Study on Lightning Overvoltage in Long Span Section After AC to DC Operation of Transmission Lines

Houkun Cui, Fengju Zhu, Qing Wu, Zhihao Lin, Xueqin Zhang, and Yujun Guo

Abstract Transmission lines to DC operation, due to the polarity effect of the wire and the space electric field is different, the lightning pilot development process has changed, and large span section of the line gear distance is long, tower height is more vulnerable to lightning strikes. Therefore, it is necessary to compare and analyze the similarities and differences of lightning overvoltage under different operation modes of AC and DC. In this paper, through the establishment of large span section transmission line electromagnetic transient simulation model, calculate the transmission line in the original AC insulation configuration, AC and DC operation mode of the difference between the large span section lightning overvoltage. The results show that the same insulation configuration of DC operation when the line is subject to lightning overvoltage value is greater than the overall AC mode of operation. When the lightning current is above 100 KA, the lightning current bypasses the transmission line, the DC line overvoltage is about 18.3% larger than the AC line overvoltage, bringing a hidden danger to the insulation configuration of the original AC line.

Keywords Change from AC to DC · Long-span · Lightning overvoltage · Shielding failure and back flashover

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1 Introduction

With the rapid development of China's economy and the diversification of electricity demand, some areas, especially economically developed areas, have the problem of insufficient power supply capacity [1]. DC distribution networks can ensure higher power quality as well as better operation, in addition to reducing power losses [2] and effectively increasing transmission capacity [3, 4]. However, additional DC transmission networks require expensive costs and precious land resources, and line siting is more difficult across large spans. Therefore, converting existing AC lines to DC transmission is a better option to solve the above problems.

After the AC to DC operation, the structure and operation of the large span section of the line also changed, the positive polarity of the DC transmission line conductor is more susceptible to lightning strikes, showing an obvious polarity effect, when passing through the large span section, the transmission line due to high tower height, long line stall distance, large lightning area, the probability of suffering a lightning strike at this time is much greater than the ordinary section of the transmission line [5]. And DC voltage has an electrostatic adsorption effect, insulators operating under DC voltage, transmission conductor surface dirt accumulation is more serious, more prone to flashover phenomenon; existing standards for DC overhead lines of lower voltage levels lack effective lightning protection configuration of the study. To address the above problems, building ATP/EMTP model can effectively simulate the lightning strike process in large span sections [6], and better study the lightning overvoltage propagation law and insulation coordination scheme of DC transmission lines.

In this paper, we study the lightning overvoltage characteristics of transmission lines when lightning strikes towers at different locations under the original AC configuration of the large span section, as well as the overvoltage characteristics of lines at different locations when lightning current strikes back at transmission lines, combined with grounding resistance, insulators and other related configurations to analyze the lightning protection design of the large span section after changing to DC operation, and propose practical line lightning protection design solutions.

2 Calculation Parameters of Long-Span Section

Due to the project cost and transmission corridor saturation and other factors, China's current stage of high-voltage AC to DC transmission line crossing section mostly along the original channel, its foundation and the main structure of the tower is still utilized. In this study, the large span program is a tension tower—stress tower—stress tower—tension tower program, using a combination of span tower and anchor tower to transform the AC transmission line into a DC transmission line, mainly replacing the number or type of insulators and recalibrating the tower grounding resistance. Cross-sectional schematic diagram at the crossing point is shown in Fig. 1.

