Electrical Power and Energy Systems 63 (2014) 618–624

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

An appraisal of wind turbine wake models by adaptive neuro-fuzzy methodology

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ARTICLE INFO

Article history:
Received 27 April 2014
Received in revised form 4 June 2014
Accepted 13 June 2014

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

ABSTRACT

Production losses and increased turbine loadings are observed in wind farms, when wind turbines interact with each other. If a wind turbine is located in the wake of another one, its incoming flow is disturbed, slowed down, and its potential wind power is decreased. It is therefore necessary to study the wind turbine wakes and their interactions. It is important to consider these wake effects in the design of a wind farm in order to maximize the energy output and lifetime of the machines. The exact modeling of the wind speed distribution within a wind park is a fairly complicated task and many of the necessary parameters are not routinely available. A large number of studies have been established concerning the calculation of wake effect. Even though a number of mathematical functions have been proposed, there are still disadvantages of the models like very demanding in terms of calculation time. Artificial neural networks (ANN) can be used as alternative to analytical approach as ANN offers advantages such as no required knowledge of internal system parameters, compact solution for multi-variable problems and fast calculation. In this investigation adaptive neuro-fuzzy inference system (ANFIS), which is a specific type of the ANN family, was used to predict the wake power deficit. Neural network in ANFIS adjusts parameters of membership function in the fuzzy logic of the fuzzy inference system (FIS). This intelligent algorithm is implemented using Matlab/Simulink and the performances are investigated. The simulation results presented in this paper show the effectiveness of the developed method.

Introduction

Wind turbines separate vitality from the wind to transform power. In this manner, the wind leaving the turbine must have a more level vitality content than the wind upstream of the turbine. As an outcome, the wind downstream of a wind turbine has diminished pace and is turbulent. This downstream wind is the wake of the turbine. As the wind stream returns further downstream this wake will start to spread and step by step come back to free stream conditions. In the event that a wake meets with the cleared region of a downwind turbine the downwind turbine is said to be shadowed by the turbine handling the wake.

The two fundamental impacts of a wake are: a decrease in the wind speed, which thusly diminishes the vitality generation of the wind ranch and an expand in the turbulence of the wind, conceivably expanding the element mechanical stacking on downwind turbines. A large number of numerical models, of varying complexity, have been developed to describe a wake. In paper [1] was evaluated the impact of the wake of a wind farm and provided conclusions that can be used as thumb rules in generic assessments where the full details of the wind farms are unknown. Results for two wind farm layouts were presented to illustrate the importance of wind turbine spacing and the directionality of wind speeds when assessing the wake effect. A particle model for calculating turbine wake flow during the optimization of wind farm micro-siting was presented in [2]. This model treats the wake flow as virtual particles generated by the turbine rotor. On flat terrain, the proposed particle model fits the experimental data better than the previous linear model. Experimental results on the unsteady behavior of the wake of a modeled wind turbine in an atmospheric boundary layer (ABL) wind tunnel were presented in

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http://dx.doi.org/10.1016/j.ijepes.2014.06.022
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[3]. This study has used mainly an indirect approach to show that the wake meandering is certainly inextricably linked to the large turbulent eddies. Accurate prediction of ABL flow and its interactions with wind turbines and wind farms is critical for optimizing the design (turbine siting) of wind energy projects [4]. The aerodynamics of horizontal axis wind turbine wakes was studied in [5]. The contents was directed towards the physics of power extraction by wind turbines and reviews both the near and the far wake region. Wind turbine wakes and the neutral atmospheric wind flow over complex terrain were investigated in paper [6] using the Computational Fluid Dynamics software Fluent. An actuator disc model based on the Blade Element Theory is implemented for the simulation of the rotor effects. An actuator disc concept was applied in [7] to model the wakes of wind turbines. Large Eddy Simulation on the turbulent wake characteristics behind wind turbine was performed in [8] to achieve a better understanding of the wind turbine wake formation and propagation. The results provide sufficient evidence that the predictions of the wake characteristics behind the wind turbine are accurate, since the aerodynamic characteristics of the blade are closely related to the wake characteristics. A Large Eddy Simulation of wind turbine, with uniform inlet conditions, was carried out in [9] in order to analyze and better understand the turbulent characteristics of the wake, its instability and its consequent breakdown behind the wind turbine. Accurate prediction of power losses from wind turbine wakes in large wind farms remains elusive. At present there are a number of approaches to modeling power losses due to wind turbine wakes in large wind farms that range in complexity, but all require further evaluation and refinement. Significant issues limiting the improvement of models are the lack of appropriate data for evaluation, limited application of evaluation metrics to quantify model skill and very limited attempts at attribution of model error. Paper [10] outlined some of the issues involved in using different types of data for evaluating wind turbine wake modeling and shows how these data can be used to characterize wake properties using examples based on data from the open access Virtual Wakes Laboratory. The paper also described some of the issues involved in using data to evaluate models, with a focus on wake width. The properties of the wake behind a three-blade rotating wind turbine and behind a porous disc generating a similar velocity deficit were compared through wind tunnel experiments in [11]. The goal was to determine whether the use of a simple model as a porous disc (based on the actuator disc concept) to reproduce the wind turbine far wake is satisfactory. Even though a number of mathematical functions have been proposed for modeling the wake effect is wind farm, there are still disadvantages of the models like very demanding in terms of calculation time. Artificial neural networks (ANN) can be used as alternative to analytical approach as ANN offers advantages such as no required knowledge of internal system parameters, compact solution for multi-variable problems and fact calculation.

