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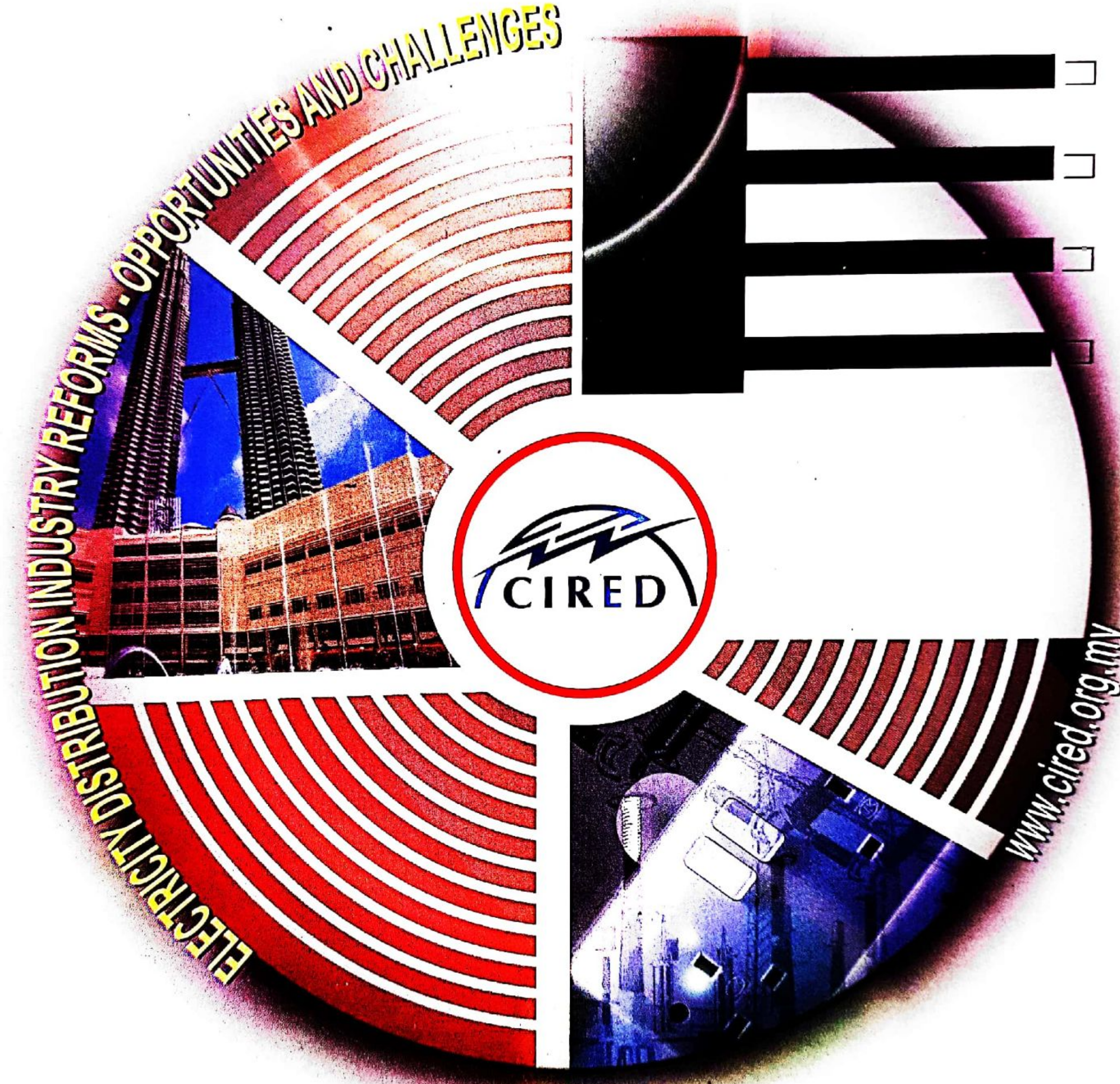

