Measurements of losses on three-core submarine power cables

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ABSTRACT

Armour losses are calculated during the design process of submarine cables using IEC 60287-1-1 formulae. Several recent papers underline the possible overestimation of armour losses given by IEC standards. In this paper, armour losses are investigated on two different High Voltage (HV) three-core submarine power cables. Measurements have been made in air and in salt water and results are compared to IEC 60287 calculations.

KEYWORDS

Three core submarine cable, armour losses, measurements, IEC standards

INTRODUCTION

Submarine power cables are designed with an armour to protect the cable during storage and laying operation but also from external hazards like anchors or trawling gear. The armour is composed of wires, generally steel wires, helically wound around the three-core cables. Such metallic and magnetic armouring provides additional losses when alternating current flows in the cores and thus reduces the cable ampacity.

IEC 60287-1-1 [1] gives formulae in order to estimate the armour losses but recent studies highlight that the use of this formulae yield substantial overestimation.

The overestimation of armour losses during the design process leads to the use of larger cables. Thus the development of an accurate formula can lead to a reduction of conductor size and consequently cable size and price.

Measurements have been performed in the EDF Lab Les Renardières on three-core submarine power cables the last two years in order to address the (over)estimation of armour losses, to provide comparison data for future implementation in Finite Element Model(s) and to perfect measurement protocol to assess armour losses.

After a short introduction on the analytical calculation given by IEC standard, the paper presents the set-up used in order to measure the armour losses and analysis of the results obtained on the two cable designs. It addresses also the influence of sea water on armour losses by immersing the cable in salt water. Finally results are compared to those given by the IEC formulae.

CABLE DATA

Two different three-core submarine cables (150 kV, 1200 mm²) with copper conductors and single-layer armour were considered: the first armour was composed of 84 Ø7 mm zinc-anodized steel wires and the second armour was made with a mix of 28 Ø7 mm PE wires and 56 Ø7 mm steel wires (one wire out of three is a PE wire). Each single phase metallic screen is covered with an extruded lead-screen and a complete semi-conductive PE sheath. The electrical resistivity of the semi-conductive PE sheath is different between the two armoured samples. Apart from the armour and the PE sheath, both samples are based on the same design.

A third sample without armour and common external recovering (same production that the sample with mixed armour) is used for the measurements. Table 1 gives some further sample dimensions.

Table 1: Dimensions of the three 50 m cable samples

Component	Dimension
Copper conductor Area/OD	1200 mm²/41 mm
Lead-screen Area/OD	755 mm²/89 mm
Cable core OD	94 mm
Armour average diameter	216 mm
Cable OD	235 mm

IEC STANDARDS CALCULATION

IEC 60287-1-1 gives formulae to calculate power losses in the different components of the cable (cores, screens, tapes, armour…). Different formulae depending on cable types are given. For a three-core submarine power cable, the armour losses are given as a fraction of the resistive conductor losses at the maximum temperature by the λ_2 coefficient:

$$\lambda_2 = 1.23\frac{R_A}{R}\left(\frac{2c}{d_A}\right)^2 \frac{1}{\left(\frac{2.77 R_A 10^6}{\omega}\right)^2 + 1}$$

With R_A the AC resistance of the armour, R the AC resistance of the conductor, d_A the mean diameter of the armour, c the distance between the axis of the conductors and the axis of the three-core cable (mm) and ω the angular frequency of the system.

The submarine power cable considered in this study has individual screens. As the screening effect of the screen currents reduces the armour loss, the λ_2 coefficient given above shall be multiplied by the correction factor below:

$$\left(1 - \frac{R}{R_s}\lambda_1'\right)$$

With R_s the AC resistance of the screen and λ'_1 the ratio of the losses in one sheath due to circulating currents to the losses in one conductor