The Analysis Results of Lightning Overvoltages by EMTP for Lightning Protection Design of 500kV Substations

Hyung-Jun Ju† and Heung-Ho Lee*

Abstract - To meet increasing power demand, 500 kV power systems are under consideration in the regions of some Middle Asian countries. As the power system voltage becomes higher, the cost for the power system insulation increases significantly. 500 kV transmission systems will become the basis of a region's power system and they require much higher system reliability. Consequently, by the methods of limiting overvoltages effectively, a reasonable insulation design and coordination must be accomplished. In particular, the Substations must be constructed to be of outdoor type. In order to determine the various factors for the insulation design, the EMTP (Electro-magnetic transient program) is used for the magnification of transient phenomena of the 500 kV systems in the planned network. In this paper, we will explain the calculation results of lightning overvoltages by the EMTP for lightning protection design for the 500 kV substations. To obtain reliable results, the multi-story tower model and EMTP/TACS model are introduced for the simulation of dynamic arc characteristics.

Keywords: EMTP (Electro-magnetic Transient Program), Lightning, Lightning overvoltage, Overvoltages, Substation, Transmission Line

1. Introduction

To meet increasing power demand, the 500 kV power ystems are under consideration in the regions of some Middle Asian countries. As power system voltage becomes higher, the cost for power system insulation is much more amplified. Also, as power system voltage becomes higher, the cost for power system insulation significantly increases. The 500 kV transmission systems will become the basis of the power system in its country and they require much higher system reliability. Consequently, by the methods of limiting overvoltages effectively, a reasonable insulation design and coordination must be accomplished.

We took into account the transient phenomena in the 500 kV transmission system and the insulation coordination criteria. The procedures of insulation coordination for the 500 kV transmission systems are;

(1) First of all, we calculated a transmission line charging current and decided a maximum operating voltage. We then reviewed the necessity of the installation of phase modifying equipment, and calculated the capacity of the circuit breaker according to transmission line charging current. Next, we reviewed a reclosing time after calculation of the transmission line unbalance factor.

(2) For transmission line insulation design, we first analyzed power frequency temporary overvoltage and decided an overvoltage target value for insulator stain. We then suggested a surface creepage distance and number of insulators, and also suggested an air insulation distance for the insulator after calculation of the criteria between phase to phase and phase to ground switching overvoltage, with utilization of EMTP for a contingency breakdown. Next, we calculated an induced current of the overhead ground wire and lightning flashover rate.

(3) For substation insulation design, we reviewed results of power frequency temporary overvoltage to calcuate the surface distance of bushing and utilized the reviewed results of switching overvoltage to calcuate air insulation distance. Also, by compare-son of international criteria for TRV (Transient Recovery Voltage) and satisfaction of calculation results, we examined the circuit breaker's transient recovery voltage rating. Moreover, we determined a screen rate for substation lightning, criteria for the lightning arrestor and BIL for each substation's facility.

But, in this paper, we would like to make clarification only concerning the calculation results of lightning overvoltages by EMTP for the lightning protection design of 500 kV substations.

To obtain reliable results, the multi story tower model and EMTP/TACS model were introduced for the simulation of dynamic arc characteristics.

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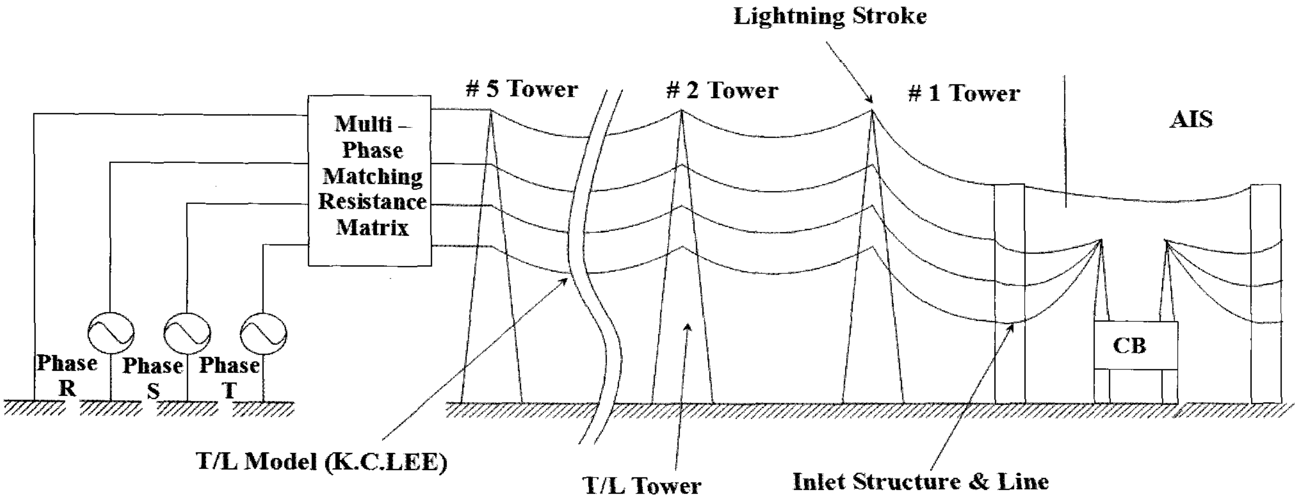

