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Wind farm efficiency by adaptive neuro-fuzzy strategy

Dalibor Petković *, Nenad T. Pavlović, Žarko Ćojbašić

University of Niš, Faculty of Mechanical Engineering, Department for Mechatronics and Control, Aleksandra Medvedeva 14, 18000 Niš, Serbia

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ABSTRACT

A wind power plant which consists of a group of wind turbines at a specific location is also known as wind farm. The engineering planning of a wind farm generally includes critical decision-making, regarding the layout of the turbines in the wind farm, the number of wind turbines to be installed and the types of wind turbines to be installed. Two primary objectives of optimal wind farm planning are to minimize the cost of energy and to maximize the net energy production or to maximize wind farm efficiency. In the design process of a wind farm the aerodynamic interactions between the single turbines have become a field of major interest. The upwind turbines in a wind farm will affect the energy potential and inflow conditions for the downwind turbines. The flow field behind the first row turbines is characterized by a significant deficit in wind velocity and increased levels of turbulence intensity. Consequently, the downstream turbines in a wind farm cannot extract as much power from the wind as the first row turbines. Therefore modeling wind farm power production, cost, cost per power unit and efficiency is necessary to find optimal layout of the turbines in the wind farm. In this study, the adaptive neuro-fuzzy inference system (ANFIS) is designed and adapted to estimate wind farm efficiency according to turbines number in wind farm. This soft computing methodology 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 energy is a promising renewable energy resource to help overcome global warming and environmental pollution from the use of fossil fuel. Renewable energy sources are the greatest resource for this purpose. The world's fastest growing renewable energy source is the wind energy [1]. Wind turbines are machines which convert the wind energy to the electricity [2]. Rapid advances in technical aspects and materials lead to an increase in size and output of the produced power [3]. A problem is in wind turbine sizing and choosing the optimal configuration of the turbine's parts [4]. Merely, by considering technical aspects, the best turbine is the most efficient one, which has the highest coefficient of energy or capacity factor [5]. However, taking economic aspects into account can modify the optimum size and design. Rotor radius, generator capacity and hub height are the most influential sizing parameters of the turbines. However, some limitations are available for their relationship and ratios. It may vary from site to the site and will be a function of the wind speed distribution at a given site.

Wind farms composed of large capacity wind turbines are main electrical energy sources. The modeling and simulation of the complete model of a wind farm with high number of wind turbines suppose the use of a high-order model and a long computation time if all the wind turbines are modeled. In order to reduce the model order and computation time, equivalent models was developed to represent the collective response of the wind [6]. These models are based on aggregating wind turbines into an equivalent wind turbine. As wind turbines become larger, wind farm layout design becomes more important. In [7] authors was enabled simultaneously optimization of the placement and the selection of turbines for commercial-scale wind farms that are subject to varying wind conditions. Among several wind farm layout design factors, wind turbine arrangement according to separation distance is one of the most critical factors for power output, annual energy production, availability, and life time of the wind turbine. Article [8] showed the effect of separation distance between two turbines and it was found to be crucial for the conceptual design of a wind farm layout. Therefore, during wind farm layout design, separation distance and interaction between wind turbines must be carefully considered because they are directly connected to the initial investment cost, payback period and economic efficiency. In article [9] the characteristics of turbine spacing for

* Corresponding author. Tel.: +381 60146266763.
E-mail address: dalibortc@gmail.com (D. Petković).

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optimal wind farm efficiency were investigated using combined numerical models. The results showed that the spacing between the first and the second turbines had the importance to the entire farm's efficiency. Efficiency and effectiveness of wind farms as keys to cost optimized operation and maintenance were analyzed in [10]. In [11] authors focused on the site specific optimization of wind turbines by minimizing cost of electricity production. The study utilizes the complete and comprehensive capital cost model for wind turbines plus technical aerodynamic model based on blade element momentum theory with twenty blade elements. In article [12] was measured the productive efficiency of a group of wind farms during the period 2001–2004 using the frontier methods Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA).

The objective of the present study is to analyze relationship between wind farm efficiency, power production, cost, cost per power unit and the number of wind turbines in wind farm. Aiming at optimizing such systems to ensure optimal functioning of the wind farm, new techniques are used today such as the fuzzy logic (FL) [13], artificial neural network (ANN) [14] and neuro-fuzzy [15].

