

Research on Lightning Over-voltage Protection for 500kV GIS Substation

Zhuo Wang

School of Electric and Information Engineering

BeiHua University

Jilin Province, China

Email: wwzz_6666@163.com

Lei Li, Ling xia Gan, Ning Li, Hong tao Li

College of Electrical and Information Engineering Changsha

University of Science & Technology

Hunan Province, China

Email: lilei0728@163.com

Abstract—This paper combines incoming lines with 500kV GIS substation, considering the influence of the impulse voltage-second characteristics of insulator strings, the impulse corona of incoming lines, the impulse grounding resistance of tower and the position of lightning. ATP-EMTP simulation program is applied to analyze the lightning over-voltage of 500kV GIS substation. The result shows that impulse corona and the resistance of tower which is close to the substation have great influence on over-voltage, when lightning strike the tower which is close to terminal door-typed structure, the lightning over-voltage may be not the most serious, and when the over-voltage of the equipment is very serious, a group of arrester is installed which can decrease the over-voltage effectively. This research thinking takes safety and economy into account, which can provide new reference for the engineering.

Key words—GIS substation; impulse corona; grounding resistance; position of lightning; over-voltage

I. INTRODUCTION

With the 500kV power transmission project construction and development, the electric power scientific research and design units are gradually in depth study and test, calculation and analysis of lightning incoming surge protection of 500kV substation as an important part has also made great progress. However, a number of scheme is not practical, some of them just over-emphasis on insulation margin not considered from the view of economic; some only through unilateral calculation gives scheme which left hidden troubles for safety. The 50% discharge voltage of insulator string as invaded wave was selected as in literature [1-2], such that method to select is not

recommended because the impulse voltage-second characteristics of insulator strings change with time. The impulse grounding resistance of tower and impulse corona was ignored as in reference [3], according to the actual situation in view, the model appears to be conservative and rough. The lightning strike spots was chosen 1[#] tower which close to door-typed structure (0[#] tower) as most serious to deal with, in some cases may be correct but not all cases. A large number of studies have shown that 1[#] tower top potential was reduced as 1[#] tower near 0[#] tower when lightning strike 1[#]. A large number of studies show that a large number of studies have shown, when the lightning strike 1[#] tower which is next to the terminal gate-type framework, top potential of the 1[#] tower is reduced, because the negative reflection wave return to the 1[#] tower by 0[#] tower, which make the overvoltage decreased^[4]. So only calculation lightning strike 1[#] is not complete.

This paper combines incoming lines with 500kV GIS substation, considering the influence of the impulse voltage-second characteristics of insulator strings, the impulse corona of incoming lines, the impulse grounding resistance of tower and the position of lightning. ATP-EMTP simulation program is applied to analyze the lightning over-voltage effect about distant and near impact grounding resistance, the position of arrester which provide new reference for the engineering.

II. MODEL FOUNDATION AND PARAMETER SELECTION

ATPDraw is the most widely used on a electro-magnetic transient simulation, due to the graphic interface, makes this software convenient and accuracy by using. In this research,

lightning models, transmission line models, tower model, arrester model, all of that be defined based on the characteristics of parameter, the transformer, disconnector, breaker etc, all of these can be expressed by equivalence impact entrance capacitance under the lighting wave.

A. The equivalent circuit diagram of 500kV GIS Substation

As shown in figure 1: this is a equivalent circuit diagram of 500kV GIS Substation, considering the security of system, "One Bus One Transformer" was chose as the most serious running model of lighting over-voltage to simulation computation. As shown in figure: CVT is capacitor voltage transformer; DS is disconnector; CT is current transformer; CB is circuit breaker; F is arrester; T is transformer

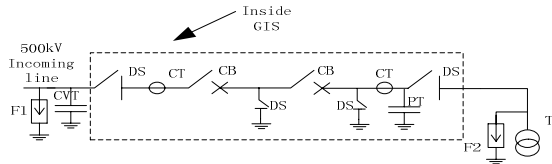


Figure 1. Equivalent circuit diagram of 500kV substation

B. Lightning Simulation

Lightning current is belonging to unipolar pulse wave, China's standards recommended by lightning current amplitude probability distribution as follows:

$$\lg P = -\frac{I}{88} \quad (1)$$

In this equality, I is lightning current, P is the probability of amplitude greater than I. This article taking the probability of 0.14% amplitude is 240kA wave of 2.6/50us as simulation lightning current.

