEEE Transaction on Power Apparatus and Systems, Vol. 9, pp. 2502-2518, 1984.

[7] Master.M.J, M.A.Uman, W.Beasley, and M.Darveniza "Lightning Induced Voltages on Power Line: experiment", IEEE Transaction on Power Apparatus and Systems, Vol. 9, pp. 2519-2529, 1984.

[8] Nucci.C.A, and F.Rachidi "Lightning Induced Overvoltages", in IEEE Transmission and Distribution Conference, pp. 4, New Orleans, 1999.

[9] Nucci.C.A, F.Rachidi, M.Lanoz, and C.Mazzetti "Lightning Induced Voltage on Overhead Lines", IEEE Transaction on ElectroMagnetic Compatibility (EMC), Vol. 35, 1993.

[10] Wagner.C.F, and G.D.McCann "Induced Voltages on Transmission Lines", AIEE Transaction, Vol. 61, pp. 916-930, 1942.

[11] Rachidi.F, M.Rubinstein, S.Guerrieri, and C.A.Nucci "Voltages Induced on Overhead Lines by Dart Leaders and Subsequent Return Strokes in Natural Rocket-Triggred Lightning", IEEE Transaction on ElectroMagnetic Compatibility (EMC), Vol. 39, No. 2, pp. 160-166, 1997.

[12] Renato RIZZO1, Amedeo ANDREOTTI1, Andrea DEL PIZZO1, Luigi VEROLINO1, "Lightning induced effects on lossy multiconductor power lines with ground wires and non-linear loads - Part II: simulation results and experimental validation", PRZEGLĄD ELEKTROTECHNICZNY (Electrical Review), ISSN 0033-2097, R. 88 NR 9b/2012.

[13] "Protection contre les effets de la foudre dans les installations faisant appel aux energies renouvelables", Guide ADEME Agence de l’Evironnement et de la Métrise de l’Energie.