Fig. 1 Concept on the modeling of transmission line

2. Outline of Lightning Analysis Model

We can assume the lightning current that comes to the substation as either of two cases; one is the direct lightning stroke occurring on the power line and the other is the back flashover of the transmission tower by the lightning stroke occurring on the top of the tower. The commercial transmission line has ground wires to prevent direct contact with lightning, so we consider only the back flashover case here.

2.1 Lightning Current Assumption

We assumed that the occurrence of lightning stroke is on the first tower, which is nearest to the substation. The lightning surges would travel to the substation if the back flashover occurs in the tower. The assumed lightning current is 170 kA of peak, 1 microsecond wave front and 70 micro second wave tails. Fig. 1 and 2, and Table 1 show the simulation conditions for lightning surge calculation by EMTP.

2.2 Transmission Line and Transmission Tower

The power line conductor is 330㎟ ACSR 4 bundle conductor having 40 cm spacing, and the ground wire is ACSR 97 ㎟ having a single conductor. The average span was assumed to be 500 meters. The transmission tower is arranged up to 5 towers from the substation, and the rest of the towers are modeled as matching resistance matrix to prevent the reflection of the traveling wave. In the calculation, we obtained the resistance matrix value by EMTP/LINE CONSTANTS.

The frequency independent K.C.Lee model is used because the surge frequency is very high in the lightning phenomena and the calculated result is identical to that of the frequency dependent model. The standard of tower footing resistance is 10 ohms for the modeling. The tower model directly affects the wave shapes of lightning surges that appear on the arcing horn gap. So the three section tower model with distributed line parameters is used for the high accuracy transmission tower model.

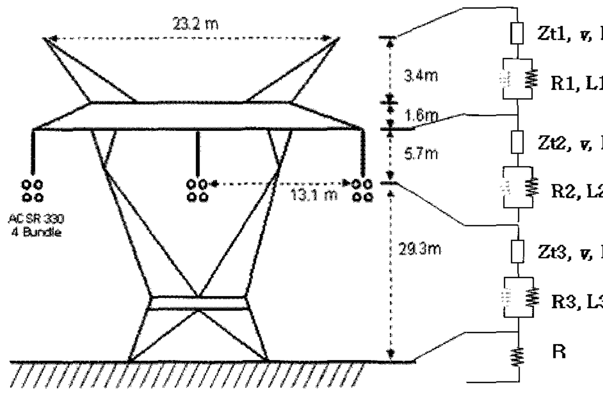

Fig. 2 Tower Configuration

Table 1 Analysis Condition for Substation Bil Design

	applied parameter	base model	remark
Lightning Condition	Magnitude	170kA	
	wave front	1/70㎲ Triangular wave	
	Superposition of Power frequency	Yes	
	Stroke point	Top of No.1 Tower	
Transmission Line	T/L model	Line constant	
	Conductor Type / number of bundles	ACSR 330, 4 conductor	K.C.LEE Model
	Tower model/span	Two step ,500m	
	Footing Resistance	10Ω	
Substation&Power plant	Circuit condition	Three circuit/ single bundle	
	AIS	Yes	
	LA characteristic	Yes	

In Fig. 2, the electrical parameters are as follows;

- Tower heights between arms (H1, H2, H3) are 5.0, 5.7 and 29.3 meters, respectively.
- Equivalent resistance between arms (R1, R2, R3) are 22.95, 26.16 and 33.48 ohms, respectively.
- Equivalent inductance between arms (L1, L2, L3) are 6.12, 6.98 and 8.93 micro-Henry, respectively.
- Tower surge impedance between arms (Zt1=Zt2) is 220 and Z t3 is 150 ohms.

2.3 Arching Horn Gap Model with EMTP/TACS

The arcing horn gap can be modeled as a time controlled switch or linear arc inductance with time controlled switch or nonlinear arc inductance with controlled switch.
Among these models, the nonlinear arc inductance model is the most accurate one that can represent the dynamic arc characteristics of arcing horn gap. We used the linear inductance model because we do not have any experimental data for that.

2.4 Substation Layout and Operating Conditions

We calculated the surge impedance of substations according to EMTP/LINE CONSTANTS. The type of the model substation is AIS, 1.5 circuit breaker systems, which has one transmission line and two transformer banks.

