Reliability Design Method of Ground Wires in Transmission Lines

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Abstract. To satisfy the uniformity of design within the international standards, reliability design method is used to design ground wires in transmission lines. Based on the reliability calibration due to the Chinese national standard, it is found that the reliability indexes of ground wires meet safety levels. Then the load and resistance partial coefficients of ground wires in the ultimate state are calculated by the target reliability index. When the design method based on reliability theory is adopted, the suggested partial coefficients of ground wires can be obtained by analysing and optimizing. This method provides a popularization of reliability theory in the designing ground wires of transmission lines.

1. Introduction

The overhead transmission line is an important part of power system, and its running state will have a great impact on the reliability of the whole system[1]. In recent years, overhead transmission lines are developing towards the direction of large cross-section and multi-splitting and accidents are becoming more and more frequent, which seriously threatens the safe and stable operation of power grid[2]. As an important component of overhead transmission lines, the reliability of ground wires directly affects the safety and stability of the whole power transmission system.

Reliability design method uses probability theory to describe the safety of structures. Uncertainty factors such as geometric dimensions, loads, material properties and calculation methods are considered comprehensively and the safety of different structures can be measured by the reliability index[3]. Based on reliability theory, the safety factor in allowable stress design expression is decomposed into resistance and load partial coefficients by separating function[4-6]. In order to maintain the uniformity of design and to be in line with the international standards, reliability design method is used to design ground wires in transmission lines. By analysing and calculating, the data provides a reference for the design of transmission line engineering and the popularization of reliability theory in the field of transmission lines.

2. Calibrating the reliability

2.1. Statistical parameters of loads

In general, the coefficient of mean value (k) and the coefficient of variation (δ) are used to represent statistical parameters of the structure. k is the ratio of the mean value to the standard value, and δ is the...
ratio of the squared error to the mean value. According to the different characteristics of probability, loads involved in the process of designing for reliability of transmission lines are divided into the dead load and the live load according to their time-varying characteristics.

Dead load in transmission lines mainly refers to the self-weight of components. According to the statistical data of building codes, the dead load obeys normal distribution, the mean coefficient is 1.06, and the variation coefficient is 0.07.

The design of the wind load in transmission lines follows the relevant model in the code of building structure and is amenable to extreme value type I distribution[7]. Considering that the transmission lines bear dead load and wind load, the mean coefficient of wind load \( (k_{WT}) \) is 0.999 and the discrete coefficient of wind load \( (\delta_{WT}) \) is 0.193[8] when referring to the code of building structure design.

### 2.2. Statistical parameters of resistances

Based on the statistical data about resistances to four types of ground wires from China Electric Power Research Institute, the results are shown in table 1.

| Types of ground | \( k_{r,j} \) | \( \sigma_{r,j} \) | \( \delta_{r,j} \) |
|----------------|----------|----------|----------|
| JL/G1A-300/25 | 1.021    | 0.042    | 0.041    |
| JL/G1A-400/35 | 0.972    | 0.101    | 0.104    |
| JL/G1A-240/30 | 1.114    | 0.048    | 0.043    |
| JL/G1A-300/40 | 1.047    | 0.030    | 0.029    |

According to the table 1, the mean coefficient \( (k_{r,p}) \), the standard deviation \( (\sigma_{r,p}) \) and the discrete coefficient \( (\delta_{r,p}) \) to the resistance of ground wires are 1.038, 0.093 and 0.09 separately. The resistance of ground wires \( (R) \) can be expressed as follows. \( \Omega_p \) is the uncertainty coefficient of calculation mode for resistance of ground wires.

\[
R = \Omega_p T_p \tag{1}
\]

The mean and discrete coefficients to the resistance of ground wires are as follows.

\[
k_r = \frac{m_r}{R_k} = \frac{\Omega_p T_p}{T_{pk}} = k_p k_{r,p} \quad \delta_r = \sqrt{\sigma_r^2 + \delta_{r,p}^2} \tag{2}
\]

where \( k_p \) and \( \delta_p \) represent the mean and discrete coefficients of the uncertain calculation mode in ground wires, which are 1.05 and 0.07 respectively. From formula (2), the mean and the discrete coefficients to the resistance of ground wires are 1.09 and 0.114 separately. It is considered that the resistance of ground wires obeys logarithmic normal distribution.

#### 2.3. Calculating reliability index

Referring to the national standard on the design of ground wires, the maximum tension of ground wires \( (T_{max}) \) and the standard value of minimum failure load \( (R_0) \) are as follows when the dead load is combined with the wind load.

\[
T_{max} \leq \frac{T_{pk}}{K_c} \quad R_k = T_{pk} = K_c T_{max} = K_c (T_{Gk} + T_{Wk}) \tag{3}
\]

where \( T_{pk} \) is the standard value of failure load. \( K_c \) is the design safety factor of ground wires, which of the lowest sag point and suspension point are not less than 2.5 and 2.25 respectively under wind load and dead load. \( T_{Gk} \) and \( T_{Wk} \) represent the standard value of tension generated by dead load and wind load of ground wires separately.

