STUDY OF LIGHTNING INDUCED VOLTAGES ON OVERHEAD CONDUCTORS

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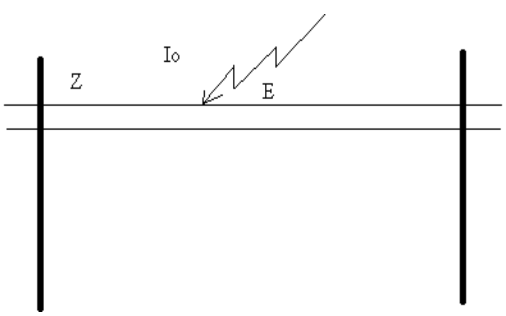
1. Introduction

Electrical power delivery consists of two parts. They are transmission and distribution. The conductors are drawn through the country area exposing them to the normal environment. For the protection of these two line systems from the surge voltages are of utmost importance for the proper operation of power system. It is needed to decide maximum transient surge voltage to set the protections (Basic insulation level) for lines and substation equipments.

Lightning over voltages are important when the distribution system is considered rather than transmission systems which have higher basic insulation levels. For lightning over voltages on distribution lines, the induced voltage due to direct stroke and induced voltage due to lightning to a near place or object are considered. In this context we are considering only voltage magnitudes but not flash densities and their occurring probabilities. The theory for deciding the voltage due to direct stroke is straight forward and to decide the induced voltage is somewhat complex. In this context we are using the equations from IEE & IEEE transactions and some other references. Using these equations we have implemented computer program to calculate the induced voltage on a distribution line of a multi-conductor system and to draw the graphs between induced Voltage vs Time. In this program we have taken into consideration the effect of a single earth wire with grounding only at one point for simplicity.

Also some effort to explain the reasons for the incident that says "Lightning surges are affected severely to the end users of the line rather than other users." has been taken in this context and we are suggesting a method for minimizing that effect.

2. Over voltage due to direct stroke



Io-Lightning current magnitude
Z- Surge impedance of the line
E- Induced voltage on the line

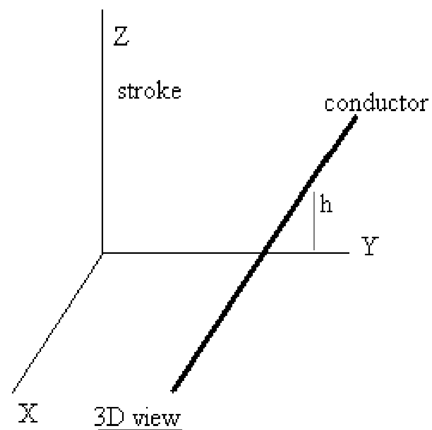
This induced voltage will travel along the line instantly to both ways from the point of strike. Voltage magnitude is given by following equation. [1]

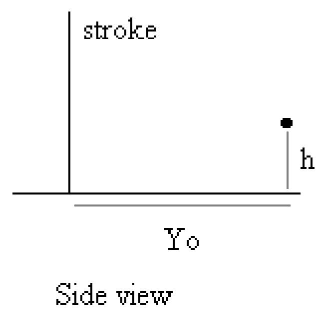
$$E = (Io/2) * Z$$

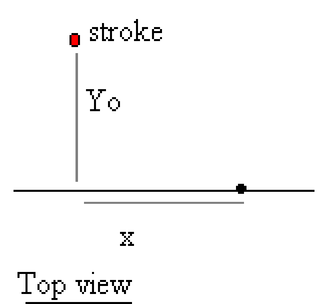
3. Induced voltage on a conductor due to lightning to a nearby place

The Chowdhuri model [2] will be used in our analysis.

3.1 Geometrical model of the position of strike and conductors.







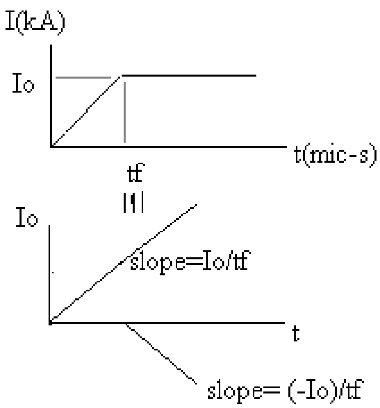
3.2 Basic assumptions

a) The lightning stroke is a vertical channel with the single return stroke originating from the ground plane at time t=0.
b) Velocity of return stroke is constant.

c) Charge distribution along the leader stroke is uniform.
d) Line conductor is loss free and earth is perfectly conducting.
e) A rectangular system of co-ordinates in space is chosen and its notation is shown in above figures.

