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Adaptive neuro-fuzzy estimation of building augmentation of wind turbine power

Dalibor Petković [a], Shahaboddin Shamshirband [b,*], Žarko Ćojbašić [a], Vlastimir Nikolić [a], Nor Badrul Anuar [c], Aznul Qalid Md Sabri [e], Shatirah Akib [d]

[a] *University of Niš, Faculty of Mechanical Engineering, Department for Mechatronics and Control, Aleksandra Medvedeva 14, 18000 Niš, Serbia*
[b] *Department of Computer Science, Chalous Branch, Islamic Azad University (IAU), 46615-397 Chalous, Mazandaran, Iran*
[c] *Department of Computer System and Technology, Faculty of Computer Science and Information Technology, University of Malaya, 50603 Kuala Lumpur, Malaysia*
[d] *Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia*
[e] *Department of Artificial Intelligence, Faculty of Computer Science and Information Technology, University of Malaya, 50603 Kuala Lumpur, Malaysia*

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ABSTRACT

Wind power is generating interest in many countries as a way to produce inexpensive and sustainable electrical power. Building integrated wind turbines (BIWTs) are an interesting option in this respect. BIWTs are low cost renewable sources of energy. Since the power in wind is proportional to the cubic power of the wind velocity approaching the wind turbine, a small amount of wind speed acceleration leads to a large increase in energy output. To augment free wind speed streams, the open area between two buildings can be used as diffuser by taking advantage of the Venturi effect. A system where two buildings are used to increase the winds kinetic energy is called building augmented wind turbine (BAWT). This article shows that the shape of buildings can be changed to maximize the power generated by wind and power augmentation. To estimate building power augmentation using a simplified turbine model, this paper constructed a process that simulated the augmented power and wind velocity in regard to different building geometries using an adaptive neuro-fuzzy (ANFIS) method. This intelligent estimator was implemented using MATLAB/Simulink. The simulation results presented in this paper demonstrated the effectiveness of the method developed in this study.

1. Introduction

The use of renewable and clean energy has become a very important issue. Wind energy is one of the fastest utilizing energy sources. The power generated by the wind is proportional the velocity of the free stream, cubed. In order to take higher power outputs from the free wind stream, a suitable system must be constructed to increase its flow velocity [1–3]. Enclosing a wind turbine in a specially designed shroud will increase its output power [4,5] as demonstrated by several researchers [6,7]. In urban environments, shrouding, or using diffuser augmentations on horizontal wind turbines [8] are one way to improve their performance [9,10].

Generating energy from the wind in an urban environment is a worthwhile endeavor, but [11,12] there are significant challenges implementing it on a large scale [13,14]. In urban environments, the wind is usually insubstantial, inconsistent, and erratic in terms of direction and speed [15,16], because of the presence of buildings and other nearby obstructions. To create a reasonable amount of energy from a wind turbine located in urban environments, the turbines must increase the amount of energy they capture [17,18]. In other words, turbines must be designed to work effectively in areas with poor wind resources [19,20].

The ducted wind turbine (DWT) is a recent improvement that may lead to the development of a new paradigm [21–23]. The DWT is a small device that can be incorporated into a building to produce power through wind energy conversion [24–26]. The ducted wind turbine overcomes many of the issues related to the of conventional wind turbines in urban environments [27–29] were the generation of wind power is hindered by high levels of air stream turbulence and are constrained by concerns over their visual impact, the noise they make, and public safety [30].

The current trend is to incorporate wind turbines in the structure of a building or above it. Wind turbines that are incorporated within a building are described as being building integrated wind turbines (BIWTs) [31–33]. The size of urban turbines is constrained by the space available, which makes them less viable than their larger standalone counterparts [34]. One way to combat size constraints is to increase power by increasing the kinetic energy

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* Corresponding author. Tel.: +60 146266763.
E-mail address: shamshirband1396@gmail.com (S. Shamshirband).

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of the air. One method for increasing the kinetic energy of the air is to accelerate velocity by forcing air s through a duct and a turbine by means of a pressure drop between two buildings. The increased wind velocity that occurs between buildings is known as the Venturi effect. Many researchers are using the Venturi effect to increase the kinetic energy of the wind to drive smaller turbines. A system where two buildings are used to increase the kinetic energy of the wind is called a building augmented wind turbine (BAWT) [35–37].

In this study, various building geometries and their effects on power augmentation with a simplified turbine model were analyzed. Since computational fluid dynamics (CFD) for all building geometry parameters would be very challenging and time consuming, soft computing techniques were preferred in this study to estimate power and wind velocity augmentations. This study used soft computing methodologies, such as an adaptive neuro-fuzzy inference system (ANFIS) to estimate the augmented building power and wind velocity. At the same time, the augmented power density of a simplified turbine model was calculated.

