

Temperature Distribution in High Voltage Dummy Cable

G.Y. Sun*, O. Sekula, C. Albanbauer
 Brugg Kabel AG
 Klosterzelgstrasse 28
 CH-5201 Brugg
 Switzerland
 *Corresponding author: sun.guoyan@brugg.com

Abstract: A 2D model of coupled electric-thermal application is used to calculate the temperature distribution in a high voltage dummy cable laid in free air, where no high voltage is applied. Resistive loss heats the cable while the surrounding air cools it down. The steady-state condition is reached when heat balances. The steady-state temperature depends not only on the resistive loss but also on the cooling of the surrounding air. The heat transfer between cable and surrounding air is simulated by using a semi-empirical heat transfer coefficient [1]. Skin effect of alternating current (AC) is included in calculating the resistive loss. The simulation results from COMSOL are compared with experimental data.

Keywords: High voltage dummy cable, resistive loss, skin effect, temperature distribution, heat transfer

1. Introduction

To avoid cable aging maximum conductor temperature is limited for high voltage cable according to IEC standards [2], for instance it is 90 °C for XLPE insulation cable. The key of current rating calculation is the determination of heat generation in the cable and heat dissipation to ambient surrounding it. In this work temperature is calculated for high voltage dummy cable laid in free air, which is loaded with AC current.

There is no voltage-dependent energy loss because no high voltage is applied. The resistive loss of current-carrying conductor is the main source to heat the cable, while nature convection and thermal radiation dissipate heat from it. The resistive loss $Q=J^2 \cdot \rho(T)$, J is current density and ρ is the resistivity of conductor, which is a function of temperature T . For AC current ρ depends also on the dimension of the cable because of skin effect. Skin effect enhances the current density near the surface of the conductor

and therefore causes the effective resistivity to increase. To reduce the magnitude of this effect large cross section stranded conductors are segmented. IEC 60287 [2] provides methods to calculate the effective resistivity of segmented conductor.

The heat transfer between surface of cable and surrounding air is simulated by applying a semi-empirical heat transfer coefficient [1], which is valid for natural convection around a cylinder. For a hot object embedded in cooler surrounding the thermal radiation should be taken into account.

2. Model Definition in COMSOL

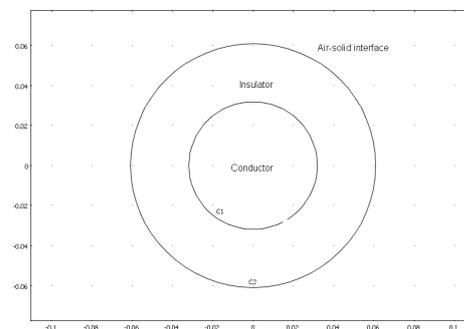


Fig.1 Schematic of model

This is a coupled electric-thermal application, which combines a Perpendicular Induction Currents, Vector Potential (emqa) mode with a Heat Transfer by conduction (ht) mode. The resistive loss Q is obtained in emqa mode and set as the heat source for ht mode. The ht mode calculates the actual temperature. A steady-state condition is reached if the heat transfer between cable and the surrounding air balances. The cable is long and the temperature change in cable direction can be neglected. The problem can be solved using a 2D model. Fig. 1 shows the schematic of the model. For comparison to

experimental data the real geometry of cable, including semiconductor layers, shielding layers, should be used in simulation.

2.1 Perpendicular Induction Current, Vector Potential mode

The cable is one-end grounded. There is no induced current in the shielding layer and hence the energy loss in it can be neglected. Only the resistive loss in conductor is taken into consideration. The analysis type of Static is selected. The effective resistivity of segmental cable for AC current is calculated according to IEC 60287 [2].

$$\rho_{AC}(T) = (1 + Y_s) \cdot \rho_{DC}(T_0) \cdot (1 + \alpha \cdot (T - T_0))$$

$\rho_{DC}(T_0)$ is the resistivity of conductor for DC current at reference temperature T_0 , α is temperature coefficient. The skin effect factor Y_s is defined as:

$$Y_s = X_s^4 / (192 + 0.8 \cdot X_s^4)$$

Where $X_s = \sqrt{(K_s \cdot \omega \cdot \mu / (\pi \cdot R))}$

$$\omega = 2 \cdot \pi \cdot f$$

f: frequency

R: DC resistance at reference temperature

K_s : correction factor for segmented conductor

μ : magnetic permeability

The amount of current is constrained by integrating the variable of current density. A potential difference is defined to drive the current flowing along the conductor.

