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Insulated Cable Temperature Calculation and Numerical Simulation

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Abstract. A mathematical model of electrified insulated cable was established to calculate temperature of insulating layer. The insulating layer temperature is determined as a function of the current intensity, time, insulation layer thickness, etc. A widely used polyvinyl chloride (PVC) cable with sectional area of 4 mm2 was selected as example and its insulating layer temperature was simulated using ANSYS. The simulation revealed the evolution of insulating layer temperature with time, and also along radius after a certain time when the cable was applied with 40A and 60A constant current respectively. The analysis method has practical significance to prevent electrical fire and can be applied to analyze spontaneous combustion accident of insulated cable.

1 Introduction

With economic development in recent years the demand for electricity energy keeps growing. Cable fire also happens more frequently with cable load increasing. In industry and agriculture and daily life, electrical fire has large percentage in all the various fire, even statistics in the few years show that more than 60% of the buildings electrical fires results from the cable [1]. The daily operation and maintenance of power cable face great challenge, so it is urgent to present measures to prevent cable fires.

Du Zhiming et al. [2] analyzed the cause of cable spontaneous combustion and established two kinds of fire models. The corresponding initial and boundary conditions are also given. The model reveals the relationship of the current, insulation layer thickness, heat dissipation condition, and physical and chemical properties. The model has practical significance to analyze cause of the fire and prevent electrical fires. He Jie et al. [3] analyzed the cause and spread of fire, insulation layer and sheath combustion mechanism. Based on the analysis corresponding measures was presented to prevent fires. Cui Liufang [4] analyzes thermal decomposition and insulating characteristics of PVC cable insulation layer when the cable is applied with lower overload current and studies fire risk when cable is overloaded. The results showed that the cable applied overload for a long time has less combustion risk relatively, but accompanied by insulating property degradation.

2 Heat transfer model of electrified cable

For insulating layer, its outer surface contacts with low temperature atmosphere, and its interior is high temperature electrified copper conductor. The electric energy consumed by resistance converted into heat energy according to joule's law. Converted heat is conducted into the insulating layer and then flows out into the outer atmosphere. When the heat flowing into insulating layer exceeds the heat dissipating out into the atmosphere, the insulating layer temperature will rise. The insulating layer temperature continues to rise. Once reaching the auto ignition temperature, the insulating layer will burst into flame and electrical fire will happen certainly.

It is assumed a cable is composed of two parts, the copper conductor and the insulating layer. A cylindrical coordinate system is established with the centre of cable as origin, which is shown in Figure. 1.

For cable insulation layer, no internal heat source exists and the temperature only varies along radial. Assume its thermal conductivity, density, specific heat capacity is constant with time, and temperature, and the air heat transfer coefficient is also constant. Temperature only varies along the radial. The one-dimensional transient heat transfer equation is derived according to heat transfer and energy conservation law [5, 6]. The equations are as follows:

$$\frac{\partial T}{\partial t} = a_0 \frac{1}{r} \frac{\partial\left(\lambda_0 r \frac{\partial T}{\partial t}\right)}{\partial r} = a_0\left(\frac{\partial T}{\partial r}\frac{1}{r} + \frac{\partial^2 T}{\partial r^2}\right) \tag{1}$$

The initial condition:

$$T(\mathrm{r},0) = T_0 \qquad (\mathrm{r}_1 \le r \le r_2) \tag{2}$$

Boundary condition:

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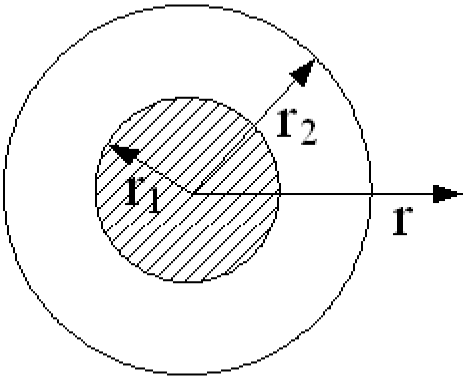

