Research on the Method of Improving the Current-carrying Capacity of Power Cable

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Abstract: The inadvertent current carrying capacity of power cable is bound to be affected by many factors, such as air temperature, ground temperature, backfill sand, soil covering depth, grounding mode, soil thermal resistance coefficient, number of circuits, ventilation design, laying mode, groundwater, metal sheath circulation, layout mode, solar radiation, surrounding heat source. This paper analyzes the common factors in the work, and expounds the mode of flow promotion through the analysis and numerical calculation of power cable ampacity. It also compares the effects of the two methods, hoping to provide new ideas for the follow-up research on related issues.

1. Introduction

At present, most of the power transmission work in cities will be implemented by cable. When the power cable is installed and put into operation, the conductor temperature is the basis for confirming the cable ampacity, and the ampacity itself is the key to judge the cable operation and work quality.

2. Analytical calculation of current carrying capacity of power cable

2.1 IEC standard

The current carrying capacity calculation method of power cable given in ice standard is very similar to nm method in working principle. It not only includes the original calculation formula, but also makes corresponding distinctions for different types of cables and laying conditions [1]. This standard can eventually expand the loss calculation in single core cable to a wider category. At the same time, it can also improve the eddy current loss of large section split conductor cable missing in nm theory. It can be seen that the details in IEC standard are more comprehensive than those in traditional nm theory.

From the perspective of form, the difference between the two calculation methods is very obvious, which is mainly reflected in the unit of measurement of the two methods. Nm is inch and IEC is meter, but it is essentially the same.

After improvement, IEC standard is more suitable for the diversified use of power cables, although
there are still deficiencies. However, the formula in the new standard can be used to calculate the ampacity conveniently. It should be noted that some algorithms in this standard are complex, and the results are mostly conservative.

In fact, the mixing amount and expected value of cable operating conditions in various regions and countries are different, which is in IEC standards. It is also advocated to implement the work from different angles and calculate the fixed values in different regions. For the soil thermal resistance coefficient, it is very sensitive to the water content in the soil, and this coefficient will change significantly over time.

2.2 Nm theory
At first, the calculation method of power cable flow was rough. After improvement and research, the calculation method of cable ampacity and temperature rise was formed, which is nm theory. The theory is based on the following assumptions. First, the soil surface is used as the isothermal surface [2]. Secondly, the cable surface is taken as the isothermal surface, and finally the thermal resistance of the power cable and the surrounding soil environment does not change. These assumptions can fully cover the set parameters and installation conditions of a large number of power cables, and have a very high-quality effect on the temperature investigation and analysis of cable conductors and surrounding environment. If you want to further understand the thermal circuit model, you can also use this theoretical calculation and master the actual difference of cable ampacity.

When the current passes through the power cable, the conductor resistance will produce loss, causing the conductor to heat up. Some of the heat energy generated in this process will be stored in wires and insulating materials [3]. The remaining heat energy is transmitted to the surface of the power cable through insulating materials through conduction, and finally converted into convection and radiation and transmitted to the surrounding environment [4].

The transmission path of heat energy is shown in Figure 1.

![Figure 1 simplified thermal circuit model of power cable](image)

The application of nm calculation method needs to clarify the set parameters and radiation conditions of power cable, and finally establish a reasonable heat path model as a reference. In this way, technicians can more conveniently calculate the thermal resistance in series in the thermal circuit, and then only add each thermal resistance to obtain the total thermal resistance in the surrounding environment of the cable [5].

2.3 Existing calculations
Both nm theory and IEC theory are actually established on the basis of industry work experience. However, in fact, the laying of power cables is very complex, and the environmental difference of each laying is relatively large, so the application of nm theory and IEC theory will be limited in most occasions.

IEC standard is a method to determine resistivity and loss based on given cable conductor and metal sleeve temperature. In fact, the temperature difference of power cable conductor and metal sleeve at different positions is very obvious, which is also the key to the different resistivity and loss degree of different power cables.
The calculation of the influence of IEC standard on the thermal effect between power cables needs to be based on the nm theoretical hypothesis. The subsequent calculation work needs to cooperate with the image method. In fact, the ground surface and power cable table are not isothermal surfaces, and the power cable temperatures at different locations are shown in Figure 2.

![Fig. 2 Schematic diagram of power cable temperature at different positions](image)

The temperature in the deep underground layer can be kept constant for a long time, and there must be backfill around the power cable. In the laying stage of cable cluster mode, the thermal effects between cables will also affect each other. In fact, this cannot be combined with the superposition calculation of the image method in a general way.

In IEC standards, the cable surface temperature is the basic standard to judge whether soil moisture migrates, and the specific value is whether it is \( > 50 \) ℃. Generally, the backfill soil around the cable is relatively dry, and the farther away from the cable, the more natural the soil state is. Therefore, if the whole soil is directly considered as dry, the calculated ampacity will be too small.

If the laying methods such as pipe laying, tunnel laying and trench laying are analyzed, the IEC standard is highly dependent on the experience of technicians, that is, the calculation formula can be summarized according to the experience. There are three heat conduction modes in the air: natural convection, heat radiation and heat conduction. It is worth noting that these three methods can be coupled with hydrodynamics and heat transfer. However, if the external heat source around the cable is not conducive to heat diffusion and regional laying, there is no targeted calculation formula in IEC standard.
3. Numerical calculation of cable ampacity

3.1 Finite element method

Finite element method is essentially a combination of finite difference method and variational method, which is also the implementation principle of this method. The advantage of this method is that it can discretize the differential equations and variational problems in the physical field, and even divide the field into small units. The vertex of each small cell can be used as a separate sampling point of the unknown function, which is very similar to the node function of the difference method. In general, the experimental function of each unit adopts a relatively unified function form, and the undetermined coefficients used in the calculation process are also related to the sampling values of other functions in the vertices of the unit.

