

# ANALYSIS OF LIGHTNING TRANSIENT EFFECT ON A TRANSFORMER SUBSTATION

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**ABSTRACT:** When designing the large scale of the transmission line, the risk of the lightning strikes is very important to take into consideration. Lightning strikes have been proven to be the major cause of overhead transmission line outage in Malaysia especially for 275kV line and below. Lightning is a major cause of faults on typical transmission lines. The aim of the study of this paper is to measure the voltage level at the particular points in substation to gain the result of the lightning stresses. The Basic Insulation Level (BIL) of transformer is calculated with reference of IEEE Std 1313.2-1999. The simulation results are compared with the suggested BIL. Analytical studies are also performed to compare the calculated results with the results obtained from the simulation.

**Keywords:** Substation, Lightning, Basic Insulation Level (BIL), ATP/EMTP.

## 1. INTRODUCTION

Lightning interference has been a major cause of transmission line tripping and power outage in Malaysia due to severe lightning environment [1]. Power quality concerns have created more interest in lightning however by improving lightning protection of overhead transmission lines against faults is being considered as a way of reducing the number of over voltages.

Malaysia has the highest annual average number of lightning storms. This is called isokeraunic level for an area. On average, Malaysia received 180 – 260 days per annum [2, 3]. There are two kinds of lightning interrupting in substation: one is direct lightning stroke from the power line and the other one is back flashover of transmission tower by the lightning stroke on top of the tower. The commercial transmission line has

ground wire to prevent lightning stroke, so this project will only consider the back flashover case.

From day to day, the power demand keeps increasing, so does the apparatus and the protection equipment. Most substation equipment is designed to match with the insulation coordination. To prevent the outage of the substation, the protection is needed. So to diminish this, the lightning arrester has to be placed in front of the protected equipment and protected zone. Proper selection of the lightning arrester significantly results in optimum lightning protection.

The scope of this project has been narrowed down to focus only on analyzing the BIL of the transformer at the substation. This project aims to investigate the use of arrester before the transformer substation and measure the BIL of the transformer itself. ATP/EMTP (Alternative Transients Program/ Electromagnetic Transients Program) software is a computer aided design which has been used to model double circuit 132kV transmission line, towers and also the substation for this study. Some of the major components involved in the modeling stage are phase conductor, shield wire, insulator string and tower footing resistance. Modeling of line surge arrester based on frequency dependent model is also conducted for the purpose of improving transmission line lightning performance.

### a. Modelling of 132kV Overhead Transmission Lines Tower and Substation

ATP-EMTP software has been used for modelling of 132kV overhead transmission line to simulate back flashover pattern recognition. The software is known to

be one of the best tools for analysis of power-system transient problems. However, modelling the real 132kV overhead transmission line in ATP-EMTP software for back-flashover simulation is not so easy, as past researchers were more interested on modelling higher-voltage (above 275kV) transmission-line system rather than lower-voltage transmission-line system (below 275kV).

**b. Tower and Line Parameters**

A transmission tower modelling is one of the important aspects that need to be considered in lightning surge analysis for the electric power system. Previous studies conducted have proposed variety of transmission tower modelling approaches [4]. The 132kV tower model with two ground wire is considered with two ground wire transmission line system. The transmission lines are constructed by six towers with 300m span each as shown in Figure I.1.

This work modelled a 132kV double circuit with two overhead ground wire transmission towers. The phase conductor and ground wire are explicitly modelled between the towers; five tower spans were used. This was done by terminating the phase conductor with AC operation voltages, and by grounding the shield wire. Figure 1 shows the span of five towers, with line termination at each side of the model. At the end of the tower, it is connected to the substation system.

The system developed in the ATP/EMTP software includes the actual representation of a transmission tower together with the cross arm and insulator string models. The towers are also constructed geometrically similar to that of the physical steel lattice tower as shown in Figure I.2.

**c. Cross Arm Model**

The purpose of cross arm feature in transmission tower system is to improve lightning performance of the line due to its high impulse level and good arc quenching characteristics. Cross-arms model in ATP-EMTP is expressed basically by wave impedance and calculated via the formula:

$$Z_{AK} = 60 \ln \left( \frac{2h}{r_A} \right) \tag{I.1}$$

$h$  is height of the cross- arms,  
 $r_A$  is radius of the cross- arms.

