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

J. W. Woo, J. S. Kwak, H. J. Ju, H. H. Lee, J. D. Moon

Abstract--To meet increasing power demand, the 500 kV power systems are under consideration in some regions of Middle Asia country. As the power system voltage becomes higher, the cost for the power system insulation greatly increases. The 500 kV transmission system will become the basis of 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 have to be accomplished. Especially, the Substations will be constructed as outdoor type. We had calculated about the transient phenomena of the 500 kV power systems. 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 in the planned network. In this paper, we would like to explain about the calculation results of lightning overvoltages by EMTP for lightning protection design of 500 kV Substation. To get the reliable results, the multi-story tower model and EMTP/TACS model were introduced for the simulation of dynamic arc characteristics.

Keywords: Lightning, Transmission Line, Substation, Overvolt ages, EMTP(Electro-magnetic Transient Program)

I. Introduction

To meet increasing power demand, the 500 kV power systems are under consideration in some regions of Middle Asia country. As the power system voltage becomes higher, the cost for power system insulation is much more increased. As the power system voltage becomes higher, the cost for the power system insulation greatly increases. The 500 kV transmission systems will become the basis of 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 have to be accomplished.

We had considered the transient phenomena in the 500 kV transmission system and the insulation coordination criteria. The procedures of insulation coordination for the 500 kV transmission system are;

(1) First of all, it is calculated a transmission line charging current and decided a maximum operating voltage and then, reviewed a necessity of phase modifying equipment installation's whether or not, and calculated a capacity of circuit breaker according to transmission line charging current, and reviewed a reclosing time after calculation of unbalance factor of transmission line.

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

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

But, in this paper, we would like to explain only about the calculation results of lightning overvoltages by EMTP for lightning protection design of 500 kV substations. To get the reliable results, the multi story tower model and EMTP/TACS model were introduced for the simulation of dynamic arc characteristics.

II. Outline of Lightning Analysis model

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

A. Lightning Current Assumption

We assumed that the lightning stroke is on the first tower, w hich is nearest to the substation. And the lightning surges woul d travel to the substation if the back flashover occurs in the to wer. The assumed lightning current is 170 kA of peak, 1 micro second wave front and 70 micro second wave tails. Figure 1, 2 and table 1 show the simulation conditions for lightning surge calculation by EMTP.

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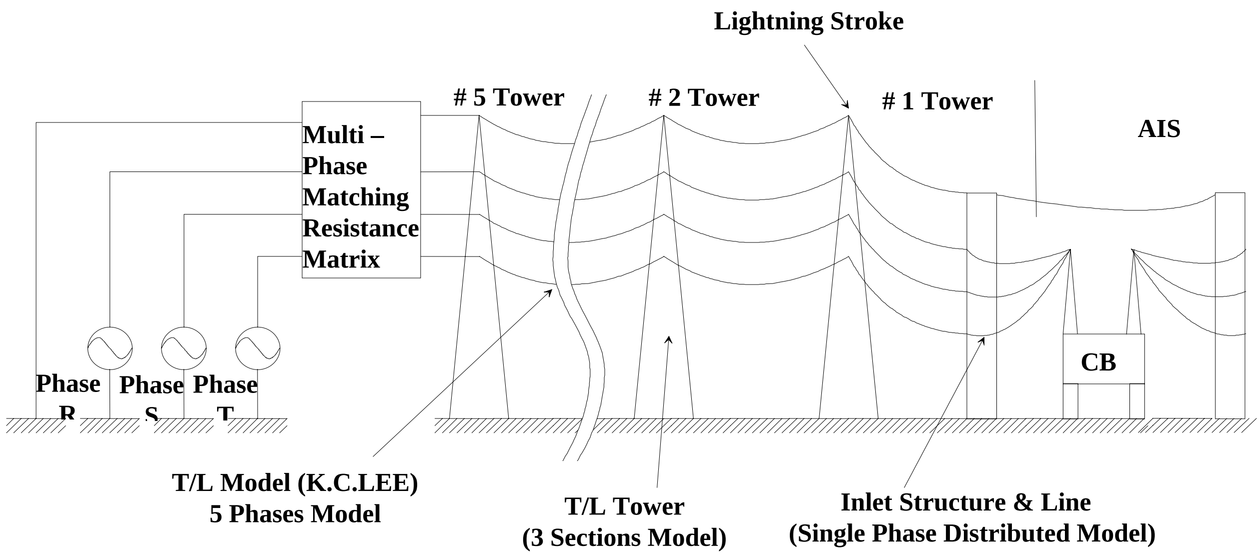

