Lightning Disturbance Analysis and Improvement Measures for "Generation-Grid-Load-Storage " Type Distribution Line

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Abstract—For economy, the traditional lightning protection method is simple and the lightning protection effect is unsatisfactory. With China's call and demand for energy transformation, a new distribution network based on "Generation-Grid-Load-Storage" will be the general direction of China's distribution network development. The new distribution network puts forward higher requirements for the stability, and its lightning protection problem must be solved. In this paper, the overhead ground wire is proposed as the main lightning protection measure of the new distribution network, and the optimal erection range of the overhead ground wire of the distribution line is proposed through simulation, which can effectively reduce the amplitude of lightning overvoltage by 24.1%, which provides an application reference for the lightning protection concept of the new distribution line in the future.

1. Introduction

With the continuous improvement for energy transformation and new energy technologies, renewable energy and energy storage equipment are being installed on a large scale in the power grid. A friendly and interactive distribution power grid is gradually forming, which called "generation-grid-load-storage" type distribution network[1]. It also puts forward higher requirements for the reliability and stability of the operation of the new type distribution network. Lightning protection measures of traditional distribution lines mainly prevent flashover and insulation damage caused by direct lightning or lightning induction overvoltage. The status of distribution network lines in China is uneven, and most distribution lines only rely on substation recloser operation to avoid lightning damage to the lines, and only in some important lines, the mode of laying underground cables is adopted. However, the line recloser action can only prevent power interruptions, but can not effectively prevent the intrusion of lightning strikes; and it is neither economical nor realistic to change all overhead distribution lines to underground cables.

In summary, the erection of overhead lightning protection lines on the distribution network line is not only relatively economical, but also can effectively prevent and control lightning direct strikes and counterattacks, reduce the lightning induction overvoltage of the line, and improve the lightning resistance level [2–4]. Therefore, for the relatively complex and important "generation-grid-load-storage" type distribution network, erecting lightning protection lines is a cost-effective measure, and this paper proposes an optimal installation method for lightning protection lines through simulation and comparative analysis on the basis of predecessors.
2. Set up wire suppress lightning overvoltage analysis

2.1 Wire erection height calculation

Lightning protection performance, stress check and electrical safety distance should be considered to determine the proper height of overhead ground wire. For example, we assume that wire line guide ground wire sag is shown in figure 1.

![Fig. 1. 10 kV overhead power distribution line construction ground wire sag](image)

\[ H \] for erection bracket height of the ground wire; \( f_D, f_B \) as the span of wire, the wire sag respectively; \( S \) for the safe distance of wire and wire sag point.

We choose a typical meteorological condition of China southern region for calculation. The temperature 20 °C, there is no wind, the safe distance of wire and wire sag point according to the following formula:

\[ S \geq 1 + 0.012l \]  

\( S \) is the safety of the conductor and ground wire sag point in the distance, unit m; \( l \) is line span length, m.

According to the safe distance of wire and wire, calculate wire erection height \( H \). Line wire bracket height within any span calculation formula is:

\[ H = 1 + 0.012l - K l^2 \]  

\[ K = g_B \sigma_D - g_D \sigma_B \]  

\( g_D, g_B \) are wire, ground wire respectively their self-respect than load; \( \sigma_D, \sigma_B \) are wire, ground wire low stress respectively.

Combined with the actual situation of 10 kV overhead distribution line wire parameters, line for LGJ - 240/40, ground wire for GJ – 50. With reference to wire sectional specification parameter table, find out conductor and overhead ground wire corresponding to calculate the parameters such as cross-sectional area, tensile strength, thermal expansion coefficient and elastic coefficient values. At the same time, based on line and overhead ground wire state equation and the maximum stress, calculation under different span wire support the height of the largest scope. The relevant data shown in table 1.

