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Adaptive neuro-fuzzy estimation of diffuser effects on wind turbine performance

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ABSTRACT

Wind power is generating interest amongst many countries to produce sustainable electrical power. It is well known that the main drawback of wind power is the inherent variable behavior of wind speed. Significant research has been carried out to improve the performance of the wind turbines and establish the power system stability. As power output is proportional to the cubic power of the incident airspeed, any small increase in the incident wind yields a large increase in the energy output. One of the more promising advanced concepts for overcoming the inherent variable behavior of wind speed is the DAWT (diffuser-augmented wind turbine). The diffuser or flanged diffuser generates separation regions behind it, where low-pressure regions appear to draw more wind through the rotors compared to a bare wind turbine. Thus, the output power of the DAWT is much larger than for a unshrouded turbine. To estimate rotor performance of the diffuser-augmented wind turbine, this paper constructed a process which simulates the power output, torque output and rotational speed of the rotor in regard to diffuser effect and wind input speed with ANFIS (adaptive neuro-fuzzy) method. This intelligent estimator is implemented using Matlab/Simulink and the performances are investigated.

1. Introduction

The usage of renewable, clean energy has become a very important issue in recent years. Among all renewable energy of different styles, wind energy possesses many advantages such as extensive distribution, high efficiency, low cost, low maintenance and environmental friendliness. The power in the wind is well known to be proportional to the cubic power of the wind velocity approaching a wind turbine. This means that even small amount of its acceleration gives large increase of the energy generation. People have long been seeking designs of enhancements to the conventional wind turbines, and one of the most assuring proposals is the DAWT (diffuser augmented wind turbine) [1–3]. Some attractive studies regarding augmented wind turbines were reported by Refs. [4–7]. A DAWT [8–10] has a duct or shroud that surrounds the wind turbine blades and increases in cross-sectional area in the stream wise direction. The resulting sub-atmospheric pressure within the diffuser draws more air through the blade plane, and hence more power can be generated compared to a conventional turbine of the same rotor blade diameter [11–13]. Several researchers have examined the benefits and economics of placing a diffuser around a wind turbine [14,15]. It has been reported that the speed of wind passing through the shroud is dramatically increased [16,17]. Shrouding (diffuser augmented) horizontal axis wind turbine has been shown to be an effective way to potentially improve the performance of wind turbine for applications in built or urban environments [9,10]. The ducted wind turbine overcomes many of the problems associated with the use of conventional wind turbines in an urban environment [18–20], which are hampered by high levels of turbulence in the air stream, and are also constrained by concerns over visual impact, noise and public safety [21]. Generating energy from the wind in an urban environment is an attractive idea [22,23]. However, there are major problems over its practical implementation at a significant scale [24,25]. In such location, the wind is normally weak, turbulent and unstable in

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Nomenclature

ANFIS	adaptive neuro-fuzzy inference system
DAWT	diffuser-augmented wind turbine
CFD	computational fluid dynamics
Cp	power coefficient
Ct	torque coefficient
FIS	fuzzy inference system
P	power of wind
ρ	air density
r	rotor radius
u	wind velocity
η	efficiency of the wind turbine
U_x	stream wise velocity
C_{trq}	torque coefficient
n	number of blades
c	chord length
C_D	Drag coefficient
C_L	lift coefficients
r_0	radius of blade
r_h	radius of hub
C_η	rotation coefficient
μ	membership function
$\{p, q, r, s\}$	premise parameters
$\{a,b,c\}$	variable parameters
$\{p_i, q_i, r_i, s_i\}$	consequent parameters
RMSE	root-mean-square
R^2	coefficient of determination
r	Pearson coefficient

terms of direction and speed [26,27], because of the presence of buildings and other adjacent obstructions. To yield a reasonable power output from a wind turbine located in this turbulent environment the turbines have to improve their energy capture [28,29]. This means that turbines need to be specifically designed to work effectively in low and turbulent wind resource areas [30,31].