C. Insulator Strings Simulation

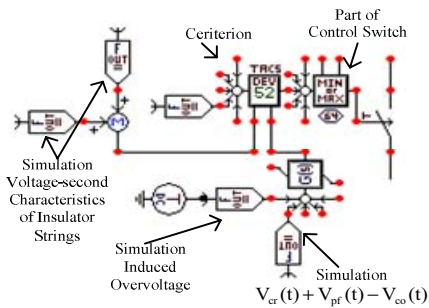


Figure 2. The model of insulator strings

As shown in Figure 2 is Insulator strings model, when the induced over-voltage is higher than voltage-second characteristics of insulator strings, the control switch will keep this export state which the part of criterion passed to 25 pieces of insulators of XP-160 style is used in this article the voltage-second characteristics of insulator strings which structure linear coefficient to close by least square method. The voltage-second characteristics as shown in table. I

TABLE I. THE VOLTAGE-SECOND CHARACTERISTICS OF INSULATOR STRINGS OF 500KV

$t / \mu s$	2	3	4	5	7	10	14
V_+ / kV	3330	2830	2630	2500	2330	2260	2200

The function of voltage-second characteristics of insulators is structured by linear regression analysis in matlab. The exponential function after calculation is that:

$$u(t) = 2169.1 + 993.9e^{-t/4} + 853.5e^{-t/1.5} + 3669.5e^{-t/0.8} \quad (2)$$

D. Incoming line of substation simulation

This article choose 2 kilometer incoming line simulation 6 tower, lightning strike TW1[#], TW2[#], TW3[#] is considered.

Tower simulation: The tower which lightning strike use natural size distributed parameter simulation, In this article the tower of wave impedance is 115Ω, wave velocity is 210m/us.

Incoming line parameter: The conductor is 4×LG-300, bundle spacing is 400mm, diameter is 23.94mm, average height is 27m, arc sag is 17m, the dc resistance is 0.09614Ω/km under 20℃; The lightning shield line is OPGW-140A, diameter is 15.7mm, average height is 37m, arc sag is 15m, the dc resistance is 0.51Ω/km under 20℃.

E. Corona Simulation

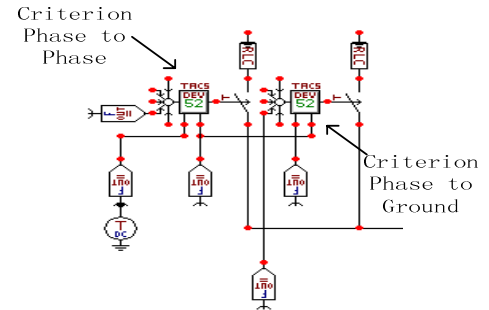


Figure 3. The model of corona

In order to research the wave attenuation and distortion influence on results the corona is considered in this article. Reference [5-6] show that the conductance can be ignored only use dynamic capacitance to simulate the attenuation and distortion under lightning over-voltage. The combined model of TACS is used to simulation based on the lines of corona characteristics in this article, The DEVICES in Fig.3 is criterion which phase to phase and phase to ground to start corona.

F. Parameters of arrester

The enclosed type ZnO arrester is installed inside of GIS, the open type ZnO arrester is installed outside of GIS. The electrical characteristics of ZnO arrester shown in table. II

TABLE II. THE ELECTRICAL CHARACTERISTICS OF ZNO ARRESTER

Level	Rated voltage (kV)	DC 1mA Ref Voltage (kV)	8/20 μ s Impulse Residual Voltage (kV)	
			10 kA	
			20 kA	
500kV	444	597	1015	1106
	420	565	960	1046

III. EFFECT OF VARIOUS FACTORS UNDER LIGHTNING INCOMING SURGE

A. Position of lightning strike

The tower 0[#] to 2[#] is named near region tower which impulse grounding resistance is 15 Ω , The tower 3[#] to 6[#] is named far region tower which impulse grounding resistance is 20 Ω . The over-voltage of equipment on Single line single transformer under different lightning strike position as shown in the table.III

TABLE III. THE OVER-VOLTAGE OF DIFFERENT POSITION OF LIGHTNING

Lightning Strike Spot	T (kV)	CVT (kV)	PT (kV)	GIS Casing (kV)
TW1	1042	1040.5	1035.1	1030.2
TW2	1183.2	1174.8	1158.6	1097.6
TW3	891.3	830.3	801.8	807.3
TW6	883.9	785.3	789.9	790

According to table.III the over-voltage of lightning strike TW2[#] is more serious than TW1[#]. In research if chose lightning strike TW1[#] as most serious condition to deal with is unreasonable it will bring security hidden danger.