Width of the arms at junction point, for upper, middle, and lower, phases of conductor, is the same, and the three conductors have the same wave-impedance value. Width of the arms at junction point for shield wire is different from conductor's width, resulting in a different wave-impedance value.

**d. Insulator Model**

In ATP there is no specific insulator model, however, it can be modelled in several ways. For this discussion, a voltage controlled switch is used. The insulator flashover voltage can be set as the voltage at which the switch conducts if it closed. The switches are connected between the phase conductors and the tower arms.

**e. Lightning Source Model**

The lightning source model selected for this study is the Heidler type. Heidler lightning source model can be used as a current-type or voltage-type surge source. Here the source is modelled as an impulse current parallel with lightning-path impedance; see Figure I.3. The resistance value selected is 400Ω [5].

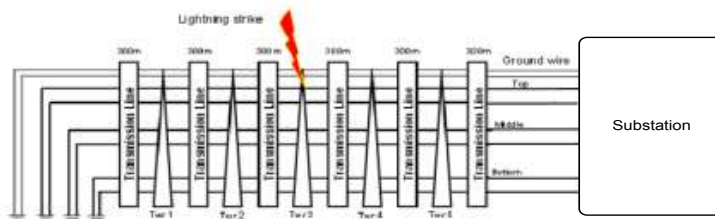


Figure I.1 Figure 1 Span of five tower

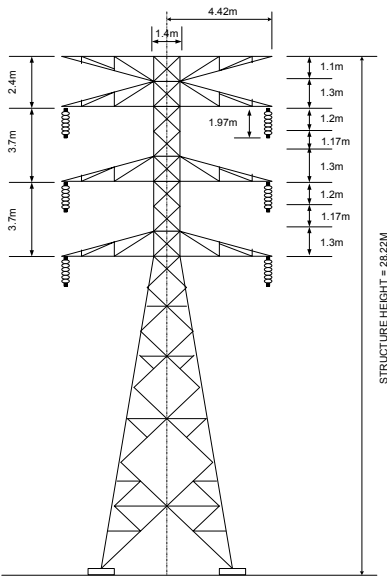


Figure I.2 132kV transmission tower model

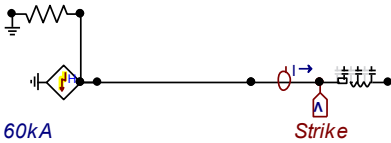


Figure I.3 Lightning model in ATP/EMTP

**f. Substation Model**

The station contains step down transformer, TR2 from 132kV to 11kV. The transformer is protected with a 98kV MCOV arrester. Each of the transformers also has a circuit breaker between it and the line terminal. The station is shielded which makes direct strikes to phase conductor is impossible in the station. The line terminal for the station is a steel A-frame that supports and insulator if desired.

**g. Transformer Model**

From a lightning study perspective, the transformer can be represented purely by a capacitance. For 132/11kV transformers the suggested capacitance is 3nF.

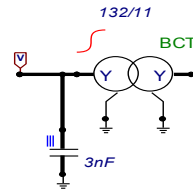


Figure I.4 Transformer Model

**h. Arrester Model**

The best method of modelling arresters is to use the non-linear resistor model. The settings of the arresters are as per voltage-current characteristics.

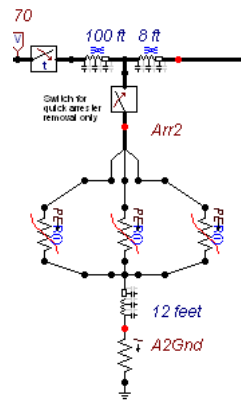


Figure I.5 Arrester Model

**II. MAIN RESULTS**

**a. Lightning Surge Simulation for 132kv transmission lines**

Lightning surge event is simulated on the double circuit 132kV overhead transmission line modelled in the previous chapter. The transmission line and towers are constructed together as waist towers using the distributed lossless parameter line model. Five towers with total height of 28.22m each are modelled in this study. The span length of the transmission line is taken to be 300m.

