Research on effect of lightning shielding level of EHVDC transmission line by installing coupling ground wire

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Yanhui Zou[1*], Yishi Yue[1], Fuyong Huang[1] and Haiyue Wang[2]

[1]Electric Power Research Institute, State Grid Hunan Electric Power Company, Changsha, Hunan, 410007, China

[2]Equipment Department, State Grid Hunan Electric Power Company, Changsha, Hunan, 410007, China

[*]Corresponding author's e-mail: 987519929@qq.com

Abstract. Lightning shielding failure is the main reason causing lightning flashover of Jiangcheng EHVDC transmission line because of the designed ground wire protection angle. Based on the electric-geometry model, a simulation model including the coupling ground wire is established by using MATLAB. The effect of the coupling ground wire at different height and horizontal position on lightning shielding failure flashover rate is analysed. Results show that coupling ground wire can reduce the lightning shielding failure flashover rate and the lightning shielding performance increases with the increase of the height of the wire and the horizontal distance between the axis of the tower and the coupling ground wire.

1. Introduction

±500kV Jiangcheng transmission line is the main channel transmitting the electricity of the Three Gorges. According to the operating data, the lightning shielding failure flashover rate (SFFOR) accounts for more than 40% of the total lightning flashover rate. The total 38 lightning faults of Jiangcheng transmission line are all caused by lightning surround thunder-struck since its commissioning. Lightning shielding failure becomes the main factor to threaten the safety of the EHVDC transmission line. The statistics show that the protection angle of the ground wire ranges from 11.5° to 17.5° of the lightning strike towers. According to Lin Feng's calculation, the large protection angle of the ground wire is the main reason for the high lightning shielding failure flashover rate of Jiangcheng transmission line [1].

Transforming the tower head directly to reduce the lightning flashover rate is difficult to implement because of the high cost. Zhou Kaibin put forward a governance measure by installing lightning rod against shielding failure e[2]. Huang Fuyong analyzed the effect of lightning rod against shielding failure used on Jiangcheng transmission line and proposed that due to the size of lightning rod is much smaller than the tower, the operation effect was poor [3]. Peng Xiaoliang and Wang Feng studied the application effect of DC line lightning arrester on Jiangcheng lines [4][5]. Howerver, DC line lightning arresters had high cost and were difficult to install on high mountainous areas and carry out regular tests. According to Chao Yafeng's research, insulation damage often occurred on the base of the DC line lighting arresters under strong wind because of its long length [6].

Coupling ground wire is a typical lightning protection method. At present, research on coupling ground wire mainly focuses on its influence on lightning strike-back flashover characteristics through theoretical electromagnetic transient calculation. Le Xi studied the strike-back lightning-withstand level of coupling ground wire with EMTP [7]. Li Jingli studied the influence of different coupling ground

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wire erection methods on the strike-back lightning-withstand level by electromagnetic field model [8]. The influence of different erection positions of coupling ground wire on the lightning strike-back protection performance of double-circuit transmission line on the same tower was calculated by Zhang Sihan and Gan Tuanjie using ATP simulation [9]. Wang Xi studied on the effect of the position and number of coupling ground wire on lightning protection characteristics of 500kV and 220kV four-circuit lines on the same tower [10].

In summary, the current research on coupling ground wire mainly focuses on how to reduce the flashback rate, but currently there is little research on reducing the lightning shielding failure flashover rate of overhead transmission line. In this paper, the electrical geometry model considering the arc sag and topography is established for the typical lightning strike flashover section of the ±500kV Jiangcheng transmission line, and the influence of the coupling ground line on the lightning shielding performance of the overhead transmission line is studied. By calculating the effect of different installation positions of the coupling ground wire, the variation law of the lightning shielding effect of the coupling ground wire with the installation position is obtained.

