COMPUTATION OF LIGHTNING INDUCED OVERVOLTAGE ON OVERHEAD POWER LINE

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Abstract

This paper presents the results of the lightning induced voltage computation on various conductors of a 33kV, 3ϕ overhead power line with different conductor arrangements. It has been seen that the induced voltage is more on the conductors in case of a vertical configuration as compared to a horizontal configuration for single circuit arrangement. Voltages induced on the conductors closer to the strike point are more and depends on the conductor height from ground. Computations also show that presence of ground wire reduces the induced voltage on phase conductors.

1 Introduction

Lightning overvoltages on power distribution lines or communication lines may be grouped as (1)voltages caused by lightning current injection from direct strikes and (2) voltages induced due to the electromagnetic fields from nearby lightning, referred to as indirect strikes. The lightning induced voltage due to an indirect strike is an important factor in the insulation design of over head distribution lines. The voltages induced on an overhead line due to lightning return strokes in the vicinity of 50 to 500m, constitute a more dangerous cause of damage than direct strikes, because of their frequent occurrence[1,2]. The estimation of magnitude and waveshape of the lightning induced overvoltages on power lines has been the subject of several studies in the past[1-4]. The aim of this paper is to study the induced voltage magnitude and waveshape due to a nearby lightning stroke on a 33kV distribution line with different conductor configurations.

2 Theory

The evaluation of lightning induced over voltages involves

1. The specification of the spatial and temporal distribution of the lightning current along the channel from ground strike point,

2. Calculation of the electric fields produced by this channel current at the overhead line conductors and finally,

3. The induced voltage due to the coupling of these fields to the line, using a suitable coupling model, eg.,Agrawal's model[3].

For the calculation of the lightning electromagnetic fields a straight, vertical channel over a perfectly conducting ground is assumed.

2.1 Lightning return-stroke current

For the current i(0,t) at the channel base, the following analytical expression given in [1] has been adopted.

$$i(0,t) = \frac{I_0}{n} \frac{(\frac{t}{\tau_1})^m}{[(\frac{t}{\tau_1})^m + 1]} e^{(-t/\tau_2)} \qquad (1)$$

where I_0 is the amplitude of the channel-base current.
τ_1 front time constant.
τ_2 decay time constant.
n amplitude correction factor.
m exponent varies from 2 to 10
The above expression is preferred than the double-exponential function which are normally used, since it has time derivative equal to zero at t=0. Further, adjustment of the current amplitude and maximum current derivative can be done by changing I_0, τ_1 and τ_2
The adopted parameters of the function that has been used to reproduce the channel-base current waveshape of a typical return stroke is the same as that used by Nucci et.al[4]. The channel-base current waveform is shown in figure 1. The lightning-channel model used for this study is the
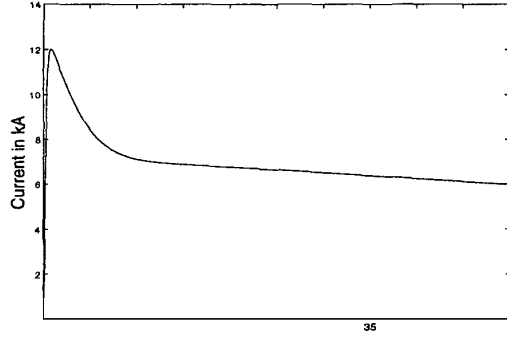
Figure 1: Lightning channel current at ground level for the return stroke model used.

Figure 2: Single line equivalent circuit of the overhead line for coupling analysis.

modified transmission line(MTL) model given by Nucci et.al.[4].

$$i(z',t) = e^{(-z'/\lambda)} i(0, t - z'/v) \qquad (2)$$

where λ- is the decay constant introduced to account for the effect of vertical distribution of charge stored in the corona sheath of the leader and subsequent discharge during the return stroke phase. v is the velocity of the return stroke and is taken as 1.3×10^8m/s.

2.2 Lightning Electromagnetic field

By assuming that earth is perfectly conducting, the vertical and horizontal electromagnetic fields radiated by a nearby lightning channel is calculated in time domain using the equations given by Uman[7]. For the vertical component of the electrical field at distances from the lightning channel that do not exceed a few kilometers, its intensity is not affected much by assuming the ground as a perfect conductor, whereas the horizontal electric field intensity is more affected by the finite conductivity of ground[4]. Still, for distances not exceeding a few hundred meters, the calculation by assuming perfect ground conductivity is reasonable.