Thermal transient refers to the dynamic change details of temperature over time during cable operation. If the finite element method is selected to calculate the thermal transient operation details of power cable, the following formula can be used:

\[ \text{div}(k \times \text{grad}T) + q - C \frac{\partial T}{\partial t} = 0 \]

Among them:
- Temperature T is a function of X, y, and t
- k -- thermal conductivity
- q -- energy conversion rate per unit volume (heat production)
- c -- heat capacity coefficient

A scholar once used the finite element method to solve the external thermal resistance of power cable duct, and then discretized the convenient area, and established the corresponding equation to solve it. The scholar believes that the water migration and water content of temperature gradient will have a significant impact on the thermal conductivity of soil.

According to the principle that surface convection and deep soil temperature will not change, the temperature field model of power cable group is established, and the details are shown in Figure 3.

![Temperature field model of single loop soil directly buried cable](image)

If the open domain temperature field of the light blue group is used as the closed domain temperature field, the effective element method can be used to carry out the analysis, so as to comprehensively grasp the details of the underground cable temperature distribution of the cable current. Subsequently, if you want to improve the accuracy of calculating the ampacity of underground cables, you can also use the temperature field of underground cables as the steady-state temperature field.

3.2 Boundary element method

Contrary to the working details of the boundary element method and the finite difference method, the selected function must meet the computational requirements of the governing equation in the region, and the purpose can be achieved by gradually approximating the boundary conditions with the correlation function. The advantage of this work is that it can comprehensively take into account the
boundary of the calculation area, but it should be noted that the integral itself is at the boundary position, which can directly transform the three-dimensional problem into a two-dimensional or even more concise problem, reducing the difficulty of solution.

In addition, this method can also be directly established on the basis of basic differential equations and convenient conditions. It does not require technicians to master the functional in advance, but can solve the changing physical field problems through simple transformation.

3.3 Finite difference method
Among the numerical analysis and calculation methods of physical field, the finite difference method is an early application. Until now, this method is still widely used in the industry, mainly because it is simple and the calculation results are intuitive. In the finite difference method, it is time-consuming to simply change the grid step size according to the position in the region. When approaching the curve boundary, the boundary itself is difficult to be consistent with the nodes. Obviously, this method is not suitable for dealing with complex boundary conditions.

3.4 Finite volume method
The finite volume method can divide the calculation area into a series of control volumes, and each control volume is represented by an independent node. Make several copies of the control volume using the conservative control equation, and finally derive the discrete equation [5].

In the derivation stage, technicians need to assume the composition of the solved function and other first-order derivatives on the interface, which is the discrete process of finite volume mode. This method is more suitable for fluid calculation and can also be applied to irregular meshes, but the accuracy is not high.

4. Comparison between analytical algorithm and numerical algorithm
Under the IEC standard, the advantage of analytical calculation is that the ampacity of approximate cable can be calculated even using simple formula. However, the analytical method can only solve the problem of relatively simple geometric categories. For example, in the stage of carrying capacity calculation, the soil thermal conductivity and heat capacity in the formula are set as constants. At the same time, the earth’s surface is taken as an isothermal surface and the conductor resistivity is constant.

The numerical calculation method is to analyze the whole temperature field under the given conditions of power cable laying and arrangement. The temperature of the earth surface and the cable surface need to be calculated, which is close to the actual conditions. It can be seen that the numerical method is more suitable for solving complex problems such as geometry and physics. Therefore, its application in complex power cable system is very flexible, and the calculation results will be more accurate.

In practical applications, analytical algorithms are more common than numerical algorithms. The main reason is that it is very common to calculate and improve the cable ampacity based on nm model and IEC standard. For the cable system with simple structure, the working mode of numerical calculation is more complex. Therefore, combined with the detailed analysis of the structure and materials of the power cable, the equivalent thermal path model of the single core cable is shown in Figure 4.

![Figure 4 equivalent thermal path model of single core cable](image-url)
Among them, $\theta$ refers to the temperature of the conductive core, $\theta_0$ refers to the cable surface temperature, $w$ refers to the resistance loss of conductive core, and $WD$ refers to the insulation medium loss. $\lambda_1W$ refers to the resistance loss of metal sheath and shielding layer, $\lambda_2W$ is the resistance loss of armor layer, $\lambda_1$ is the loss coefficient of metal sleeve and shielding layer, $\lambda_2$ is the loss coefficient of armor layer. $T_1$, $T_2$ and $T_3$ are the thermal resistance of insulation, inner liner and outer sheath respectively, and $T_4$ is the thermal resistance of cable and surrounding media.

5. Conclusion:
To sum up, as the lines of power cables tend to be densely radiated, and the actual working envis easily affected by layout, solar radiation, surrounding heat sources and other factors. Therefore, the calculation and lifting of its carrying capacity are very complex problems, and it is necessary to study the relevant work details.

Acknowledgments
Fund Project: Science and technology project support of State Grid Tianjin electric power company (kj21-1-31)

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