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Analysis for Chemical Thermal Reaction of Optical Fibre Composite Low-Cable Based on Finite Element Analysis

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In order to monitor the current magnitude and temperature field distribution of optical fibre composite low-cable (OPLC) under working condition, this paper uses COMSOL Multiphysics software to simulate the internal thermochemical reaction of OPLC under different conditions and temperatures, and obtain the influence law of different factors on its temperature field distribution. Then, it further studies the variation of current and temperature in the erected and buried composite cable. The research shows that the temperature of the inner conductor in OPLC gradually increases with the increase of the external environment temperature; the wind speed between 0.1m/s and 3m/s is beneficial to reduce the temperature inside the composite cable conductor; the maximum internal temperature of direct buried composite cable is positively correlated with soil temperature, and the maximum temperature value inside the composite cable also gradually increases with the increase of soil volume fraction and buried depth; the variation of current in the overhead composite cable is linearly positively correlated with the maximum temperature value of the temperature field, while the maximum eigenvalue of the internal temperature field in the direct buried composite cable is nonlinearly positively correlated with the current magnitude.

1. Introduction

With the rapid development of information technology in the 21st century, people’s demand for data information and multimedia information in all aspects of their work and life has been increasing with the progress of society, and the requirements for the transmission rate of the network have been also higher (Gao, et al, 2018, Huang and Dong, 2012). The power grid is a dedicated network for power transmission in the country. Therefore, optimizing the network transmission path will help improve the power channel, construction quality, safe economic and technical indicators of the power grid (He et al., 2016). In order to meet people’s demand for network information and adapt to the development of the times, the government has intensified the construction of smart grids, and is committed to the integration of power grids, telecommunications networks and the Internet into one network, namely, the erection of power cables, which has greatly promoted the construction of smart grid and information industry networking (Jin et al., 2013; Meng et al., 2016).
Optical fibre composite low-cable (OPLC), also known as opto-electric composite cable (composite cable), is a composite cable that connects optical units into low-voltage cables for photoelectric composite communication transmission (Yao et al., 2018; Aqib et al., 2017). OPLC is an important transmission channel in the smart grid channel, so the safe operation of the smart grid is closely related to the its safety and reliability (Del, 1921; Acott et al., 2015). The reasonable rated current capacity and the internal material temperature limit of the cable is the guarantee for the normal operation of the OPLC, so it has important social and theoretical significance for the research of the OPLC temperature field (Kim et al., 2017; Assink et al., 2005). Based on the finite element (FE) analysis technology, this paper simulates the internal thermochemical reaction of OPLC under different external conditions, and uses fibre temperature sensing technology to conduct simulated analysis for the relationship between current and temperature of OPLC. This shall provide theoretical support for detecting the current changes in OPLC.

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2. OPLC chemical thermal reaction theory

2.1 Chemical thermal reaction theory

If the cable is subjected to short-circuit current caused by lightning current or grid channel failure during operation, the temperature inside the cable will increase rapidly within a short time (Hara et al., 1999; Al-Lawati, 2015). Too high temperature rise in the cable will accelerate the fibre aging or even damage the fibre, causing serious problems such as communication interruption and power supply stoppage, and resulting in immeasurable economic and material losses. Therefore, chemical thermal reaction analysis in composite cables is especially important for the safe operation of smart grids. When the current passes through the cable, the temperature of the cable rises due to its resistance. The heat generated by this conductor is present in the cable and the external insulating material, and also some part of the heat energy is diffused to the external environment by heat transfer.

Heat transfer includes heat conduction, heat convection, and heat radiation (Greebler and Barnett, 1950). Heat conduction is a contact-type heat transfer method, which refers to the process of heat transfer through microscopic particles inside or between objects with the temperature difference inside the object. For fluids with uneven temperature distribution, there is also heat convection, that is, a way in which macroscopic motion inside the fluid causes heat transfer. Heat radiation refers to the heat transfer process in which the energy inside the object emits heat outward in the box-type electromagnetic waves. The higher the temperature of an object, the stronger its radiation ability, and the greater the energy radiated.

2.2 Optical fibre transmission loss theory

In OPLC communication system, light shall have transmission loss during its transmitting in cable, even if the intensity or power of the light is attenuated. The study found that the loss of light in the composite cable can be divided into the scattering loss of the fibre, the absorption loss of the material, and the radiation loss. The scattering loss of the fibre is sub-divided into Rayleigh scattering loss and nonlinear loss. The absorption loss of the fibre mainly includes the absorption loss caused by the energy absorption of the silica fibre and the additional energy in the fibre transmission process due to the insufficient material purity and the processing technology. In addition, for the radiation loss, due to the bending of the fibre during use, radiation loss will be generated inside the fibre when the radius of curvature reaches a certain length.