2.3 The coupling model

The transmission-line coupling equations introduced by Agrawal et.al.[3] has been used. These equations in terms of scattered voltage, for lossless lines are given by

$$\frac{\partial}{\partial x}[v_i^s(x,t) + [L_{ij}]\frac{\partial}{\partial t}[i_i(x,t)] = [E_x^i(x,h_i,t)] \quad (3)$$

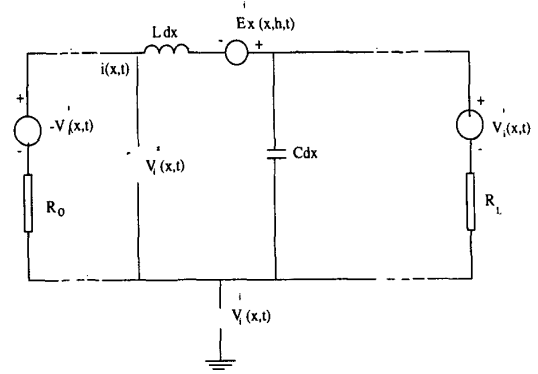$$\frac{\partial}{\partial x}[i_i(x,t)] + [C_{ij}]\frac{\partial}{\partial t}[V_i^s(x,t)] = 0 \qquad (4)$$

where $[E_x^i(x,h_i,t)]$ is the matrix of the horizontal component of the incident electric field along the x-axis at the conductor height hi, and the sub index i denotes the particular conductor of the multiconductor overhead line. $[L_{ij}]$ and $[C_{ij}]$ are the inductance and capacitance matrices per unit length of the line respectively. $[i_i(x,t)]$ is the line current matrix. $[v_i^s(x,t)]$ is the scattered voltage matrix.

The total voltage at a given point along the line is found by adding the scattered voltage $[v_i^s(x,t)]$ and the incident voltage $[v_i^i(x,t)]$. The incident voltage $[v_i^i(x,t)]$ is given by

$$[V_i^i(x,t)] = -\int_0^{h_i} E_z^i(x,z,t)dz \simeq h_i E_z^i(x,0,t)$$
$$(5)$$

E_z^i(x,z,t) is the vertical electric field that can be considered as unvarying in the height range $0 < z < h_i$ The boundary conditions for the scattered voltage vector $[v_i^s(x,t)]$ are given by

$$[V_i^s(x_0,t)] = -[R_0][i_i(x_0,t)]$$
$$+ [h_i E_z^i(x_0,0,t)] \qquad (6)$$

$$[V_i^s(x_L,t)] = [R_L][i_i(x_L,t)] + [h_i E_z^i(x_L,0,t)] \quad (7)$$

where $[R_0]$ and $[R_L]$ are the matrices at line terminations. The single line equivalent circuit of a lossless overhead line is shown in figure 2.

3 Voltages induced on overhead three phase distribution lines

To study the induced voltages due to lightning on overhead line, three different configurations of a typical 33kV, 3ϕ power line are considered.
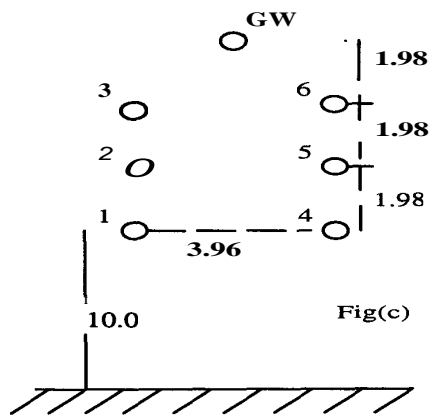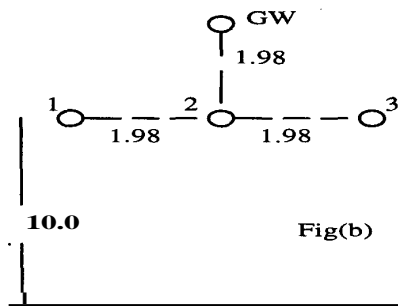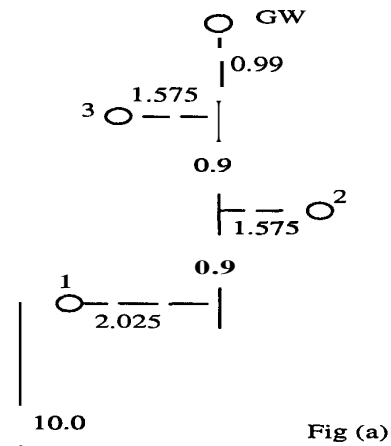
Figure **4:** Induced voltage for single circuit vertical configuration.

