Study on Lightning inrush overvoltage of 500kV GIL-GIS Hydropower Station

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Abstract. Aiming at the overvoltage of the equipment in GIL-GIS system when the tower outside the station strikes back, a calculation model based on EMTP program is proposed to analyze the influence of GIL distance length, lightning tower position and tower name on the lightning inrush overvoltage. Combined with the calculation results, it shows that the lightning inrush overvoltage level varies with GIL distance length, lightning tower position and tower name. The variation law of tower nominal height can provide reference for overvoltage calculation and electromagnetic disturbance source calculation of hydropower plant.

1. Introduction
With the improvement of the voltage level of power transmission and transformation projects, the development of hydropower projects and the continuous updating of electrical equipment, the requirements of large capacity and high reliability become increasingly prominent. GIL and GIS are more and more popular because of their advantages of large transmission capacity, high reliability, less land occupation and maintenance free. Currently, GIL-GIS mode is gradually applied to hydropower stations in the form of underground powerhouse.

From the actual operation of various countries, lightning is one of the main hazards to the safe and reliable operation of transmission lines, and lightning accidents account for more than 50% of power system accidents. For the substation of nuclear power plant, there are three sources of lightning damage: one is the direct strike of lightning on the substation; the other is the lightning wave along the road; the third is the induced overvoltage when the substation thunders. Because the chance of lightning strike on the line is far more than that of lightning strike on the substation directly, the lightning overvoltage invading the substation along the line is common, which is one of the main ways to threaten the electrical equipment of the substation [1-2].

When the lightning wave invades the substation, due to the distribution parameters of the transmission line and the non-linear volt ampere characteristics of the arrester, as well as the large number of equipment and circuit branches in the substation, the lightning wave will have complex refraction and reflection [3]. The high amplitude and wide-band lightning intrusion wave can not only endanger the insulation of the equipment in the station, but also act as the source of electromagnetic disturbance, which can affect the secondary system through the conduction coupling of the transformer.

For this reason, the author takes a hydropower station as an example, and establishes the 500kV transmission line of the hydropower station. Based on the general electromagnetic transient program
EMTP, the overvoltage of voltage transformer and main transformer caused by lightning inrush wave in GIL-GIS system is calculated and analyzed. On this basis, the influence of wave resistance of lightning main discharge channel, entrance capacitance of TV and CVT on overvoltage is analyzed. Finally, the overvoltage calculation is discussed. The conclusions are of guiding significance for insulation design of hydro power plant and substation.

2. Simulation introduction

2.1. Introduction of hydropower station
Taking a 500kV hydropower station as an example, the 500kV GIS equipment and the main transformer are arranged in the underground powerhouse, and the GIS equipment is arranged in the upper layer of the main transformer. The two circuit 500 kV split phase GIL is an underground 500 kV GIS room which is led out to the ground through an outlet inclined hole with an inclination of 15% and a length of 1.5 km. It can be seen that the structure of the power station can be divided into four parts. The location, composition and interconnection of each part are as follows:

1) Generator set and step-up transformer
The voltage connection mode of generator is unit connection, three-phase main transformers are set for each generator, and the capacity of each single-phase transformer is 360mva. The terminals at the low voltage side of the main transformer are connected with the generator through the isolated phase bus (IPB), and the high voltage side is directly connected with the upper GIS equipment through the gas insulated bushing (GIB).

2) GIS equipment and GIL
500kV GIS and GIL bus adopt split phase structure. The GIS incoming line is connected with the high voltage side of the main transformer through GIB, and the GIS outgoing line is connected with the outgoing line of outdoor switch station through GIL.

2.2. Introduction of main wiring diagram and operation mode of hydropower station
The 4 × 300MW unit of the pumped storage power station is sent out after being boosted by four 360MVA main transformers and then sent out through 500kV cable to 500kV ground switch station. The 500kV side is connected by single bus section, and the outgoing line is two times and connected to 500kV substation. Among the four units, unit 1 and 2 share high voltage circuit breaker, and unit 3 and 4 share high voltage circuit breaker.

