

Analysis of lightning withstand level and flashover phases of tower double circuit transmission line

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Abstract. The overhead transmission lines stretching thousands of miles, accounted for a large part of power system, and lightning transmission line fault is the most main form of power system fault. In order to reduce the transmission corridor area, double circuit and even more loop transmission lines were more and more adopted, and therefore the tower is higher and higher. And the higher the tower, the greater the possibility of being struck by lightning. Thus it is very necessary to research and analyze the tower double circuit transmission line. The model of canal 110kV substation was established and the lightning withstands level and flashover phases were analyzed through the electric transient simulation program ATP-EMTP.

Keywords: tower double circuit; flashover phases; ATP-EMTP; lightning withstand level.

1 Introduction

Lightning is a spectacular natural phenomenon but common, but due to its great energy, when lightning occurs, it will produce a great impact on the safety of human life and the normal operation of our daily life and production of telecommunications, electricity, construction and other industries. Lightning over-voltage is the most main reason of power system lightning trip and insulation failure[1].

The rate of transmission line tripping accidents caused by lightning is more than 50% in Japan, Sweden, the United States, Canada and some other countries. In China, lightning trip rate can reach 70% in the areas of Frequent lightning activity and high soil resistivity, it has reached 40% even in the areas of ideal soil resistivity and flat terrain. So it is necessary to research on the lightning activity and its prevention.

In the early time, tower double circuit transmission is mainly used in 500kV and above grade EHV (Extra High Voltage) transmission lines, with the development of smart grid, power grid at all levels are in continued development, and the applications of double-circuit transmission line towers in 110kV and 220kV power systems are also increasing. With respect to 500kV and above EHV, the analysis of tower double circuit transmission on 110kV and 220kV is relatively less[2]. Due to the erection of the two-circuit transmission lines on the same tower, it is easy to cause lightning trip in both lines and bring greater threat to the safe operation of the power system. Therefore, the research of lightning flashover situation of tower double circuit transmission lines is of practical significance.

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2 Simulation models

2.1 Lightning current source

The 2.6 / 50 μ s standard lightning surge is adopted the simulation, there are two types of impact current source in ATPDraw, which are Surge type and Heidler type, Heidler type 15 is adopted in this paper. Lightning channel impedance is connected in parallel with the current source, the lightning current model is shown in Figure 1.

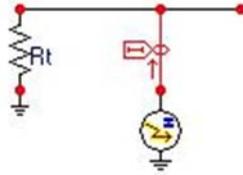


Figure 1. Model of lightning current source.

2.2 Insulator string

Canal 110kV substation’s double circuit transmission line use the insulation method of balanced insulation. Each phase have adopted the insulator string consisting of seven disc-shaped suspension glass insulator, 50% flashover voltage of the insulator string is 776kV. Considering the advantages and disadvantages of the various methods, the regulation method has the most simple structure and practical engineering operation basis, therefore the regulation method is adopted to judging insulator’s flashover[3].

Insulator’s flashover is simulated by gap switch in ATPDraw. This switch is always turned on at steady-state, switch is closed when the absolute value of the voltage across the switch exceeds U50%, which represents the insulator’s flashover.

2.3 Transmission line

LCC multiphase coupling line J. Marti model is selected to simulate the transmission line, Since the coupled voltage between the wires and the ground wires has been automatically accounted, there is no need to take into account in simulation. Canal 110kV substation’s transmission line and location arrangement simulated by LCC are shown in Figure 2, a total of eight phases, where phase 1 to 3 are the phase conductors of circuit I, phase 4 to 6 are the phase conductors of circuit II, and phase 7 and 8 are the ground wires.

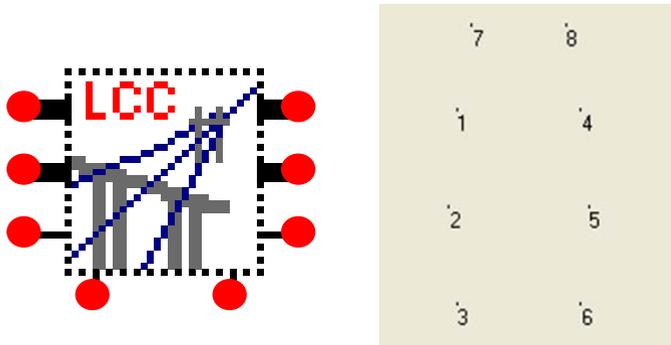


Figure 2. Modeling of transmission line by LCC

2.4 Transmission tower

The tower type of Canal 110kV substation is double circuit transmission tower SZT-35, its structure and parameters are shown in Figure 3.