2. Simulation principle

2.1. Calculation Formula

Based on the concept of lightning strike distance, the electrical geometry model links the lightning current amplitude (electrical parameters) with the lightning range (geometric parameters) of the transmission line, and analyses the lightning shielding performance of the transmission line through geometric mapping [11] [12]. In this paper, the lightning strike distance of ground wire and coupling ground wire uses the IEEE recommendation formula as follow [13].

$$r_g = 10I^{0.65} \tag{1}$$

Where r_g is the lightning strike distance of ground wire and coupling ground wire (m), I is the lightning current amplitude (kA).

Considering the operating voltage, the lightning strike distance of conducting wire is calculated using follow formula [14].

$$r_c = 1.4 \times (5.147 \bullet I^{0.0.5417} + U_{dc})^{1.2} \tag{2}$$

Where r_c is the lightning strike distance of conducting wire (m), U_{dc} is the operating voltage (MV).

The exposed arc of ground wire, coupling ground wire and the conducting wire under different lightning currents is calculated by MATLAB simulation. The lightning shielding failure flashover rate is obtained in combination with the line flashover voltage.

2.2. Parameters of simulation object

The terrain of the ±500kV Jiangcheng transmission line corridor is complex and diverse, including rivers, hills, mountains, fields, etc. The towers are located in complex landforms such as flat land, slopes, hills and hilltops. In this calculation, #0600-#0601 long spans of Jiangcheng lines is selected as simulation object and its three-dimensional topographic map is shown in figure 1. The parameters of tower, ground wire and conducting wire are shown in Table 1.

The ground lightning density in this calculation is set as 3.58 times/km^2 according to the average numerical value of Jiangcheng lines in the past 10 years. Since 90% of the lightning strikes on the Jiangcheng lines are taken place on the positive side, this simulation only analyzes the positive side.

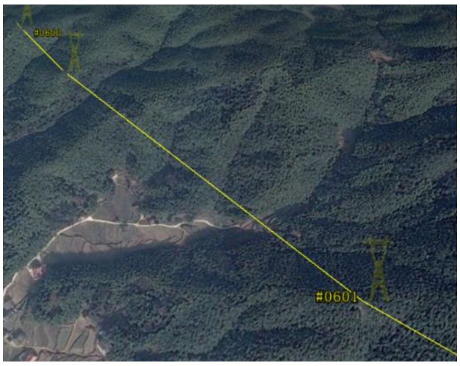

Figure 1. Three-dimensional topographic map of #0600-#0601 long spans.

Table 1. The parameters of tower, ground wire and conducting wire.

Tower Type	**G3-45(#0600)**	**G4-51(#0601)**
Parameters of Ground Wire		
Height(m)	49.6	56
Horizontal Distance(m)	6.3	6.7
Radius(m)	0.0076	0.0076
Parameters of Conducting Wire		
Height (m)	38.62	44.62
Horizontal Distance (m)	8.8	9.2
Insulator String Length (m)	6.38	6.38
Number of Bundle-conductor	4	4
Bundle Spacing(m)	0.45	0.45
Radius of Bundle-conductor(m)	0.0362	0.0362
Altitude(m)	160	188

3. Simulation model

At present, the calculation of electrical geometry model mainly considers the influence of the ground slope angle on the terrain. The influence of the ground height of each span is not considered. Firstly, the influence of the ground height on lightning shielding performance without coupling ground wire is calculated.

3.1. Effect of ground height on SFFOR

As the rigidity of the wire material has little effect on the geometry of the wire suspended in the air because of the large span distance, so the wire is assumed to be a soft chain hinged at each place. The load on the wire is evenly distributed along the length of the wire as shown in figure 2. So the arc sag of the wire can be calculated as follow.

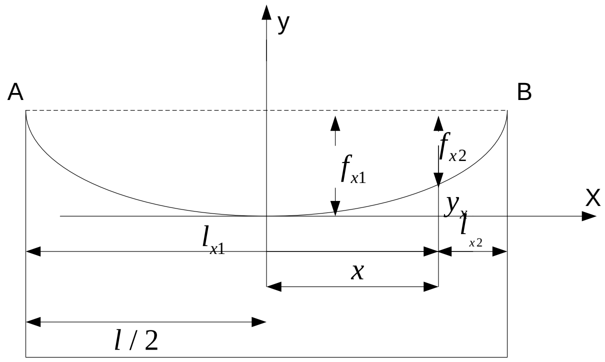

Figure 2. Arc sag calculation schematic diagram.

$$f_x = \frac{gl^2}{8\sigma_0} \tag{3}$$

Where f_x is Arc sag (m), x is the horizontal distance of any point P from the lowest point of the arc sag (m), y is the vertical distance of any point P from the lowest point of the arc sag (m), σ is the stress of the lowest wire point under certain meteorological condition (N), l is the span distance of transmission line (m).