2.2 Heat Transfer by conduction mode

This mode calculates heat transfer. It is conductive inside the cable and convective on the cable surface. The analysis type of this mode can be selected as Transient or Stationary. With Transient analysis the temperature is changed with time. The Stationary analysis gives the temperature of steady-state.

A convenient method to calculate convective heat transfer between a solid and fluid is using a heat transfer coefficient. The heat exchange is defined as $H_c \cdot (T_{inf} - T)$, H_c is the heat transfer coefficient, T_{inf} is the ambient temperature. In

this model the coefficient for natural convection around a cylinder [1] is applied. It is a function of cable surface temperature and cable dimension.

$$H_c = \kappa / D \cdot f(\theta) \cdot Gr^{1/4}$$

κ the thermal conductivity of air, D the outer diameter of cable, $f(\theta)$ an empirical coefficient function dependent on the angle relative to direction of gravity (Fig. 2). $\theta = 0^\circ$ is for the bottom and $\theta = 180^\circ$ for the top of the cable. Gr is the Grashof number.

$$Gr = \beta \cdot g \cdot (T - T_{inf}) \cdot D^3 / \nu^2$$

β the thermal expansion coefficient, ν the kinematic viscosity of air, g the gravitational acceleration.

The heat transfer due to thermal radiation is $\epsilon \cdot \sigma \cdot (T_{inf}^4 - T^4)$, ϵ : the surface emissivity, σ : Stefan-Boltzmann constant.

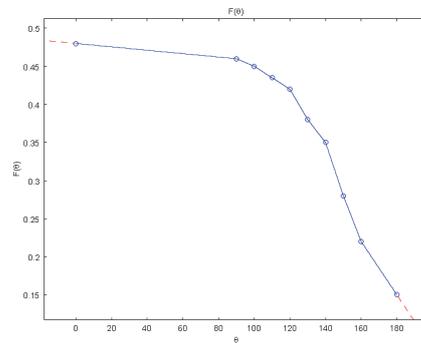


Fig.2. Empirical coefficient function

3. Experimental

A 2500 mm² XLPE insulation segmental cable is used for experiment. The cable is loaded with AC current of 50 Hz with the amount of 2000 A and 2900 A separately. The temperature on conductor surface, XLPE insulator surface and cable surface as well as room temperature are measured and recorded by using a 6-Channel-Pointprinter, a product from the company Eurotherm Chessell [3]. Each measurement takes

over 10 h. At the end of measurements heat balances and steady-state is reached.

4. Results and Discussion

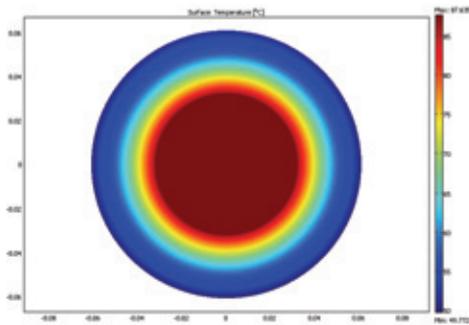


Fig.3 Temperature distribution of steady-state

Fig.3 shows the steady-state temperature distribution of the cable loaded with 2900 A current. For steady-state the equation $\nabla \cdot (-k\nabla T) = Q$ governs the temperature distribution, where k the thermal conductivity and Q the heat source. The copper conductor has a very high thermal conductivity (400 W/m·K) and the temperature of conductor is almost a constant. There is a big temperature drop over the insulator because of its low thermal conductivity (0.286 W/m·K). Fig.4 shows the heat transfer coefficient H_c of the steady-state. At bottom of the cable ($\theta=0^\circ$) H_c has the biggest value and the heat deposition $H_c \cdot (T - T_{inf})$ to the surrounding air is maximum. The surface temperature at the bottom of the cable is expected to be the lowest. In Fig. 5 one can see the temperature in the outer layer of the cable. It is 50°C at the bottom and 51.5 °C at the top.