2.3 Function expression of chemical thermal reaction

The temperature field within the OPLC (temperature distribution at various points within the object) is usually caused by a chemical thermal reaction, which can be expressed as a function of time and space coordinates. Then the temperature field of (*x, y, z*) at time t is expressed as:

$$T = f(x, y, z, t) \tag{1}$$

According to whether the temperature field changes with time, the temperature field is divided into a steady-state temperature field and an unsteady temperature field. The temperature field changing with the test piece is taken as an unsteady temperature field, and that not changing with the test piece as a steady-state temperature field. In addition, the basis for solving the thermal conduction problem of OPLC is the division of the temperature field inside the cable, and the thermal conduction problem of the composite cable includes solving the temperature field under certain boundary conditions, the temperature field inside the object, and calculating the heat of the object.

3. Finite element analysis of chemical thermal reaction in composite cable

Based on partial differential equation modelling, this paper uses COMSOL Multiphysics finite element software to simulate the temperature field in the composite cable. According to the basic principles of heat transfer and numerical models, the heat conduction equation used in the FE analysis is shown in formula 2:

$$\rho C_p \frac{\partial T}{\partial t} = Q_{\mathrm{hs}} + \nabla \cdot (\lambda \nabla T) - \rho C_p u \cdot \nabla T \tag{2}$$

where, $\mathrm{p}C_p \frac{\partial T}{\partial t}$ is the accumulated thermal energy in the composite cable, p is the density of the composite cable material, C_p is the hot melt of the material under atmospheric pressure, Q_{hs} is the heat generated by the optical fibre when the composite cable is energized, that is, the heating power per unit volume of the material in the FE simulation, $\nabla(\lambda\nabla T)$ is the heat conduction, *u* is the dynamic viscosity (kg/(m·s)), and $\mathrm{p}C_p u \nabla T$ is the heat lost during the convection process.

The external boundary conditions of the heat transfer equation in the composite cable are given as:

$$-n\cdot(-\lambda\nabla T)=h\cdot(T_{ext}-T)+\varepsilon\delta_b\left(T_{amb}^4-T^4\right) \tag{3}$$

where, -n(λ∇T) is the heat flux at the outer boundary, $h(T_{ext}-T)$ is the thermal convection term of the composite cable, and $\varepsilon\delta_b(T_{amb}^4-T^4)$ is the thermal radiation term of the composite cable, and ε is the surface emissivity of the fibre surface to ambient radiation.

3.1 Influence of external temperature change and wind speed on the internal temperature field of overhead composite cable

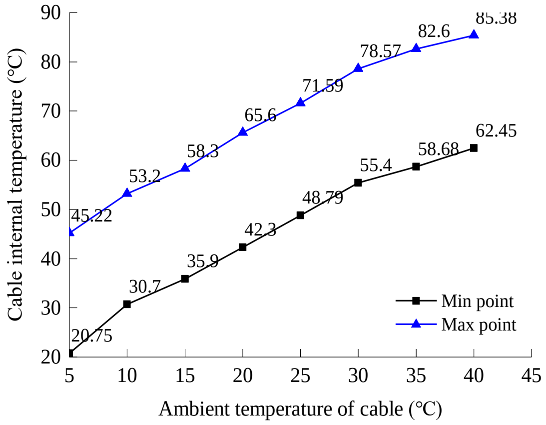

Figure 1: Influence of ambient temperature around cable on temperature field of cable

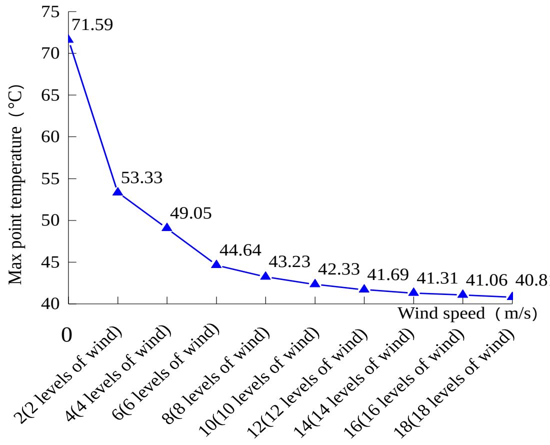

Figure 2: Influence of external wind speed on temperature field of cables

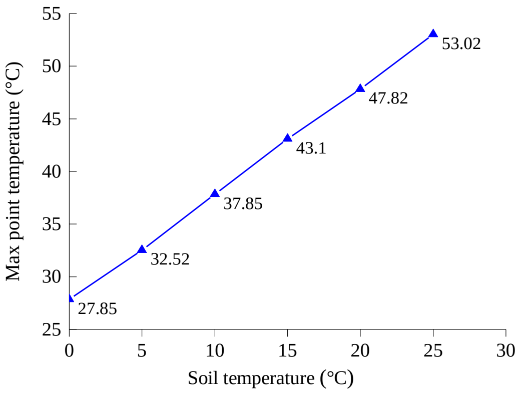

Figure 3: Influence of soil temperature on temperature field of cable

Based on the heat transfer analysis, the internal temperature field of the overhead composite cable is related to the cable surface temperature, the ambient temperature of the external contact, and the wind speed. Temperature changes in the environment and the magnitude of the wind speed generally have a large effect on the internal temperature field of the overhead composite cable. Through the FE simulation analysis, the variation curve of the internal temperature field for the composite cable with the external ambient temperature is obtained (Fig.1). The max and min points in Fig.1 are the maximum and minimum values of the external ambient temperature. It can be seen that as the external ambient temperature increases, the temperature of the internal conductor in the composite cable gradually increases. This is because the heat accumulated in the inner conductor of the composite cable cannot be effectively diffused outward, causing an increase in its internal temperature, when the external ambient temperature is higher.

Fig.2 shows the variation of the internal temperature field of the composite cable with the external wind speed. The external wind speed does not change with time, and the wind speed is in a steady state. It can be seen from the figure that the change of the maximum temperature inside the composite cable has a nonlinear relationship with the wind speed of the external environment, and when the wind speed of the external environment is 0-2 m/s, the temperature drop in the composite cable is the most obvious as the wind speed increases. When the wind speed reaches 8 m/s or more, the influence of the wind speed change on the temperature inside the composite cable will be small. In summary, at the wind speed of about 2m/s (1-2 levels of wind) in the external environment, the external wind speed has a great influence on the internal temperature field of the composite cable, and the external air and the composite cable generate heat convection and heat radiation in the breeze state, which accelerates the diffusion of heat from the cable to the external environment and helps to reduce the temperature inside the composite cable conductor.

3.2 Influence of various factors on the internal temperature field of direct buried OPLC

For direct buried OPLC, its internal temperature field is susceptible to factors such as soil temperature, soil volume fraction, and buried depth of composite cable. Fig.3 shows the curve of the internal temperature changing with the soil temperature. It can be seen that the maximum temperature inside the composite cable is positively correlated with the soil temperature. This is because when the soil temperature is high, the thermal energy of the inner conductor in the composite cable is difficult to effectively diffuse to the external environment, causing energy accumulation in the cable, that is, as the soil temperature increases, the internal temperature of the composite cable gradually increases.

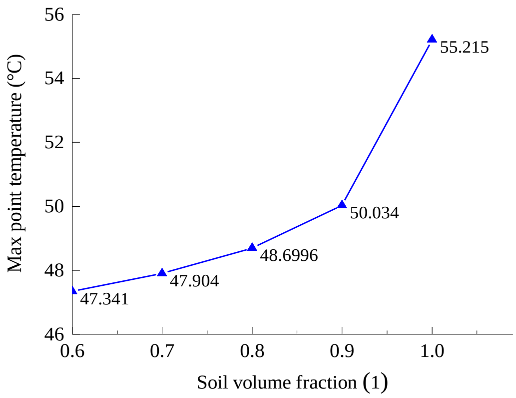

Figure 4: Influence of soil volume fraction on temperature field of cables

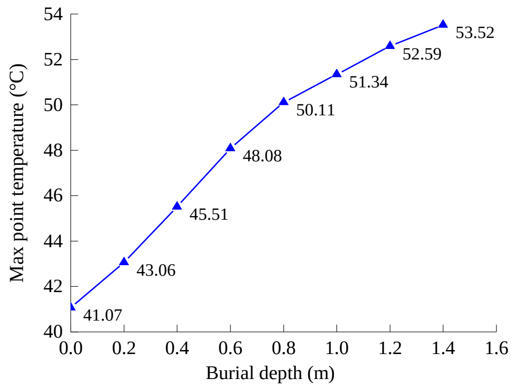

Figure 5: Influence of cable embedding depth on cable temperature field

Fig.4 shows the variation of the maximum temperature field inside the buried composite cable with the soil volume fraction (the degree of soil moisture, i.e., the ratio of soil volume to the total volume of soil and water). It can be seen that when the soil volume fraction is 0.6-0.9, the maximum temperature value of the temperature field in the composite cable changes little. When the soil volume fraction is above 0.9, the maximum temperature value in the cable increases rapidly with the increase of the soil volume fraction, indicating the soil volume fraction has a great influence on the internal temperature field of the direct buried OPLC.

In addition, the results of FE simulation analysis show that the buried depth of soil also has certain influence on the internal temperature field of the composite cable. As shown in Fig. 5, as the buried depth increases, the heat dissipation capability of the composite cable deteriorates, and the heat accumulates in the conductor to gradually increase its temperature. However, as the buried depth increases, the increasing trend of temperature inside the composite cable gradually slow down.

4. Temperature analysis of OPLC composite cable

Based on the above FE simulation analysis, this paper further conducts simulated analysis for the internal temperature field of the composite cable in the steady-state and short-circuit conditions, and obtains the maximum feature point of the temperature field change. In this study, eight feature points (18, 25, 26, 34, 37, 44, 45, 46) were selected for analysis. Fig.6 shows the variation of the temperature field from the initial energization state to the steady state at each feature point. It can be seen that the temperature at the four feature points 18, 25, 34 and 37 close to the heat source is higher, while the temperature at the distant other feature points is relatively lower.

Fig.7 and 8 show the temperature variation curve of the feature points for OPLC1 and 2 respectively in the short-circuit state. It can be seen from the simulation results that the OPLC 1 has greater temperature changes in the short circuit state at the feature points of 18 and 25, while the OPLC 2 has it at the feature points of 25, 34 and 37 in the short-circuit state.

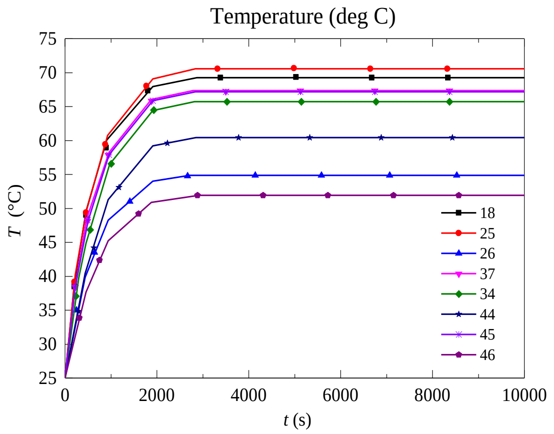

Figure 7: Temperature curve of characteristic points

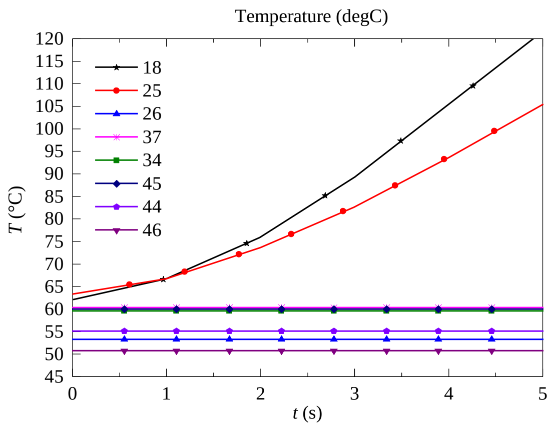

Figure 8: Temperature variation curve of composite cable 1 short circuit 5S

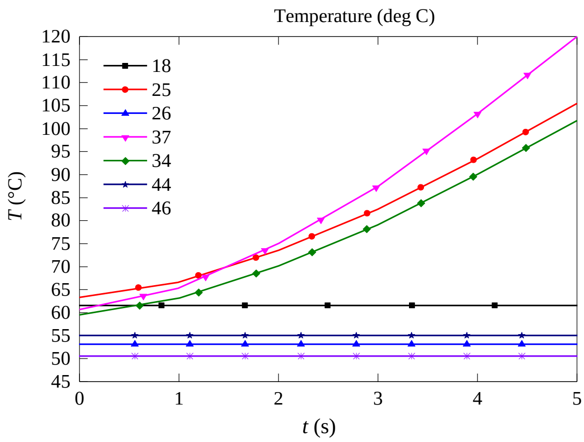

Figure 9: Temperature variation curve of composite cable 2 short circuit 5S

5. Conclusions

In this paper, the finite element simulation software COMSOL Multiphysics was used to simulate and calculate the internal thermochemical reaction (temperature field change) of OPLC under different external conditions and ambient temperature. Then, it conducts a simulated analysis for the relationship between current and temperature of the overhead erected and underground buried composite cables by using the optical fibre temperature sensor technology. The main conclusions are as follows:

For the OPLC erected overhead, the temperature of its internal conductor gradually increases with the increase of the external temperature; the change of the maximum temperature inside the composite cable has a non-linear relationship with the wind speed of the external environment, and the breeze state is beneficial to reduce the temperature inside the composite cable conductor.

For the direct buried OPLC, the maximum temperature inside the cable increases with the increase of soil temperature, and also shows an increasing trend as the soil volume fraction and buried depth increase, but with the increase of the buried depth, the increasing trend of the temperature in the composite cable gradually slows down.

The current variation in the overhead composite cable is linearly positively correlated with the maximum temperature of the temperature field. For the buried composite cable in the ground, the internal temperature field increases with the increase of soil temperature, and the maximum eigenvalues of the temperature field is nonlinearly positively correlated with the magnitude of the current, and as the current increases, its effect on the temperature field in the composite cable becomes more significant.

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