Fig. 1. Concept on the modeling of transmission line

TABLE I
BASIC 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	

B. Transmission Line and Transmission Tower

The power line conductor is 330 ㎟ ACSR 4 bundle conductor has 40 cm spacing, and the ground wire is ACSR 97 ㎟ with single conductor. 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 got 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 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 which appears on the arcing horn gap. So the three section tower model with distributed line parameters is used for high accuracy transmission tower model.

In the figure 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.

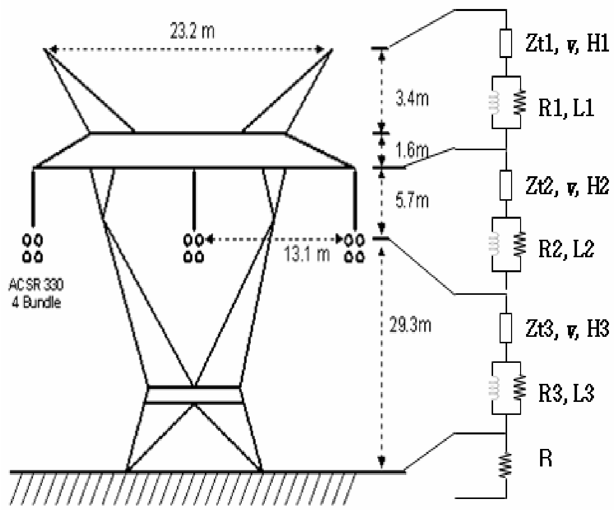

Fig. 2. Tower Configuration

C. 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 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.

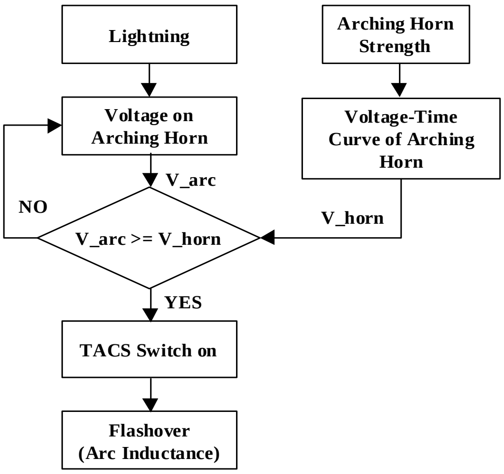

Fig. 3. Flow Chart of Arcing Horn and TACS

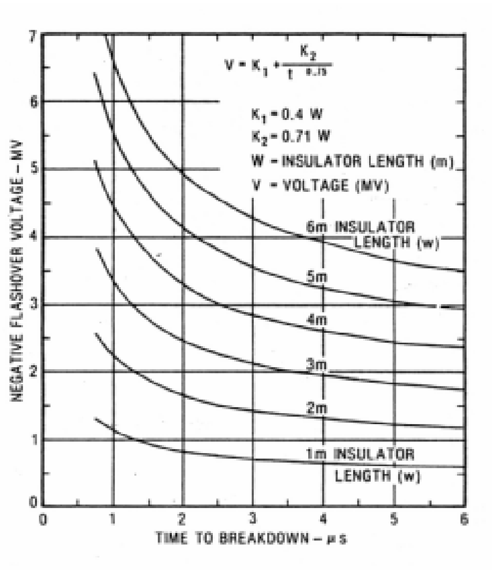

Fig.4 CIGRE volt-time characteristics for flashover of line insulators

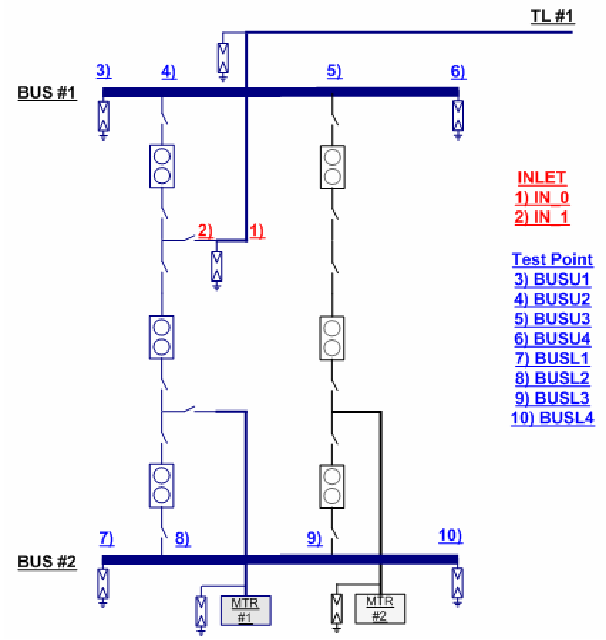

Fig. 5 diagram for lightning surge analysis

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

D. Substation Layout and Operating Conditions

We calculated the surge impedance of substations according by 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; the one is for protecting the incoming of AIS which include the surge arresters, the second one is for buses and circuit breakers and the last one is for main transformer. Figure 5 is the line diagram for lightning surge analysis of 500 kV S/S.

E. Surge Arrester Characteristics

The surge arrester characteristics and its location are very i mportant to simulate the lightning surge. Rated voltages and cu rrent of arrestors for 500 kV systems are recommended as sho wn in table 2.

F. Tower Footing Resistance

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 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.

III. ANALYSIS RESULTS

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

First, for optimal insulation design, we will install the surge arrester at the incoming point of the line. So, we had considere d the first simple case as case 1 in figure 6, which has one arres ter at incoming point of transmission line and power is charged from line to the front of circuit breaker.