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DISTRIBUTION OPERATION & ASSET MANAGEMENT

PSCAD/MTDC Simulation of Voltage Surge Build-up on EHV Lines

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Abstract: This paper reports the simulation study of voltage surge resonance on transmission network during repetitive lightning stroke on the three-phase lines. The incident surges set up standing wave on the line by high reflection terminal components such as open circuits and transformers. Under appropriate boundary conditions the oscillating voltage surges are likely to buildup in magnitude during back and forward oscillations. This feature has been attempted to explain using PSCAD/MTDC software. The lattice diagram has been widely been recognized and adopted to analyze the voltage surge buildup at a particular location in electrical power system. These transient surges are caused by traveling waves, induced on power system by lightning strike or switching operations. The lattice diagram can be used effectively but requires extensive computations that are generally considered tedious.Without use of simulation program, this project can be difficult to do and understand. PSCAD/MTDC (Program System Computer Aided Design/Electromagnetic Transient Direct Current) was selected as the software to generate the appropriate data needed to graphically demonstrate the phenomenon of voltage surge buildup on high voltage lines.

Keyword: Lightning, Voltage Surge, Surges and Resonance

INTRODUCTION

Power systems contain, in large numbers, elements capable of storing electric and magnetic energy – capacitances and inductances (for example, capacitance of the line, inductance of the transformers and so on). Combination of these elements from a large number of oscillatory contours, hence there are large probabilities in electric systems for development of resonance phenomenon.

Resonance over-voltage are one of the most complicated type of over-voltages to analyze, since majority of inductances present in electric systems have steel cores, the magnetizing characteristics of which are nonlinear. Oscillatory processes in non-linear circuits are complicated and diverse. The processes are accompanied by rises of voltage on the elements of oscillatory contours.

The voltage surges may occur on transmission network during lighting strikes or switching operations of transformers, capacitors or reactors. The surge appears on electrical system due to release of energy stored in inductors, capacitors and clouds. The energy stored in inductors $1/2LI^2$ and capacitors $1/2CV^2$ during repetitive switching operations, external vibrating touches and partial sparking may take the form of lightning strokes due to its periodic occurrence.

Lightning transients to the low voltage system can occur from either direct strikes to the secondary circuit or strikes to the primary circuit where transient voltages pass through the distribution transformer. Although those transient which pass through the transformer are reduced in magnitude, they are not reduced by the turns ratio of the transformer (approximately 60 to 1) because the transformer windings appear, electrically, to be a capacitor. Lightning transient voltages on the utility primary are limited to equipment flashover levels (approximately 95 kV – 300 kV for a 15 kV class system) and by arrester protective levels which are approximately 40 kV crest (see Figure 1.1)

The analysis of transient surges is an integral part of an electrical system design, since Bewley first proposed the method, the lattice diagram has been recognized and adopted to analyze voltage surges effectively at a specific location of an electrical system. These method uses reflection and refraction coefficients, which are determined by the surges impedance of electrical element involved.

In this project, based on the commonly used model of three elements in series represented by their surges impedance, the voltage surge at the junction of two elements can be computed using the mathematical expression for the reflection and refraction coefficients.