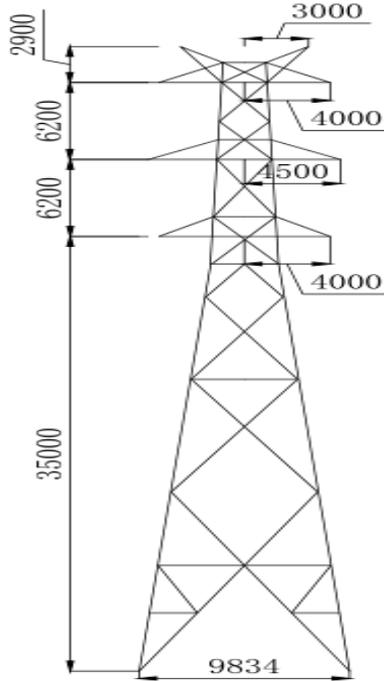


Figure 3. Structure of tower.

When lightning strikes, different tower models will directly affect the propagation characteristics of lightning in the tower, the tower’s overhead potential and the flashover time. Tower model experienced a lumped parameter inductor model, a single wave impedance model to a multi-wave impedance model. The early tower less than 40 meters is usually simulated by lumped parameter inductor model. Later, with appearance of high tower, single wave impedance model is proposed to represent propagation characteristics of wave by the wave impedance and propagation velocity. But in fact the wave impedance of tower can not be single, it should be a function of time, so later a multi-wave impedance model, each part of the tower represented by different wave impedance is proposed. The multi-wave impedance model is generally used in the calculation of lightning protection domestic and overseas currently [4]. The most representative models of multi-wave impedance model are the lossless line model proposed by Hara and multilayered transmission tower model proposed by Yamada.

Hara lossless line model is adopted in this paper to simulate SZT-35 tower, its characteristic is broken the tower down into the main timber tower, oblique sheet and cross arm three parts, then each unit are respectively simulated by different impedance, the calculation processes of the impedances of each part are as follows[5]:

The main timber tower is calculated as follows:

$$Z_{Tk} = 60(\ln \frac{2\sqrt{2}h_k}{r_{ek}} - 2) \quad (k = 1,2,3,4) \tag{1}$$

Where Z_{Tk} —wave impedance values of k-th portion of the main timber tower, Ω ;
 h_k —k-th cross arm height, m;
 r_{ek} —k-th cross arm at the equivalent radius, m, equivalent radius is calculated as follows:

$$r_{ek} = \begin{cases} \sqrt[8]{2} \cdot \left[\sqrt[3]{r_{Tk} \cdot (r'_B)^2} \right]^{1/4} \cdot \left[\sqrt[3]{R_{Tk} \cdot (R'_B)^2} \right]^{3/4} & (k = 1,2,3) \\ \sqrt[8]{2} \cdot \left[\sqrt[3]{r_{Tk} \cdot (r_B)^2} \right]^{1/4} \cdot \left[\sqrt[3]{R_{Tk} \cdot (R_B)^2} \right]^{3/4} & (k = 4) \end{cases} \quad (2)$$

Significance of h_k , r_{Tk} , R_{Tk} and r_B , R_B are shown in Figure 4, whose units are m.