3.3 **Equation with the correction**

For current waveform as below



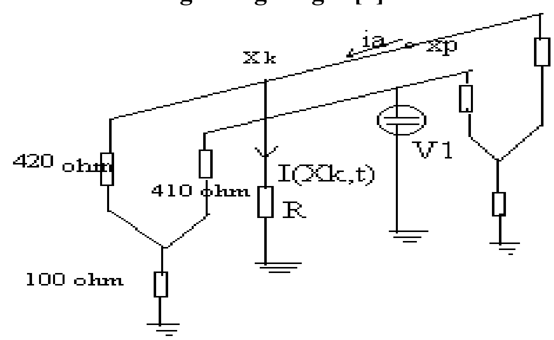
V(x,t) = u(x,t) for to < t < tf
=u(x,t)-u(x,t-tf) for t>tf
=0 for t<to

Where to=Zo/(B*c)
Zo-Retarded height of the stroke
V-velocity of return stroke where V=B*c
c-velocity of light

$u(x,t)=30*Io*h/(tf*B*c)*[\ln(q1-q2)] +60*Io*h/(tf*c)*[q3-q4]+30*Io*h/(tf*B*c) *[q5+q6+q7+q8+q9+q10+q11+q12+q13]$
$q1=[(1-B^2)*(B^2*x^2+Yo^2)+B^2*c^2*t^2*(1+B^2)]/(1-B^2)^2*Yo^2$
$q2=[-\{2*B^2*c*t*(B^2*c^2*t^2(1-B^2)*(x^2+Yo^2)\}/(1-B^2)^2*Yo^2]$
$q3=\sinh^{-1}[B*c*t/(1-B^2)^{1/2}]$
$q4= -\sinh^{-1}[B*c*to/(1-B^2)^{1/2}]$
$q5= -\ln[(c^2*t^2-x^2)/Yo^2]$
$q6=1/2*\cosh^{-1}\{(u1+p)/(p^2-q1^2)^{1/2}\}$
$q7= -1/2*\cosh^{-1}\{(uo+p)/(p^2-q1^2)^{1/2}\}$
$q8=1/2*\cosh^{-1}\{(z1+p/q1^2)/(p^2/q1^4-1/q1^2)^{1/2}\}$
$q9= -1/2*\cosh^{-1}\{(zo+p/q1^2)/(P^2/q1^4-1/q1^2)^{1/2}\}$
$q10=1/2*\cosh^{-1}\{(w+p)/(p^2-q1^2)^{1/2}\}$
$q11= -1/2*\cosh^{-1}\{(wo+p)/(p^2-q1^2)^{1/2}\}$
$q12=1/2*\cosh^{-1}\{(v1+p/q1^2)/ (P^2/q1^4-1/q1^2)^{1/2}\}$
$q13= -1/2*\cosh^{-1}\{(vo+p/q1^2)/ (P^2/q1^4-1/q1^2)^{1/2}\}$

$w=(c*t+x)^{-2}$ $wo=(c*to+x)^{-2}$
$v1=(c*t+x)^2$ $vo=(c*to+x)^2$
$u1=(c*t-x)^{-2}$ $uo=(c*to-x)^{-2}$
$z1=(c*t-x)^2$ $zo=(c*to-x)^2$
$p=(Yo^2+2*Zo^2)/Yo^4$
$q1=1/Yo^2$

4. **Analysis of effectiveness of earth wires for induced lightning surges.[3]**



$I_u(X_k,t)$-Current flowing through the earth connection at the point X_k
$U_v'(Xp,t)$-Suppressed voltage at point Xp
$U_v(Xp,t)$-Induced voltage without earth connection
Z_{vu}-Mutual surge impedence between conductor u and v.
Z_{uu}-Self surge impedence of conductor u.

$$U_v'(Xp,t) = U_v(Xp,t) -\sum_{u=1}^{m}\{1/2*Z_{vu}* \sum_{k=1}^{n} I_u[X_k,t-mod(X_k-X_p)/V_c]\}$$