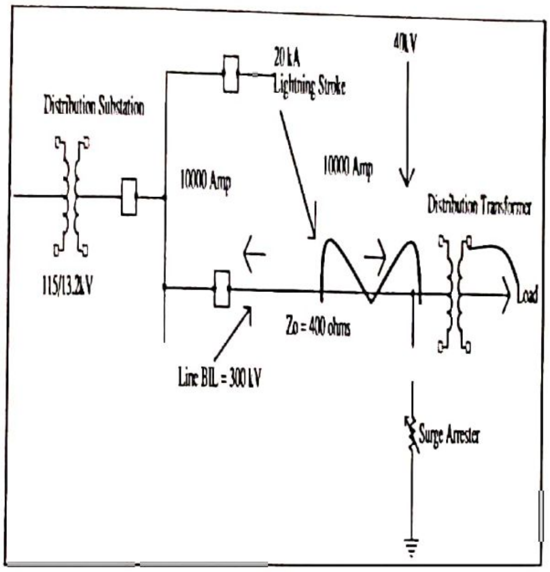

Figure 1.1. - Lightning Induced Voltage Surges

2. CASE STUDY ON VOLTAGE SURGES RESONANCE

2.1 The Bewley Lattice Diagram

The successive reflection of a traveling wave at the sending and receiving ends of a transmission line may lead to build up in the voltage or current at some points along the line. A method normally called the lattice diagram (Bewley, 1963) is applied in Figure 2.6 to the simple case of a lossless transmission line with surge impedance Z_0 connected at sending end to an infinite bus (i.e., one that has a zero internal impedance) and terminated at the receiving end by a load impedance Z. The time space diagram following the issuing of a voltage surge at the sending end of 1 p.u. is illustrated . The time taken by surge to cross the entire line is constant and denoted by T. Incident waves at the receiving end are reflected with a reflection coefficient of

$$a = \frac{Z - Z_0}{Z + Z_0} \qquad (2.1)$$

Subsequent reflections at the sending end occur with reflection coefficient of −1.

The voltage buildup at any chosen point along the line can be estimated by the algebraic summation of the voltage surge magnitudes after each surge reflection. For example, the voltage at the receiving end (R.E.) of the system can be evaluated to take the form indicated for the case :

R.E. voltage $[\, rT < t < (r+2)T \,] =$

$(1 - a)(1 - a + a^2 - a^3 + \ldots..) \qquad (2.2)$

After a sufficiently long time the receiving – end voltage in this case settles at a final value of

$$\text{R.E. voltage (final)} = \frac{1-a}{1+a} \text{ p.u.} \qquad (2.3)$$

The increment of voltage at the receiving end due to any reflection is twice the amplitude of the incident wave, because of the reflection without change of sign. Also the final voltage at this end is the sum to infinity of all such increments.

As far as the sending end is concerned, the voltage at the moment of incident of a wave sent from the far end is unity plus the amplitude of this wave. The lattice shows the amplitudes of these incident waves to be $+ a^2$, $- a^4$, and so on, successive sending-end voltages thus being 1, $1 + a^2$, 1, $1 - a^4$, 1 , and so on. Thus the voltage oscillates about unity, the amplitude of the oscillation rapidly diminishing so that eventually the voltage becomes the generator voltage of unity, as would expected.

Thus the voltage at the receiving end finally settles down to that at the sending end, and consequently the current settles down to the simple Ohm's law value E/R. The increments of voltage at the receiver end, and therefore the voltage-time and current- time curves for this end is equal to a.

2.2Surge Resonance Model

The lightning or switching surge propagates on both sides of the point incidence on transmission line. High surge impedance transformers or open lines usually bound the transmission lines or cables. The incident surge wave front is mostly reflected at transformer junction but partly is refracted into it.

Let r and t are the reflection and refraction coefficients of two transformers. The surges reflected from right hand side (RHS) transformer go to LHS transformer and upon reflection again propagate toward the RHS transformer. As the reflected surge, after a few round trips, traverses through the point of lightning strike, the arrival of second stroke may enhance its crest voltage.