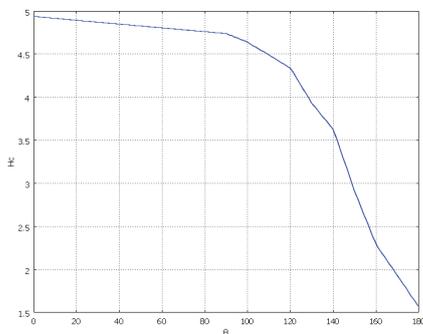


Fig.4. Heat transfer coefficient of steady-state

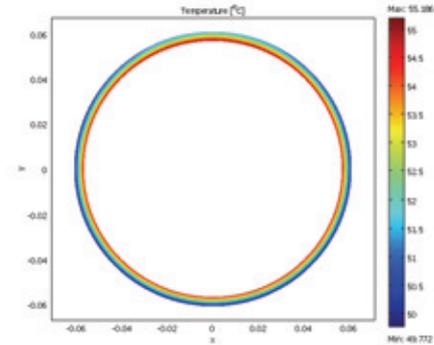


Fig.5 Temperature in the outer layer of cable

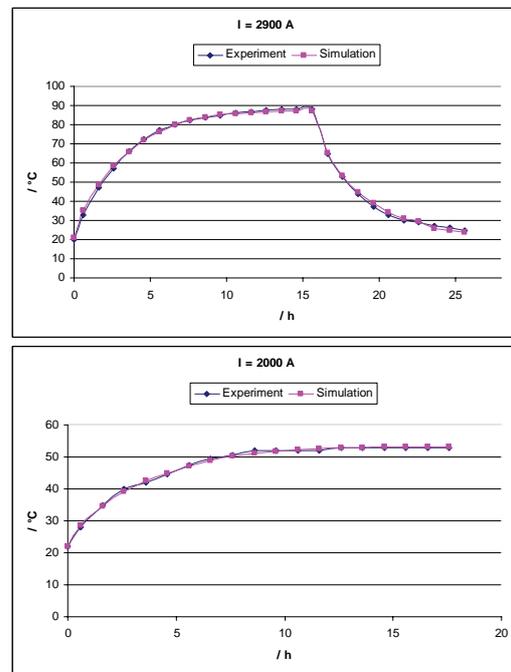


Fig. 6 Comparison of simulated and experimental data

In order to get comparable results to experimental all the electric and thermal parameters of material should be checked carefully. One of the most important parameter is the factor K_s , which is used to correct the skin effect for segmental cable. In IEC 20287 a value of 0.435 is given, which is based on measurements performed on 1600 mm² oil-filled segmental cable. But in fact K_s depends very much on construction of the cable, i.e. insulator material, design features of

conductor etc [4]. K_s should be defined for individual cable by measuring the AC resistance or by simulation. With $K_s=0.435$ the simulated temperature is far lower than the measured one. The simulation fits better to experimental data if K_s is set to be 0.9. Fig.6 shows the comparison of the results. The black points are the measured temperature of the conductor, with current of 2900 A and 2000 A separately. The red data are the simulated results with $K_s=0.9$. The Analysis type of Transient has been chosen in the simulation. For the case of $I=2900$ A the current is shutout after 16 hours.

5. Acknowledgements

Many thanks for the technical supports from COMSOL support team.

6. References

- [1] IEC 60287, "Electric cables - Calculation of the current rating", 1994 and later versions
- [2] COMSOL library model "Cooling Flange"
- [3] <http://www.chessell.com>
- [4] Large Cross-sections and Composite Screens Design, CIGRE Working Group B1.03