Simulation and Analysis of Radial Temperature for Aluminum Conductor Steel Reinforced with 1250mm² Large Cross-Section

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Abstract. In order to meet the growing demand for electricity, the construction of UHV DC project has vigorously carried out. With the improvement of voltage level, the cross-section of conductor also increases. For large cross-section conductor, the number of steel and aluminum single wires and layers of the conductor are large, and the internal structure is very complex. It has been proved that there is a temperature difference in the radial direction of the conductor due to the contact heat transfer between steel and aluminum based on previous studies. However, most studies are focused on normal conductors, not large cross-section conductors. Therefore, in this paper, the geometric model and temperature calculation model for 1250mm² large cross-section ACSR conductor, which is widely used in UHVDC, were established. Simulation of conductor temperature distribution was carried out, and the influence of wind velocity, environment temperature and current on radial temperature difference was analyzed. The results show that, with the increase of wind velocity and the decrease of current, the radial temperature difference of conductor decreases gradually, while the environment temperature has little influence on the radial temperature difference.

1. Introduction
With the development of economy, the social demand for electricity is increasing continuously. In China, UHVDC transmission has developed very rapidly because of large transmission capacity, small loss, long transmission distance and saving line corridor resources which is especially suitable for high-voltage, long-distance and large-capacity transmission [1-3]. With the increase of voltage level, transmission capacity and distance, the transmission loss is increasing. By increasing the conductor cross-section and reducing the conductor resistance, the transmission loss can be effectively reduced, which leads to a better economy [4].

Conductor temperature is an important factor that influences the transmission capacity. For aluminum conductor steel reinforced (ACSR), it’s usually required that the conductor temperature should not exceed 70 °C. At a long operation with a temperature of over 70 °C, the tensile strength of the conductor will decrease, which perhaps causes transmission line accidents. Conductor temperature is mainly affected by current, environment temperature and wind velocity. Based on the heat balance theory, the relationship between conductor temperature and current is proposed in CIGRE, IEC and IEEE [5-7]. However, in the above calculation models, it is usually assumed that the conductor is an isothermal cylinder and the heat transfer inside the conductor is ignored, which is not consistent with
the real situation. The conductor is composed of steel wires and aluminum wires. There is contact thermal resistance between single wires, resulting in a certain temperature difference inside the conductor. In previous studies, it’s shown that the steel wires inside have a higher temperature while the aluminum wires outside have a lower temperature, and the radial temperature difference is generally 0-5 °C [8, 9].

A large number of research on the radial temperature distribution of the conductor has been carried out, and a variety of theoretical models has been established [10-12]. However, most studies are focused on normal ACSR, which usually has a cross-sectional area of less than 500 mm² and an aluminum strand layers of 2. Besides, the voltage level and current are also small. 1250 mm² large cross-section conductor, commonly used in UHVDC [13, 14], has a large cross-sectional area and aluminum strand layers, and the voltage level and current are also very high, so the radial temperature difference may be different from that of the normal conductor. Therefore, the geometric model and temperature calculation model of 1250 mm² large cross-section ACSR were established, and the temperature distribution was calculated, and the influencing factors of radial temperature difference were analyzed.

2. Geometric model
1250 mm² large cross-section ACSR is selected, and the specific parameters are shown in Table 1. The geometric model is shown in Figure 1.

| No. | Item                                      | Value          |
|-----|-------------------------------------------|----------------|
| 1   | Type                                      | 1250-A1/S1B-84/19 |
| 2   | Diameter(mm)                              | 47.9           |
| 3   | Cross-section area of aluminum wires (mm²) | 1248           |
| 4   | Number of aluminum wires                  | 84             |
| 5   | Diameter of aluminum wires (mm)           | 4.35           |
| 6   | Cross-section area of steel wires (mm²)   | 102            |
| 7   | Number of steel wires                     | 19             |
| 8   | Diameter of steel wires (mm)              | 2.61           |

Figure 1. Geometric model of 1250mm² conductor.