Figure **5:** Induced voltage for single circuit horizontal configuration.
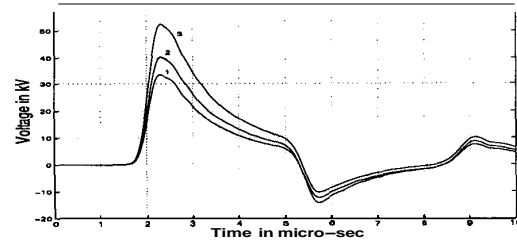
Figure 6: Induced voltages on conductors 1,2,3 for the double circuit configuration.

Figure **3:** conductor configurations used.(a) Single circuit vertical,(b) Single circuit horizontal and (c) Double circuit. GW-ground wire. All dimensions are in meters.
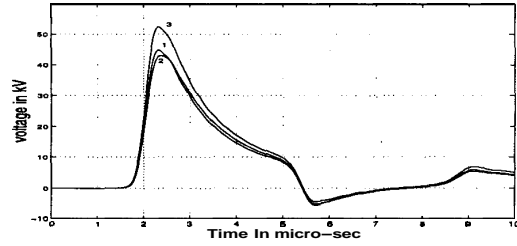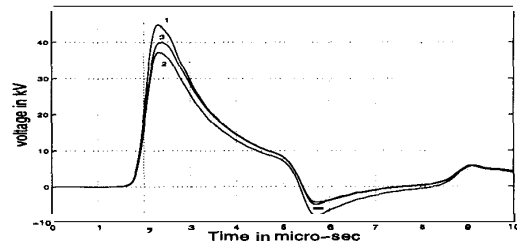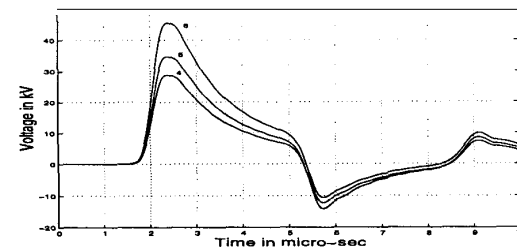

Figure **7:** Induced voltages on conductors 4,5,6 for the double circuit configuration.

The configurations studied are (1) vertical single circuit with earth wire, (2) horizontal single circuit with earth wire, and (3) double circuit with earth wire. The chosen configurations are shown in figure 3.

The length of line is taken as 1km. The radius of each of the phase conductors is 5.25mm and that of the ground wire is 2.0mm. Each conductor is terminated with a resistance equal to its characteristic impedance, and the earth wire by the tower surge impedance[6]. The calculations are done for lightning stroke at a distance of 50m from the line center and equidistant to the line terminations. The calculated induced voltage waveforms at line terminations are shown in figures 4,5,6 and 7.

4   Results and Discussion

Lightning induced over voltages on $33kV$, 3ϕ overhead line has been computed. Modified transmission line(MTL) model has been used for the computation of field radiated by a lightning return stroke channel. Coupling model proposed by Agrawal et.al. has been used for computing the induced voltages on the overhead lines due to the radiated field. It has been noticed that the induced voltage is more on the conductors in case of vertical configuration as compared to a horizontal configuration for single circuit arrangement. Voltages induced on conductors close to the strike point are more than other conductors and this again depends on the conductor height from ground. Computations have also been done without ground wire and has been observed that absence of ground wire leads to an increase in the induced voltage on the conductors. For conductors at the same height from ground and same distance from strike point, the induced voltage is less in that configuration where the total number of conductors are more, eg., in conductor 1 in double circuit line as opposed to conductor 1 in the other two configurations. This is because when the number of conductors are more, there is a mutual shielding effect coming into effect there by reducing the induced voltage.

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