Temperature field simulation of 10kV three-core cable based on finite element method

CHEN Mengxi, FU Zhouxing, LIU Baoxiang
School of Electrical and Control Engineering, Xi’an university of science and technology, Xi’an 710000, China;
bestcmx@163.com.

Abstract. Temperature is an important parameter to reflect the running state of cable. In this paper, the finite element calculation parameters of the three-core cable commonly used in distribution network are established, and the principle of loss calculation in the thermal calculation of temperature field is expounded. In addition, the three-dimensional finite element model of three-core cable is established, and then the temperature field is constructed and the distribution mode of temperature field is analyzed. In each structure layer assignment model good thermal physical parameters, the corresponding materials for conductor temperature is 90℃ temperature field distribution, which shows three core cable internal temperature field of the center is the hottest temperature,. And in the direction of heat transfer to the cable skin, there is always a temperature gradient. Finally, the factors affecting the temperature distribution are analyzed.

1. The introduction
With the development of economy, People have higher and higher requirements on the reliability of power supply, and People's Daily operation and maintenance of the operation and maintenance units have also appeared new changes and new requirements. Three-core cable is the key transmission equipment in the distribution network. Improving the condition monitoring level of three-core cable is conducive to ensuring the reliability of power supply in the distribution network. At present, the city distribution network of the cable rate is more and more high, cable intermediate joint so also a large number of applications. Among them, the cable cold shrink intermediate connector, because of its installation is convenient, good insulation performance, high temperature resistance and good acid and alkali performance, etc. in the distribution network has been widely used.

However, the subsequent cable and intermediate joint fault problem is also on the rise, which seriously threatens the safety and stability of the power grid, and even causes the feeder trip. The aging and current carrying of power cables are closely related to temperature. The running state of cables can be judged by monitoring the temperature. The cable accessories are always the weak links in the operation of the cable system. The temperature is an important index to measure whether the insulation state of the cable joints is good or not. With the increase of joint temperature, the contact resistance of the joint increases, which will aggravate the aging of insulation and pose a serious threat to the safe operation of the cable joint. Conductor temperature, as the key state parameter of the actual operation of the three-core cable, not only determines the service life of the cable insulation material, but also affects the safe and reliable operation of the cable. At present, it is difficult to directly measure the temperature of the cable core in operation. In the project, temperature measurement is mostly based on the cable surface, and then the cable temperature rise is analyzed through three-phase
temperature comparison, calculation of temperature rise rate, comparison of temperature warning value, etc., which has little effect on load regulation. Therefore, the temperature field calculation is needed to determine the core temperature and carrying capacity.

2. Establishment of finite element model of three-core cable

2.1 Set the finite element calculation parameters
This paper takes YJV22-8.7/15-3×400 cross-linked polyethylene three-core cable commonly used in distribution network as the research object, which is composed of cable core, conductor shielding, insulation, insulation shielding, copper tape shielding and sheath. Its schematic diagram is shown in Figure 1.

![](image)

Fig. 1 Schematic diagram of 10kV three-core cable structure

2.2 Calculate the loss
The heat source of the entire temperature field includes conductor loss, dielectric loss, metal sheath loss, etc. which can be calculated according to the Standard IEC-60287. When the current flows through the cable, the conductor of the cable core will get heat up. According to ohm's law and ignoring the heat loss in the cable conductor, the calorific value of the cable core per unit length can be obtained as

\[ S = I^2R \]

The effective resistance \( R \) of the core per unit length can be generally calculated as follows:

\[ R = R'(1 + y_s + y_p) \]
\[ R' = R_0[1 + \alpha_{20}(\varphi_c - 20)] \]

Type: \( R_0 \) per unit length of cable at 20°C dc resistance of the cable core;

\( R' \) is the dc resistance of a unit length core at \( \varphi_c \); \( \varphi_c \) is the core temperature; \( y_s \) is the skin effect coefficient; \( y_p \) is the coefficient of proximity effect. \( \alpha_{20} \) for cable conductor materials based on 20°C temperature coefficient of resistance, 1/°C. When the calculated cable voltage grade is high, the dielectric loss of the insulation layer cannot be ignored.

Metal sheath losses include circulation losses and eddy current losses. When the cable conductor passes alternating current of power frequency, power frequency electromagnetic field will be generated around it, and eddy current loss will be generated in the metal sheath of cable outer layer. When the cable metal bushing is grounded at both ends, circulation loss will be generated in the metal bushing due to the unequal electromagnetic induction potential between the metal bushing of each phase.

3. Temperature field simulation of three-core cable

3.1 Establishment of simulation model
The study on the internal temperature field distribution of 10kV three-core cable is a two-dimensional steady-state thermal conductivity problem in finite element analysis. Firstly, material elements and
material properties are defined for each part of the model. The properties needed to be added for the cable materials used in this simulation mainly include thermal conductivity, specific heat capacity and density. A two-dimensional steady-state geometric model was established according to the structural parameters and thermophysical parameters of the three-core cable of model YJV22-8.7/15-3×400 in terms of voltage grade, conductor cross-sectional area, whether to be unified or not, and whether to be armored. This is because the conductor shield and the insulating shield are made of a mixture of semiconductor silicon and organic matter, and are very thin relative to the insulating layer. In order to simplify the model, the conductor shielding layer and the insulation shielding layer are reduced to the insulation layer. Since the copper shielding layer has a certain soaking effect, the metal shielding layer needs to be considered in the model, and its thickness is 0.2mm.

![Fig. 2 Geometric model of temperature field for three-core cable](image)

3.2 Comparative analysis of cable simulation temperature

In each structure layer assignment model good thermal physical parameters, the corresponding materials in order to make the conductor temperature is 90 °C, so that when calculating the conductor loss by 90 °C when the conductor alternating current resistance, on the first kind of boundary load cable epidermis 58 °C temperature.

Then the heat generation rate is loaded on each conductor. The heat generation rate is calculated by dividing the total loss of the cable after reduction by the conductor sectional area, and the specific calculation is derived as follows

$$Q = \frac{I^2 R_1}{V} = \frac{I^2 R}{S}$$

Type: Q for heat production rate of single conductor section W/m²; I is the current of A single conductor, A; R₁ for cable ac resistance per unit volume, Ω; R for cable ac resistance, Ω; V for cable size, m³; S for cable size, m².

Finally, the distribution of temperature field inside the three-core cable is shown in the figure after mesh division and solution.
It can be seen from the figure that the hottest temperature in the internal temperature field of the three-core cable is not only the region of three conductors, but also the same highest temperature region similar to the shape of a plum blossom, which is connected by three conductors, part of the insulation layer and the filling layer of the cable axis. Through an analysis of heat transfer principle, the hypothesis three core cable 10 kV every 120 ° is symmetrical, the internal structure of each layer of the material thermal resistance distribution uniformity, three conductors can be thought of as calorific value the same three isothermal heat source, heat source can transfer heat to the surrounding medium at low temperature, each conductor in the cable skin for heat transfer, due to the cable skin temperature so that the cable laying environment temperature is always below the cable conductor temperature, heat transfer direction and so on cable surface temperature gradient is always exist. However, three conductors of heat transfer between, surrounded by three isothermal heat source area at the beginning of a conductor temperature will continue to absorb heat, and is surrounded by high temperature heat source, there is almost no way into the surrounding medium at low temperature heat transfer, until temperatures to rise to the region and, after three conductors in the same temperature to transfer heat to cable epidermis direction, thus formed in a similar to the same temperature zone of the plum flower form. At the same time, it can be seen from the simulation results that the isothermal surface treatment of the cable skin does not affect the distribution characteristics of the isothermal zone in the internal temperature field of the three-core cable.

4. Analysis of influencing factors

4.1 Effect of soil thermal conductivity

Soil thermal conductivity directly affects the heat dissipation of buried cable, which is one of the main factors affecting the temperature distribution of buried cable. When the soil temperature around the cable is high, most of the surrounding moisture will migrate, and the thermal resistance coefficient will rise sharply, and the ability of the cable to radiate heat will also become worse, so that the cable conductor temperature will rise. Figure 4 for the cable laying cable conductor in the different coefficient of thermal conductivity of soil temperature distribution curve, can be seen from the diagram, under the same current value, with the increase of soil thermal resistance coefficient, cable conductor temperature will increase, and increases the amplitude increases along with the increase of current, for example, when the current value of 100 A, under different thermal resistance coefficient of cable conductor temperature difference of 4 K, and when the current value of 500 A, 62 K maximum temperature difference.
4.2 Influence of air temperature to cable

Ambient temperature mainly refers to the temperature of the medium surrounding the cable laying place. For underground cables, the influence of ambient temperature is mainly considered as the influence of air temperature. The higher the air temperature is, the worse the convection heat transfer ability between soil and air is, and the worse the heat dissipation ability is, and the higher the cable conductance temperature is, and vice versa. The Figure below shows the relationship between the cable conductor temperature and the air temperature. Shown in the figure in the world outside of the air temperature is the cable conductor temperature obtained under the condition of same other installation conditions, the figure shows that with the increase of air temperature, under the condition of the guide body same current, cable conductor temperature gradually raised, and in the air temperature range shown in the figure, the relationship between the two approximation for slope gradually rising curve. Taking the air temperature of 293 K as an example, when the current increases from 100 A to 200 A, the conductor temperature increases by 4 K, while when the current increases from 500 A to 600 A, the conductor temperature increases by 14 K.

5. Conclusion

The three conductors of the 10kV three-core cable, the insulation close to the axis and the filling layer of the axis of the cable are connected to form a co-temperature zone similar to the plum blossom shape.
with the highest temperature. There is always a temperature gradient in the direction of heat transfer on the cable skin. The isothermal surface treatment of the cable skin does not affect the distribution characteristics of the isothermal zone in the internal temperature field of the three-core cable.

The sensitivity of ambient temperature to core temperature decreases with the increase of cable loading current. When the running state of the three-core cable is not stable, the temperature of the cable core is mainly determined by the loading current. When the operating state of the three-core cable is stable, the variation trend of the cable core temperature is basically the same as that of the ambient temperature, and the core temperature is determined by the radiation ambient temperature.

At the same current value, the temperature of the cable conductor increases with the increase of the soil thermal resistance coefficient, and the increased amplitude increases with the increase of the current. With the increase of air temperature, the cable conductor temperature increases gradually under the same conductor current condition.

References

[1] TANG Ke, WEN Wu, DING Junjie, et al. Simulation of cable joint temperature field based on finite element method [J]. Electric power construction, 2016, 37(2): 145-150.

[2] LI zhaozhong, Yang Lin, Tian Ye, et al. Steady-state temperature field distribution of HVDC cable joints and its influencing factors [J]. China electric power, 49(2). More references.

[3] HU Wanqing , Hu Qingyi, Lin Xue, et al. The cable joint temperature monitoring system based on temperature field study [J]. Journal of industrial automation, 2013, 39 (6) : 90-93.

[4] WANG Peng. Calculation and experimental research on temperature of 10kV three-core cable and its accessories [D].

[5] LIANG Yongchun, CAI Jinai, LI Yanming, et al. Calculation of eddy current loss in crosslinked cables by finite element method [J]. High voltage technology, 2007, 33(9): 196199.

[6] WANG Youyuan, CHEN Rengang, CHEN Weigen, et al. Calculation of static temperature field of buried cable based on FEM and analysis of influential factors [J]. High Voltage Engineering, 2009, 35(12): 3086-3092.

[7] XU Yan, WANG Lina, LI Yanfei. Analysis of temperature field of the cable based on FEM [J]. Heilongjiang Electric Power, 2011, 33(1): 31-36.

[8] YU Jianli, CHANG Shusheng, NIU Yuanfang, et al. Numerical simulation of thermal fields and ampacity of underground powercables [J]. Journal Of Northeast Dianli University, 2008, 28 (4): 62-65.

[9] YAN Lanfeng. Simulation and experimental study on 10kV three-core cable temperature distribution characteristics and conductor temperature calculation [D]. Guangzhou: South ChinaUniversity of Technology, 2012.

[10] YANG Xiaojing. Calculation of rated current of XLPE cable [J].High Voltage Engineering, 2001, 27(14): 11-12.

[11] WU Wei. The coupling analysis and research of cable accessories electric field-temperature field based on equivalent capacitance method [D]. Changsha: Hunan University, 2011.

[12] YAN Nu, ZHU Panyong, XIONG Xiaochen. Journal of north China electric power university: natural science edition, 2015(4): 29-33.