As shown in Figure 1, the conductor has a two layers of steel wires and four layers of aluminum wires. Due to the large number of steel and aluminum wires, the internal structure is more complex than normal conductors, and the contact heat transfer between wires will lead to the radial temperature difference inside the conductor.

3. Temperature calculation model
When the transmission lines are in operation, the conductor temperature will rise because of the Joule heat and solar heat, which results in convection and radiation heat transfer with the environment. When
the heat absorption is equal to the heat dissipation, the conductor temperature will keep stable. Then the heat balance equation can be established as following [5].

\[ q_j + q_s = q_c + q_r \]  \hspace{1cm} (1)

Where \( q_j \) is the Joule heat, \( q_s \) is the solar heat, \( q_c \) is the convection heat, and \( q_r \) is the radiation heat. The Joule heat is calculated as follow,

\[ q_j = I^2 R \]  \hspace{1cm} (2)

Where \( I \) is the current, and \( R \) is the conductor resistance.

The solar heat is calculated as follow,

\[ q_s = \alpha_s J_s D \]  \hspace{1cm} (3)

Where \( \alpha_s \) is the solar heat absorption coefficient, \( J_s \) is the solar heat intensity, \( D \) is the conductor diameter.

The convection heat is calculated as follow,

\[ q_c = hA(T_c - T_e) \]  \hspace{1cm} (4)

Where \( h \) is the convection heat coefficient, \( A \) is the conductor surface area, \( T_c \) and \( T_e \) are the conductor surface temperature and environment temperature respectively.

The radiation heat is calculated as follow,

\[ q_r = \varepsilon \sigma A(T_c^4 - T_e^4) \]  \hspace{1cm} (5)

Where \( \varepsilon \) is the conductor emissivity, and \( \sigma \) is Stefan-Boltzmann constant.

When calculating the temperature distribution inside the conductor, it is assumed that the temperature of a single wire is fixed and there is no temperature difference. The heat transfer between single wires is contact heat transfer, as shown in Figure 2. The heat is calculated as follow [6, 15],

\[ q_{ch} = h_{ch} A_{ch} (T_1 - T_2) \]  \hspace{1cm} (6)

Where \( q_{ch} \) is the contact heat, \( h_{ch} \) is the contact heat coefficient, \( A_{ch} \) is the contact area of two wires, \( T_1 \) and \( T_2 \) are the temperature of two wires.

![Figure 2. Contact diagram for single wires.](image)
Combined with equations (1) ~ (5), the surface temperature of the conductor can be calculated. The heat transfer inside the conductor can be analyzed by equation (6), and then the temperature distribution inside the conductor can be simulated.

4. Calculation and analysis of radial temperature difference
Based on the temperature calculation model, the simulation of conductor temperature distribution was carried out, and the influence of wind velocity, environment temperature and current on the radial temperature difference was analyzed.

4.1. Calculation of radial temperature difference
Temperature distribution inside the conductor is shown in Figure 3. Obviously, there is a temperature difference in the radial direction of conductor. The steel wires have a higher temperature while the aluminum wires have a lower temperature, which is consistent with the conclusion of theoretical analysis. Inside the conductor, the heat is mainly transferred through the contact between single wires. Due to the large contact thermal resistance, the internal temperature of the conductor is higher than the external temperature, which results in the radial temperature difference.