This process continues till the last stroke during lightning strike is over or refracted voltage build-up is strong enough to damage the insulation of line or transformer. The impressed surge of amplitude V_o become $t_1 V_o$ due to its initial transmission from clouds or switching operations to the line. The synchronized arrival of the second stroke may amplify support the previous decaying surge.
To explain the mechanism of amplification it is supposed that the transmission system acts as gain medium during the second stroke. The change in crest voltage of the decaying surge during propagation from LHS to RHS may be given by

$$\Delta V(X) = V(X + \Delta X) - V(X) \qquad (2.4)$$

The change in voltage level is proportional to the product of V (X) and Δ X. Therefore

$$\Delta V(X) = -\alpha V(X) . \Delta X \qquad (2.5)$$

Where α is a loss coefficient. Writing equation (2.5) in differential from

$$\frac{dV(X)}{dX} = -\alpha \; V(X) \qquad (2.6)$$

Integration of equation (50 gives

$$V = V_o a^{-ax} \qquad (2.7)$$

If β is gain coefficient of reflected surge during subsequent incident lightning stroke then it will grow exponentially as

$$V = V_o a^{(\beta - ax)} \qquad (2.8)$$

The $\alpha > \beta$ during forward and backward oscillations but $\alpha << \beta$ during the time of stroke occurrence when amplification of decaying surge occurs. Let us choose an other coefficient γ such that, $\gamma = \beta - \alpha$, then (2.8) simplifies to

$$V = V_o a^{\gamma X} \qquad (2.9)$$

The above treatment tells how the exponential growth of surges occurs in the transmission medium. The process of incident voltage surge amplification is shown above. Suppose the length of resonator is such that surge transit time on one half of line equal to the time elapsed between two consecutive lightning strokes then oscillation may start under positive feedback.

Each stroke will build its own refracted voltage surge but it will not assist the subsequent refracted voltage surge due to long time difference. However, the trapped decaying voltage surge can be added up in the subsequent voltage surge so as to project an overall increased surge voltage. This is greater in magnitude than the actual 2nd stroke surge voltage. Voltage surge build up due to refraction of various surges. Final voltage build up of refracted surges mutually displaced by small intervals of time is given by

$$V_f = t_1 t_2 V_o a^{\gamma X} \left(1 + r_1 r_2^{m} e^{i\delta} + r_1^{2m} r_2^{2m} e^{2i\delta} r_1^{mm} r_2^{nm} e^{ni\delta} \right) \qquad (2.10)$$

Where δ is the phase difference between the refracted surges , n is an integral and m is the number of round trips after which second stroke arrives. The number m is equal to Ts-s / 2 T (T=v/L). The resultant voltage is given by

$$V_f = Vo\,a^{\gamma l} \left[\frac{t_1 t_2}{1 - r_1^m r_2^m e^{i\delta}} \right] \qquad (2.11)$$

If denominator in equation (2.11) becomes zero then ratio V_f / V_o tends to be infinite. Therefore

$$r_1^m r_2^m e^{i\delta} = 1 \qquad (2.12)$$

If $r_1^m r_2^m e^{i\delta} = 1$ then $e^{i\delta}$ can be equal to 1 for $\delta = n2\pi$ where n=0,1,2,3 ect. If the phase difference δ^{iii} is very small then the crest voltages of the refracted surges get accumulated and result in an overall increased potential which when exceeds the basic insulation level (BIL) results in collapse of the electrical equipment.

Due to exponential growth on the line resonator each of the succeeding strokes results in even higher built-up voltage. So the voltage builds up on the transformer junction in an exponential manner. Further work is needed on lightning strike regarding inter-stroke duration, stroke lengths and their frequency of occurrence.

RESULT AND DISCUSSION

This report will comment on the result obtained from the PSCAD/ EMTDC simulation. From the simulation of three category of length transmission line, they have some difference of the of output voltage at the transmission line.

The waveforms of the voltages to the step current injection are characterized by the exponential rise and decay, which are physically ascribe to the initial electromagnetic field expanding around the transmission line.

From the result we can see the voltage surge occur on the transmission line by measurement by the plot of graph at the line (Three Phase Line).

Simulation Result

a. Voltage surges at 2km transmission line

From the result Figure 4.0 there are shown the voltage oscillating on the transmission line when the lightning induce on the transmission line. Figure 4.1a shown the voltage surges appear on transmission line after inducing of lighting stroke. Voltage surge amplifying on the transmission line at a short time depends on the lightning induce but have high magnitude.