Therefore, the arc sag of the wire is inversely proportional to the stress and proportional to the square of the span distance, that is, the greater the stress, the smaller the arc sag; the larger the span distance, the larger the arc sag. The calculation of the arc sec between #0600-#0601 long spans of Jiangcheng lines is shown in figure 3.

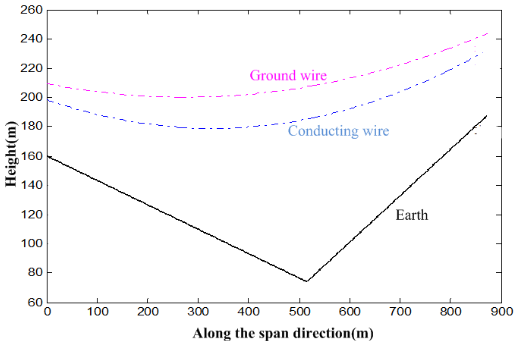

Figure 3. Arc sec between #0600-#0601 long spans of Jiangcheng lines.

Considering the influence of ground terrain and arc sag, the lightning shielding failure flashover rate is calculated along #0600-#0601 long spans and is shown in figure 4.

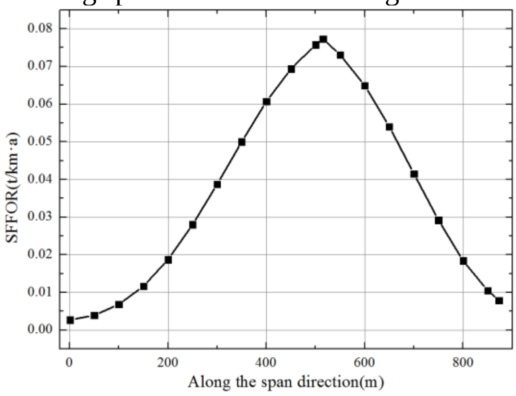

Figure 4. SFFOR at different point between #0600-#0601 long spans.

The lightning shielding failure flashover rate of the transmission line is increased first and then decreased from #0600 tower. The variation of the SFFOR is the same as the variation of the height of the conducting wire and the ground wire in the valley terrain. With the height of the conducting wire and the ground wire to the ground increases from the #0600 tower, the shielding effect of the earth on the wire is weakened, and the lightning shielding failure flashover rate increases accordingly. When the distance from #0600 tower is about 515 meters, the height of the conducting wire and the ground wire reaches a maximum value and the SFFOR also reaches the maximum value. Subsequently, the height of the conducting wire and the ground wire to the ground begins to decrease, and the SFFOR decreases. Results show that the lightning shielding failure flashover rate differs a lot in a span of transmission line. The SFFOR represents one span should use the the weighted average value considering the specific terrain.

3.2. Simulation of lightning shielding performance with coupling ground wire

Figure 5 shows the effect of coupling ground wire on the lightning shielding performance. The blue dotted line, the purple dotted line, the black dotted line represents the lightning drawing range of ground wire, conducting wire and coupling ground wire respectively, while the black solid line is the lightning strike distance of the ground and the red solid line is the exposed arc. The lightning strike on the exposed arc will hit the wire, and by calculating the lightning current of a certain range, the lightning shielding failure flashover rate will be obtained considering the insulation level. Due to the coupling ground wire, part of the exposed arc of the conducting wire is shielded resulting in the decrease of the SFFOR.