Artificial neural networks are flexible modeling tools with the capability of learning the mathematical mapping between input and output variables of nonlinear systems. An adaptive neuro-fuzzy inference system (ANFIS) is a powerful neural network system [38]. It excels learning and predicting and it is an efficient tool for dealing with uncertainties in any system. ANFIS is a hybrid intelligent system that enhances the ability to automatically learn and adapt. It was used by researchers in various engineering systems [39–41]. Currently, there are many studies regarding the application of ANFIS for estimating and real-time identification of many different systems [42–44].

A Fuzzy Inference System (FIS) is at the heart of ANFIS. FIS is based on 'IF–THEN' rules and can be used to predict the behavior of uncertain systems. The advantage of FIS is that it does not require any knowledge of the underlying physical processes as a precondition for its application because ANFIS integrates the FIS with a back-propagation learning algorithm provided by the neural network.

The primary goal of this study was to establish an ANFIS for estimating a building's augmented power, wind velocity and power density in regards to the geometry characteristics of the building (building shape and position) and input angle of the wind. The fundamental idea behind soft computing methodology is to collect input/output data pairs and to learn the network from this data. This technique provides fuzzy logic with the ability to change the parameters of the membership function so that the associated FIS can track the input/output data [45–47].

2. Building augmented wind turbines

Wind turbines produce power, represented as P: P

$$P = \frac{1}{2}\rho r^2 \pi u^3 \eta \tag{1}$$

where the density of the air is represented by ρ, rotor radius is indicated using r, u is the wind velocity, and η represents the efficiency of the wind turbine. Eq. (1) illustrates that the power generated by the wind is proportional the velocity of the free stream, cubed. A building augmented wind turbine (BAWT) system utilizes the Venturi effect where building is used to create a drop of air pressure through the system to increase the kinetic energy of the wind at the turbine rotor. Augmentation of the wind using buildings can be accomplished either by integrating existing buildings with wind turbines or designing buildings aerodynamically. This study focused on BAWT systems where two buildings are using as a wind augmenter with turbines inserted between the buildings as shown in Fig. 1. In this study, developed and tested a BAWT system using building designs that considered the aerodynamic performance of the augmenters. The key characteristics of these building geometries are smooth and rounded surfaces that avoid creating any obstacles for wind stream flow as shown in Fig. 2.

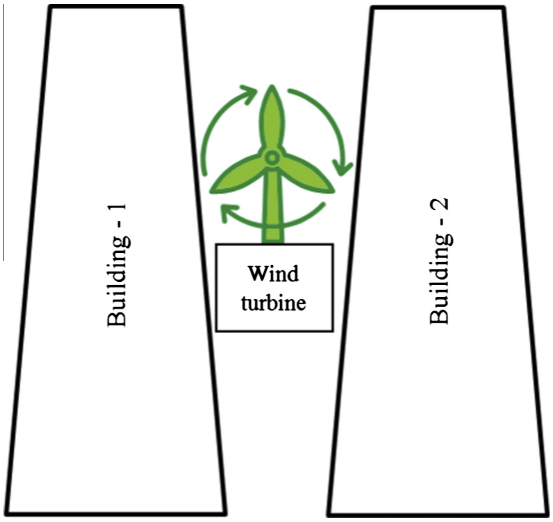

Fig. 1. Two buildings used as wind turbine augmenter.

This study analyzed various building geometries with respect to three different parameters to determine their effects on power augmentation for various wind input angles. The three building parameter were taper (R_t), forward lean (R_x) and spread (R_y). All BAWT configurations were analyzed with the wind input angle as a factor in the overall performance. The parameters governing the vertical taper (R_t), forward lean (R_x) and spread (R_y) were:

$$R_t = 1 - D_t/D_0$$
$$R_x = x_t/R_t D_0$$
$$R_y = y_t/R_t D_0$$

where D_t is the building diameter at half height, D_0 is the base diameter of the buildings, x_t is the distance from the symmetry plane to the edge of the top of the building, and y_t is forward shift of the top of the building with respect to the base of the building (Fig. 3).

The goals of this study were as follows:

- To determine the power and wind velocity augmentation factors for each BAWT configurations using ANFIS methodology.
- To determine the augmented power density for each BAWT configurations using ANFIS methodology.

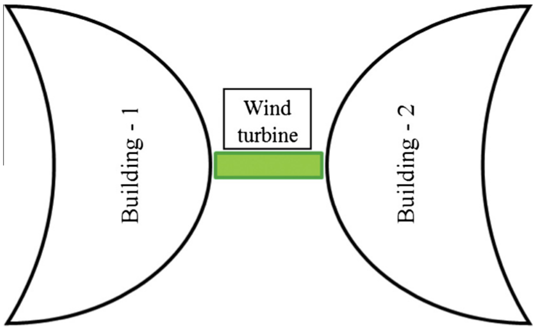

Fig. 2. Design for an aerodynamic building augmenter.