Figure 4.1b show the phenomena of voltage buildup on the transmission line when inducing the lightning strike at a short time. The figure also show the maximum voltage on the three phase transmission line.

Some difference value of voltage surge and voltage build up at difference distance of transmission line.

Time of lightning induce : 640µs
Voltage Surges Magnitude: 800kV
Voltage Build up : 3.8 p.u
Voltage Maximum :890kV

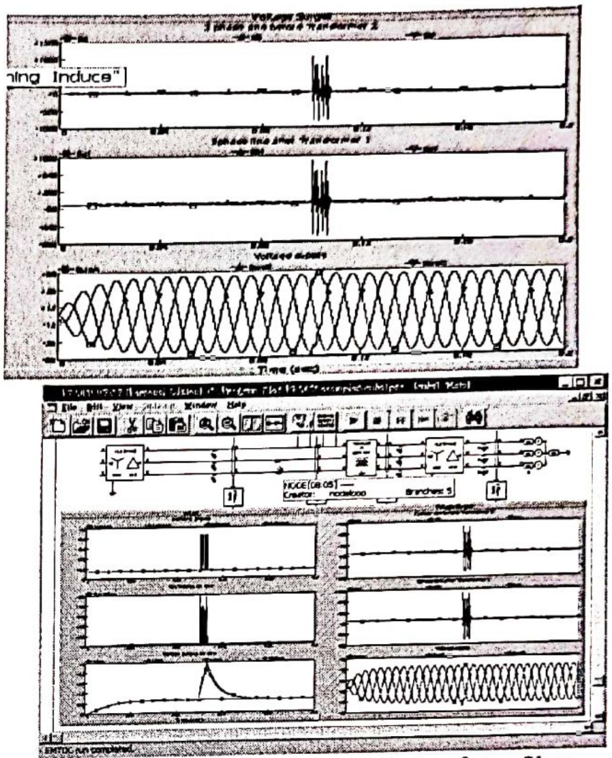

Figure 4.0 Simulation output for 2km Transmission Line

Figure 4.1a Result of voltage surges on transmission line 2km long

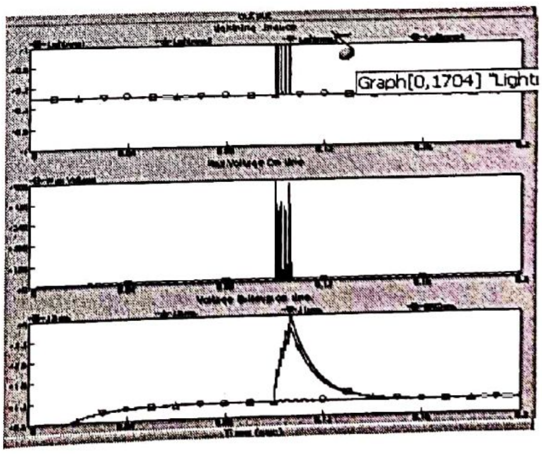

Figure 4.1b Result of Voltage Build up on the Transmission Line 2 km long

c.Voltage Surges at 50km transmission line

From the result Figure 4.3 there are shown the voltage oscillating on the transmission line when the lightning induce on the transmission line. Figure 4.3a shown the voltage surges appear on transmission line after inducing of lighting stroke. Voltage surge amplifying on the transmission line at a short time depends on the lightning induce but have high magnitude.

Figure 4.3b show the phenomena of voltage buildup on the transmission line when inducing the lightning strike at a short time. The figure also show the maximum voltage on the three phase transmission line.

Some difference value of voltage surge and voltage build up at difference distance of transmission line.

Time of lightning induce : 640μs
Voltage Surges Magnitude: 2000kV
Voltage Build up : 24 p.u
Voltage Maximum :1100kV

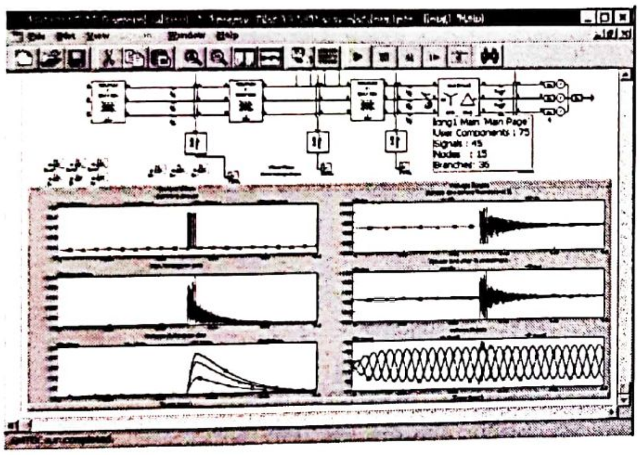

Figure 4.3 Simulation output for 50km transmission line

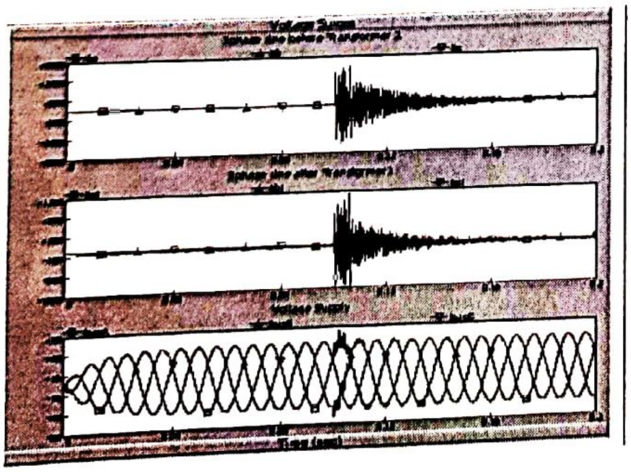

Figure 4.3a Result of voltage surges on transmission line 50km long

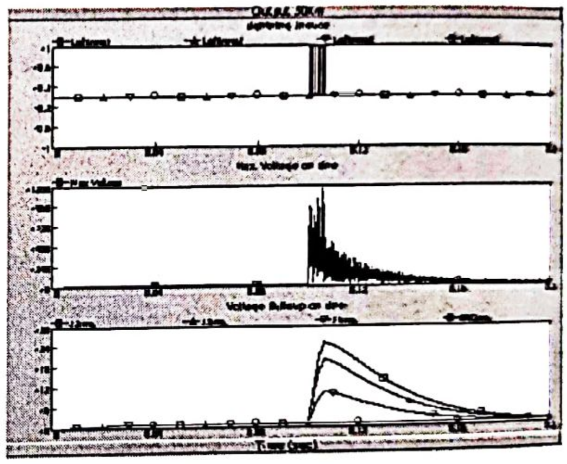

Figure 4.3b Result of Voltage Build up on the Transmission Line 50 km long

b.Voltage Surges at 10km transmission line

From the result Figure 4.2 there are shown the voltage oscillating on the transmission line when the lightning induce on the transmission line. Figure 4.2a shown the voltage surges appear on transmission line after inducing of lighting stroke. Voltage surge amplifying on the transmission line at a short time depends on the lightning induce but have high magnitude.

Figure 4.2b show the phenomena of voltage buildup on the transmission line when inducing the lightning strike at a short time. The figure also show the maximum voltage on the three phase transmission line.