Lightning surge current simulated in this study is modelled based on the standard IEC triangular wave shape. Peak lightning current of different magnitudes have been used to investigate effects of shielding failure phenomenon on arrester discharge energy. Transmission line shielding failure tends to occur for

low current levels in the lightning strike even, ranging from 10,000 amps to 20,000 amps[6]. Hence, the phenomenon is simulated by injecting single stroke of 10kA, 13kA, 15kA, 17kA and 20kA to a line phase conductor of the third tower. Time to rise,  $t_r$ , is taken to be  $1.2\mu s$  while time to half,  $t_f$ , is  $50\mu s$ . Discharge energy of the arrester installed in parallel with the insulator string of the first phase conductor is measured during lightning strike event. A comparative study between the calculated and simulated results is then performed to investigate the arrester energy absorption capability in withstanding the discharge energy from lightning current.

**b. Simulation result**

Surge enters the substation from a backflash on tower 38 due to 60kA surge to the shield. No arresters are installed either on the line or at the transformer. The lightning strike current waveform is shown in Figure II.1.

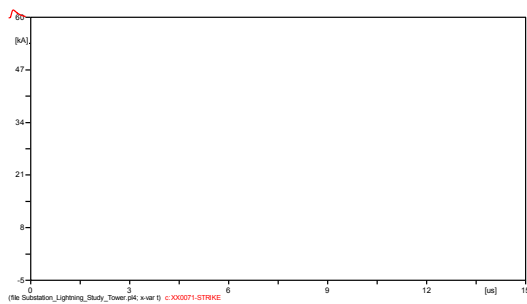


Figure II.1 Lightning strike current waveform

Following the surge:

1. Red – The voltage on C phase at tower 38. After the insulator flash over, the voltage continues to rise on the phase conductor due to the ground resistance of the tower.
2. Green – The voltage at tower 37 on C phase is delayed by the transmission line and lower in amplitude.

3. Blue – The same surge now one tower away from the substation.
4. Brown – The surge on the right bus
5. Violet – The surge has risen back to 1 million volts due to reflection of the surge at the transformer

As seen in Figure II.2, the surge starts out high, decreases as it travels to the substation and then increases again in the substation due to reflection from the transformer. This voltage rise is the reason for installing arresters at the transformer.

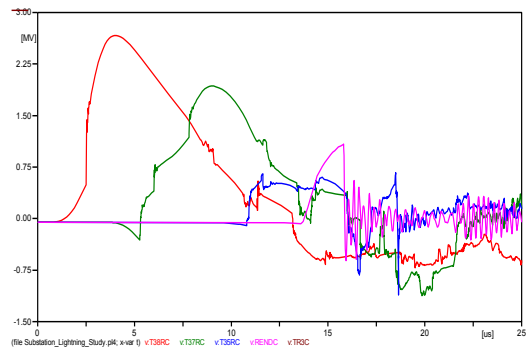


Figure II.2 Surge voltage along the line and substation

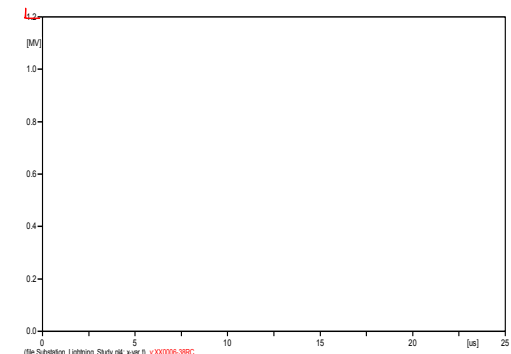


Figure II.3 Voltage across phase C insulator (lowest phase on tower) shows drop to zero indicating a flashover

In Figure II.4, 98kV MCOV arrester is installed 10ft in front of the transformer T2. Note the voltages as far back as the A-Frame is lowered by the arrester. Figure II.4 shows that the voltage at transformer and on the bus are examined closer.

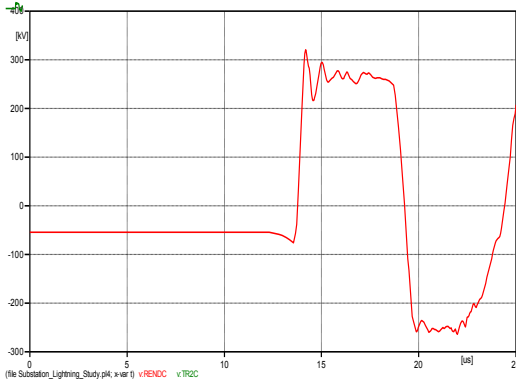


Figure II.4 Voltage on Bus and T2 after arrester is installed

Figure II.5 The current through all three arresters at T2 shows that the current through the arresters total is only 1.5 kA from the original 60kA lightning strokes. Parameters used in the modelling (transmission-line and tower models, cross-arms model, insulator-strings model, AC voltage source, tower surge impedance, tower-footing resistance, arrester, substation and lightning-strike current model) were based on reliable references.