Figure 1. Cross-section of insulated cable. Bias part is copper conductor. r_1 is copper conductor radius, and r_2 is cable radius.

$$I^2R - 2\mathrm{r}\pi\lambda_0 \frac{\partial T}{\partial r} = 0 \qquad (\mathrm{r} = r_1) \tag{3}$$

$$\lambda_0 \frac{\partial T}{\partial \mathrm{r}} + h(T - T_0) = 0 \qquad (r = r_2) \tag{4}$$

Where T = temperature of the insulation layer, °C; T_0 = ambient temperature, °C; r_1 = radius of copper conductor, m; r_2 = radius of cable, m; t = time, s; r = any point radius in insulating layer, m; $\mathrm{a}_0 = \frac{\lambda_0}{\rho_0 \cdot c}$ = insulation thermal diffusivity, m^2/s; λ_0 = insulation thermal conductivity, W/m·K; ρ_0= density of the insulating layer, kg/m^3; c = specific heat, J/kg·K; I = current intensity, A; R = conductor resistance of unit length, Ω/m ; h = surface heat transfer coefficient for the sheath with air, W/m^2·K.

3 Calculation examples

Figures and tables, as originals of good quality and well contrasted, are to be in their final form, ready for reproduction, pasted in the appropriate place in the text. Try to ensure that the size of the text in your figures is approximately the same size as the main text (10 point). Try to ensure that lines are no thinner than 0.25 point. ANSYS is a large-scale universal finite element analysis (FEA) software developed by ANSYS INC. It is one of the world's fastest growing computer aided engineering (CAE) software, and allows engineers to share and exchange data with the majority of computer aided design (CAD) software interface. Furthermore, it is a large-scale universal FEA software, can accomplish various analysis, such as structure, fluid, electric field, magnetic field, and sound field. It has been widely used in the nuclear industry, railway construction, petrochemical industry, aviation and aerospace, machinery manufacturing, energy engineering, national defence industry, electronics, civil engineering, shipbuilding, mining and other fields [7, 8].

The most commonly used non-sheathed copper Polyvinyl chloride cable with sectional area of 4 mm^2 is selected as the example. The parameters of the cable are as follows: thermal conductivity of PVC insulation layer is 0.16 W/m·K, density is 1.38 g/cm^3, specific heat capacity is 0.9 kJ/kg·K, and the air convection coefficient is 5 W/m^2 K; copper core radius is 1.1mm, electric resistance of per unit length is 0.44×10-2 Ω/m. Thickness of PVC insulation layer is 0.8mm. PVC insulation layer will soften at temperature of 80℃ and begin to decompose at temperatures of 130 °C.

Rated voltage of 4mm^2 copper PVC cable is no more than 32A, and 40A and 60A over current are applied to the cable respectively. ANSYS is employed to simulate temperature distribution of insulated layer. Assume heat generated by the copper conductor wholly conducts to the insulated layer and the environment temperature is 20 ℃.