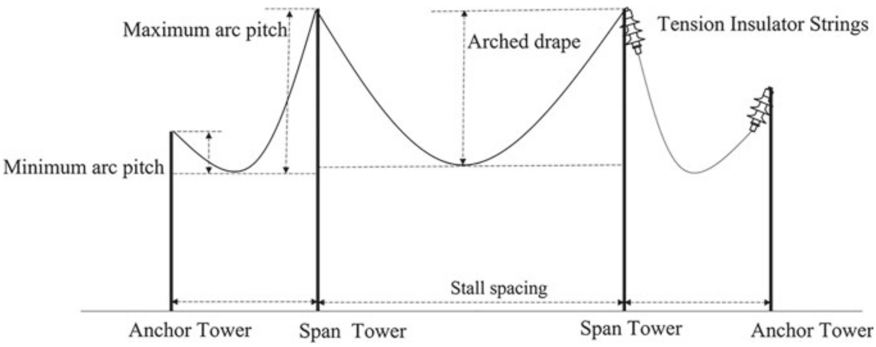


Fig. 1 Section diagram at the crossing point

Not changing the main structure of the spanning tower can reduce the construction difficulty, and choosing reasonable conductors can improve the transmission density of the transmission channel [7] and tap the transmission potential of the existing grid equipment. At present, the main conductors used in China's long-span lines are high-strength steel-core aluminum alloy strand and high-strength steel-core heat-resistant aluminum alloy strand. Compared with the general section of the transmission line, the increase in the cross-section and splitting number of large span wires has a greater impact on the load size and investment. long-span section as an important channel of high-voltage AC to DC lines, high transmission capacity and susceptible to lightning strikes, in order to meet the requirements of the transmission capacity, taking into account the strength of the wire, engineering costs, maintenance costs and other factors. The transmission line conductor type in this study is 4 × JLHA1/G4A-400/150 with 600 mm split spacing and OPGW-210 for ground wire.

3 EMTP Simulation Model of Long-Span Section

3.1 Power Transmission Tower Simulation Model

Multi-wave impedance tower model. The height of the tower and the structure of the transmission line lightning overvoltage amplitude has a great impact [8], scientific and reasonable in the electromagnetic transient simulation software to build the tower model closer to the accuracy of the simulation results. Large span section tower has a very high height (more than 100 m) characteristics, lightning current wave process is more obvious, a single wave impedance method does not take into account the structure of the tower itself, it is difficult to reflect the impact of the tower on the level of line lightning resistance. The multi-wavelength impedance model of the tower reflects the wave process when the wave passes through the tower, and also considers the wave attenuation and distortion [9–11], which reduces the simulation error. In this study, the height of the spanning tower is 106 m and the full height is 141 m. The spanning tower is located in the ditch and crosses the river in a "straight-straight" way.

Line model of long-span section. In the simulation software distribution parameter model, JMarti model can be fitted to the line dependent characteristics of the ground line, responding to the amplitude and phase distortion of the traveling wave, more reflective of the actual line in the lightning bypass when the transmission characteristics of the traveling wave. This study selected the basic physical parameters of the large span section of the guide line as shown in Table 1.

The selected span of the main span is 1100 m, and the DC resistance of the conductor running at normal atmospheric temperature (20°) is 0.06418 Ω/km.

Lightning current model. China's lightning current mostly uses 2.6/50 us standard lightning current, and the model uses the double exponential waveform closest to the actual lightning current waveform, with the waveform function.

$$U_t = A\left(e^{-at} - e^{-bt}\right) \tag{1}$$

where A is the lightning current amplitude, a, b is the time constant related to the wave head and wave tail, by the relationship between the thunderstorm day and the peak of the lightning current, take the peak of the lightning current is 100 KA. The size of the main discharge channel wave impedance and the size of the lightning current, in general, the larger the lightning current wave impedance, scientific observation calculations when the lightning current amplitude between 30 and 100 KA, wave impedance of 700–300 Ω, negative polarity lightning amplitude and regional altitude, soil resistivity and the shape of the object struck by lightning, the lightning current size and probability distribution results from the formula (2) to determine.

$$p = \frac{1}{\left[1 + \left(\frac{I}{31}\right)^{2.6}\right]} \tag{2}$$

where p is the relative lightning current probability size and I is the lightning current size. In order to explore the margin of the insulation configuration of AC and DC transmission lines under the maximum lightning current in the large span section,

Table 1 Basic parameters of transmission line ground conductors

Type	Model	Splitting number	Intrabundle spacing (mm)	The lowest point (m)	Sub line radius (cm)
Transmission lines	JLHA1/ G4A-400/150	4	600	51.6	1.527
Lightning conductor	OPGW-210	0	0	48	0.955

this study takes the lightning current of 100 KA with a lightning strike probability of 15%, while taking the wave impedance of 300 Ω.

