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Research paper

Thermal behavior of power cables in offshore wind sites considering wind speed uncertainty

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HIGHLIGHTS

- Thermal behavior of a submarine cable connecting an offshore wind farm to the coast.
- Estimation of the variable load due to wind's variability.
- Estimation of the variable heat transfer coefficient.
- The effect of the wind speed on the cable's temperature.

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ABSTRACT

A novel method for sizing power cables that connect offshore wind parks to the grid is presented. The followed methodology consists of two different and independent tasks: The stochastic wind power generation of the wind park is estimated based on historical data and, then, the cooling effect of high wind speeds on the temperature of the cable's aerial part is evaluated. In contrast to the IEC60287 standard, the effect of the variable heat transfer coefficient (h) caused by the variable wind speeds, is taken into account following a Finite Element Method approach which leads to a different thermal behavior than the expected one. Higher h values are caused by high wind speeds increasing, therefore, the current carrying capacity of the cable. The results of this study lead to a more efficient way of sizing power cables, avoiding power curtailment in periods with particularly high wind speeds, leading to a more cost efficient cable design.

1. Introduction

Submarine power cables that connect an offshore wind farm to the grid consist usually of three parts, Fig. 1: (1) the underwater part starting from the wind farm and approaching the coast, (2) an underground part at the coast approaching the coastal station and, finally, (3) an aerial part that reaches the coastal station [1]. Such cables show particularly high temperatures at periods with high wind power generation, i.e., high wind speeds. The current carrying capacity of the cable is defined by its hottest part, which is the aerial part due to its exposition to solar radiation. In this study, the temperature of the cable and its current carrying capacity are estimated using a combination of time series modeling for the estimation of the cable's load and Finite Element Methods (FEM) for the evaluation of its thermal behavior.

1.1. Literature review and contribution

Investments in wind power have increased rapidly during the last years due to political decisions supporting green energy sources and the fact that wind power can be an efficient and economically attractive alternative. However, the stochastic nature of wind raises a lot of challenges and has been the subject of a lot of research efforts for the last decade. The literature on forecasting and estimating wind speed/power has been very rich concerning various

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Nomenclature

h	Heat Transfer Coefficient (W/m^2 K)
ε_t	White noise
p, q	The orders of the ARMA model
φ_i, θ_i	ARMA model's parameters
C_p	Power coefficient
A	Area (m^2)
Q	Dissipated heat (W/m)
R	Resistance (Ω/km)
E	Kinetic Energy (J)
Y	Wind Speed (m/s)
q_s	Solar heat gain in the conductor (W/m)

time horizons from very short-term [2–6] to day-ahead and long-term predictions and estimations [7–9]. Most of the aforementioned studies focus on improving the prediction results and reducing the prediction error, as in Ref. [10] where the relationship between the accuracy of the forecast and wind power variability is studied for ARMA processes. Depending on the horizon of the prediction, these studies can be useful for real-time control, decision making, energy trading and energy markets, operational and long-term planning. Even though the literature is rich, wind power predictions and estimations have not yet been used for equipment sizing decisions with respect to the power cables that connect wind farms to the grid. In the current study a combination of Time Series Models and Monte Carlo Methods is used, as it is presented in Ref. [11], in order to estimate the long-term load of the transmission power cable and therefore its thermal behavior. The transient thermal behavior of such power cables have been studied thoroughly the last years. IEC60287 standards have been the reference for most fundamental works, being however quite outdated. Therefore a lot of research efforts have been made with new approaches especially regarding underground cables. Ref. [12] presented a numerical model of coupled liquid water, vapor and heat flow, to describe heat dissipation from underground cables. Ref. [13] compared an experimental study with the numerical one for an underground cable and for various configurations and thermal properties of the soil. In Ref. [14] the soil parameters were also investigated for an underground installation and in Refs. [15,16] a transient analysis of the thermal behavior of underground power cables was presented numerically and experimentally. Finally, FEM are widely used the last years for thermal modeling of power cables as in Refs. [17–19].

Recent research study [20] has proposed the use of CFD for the modeling of Lynx overhead conductors in distribution networks with integrated renewable energy driven generators. In this study, among other parameters, the effect of the wind speed on the cable's temperature was investigated. However, to the best of the authors' knowledge, there is no such study that estimates the effect of a varying heat transfer coefficient (h) (due to varying wind speeds) on the temperature of the cable in combination with the variable load of a wind power plant. In fact, in such installations the dynamic evolution of wind speed is important for two reasons:

- The resulting variability of the heat transfer coefficient
- The resulting variability of the load, which equals to the wind power generation.

The contribution of this study is, therefore, threefold:

1. The heat transfer coefficient and the wind power generation are estimated by the wind speed time series, which is described by the well-established time series models.
2. The effect of the variable heat transfer coefficient on the cable's temperature is investigated.
3. The effect of the variable wind power generation, serving as the cable's load, on the cable's temperature is evaluated.

As indicated in the literature review, wind speed estimation and prediction as well as FEM models are widely used and presented in previous research papers. The contribution of this work is, therefore, the combination of these methods in order to study the effect of the variable wind generation and the variable heat transfer coefficient on the cable's temperature.

1.2. Paper organization

In Section 2 of this study, a method for estimating the wind power generation of a small-sized offshore wind park based on historical hourly wind speed data is described, and then a scenario tree is constructed to describe wind speed uncertainty. In Section 3, a FEM model is built based on the hottest part of the cable, i.e., the aerial one. The thermal behavior of the model is studied for three different cases:

- The well-established IEC60287 study which is used as a benchmark
- The case where variable h is taken into consideration
- And, finally, the case where both variable h and variable load are considered.

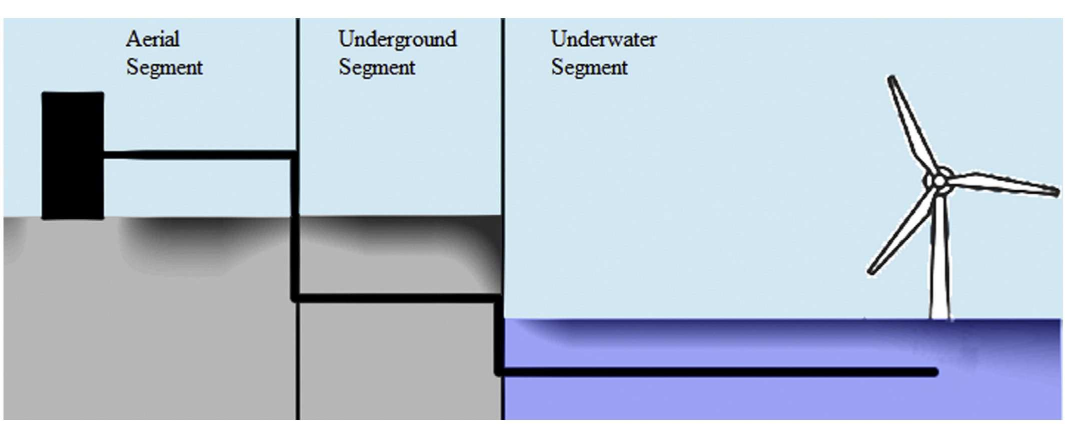

Fig. 1. Installation geometry.