Artificial neural networks are adaptable demonstrating apparatuses with proficiencies of taking in the numerical mapping between data and yield variables of nonlinear frameworks. A standout among the most compelling sorts of neural system framework is adaptive neuro-fuzzy inference system (ANFIS) [16]. ANFIS indicates great taking in and expectation competencies, which makes it a proficient device to manage experienced vulnerabilities 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 [17]. There are numerous investigations of the provision of ANFIS for estimation and ongoing distinguishing proof of numerous distinctive frameworks [18].

The key objective of this examination is to create an ANFIS for estimation of the wind farm efficiency. An endeavor is made to recover association between wind farm efficiency in regard to number of wind turbines. The training experimental data will be extracted by an analytical, closed-form wake model [19] which quantifies the aerodynamic interaction between turbines.

Materials and methods

Wind farm efficiency model

Analytical wake model named as Jensen's wake model [20] is chosen in the study, since energy is considered as saved inside the wake by this model. The wake grows straightly with downstream separation. In this manner, this model is suitable for the far wake locale. The wake has a sweep, at the turbine which is equivalent to the turbine range R_r while, R_1 is the radius of the wake in the model. $R_1$is considered as radius of the downstream wake; the relationship between R_1 and X is that downstream distance when the wake spreads downstream the radius R_1; that increases linearly proportional, X. The wake extends directly with downstream separation, as expressed in Jensen's model as demonstrated in Fig. 1.

Following equation was used to determine the wind speed after wind turbine rotor as it shown in Fig. 1:

$$u = u_0 * \left(1 - \frac{2a}{1 + \alpha\left(\frac{X}{\left(R_r\sqrt{\frac{1-a}{1-2a}}\right)}\right)^2}\right) \quad (1)$$

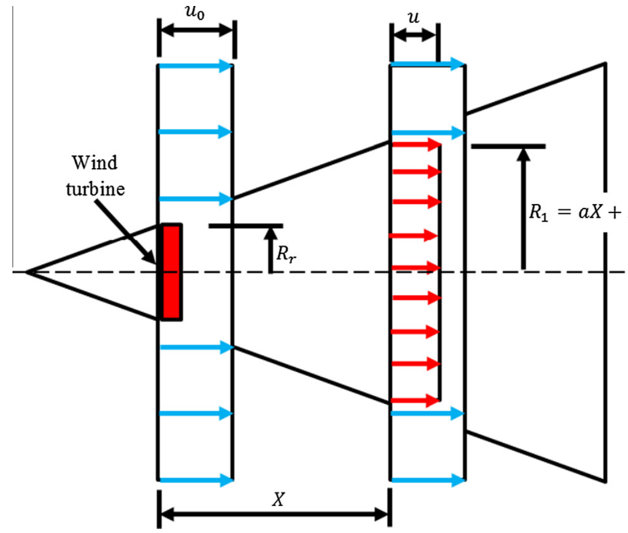

Fig. 1. Schematic of wake model.

In Eq. (1) we have:

- u_0 is the mean wind speed or which might be clarified as the free stream wind speed and in this study was utilized u_0 = 12 m/s,
- axial induction factor is denoted by a which can be calculated from the C_T, thrust coefficient. This can be determined from the equation:

$$C_T = 4a(1-a)$$

- X is the distance downstream of the turbine, while R_1 is related with R_r as represented using following equation:

$$R_1 = R_r\sqrt{\frac{1-a}{1-2a}}$$

- α is the entertainment constant and by using the following equation:

$$\alpha = \frac{0.5}{\ln\frac{z}{z_0}}$$

In the above equation, z is used to denote the hub height and roughness of the surface is denoted by z_0. The value for surface roughness varies from field to field. For plain terrains the value for z_0 = 0.3.

The accessible wind power could be computed by utilizing the accompanying comparison:

$$P_a = \frac{1}{2}\rho A u^3 \quad (2)$$

If the power production from each wind turbine contains the efficiency η of wind turbine then the following equation for the energy or power generated from a wind turbine can be used:

$$P_p = \eta\frac{1}{2}\rho A u^3 \quad (3)$$

If that the efficiency of wind turbines is equal to 40%, then the equation will be:

$$P_p = \frac{40}{100}\frac{1}{2}\rho A u^3 \quad (4)$$

In the above equation A represents cover surface of the turbine blades during rotation and it is $A = \pi 40^2$ since the used rotor radius in the study is R_r = 40 m, and ρ = 1.2. The following equation will be derived: