

Research on Lightning Over-voltage and Lightning Protection of 500kV HGIS Substation

Tong Wang^{1, a*} and Youping Fan^{1, b}

¹School of Electrical Engineering, Wuhan University, Wuhan 430072, China

^awtwhu2010@163.com, ^bypfan@whu.edu.cn

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Abstract. To ensure safe and reliable operation of the substation, avoid the equipment damage caused by lightning wave invasion, which threatens the safe operation of power system, it is necessary to research the influence factors of the substation lightning overvoltage and lightning protection measures. Taking a 500kV HGIS substation as the research object, a simulation model is established. Based on EMTP-ATP, this paper simulates the lightning striking the top of the tower and back-flashover occurring at the coming line of transmission line. Based on the principle of single variable, the factors which affect lightning overvoltage amplitude was studied, the change rule of amplitude was summarized. By configuring the quantity of arrester and the location of installation, through simulation, it determined that installing arresters at the line entry and GIS bus is the most reasonable lightning protection scheme.

Introduction

As the hub station of "west-to-east transmission" project, 500 kV substation plays an extremely important role in the power system. The equipments of substation once suffer damage to the over-voltage, which will seriously affect the safe and reliable operation of power system. And in all power system accidents, the lightning accident generally accounted for more than 50%, which has become the main threat to the safe operation of substation [1].

Taking a 500kV substation as an example, this paper chooses the appropriate simulation scheme, and establishes a complete substation lightning overvoltage simulation model by using EMTP-ATP [2,3]. According to the principle of the single variable, the influence factors of lightning over voltage amplitude are studied including lightning, tower resistance, power frequency voltage, and the variation of the voltage amplitude are determined. The paper presents some reasonable lightning protection scheme of substation, and the most appropriate protection scheme is defined by comparing the simulation results and considering the reliability, safety and economy requirements, which provides practical guidance and reference for 500 kV substation lightning protection [4].

Model foundation and parameter selection

Lightning simulation. In order to make a more accurate quantitative analysis, this paper uses the Heidler function to simulate the lightning, which is recommended by International Electrical Commission (IEC) [5],

$$i(t) = \frac{I}{h} \cdot \frac{(t/t_1)^n}{1 + (t/t_1)^n} \exp(-t/t_2) \quad (1)$$

where I_0 is lightning current amplitude, t_1 is wave head time constant, t_2 is the wave tail time constant, h is the correction factor of lightning current amplitude, n is the steepness factor of lightning current, and $n = 10$.

In the simulation calculation, the lightning wave head time and amplitude are determined according to China's current lightning current amplitude probability distribution as follows,

$$\lg P = -\frac{I}{88} \quad (2)$$

where I is the lightning current amplitude, P is the probability of amplitude greater than I . This paper taking the probability of 0.35% amplitude is 216kA wave as simulation lightning current.

Tower simulation. There are three kinds of tower simulation method at present, including lumped inductance model, single wave impedance model and multi wave impedance model. The multi wave impedance model is chosen in this paper. And because when lightning invasion wave spreads on the tower, the wave impedance is different in different parts, the tower is divided into segments to calculate the wave impedance of different parts of the tower.

The Eq. 3 is used to calculate the wave impedance the main part of the tower,

$$Z_{Tk} = 60 \left(\ln \frac{2\sqrt{2}h_k}{r_{ek}} - 2 \right) (k=1,2,3) \quad (3)$$

where h_k is the height of each tower, r_{ek} is the corresponding equivalence radius.

The Eq. 4 is used to calculate the equivalent radius of each section of the tower,

$$r_{ek} = 2^{1/8} (r_{Tk}^{1/3} r_B^{2/3})^{1/4} (R_{Tk}^{1/3} R_B^{2/3})^{3/4} \quad (4)$$

where r_{Tk} is the width of steel in each section of the tower, r_B is the width of steel in tower

footing, R_{Tk} is the width of each section of the tower, R_B is the width of the tower footing.

According to the actual operation experience shows that, wave impedance of the tower with bracket tends to be about 10 percent less than that without bracket, so wave impedance of tower with bracket is 9 times the corresponding main wave impedance, as follows,

$$Z_{Lk} = 9Z_{Tk} \quad (5)$$

The Eq. 6 is used to calculate the wave impedance of each cross arm of the tower,

$$Z_{Ak} = 60 \ln \frac{2h_k}{r_{Ak}} \quad (6)$$

where h_k is the height of corresponding cross arm from the ground, r_{Ak} is equivalent radius of corresponding cross arm, and its value is 1/4 of the width of the junction position between cross arm and tower main part.

Insulator strings simulation. In this paper, the pilot measure recommended by CIGRE and Rizk is used as the pilot flashover criterion of insulators. When the field intensity of the gap is greater than the initial field intensity (35 kV/cm) of the streamer, flashover occurs. And in the development of the pilot, if the applied voltage is less than the initial voltage of continuous pilot,

it can be judged that the development of pilot has terminated. The Eq. 7 recommended by CIGRE is used to describe the initial voltage of the continuous pilot,

$$U_{lc} = \frac{1556}{1+3.89/D} \quad (7)$$

where U_{lc} is the initial voltage of the continuous pilot, D is the length of the gap.

According to flashover model of the insulator string and linear analysis, the function of the insulator string length are constructed as follows, which is used to simulate the volt-ampere characteristic,

$$v_{s-t} = 400L + 710/t \times 0.75 \quad (8)$$

where L is the length of the insulator string, t is the time required for the occurrence of flashover from the lightning.

The $U_{50\%}(kV)$ flashover voltage of the composite insulator string and the standard disc suspension insulator string is only related to the length of insulator string, and the relationship between them is linear positive correlation, which can be expressed by the following equation,

$$U_{50\%} = 5.33 \cdot L + 110 \quad (9)$$

where L is the length of the insulator string.