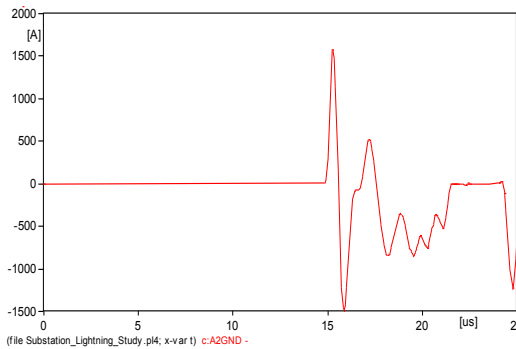


Figure II.5 The current through all three arresters at T2

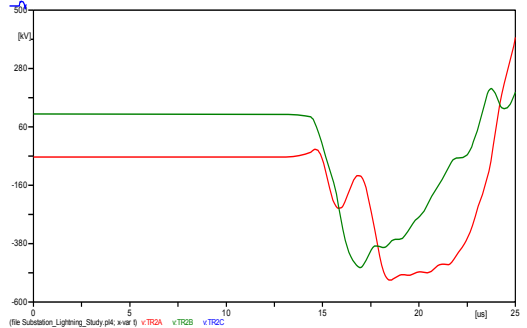


Figure II.6 Voltage at the transformer when  $C_T=4nF$

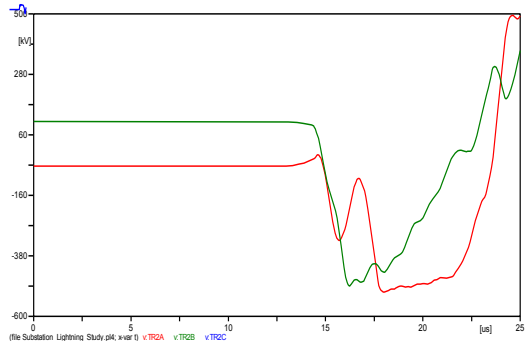


Figure II.7 Voltage at the transformer when  $C_T=2nF$

The value from the simulation and the calculation is tabulated in the Table II.1. From Table II.1 Comparison of results for single line station. The results showed that the voltages at the transformer are higher than the voltages found by the simulation in ATP/EMTP, i.e : 0% to 6.5%. The selected BIL is shown in Table II.2. The BIL produced by calculation are listed under “Req’d BIL”. These are usually non-standard values. The next highest standard BIL is selected from 4.6 of IEEE Std 1313.1-1996 and listed under “Std BIL” in Table II.1. The final “Selected BIL” is taken from the relevant apparatus standards.

Calculated, Et	Digital Transient Program	
	CT=2nF	CT=4nF
437.11 kV	464 kV	432 kV

Table II.1 Comparison of results for single line station

The next standard BIL from 4.6 [7] of IEEE Std 1313.1-1996 is 450 kV. From the applicable apparatus standard, the minimum BIL is 550 kV.

<b>Voltage</b>	<b>Crest, kV</b>	<b>Req'd BIL, kV</b>	<b>Std BIL, kV</b>	<b>Selected BIL, kV</b>
$E_t$	437.1	456.98	550	550

*Table II.2 Selection BIL for single line station*

However, to permit the impulse test of the transformer the BIL of the transformer, the BIL of the external insulation should be equal or greater than the internal BIL. Therefore, the selected BIL for the external and internal insulation is 550kV.

### III. CONCLUSION

For economic reason, the objective of the design is to select the minimum insulation strength. This is not to permit one criterion to dictate the design. In the case of the station design, if the lightning or switching surge criterion dominated the design, measures such as additional arrester may be considered. Further study and improvements are needed to have a clear assessment about the surge arrester energy duty capability and performance on lightning protection of a transmission line system. For example, an arrester with a higher energy absorption capability which exceeds design requirement of a system will definitely reduce the risk of failure but will result in an increased installation cost. Hence, proper selection of surge

arrester is essential so that it can provide required degree of protection for any specific application.

### IV. REFERENCES

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