Where m-number of earthing wires
n-number of earth connections for a line
$I_u(X_k,t)=[U_u'(X_k,t)]/(R+Z_{uu}/2)$

- In most cases one earth wire and one earth connection is used

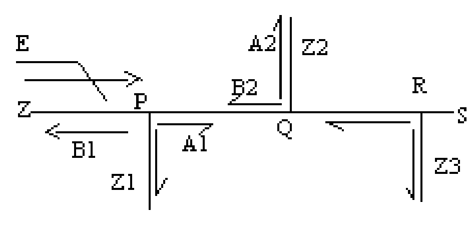
$U_i (X_p,t) = U_v (X_p,t)-Z_{vu}/(2R+Z_{uu})*U_u(X_p,t)$

- Magnitude of induced voltages is proportional to the height of the conductor.

5. **Lightning effect to the end user**

Explanation for the problem that the end user of the line is subjected to the highest effect of the lightning induced voltage.

Suppose the below simple distribution system



First reflection at point P,Q and R

P,Q and R-user points
E-Surge voltage magnitude
Z-Surge impedance of the distribution line
Z1, Z2, Z3- Surge impedances of user lines
S- End point of the line
A1, A2, A3- First transmission coefficients at P,Q and R
B1, B2, B3- First reflection coefficients at P,Q and R

Consider point P...[1] ,

$$Z' = Z*Z1/(Z+Z1)$$

$$B1 = (Z'-Z)/(Z'+Z) \qquad A1 = 2Z'/(Z'+Z)$$

- Surge impedance of distribution line is $Z = 60\ln(d/r)$
- Surge impedance of user line is $Z1 = 60/\epsilon_r \ln(d/r)$

Where d-conductor spacing
r-conductor radius
ϵ_r-relative permittivity of the insulating material of user lines.

As ϵ_r is a higher value, Z1 is small. Due to that A1 is very low. Therefore surges felt by the user (A1*E) is small at points like P & Q.

At 'S' the total surge voltage is 2E due to reflection at open end. There fore the surge voltage felt by the user at 'R' is A3*2E. So maximum surge voltage is felt by end user.

6. Methods for overcoming this problem.

6.1 By using a earthing transformer at end (S).

Surge impedance of the earthing transformer should be low so that reflection coefficient at end to be less than 1. Then total voltage due to reflection will be less than 2E.

6.2 By using a surge arrester at the end.

Use a surge arrester with discharging voltage slightly higher than the maximum operating voltage at the end. Then it limits the voltage build up at the and to a safe value.

7. Program algorithm

1) Starting the application.
2) Show the geometrical model of lightning.
3) Selection of the system without earth wire or with earth wire.
4) Selection of whether we want to calculate the induced voltage or draw the induced voltage Vs time.
5) Feed the inputs.
6) If Calculation is selected, calculate the induced voltage.
7) If drawing is selected ,draw the graph between induced voltage Vs time.
8) Present the results.

8. Conclusion

The experiments relevant to lightning is very rare, because actual lightning can not be produced in a laboratory. Therefore verifying the results are difficult. But the theoretical results satisfactorily comply with the few recordings and few experiments which have been done.

In 5th part we are only suggesting a method to explain the given incident by using our high voltage knowledge.

9. References

1) "High voltage engineering" final year lecture notes, Prof. J.R. Lucas

2) IEEE transaction on power delivery, vol. 4, No 1, January 1989. Analysis of lightning induced voltages on overhead lines, P. Chowdhuri, senior member.

3) IEE Proc., vol 127.Pt. C. No 1, January 1980. Experimental analysys of earth wires for induced lightning surges, S. Yokohama, B.E.

4) IEEE transaction on power delivery, vol. PWRD-1, No. 2, April 1986. Extention of the Chowduri –Gross model for lightning induced voltage on overhead lines, A.C. Liew and S.C. Mar.

5) IEEE transaction on power delivery, vol. 10, No 1, January 1995. Comparison of two lightning models for lightning induced overvoltage calculations, C.A. Nucci, F. Rachidi & C. Mazzetti

6) Lightning protection of pole mounted transformers and its applications in Sri Lanka, Prof. J.R. Lucas & D.A. Nanayakkara.

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8) IEE Proc.,vol. 129. Pt. C., No 2, March 1982. Lightning performance and overvoltage surge studies on a rural distribution line, A.J. Eriksson & D.V. Meal.