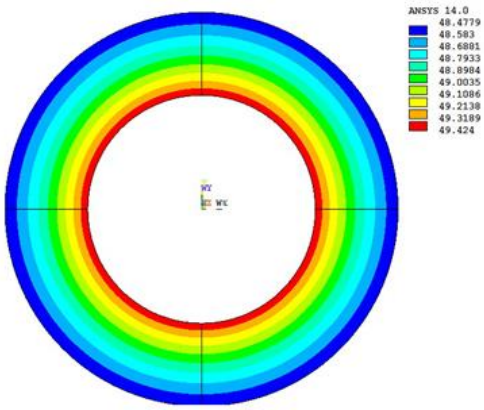

Figure 2. Insulating layer temperature with current intensity I=40A, time t=600s

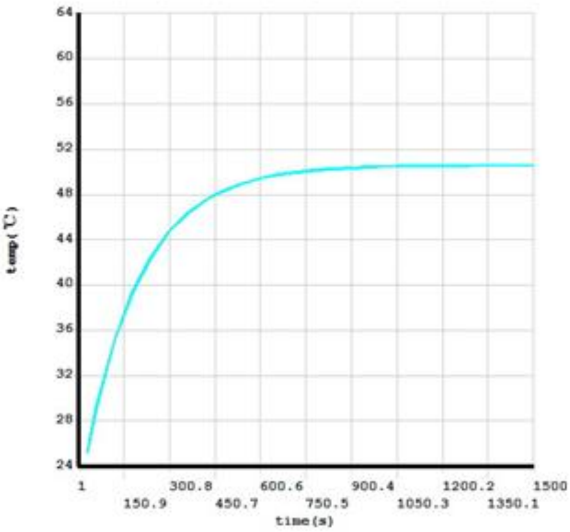

Figure 3. inner insulation layer temperature vs time with current intensity I=40A

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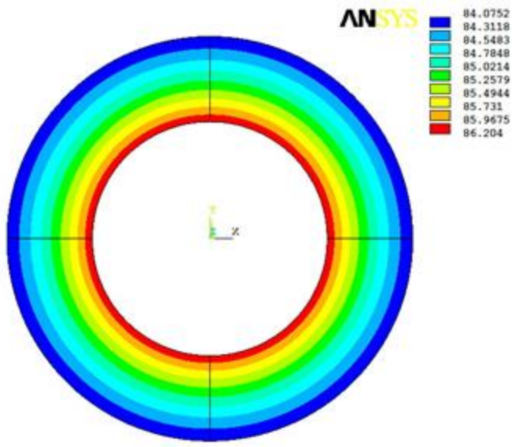

Figure 4. Insulating layer temperature with current intensity I=60A, time t=600s

40A current is applied on the cable. Temperature distribution contour after 600s is shown in Figure. 2. Temperature of all points on the inner insulated layer contacting with copper conductor is equal because of axial symmetry. Temperature of the inner insulated layer versus time is shown in Figure. 3.

The current intensity is increased to 60A. The temperature contour after 600s is shown in Figure. 4. Temperature of the inner insulated layer versus time is shown in Figure. 5.

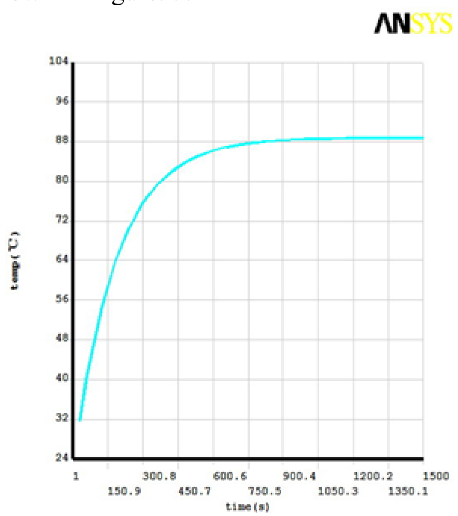

Figure 5. Inner insulation layer temperature vs. time with current intensity I=60A

From the above figures it is found that the maximum temperature of insulation layer reached 80 degrees with I=60A, after 400s. The insulating layer began to soften and its temperature will keep increasing gradually. The insulation layer began to deform. The temperature of inner layer contacting with copper conductor is the highest but the temperature difference is not more than 3 ℃. When applied with 40A current, the insulating layer temperature may reach approximately 50℃. The cable can be used a short time, but for a long time by such a large current, will have an effect on the cable life.

4 Conclusions

Based on heat transfer theory and energy conservation law, a differential equation of PVC insulating layer temperature is established. The equation reveals the relationship of temperature, current intensity, time, insulation layer thickness, etc. PVC insulating layer temperature is simulated using ANSYS when the cable is applied with 40A and 60A current respectively.

With the insulating layer temperature versus time plots the time would be estimated the insulating layer begin to soften. It could be used to analyze the damage process when the cable temperature exceeds limit.

Analysis above is based on the assumption that some parameters, e.g. PVC thermal conductivity, density, and specific heat capacity remain constant with temperature, but in fact these parameters will vary with temperature. Further research may solve this problem.

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