Energy 183 (2019) 983–995

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Wind farm layout optimization for wake effect uniformity

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ARTICLE INFO

Article history:
Received 6 April 2019
Received in revised form
18 June 2019
Accepted 2 July 2019
Available online 4 July 2019

Keywords:
Wind energy
Wind farm layout optimization
Simulated annealing algorithm
Energy maximization
Wake effect uniformity

ABSTRACT

The basic objective of wind farm layout optimization is to maximize the energy produced by wind farms. However, when wind turbines are arranged in a limited space like an onshore wind farm, specific wind turbines may have greater wake exposure than other wind turbines. This phenomenon can be conspicuous in a mixed layout that consists of turbines with different capacities and hub heights. In this study, we developed and tested a new objective function to increase wind farm energy output while making the wake loss of each wind turbine uniform. The purpose of this function is to adjust the wake effects of all of the wind turbines on a wind farm to similar levels, thereby promoting the operational stability of all of the wind turbines. Layout optimization was performed using a simulated annealing algorithm, which is a heuristic method, with actual wind conditions for an existing wind farm in operation. Then, the results obtained using the proposed method were compared with those yielded by layout optimization for energy maximization. The layout generated using the proposed objective function had lower energy output than that obtained by energy maximization. However, this difference was small and the proposed method prevented wake effect concentration on specific turbines by making the wake effect levels uniform.

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1. Introduction

The main objective in wind farm design is energy output maximization. To achieve this objective, the losses must be minimized while maximizing the energy generated by the wind farm. The greatest losses are called wake losses, which are caused by wakes and result from the mutual interference between wind turbines. As wind consumes energy while passing through the rotor of a wind turbine, its speed is lower behind the turbine, which decreases the outputs of other downstream wind turbines [1]. Furthermore, an arrangement of wind turbines in a row along the wind direction causes additional wind speed and power output reduction. These reductions of wind speed and energy output are related to the problem of how to arrange wind turbines on a wind farm. To solve this problem, an effective wind farm layout is required to minimize the wake losses [2].

To minimize the wake losses, the turbines must be arranged considering the directions of all of the winds around the wind farm. However, numerous layout options are necessary for this purpose, making determination of the optimal wind turbine layout an extremely difficult task. The problem becomes more complicated if constraints present when turbines are actually arranged are considered, such as the presence of power cables, development-prohibited areas, and geographical characteristics.

As shown in Table 1, many studies have been conducted from the 1990s until recently to solve the problem of wind farm layout optimization (WFLO). The first report was published in 1994 by Mosetti et al. [3], who addressed the WFLO problem using a GA based on a discrete model. Mosetti et al. assumed and applied three simple wind conditions, which are different from those in actual situations, but nonetheless demonstrated the applicability of an optimization algorithm to solve the WFLO problem. After that, WFLO research ceased, but it started again in the mid-2000s. In 2004, Ozturk et al. [4] published a report on wind turbine layout optimization using a GHA. Grady et al. [5] investigated the same example as Mosetti et al. by employing a GA that introduced a subpopulation and compared the results. Marmidis et al. [6] introduced MCS, and Rivas et al. [7] conducted a study on WFLO

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https://doi.org/10.1016/j.energy.2019.07.019
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