Influence of Temperature Characteristics Based on Big Data on Cable Accessories under HV DC Field

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Abstract. Cable accessory is a weak link in cable line operation, which is prone to accidents. It is of great significance to study the influence of temperature characteristics on cable accessory and determine the temperature field distribution of cable accessory for ensuring the safety of cable accessory operation and improving the overall reliability of cable line. This paper mainly studies the influence of temperature characteristics based on big data analysis on cable accessories under HV DC field. This paper first gives an overview of big data related technologies, and then introduces the calculation method of cable loss, which provides a theoretical basis for analyzing the influence of temperature characteristics on cable accessories. Furthermore, by setting the contact resistance coefficient K at the conductor of the cable connector, the temperature field calculation model of the contact resistance of the cable connector is established, and the distribution law of the temperature characteristics of the cable connector when the contact resistance of the conductor is too large is studied. With the increase of the contact resistance, the temperature of the connector core and the temperature of the connector indicate that the temperature increases gradually.

Keywords: Big Data Analysis, Temperature Characteristics, Cable Accessories, HVDC Field

1. Introduction

In recent years, urban power construction has been developing continuously. Power cables have been widely used in power distribution network because they can effectively save line corridors and reduce the impact on urban environment. With the rapid growth of power cable lines, the use of cable accessories (including terminal joints and intermediate joints) is also increasing. Cable accessories are used together with the cable for a long time, which is an important part of the cable line as important as the cable to ensure safe operation. However, once the power cable fails, the power supply enterprises need to invest a lot of manpower, material resources and financial resources to repair after the failure. The maintenance and inspection are not only a heavy task, but also consume a lot of resources. Temperature is an important state characteristic quantity of electrical equipment, and the
monitoring value of temperature in power system can be used as the basis of equipment condition analysis and evaluation. The use of big data to analyze and calculate the temperature distribution and load flow of cables and accessories and the maximum utilization of cable capacity can avoid the waste of resources caused by blindly increasing lines, and also provide a reliable scientific basis for power grid dispatching to ensure the safe operation of power grid [1]. In addition, by making full use of the transmission capacity of the existing cable lines and improving the transmission efficiency, the operation personnel can not only master the cable operation status, but also carry out load scheduling based on this basis, so as to cut the peak load and fill the valley in the urban area.

At present, the calculation of cable temperature distribution at home and abroad is mainly based on the thermal circuit analysis and numerical calculation method of IEC standard. Yasui introduced the calculation of cable temperature distribution based on thermal circuit model in detail, and gave the corresponding calculation formula of equivalent heat and cable temperature rise. The parameters involved include thermal resistance of the cable body, thermal resistance of the media around the cable and loss of each layer of the cable. For a single core cable, the loss includes conductor loss, insulation loss and metal sheath loss. For three-core cables, the losses include conductor losses, insulation losses and armor losses [2]. Ohsaki combined the cable laying situation and the surrounding environmental parameters, and used the finite element method to establish the steady-state temperature field simulation calculation of the steady-state temperature field distribution of the buried cable [3].

This paper takes the cable accessories as the research object, based on the mathematical model of electrothermal coupling field, uses the finite element analysis software to carry out the numerical simulation calculation of the finite element temperature field of the cable and its joint, introduces the contact resistance coefficient $K$ for the defect state of the internal pressing technology of the cable joint, and establishes the corresponding model. According to the calculated thermal distribution of the cable joint, the temperature characteristic distributions under different $K$, load current $I$ and ambient temperature $T$ are studied.

2. Temperature Characteristics of Cable Accessories under Big Data

2.1. Overview of Big Data Technology

Due to the huge amount of big data mining, storage and calculation, the sampling survey method is not applicable to the massive big data. The traditional technical architecture and scheme of data processing can no longer efficiently process such massive data. At the same time, for relevant organizations, if they cannot timely collect and process the important big data information and timely process the effective feedback information, it will be very detrimental to the development of the organization in the long run. Therefore, the arrival of the era of big data poses a new challenge to human's ability to control data, requiring people to propose a new powerful scheme to effectively and quickly collect such a huge amount of data information, and to use new technologies and methods to process and analyze data aggregation in full volume. In order to provide the possibility for people to gain a deeper and more comprehensive insight into the value of data [4-5].

Big Data technology is composed of Data Mining, Distributed computing, Distributed storage, Machine Learning, Natural Language Process and Graph Computation.

(1) Data mining extracts required data from mass data aggregation and mines useful data with corresponding analysis software.

(2) Distributed computing can help big data to complete the storage and calculation of a large amount of data. By decomposing a large computing task into several small computing tasks, it can be distributed to multiple computers for parallel completion.

(3) Distributed storage distributes the running programs and acquired applications in the local and cloud by deploying virtual machines in the cloud server, which not only increases the fault-tolerant resistance of the whole system to downtime and failures, but also further improves the performance of the big data system by expanding the cloud server.

(4) Machine learning and natural language are used to process unstructured data such as audio,
pictures, web addresses, e-commerce reviews and price tags in big data.