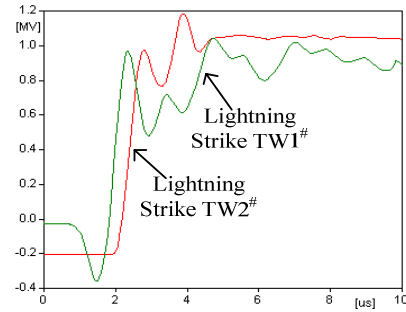


Figure 4. The wave of over-voltage on transformer when lightning strike different tower

The wave on transformer under lightning strike is shown in fig.4, then the following conclusions are drawn: the steepness of striking TW1[#] is greater than TW2[#], the transform have different distance from the transformer, so there is a certain delay in the wave. TW1[#] short distance away from the substation, the lightning wave negative reflection to TW1[#] and reduce the over-voltage.

B. Impulse Corona

To make study convenient the corona was ignored so there had a certain error. This article discuss the effect of corona in actual. When corona produced, there have volume and velocity greater difference negative and positive ions around conductor form corona envelop. The corona envelop can increase the capacitance and conductance of conductor. The wave which lightning strike TW2[#] considered corona as shown in fig.5

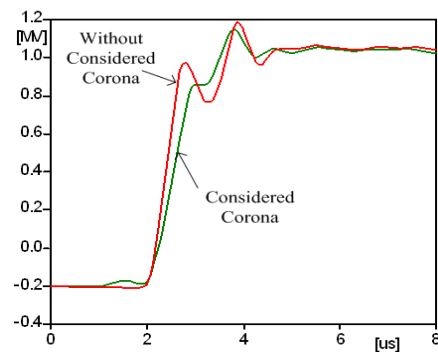


Figure 5. The Voltage Waveform of Transformer

The following conclusions can be found according to fig.5: There have attenuation and distortion and also have a certain delay under corona. The maximum over-voltage value on transformer is 1152.4kV when considered corona else is 1183.2kV, the decay caused by corona is 30.8kV. Corona have favorable for over-voltage protection which can reduce the amplitude and steepness.

C. Impulse Grounding Resistance of Tower

In order to make study convenient, the impulse grounding resistance of TW0[#]~TW2[#] expressed as near region resistance labeled as R1, and the TW3[#]~TW6[#] expressed as far region resistance labeled as R2. Change R1 and R2 the over-voltage of equipment is shown in table.IV

TABLE IV. THE OVER-VOLTAGE OF DIFFERENT GROUNDING RESISTANCE

R1	R2	T(kV)	CVT(kV)	PT(kV)	TG(kV)
15	15	1182.9	1173.9	1184.7	1097.5
	16	1182.9	1174.2	1184.7	1097.5
	17	1183.1	1174.5	1184.7	1097.5
	18	1183.3	1174.8	1184.7	1097.6
10	20	1178.4	1158.3	1171.9	1089.9
15		1183.2	1174.8	1184.7	1097.6
16		1184.6	1178.5	1187	1121.8
17		1186.1	1181.6	1189.2	1154.9

As shown in the table.IV smaller impulse grounding resistance, the lower over-voltage in equipment. When the R2 decreasing, the voltage decrease slightly; when the R1 decreasing, the voltage decrease more. For example, resistance reduce 1Ω, the over-voltage reduce thousands of kV. Therefore, reduce near region impulse grounding resistance have great significance for limit over-voltage level and save cost.

D. The position of arrester

In order to analyze the effect that the number and the position of arrester, this article calculated as follows: (1) add a set of arrester on outgoing line; (2) remove the arrester of transformer; (3) remove the arrester of outgoing line; (4) remove the arrester both outgoing line and transformer. The transformer and CVT configuration model of Y10W5-420/960

arrester and The most serious condition “Single line single transformer, lightning strike TW2[#]” is chose.

