3D FEM analysis of armour loss in three core submarine cables

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ABSTRACT

2D and 3D FEM has been performed to evaluate sheath and armour loss of three-core armoured submarine power cable. Preliminary study revealed that 2D FEM is sufficient for the present cable construction, where conductors and armour wires are laid in the same direction and considered to be almost parallel. 2D FEM results showed that the IEC formula uniformly overestimates λ_2 regardless of conductor size. In addition, the results indicated that metallic sheath thickness, which is not included factor in the IEC formula, had an effect on λ_2.

KEYWORDS

Armour losses, three-core submarine cable, FEM analysis

INTRODUCTION

Armour loss in three-core submarine cable is generally calculated by following the formula described in the IEC 60287 standard [1]. However, it is commonly known that this evaluation probably overestimates the loss compared to the actual loss, which has an effect on cable design, that is, the adopted conductor size will be larger than it really needs to be. Therefore, if more accurate armour loss can be applied in the current rating calculation, a more optimized conductor size selection becomes possible. It is currently well known that this overestimation of armour loss qualitatively happen in many cases, and various studies have actually been conducted from the viewpoint of actual measurement and simulation analyses to quantitatively understand the actual loss [2-6]. However, at present, an improved calculation formula in the IEC standard has not been established yet. One of the reasons for this is the difficulty in accurately evaluating the loss in actual measurements due to measurement precision. Additionally, preparing many kinds of cables with various cable parameters (e.g. conductor size, thickness of metallic sheath, and armour) adds a burden in terms of cost and manufacturing facility. On the other hand, simulation can set the variety of design parameters and investigating the loss in each case with much less trouble in comparison to the measurement, which will provide a lot of insight regarding cable design.

Armour loss is attributed to the induced current in armour caused by conductor current in this study. However, the mechanism is not that simple due to the complexity of the configuration of each cable component. In general, three cores and armour wires are laid with different pitch, which makes it harder to clearly understand the distribution of induced current.

On the other hand, some elements currently are not included in the calculation formula for λ_2 for estimation of armour loss in the IEC standard. Specifically, the absence and thickness of the metallic sheath that will possibly affect actual armour loss [3] are not included in the current IEC formula. Additionally, it has been reported that the laying angle of the core and armour has a strong influence on armour loss [5], and this factor is also not included in the formula. In fact, the induced current providing armour loss is associated with the laying angle. Also, the IEC formula appears to be derived from the model where one tube is assumed, although the actual armour structure consists of single wires insulated from each other.

In the study of armour loss by simulation analyses, two-dimensional (2D) and three-dimensional (3D) models are used in many cases, and 3D model is better in terms of the accuracy. The main difference between both models is in the existence of the laid core and armour generated over the longitudinal direction of the cable. In the 2D model, the elements of the laying pitch and laying angle cannot be incorporated into the model. However, in the actual simulation, the 3D model has the disadvantage of an operating load; therefore, if it is possible to obtain an accurate value in the 2D model, machine time and workload will be highly reduced.

In this study, the FEM analyses have been conducted and compared between the 2D and 3D models. Next, the dependence of sheath loss and armour loss on the design parameters (specifically, conductor size and metallic sheath) has been investigated in the 2D model. In the evaluation of loss, not only the armour loss rate λ_2 but also the lead sheath loss ratio λ_1 were evaluated in consideration of the possibility that the two losses were mutually dependent. The derivation of λ_1 and λ_2 were calculated with the following formula, which is currently described in IEC standard.

$$\lambda_1 = \frac{W_s}{W_c} \qquad (1)$$

$$\lambda_2 = \frac{W_a}{W_c} \qquad (2)$$

Where, W_c, W_s, and W_a are the loss in the conductor, lead sheath, and armour, respectively.

SIMULATION MODEL

In this study, simulation analyses were carried out by the Finite Element Method (FEM) using the COMSOL software, and each of the 2D and 3D models is as shown in Figs. 1 and 2. The model mainly consists of the conductor, lead sheath, and armour, and the 3D model reflects the laying of the core and armour. Also, the example of the distribution of loss density in conductor, lead sheath, and armour are also shown in Figs. 3 and 4.

In this study, the laying angle of the core (ϕ_c) and armour (ϕ_a) are defined as the angle to the longitudinal axis of the cable, respectively. Both are 90° in 2D model, but in the