![Figure 3. Conductor internal temperature distribution at a certain condition.](image)

4.2. Wind velocity
The environment condition is shown in Table 2 and the simulation results are shown in Figure 4.

| No. | Item                        | Value             |
|-----|-----------------------------|-------------------|
| 1   | Type                        | 1250-A1/S1B-84/19 |
| 2   | Environment temperature (°C)| 20                |
| 3   | Wind velocity (m/s)         | 0~10              |
| 4   | Solar heat intensity (W/m²)  | 1000              |
| 5   | Current (A)                 | 2000              |

Table 2. Environment condition.
It is shown in Figure 4 that the radial temperature difference of conductor decreases with the increase of wind velocity. At first, the temperature difference decreases quickly at a low velocity, and then with the increase of wind velocity, the temperature difference gradually tends to be stable. With the increase of wind velocity, the convection heat between conductor surface and environment increases gradually, which means that the Joule heat generated is more easily transferred to the environment, resulting in the decrease of radial temperature difference. When the wind velocity is low, the convection heat is little. With the change of wind velocity, the change of convection heat takes a large proportion in the total heat loss, which has a great impact on the radial temperature difference. When the wind velocity is high, the convection heat is large. With the change of wind velocity, the change of convection heat takes a small proportion in the total heat loss, which has a little impact on the radial temperature difference.

4.3. Environment temperature
The environment condition is shown in Table 3 and the simulation results are shown in Figure 5.

Table 3. Environment condition.

| No. | Item                                | Value                  |
|-----|-------------------------------------|------------------------|
| 1   | Type                                | 1250-A1/S1B-84/19      |
| 2   | Environment temperature (°C)        | -10~30                 |
| 3   | Wind velocity (m/s)                 | 0.5                    |
| 4   | Solar heat intensity (W/m²)         | 1000                   |
| 5   | Current (A)                         | 2000                   |
Figure 5. Relationship between environment temperature and radial temperature difference.

It is shown in Figure 5 that the radial temperature difference increases gradually with the increase of environment temperature. However, the increase is quite little, so it could be considered that the temperature difference keeps stable. Environment temperature does not influence the heat transfer directly, but influence convection and radiation heat through the temperature difference between conductor surface temperature and environment temperature. Therefore, when the other environment conditions keeps the same, the temperature difference between conductor surface temperature and environment temperature is basically fixed, which means that the temperature distribution inside the conductor keeps basically unchanged. That is, the change of environment temperature will cause the change of conductor temperature, but it has no influence on the temperature distribution and radial temperature difference. In addition, the environment temperature has influence on the density and dynamic viscosity of air, but the influence is quite little. Therefore, when the environment temperature increases, the radial temperature difference of the conductor is considered to be stable.

4.4. Current
The environment condition is shown in Table 4 and the simulation results are shown in Figure 6.

| No. | Item                          | Value         |
|-----|-------------------------------|---------------|
| 1   | Type                          | 1250-A1/S1B-84/19 |
| 2   | Environment temperature (°C)  | 20            |
| 3   | Wind velocity (m/s)           | 0.5           |
| 4   | Solar heat intensity (W/m²)    | 1000          |
| 5   | Current (A)                   | 0–2500        |
Figure 6. Relationship between current and radial temperature difference.

It is shown in Figure 6 that the radial temperature difference increases gradually with the increase of current. When the current increases, the Joule heat generated inside the conductor increases, and the heat could not be transferred to the environment quickly, which leads to the rise of temperature for wires inside the conductor and the increase of radial temperature difference.

5. Conclusion
In this paper, the geometric model and temperature calculation model of 1250 mm$^2$ large cross-section ACSR are established, and the temperature distribution was simulated, and the influence of wind velocity, environment temperature and current on radial temperature difference were analyzed. The specific conclusions are as follows.

(1) The geometric model and temperature calculation model of 1250 mm$^2$ large cross-section ACSR are established, and the temperature distribution was simulated.

(2) There is a temperature difference in the radial direction of conductor. The steel wires have a higher temperature while the aluminum wires have a lower temperature.

(3) With the increase of wind velocity, the radial temperature difference of conductor decreases. At first, the temperature difference decreases quickly at a low velocity, and then with the increase of wind velocity, the temperature difference gradually tends to be stable.

(4) With the increase of environment temperature, the radial temperature difference increases gradually. However, the increase is quite little, so it could be considered that the temperature difference keeps stable.

(5) With the increase of current, the radial temperature difference increases gradually.

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