Some difference value of voltage surge and voltage build up at difference distance of transmission line. (refer appendix A2)

Time of lightning induce : 640μs
Voltage Surges Magnitude: 1300kV
Voltage Build up : 7 p.u
Voltage Maximum :1000kV

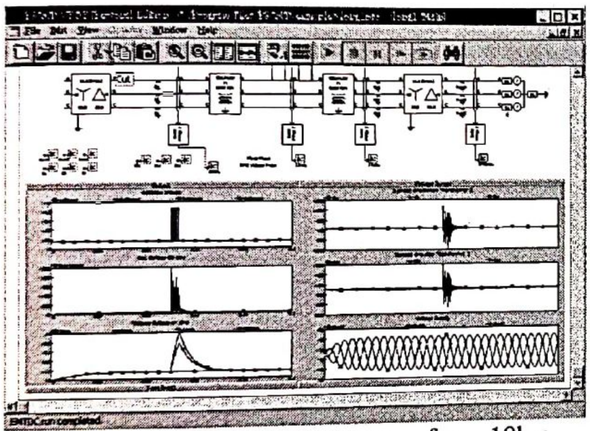

Figure 4.2 Simulation output for 10km transmission line

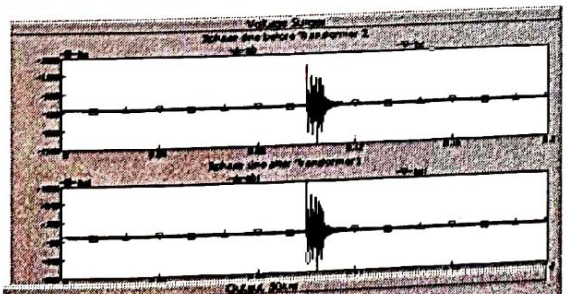

Figure 4.2a Result of voltage surges on transmission line 10km long

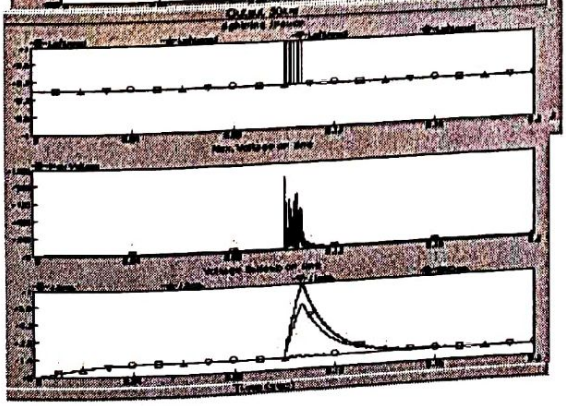

Figure 4.2b Result of Voltage Build up on the Transmission Line 10 km long

From the above three result simulation they have show some difference between three of the line difference length.. The voltage surge will occur at any transmission line ant the voltage would normalize after the lightning stroke done with some delay time. It is dependent on the transmission line distance.

After injected of the lightning stroke on the transmission line, the voltage will buildup on the line from the buildup of the voltage on the line it called voltage surges.

This phenomena will occur very shortly depends on the repetitive lightning strike on the line. The oscillating voltage surges are likely to amplify during back and forward reflections.

Discussion

From the result of the simulation the voltage surges can occur at any transmission line on the power system with no care of the voltage source, transformer winding. As we know voltage surges are one of the over-voltage causes where it can effect to the any sensitive equipment.

In Malaysia the longer length of transmission line is 100km long, so here we chose the 50km long as a longer because we use coupled PI section from PSCAD and cascade to series each one is 50km long.

From the project, the circuit diagram don't have the surges lightning arrester because here, I would like to present the phenomena of an amplifying voltage surges on the transmission line.

Conclusion And Recommendation

This project are present the voltage buildup on the transmission line during the lightning stroke by simulation the circuit using the PSCAD/EMTDC software. Where the lightning stroke are an injected to the line to see the resonance phenomena.

From the result of output we can see the difference output for difference line length where the shorter line can produce the high voltage build up on the line its because of the impedance of the line take part for the traveling wave distance.

The synchronous surge amplification model based on general theory of microwave oscillators can explain the voltage build up by short or surges on short, medium and long lines.

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