The magnitude of lightning inrush overvoltage in substation is related to its operation mode. From the previous research and a large number of calculation and analysis, it can be seen that the lightning inrush overvoltage of substation under the operation mode of one line one transformer is the most serious \[1,4-5\]. Due to the limited space, the calculation results of other operation modes are not given in this paper. The research of this paper is based on the operation mode of one line one change of the system.

2.3. The way of lightning invading substation
There are two ways of lightning inrush wave in substation: shielding and counterattack. Counterattack can be divided into near zone lightning strike and far zone lightning strike: far zone lightning strike is 2km away from the substation and beyond, and near zone lightning strike is within 2km. Previous studies have shown that the maximum shielding current is much smaller than the calculation current of counterattack, resulting in lower overvoltage \[6-7\]. Previous operation experience also shows that the amplitude of voltage wave formed during shielding failure on 500kV Line is low, which is not the control condition to determine the lightning protection wiring of 500kV substation \[8\]. The main threat to the equipment in the substation is the lightning strike in the near area. A large number of studies show that the inrush overvoltage of lightning strike in the near area is generally higher than that in the far area \[9\].
According to the above analysis, the lightning wave formed by the lightning counterattack outside the substation is taken as the intrusion wave for calculation and analysis.

2.4. Simulation model

The local simulation model of lightning inrush overvoltage of Pumped Storage Power Station studied in this paper is shown in Figure 1. In the calculation, the amplitude of lightning current is 240kA, and the probability of greater than or equal to it is 0.14%; according to the calculation of single-phase negative lightning, the wave impedance of main discharge channel is 400 Ω, and the wave head and wavelength of lightning current are 2.6/50μs [10-12].

![Fig. 1 Main wiring diagram of 500kV Hydropower Station](image)

3. Calculation results and analysis

Based on the analysis of the operation mode of one line one transformer of the system, the operation mode of one line one transformer of the substation is studied, and the lightning inrush overvoltage at both sides of GIL and main transformer when lightning strikes 1 tower is analyzed. The calculation results are shown in Table 1.

It can be seen from Figure 2 that the overvoltage waveform is a shock wave, which is due to the distribution parameters of the transmission line and the non-linear volt ampere characteristics of the arrester. In addition, there are many branches of equipment and circuits in the substation, so the lightning intrusion wave has complex refraction and reflection. In addition, the inductance and capacitance in the substation produce electromagnetic vibration under the residual voltage of the arrester.

It can be seen from Figure 2 that under the counterattack of lightning invasion wave, the transient signal is superimposed by refraction and reflection through connecting the transmission line outside the station, resulting in local waveform oscillation. This phenomenon also exists in GIL as a long transmission line connecting the bus site and the main transformer site. The maximum overvoltage on the equipment side of GIL bus can reach 1027kV, while the maximum Overvoltage on the inner side of GIL station can reach 1141kV, the latter can reach 1141kV. It is 11.1% larger than the former because the 1.5km GIL transmission line makes the refraction and reflection superposition of lightning intrusion wave, resulting in the terminal signal being significantly stronger than the first signal.
As can be seen from Figure 3, under the operation mode of one line one transformer, the overall amplitude of lightning overvoltage generated by lightning strike on No.1 tower is relatively large at the CVT of the line side, and the maximum overvoltage can reach 1073kV. However, due to the short transmission line of lightning invasion wave at this time, it is obvious that there is less local oscillation of transient overvoltage at the CVT of the line.

4. Influencing factors of lightning inrush overvoltage

4.1. Influence of different lightning strike points

Based on the analysis of the operation mode of one line one transformer in the system, the operation mode of one line one transformer in the substation is studied, and the lightning inrush overvoltage at GIL, voltage transformer (CVT) and main transformer (TR) is analyzed when the towers 1-6 are struck. The calculation results are shown Table 1.
It can be seen from the results that for the GIL-GIS system of the nuclear power plant, when lightning strikes tower 1 outside the station, the lightning inrush overvoltage is the most serious. In addition, when the gate frame is struck by lightning, the overvoltage of lightning invasion wave is very small. This is because the total wave impedance and impulse grounding resistance of the gate frame are relatively small, and the negative reflection wave returns to the lightning strike point quickly, which reduces the potential of the lightning strike point and reduces the overvoltage of the invasion wave. With the increase of the distance between the struck tower and the substation, the lightning inrush wave overvoltage generally decreases. This is because each tower has a shunt effect on the lightning current, and the farther away from the substation, the greater the attenuation of lightning current before entering the substation, and the smaller the lightning current flowing into the substation.