To investigate the most severe operation condition, we classified it as three circuit conditions; one is for protecting the incoming of AIS, which includes the surge arresters, the second is for buses and circuit breakers and the last is for the main transformer. Fig. 5 is the line diagram for lightning surge analysis of 500 kV S/S.

2.5 Surge Arrester Characteristics

The surge arrester characteristics and its location are very important when simulating a lightning surge. Rated voltages and current of arrestors for 500 kV systems are recommended as shown in Table 2.

Table 2. Arrester rating for 500 kV systems

System Voltage [kV]	Volatge rating [kV]	MCOV [kV]	Nominal discharge current [kA]	Residual Volatge [kV]	Line Discharge Class
500	420	340	20	1220	4
Impulse (8/20μs)					
1kA	3kA	5kA	10kA	20kA	40kA
944	977	999	1042	1085	1194

2.6 Tower Footing Resistance

Table 3 Analysis Results

	Calculated Voltage [kV]	BIL [kV]	margin [%]
Incomong	1,281	1,550	21
Bus	987	1,550	57
Transformer	987	1,425	47

$$\text{Margin} = \frac{\text{Test Volt.} - \text{Max Volt.}}{\text{Max.Voltage}} \times 100\ [\%]$$

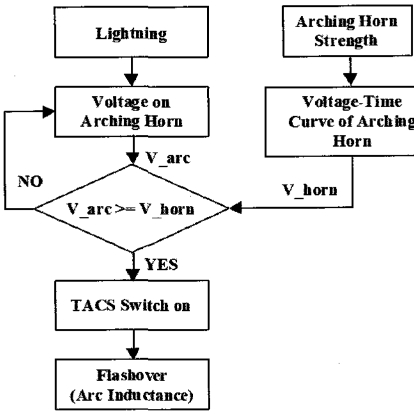

Fig. 3 Flow Chart of Arcing Horn and TACS

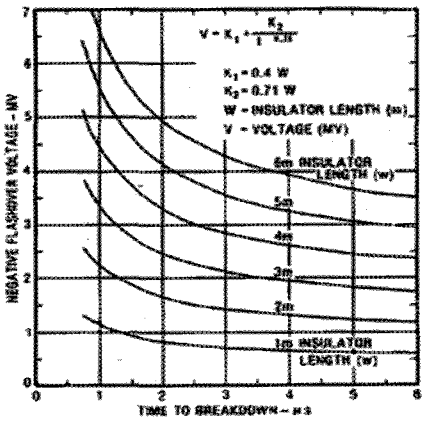

Fig. 4 CIGRE volt-time characteristics for flashover of line insulators

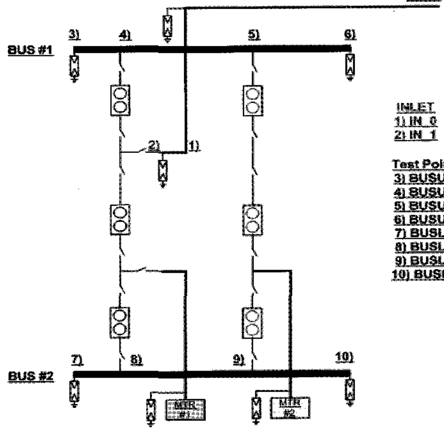

Fig. 5 Diagram for lightning surge analysis

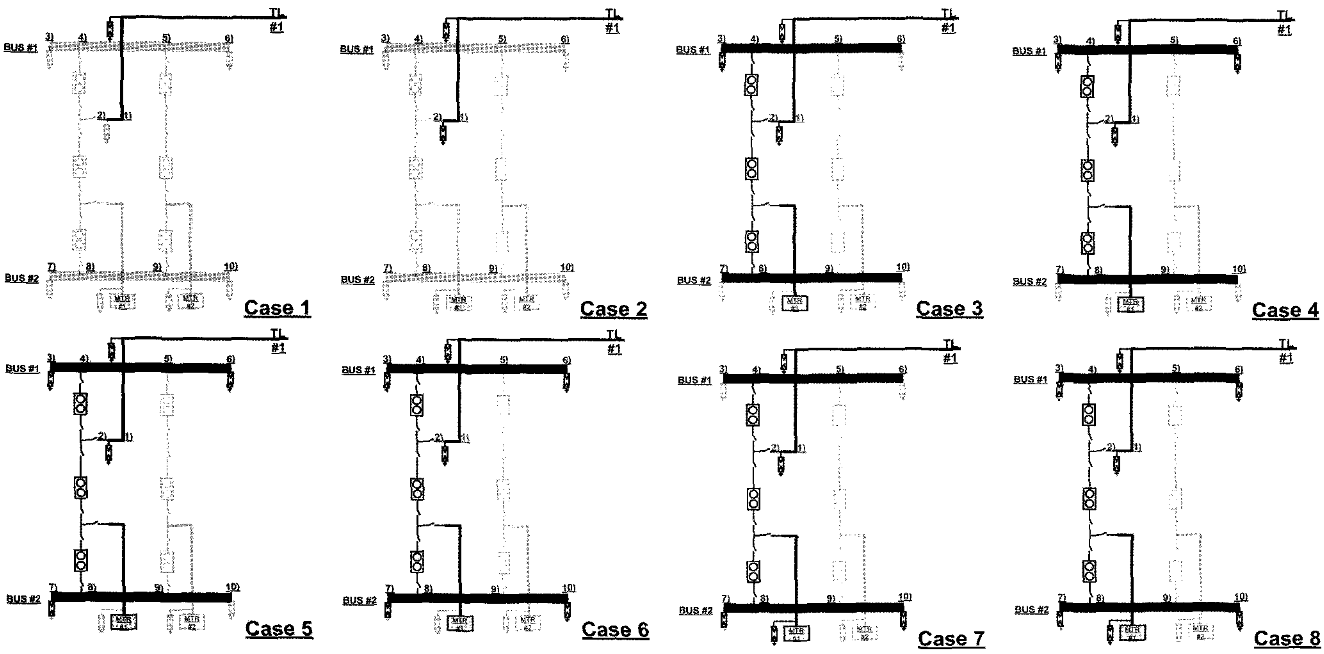

Fig. 6 Example of each operating condition

We represented the earth resistance as a concentrated pure resistance considering the most severe condition, because the transient voltage time characteristics of the tower footing resistance are not yet specified. The represented value of the tower footing resistor of the transmission tower is 10 ohms, however 10 to 50ohms are used for comparing the result with another, whereas the resistance of the mesh of substation is set to 1 ohm.

3. Analysis Results

We examined the variation of overvoltage at the substation according to the location of the arresters. Fig. 6 is the example of each operating condition at 500 kV S/S.

First, for optimal insulation design, we installed the surge arrester at the incoming point of the line. So, we had considered the first simple case as Case 1 in Fig. 6, which has one arrester at the incoming point of the transmission line and power is charged from the line to the front of the circuit breaker.

The maximum overvoltage that appears on the connection point between incoming and bus is 2,184 kV, which is bigger than 1,550 kV (BIL). Fig. 7 shows the waveform of calculated overvoltages of Case 1.

