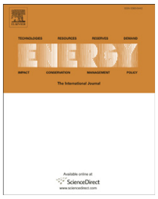
Energy 80 (2015) 361–372

Contents lists available at ScienceDirect

Energy

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



Wind wake influence estimation on energy production of wind farm by adaptive neuro-fuzzy methodology

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ARTICLE INFO

Article history:
Received 5 May 2014
Received in revised form
27 November 2014
Accepted 29 November 2014
Available online 6 January 2015

Keywords:
Wind energy
Wake wind speed
Wake model
Wake effect
ANFIS (adaptive neuro-fuzzy system)

ABSTRACT

Dissection of the power output in a row of working turbines and the reliance on wind course in respect to the column heading is examined. The point is to portray the extent of the wake impacts and give a sign of the indication of wind bearing. The target is to delineate whether the uniting of wakes inside extensive wind homesteads can be depicted by basic direct models or whether the consideration of the two-route collaboration between the wind turbines and the limit layer is a fundamental essential for precise models of wakes to be utilized within future wind farm plan. Soft computing methodologies may be utilized as substitute for analytical approach since they provides some benefits such as no need to information of internal system parameters, compact solution for multi-variable problems. This investigation dealt with application of ANFIS (adaptive neuro-fuzzy inference system) for predicting the wake power and wind speed deficit. To provide statistical analysis, RMSE (root mean square error), coefficient of determination (R^2) and Pearson coefficient (r) were utilized. The study results suggested that ANFIS would be an efficient soft computing methodology to offer precise predictions of wake wind speed deficit and power deficit ratio in wind farms. According to the achieved results, the best prediction was observed for free wind speed of 8 m/s. The RMSE, R^2 and r were computed as 0.0763, 0.9893 and 0.9946 for ANFIS prediction of wake wind speed deficit and as 0.0128, 0.9967 and 0.9984 for ANFIS prediction of power deficit ratio.

1. Introduction

Wind turbines extract energy from the wind to generate electricity. Hence, the wind behind the wind turbine will have lesser energy compared to the wind in front of the wind turbine. In other words, the wind downstream of wind turbines has reduced speed. This downstream wind is the wake of the turbine. In case, a wind turbine positioned in the wake of another turbine, it will generate lower electricity compared to undisturbed wind turbines.

Formation of a wake has some negative consequences such as reducing the wind speed which subsequently decline the level of energy generated by the wind farm as well as amplifying the turbulence intensity which increase the dynamic mechanical loading on downwind turbines. In order to explain a wake, a substantial number of numerical methods have been suggested so far. González-Longatt et al. [1] developed a simplified model to appraise the influence of wake on steady-state and dynamic behaviors of two wind farms. Song et al. [2] suggested a particle model to consider the wake flow as virtual particles produced by the wind turbine blades. It was found that the proposed model shows further accuracy on flat terrain compared to the previous linear model. Vermeer et al. [3] studied the aerodynamics of horizontal axis wind turbine wakes for two near and far wake regions. Makridis and JohnChick [4] by means of Fluent software developed a CFD model to investigate the wind turbine wakes and the neutral atmospheric wind flow over complex terrain. Crasto et al. [5] utilized the concept of actuator disc for modeling the wakes of wind turbines. Mo et al. [6] performed Large eddy simulation to identify the wake characteristics. They compared the results experimental results of wind turbines. Precise prediction of power losses from wind turbine wakes in large wind farms has not conducted conclusively. Even though,

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http://dx.doi.org/10.1016/j.energy.2014.11.078
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there exist several approaches for modeling the power losses raised by wind turbine wakes in large wind farms, further appraisal and enhancement is still requisite. Absence of reliable and proper data for assessment, limited application of evaluation metrics to measure the models' capability as well as imperfect efforts made at attribution of models error are the most notable issues which have provided limitation on models enhancement.

It is evident that wake of wind farm models have not been evaluated for very large wind farms. Since the combination of single wakes is the current approach to modeling wakes within offshore wind farms, there is major uncertainty in these predictions of wake interactions.

This paper introduces an examination focused around a lot of information from an extensive wind farm in operation. Investigation of the power yield consecutively of working turbines and the reliance on wind course in respect to the column bearing is examined. The point is to depict the greatness of the wake impacts and give a sign of the indication of wind heading. A piece of the paper includes improvement of a model focused around the systematic arrangements of wake advancement portrayed by a few routines. The destination is to show whether the combining of wakes inside huge wind ranches can be portrayed by straightforward direct models or whether the incorporation of the two-route cooperation between the wind turbines and the limit layer is a fundamental essential to precise modeling of wakes for utilization as a part of future wind homestead plan.

Physical modeling of wake effects in large wind farm demands high costs to model the prototype and requires extensive work in the laboratory [7]. For the first time, this paper presents and compares the results of wake wind speed deficit and power deficit ratio prediction in large wind farm using soft computing methodology; to date, no such work has been carried out in this area.

Recently, soft computing techniques such as SVR (support vector regression) with mimetic algorithm has gained importance in electrically load forecasting issue [8]. An application of soft computing by combining different approaches including wavelet and firefly algorithms as well as fuzzy ARTMAP to predict day-ahead electricity price was presented in Ref. [9]. Prediction of short-term load of power systems was conducted in Ref. [10] by developing a hybrid wavelet transform with neuro-evolutionary model. In study [11], a novel modeling framework integrating BEMD (bivariate empirical mode decomposition) and SVR (support vector regression), extended from the well-established EMD (empirical mode decomposition) based time series modeling framework in the energy demand forecasting literature, was proposed for interval forecasting of electricity demand. The correctness of a soft computing model is to a great extent relies on determination of its model parameters. Although organized strategies for selecting parameters are important, model parameter alignment also need to be made. Computational complexity is a major drawback of wake modeling approaches in large wind farm.

In this paper, a soft-computing methodology (adaptive neuro-fuzzy inference system - ANFIS (application of adaptive neuro-fuzzy inference system)) [12] has been proposed for wake wind speed deficit and power deficit ratio prediction in wind farm according to wind turbine row number in wind farm and wind direction and for three free wind speeds: 6 m/s, 8 m/s and 10 m/s. The proposed ANFIS model is obtained with the combination of the two methods, neural network and fuzzy logic. The neural network searches the optimal parameters for fuzzy logic membership functions thus giving more reliable and accurate forecasts. The suggested combination of methodologies is new and unique which boost the capability of the suggested model compared to those models previously presented in the literature. The ANFIS models are designed based on experimental data and three analytical methods of calculating the wake effect: N.O. Jensen [12], Eddy Viscosity Model [13–16] and G.C. Larsen [17,18]. In other words the ANFIS model should estimates average wake power deficit in wind farm based on the established analytical models.

2. Materials and methods

Power losses because of turbine wakes in extensive offshore wind farms are anticipated by condition of-the-craftsmanship models to be of the request 10–20% and thus is a critical segment of the general money making concerns of these wind ranches. To build the understanding of the wake impacts from substantial wind farms various undertakings are currently being completed with the reason for depicting and evaluating wakes. Owing to the fact that economical aspect is a crucial driver in this venture, an improved capacity to anticipate wake losses would certainly augment the viability of expansive wind farms.

Power losses raised by wakes were examined on the basis of observations from wind farm depicted schematically in Fig. 1. The wind farm data were utilized to appraise all models to the parameterization of wake addition/expansion as the wake develops directly down a row of wind turbines.

The adapted databases are utilized to determine the downstream influence of several wind farms, and screen the in-park wake impacts. In parallel to the information examination, wind farm models are certainly created and assessed. The wake models include many variables such as the turbine introduction and separating, wind atmosphere as well as turbine sort.

2.1. Wake effect models

Whenever, the turbine concentrates power from the wind, a wake is developed downstream of the turbine. Provided that an alternate adjacent turbine is working inside this wake, the power generated from this downstream turbine is declined in comparison to the turbine working in the free wind. The obtained loss of power which is typically in the range 2%–20% is contingent upon a series of factors including the wind dispersion, the wind turbine attributes and the wind ranch geometry.

The turbines operating in the wake flow of others are confronted with a diminished wind speed as well as expanded element stacking emerging from the expanded turbulence incited by the upstream turbines. This expanded turbulence should be considered, when selecting a suitable class of turbine. In case of having different turbines, the achieved results by the single wake simulation are amassed into a consolidated come about by utilizing exact consolidation standards.

2.2. Parameters required for modeling the wake

The wake models require distinctive inward wake model parameters as info and a shifting number of extra parameters depicting the landscape and wind atmosphere conditions. Info parameters for a wake model may usually be turbulence force and harshness length. Commonly, such parameters are dependent upon the harshness class (or roughness length). Table 1 suggests corresponding estimated wake model parameters [19–21].

2.3. N.O. Jensen wake model

The N.O. Jensen wake model, which is based upon the assumption of a linearly expanding wake diameter, is a simple single wake model [12]. Fig. 2 schematically illustrates the overview of N.O. Jensen wake model which it is seen that the wake is expand linearly with downstream distance, *X*. There is a