Analysis of Current Carrying Capacity of Power Cable Based on DTS

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Abstract. This article uses a distributed optical fiber temperature measurement system (DTS, Distributed Temperature Sensing) to fix the temperature measurement optical fiber on the surface of the power cable, collect the real-time operating temperature of the power cable, conduct the ampacity test, and analyze the cable laying method and depth, soil temperature, Soil thermal resistance coefficient, cable spacing and irradiation strength and other test conditions, the impact on the current carrying capacity of power cables. According to the real-time monitoring temperature of the cable, the alarm can be made when the cable temperature is too high or the temperature rise speed is too fast. And on the basis of determining the working temperature and load operating conditions of the cable conductor core, dynamically calculate the current carrying capacity of the cable, which is conducive to improving the performance of the power cable and increasing the load capacity of the power cable.

1. Introduction
With the continuous advancement of the three types and two networks of the State Grid and the development of the Internet of Things in the power system, power equipment can provide technical support for real-time online monitoring, and fiber temperature measurement is an important part of online monitoring technology. With the continuous development of urbanization, the use of cables is increasing. In order to beautify the city, overhead transmission lines are gradually transformed into power cables. However, there are many shortcomings in the online monitoring of power cables. Up to now, there has not been a scientific and reasonable monitoring method in China. During the operation of the cable, the temperature of the cable core will increase, which will cause a threat to the insulating material. Therefore, measuring the cable temperature has become the main way to monitor the operating status of the cable, thereby ensuring the stable and reliable operation of the power grid and providing strong technical support. At the same time, the cable temperature is used as one of the reference standards for analyzing its own ampacity, and if there is an abnormal temperature increase, there may be some defects in the cable[1].

2. DTS System Principle
This article uses fiber optic temperature measurement technology to analyze the cable operating temperature, which can effectively guide the operating department to manage the current carrying
capacity. At present, the optical fiber temperature measurement technology mainly selects a distributed optical fiber temperature measurement system (DTS, Distributed Temperature Sensing), which selects a certain frequency of light pulses and radiates the internal glass core, which will form scattering phenomena, including Rayleigh scattering and Brillouin scattering. And Raman scattering, etc., and Raman phenomenon is closely related to temperature. Since Raman phenomenon can be formed at various positions in the optical fiber, and at the same time, Raman phenomenon appears steadily in all directions. Therefore, this phenomenon can realize fiber temperature measurement [3-5].

The working principle of DTS is shown in Fig.1. Through the time difference between incident light and Raman phenomenon, multiplied by the speed of light, the power cable positioning analysis can be completed[2].

![DTS working principle diagram](image)

**Figure 1. DTS working principle diagram**

**3. System Installation**
The temperature of the power cable is measured by fixing the optical fiber on the surface of the power cable. This method is flexible and convenient. When the power cable is placed horizontally, choose nylon tape to directly fix the optical fiber on the surface of the power cable; when the power cable is placed on the character, select the fixing jig to fix the optical fiber on the surface of the power cable, as shown in Fig.2. In order to improve the accuracy of optical fiber temperature measurement, the optical fiber is usually fixed on the side of the power cable, which can also reduce the probability of optical fiber damage.

![Schematic diagram of optical fiber temperature measurement installation](image)

**Figure 2. Schematic diagram of optical fiber temperature measurement installation**

**4. Ampacity Test**
Cable laying methods mainly include direct burial, pipe penetration, and tunnel laying. Different laying methods and different heat dissipation conditions. In general, tunnel>buried directly>through pipe. Generally, there are arrangement methods such as horizontal contact or separation, and zigzag contact. When the other external conditions are the same, the current-carrying capacity of the zigzag contact arrangement is larger than that of the horizontal contact arrangement, and that of the non-contact arrangement is larger than that of the contact arrangement; when the non-contact arrangement, the current carrying capacity becomes larger when the phase spacing increases, but tends to saturate. When
the two ends of the metal sheath cross-connect are grounded, if the cross-connected segments are uniform, then the metal sheath circulating current is zero or very small; if the segments are not uniform, then there will be circulating current in the metal sheath. The more uneven the segmentation, the greater the circulation. The circulating current in the metal sheath increases the heating of the cable, resulting in a reduction in the current carrying capacity of the cable. The current-carrying capacity of the cable depends on the maximum temperature rise of the conductor at ambient temperature. The higher the ambient temperature, the smaller the allowable temperature rise and the lower the current carrying capacity; surrounding media: whether it is exposed to sunlight in the air; whether there is a heat source near the cable line; the thermal resistance coefficient of the soil changes; the backfill medium enhances heat dissipation near the cable ability etc. The overall scheme of current carrying system test is shown in Fig.3.

