Evaluation of simplified heat transport for power cables in pipes

Kristian Solheim **THINN**, Svein-Magne **HELLESØ**, Espen **EBERG**, Emre **KANTAR**, SINTEF Energy Research, Norway, kristian.solheim@sintef.no, svein.m.helleso@sintef.no, espen.eberg@sintef.no, emre.kantar@sintef.no.

☐ **Young Researcher** (Proved full-time engineering and science university researchers and Ph.D.students under 35 YO)

ABSTRACT

Power cables in air- or water-filled pipes are the thermal bottleneck in many installations. Some parts of the industry reduce the complexity of their numerical models by combining conduction, convection, and surface-surface radiation into an effective thermal conductivity by formulas and constants from IEC 60287. In this work, case studies show that such simplification can become too inaccurate for air-filled pipes. The simplification can be used as an estimate for some engineering purposes in water-filled pipes. A brief review of the heat transfer equations shows that IEC 60287 thermal resistance does not accurately represent the actual thermal resistance T4'.

KEYWORDS

Power cables; ampacity calculations; cables in pipes; finite element analysis; IEC 60287.

INTRODUCTION

In many power cable installations, the thermal bottleneck is where the cable is located in the air- or water-filled ducts, conduits or pipes. The industry standard is to perform ampacity calculations either by analytical formulas (such as those provided in IEC 60287), analytical tools (such as Cymcap or Cableizer, based on IEC 60287), or numerical tools (such as Flux 2D or COMSOL Multiphysics, based on finite element analyses - FEA).

Calculations by IEC 60287 are time efficient, but the formulas are based on a set of assumptions that are not always met. The empirical formula for the thermal resistance of the air inside the duct do not consider pipe dimension and was developed for ducts up to 50 cm in diameter. The equations were developed for concentric cables and pipes, which have different contributions from the heat transfer mechanisms (conduction, convection, and radiation) compared to cables placed on the bottom of the pipe. This is, however, addressed by using the coefficients in the final formulas on results from experiments with cables in pipes. Calculations based on numerical tools can be time-consuming when including the multi-physics behaviour such as electromagnetic (dielectric losses and joule/induction heating) and thermal (conduction, convection, and radiation) effects.

Simplifying the convection physics of air or water volumes in the pipe makes the FEA models more computationally friendly. It is a well-documented fact that while convection is the most difficult to model, radiation plays the predominant role in heat transfer in air-filled pipes. In one simplification, as shown in [1], empirical formulas replace convection physics, thus removing the need for computational fluid dynamic (CFD) evaluations. There also exists optimization of the IEC framework, such as [2-3], but these methods are not considered further in this article.

One method to simplify convection is by introducing an effective thermal conductivity, which combines convection and conduction [4]. Some parts of the industry simplify the convection of air or water volume in their FEA tools by calculating an effective thermal conductivity of the fluid based on formulas and tabulated constants provided in IEC 60287. This gives an even more computationally friendly tool than the tool in [1]. The main difference is that radiation for air-filled pipes, in addition to convection, is integrated into effective thermal conductivity. The accuracy of this method has not been quantified in the literature.

This article focuses on the accuracy of simplifying the air or water volume into a volume with an effective thermal conductivity based on IEC constant s and equations. The equations are implemented in a numerical FEA tool and compared to a model with full thermal FEA models, i.e., heat transport by conduction, convection, and surface-surface radiation. The evaluations are mainly based on case studies. A review of heat transfer equations and their accuracy is also considered. The case studies include a typical subsea power cable (72.5 kV, 800 mm^2 Cu) from a wind farm and an onshore transmission cable (145 kV, 1000 mm^2 Al).

REVIEW OF HEAT TRANSFER EQUATIONS

The IEC 60287 formulas for determining the air-gap thermal resistance *T4'* are based on assuming that the three heat transfer mechanisms, radiation, conduction, and convection, can be considered as three thermal conductivities in parallel. The overall thermal resistance is then the inverse of the total conductivity from the three contributions, see Eq. 1.

$$T'_4 = \frac{(\theta_c - \theta_p)}{W_{cond} + W_{conv} + W_{rad}} \qquad \textbf{Eq. 1}$$

For an assumed concentric arrangement, this is a reasonable assumption as the surfaces are fairly isothermal. For an eccentric configuration, these assumptions are not entirely appropriate, as the assumptions of isothermal surfaces break down. The most obvious change for an eccentric configuration is that the heat transfer by conduction increases significantly as the air gap between the cable and pipe is reduced. The conductive heat transfer can, for concentric isothermal cylinders, be expressed as in Eq. 2:

$$W_{cond} = \frac{2\pi}{\ln\left(\frac{D_p}{D_c}\right)} \cdot \mathbf{k} \cdot (\theta_c - \theta_p) = S \cdot \mathbf{k} \cdot (\theta_c - \theta_p) \qquad \textbf{Eq. 2}$$

where *S* is the shape factor, $S = 2\pi / \ln(\frac{D_p}{D_c})$. For eccentric configurations with isothermal surfaces, there is also possible to derive a shape factor analytically [5]. For large