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A review and recent developments in the optimal wind-turbine micro-siting problem

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ABSTRACT

This paper presents a review of the current state of the art solutions to the problem of wind farm optimal design. The aim of this work is to present the problem by identifying the most relevant issues involved in the design of a wind farm, as well as to discuss the optimization techniques and wind farm models used in the published literature.

An appropriate wind turbine layout is vital in order to obtain adequate performance in relation to the exploitation and operation of the plant during its lifespan. There are several factors that influence wind farm design, chief among them are the calculation of the overall energy yield by the wind farm and the initial investment. The energy produced depends on the local wind conditions and the interference caused by wind turbines nearby. The investment is mainly related to wind turbine acquisition, civil works and electrical infrastructure. However, these are not the only items that influence the design of a wind farm since economic indicators, environmental issues, local regulations, or the presence of wind farms should also be taken into account when deciding the design of the wind farm.

Even in the case of the most simplified objective function (maximizing the annual energy produced) the optimization problem cannot be solved by classical optimization techniques. To cope with this problem, most authors have used meta-heuristics techniques which have proved to be efficient when searching for the optimal solution to this problem.

The purpose of this paper is to review previous work by offering a clear outline of the latest advances, as well as to highlight the main aspects which need to be taken into account when tackling the wind farm design problem. In addition, in a conclusion of the review, future needs have been identified.

Contents

Abbreviations: ACO, ant colony algorithm; AEP, annual energy produced; CFD, computational fluid dynamics; CMA-ES, covariance matrix adaptation evolution strategy; GPSO, Gaussian particle swarm optimization; GA, genetic algorithm; HV, high voltage; LCOE, levelized cost of energy; *LPC*, levelized production cost; MV, medium voltage; *NPV*, net present value; PSO, particle swarm optimization; SPEA, strong Pareto evolutionary algorithm; WF, wind farm; WT, wind turbine.

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1. Introduction

This paper reviews the optimal wind turbine micro-siting problem, offering a survey of the relevant technical literature published on the latest developments on this issue.

Although most existing research focuses on the optimization of onshore wind farms, the optimization techniques and the process of assessing the annual energy produced by the wind farm can be applied to offshore plants with minor variations. The main difference is in the model used for calculation of the initial investment, which must be tailored for the case of offshore wind farms (OWFs).

The first step to be taken when planning a wind farm (WF) is the site selection whereby several factors must be taken into account, which include: the wind resource, land availability, environmental conditions, possibility of connection to the electrical transmission system, and proximity to access roads. This issue has been addressed and solutions have been offered in several papers [1–4] which enable the conditions necessary for the implementation of a wind project on a particular plot of land to be established.

After selecting the plot, the next step consists of solving the problem studied in this work, i.e., the optimal selection of the geographical location of each individual wind turbine (WT). Although there are currently several examples of commercial software available that enables the design of a WF to be undertaken, the problem is usually tackled by experts or consultants by following a set of guidelines, which ensures a minimum level of production. The general trend (in the case of onshore WFs) has been to iteratively place the WTs in positions where the wind potential is the greatest, whilst observing a given distance between WTs in the prevailing wind direction in order to prevent any excessive wake effect (when a wind turbine captures part of the kinetic energy of the wind that goes through its rotor, it extracts a certain amount of it from the wind flow, generating a wake of wind that is slower and more turbulent in the rear area). In offshore WFs, the general trend has been to place the WTs in regular structures, whilst maintaining a greater distance between those WTs affected by the prevailing wind direction.

However, several studies show that such configurations are not necessarily optimal in terms of total energy and final profitability of the project [5–12]. This lack of optimality is mainly due to the wake effect, since in a wind farm composed of a cluster of turbines, this disturbance causes the wind speed field to be highly dependent on the position of each individual WT. This can be observed in Fig. 1, where the following arrangements of the Middelgrunden offshore wind farm [7] are shown: (a) the actual layout of the wind turbines; (b) a symmetrical optimized layout, and (c) an irregular optimized layout. According to [7], the layouts shown in (b) and (c) would provide an increase in the annual energy produced (AEP) of 5% and 6%, respectively. Obviously, this improvement in AEP would have significant consequences in terms of annual revenue and hence on the profitability of the project. The attention paid to optimization techniques applied to the problem of the micro-positioning of WTs on a wind farm is therefore justified.

The AEP is not the only factor to take into account when undertaking the design of a WF, since it is also necessary to consider other factors, such as the initial investment of the project, (which depends, for an onshore WF, on aspects such as acquisition of WTs, electrical infrastructure, access roads, and foundations, among others), and issues that influence the annual cash flow, such as maintenance and operation costs, and electrical losses. Furthermore, in order to financially evaluate the project, it is necessary to ascertain several economic variables, such as the sale price of energy and the evolution of the interest rate. In Fig. 2, an overview is presented of those diverse factors and relationships that must be borne in mind when undertaking the design of a WF. All these factors lead to the involvement of extremely complex mathematics in the solution for the optimal micro-siting of WTs.

Furthermore, the design of WFs is not only subject to internal factors but it can also depend on the design of other nearby WFs. When designing a wind power plant, conflicting situations involving other nearby projects have to be taken into account. These conflicting

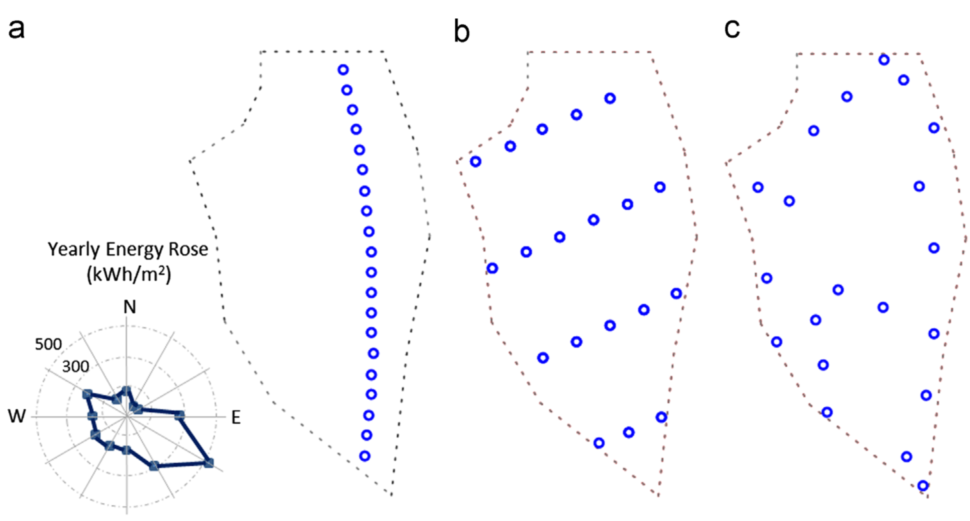

Fig. 1. Layout of the Middelgrunden offshore wind farm: (a) actual, (b) optimized with symmetrical constraints, (c) optimized [7].