Contributions for the modelling of submarine cables – current density and simplified modelling of wired layers

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ABSTRACT

This article researches two topics relevant for the development of accurate formulae able to estimate the ampacity of HVAC submarine cables.

Simplified formulae for estimating the current density distribution, which can be used for theoretical analyses, are developed and compared with the exact formulae.

The substitution of round wires by equivalent solid layers is tested and tuned by changing the permeability of the insulation and the resistivity of the of the substitution layer. The tuning of these two parameters allows obtaining similar results for both cases even for materials with high permeabilities, like steel.

KEYWORDS

HVAC cables, Permeability, Current Density, Losses, Wires, Equivalent Area

INTRODUCTION

The installation of submarine cables increased steadily in recent years and this trend is expected to continue in the future. A topic in need of further research, for different reasons, is the magnetic field generated by cables.

One of the reasons is the possible effects of the magnetic field in animal health. Changes in the behaviour of sea life have been registered after the installation of submarine cables and differences sources [1], [2] point out magnetic fields as the cause.

A second reason is the overestimation of the losses in submarine cables. Several parties have studied and measured these losses [3], [4], [5], [6], [7] and verified that they were lower than indicated by the IEC standard [8]. Different authors propose different reasons for this, but several indicate that the influence of the armour in the magnetic field generated by the cable is the main reason for the overestimation. Research is currently being made by Aalborg University – Department of Energy Technology and Energinet.dk for the development of new analytical formulae capable of an accurate estimation of the losses in submarine cables, when in steady-state, which can lead to potential financial savings via a reduction of the required cross-section. This paper is one in a series of several that will build the path for the new equations and that can also support other researchers in related topics.

With this objective in mind the analyses in the paper are focused on conductor+screen cables. The parameters of the screen are altered in such way that it results in non-realistic cases, e.g., the screen's relative permeability varies between 1 and 1000. This allows a simplification of the problem and the testing of new approach, which can later be adapted to more realistic scenarios.

PAPER OBJECTIVES

The paper has two main objectives:

- Formulae for the current density distribution;
- Hypothesis for simplifying the modelling of round wires in an armour;

These two objectives are chosen, because they are relevant for an improvement of the formulae used in [8] to estimate the losses in submarine cables. The first one will allow developing analytical equations for the current density that can be later used when estimating impedances, whereas the second may allow approximating the results using today's methods.

Given the complexity of the task, the majority of the work in this paper is for cable with just one conductor and screen. This approach is chosen as it allows the simplification of the problem, while continuing researching the main factors of influence. Future works will continue the research for three-core submarine cables.

TEST CASES

Fig. 1 shows the two cases used in this paper.

Case 1: Single-core and solid screen
Case 2: Single-core and wired screen

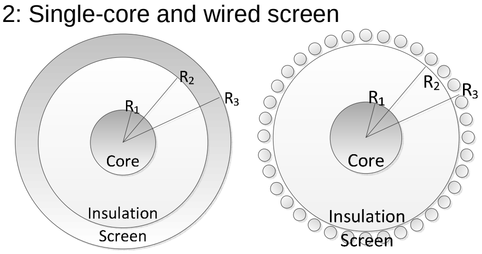

Fig. 1: Example of configurations used in the paper: Left: Case 1; Right: Case 2;

CURRENT DENSITY

The understanding of the current density in the armour is required for the design of new formulae, as this parameter influences the magnetic field distribution. The formulae presented next are for cables with solid screens, and both exact and approximated formulae are presented. The expression (1) used for the calculation of the current density inside of the core is well known [9].

$$J(x) = \frac{\overline{p} \cdot I_C}{2\pi R_1} \cdot \frac{J_0(\overline{p} \cdot x)}{J_1(\overline{p} \cdot R_1)}, 0 \leq x \leq R_1$$

$$\text{where, } \overline{p} = \sqrt{\frac{-j\omega\mu}{\rho}} \quad (1)$$

Where, I_C is the current in the conductor of the cable, J_0