| LDB | 40  | 50  | 60  | 70  |
|-----|-----|-----|-----|-----|
| \( \sigma_D \) | 84.56 | 84.79 | 85.06 | 85.37 |
| \( \sigma_B \) | 380.3 | 380.4 | 380.5 | 380.6 |
| \( H_m \) | 2.585 | 2.594 | 2.605 | 2.620 |

The table 1 shows that under the condition of overhead ground wire and the line type determine, overhead ground wire bracket height is proportional to the span. The relationship is shown in figure 2, the line span, the greater the same conditions overhead ground wire bracket height will increase, also must ensure that sufficient electrical safety distance between conducting line and the overhead ground wire.
Fig. 2. biggest bracket height under different span measured values.

Considering the effect of lightning protection, stress of tower and benefits, bracket height should be controlled in the height of the security and economic range. Through the statistics and analysis of the calculation results, when the span and overhead ground wire model is certain, overhead ground wire support height is inversely proportional to the line cross section size; and as the 10 kV overhead distribution lines, within the scope of the codes allowed wire mechanical strength, Combining with the ground wire protection angle and lightning protection effect of scaffold height restrictions, bracket height general choice in 1.5 m - 2.6 m [8].

2.2 wire inhibition of lightning induced over-voltage calculation

Under the coupled action of overhead ground wire, 10 kV overhead distribution lines can effectively reduce the induced lightning overvoltage on the line and tower. Based on the coupling effect of induction lightning overvoltage \( U'_{o} \) according to the following formula:

\[
U'_{o} = U_{o} \times \left(1 - k \cdot \frac{h_B}{h_D}\right) \tag{4}
\]

\[
k = \frac{Z_{BD}}{Z_{BB} + 2R_g} \tag{5}
\]

\( k \) is the coupling coefficient, \( Z_{BD} \) is the interwave impedance between the phase conductor and the lightning arrester; \( Z_{BB} \) is set up since the wave impedance between overhead ground wires; \( R_g \) for erection wire grounding resistance.

In general, 10kV overhead distribution lines usually adopt single back to 10 kv overhead distribution lines usually adopts triangle arrangement mounted on concrete pole. The following selected for the analysis of the arrangement of the lever type, as shown in figure 3. Triangle arranged on the concrete pole cross arm calls to 10 m high, selecting tower span between 50 m, between two phase single cross arm back to concrete pole central line distance of 0.7 m, photogenic wire to cross arm in the distance of 1 m, set up by the wire above the ground height is 11 + h. Analysis of change bracket height h, between the phase conductors and ground wire, the change of the induced over-voltage and the coupling effect.

Fig. 3. equilateral triangle arrangement concrete pole set up wire diagram
Table 2. the phase conductors and ground wire under different bracket height of induction overvoltage coupling coefficient

| H/m | 1.8  | 2.0  | 2.2  | 2.4  | 2.6  |
|-----|------|------|------|------|------|
| A   | 0.242| 0.234| 0.228| 0.222| 0.216|
| B   | 0.291| 0.280| 0.269| 0.260| 0.252|
| C   | 0.242| 0.234| 0.228| 0.222| 0.216|

In conclusion, when set up 10 kV overhead distribution lines, the closer between the overhead ground wire and the line wires, the coupling effect is more obvious. The height of overhead ground wire support is inversely proportional to the effect of reducing lightning induced overvoltage. The calculation and statistical analysis show that setting up the overhead ground wire can increase lightning resisting level by 20% ~ 30%. The greater the coupling coefficient $k$, the lower the lightning induced overvoltage on the line.

3. The simulation and analysis of the characteristics of overhead ground wire

We will select the following three cases for simulation: 1) 10kV distribution line without overhead ground wire; 2) set up 1.8m overhead ground wire; 3) set up 2.5m overhead ground wire. In our cases, we set the line distance to 80m, conductor for LGJ-240/40, overhead ground wire for GJ - 50. Concrete pole grounding resistance of 10 Ω, tower model by using the wave impedance model of the value of 30 Ω; Ray waves using Heidler current source model, the equivalent of 10 kV overhead line set up wire circuit diagram as shown in figure 4.

