Rating of HVDC Submarine Cable Crossings

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ABSTRACT

To construct a European super grid, HVDC submarine cable circuits will be needed for long-distance bulk power transmission. Under complex bathymetric conditions, cable crossings become inevitable in some cases. However, due to the thermal conditions in protective rock placements, the traditional IEC60287-3-3 crossing rating method doesn't apply. This paper presents a preliminary study on submarine crossing ratings and the associated thermal performance through 3D finite element analysis. The paper aims to provide practical guidelines for crossing installation and operation. Interesting results suggest that thermal interference might be effectively mitigated by restructuring the protection layer.

KEYWORDS

Numerical modelling, Submarine cable crossing, Thermal rating and analysis

INTRODUCTION

With a plan to develop the European wide super grid via HVDC submarine cable connections [1], offshore cable crossings become inevitable due to route planning, and seabed topographies. It is important to accurately rate these circuits, because the cable may age prematurely if the cable runs at higher temperatures at crossing points.

At present, the analytical crossing rating calculation IEC60287-3-3 [2] is found inapplicable for submarine crossings. This is because unlike the directly buried land cable crossing, the submarine crossing normally requires a post-lay trapezoidal rock berm protection to resist hazardous activities (e.g. scouring, anchoring). Therefore, the key assumption of an isothermal ground surface in the IEC method is not valid. Although some papers [3] suggest that a minimum 30cm to 45cm vertical separation is adequate to prevent the thermal interference, no comprehensive modelling study has been completed.

To address the above concerns, this paper adopts a 3D finite element analysis (FEA) modelling method to evaluate the rating of cables at the crossing and the associated thermal performance. Unlike the IEC method, FEA method numerically solves partial differential equations (PDEs) at the nodes of automatically generated meshes, rather than deriving an exact analytical expression. Therefore, a more reasonable model can be built, by removing some idealistic assumptions in the IEC method. For instance, 'hybrid' heat transfer (i.e. conduction, convection) within rock berm pores can be modelled and various arbitrary protective structures can be considered.

In this paper, the general design principles of submarine cable protection and relevant parameter calculations are reviewed. A brief FEA modelling approach is then presented, with key modelling steps being highlighted. Finally, the thermal performance of four different crossing installations is evaluated with various cable rating combinations, before drawing recommendations for crossing installation and operation.

SUBMARINE CABLE PROTECTION AND HEAT TRANSFER MECHANISM

For submarine cable projects, a proper mechanical protection against accidental mechanical damage is crucial. Otherwise, the resulting downtime can last for months and causes a huge amount of economic loss for system operators. Generally, the primary protection method in any submarine condition is to deeply bury the cable. In [4], this method is guided by the Burial Protection Index (BPI) in terms of minimum burial depth. As outlined, a minimum burial depth between 0.5m and 2m is required for most seabed conditions to achieve BPI = 1 against most submarine hazards. However, when a sufficient burial cannot be guaranteed, remedial protection methods will be applied which include rock placement and concrete mattress covering.

Rock placement installs a rock berm over the submarine cable on the seabed. The typical rock berm cross section is trapezoidal with typically 0.5m – 1.5m height, 5m – 12m base width and either 1:4 or 1:3 side slope [5]. Alternatively, concrete slabs are linked by rope and placed over the cable. Note that for crossing installations, the concrete mattress is used as the major vertical separator between two crossing circuits. Typical commercial concrete mattress can reach up to 10m×4m plane area with 150mm – 450mm thickness [3].

In terms of FEA modelling, one difficult part is to accurately model the heat transfer mechanism for the rock berm, which is an unconsolidated porous media filled with sea water. Theoretically, three heat transfer mechanisms may occur:

1. Thermal conduction in the solid phase, liquid phase and across the solid-liquid interface.
2. Thermal convection between the solid phase and the liquid phase.
3. Thermal radiation from one internal solid wall to another.

In practice, the thermal conduction inevitably exists for the fundamental heat dissipation, and a free convection can occur within rock pores based on the pore-size related rock permeability. However, as the maximum temperature is limited to 50°C for MI paper insulated cables in this study, the thermal radiation is considered weak and thus neglected [6].

Pure Porous Medium Thermal Conductivity

Two well-established models are found in literature to calculate the thermal conductivity, λ_c, of a two-phase porous system (i.e. solid phase λ_s, liquid phase λ_f) with given volume fraction (i.e. solid phase porosity, ϕ).