4 Current Characteristics of the Line When Struck by Lightning

In this section, the electromagnetic transient simulation model of the large span section is established based on the calculation parameters selected above, and the transient currents at each of the AC and DC towers and on the transmission lines are observed by simulating lightning strikes on transmission lines, lightning arrester lines, and lightning strikes on towers at different locations to compare and analyze the current distribution between AC and DC in the same lightning strike conditions.

4.1 Lightning Arrester and Transmission Lines in AC and DC Cases

Combined with the local area lightning current size probability of lightning strike large span at the lightning line and the connection of the tower, Fig. 2 DC transmission line power supply for 200 kV, using the same tower three circuits with the same voltage operation mode, the tower three different height cross-arms corresponding to Three independent DC transmission lines.

Figure 3 for the lightning current amplitude of 100 KA around the AC transmission line A phase and the same location of the DC transmission line of the positive polarity wire, the corresponding line on the lightning current waveform, Fig. 3a AC transmission line A phase lightning overvoltage peak value of 3.27 kV, DC transmission line positive polarity wire overvoltage peak value of 4.18 MV, selected far from

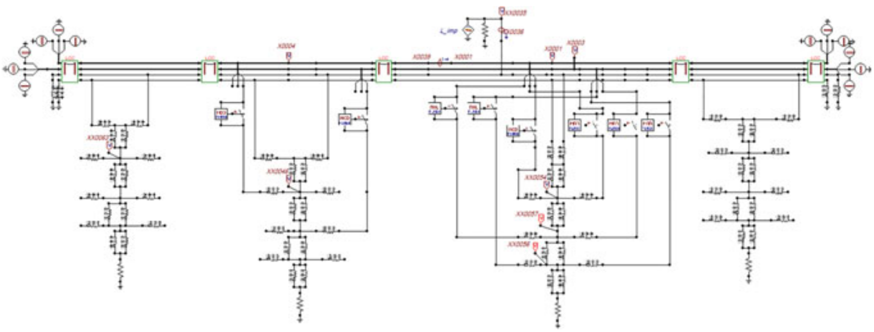
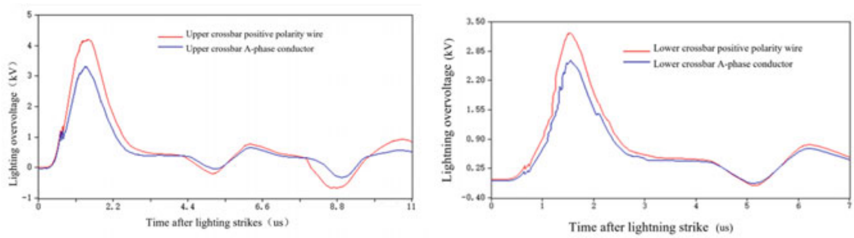


Fig. 2 Simulation diagram of lightning strike lightning line in DC operation mode

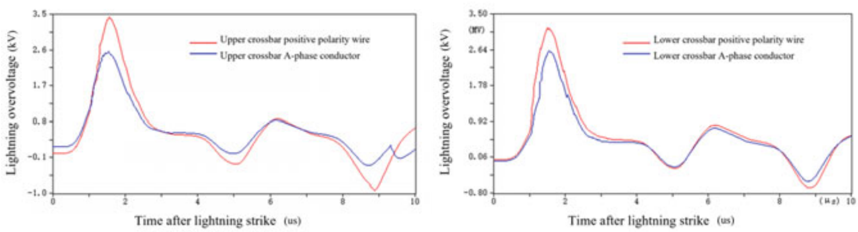
the lightning strike point at the lower cross-arms transmission line Fig. 3b shows that the AC operation of the C-phase transmission line overvoltage amplitude of 2.64 kV, and DC operation under the cross-arms at the positive conductor overvoltage amplitude of 3.25 kV. Figure 6 for the lightning current 100 kV when lightning arrester line under the AC and DC transmission lines under the same configuration of different locations of the overvoltage value, from Fig. 4a can be seen, across the tower on the cross-arms connected transmission line AC operation under the peak overvoltage of 2.61 MV, DC mode operation under the peak overvoltage of 3.41 MV; from Fig. 4b can be seen, across the tower under the cross-arms connected transmission line The peak overvoltage under AC operation is 2.51 MV, while the peak overvoltage under DC mode operation is 3.18 MV.