The force equation of ground wires is as follows. \( T_G \) and \( T_W \) represent the value of tension generated by dead load and wind load of ground wires separately.

\[
Z = R - T_G - T_W \tag{4}
\]

The average resistance of ground wires is as in equation (5).

\[
m_R = k_R R_k = k_R K_c (T_{Gk} + T_{Wk}) = k_R K_c (1 + \rho_W) T_{Gk} \quad \rho_W = T_{Wk} / T_{Gk} \tag{5}
\]
The reliability index for resistance of ground wires can be calculated by JC method and is shown in figure 1 when $\rho_W$ takes 1 to 12. From the figure 1, it can be seen that the reliability index for resistance of ground wires is inversely proportional with $\rho_W$ and the reliability index of the lowest sag point is higher than that of the suspension point. The average reliability index for the lowest sag point and the suspension point of ground wires is 4.372 and 3.968 separately.

![Figure 1. Reliability index for resistance of ground wires (dead load + wind load).](image)

3. Study on design parameters

3.1. Target reliability index

According to relevant provisions in the building code, when the safety level of ductile failure is the first level, second level and third level, the corresponding target reliability indexes are 3.7, 3.2 and 2.7 respectively. For engineering structures, it is considered that annual failure rate less than $10^{-4}$ is relatively safe, less than $10^{-5}$ is safe, and less than $10^{-6}$ is very safe. The design reference period of a general structure is 50 years. Therefore, when the failure probability is less than 5 times $10^{-3}$, 5 times $10^{-4}$ and 5 times $10^{-5}$ respectively in the design reference period, the structure can be considered relatively safe, safe and very safe. The table 2 gives a one-to-one relationship between reliability index and failure probability. From the table 2, it can be seen that the corresponding reliability index is between 2.5 and 4.0.

| $\beta$ | $P_f$   |
|--------|--------|
| 1.0    | $1.59\times10^{-1}$ |
| 1.5    | $6.68\times10^{-2}$ |
| 2.0    | $2.28\times10^{-2}$ |
| 2.5    | $6.21\times10^{-3}$ |
| 3.0    | $1.35\times10^{-3}$ |
| 3.5    | $2.33\times10^{-4}$ |
| 4.0    | $3.17\times10^{-5}$ |
| 4.5    | $3.40\times10^{-6}$ |

According to the results of reliability calibration, when under dead load and wind load, the reliability index of ground wires designed according to the current code for transmission lines design is much higher than the target reliability index of structural components with ductile failure whose safety level is the first level, which is 3.7. Referring to GBJ 68-84, the target reliability index is taken as 3.2.
3.2. Partial coefficients
The function of ground wires is linear and as in equation (4). When the reliability index is known, the general separation method is used to obtain the partial coefficients of ground wires. Considering that the loads of ground wires are dead load and wind load, the formula for calculating the reliability index ($\beta$) is as follows.

$$\beta = \frac{m_Z}{\sigma_Z} = \frac{m_R - m_G - m_W}{\sqrt{\sigma_R^2 + \sigma_G^2 + \sigma_W^2}} \quad (6)$$

The separate function is as in equation (7).

$$\alpha_R = \frac{\sigma_R}{\sigma_Z}, \quad \alpha_G = \frac{\sigma_G}{\sigma_Z}, \quad \alpha_W = \frac{\sigma_W}{\sigma_Z} \quad (7)$$

The partial coefficients to the mean value of ground wires are obtained as follows. $\delta_R, \delta_G$ and $\delta_W$ represent the discrete coefficients of the resistance, dead load and wind load respectively.

$$\gamma_R = 1 - \alpha_R \delta_R \beta \quad \gamma_G = 1 + \alpha_G \delta_G \beta \quad \gamma_W = 1 + \alpha_W \delta_W \beta \quad (8)$$

The partial coefficients to the standard value of ground wires in the code are as in equation (9). $k_R, k_G$ and $k_W$ represent the mean coefficients of the resistance, dead load and wind load respectively.

$$\gamma_R = \gamma_R k_R^{-1} \quad \gamma_G = \gamma_G k_G \quad \gamma_W = \gamma_W k_W \quad (9)$$

The reliability index is taken as 3.2. According to the formulas (8) and (9), the partial coefficients of ground wires can be calculated and are shown in figure 2. The results show that the mean values of resistance coefficient, dead load coefficient and wind load coefficient are 1.084, 1.072 and 1.828 respectively. Considering that the current research on the partial coefficient of dead load is mature, the dead load coefficient is 1.2. It is suggested that the resistance coefficient, dead load coefficient and wind load coefficient are 1.1, 1.2 and 1.8 respectively after optimization.

![Figure 2. Partial coefficients of ground wires](image)

4. Conclusion
Through calibrating the reliability of ground wires designed according to the current national standard and industry standard, the average reliability indexes of the lowest sag point and the suspension point are 4.372 and 3.968 respectively when under the dead load and wind load. Taking the target reliability index as 3.2, the partial coefficients of ground wires can be calculated and optimized. If the design method based on reliability theory is adopted, it is suggested that the resistance, dead load and wind load partial coefficients of ground wires are 1.1, 1.2 and 1.8 respectively.

Acknowledgments
This work was supported by the National Natural Science Foundation of China (No. 51579088), the Natural Science Foundation of Jiangsu Province-China (BK20161507) and science and technology...
project of State Grid Corporation of China (Research on Design Method of Overhead Transmission Line Based on Mechanical Strength Matching Theory, No. GC71-17-018).

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