From this result, we conclude that the connection point needs to have a surge arrester installed for suppression of overvoltages. By installation of the surge arrester at this point in Case 2, we can obtain lower overvoltages.

The maximum overvoltage is 1,281 kV, which has 21 percent of margin to the test voltage of 1,550 kV.

Cases 3, 4, 5, and 6 are for confirming the location of surge arresters at the bus. At the first two cases (Cases 3 and 4), the maximum overvoltages are 1,735 kV and 1,722 kV, which are higher than 1,550 kV (BIL). From this, both ends of each bus require the installation of a surge arrester. After installation of the surge arrester at these points in Case 6, the maximum overvoltage is 987 kV.

Without the surge arresters at the MTR in Cases 7 and 8, the maximum overvoltage is 1,216 kV. After installation of the arresters, the maximum overvoltage that appears on the transformer is 957 kV, which has 47 percent of margin to the test voltage of 1,425 kV. Fig. 8 shows the waveform of the calculated overvoltages of Case 8.

From these results, we selected the installation location for the surge arrester as follows.

- Incoming of the line
- Connection point between incoming and bus
- Each end of the bus
- Transformer primary side

4. Conclusion

It was found from the simulation results that overvoltage at the substation varies according to the location of arrestors and each operating condition at 500 kV S/S. From the results, we recommended the installation location of the surge arresters for lightning surge protections. With the installation of arresters, we confirmed that the overvoltage does not exceed the insulation level for lightning surge with the proper margin.

- The maximum overvoltage that appears on the income-ing point is 1,281 kV, which has 21% of margin to the test voltage of 1,550 kV.
- The maximum overvoltage that appears on the bus is 987 kV, which has 57% of margin to the test voltage of 1,550 kV.
- The maximum overvoltage that appears on the transformer is 957 kV, which has 47 percent of margin to the test voltage of 1,425 kV.
- The overvoltage does not exceed the basic insulation level for lightning surge with proper margin to the test voltage.

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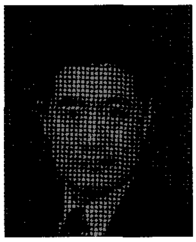

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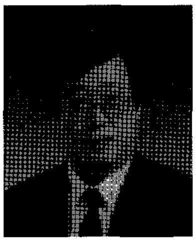

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