From the above Figs. 3 and 4 multiple experimental analysis can be obtained, large span section of transmission lines under the action of 100 KA lightning current, DC operating mode produced by the backlash, bypass over-voltage is greater, it can be seen that the same insulation configuration of AC and DC lines on the response to lightning over-voltage there is a difference in over-voltage above. Combined with the local area lightning current size distribution probability, calculate the different lightning current size lightning back strike lightning line, bypass transmission line to get the AC and DC transmission line overvoltage size, its lightning current size and transmission line overvoltage between the fitting curve shown in Figs. 5 and 6.



(a) Overvoltage at upper cross-arms (b) Overvoltage at lower cross-arms

Fig. 3 Lightning currents wind around transmission lines



(a) Overvoltage at upper cross-arms (b) Overvoltage at lower cross-arms

Fig. 4 Lightning current counterattacks the lightning protection wire

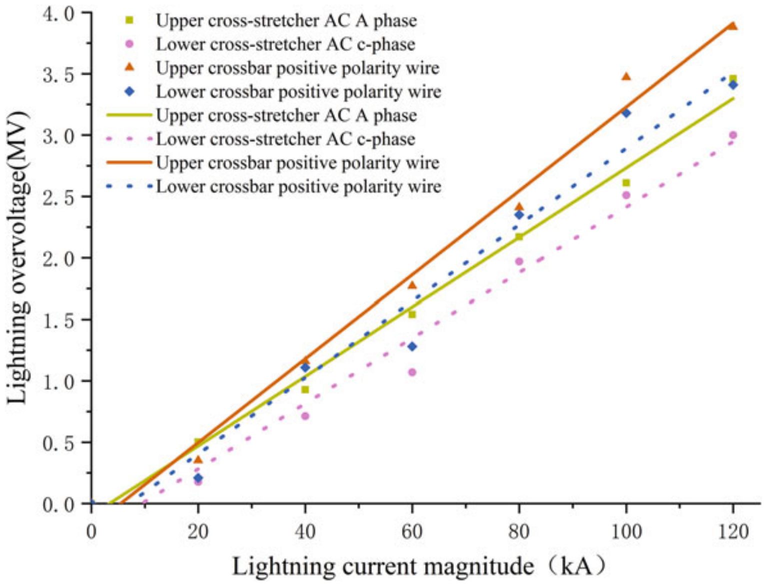


Fig. 5 Different lightning current magnitudes counter lightning protection wires

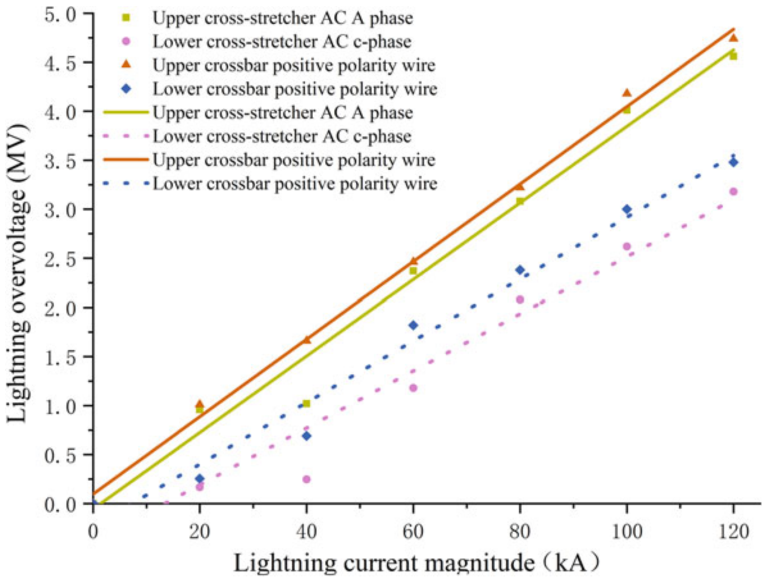


Fig. 6 Different lightning currents hit the upper transverse transmission line

From the data in Fig. 5 and the fitted curve, it can be seen that the large span section of the transmission line suffers from lightning backlash lightning line, its tower at the upper cross-arms and the lower cross-arms connected to the transmission line, DC operation mode overvoltage size are greater than the AC operation mode, and with the increase in lightning flow, the difference in overvoltage size between the two modes of operation in gradually increasing, it is clear that the larger the lightning flow on the different modes of operation of the line impact more obvious. As can be seen from Fig. 6, when lightning bypasses the transmission line at the transmission line, the line overvoltage trend is similar to the lightning line, but the figure shows that with the increase in lightning flow, AC and DC operation mode overvoltage size gap basically remains constant, it can be seen when lightning bypasses the transmission line, the size of the lightning flow is not the main factor affecting the difference between the lightning flow in the two modes of operation.

5 Conclusion