4.2. The effect of tower's nominal height
The calling height of each tower in the line section is different. When lightning strikes the tower top, the time required for the negative reflection wave to the tower top or cross arm caused by the transmission to the grounding body along the tower is different, the potential of the tower top or cross arm is different, and the amplitude and steepness of lightning intrusion wave after the insulator string flashover are different. The lightning stroke tower 1 is studied. The call height is selected as 30m, 60m and 80m, and the simulation data are shown in Table 2.

| Tower nominal height (m) | Lighting inrush overvoltage / kV |
|--------------------------|---------------------------------|
|                          | GIL    | CVT    | TR     |
| 30                       | 1141   | 1073   | 1056   |
| 60                       | 1443   | 1216   | 1108   |
| 80                       | 1506   | 1304   | 1125   |

Comparing the simulated overvoltage amplitudes of different call heights, it can be seen that the overall development trend of the waveform is the same, which is the oscillation attenuation after lifting, and the higher the tower call height is, the greater the overvoltage amplitude is. For example, the overvoltage amplitude of 80m call height at the ground cable terminal increases by 16.14% compared with that of 30m.

4.3. The effect of tower's nominal height
The length of GIL affects the distance between No.1 tower and the station, and affects the transmission distance of lightning invasion wave. The amplitude attenuation of invasion waves and the degree of wave head slowing down in the process of wave propagation are different, which will affect the overvoltage amplitude of power station.

Table 1 list of lightning overvoltage peak value under different tower lightning stroke conditions

| Tower | Lightning inrush overvoltage / kV |
|-------|---------------------------------|
|       | GIL    | CVT    | TR     |
| 1     | 1141   | 1073   | 1056   |
| 2     | 986.4  | 968.4  | 946.3  |
| 3     | 953.2  | 937.8  | 925.6  |
| 4     | 931.5  | 918.4  | 908.4  |
| 5     | 949.7  | 933.2  | 941.3  |
| 6     | 935.2  | 936.5  | 936.5  |
Take the distance between the #1 tower and the closing station, that is, the length of GIL is 500m, 1.0km and 1.5km respectively for simulation analysis. For the overvoltage simulation at the key position under the condition of the distance between the larger and smaller groups of towers from the closing station, the simulation results are compared and shown in Table 3 below.

| GIL length (km) | Lightning inrush overvoltage / kV |
|-----------------|----------------------------------|
|                 | GIL   | CVT   | TR   |
| 0.5             | 1241  | 1135  | 1128 |
| 1               | 1138  | 1067  | 1052 |
| 1.5             | 1141  | 1073  | 1056 |

By comparing the simulated overvoltage waveforms of #1 tower with different distances from the station, as GIL length of 0.5km and 1.5km respectively, it can be seen that the overall development trend of the waveforms is the same, which is the oscillation attenuation after lifting. There is little difference in the maximum overvoltage amplitude between the two different distances. The maximum overvoltage amplitude of 1.5km is lower than that of 0.5km. The reason is that when the GIL length is greater than 1km, the wave loss in the propagation process is greater than the superposition of refraction and reflection. Theoretically, the GIL distance length is about 1km.

5. Conclusion
Based on the calculation and analysis of a 500kV GIL-GIS system of a hydropower plant, the overvoltage of the equipment in the station when the lightning strikes different towers outside the station. The variation rules of tower location, tower nominal height and GIL distance are obtained. In order to consider the envelope property, the appropriate model and parameters can be selected according to the content of this paper when calculating the overvoltage of lightning intrusion wave and electromagnetic disturbance source of 500kV GIL-GIS system is calculation. The conclusions obtained in this paper have reference significance for insulation design of nuclear power plant and substation and anti-electromagnetic interference analysis of secondary system.

(1) With Gil transmission mode, the lightning overvoltage of hydropower station is within the range of equipment.

(2) The length of GIL has obvious influence on the induced lightning intrusion wave overvoltage. With the increase of the GIL length, the overvoltage amplitude will first increase and then decrease.

(3) The higher the tower height, the greater the overvoltage.

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