Multi-objective Cable Size Optimisation in Offshore Wind Farms Based on Accurate Loss Calculation

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ABSTRACT

Offshore wind farms have grown rapidly in recent years and their numerous possibilities in design have motivated the use of optimisation techniques. This paper applies an optimisation formulation using a multi-objective function and Pareto efficiency to find the techno-economic optimum for the cable sizing in string feeders. This is succeeded by minimising the sum of capital and operational costs, with the latter being calculated by more accurate formulae compared to IEC standard. Results are contrasted against a reference case, where the cables are dimensioned to just fulfill the ampacity requirement. It is concluded that a more cost-effective solution is achieved by the proposed method.

KEYWORDS

Cable sizing, capital expenditure, inter-array cable, multi-objective optimisation, offshore wind farm, operational expenditure.

INTRODUCTION

The transition to renewable energy sources has led to tremendous advances in wind energy. Environmental and technical reasons have raised the demand for increased offshore wind power and, consequently, a significant number of Offshore Wind Farms (OWFs) have been rapidly developed [1]. The latter consists of several strings, interconnecting a series of Wind Turbine Generators (WTGs) to the offshore substation via three-core inter-array cables (IACs). The fixed capital expenditure (CAPEX) and the operational expenditure (OPEX) of these cables are a significant amount of the OWF total cost throughout the project lifetime. Optimising the cable size by aiming at minimising both CAPEX and OPEX can reduce the total cost of the project and lead to a more cost-effective investment [2]-[4].

IEC Standard 60287-3-2 [5] suggests methods to estimate the optimal cable size by minimising the sum of cable CAPEX and OPEX. In [6], [7], a multi-objective problem of this form is solved in a brute-force manner with the help of Pareto optimality [8], including also additional criteria, such as voltage drop and cable size rationalisation, to narrow down the possible combinations. The current rating calculation in each IAC is performed using the same standard series, estimating the cable size and consequently the CAPEX. The OPEX is also determined by the cable losses in terms of Net Present Value (NPV) given an electricity price, a discount rate and the project lifetime. However, it is generally recognised that the cable rating and losses as per the IEC standard may be underestimated and overestimated [9], [10], respectively. This might lead to questionable or even erroneous results with respect to the optimisation solution.

This paper extends the formulation of [6], [7] for radial networks and solves the multi-objective optimisation problem by employing more accurate analytic formulae, such as [11], [12] instead of the IEC standard, for the current rating and the calculation of losses in IACs. A bottom-up approach of the Pareto optimality is implemented to determine the optimum solution in a reasonable timeframe, even in cases of very large OWFs. Additional constraints are also included to confine the possible combinations, further enhancing the algorithm performance. The proposed method is demonstrated in a typical OWF case study. CAPEX-only and CAPEX-OPEX solutions are compared and the investment in the OWF project is evaluated in terms of the total cost during the entire operational lifetime. It is concluded that the latter solution may lead to a further reduction of the total cost. Finally, the use of the IEC standard for current rating and calculation of losses is also assessed, leading to the miscalculation of the economic figures.

PROPOSED METHOD

The proposed method is best described by the flowchart of Fig. 1. The algorithm starts with the insertion of various input data. Among them, the OWF layout is provided which includes the cable sections, their burial depth, the seabed properties as well as the required lengths and currents for each feeder string. A cable library is also introduced consisting of all cable cross-sections along with their CAPEX data from which the optimum solution is to be sought. Finally, the OPEX data are also provided given the cable anticipated lifetime, the OWF uptime and the annual discounting rate.

The flowchart continues by performing the current rating for all cable sections. This is mainly done based on the steady-state thermoelectric network of IEC 60287 Standard series, however, a revised version of [11] suitable for three-core IACs can be also employed, which yields more accurate current-dependent losses [9]. In more detail, the original methodology of [11] is applicable to SL-type cables, thus, slight modifications in the calculation routine are needed to consider the composite screen of IACs.

Then, the algorithm applies a series of constraints to narrow down the number of possible combinations. Based on the results of current rating, it discards all non-feasible choices due to excess in the conductor maximum temperature, which is set to 90 °C for cables with XLPE insulation. Due to logistic reasons, the algorithm can optionally exclude all combinations that surpass the maximum allowable number of different cross-sections. In addition, combinations with cross-sections that do not follow an ascending order along a feeder string with respect to DC resistance [13] can be also discarded.