This paper analyzes the change of transmission line lightning overvoltage in the original AC operation insulation configuration to DC operation, and the influence of different factors on DC operation under lightning overvoltage by establishing a simulation model of electromagnetic transients in AC to DC transmission lines in large span sections. The main conclusions drawn are as follows: different operation modes have a significant impact on the transmission line lightning overvoltage value, the same insulation configuration under the line suffers lightning bypass and backlash, DC transmission line overvoltage value is significantly greater than the AC transmission line. And the larger the lightning current, the greater the difference between AC and DC lines suffer overvoltage value. When the lightning current is above 100 KA, the lightning current bypasses the transmission line, the DC line overvoltage is about 18.3% larger than the AC line overvoltage, bringing a hidden danger to the insulation configuration of the original AC line.

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References

1. Chen Q, Wang J, Xiong S, Wang Q, Long Y (2020) Emergency overload operation strategy for wind power delivery channel considering dynamic overload capacity of equipment. Power Syst Autom 44(15):163–171 (in Chinese)
2. Chen HX, Li T, Li A (2021) Research on the coordinated control strategy of AC-DC system to enhance grid operation. Power Syst Protect Control 49(10):123–134 (in Chinese)

3. Wood TB, Macpherson DE, Banham-Hall D et al (2014) Ripple current propagation in Bipole HVDC cables and applications to DC grids. IEEE Trans Power Deliv 29(2):926–933
4. Elserougia A, Massoud AM, Abdelsalam I et al (2018) Self-balanced non-isolated hybrid modular DC-DC converter for medium-voltage DC grids. IET Gener Transm Distrib 12(15):3626–3636
5. Tian H, Wang N, Chen T et al (2015) Simulation study of line arrester to improve the lightning resistance level of UHV large span overhead line bypassing strike. High Volt Technol 41(01):63–68 (in Chinese)
6. Hu J, Zhang D, Zhou L et al (2022) Study on the installation strategy of lightning arrester for extra-high voltage DC lines considering the distribution characteristics of lightning overvoltage. Electr Porcelain Lightning Arrester 4:177–184 (in Chinese)
7. Jaber DS, Fardin E (2023) Operation recommendations for tension joints and clamps on a 63 kV overhead transmission line conductor based on experimental tests. Electr Power Compon Syst 51(7)
8. Si, Ma WX, Xie B, Yang Q et al (2010) Classification and identification method of lightning overvoltage in UHV transmission line. High Volt Eng 36(2):306–312 (in Chinese)
9. Zhou LJ, Huang L, Wang LJ, Zhang D, Liu B, Xu H, Chen SX (2020) Multi-wave impedance modeling and transient response analysis of 110 kV transmission towers with lightning strikes. Power Autom Equip 40(10):158–164 (in Chinese)
10. Singh RS, Ćuk V, Cobben S (2020) Measurement-based distribution grid harmonic impedance models and their uncertainties. Energies 13(16)
11. Du L, Mi X, Xiao Z et al (2012) Study on transmission line tower cross-load and inclined material equivalent model. High Vol Eng 38(11):3025–3032