In this study is an analyzed diffuser effect on wind turbine rotor performance. Since the using of CFD (computational fluid dynamics) for the ducted wind turbine performance analyzing could be very challenging and time consuming, soft computing techniques are preferred. It is attempted to estimate the rotor performance with diffuser for different number of blades and for different wind input speed by soft computing methodology i.e. ANFIS (adaptive neuro-fuzzy inference system). As the rotor performance, power output, torque output and rotor rotational speed of the rotor are tracked. Cp (power coefficient) and Ct (torque coefficient) are used as the measure for power output and torque output respectively.

ANFIS is one of the most powerful types of neural network system [32]. ANFIS shows very good learning and prediction capabilities, which makes it an efficient tool to deal with encountered uncertainties in any system. ANFIS, as a hybrid intelligent system that enhances the ability to automatically learn and adapt, was used by researchers in various engineering systems [33–35]. So far, there are many studies of the application of ANFIS for estimation and real-time identification of many different systems [36–38]. FIS (fuzzy inference system) is the main core of ANFIS. FIS is based on expertise expressed in terms of 'IF–THEN' rules and can thus be employed to predict the behavior of many uncertain systems. FIS advantage is that it does not require knowledge of the underlying physical process as a precondition for its application. Thus ANFIS integrates the FIS with a back-propagation learning algorithm of neural network.

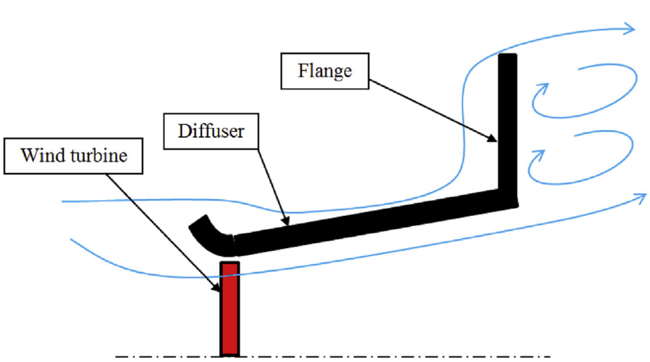

Fig. 1. Schematic view and a flow mechanism around a diffuser-shrouded wind turbine.

The key goal of this investigation is to establish an ANFIS for estimation of the wind turbine rotor performances, power output, torque output and rotor rotational speed in regard to diffuser effect and wind input speed. The basic idea behind the soft computing methodology is to collect input/output data pairs and to train the proposed network from these data. This technique gives fuzzy logic the capability to adapt the membership function parameters that best allow the associated FIS to track the given input/output data [39–41]. A CFD simulation is carried out to extract the training and checking data for the ANFIS network.

2. Materials and methods

2.1. Diffuser augmented wind turbines

The power in wind is proportional to the cubic power of the wind velocity approaching the wind turbine:

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

where the air density is represented by Refs. ρ, rotor radius is r, u is the wind velocity and η is the efficiency of the wind turbine. The ratio of captured power to available power is referred to as the power coefficient C_p. Equation (1) shows that a small amount of acceleration leads to a large increase in the energy output. Fig. 1 illustrates an overview of the present DAWT (diffuser augmented-wind turbine system). A flange generates a large separation behind it, where a very low-pressure region appears to draw more wind compared to a diffuser with no flange. Owing to this effect, the flow coming into the diffuser can be effectively concentrated and accelerated. In this system, the maximum velocity is obtained near the inlet of diffuser and thus a wind turbine is located there as shown in Fig. 1.

The goal of this research is to determine the diffuser effect on wind turbine performances (power output, torque output and rotational speed) by ANFIS methodology.

2.2. Numerical method and computational conditions

The present flow field is generally expressed by the continuity and the incompressible Reynolds-averaged Navier–Stokes equations as follows [2]: