Evaluation of seabed effective thermal resistance and temperature decay model for the thermal rating of buried submarine cables

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ABSTRACT

In the past years, a lot of progress has been made by CIGRE B1 working groups that have verified and recommended more accurate modelling principles for the thermal analysis of submarine cables compared to IEC 60287. The installation conditions and more specifically the ground thermal properties and temperature at burial depth can have a major effect on the cables' rating. IEC 60287 requires a single value of thermal resistivity to be used for the evaluation of the external thermal resistance; the accuracy of this single value to represent complex ground conditions can lead to oversized cables. Furthermore, the identification of the necessary cable designs is an iterative process, where the installation conditions are optimized to achieve the maximum ampacity. This paper aims to present a comparison between a holistic analysis of non-uniform ground conditions with the modelling of the temperature decay with depth and the calculation of the equivalent seabed thermal resistivity and an effective thermal resistance for buried submarine power cables towards soil conditions as used for cable rating as provided by IEC 60287.

KEYWORDS

Soil Thermal Resistivity, Seabed Temperature Decay, Seabed Mobility, Burial Requirements, External Thermal Resistance, Integrated Ground Model, Cable Thermal Rating, Offshore Wind, Conformal mapping.

INTRODUCTION

The global offshore wind energy is a rapidly growing industry, where the market grew on average by 36% per year in the past decade making the total installed global capacity 56 GW [1]. Furthermore, forecasts predict that power transmitted to global energy grids are expected to reach 380 GW by 2030 and 2000 GW by 2050. This increased capacity is transmitted to shore through high voltage export cables which represent a significant capital expenditure in the construction of offshore windfarms. With increased growth coupled with rising commodity prices, to maintain offshore wind as a competive resource of renewable energy it is critical that the industry drives down the levelised cost of energy through designing efficient energy systems. In the case of export cables, this requires that the current carrying capacity is optimised to ensure that the conductor temperatures do not exceed the permissible threshold, usually 90 degrees for AC cables while still supporting as much installed capacity as possible.

One bottleneck that may arise during the design of the energy system relates to the thermal interaction between the cable and its surrounding environment when buried, such as the thermal resistivity of the seabed, height of sandwaves and ambient temperature, which are known to have significant impact on the cable rating [2] [3]. Therefore, understanding their properties as well as how they are applied in design is critical for an optimal solution.

The rating of the submarine cables, especially export submarine cables are extremely important for large scale wind farm projects as these ratings in some cases are defining the size of the windfarm and the expected energy production by the wind farm. In combination with the inter-array cables, they are very important for the overall business case of the windfarm.

Traditionally, cable sizes are initially based on IEC 60287 calculations, which estimate the maximum ampacity of the cable based on a thermal network approach to represent heat dissipation from a cable. As part of this calculation IEC recommends the use of a single value for thermal resistivity to be used for the evaluation of the external thermal resistance (T_4). The accuracy of a single value to represent the thermal resistivity of layered ground conditions can lead to oversized cables.

This paper presents a comparison for indicative design cases between an Equivalent Rating Approach and a Single Layer Rating Approach. The novelty of the presented approach is that it implements the conformal mapping transformation and a resistance network analogue model given by "ELECTRA 98-2" [4] for calculating an Equivalent Thermal Resistivity and an Effective Thermal Resistance. Moreover, a temperature decay model is incorporated to the design workflow with the aim of estimating temperatures at cable axial depths (see definition of axial depth in Figure 2).

Validation exercises have been conducted to support this design approach into the thermal rating design process for MV/HV buried submarine cables.

IEC Cable Thermal Rating Process

For the identification of the optimum design and layout of cable circuits, the windfarm's installation and operating conditions are taken into consideration. Depending on several parameters associated with the construction and operation of the windfarm, the requirements for the cables' mechanical, electrical and thermal performance are set. The latter is undoubtedly a key area where optimization techniques can have a remarkable impact and thus, exercised extensively.

For the assessment of the cables' thermal performance and current rating, IEC 60287-1-1 [2], CIGRE Technical Brochure 880 [5], IEC 60853-2 [6] are broadly recognized and used. For AC buried cables where drying out of the soil does not occur, Equation 1 is specified in [2] for the calculation of the steady-state current rating.

$$I = \left[\frac{\Delta\theta - W_d[0,5\,T_1 + n(T_2+T_3+T_4)]}{R\,T_1 + nR(1+\lambda_1)T_2 + nR\,(1+\lambda_1+\lambda_2)(T_3+T_4)}\right]^{0.5} \qquad [1]$$

Where all parameters in Equation 1 are well defined in IEC 60287-1-1 [2]. As shown in Equation 1, the cable's current