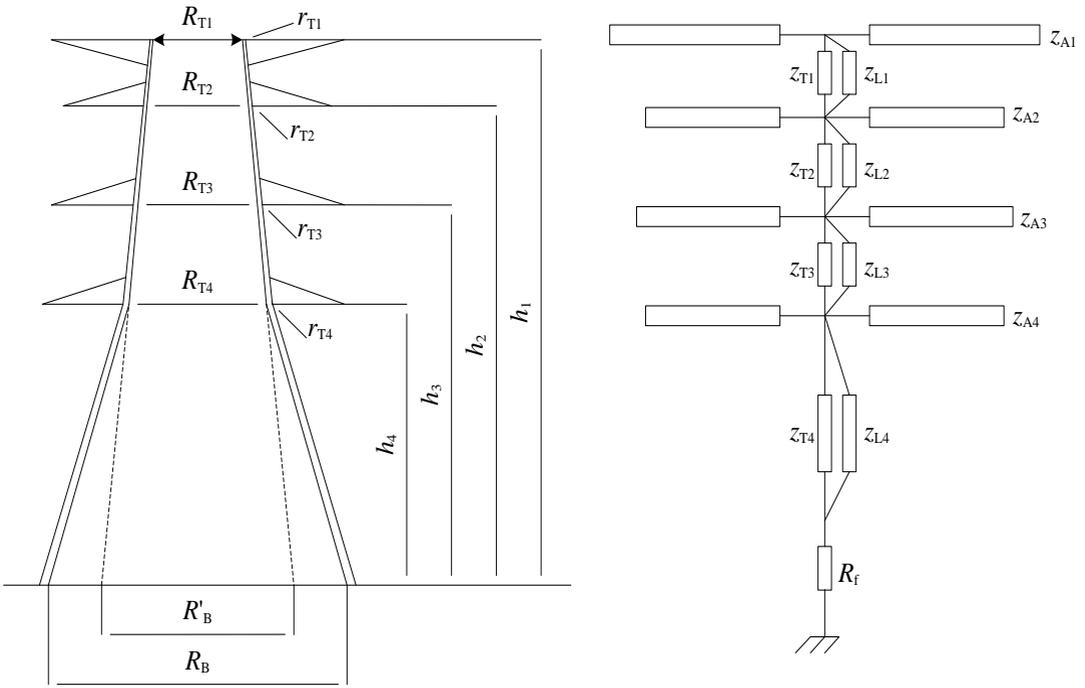


Figure 4. Model of Hara lossless line.

The existence of oblique sheet makes the impedance of tower fell about 10%, so the impedance value of the oblique sheet is generally 9 times the corresponding parts of the main timber tower. Since the impedance of oblique sheet has less impact on the tower, it can be generally ignored in the simulation of tower. The influence of oblique sheet is ignored in this paper.

As an important part of the tower, the cross arm is used to mounting insulator strings and fittings thereby supporting the wire and ground wire, it is generally treated as a normal horizontal conductor in the impedance calculation of cross arm, formula is as follows:

$$Z_{Ak} = 60 \ln \frac{2h_k}{r_{Ak}} \quad (k = 1,2,3,4) \quad (3)$$

Where Z_{Ak} —cross arm impedance values of k-th part, Ω ;
 r_{Ak} —the equivalent radius of k-th cross arm, m.

3 Lightning withstand level analysis

The simulation model of the lightning withstand level built in ATPDraw is shown in Figure 5, with irrespective of the operating voltage wires, and the three-phase impedance model adopted in the end of transmission line to eliminate the lightning waves' catadioptric[6,7].

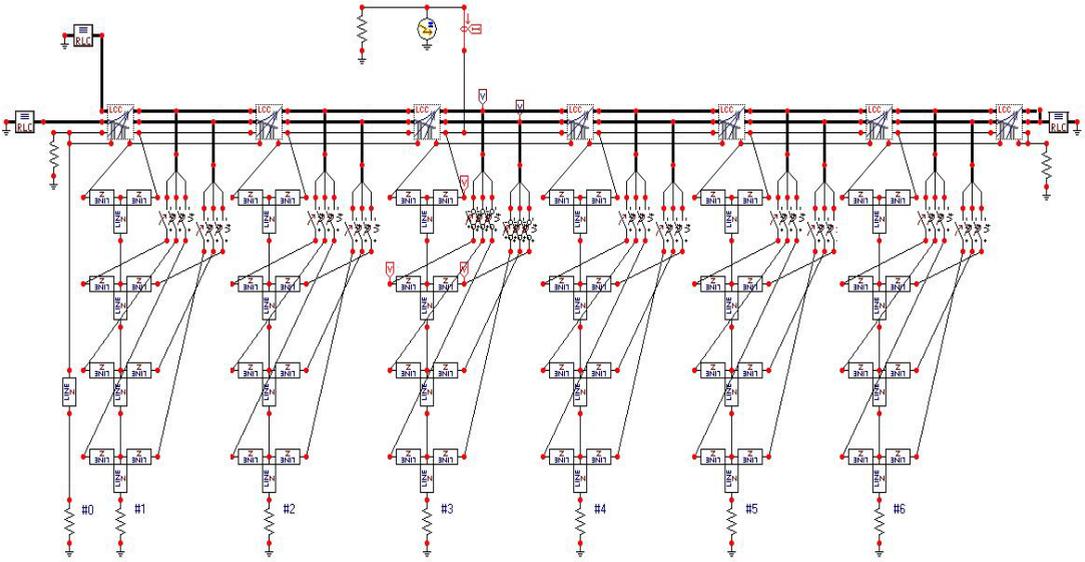


Figure 5. Modeling of lightning fight back withstand level

SZT-35 upper phase’s lightning withstands levels of ATP-EMTP simulation analysis method and regulation method is illustrated in Table 1.