In this investigation adaptive neuro-fuzzy inference system (ANFIS) [12–15], which is a specific type of the ANN family, was used to predict the wake power deficit in wind farm. For the presently developed neural network, the terrain characteristic was used as input. The ANFIS model is designed based on three analytical methods of calculating the wake effect: N.O. Jensen [16], Eddy Viscosity Model [17–20] and G.C. Larsen [21,22]. In other words the ANFIS model should estimates average wake effect power deficit in wind farm based on the established analytical models.

ANFIS indicates great taking in and expectation competencies, which makes it an effective device to manage experienced instabilities in any framework. ANFIS, as a hybrid intelligent system that enhances the ability to automatically learn and adapt, was used by researchers in various engineering systems [23–29]. There are many studies of the application of ANFIS for estimation and identification of many different systems [30–38].

Wake effect models

At the point when the turbine concentrates power from the wind, a wake develops downstream of the turbine. In the event that an alternate close-by turbine is working inside this wake, the force yield for this downstream turbine is lessened when contrasting with the turbine working in the free wind. This decrease of force yield is normally in the extent of roughly 2–20%, relied on upon the wind appropriation, the wind turbine aspects and the wind ranch geometry.

The turbines working in the wake are subjected to a diminished wind speed as well as expanded element stacking emerging from the expanded turbulence incited by the upstream turbines. This expanded turbulence must be accounted, when selecting a turbine suitable class of turbines. While having different turbines, the results from the single wake models are totaled into a consolidated come about by utilizing exact mix guidelines.

Parameters of wake model

The wake models require diverse inside wake model parameters as data and in addition a differing number of extra parameters depicting the landscape and wind atmosphere conditions. Info parameters to a wake model could be turbulence force and unpleasantness length. Commonly, one would expect that such parameters are relied on upon the unpleasantness class (or harshness length). Table 1 suggests corresponding estimated wake model parameters.

NO Jensen wake model

The N.O. Jensen wake model is a single wake model [16]. The model is based on the assumption of a linearly expanding wake diameter. Fig. 1 shows an overview of the wake model.

The reduced wind speed u_0 of downwind of the turbine then calculating the velocity deficit is derived from:

$$1-\frac{u_0}{u}=(1-\sqrt{1-C_T})/(1+2kX/D)^2 \tag{1}$$

where

D is the rotor diameter.

C_t the thrust coefficient.

It is not the actual wake wind velocity, but rather the velocity deficit $\delta u_i = (1-u_i/u_0)$. The velocity deficit is defined through the effective free wind speed, u_0.

Different wakes are ascertained through the whole of squares of speed shortages wake combo model. The combined effects of multiple wakes are found as:

$$\delta u_n=\sqrt{\sum_{k=1}^{n-1}\delta u_{kn}} \tag{2}$$

Eddy viscosity model

The wind turbine wake requisition of an axi-symmetric plan of the time found the middle value of Navier Stokes mathematical statements with a vortex thickness conclusion was at first made in [17]. The provision utilizes round and hollow directions and a supposition of incompressible liquid. A graphical review of the model setup is appeared Fig. 2.