Empirical Thermal Models for Array Cables in WTG Monopiles

Felix Benje **VAN BERGEN;** High Voltage Cables, Ørsted Wind Power, (Denmark), fbber@orsted.com
Oliver **CWIKOWSKI**, James **PILGRIM;** High Voltage Cables, Ørsted Wind Power, (UK), olinc@orsted.com, japil@orsted.com
Joachim **HOLBØLL**, Soumya **THAKUR;** Technical University of Denmark (DTU), (Denmark), johol@dtu.dk, south@dtu.dk

ABSTRACT

This paper evaluates the efficacy of rating methods and the robustness of standard assumptions for thermal design of cables in monopiles of offshore wind turbines. The cable's thermal model was validated using multiple datasets from an offshore windfarm including load current, Distributed Temperature Sensor data and additional temperature measurements from within the monopile. The results indicate significant improvement potential for the rating of array cables in wind turbine monopiles.

KEYWORDS

Array Cables, Offshore wind farms, Distributed Temperature Sensing (DTS), Current Rating, Ampacity, empirical parameterization, Thermo-electric equivalent circuit, ladder-type thermal circuit

INTRODUCTION

Most wind turbine generators ("WTG") in modern offshore wind farms are mounted onto monopile fixed bottom foundations. The Current Rating (or "Ampacity") of the array cable is often lowest at the thermal interface located inside the monopile foundation below the WTG tower, where the cables have left the water and are routed through air. This thermal hotspot can determine the Current Rating of the entire array cable section.

In engineering practice, it has been common to apply the empirically derived IEC60287 2-2 [1] section 4.2.1.1 based on [2] for cables laid in free air inside horizontally buried, air-filled troughs (IEC60287 2-2 section 4.2.6). However, offshore monopiles are dissimilar to buried troughs in terms geometry and orientation. In addition, convective and radiative heat transfer from the monopile to the surroundings are not accounted for. An empirical model for the heat balance for cable inside a vertical shafts or tunnels is given in [3]. In [4] and [5], generalized rating methods for cables laid in air inside riser poles and vertical shafts are proposed, updating the experimental work from [6]. Only limited experimental data is available to parameterize the model to account for the complex heat transfer processes inside various geometries, neither of which precisely resembles an offshore monopile. More recently, finite-element modelling of specific thermal hotspots and geometries, such as J-tubes and monopiles, has become feasible. However, such an approach is expensive, difficult to scale and assumption heavy.

The purpose of this study is to bridge the gap in the cable rating literature, by providing empirically derived guidance for engineering practitioners calculating the current rating of array cables in offshore monopiles. Commonly used rating methods are compared in terms of their performance in estimating in-service temperatures. The modelled temperatures and actual in-service temperatures are compared at the position of the embedded fibre-optical-cable ("FOC") inside the three-core cable package (Figure 3). The impact of ambient temperatures and heat accumulation from solar radiation inside the monopile foundation is also analysed.

Both steady-state and continuous (dynamic) current ratings are calculated using a ladder-type unidirectional thermo-electric equivalent model, based on the methodology described in Case study 12 in Cigré TB880 [7], incorporating relevant IEC standards. The thermal properties of the external cable environment have been estimated based on empirical temperature data as a point value at the measured peak temperature. The measured temperature of the monopile steel hull is taken as the temperature boundary ("ambient") condition.

THERMO-ELECTRIC EQUIVALENT CABLE MODEL

Heat propagation in the 3-core AC array cables inside the monopile is modelled using its thermo-electric equivalent circuit, assuming a two-dimensional symmetric cylindrical geometry for both the cable and the surrounding environment (Figure 1). The heat transfer is unidirectional, radially out of the cable and all layers have a constant temperature gradient. Inside the cable, heat transfer is assumed to be conductive only.

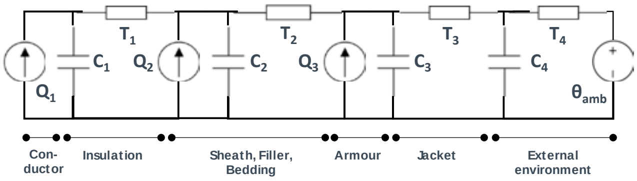

Figure 1 - Simplified thermal RC network of cable and external environment

The steady-state current rating is performed based on IEC 60287-1-1 (2006), p. 21 [10]. Eddy current losses in the cable screen/sheath and losses in the cables galvanized steel armour are calculated according to Cigré TB880, paragraph 6.6. The dynamic current rating model expands steady-state current rating model, i.e., all losses, resistances, etc. are calculated in the same way. The methodology outlined in [9] was followed.

The cable model was verified in a simple buried environment using a commercial rating calculation software, which is widely used in engineering practice and is trusted by both development engineers and cable manufacturers.