![Figure 3. Overall plan of current carrying system test](image)

It is known that the maximum allowable temperature $\theta_M$ during the stable operation of the cable is, and the temperature $\theta_0$ outside the sheath obtained by the optical fiber temperature measurement system is. According to IEC-60287, the current carrying capacity $I$ of the cable is as follows:

$$I = \frac{\left(\theta_M - \theta_0\right) \cdot W_d \cdot \left(\frac{1}{2} T_1 + T_2 + T_3\right)}{R \left[ T_1 + (1 + \lambda_1) T_2 + (1 + \lambda_1 + \lambda_2) T_3\right]}$$

(1)

In the above formula, $W_d$ represents the dielectric loss; $T_1$, $T_2$ and $T_3$ in turn represent the thermal resistance of the insulating layer, the thermal resistance of the inner lining layer and the thermal resistance of the outer layer; $R$ represent the cable resistance; $\lambda_1$ represent the ratio of the sheath loss to the core loss; $\lambda_2$ represent the armor loss and Core loss ratio.

In this paper, YJLW03 127/220 1×2000 type cable is used. The total length of the cable loop is close to 200m. It contains cable accessories such as outdoor terminals, connectors and GIS terminals. The air laying section is divided into sunlight irradiation section and tunnel laying section, and direct burial is divided into pipe laying and direct buried laying, and the length of each section is more than 10m. The schematic diagram of DTS test circuit is shown in Fig.4.

![Figure 4. Schematic diagram of DTS test circuit](image)
The test results are shown in Fig.5-9. In Fig.5, it can be found that as the laying depth increases, the current carrying capacity of the cable gradually decreases. This is because the greater the cable laying depth, the worse the heat dissipation performance; The current carrying capacity of the cable is greater than the current carrying capacity of the parallel through pipe, which is due to the large circulation formed by the zigzag arrangement and the poor heat dissipation performance. In Fig.6, it can be obtained that when the soil temperature increases, the current carrying capacity continuously decreases. For the cable directly laid underground, the greater the soil temperature, the higher the temperature of the cable sheath. In Fig.7, it can be found that as the soil thermal resistance coefficient increases, the current carrying capacity of the cable gradually decreases. This is because the soil thermal resistance coefficient is large, which reduces the heat dissipation performance of the cable. In Fig.8, it can be found that as the cable spacing increases, the current carrying capacity of the cable gradually increases. This is because the larger the spacing, the smaller the circulating current and the smaller the mutual influence, which is beneficial to the heat dissipation of the cable. In Fig.9, it can be found that as the irradiation intensity decreases, the current carrying capacity of the cable increases. For the cable in the sunlight irradiation section, the stronger the sunlight, the greater the heat absorbed by the cable sheath.
5. Conclusion
The DTS system can grasp the temperature curve on the entire cable line, which helps the power company to accurately grasp the cable operation and maximize the monitoring of cable load. The following conclusions can be obtained through experiments:

① With the increase of the laying depth of the power cable, the current carrying capacity of the cable gradually decreases. This is because the greater the laying depth of the cable, the worse the heat dissipation performance.

② The current-carrying capacity of the power cables arranged in the zigzag arrangement is larger than that of the parallel through pipes. This is because the circulation formed by the zigzag arrangement is relatively large, and the heat dissipation performance is poor.

③ When the soil temperature increases, the current carrying capacity continues to decrease. For cables laid directly underground, the larger the soil temperature, the higher the temperature of the cable sheath; as the soil thermal resistance coefficient increases, the current carrying capacity of the cable gradually decreases, which It is because the soil thermal resistance coefficient is large, which reduces the heat dissipation performance of the cable; as the irradiation intensity decreases, the current carrying capacity of the cable increases. For the cable in the sun exposure section, the stronger the sunlight, the greater the heat absorbed by the cable sheath.

④ As the cable spacing increases, the current carrying capacity of the cable gradually increases. This is because the larger the spacing, the smaller the circulating current and the smaller the mutual influence, which is conducive to the heat dissipation of the cable.

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