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A comprehensive techno-economic analysis for optimally placed wind farms

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Abstract
Wind power project development investment is based on the separate technical and financial analyses. Based on the actual wind data, data-based wind distribution map and wake effect model, a combined techno-economic analysis is proposed in this paper. Starting from deriving the wind distribution map, a comprehensive analysis extending to the feasibility assessment of the project is presented here. The problem is formulated as the maximization of net present value of the project subject to the specified initial investment cost within a fixed area and turbine spacing constraints. Simultaneous optimization of the wind turbine size, hub height and placement is realized with BPSO-TVAC. Sensitivity analysis and Monte Carlo simulation are used to investigate the feasibility of the project, against various parameters, imposed on by the techno-economic constraints. Hypothesis testing with a confidence level of 99.99% corroborates the results obtained from Monte Carlo simulation. With scenario analysis, a positive NPV is identified even in the worst-case scenario, an attractive trait for investors. An ideal decision-making tool considering technical efficiency and profitability simultaneously is presented.

Keywords Wind turbines placement · Wake effect model · Particle swarm optimization · Technical and financial analyses · Monte Carlo Simulation · Hypothesis Testing

1 Introduction

Wind turbines generating electrical energy from wind are grouped/operated together as a wind farm in order to increase the power production with merits including lower costs of installation, operation and maintenance. As a conventional wind farm layout, wind turbines are placed in rows that are 8–12 rotor diameters apart in the windward direction and in columns of 3–5 rotor diameters apart in the crosswind direction as the rule of thumb [1]. However, the different wind characteristic at specific areas may increase the wind farm array loss due to the wake effect reducing wind speed at a downstream turbine. An optimal wind farm layout, designed with a particular wind data, could reduce the wake effects and maximize both the total wind energy extraction and financial benefits to wind farm developers compared to the conventional wind farm layout [2].

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Many layout optimization algorithms are available that can help to achieve the most efficient wind farm configuration that optimizes the placement of wind turbines, within a specific area, yielding higher power outputs with a denser and staggered layout. The optimal wind turbine placement is formulated as a combinatorial problem, using both analytical and heuristic optimization techniques, which determine the near-optimal wind turbine positioning in a wind farm. The location corresponding to the maximum energy production at the minimum cost is determined using the said formulation. Most studies apply heuristic search-based optimization algorithms including the genetic algorithm (GA) [3–7], evolutionary algorithm (EA) [6] and binary particle swarm optimization with time-varying acceleration coefficients (BPSO-TVAC) [8], but with the simplified wind data and turbine cost model.

Nonlinear mathematical programming approach utilizing the exact gradient information is developed to solve the continuous-variable wind farm layout optimization problem handling land-use constraints in [9]. Sequential convex programming (SCP) is employed to maximize the wind farm power production with a fixed large number of wind turbines in [10]. Both the heuristic methods in [3–8], as well