Low-loss Cable Development through Steel Armour Optimization

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ABSTRACT

The IEC60287 standards are commonly used to predict cable losses, but they over-estimate cable armour losses due to theoretical limitations. Therefore, in this paper, a loss measuring system was designed to develop a low-loss cable, and a 3D FEM analysis model was constructed to ensure consistency between testing and analysis. Based on this, the main factors affecting cable loss were derived and the optimal cable design was proposed.

KEYWORDS

Cable loss optimization; Loss measurement; FEM analysis; Steel armoured Cable; Low-loss Cable

INTRODUCTION

Demand for offshore wind farms has increased rapidly in recent years due to growing interest in renewable energy. [1] In this market environment, reducing offshore wind farm cable losses is crucial for minimizing the cost of ownership and operation. However, the current cable ampacity theory, as described in the "Rating of Electric Power Cables" [2] and IEC Standard 60287 [3], excessively reflects cable armour losses, making it difficult to use for loss reduction design due to theoretical limitations. Therefore, customers are requesting a cable loss measurement system to establish optimal cable designs for economical cable line construction.

To address this need, a study was conducted for reducing armour losses, which account for approximately 25% or more of the total cable losses. The effect of uni-lay was investigated, where the armour and phases are twisted in the same direction, and contra-lay, where they are twisted in opposite directions, as well as the armour material impact on cable loss. An optimal cable design for low-loss cables was suggested.

To accomplish this, a cable loss measurement system was built, which was cleared by the Employer and the Korea Electro-technology Research Institute (KERI) up to 2020 and the cable losses of various cable designs were measured. To verify the effect of the armour design on total cable losses, experiments were conducted by changing the armour materials and using uni-lay or contra-lay for the same cable.

To confirm the accuracy of the experiments, a 3D FEM analysis model was built and compared with the experiments. The difference between the experiment and the analysis was ascertained to be within 3%. Therefore, it is believed that the consistency between the experiment and the analysis was secured, and optimal designs for low-loss cables could be suggested.

In conclusion, this paper verifies the factors influencing the loss of steel- armoured cables using experimental and FEM analytical methods, derives the main factors influencing the loss, and proposes a method for optimizing cable loss. However, it should be noted that only the cable loss aspect has been considered for the construction of an economical cable line, and further studies are needed to consider the mechanical properties.

CABLE LOSS PREDICTION FOR MAGNETIC STEEL ARMOUR SUBMARINE CABLES

The losses due to AC current in a submarine cable can be estimated in three ways outlined in the sections of this chapter, comprising IEC, FEM and a novel magnetic tube model seeing standardization.

IEC 60287

IEC 60287 is an existing international standard that is known to overestimate losses when using magnetic armour.

FEM (Finite Element Method) Analysis

FEM analyses are typically performed in 2D or 3D depending on the continuity of the cross-sectional geometry. In the case of a submarine cable, both the phases and armour rotate, so it is a 3D structure, and a 3D analysis should be performed. Ignoring this and proceeding with a 2D analysis will result in large armour losses.

To accurately predict the loss of the cable, a 3D analysis is required. Since it is not possible to analyse a very long cable by drawing all of it, a longitudinal periodicity can be used to analyse only certain repeated lengths and then predict the loss of the entire cable.

Therefore, additional longitudinal periodic boundary conditions are required for the 3D FEM analysis. If the correct boundary conditions are not applied, the analysis error increases at the beginning and end of the cable (end effect). 3D analysis requires a lot of computing power and is time consuming, so the analysis length should be minimized if possible. As simulation technology improves, new boundary conditions (BC) can be applied and the minimum required cable length to be analysed changes, as outlined below. [4]

LCM (Least Common Multiplier)

To apply periodic boundary conditions, which is a common boundary condition, the analysis must be performed for the LCM length of the rotating parts, phases and armour. This model is too long to analyse in most cases.

Therefore, rather than performing an analysis of the entire LCM length, it was possible to perform an analysis of an analysable length and then calculate the cable losses using only the centre section with no end effects.

Crossing pitch (CP)

The CP can be calculated as the harmonic mean of the core pitch (Lc) in millimetre and armour pitch (La) as follows: