Improvement of ampacity ratings of Medium Voltage cables in protection pipes by comprehensive consideration and selective improvement of the heat transfer mechanisms within the pipe

Constantin **BALZER**, Volker **HINRICHSEN**; High Voltages Laboratories, TU Darmstadt, Germany

balzer@hst.tu-darmstadt.de, hinrichsen@hst.tu-darmstadt.de

Christoph **DREFKE**, Johannes **STEGNER**, Ingo **SASS**; Applied Geothermal Science and Technology, TU Darmstadt, Germany

drefke@geo.tu-darmstadt.de, stegner@geo.tu-darmstadt.de, sass@geo.tu-darmstadt.de

Klaus **HENTSCHEL**, Bayernwerk AG, Germany, klaus.hentschel@bayernwerk.de

Jörg **DIETRICH**, HeidelbergCement AG, Germany, joerg.dietrich@heidelbergcement.com

ABSTRACT

In the present paper, the implementation of a finite element model of a distribution cable system, laid inside an air-filled protection pipe, will be presented. Therefore, the theoretical background of the three heat transfer mechanisms involved will be highlighted. After validating the output with data collected on a field test, the results of the simulation for stationary load cases as well as the temperature response to dynamic loads will be outlined and compared to the existing analytical approximations. Finally, the possibility of increasing the current carrying capacity with the help of specialized backfill materials that can be pumped into the protection pipes will equally be assessed.

INTRODUCTION

The exorbitant growth of dispersed power injection, which was triggered by the political subsidies in Germany, represents a major challenge for the concerned distribution system operators (DSO). Especially in Bavaria, South Germany, power generation from photovoltaic panels leads to significant changes in the load amplitude and dynamic that cable systems are facing. In order to integrate the renewable energies efficiently and avoid oversizing the cable systems, one major aim is to determine the thermal current carrying capacity of cable systems under highly fluctuating load regimes.

When considering the ampacity rating of buried cables systems, one must always consider the calculations for the "weakest link" of the whole cable length. Within distribution networks in rural areas, these thermal hot-spots often appear where the cables are laid inside an air filled protection pipe in order to prevent mechanical damages. Therefore, particular attention should be paid to this configuration.

Despite this importance with regard to the calculation of the thermal current rating, little tangible information about the temperature development is available that provides clear guidelines for cable engineers. This is due to the fact that heat transfer within such systems encompasses all three mechanisms, of whom two are temperature dependent: Conduction, convection and radiation.

In [1], an analytical simplification is given that furnishes useful approximation about the thermal resistances in steady-state operation. However, the simplifications on which the description relies – i.e., the description of the heat transfer mechanisms for isothermal, concentric cylinders - have never been the object of further investigation.

Moreover, information about the dynamic behavior and heat capacitance have not yet published, making it difficult to assess the impact of a changed dynamic in load on the ampacity rating of such cable system.

Therefore, a model was set up with the help of the commercial finite element software COMSOL in order to examine the thermal resistance and capacity per unit length of cables systems laid in a protection pipe under different load cases. The present paper first highlights the physical backgrounds of each heat transfer mechanism and gives approximations about their influence on the overall system. Then, results of a three-dimensional model are compared with recorded data at the cable test side at TU Darmstadt in order to validate the results of the simulation. Finally, the possibility of the model to study easily the effect of a changed load flow dynamic is used to evaluate the difference between the current standardized load curve and new types of load flows in regions with high penetration of dispersed photovoltaic injection.

HEAT TRANSFER MECHANISMS

In the first place, the physical basics behind the simulation will be highlighted. The understanding of these mechanisms is not only crucial to validate the results, but also provides first estimations about their impact of the thermal current rating.

Conduction

Within solids, heat is transferred by interactions of oscillating molecules, so that a flow of heat can be expressed as the product of the gradient of a potential field, i.e. the temperature distribution, and the thermal conductivity of the medium:

$$\vec{f} = -\lambda \cdot \mathrm{grad}\, T \qquad [1]$$

With:

$\vec{f}$ flow of heat in $\frac{\mathrm{W}}{\mathrm{m}^2}$

λ thermal conductivity in $\frac{\mathrm{W}}{\mathrm{m \cdot K}}$

T Temperature in K

Combining this equation with the conservation of energy, that is that the divergence of the flow of heat equals the derivative of time of the heat content, yields the well-known potential equation of conductive heat transfer in homogenous and isotropic solids:

$$\Delta T = -\frac{1}{\kappa}\frac{dT}{dt} - \frac{A(\vec{r},t)}{\lambda} \qquad [2]$$