![Fig. 4 The line equivalent circuit of 10 kV overhead ground wire](image)

To lightning to a distribution circuit part to the top of the tower overhead conductors, for example, lightning current amplitude of 10 kA, not set up wire and erection bracket height is 1.8 m, 2.5 m. The simulation results shown in figure 5, 6, 7 which show the voltage of overhead ground wire of the insulator on both ends in different heights. The result shows that set up overhead ground wire of the tower has a great influence on the transient overvoltage. Three 1) 1) kinds of case is particular analysis is as follows:

Line was not set up overhead ground wire, lightning flows in phase conductor produces higher over-voltage, its amplitude will be more than 100 kV, Directly led to the breakdown, insulator breakdown voltage waveform on one side of the insulator can present violent oscillation, waveform as shown in figure 5.

![Fig. 5 Not set up wire cases of transient voltage waveform](image)
2) The line is 1.8 m below overhead ground wire. In the line of ray voltage amplitude will be much smaller than did not set up the condition of the wire, the calculation results show that the amplitude is about 82.44 kV. Waveform is shown in figure 6. Insulator, therefore, will not be breakdown, can still be safe operation.

![Fig. 6 set up 1.8 m wire cases of transient voltage waveform](image1)

3) The line is 2.5 m below overhead ground wire. Tower voltage transient process is similar to 1.8 m high overhead ground wire, but over voltage amplitude than the 1.8 m wire under the action of the rose, is about 91.97 kV, waveform as shown in figure 7.

![Figure 7 set up 2.5 m wire cases of transient voltage waveform](image2)

There is no overhead ground wire in distribution line, building wire height of 1.8 m, 2.5 m overhead ground wire three kinds of cases. After calculation and analysis, lightning resisting level of line insulator overvoltage conditions and the calculation results as shown in table 3.

We can conclude that set up 1.8 m high overhead ground wire of 10 kV overhead line lightning overvoltage fell by 24.1%, the lightning resisting level increased by 24.5%; set up 2.5 m high ground wire of 10 kV overhead line lightning overvoltage fell by 15.3%, the lightning resisting level increased by 15.1%. To set up overhead ground wire for distribution system stability is of great significance. Therefore, in the economic conditions allow, overhead ground wire distribution system should be installed suitable height.

| TABLE 3. THE PHASE CONDUCTORS AND OVERHEAD GROUND WIRE UNDER DIFFERENT BRACKET COUPLING HEIGHT OF THE COUPLING COEFFICIENT |
|---------------------------------|--------|------|------|
| H/m                            | Not wire | 1.8m | 2.5m |
| Overvoltage generated by lightning at 10kV(kV) | 108.6   | 82.44 | 91.97 |
| Lightning withstand level (kA)  | 7.84    | 10.24 | 9.26 |

Above all, 10 kV overhead distribution lines by reasonable set up overhead ground wire, lightning resisting level of can improve 20% ~ 30%. But in the process of the wire set up highly selective, considering the lightning protection performance at the same time, must ensure that the line and overhead ground wire meet the electrical safety distance. To this, it is recommended that the lightning arrester bracket highly selective in 1.5 m to 2.6 m. We recommended distribution line segment or broadly set up overhead ground wire in strong minefield. At the same time, considering the ground wire corrosion, reduce for ordinary steel strand is susceptible to corrosion bolt wire materials are recommending the aluminum clad steel wire.
4. Conclusion
In this paper, the optimized erection range of the distribution line is obtained through simulation. The main conclusions can be summarized as follows: (1) after the overhead ground line is optimized and erected, the lightning resistance level of the line can be increased by 24.5%; (2) after optimizing, the lightning voltage amplitude can be reduced by 24.1%. In the future, the shielding failure of the new power system should be further studied.

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