Losses in Three-Core Export Cables with Magnetic Armour: Measuring and Simulation Aspects

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ABSTRACT

Subsea cables are important for the overall expenditure of offshore windfarms. The generated heat in HVAC cables is mainly due to the losses induced at metallic parts. The existing IEC Standard overestimates the losses and, particularly, the armour loss. Cigré Study Committee B1 has constituted Working Group B1.64, expected to recommend cable impedance measuring methods and calculating loss models. This paper adopts the main principles of the existing literature, intending to improve the measuring accuracy and efficiency. In parallel, state-of-the art models are used to validate measurements, proposing a holistic approach to the problem of cable loss estimation.

KEYWORDS

Cable losses, FEM, magnetic armour, MoM-SO, submarine cables.

INTRODUCTION

Subsea cables are a significant part of the overall cost for offshore windfarms. HVAC three-core (3C) cables are still the main solution for reasonable distances from shore. Besides losses in conductors, the heat generated in HVAC cables is, additionally, due to the losses induced in metallic sheaths and magnetic armour. Although non-magnetic armour could be used to reduce losses, this is costlier and harder to handle during manufacture.

It is broadly recognised that the IEC Standard 60287-1-1 [1] overestimates cable losses and, particularly, the armour loss. Many published works deal with loss measurements. The authors of [2] suggest a measuring method specifically for the armour loss, by subtracting the total loss of the armoured with that of the unarmoured sample. However, significant measuring errors occur this way, because of the changing sheath eddy loss at both samples. The allocation of losses to the several metallic parts is a questionable goal. The authors of [3] suggest that the positive-sequence cable impedance is measured. By placing voltage and temperature sensors in the conductors at positions preferrably within the armoured section to avoid end effects caused by the unarmoured parts, this method estimates the total cable losses. Although the “preferrable position” is theoretically right, its practical value has not been proven, while the drilling process required is time-consuming and might be harmful for the cable integrity.

Analytical models, calculating more realistic losses, are also suggested in [4]. Finite Element Method (FEM) models are proposed as a more accurate approach, although not always the most efficient [5]. Recently, three-dimensional (3D) FEM techniques further reduce the total set-up and solution times [6]. Although faster compared to the past, there is still margin for accuracy improvement, e.g., by concerning the wire field-dependent magnetic permeability.

For these reasons, Cigré Study Committee B1 has recently constituted Working Group (WG) B1.64, which is expected to recommend specific methods for measuring the cable positive-sequence impedance and valid theoretical models for calculating the cable losses. This paper follows the main measuring principles adopted as a common denominator in the existing literature. An electric method, being verified by a calorimetric method, is employed to measure cable losses. The cable is tested under both dry and wet conditions, i.e., before and after being immersed under sea water. Both armoured and unarmoured cable samples are tested to increase the level of confidence, allowing for loss allocation at metallic sheaths. Focus is made on cables with magnetic armouring of lower and higher steel grades. Measurements of the armour wire magnetic permeability are also performed. State-of-the-art FEM models, based on recent publications [7] but further enhanced to consider the field-dependent complex permeability of wires, are employed to validate the measured data. State-of-the-art series impedance models suitable for 3C armoured cables [8] are also investigated. Interesting outcomes occur, suggesting that the cable losses are significantly lower than those calculated by the IEC Standard, leaving margin for design optimisation and cost reduction.

MODELLING APPROACH

The twisting of power cores and armour wires in different helices makes the problem of calculating losses challenging to solve. In fact, this is 3D in nature and, thus, a 3D analysis should be considered. Besides the angular and the radial field components, a longitudinal field is also induced because of the core twisting. Furthermore, the armour wires do not touch one another: hence, the electromotive force locally induced in wires is cancelled out over a complete periodicity, resulting in zero net circulating current along each wire [9]. The existing methods are presented in this section, focusing on the key-features each one presents and the contribution of the present paper.

2.5D MoM-SO

The Method of Moments - Surface Operator (MoM-SO) is a numerical method, which is used to calculate the cable series impedance at frequency domain [8]. Although methods such as MoM-SO are traditionally used to compute sequence components at power and higher frequencies, which are necessary for power flow/protection and insulation coordination studies, they can be also used to calculate cable losses. One of the MoM-SO strong points is that it considers not only skin, but also proximity effects, which are of importance in 3C cables. Despite that it is two-dimensional (2D) in nature, it is regarded as a 2.5D approach, since it accounts for the fact that zero net current circulates in the armour. Compared to 2.5D FEM models, MoM-SO is computationally more efficient, since it requires the discretisation of each metallic component’s boundary instead of meshing the interior of the whole cable domain.