Implementation of finite element analysis and hybrid IEC-models in online ampacity tool

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ABSTRACT

Current tools for ampacity calculations are based on analytical expressions, and empirical expressions for complex laying geometries that in practice cannot be solved analytically, formulated in the IEC standards. Non-standard or highly complex laying geometries must be simplified and approximated, which often result in less accurate calculated ampacities. Norwegian utilities and industry have supported R&D to develop an online ampacity tool based on finite-element analysis (FEA). Some parts of IEC 60287 formulae have been included to reduce computation time. The result is an easy-to-use and accurate online tool for ampacity calculations.

KEYWORDS

Ampacity, software, cable, segmented, conductur, losses, IEC 60287, FEA.

INTRODUCTION

Optimal utilization of existing, and planning of new, electrical infrastructure is essential for the ongoing electrification where cables play an important role in the distribution of electric power.

Current tools for ampacity calculations are based on analytical expressions, and empirical expressions for complex laying geometries that in practice cannot be solved analytically, formulated in the IEC standards. Non-standard or highly complex laying geometries must then be simplified and approximated, which in many cases results in less accurate calculated ampacities. As a day-to-day tool, utilities often use a collection of ampacity tables for a limited set of cables and parameters, such as depth, distance, and number of cables, thus further limiting the full exploitation of true ampacity.

Since 2014 Norwegian utilities and industry have supported R&D to develop an ampacity tool that overcomes this lack of flexibility, but still is simple to use. The result of this research is an online ampacity tool based on finite-element analysis (FEA). The design tool is available through a web browser and FEA runs on a dedicated server, providing computation times from 30 seconds to a few minutes – depending on complexity. The FEA models are based on multi-physics models, but in some cases simplifications or inclusion of parts of IEC 60287 formulae have been included to reduce computation time.

In this work, challenges with implementing generic thermo-electric FEA models in such a way that non-experts can perform ampacity calculations for complex laying geometries are discussed. Further, the simplification of models is discussed with regards to decrease in both computation time and accuracy and how this compares to uncertainty due to changes in, or unknown, ambient conditions.

HEAT TRANSFER IN CABLE SYSTEMS

For determining the ampacity of a cable system, it is crucial to accurately determine heat transport in the cable system. The complexity and parameters involved vary between the three mechanisms conduction, radiation and convection [1], and should be addressed for an efficient implementation of ampacity calculations.

Conduction

Heat transfer by conduction q_{cond} is caused by exchange of random molecular motion in matter (diffusion) and is given by

$$q_{cond} = -k \cdot \nabla T, \tag{1}$$

where q (W/m^2) is the heat flux, k (W/m.K) is the thermal conductivity of the material where heat by conduction happens, and T (K) is the temperature field. An analytical solution can be obatained for Eq. (1) for simple geometries and boundary conditions, e.g., by assuming isothermal surfaces of bodies investigated.

Radiation

All matter at non-zero temperature radiate thermal energy. The energy is transmitted by electromagnetic waves, and is not dependent on matter. Matter can also absorb thermal energy through radiation. Most relevant for cable systems is the case where an object (cable) is surrounded by a larger surface (pipe or duct). If the emission and absorption of heat is equal for the surface (grey body) and surrounding surface is assumed isothermal, heat exchange by radiation q_{rad} can be expressed as

$$q_{rad} = \varepsilon\sigma\left(T_{obj}^4 - T_{surr}^4\right), \tag{2}$$

where ε is the emissivity, σ the Stefan Boltzman constant (5.67·10^{-8} W/m^2.K^4), T_{obj} the temperature of the object, and T_{surr} the temperature of the surrounding surface.

Convection

When diffusion is accompanied by a bulk movement of matter, the heat transport is termed convective. In natural convection, bouancy from temperature dependent density of matter in gas or liquid phase will provide a substantial contribution to heat transfer, and is one of the key challenges in accurate ampacity calculations. The general equation for heat transfer by convection q_{conv} is given by

$$q_{conv} = h\left(T_{obj} - T_\infty\right), \tag{3}$$

where h is the convection heat transfer coefficient and T_∞ is the gas/fluid temperature.