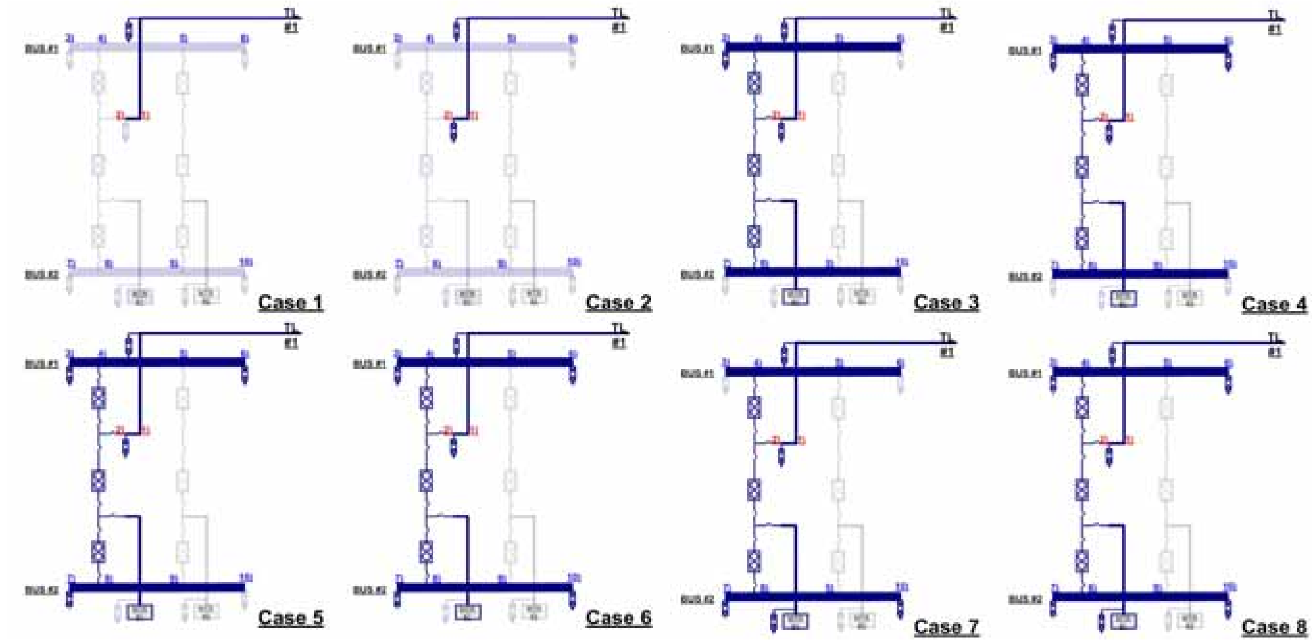

Fig.6 Example of each operating condition

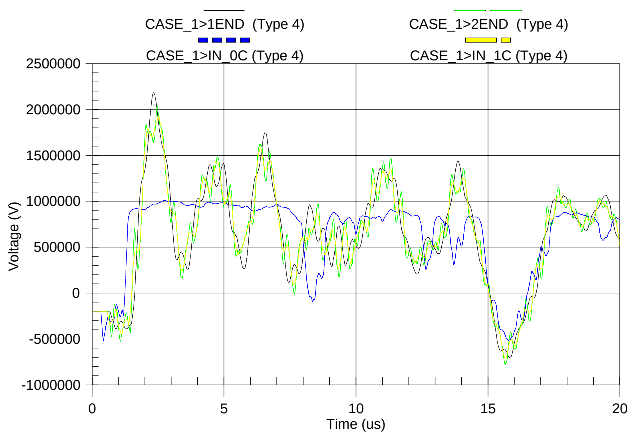

Fig. 7 Example of overvoltages (case 1)

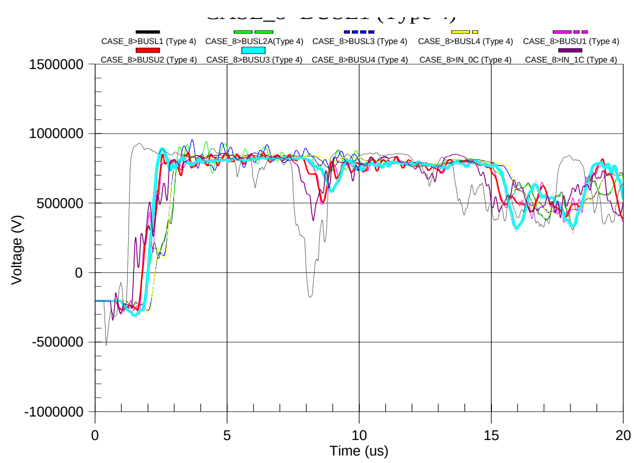

Fig. 8 Example of overvoltages (case 8)

TABLE 3
ANALYSIS RESULTS

	Calculated Voltage [kV]	BIL [kV]	margin [%]
Incoming	1,281	1,550	21
Bus	987	1,550	57
Transformer	957	1,425	47

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

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

From this result, we conclude that the connection point needs to install the surge arrester for suppression of overvoltages. By installation of the surge arrester at this point in case 2, we can get lower overvoltages. The maximum overvoltage is 1,281 kV, which has 21 percent of margin to the test voltage of 1,550 kV.

Case 3, 4, 5, and 6 are for confirming the location of surge arresters at the bus. At first two cases (case 3 and 4), the maximum overvoltages are 1,735 kV and 1,722 kV, which are higher than 1,550 kV(BIL). From this, the both ends of each bus need to install the 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 Case 7 and 8, the maximum overvoltage is 1,216 kV. After installation of the arrester, the maximum overvoltage which appears on the transformer is 957 kV, which has 47 percent of margin to the test voltage of 1,425 kV. Figure 8 shows the waveform of calculated overvoltages of case 8.

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

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

IV. CONCLUSION

It was found from the simulation result that overvoltage at the substation varies according to the arresters location and each operating conditions at 500 kV S/S. From 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 proper margin.

- The maximum overvoltage which appears on the incoming point is 1,281 kV, which has 21 % of margin to the test voltage of 1,550 kV.
- The maximum overvoltage which appears on the bus is 987 kV, which has 57 % of margin to the test voltage of 1,550 kV.
- The maximum overvoltage which 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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