LOSS EVALUATION ON THREE CORE ARMOURED SUBMARINE CABLES

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ABSTRACT

The steel-wire armour and sheath loss of two types of three-core armoured cables were estimated. One cable is a large cable assuming export cables. The other cable is a double steel wire cable assuming dynamic cables. The armour loss factor λ₂ of the former cable is about 20% compared to the λ₂ specified by IEC 60287 for confirming a large deviation. The latter λ₂ is found to be the same in the double armour as in the single armour, in addition to the above results. The sheath loss is suggested to be different from λ₁ specified by IEC 60287 depending on the cable specification.

KEYWORDS

Armour loss, three-core submarine cable, current ratings.

INTRODUCTION

The worldwide expansion of clean energy has accelerated the installation of offshore wind energy, which has increased the demand for submarine cables and made such cables more important than ever before. Submarine cables are generally equipped with steel wire on the outside to prevent anchor damage and achieve tension during installation, but the magnetic field caused by the AC current generates hysteresis loss and eddy current loss in the steel wire (called armour loss), which reduces the transmission capacity of the cable by generated heat.

The armour loss factor for determining the current ratings of submarine cables is defined by Equation (1) in IEC 60287[1], which is a semi-empirically derived equation based on experiments conducted around 1940[2].

$$\lambda2_{IEC} = 1.23\frac{R_a}{R_c}\left(\frac{2C}{d_a}\right)^2 \frac{1}{\left(\frac{2.77R_a 10^6}{\omega}\right)^2 + 1} \qquad (1)$$

where R_c [Ω/m] is the conductor AC resistance, R_a [Ω/m] is armour AC resistance, C [mm] is the distance between the center of the conductor and the center of the three-core cable, d_a [mm] is the diameter of the armoured wire cable, and ω [rad/s] is the angular frequency.

Therefore, it is thought that there is a difference between the loss calculated by the IEC standard, the actual loss caused by the effect of the metallic sheath layer is not taken into account, and that the armour layer is modeled as a pipe, which has become a more serious problem in recent years for larger submarine cables. This problem is also being studied by analysis using the finite element method and other methods[3,4].

This paper describes the results of the evaluated armour and sheath loss by power loss measurements for two types of submarine cables: (1) AC 275 kV, 1400 mm^2 with a single steel wire layer assuming export cables and (2) AC 66 kV, 400 mm^2 with a double steel wire layer assuming dynamic cables.

MEASUREMENT METHOD

Calculation

There are some studies[5-8] for armour loss based on measurements by using three-core armoured cables. In this study, these are also used as references for the experiments.

At first, the total cable losses with *n* (*n = 1* or *2*) armour layers and without this are, respectively, expressed in Equations (2) and (3). The armour loss W_a [W] is expressed in Equation (4) by taking these differences.

$$W_{total}n = Lc \cdot Rc \cdot Ic^2 + k \cdot Ls \cdot Rs \cdot Is0^2 + La \cdot Wa + Wb + \Delta W \qquad (2)$$

$$W_{total}0 = Lc \cdot Rc \cdot Ic^2 + Ls \cdot Rs \cdot Is0^2 + Wb + \Delta W \qquad (3)$$

$$Wa = \frac{W_{total}n - W_{total}0 - (\,k - 1) \cdot Ls \cdot Rs \cdot Is0^2}{La} \qquad (4)$$

where L_c, L_s, and L_a [m] are the conductor, metallic sheath, and armour lengths, respectively; R_s and R_c [Ω/m] are the AC resistance of the conductor and metallic sheath at operating temperature, respectively; I_c and I_s [A] are the conductor and metallic sheath current, respectively; W_b and ΔW [W] are bonding losses and error, respectively; and k is the value related to the sheath current expressed in Equation (5).

$$k = \sqrt{\frac{I_s n^2}{I_s 0^2}} \qquad (5)$$

On the other hand, the total cable loss can be calculated by the current, ground voltage, and power factor of the conductor as shown in Equation (6) where n is from 0 to 2.

$$W_{total}n = 3 \cdot Ic \cdot Vcn \cdot \cos\theta n \qquad (6)$$

Furthermore, the conductor temperature was performed at around 90°C in order to get close to the operating temperature. Therefore, Equation (7) was introduced to compensate for differences in current and resistance due to temperature at the measurements.

$$\Delta Wn = Lc \cdot Rc \cdot Ic^2 \cdot \alpha(90 - Tc) \pm 3 \cdot Lc \cdot Rc \cdot \Delta Ic^2 \qquad (7)$$

where T_c is the conductor temperature and ΔI_c is the