(5) Figure computing is used to deal with the relationship data between social network users and focus on the study of the relationship between user nodes.

Data mining is a relatively common big data technology. As a data acquisition and analysis technology, data mining comprehensively utilizes data acquisition, database technology, visual processing and other technical methods to obtain relevant results from data. In the era of big data, although data mining generally represents the acquisition of data value, there is more consensus in the industry that only when mining technology is closely combined with practical application scenarios can data value be better reflected [6].

2.2. Equivalent Model and Equivalent Loss Calculation of Cable Connector Contact Resistance

In order to analyze the excessive contact resistance of the cable connector and determine the heat loss value of the internal defect of the cable connector, the equivalent calculation model based on contact resistance should be established first. According to the above governing equation of electromagnetic field analysis, the input parameters for the electromagnetic field analysis of cable joints are such parameters as the conductivity and permeability of materials. Therefore, in order to consider the influence of contact resistance heat generation, this paper calculates the equivalent heat loss of the cable joint by solving the equivalent conductivity of the cable conductor and the pressure connector. By introducing the contact coefficient, the influence law of different contact states on the temperature field distribution of the cable joint is studied [7-8].

Due to the existence of copper pipe connection, the diameter of the cable core at the middle joint increases, so the core radius at the middle joint is defined as \( R_1 \) and the resistivity is \( p_1 \). Similarly, the core radius of the cable part is \( R_2 \) and the resistivity is \( p_2 \). According to the definition of resistance, the resistance per unit length of the two can be expressed as follows:

\[
R_1 = \frac{p_1}{\pi R_1^2} \quad (1)
\]

\[
R_2 = \frac{p_2}{\pi R_2^2} \quad (2)
\]

As the radius of the cable conductor of the cable connector and the cable body is fixed with the model, the contact resistance of the cable connector is mainly determined and controlled by the parameter \( p_1 \) [9]. In order to facilitate the analysis of the influence of contact resistance on the temperature field of the connector cable, a contact coefficient \( K \) is introduced and defined as the ratio between the resistance value of the pressure connector per unit length (including the cable conductor) and the resistance value of the cable conductor of that length, namely:

\[
k = \frac{R_1}{R_2} = \frac{\frac{p_1}{\pi R_1^2}}{\frac{p_2}{\pi R_2^2}} = \frac{p_1}{p_2} \cdot \frac{R_2^2}{R_1^2} \quad (3)
\]

For a well-made intermediate joint, the contact resistance between the cable conductor and the connecting pipe is not taken into account, and it is considered that the cable core is in close contact with the copper pipe [10]. Since they are all made of copper, the resistivity \( p_1 = p_2 \), and the well-made cable contact coefficient can be calculated.

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\[
k = \frac{R_1}{R_2} = \frac{R_2^2}{R_1^2} = \left(\frac{11.9}{21.9}\right)^2 \approx 0.3 \quad (4)
\]

From the above equation, it can be seen that the contact coefficient \( k < 1 \) of the well-made intermediate joint. However, in practical engineering, due to the non-standard production process of
cable joint, there is often a contact resistance at the joint with a large value that cannot be ignored, making $k > 1$. Therefore, this paper will focus on the case of $k > 1$.

Since the conductivity and resistivity of the metal conductor part of the cable joint meet the following reciprocal relation:

$$\sigma = \frac{1}{\rho}$$  \hspace{1cm} (5)

Substituting into the above equation, the equivalent conductivity of the joint conductor can be solved as follows:

$$\sigma_i = \frac{\alpha_i}{k} \cdot \left(\frac{2}{r_i}\right)^2 = \frac{0.3}{k} \cdot \frac{\alpha_i}{r_i}$$  \hspace{1cm} (6)

In the temperature field simulation calculation of the cable connector with contact resistance, the main changes are the changes of the electromagnetic loss and conductor loss of the conductor and the pressure connection of the cable connector. The electromagnetic loss is determined by the electromagnetic loss density of the cable connector conductor, and the electromagnetic loss density is related to the conductivity.

3. Consider the Temperature Characteristics of the Contact resistance

3.1. Experimental Holistic Approach

The cable connector studied in this paper is a three-core cable. Considering that the joint is made once by the same group of people in the production process, the production process is similar. In the subsequent simulation calculation in this paper, it is approximately considered that the three-phase contact resistance has little difference, that is, the equivalent $k$ value of the three-phase is the same, and the discussion is conducted. The influence of contact coefficient $K$, ambient temperature and load current on the temperature characteristics of cable joint is further studied.

(1) Contact Coefficient $K$

During cable operation, the increased contact resistance will cause more losses, which is ultimately manifested as cable temperature rise. In order to calculate the influence of contact resistance on cable temperature field, this paper will select different parameters $K$ for finite element simulation calculation and analysis, and draw the temperature distribution curve through the mapping software Origin.

