Thermal analysis of 3-core SL-type cables with jacket around each core using the IEC Standard

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ABSTRACT

This paper addresses several issues related to the calculation of the steady state and transient rating of 3-core submarine cables with a metallic screen and a jacket around each core. Indeed, nowadays, such cables are frequently used in submarine installations. Whereas there is no provision in the IEC Standard to model such cables. The proposed equations are validated and benchmarked using 2D models in software applications that use analytical and/or finite element analyses.

KEYWORDS

Submarine cables, rating calculations, SL-type cables, IEC standard, thermal analysis of power cables.

INTRODUCTION

The continuous increase of the demand for energy and the increase of the standards of service reliability have led to offshore wind farms and submarine interconnections becoming more and more common in the utilities' grid. Because of their high cost, these installations are optimized and designed to work at their maximum capacity from the beginning, requiring more accurate models than conventional cable installations. Analytical solutions to the heat transfer equations are available only for simple cable constructions and simple laying conditions [1, 2]; but the submarine cables, designed for corrosive environments, require more complex constructions. For example, the 3-core SL (Separated Lead) and SA (Separated Aluminum) type cables characterized by individual sheath (or concentric neutral), could have an additional layer (usually polyethylene), that protects the sheath against corrosion. The standard thermal analysis [1], which is briefly described below, does not provide any guidance on how to model this extra layer commonly called jacket around each core. Modeling of the transient phenomenon for the cable construction examined here has been addressed in [3]. Modifications to the approach presented there will be considered in a future publication.

Steady state analysis

To analyze the steady state conditions of the heat transfer and the temperature rise phenomena in cables and their surrounding environment, the system is represented by a lump parameters thermal circuit, which is then modelled by an analogous electrical circuit in which voltages are equivalent to temperatures, electrical resistances to thermal resistances and currents to heat flux. If the thermal characteristics do not change with temperature, the equivalent circuit is linear, and the superposition principle is applicable for solving any form of heat flux problem.

In a thermal circuit, charge corresponds to heat; thus, Ohm's law is analogous to Fourier's law. The thermal analogy uses the same formulation for thermal resistances and capacitances as in electrical networks for electrical resistances and capacitances. Note that there is no thermal analogy to inductance and in steady-state analysis; only resistance will appear in the network (see Fig. 1).

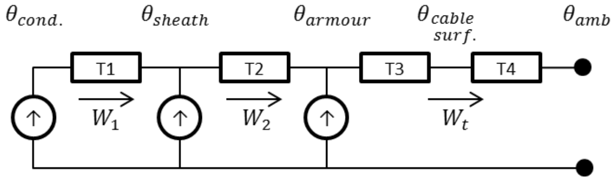

Fig. 1: Cable equivalent circuit for the steady-state analysis

T_1 is the thermal resistance per core between conductor and the sheath, T_2 is the thermal resistance between sheath and armor, T_3 is the thermal resistance of external serving and, T_4 is the thermal resistance of the surrounding medium.

The focus of this paper is the calculation of the values of T_2 since the IEC Standard [1, 2] does not treat the constructions considered in this paper.

COMPUTATION OF THE THERMAL RESISTANCE T_2

The IEC Standard approach

In the case of a three-core cable with individual sheaths, T_2 is calculated for the three cores from [1]:

$$T_2 = \frac{\rho}{6\pi}\bar{G} \tag{1}$$

ρ is the thermal resistivity of the material between sheaths and armour. A single thermal resistivity suggests that the material between sheaths and armor is homogenous. Since the layers are not specified in the IEC Standard, the material might include jackets around each core, filler and bedding, provided that these layers have the same thermal resistivity. In the presence of touching jackets, the proportion of the jacket thickness with respect to the thickness of the material between the sheath and armour is defined as:

$$t_{j\%} = \frac{t_j}{t_{s\to a}} \tag{2}$$

Where t_j is the jacket thickness and $t_{s\to a}$ is the total distance between sheaths and armour. The parameter $\bar{G}$ is obtained as follows. When the sheaths are in contact $t_{j\%} = 0\%$, the upper curve defined in (3) is used. When the distances between the sheaths and between the sheath and armor are the same, means that the jackets and bedding have the same thickness $t_{j\%} = 50\%$. In this case, the lower curve defined in (4) is used.