TABLE V. ANALYZE FLUCTUATE THE AMOUNT OF ARRESTER ON SINGLE LINE AND SINGLE TRANSFORMER

Operation mode	T(kV)	CVT(kV)	GIS BUSHING (kV)	PT(kV)
Present configuration	1183.2	1174.8	1097.6	1174.8
(1)	1012.4	1072.9	1058.5	1059.9
(2)	1752.2	1376.3	1501.7	1635.2
(3)	1278.8	1542	1363.4	1209.9
(4)	3118.1	2893.1	2971.2	2852.7

From the table.V we can conclusion that:

1. Install arrester have a large extent reduce the over-voltage, once remove the arrester transformer or outgoing line the over-voltage on equipment increase significantly even exceed insulation level.
2. The configuration of arrester at present, the over-voltage on transformer still very high, the insulation margin only 12.23%.
3. When add a set of arrester on outgoing line, the over-voltage of equipment have decreased significantly. The insulation margin have rise to 24.89%.

IV. CONCLUSION

(1)According to the simulation in the past, it was generally believed that the over-voltage caused by lightning strike TW1[#] was most serious, this paper shows that, lightning strike TW2[#] may have more serious. Only choice strike TW1[#] as the largest over-voltage to deal with is unreasonable, it will leave security hidden danger.

(2) There have attenuation and distortion and also have a certain delay under corona, it is favorable for over-voltage protection which can reduce the amplitude and steepness.

(3) Smaller impulse grounding resistance, the lower over-voltage in equipment. when near region impulse grounding resistance decreasing, the voltage decrease more. The resistance reduce 1Ω, the over-voltage reduce thousands

of kV. Therefore, reduce near region impulse grounding resistance have great significance for limit over-voltage level and save cost. As reference [3] ignore all of these effects will be bring a great error.

(4) The over-voltage on transformer is still high according to the present configuration. The over-voltage levels decrease if add a set of arrester in outgoing line. It can provide reference for the engineering.

REFERENCES

- [1] LIU Qing and ZHANG Yu-feng, "Research on protection Against Lightning Over-voltage on Transformer in a 220kV GIS Substation," High Voltage Apparatus. China, vol. 44, pp. 329-331, April 2008.
- [2] LIU Qing, "Research on Lightning Intruding Waves in 220kV Baoneng Gas Insulated Substation," High Voltage Apparatus. China, vol. 44, pp. 329-331, April 2008.
- [3] CHEN Liangjin and LI Wenyi, "Study on the protection of lightning Intruding Waves in 750kV GIL-GIS System," High Voltage Engineering. China, vol. 31, pp. 39-41, June 2005.
- [4] GU Dingxie, "The Research on Lightning Over-voltages of 500kV Transmission Engineer Design," High Voltage Engineering. China, vol. 26, pp. 60-62. June 2000.
- [5] X. R. Li, O. P. Malik, and Z. D. Zhao, "A practical mathematical model of corona for calculation of transients on transmission lines," IEEE Trans on PWRD, vol. 4, pp. 1145-1152. Feb 1989.
- [6] S. Carneiro, "Evaluation of corona and line models in electromagnetic transients simulations," IEEE Trans on PWRD, vol. 6, pp. 334-342. Jan 1991.

Author Biographies

Zhuo Wang: was born in Jilin China in 1968. Received Master degree from University of Science & Technology Beijing in 2005. Associate professor in Beihua University, The major researches include Theory and Application of Intelligent Control, Computer Control, High-voltage teaching and research, etc.

Lei Li: was born in Hubei China in 1984. Master candidate in Changsha University of Science & Technology. The major interesting include lightning protection and grounding technology. E-mail: lilei0728@163.com

Lingxia Gan: was born in Jiangxi in 1985 and is studying in the High Voltage Department, School of Electrical Engineering, changsha university of science and technology, The main research direction is lightning protection and grounding technology.

Ning Li: was born in Hunan China in 1985. Master candidate in Changsha University of Science & Technology. The major interesting include high voltage and insulation technology

Hongtao-Li: was born in Shanxi China in 1980. Master candidate in Changsha University of Science & Technology. The major interesting include control theory and control engineering.