Table 1 .lightning fight back withstand level

method	ATP-EMTP simulation method	regulation method
lightning withstand level	52.4	51.2

The results of the two methods shows that the two results were similar, lightning withstand level of SZT-35’s upper phase is roughly 52kA.

4 Effect of frequency voltage on flashover

Frequency voltage on the wire is a random quantity, it has a certain impact on flashover phase distribution when lightning strikes; while the different arrangement of the phase sequence on the same tower also has an impact on the flashover.

4.1 Same sequence arrangement

Wires on SZT-35 are arranged in the same sequence, namely circuit I and circuit II are ordered in ABC phase arrangement, as shown in Figure 6.

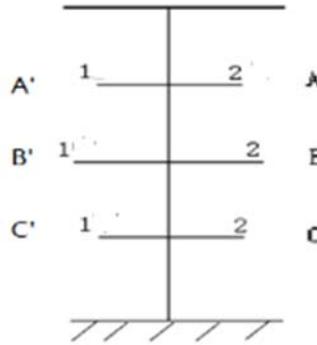


Figure 6. Arrangement of same phase sequence

Considering the impact of the double lines' frequency voltage phase, flashover phase distribution table under the lightning current impact of 60kA is shown in Table 2, the flashover phase is ordered front to back in the table.

Table 2. Distribution of flashover with same phase sequence

Circuit II	Circuit I 0°	Circuit I 90°	Circuit I 180°	Circuit I 270°
0°	2middle1 middle	2 middle	1 upper	1middle2middle
90°	1 middle	2lower2 upper	1 upper	1 middle
180°	2 upper	2 upper	2 upper1 upper	2upper1middle
270°	2middle1middle	2middle	1upper2middle	2middle1middle

It can be seen from the analysis of data in Table 2 that, when the double-circuit transmission lines with the same phase sequence arrangement, the flashover phase of the corresponding operating voltage phase is completely symmetrical. Under the impact of the lightning current, the distribution of the first flashover occurs is: upper phase 43.75%, middle phase 50%, lower phase 6.25%.

4.2 Opposed sequence arrangement

Wires on SZT-35 are arranged in the opposed sequence, namely circuit I ordered in CBA phase arrangement, but circuit II ordered in ABC phase arrangement, as shown in Figure 7.

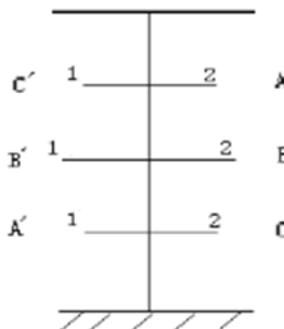


Figure 7. Arrangement of opposed phase sequence.

Considering the impact of the double lines' frequency voltage phase, flashover phase distribution table under the lightning current impact of 60kA is shown in Table 3, the flashover phase is also ordered front to back in the table.

Table 3. Distribution of flashover phases with opposed phase sequence

circuit II	Circuit I 0°	Circuit I 90°	Circuit I 180°	Circuit I 270°
0°	1upper1middle	1upper2middle	2middle	1middle 2middle
90°	1middle	1upper2lower	1lower2upper	1middle
180°	2upper1upper	2upper1upper	2upper1lower	2upper1middle
270°	2middle 1upper	2middle 1upper	2middle	2middle 1middle

It can be seen from the analysis of data in Table 3 that, when the double-circuit transmission lines with different phase sequence arrangement, the probability of flashover on cross arm of the same height is different. Similarly, the distribution of the first flashover occurs is: upper phase 43.75%, middle phase 50%, lower phase 6.25%.

Considering the simulation results of same phase sequence and opposed phase sequence, we can know that More than 90% of the flashover first occurred towers in the upper and middle phases, and opposed phase sequence arrangement effectively reduces the probability of lightning trip of both cross arms in the same height.

5 Conclusion

The lightning withstand level is analyzed in this paper by ATP-EMTP, and by comparing to the result of regulation method, verified the correctness of the calculation. At the same time, the impacts of double-loop frequency operating voltage to flashover of same phase sequence and opposed phase sequence are analyzed respectively. The results indicate that the majority of first flashover occurred in the upper and middle phases, and the same sequence arranged of double-circuit line is more likely to jump with lightning in the same time. To reduce the hazards of lightning over-voltage, the phase sequence should be arranged to avoid the same tower double-circuit line, and should be properly reinforced insulation levels of the upper and middle phases.

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