Influence of high voltage cable on insulation coordination of Pumped Storage Power Station

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Abstract. The insulation cost of electrical equipment of 330kV and above EHV power station accounts for a large proportion. This paper establishes a typical electromagnetic transient analysis model of pumped storage power station, and conducts lightning overvoltage simulation calculation based on the model. It studies the length of high-voltage cable and summarizes the amplitude law of lightning overvoltage of main electrical equipment: with the increase of cable length, the amplitude of lightning overvoltage decreases. It has guiding significance for insulation coordination of Pumped Storage Power Station.

1. Introduction
Lightning also brings great harm to all walks of life. Lightning disaster is called "a public hazard in the electronic age" by the International Electrotechnical Commission (IEC). According to the conservative estimation of the United States, the failure or damage of computer network system is mainly caused by lightning impulse, accounting for about 70% of all failures every year. According to the statistics of some provinces and cities in China, the direct loss of electronic equipment accounts for about 80% of the total loss of lightning disaster, resulting in huge direct economic loss and incalculable indirect economic loss and social impact. Pumped storage power station is an important component of the power system. Its electrical equipment is relatively concentrated. Once a lightning accident occurs, it often causes damage to the generator, transformer and other important electrical equipment, and it is not easy to repair and replace, or even causes a large area of power failure, which seriously affects people's life and national economy. Therefore, the requirements of the pumped storage power station for lightning protection are very reliable.

At present, some achievements have been made in the research of lightning over-voltage in substation. For example, in reference [1], the mathematical model of network elements is established based on the algorithm of Bergeron, so as to achieve the purpose of whole station simulation. Similarly, in reference [2], the electromagnetic transient simulation program atp-emtp is used to study the influence of waveform parameters of lightning intrusion wave, electrical distance between lightning arresters, volt ampere characteristics of lightning arresters and the equivalent entrance capacitance of primary equipment on the distribution of Lightning Overvoltage in the station. However, there are few studies on the overvoltage and insulation coordination of pumped storage power stations. Because most of the pumped storage power stations are arranged in underground workshops, high-voltage cables need to be used to connect the power grid and underground power generation units. The length of high-voltage cables in each pumped storage power station is quite different. The study on the influence of the length of high-voltage cables on the lightning overvoltage of the pumped storage power station can guide the insulation coordination of the power station value.
2. Electromagnetic transient model of Pumped Storage Power Station

2.1. Main electrical equipment of Pumped Storage Power Station

A typical pumped storage power station has 4 × 300MW units, which are boosted by 4 360MVA main transformers and sent out after passing 500kV cables to 500kV ground switch station. The 500kV side adopts single bus sectional wiring, two outgoing lines and connected to the local power grid. Among the four units, units 1 and 2 share the same high-voltage circuit breaker, and units 3 and 4 share the same high-voltage circuit breaker. See Figure 1 for the main electrical wiring diagram.

Figure 1. Electrical main wiring diagram of typical pumped storage power station

2.2. Equivalent model of main electrical equipment

According to article 7.6.7-7.6.8 of IEC60071-4 guide for insulation coordination and simulation calculation of power grid, the main electrical equipment of the power station, such as transformer reactor, capacitor voltage transformer (CVT), circuit breaker, current transformer, disconnect switch, etc., shall adopt the inlet capacitance of the equipment. The value of the inlet capacitance of each equipment is showed in Table 1.

| Equipment name                  | Symbol | Capacitance value |
|---------------------------------|--------|-------------------|
| Transformer                     | T      | 5000pF            |
| Disconnect switch               | DS     | 200 pF            |
| Circuit breaker                 | CB     | 140 pF            |
| Current transformer             | CT     | 680 pF            |
| Capacitor voltage transformer   | CVT    | 5000 pF           |
| Electromagnetic voltage transformer | PT      | 550 pF            |
| Bushing                         | TG     | 200 pF            |
| Earthing switch                 | ES     | 200 pF            |

For single-core XLPE cable and single-phase GIS conductor, distributed parameter line is used for equivalent simulation. In this paper, the wave impedance of 500kV cable is 30 Ω, wave velocity is $1.25 \times 10^8 \text{m/s}$, GIS conductor wave impedance is 70 Ω, wave velocity is $2.7 \times 10^8 \text{m/s}$. 
2.3. Operation mode selection of Pumped Storage Power Station

According to the engineering experience, the less equipment is put into operation, the more serious the over-voltage is. At this time, the over-voltage on the equipment is the largest, and the absorption energy of MOA is also large. Therefore, the operation mode of one line one transformer is selected for lightning over-voltage calculation.

![Wiring diagram of one line one transformer operation mode](image)

3. Influence of high voltage cable length on Lightning Overvoltage

In this section, the lightning over-voltage of pumped storage power station is simulated under different high-voltage cable lengths, and the lightning current amplitude is 240kA in the calculation. Choose to pay attention to the development of over-voltage and discharge current of the following two typical locations:

- Obvious changes in wave impedance, mainly including: GIS outlet sleeve, ground cable terminal and underground cable terminal.
- Expensive main electrical equipment, such as high-voltage side of main transformer and circuit breaker.

In this section, the lightning over-voltage of pumped storage power station is simulated under different high-voltage cable lengths, and the lightning current amplitude is 240kA in the calculation. Choose to pay attention to the development of over-voltage and discharge current of the following two typical locations:

![Overvoltage waveform of GIS outgoing bushing under different 500kV cable lengths](image)

Figure 3. Overvoltage waveform of GIS outgoing bushing under different 500kV cable lengths
Comparing the simulated over-voltage waveforms of the 500kV cable with the length of 600m and 1200m respectively, it can be seen that the over-voltage of the main electrical equipment is greater than that of the 500kV cable with the length of 1200m, for example, the ground cable terminal can be 30.64% larger than the latter.

4. Conclusion

In this paper, the electromagnetic transient calculation model of a 500kV pumped storage power station is established, and the lightning wave invasion is simulated. The research results show that when the length of 500kV single cable is in the range of 600m ~ 1200m, the lightning over-voltage does not exceed the insulation margin of electrical equipment, and because the impedance of cable is lower than that of overhead line and GIS conductor, the fold reflection superposition amount is less than the wave loss amount in the transmission process, therefore, with the increase of cable length, the amplitude of lightning overvoltage decreases.

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