(2) Ambient Temperature

Considering that the ambient temperature acts directly on the outer surface of cable and joint and produces convective heat transfer, the influence rule of ambient temperature on the surface temperature distribution is mainly studied here. Keep load cable $I=530\text{A}$ and contact coefficient $K$ unchanged. Calculate the distribution of cable core and surface temperature when the ambient temperature is $20$, $25$, $30$ and $40{\degree}\text{C}$.

(3) Load Current

The heat source of cables and joints is the loss of cables, and the current is the source of cable loss. Generally speaking, the higher the current of cables is, the more losses will be generated, so the higher the temperature of cables will be. Under different working conditions, the current of cable intermediate connector will change, which causes the conductor to produce Joule heat, which is an important factor affecting the temperature distribution of insulation layer. Keep the contact coefficient $K$ and the ambient temperature constant. When the load current $I$ varies from $200\text{A}$ to $700\text{A}$, the cable core and surface temperature distribution curves can be calculated.

4. Temperature Characteristics of Contact Resistance Affect the Experimental Results of Cable Accessories

4.1. Influence of Contact Coefficient $K$
Table 1. Temperature distribution of cable core with different contact coefficient k

|       | 1000 | 2000 | 3000 | 4000 | 5000 |
|-------|------|------|------|------|------|
| K=3   | 71.0 | 71.3 | 73.1 | 71.8 | 71.0 |
| K=5   | 72.6 | 74.9 | 81.5 | 74.8 | 71.0 |
| K=7   | 72.9 | 77.4 | 89.3 | 76.2 | 71.0 |

Figure 1. Temperature distribution of cable core with different contact coefficient k

As shown in Table 1 and Figure 1, with the increase of contact coefficient K, the temperature in the conductor area of the three cable core at the joint center (z=3000mm) increases with the increase of temperature, with little difference in temperature increase. When the contact coefficient increases from 3 to 7, the temperature rises from 73.1 to 89.3. The remote cable body on both sides of the cable connector (the distance from the center of the cable connector is more than 2.5m) has little influence on the temperature of the cable core by the heat generation of contact resistance, and the temperature basically remains unchanged. After considering the contact resistance at the joint, the temperature of the intermediate joint is often higher than that of the two terminal cores. Through calculation and analysis, it can be known that the contact resistance coefficient k =2.7 is about, which is the watershed value of the temperature of the cable and the connector core. With the increase of contact coefficient K, the volume heat generation rate of the equivalent conductor at the joint increases, but the larger outer diameter of the joint makes the convective and radiative heat dissipation capacity between the surface and the air stronger.

4.2. Influence of Ambient Temperature

Table 2. Cable surface temperature distribution curve at different ambient temperatures

|       | 1000 | 2000 | 3000 | 4000 | 5000 |
|-------|------|------|------|------|------|
| T=20  | 51.3 | 52.6 | 48.2 | 52.7 | 51.3 |
| T=25  | 56.1 | 56.4 | 53.9 | 56.6 | 56.1 |
| T=30  | 62.5 | 61.8 | 58.4 | 62.9 | 62.5 |

As shown in Table 1, the temperature at any position on the surface of the whole cable will rise synchronously with the rise of the ambient temperature T. In particular, the amplitude of temperature rise at all positions of the cable is consistent with that of the ambient temperature, and the rate of change is basically constant. With the increase of K value, the surface temperature difference of cables is less affected by the change of environmental temperature T.
4.3. Effect of Load Current

As shown in Figure 2, the temperature of each part of the cable increases with the increase of load current $I$, and the temperature rise amplitude also increases with the increase of load current $I$. When the load current $I$ increases from 300A to 500A, the core temperature at $Z = 3000mm$ and $Z = 5000mm$ rises from 40.7 °C and 40.9 °C to 70.4 °C and 70.6 °C respectively. The temperature decreases gradually along the radius from the core to the epidermis, and the temperature of the epidermis is the lowest. The core and skin temperature of cable connector and remote cable body have a quadratic function relation with load current, and with the increase of load current, the temperature difference between cable core and skin becomes larger and larger.

When calculating the load flow of power cable, the bottleneck of the load flow should be considered. When the contact coefficient $K$ value is relatively large, the contact resistance is easy to overheat, which will cause the temperature of the cable joint to be higher than other positions in the cable line, prone to fire and other accidents. At this time, the cable joint will become an important link restricting the cable line.

5. Conclusions

In this paper, the electromagnetic and thermal coupling field of insulated cables and their intermediate joints which are commonly used in power distribution network is simulated by ANSYS finite element method, and the temperature field and temperature characteristics of the joint with contact resistance under the internal compression defect of the cable joint are studied. By introducing the contact resistance coefficient $K$ and re-establishing the THREE-DIMENSIONAL finite element model of the contact resistance of the cable intermediate joint caused by the defect of the joint pressing process, the influence law of the contact coefficient $K$, the ambient temperature $T$ and the load current $I$ on the temperature characteristics of the cable joint is further studied emphatically. It can be known that with the increase of contact resistance, the temperature of the cable connector core increases synchronously and overheating will occur, which exceeds the temperature of the cable body core and becomes a weak link restricting the cable line.

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