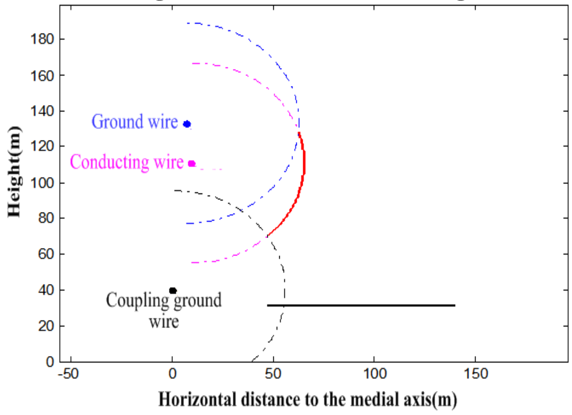

Figure 5. Effect of coupling ground wire on the lightning shielding performance.

4. Simulation results and analysis

Calculate the lightning shielding effect of coupling ground wire in different installation location at 515m from the #0600 tower. Four horizontal distances from the center of the tower at intervals of 5m and four vertical distances from 5m below the conducting wire at intervals of 5m was selected. So, a total of 16 different points to install coupling ground wire.

Results are showed in figure 6 and 7, while D_{Hcr} represents the horizontal distance from the central axis of the tower to the coupling ground wire and D_{Ver} represents the vertical distance between the conducting wire and the coupling ground wire.

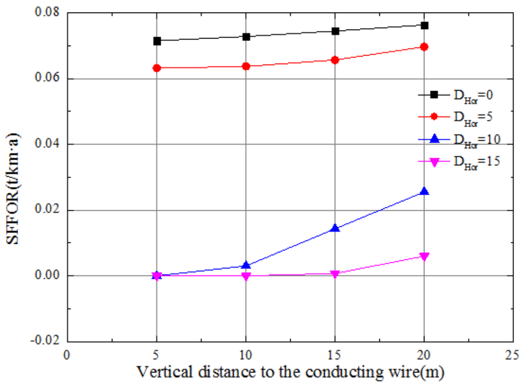

Figure 6. Effect of the height of coupling coupling ground wire on SFFOR.

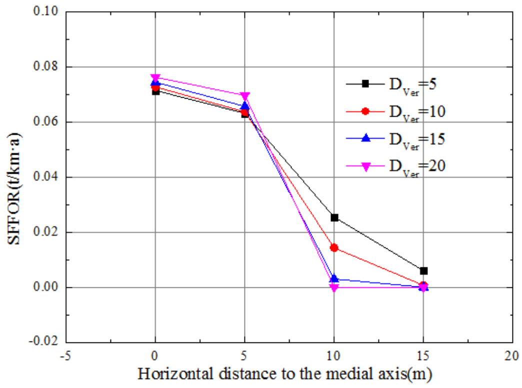

Figure 7. Effect of the horizontal position of ground wire on SFFOR.

In figure 6, the lightning shielding failure flashover rate decreases with the decrease of the vertical distance between the coupling wire and the conducting wire and shows the same law under different horizontal distance.The intersection of the exposed arc of coupling ground wire and the conducting wire is significantly increased with the decrease of the vertical distance between two wires, so that lightning shielding performance is enhanced.

In figure 7, the lightning shielding failure flashover rate decreases with the increase of the horizontal distance from the central axis of the tower and shows the same law under different height. When the horizontal distance is 0, the SFFOR is 0. This is because the upward leader is more easier to initiate and develop with the increase of the horizontal distance from the central axis of the tower, so that the shielding arc is more likely to wrap the shielding arc of the conducting wire resulting in the improvement of the lightning protection performance.

5. Conclusions

In this paper, based on the electrical geometry model, the influence of installing coupling ground wire on the lightning shielding performance considering the terrain of ±500kV Jiangcheng transmission line is studied and the following conclusions are obtained.

1) Installing the coupling ground wire under the conducting wire can effectively reduce the the lightning shielding failure flashover rate.

2) The installation position of the coupling ground wire has a great impact on the shielding effect under same external condition.

3) Results show that the shielding effect increase with the increase of the height and the horizontal distance to the axis of the coupling ground wire.

Acknowledgments

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