Effect of various factors under lightning incoming surge

According to the main electrical wiring of this substation, the model and parameter setting, the lightning overvoltage model of 500 kV HGIS substations is built based on EMTP-ATP, and the lightning invasion wave invading the substation along the Line 1 .

Position of lightning strike. It is pointed that the over voltage generated by lightning invasion wave on the substation equipment is different because the distance between the substation and the position of lightning strike. Under the mode of full operation, the over voltage waveform of incoming line is drawn out by the lightning striking TW1~TW5 tower respectively, as shown in Fig. 1. As we can see, when the lightning strikes the TW2 tower, the magnitude of over voltage is the highest.

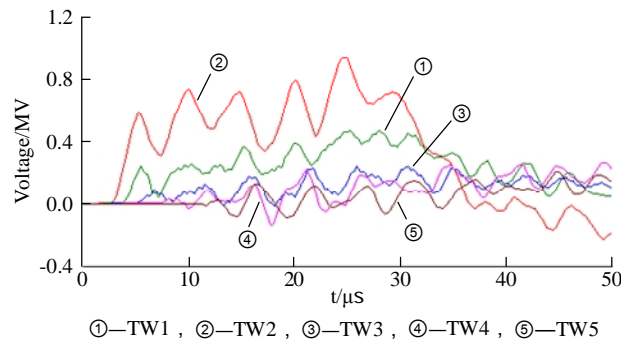


Fig.1 Over-voltages value of MOA for tower struck by lightning

Impulse grounding resistance of tower. Research shows that, impulse grounding resistance of tower is an important factor which influences the amplitude of lightning overvoltage. In the simulation, take the grounding resistance of TW1, TW2 tower as Group 1, and the grounding resistance of TW3~TW5 tower as Group 2, and analyze the relationship between over voltage and

impulse grounding resistance of tower according to changing the values of two groups of resistance. The simulation results are shown in Table 1, the amplitude of overvoltage increases with the increase of tower grounding resistance. But compared to the Group 2, the influence of Group 1 on the voltage of equipment in substation is more.

Tab 1. Impact of tower grounding resistance to maximum over-voltages value

Grounding resistance of TW1、TW2[Ω]	Grounding resistance of TW3~TW5[Ω]	Maximum over-voltages value of #1T[kV]	Maximum over-voltages value of #2T[kV]
10	11	941.035	864.684
10	12	941.318	864.932
10	13	941.648	865.252
10	14	941.911	865.496
11	10	955.590	875.174
12	10	964.422	884.715
13	10	968.347	891.790
14	10	969.859	894.804

Power frequency voltage. The superposition of power frequency voltage will affect the lightning overvoltage, and the changing angle will cause the changing amplitude of voltage. Based on simulation, the amplitudes of the lightning overvoltage for different angles are shown in Table 2.

Tab.2 Impact of frequency voltage to maximum over-voltages value

The initial angle of A phase[°]	Maximum over-voltages value of #1T[kV]	Maximum over-voltages value of #2T[kV]
0	905.699	800.014
30	923.909	813.319
60	944.264	828.122
90	961.880	840.629
120	972.665	847.715
150	974.338	848.800
180	966.349	843.583

Study on lightning protection scheme of substation

This paper hereby puts forward the following four protection schemes. Based on the most serious operation mode for lightning protection, namely Line 1 supply power to #1 transformer through Bus II, the schemes are compared according to simulation.

- 1) Scheme 1, the incoming line is equipped with a line-type arrester.
- 2) Scheme 2, the incoming line is equipped with a line-type arrester, and the transformer is equipped with a power station-type arrester.
- 3) Scheme 3, the incoming line is equipped with a line-type arrester, and the GIS bus bar is equipped with power station-type arrester.
- 4) Scheme 4: the incoming line is equipped with a line-type arrester, the transformer and the GIS bus bar are equipped with power station-type arresters.

The amplitudes of lightning over voltage on main electrical equipments for this schemes are shown as Table 3. The effect of scheme 3 and 4 are relatively better, and they both meet the requirement of insulation margin. But compared to the scheme 3, scheme 4 need to two more

lightning arresters, the economy is relatively poorer. Therefore, scheme 3 is the best solution for arrangement of arrester in this substation.

Tab 3. The comparison of four kinds of lightning protection plans

Protection schemes	Maximum over-voltages value[kV]		
	CVT	BUS II	T
Scheme 1	1398.37	920.654	1124
Scheme 2	1398.37	915.990	1050.27
Scheme 3	1398.37	792.813	1124
Scheme 4	1398.37	792.419	1050.27

Conclusions

1) Compared to the lightning of far zone, the impact of lightning of near area is lager on the substation. Due to the influence of gate-type architecture, the overvoltage produced by the lightning will decay to a certain extent. And the amplitude of over voltage is the highest when the lightning strikes the second tower.

2) The amplitude of lightning overvoltage increases with the increase of grounding resistance. Compared to the tower of far zone, the grounding resistance of tower of near zone has greater influence on the voltage of equipment in substation. The ability of lightning protection can get improved by reducing the grounding resistance appropriately in the construction of the tower.

3) When the power frequency voltage is in the negative half cycle, there are always a phase current the same negative polarity as lightning current. Due to the effect of superposition, the amplitude of lightning over voltage rises.

4) According to arranging the installation position of arrester, the amplitude of lightning overvoltage can be effectively reduced. Considering the safe, reliability and economy requirements, the incoming line being equipped with a line-type arrester, and the GIS bus bar being equipped with power station-type arrester is the most reasonable options.

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