Electrical Power and Energy Systems 69 (2015) 98–103

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

# Soft methodology selection of wind turbine parameters to large affect wind energy conversion

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ARTICLE INFO

*Article history:*
Received 7 January 2014
Received in revised form 7 December 2014
Accepted 31 December 2014
Available online 23 January 2015

*Keywords:*
Wind turbine
Adaptive neuro fuzzy system
Wind energy
Power coefficient
Variable selection

ABSTRACT

In recent years the use of renewable energy including wind energy has risen dramatically. Because of the increasing development of wind power production, improvement of the control of wind turbines using classical or intelligent methods is necessary. To optimize the power produced in a wind turbine, it is important to determine and analyze the most influential factors on the produced energy. To build a wind turbine model with the best features, it is desirable to select and analyze factors that are the most influential to the converted wind energy. This process includes several ways to discover a subset of the total set of recorded parameters, showing good predictive capability. The method of ANFIS (adaptive neuro fuzzy inference system) was applied to the data resulting from this investigation. The ANFIS process for *variable selection* was implemented in order to detect the predominant variables affecting the converted wind energy. Then, it was used to determine how four parameters, blade pitch angle, rotor speed, wind speed and rotor radius, affect the wind turbine power coefficient. The results indicated that of all the parameters examined, blade pitch angle is the most influential to wind turbine power coefficient prediction, and the best predictor of accuracy.



## Introduction

Wind power is one of the most promising renewable energy sources due to the progress experienced in the last decades. In terms of wind power generation technology, because of numerous technical benefits the modern wind turbines always use variable speed operation which is achieved by a converter system [1]. These converters are typically associated with individual generators and they contribute significantly to the costs of wind turbines. The use of the wind energy conversion systems has been significantly expanded over the last few decades. Wind power plants are generally used to convert wind energy into electrical energy. These plants consist of a wind turbine and an electrical generator connected by means of a gear box. The wind turbine converts wind kinetic energy into mechanical energy, which is transformed into electrical energy by the electrical generator. These plants are controlled by an appropriate control system [2,3]. The aim of the control system of a wind turbine is to obtain an automatic and secure operation of the turbine using an optimized flow of the generated power [4,5]. This will reduce operation costs, produce a consistent dynamic response and improve the quality of power [6,7]. Also, it helps in the assurance of the safety for the maximization of the energy captured due to the decrease of the turbine load [8,9].

The unpredictable and highly fluctuating wind generation can have consequences in terms of frequency “stability”; on the one hand, the sudden change of generated power can lead to unacceptable frequency variations [10–12]. On the other hand, difficulties in forecasting the energy production make network management more challenging [13–16].

To build a system with the best characteristics, it is necessary to identify the most relevant and influential subset of parameters and subject these to analysis. This process of selection is usually called variable selection. The purpose of this process is to find a subset of the total set of parameters that have been recorded that show good capability of prediction. Essentially, with neural network as the foundation, we modeled the complex system's architecture in function of approximation and regression. Neural networks are an architecture which is made up of extremely parallel adaptive processing elements. These are interconnected through structured networks. Therefore, the accuracy of the neural network models which are created as a result of this data rely heavily on the accuracy of the chosen sensor data in the representation of the system. To achieve a successful generation and creation of a model which is capable to estimate a special process output, the selection process of the subset of parameters that are really pertinent is crucial. This

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http://dx.doi.org/10.1016/j.ijepes.2014.12.086
0142-0615/

is achieved in the process of variable selection. As mentioned before, the purpose of this procedure is to find a subset of the total set of parameters that have been recorded to show good capability of prediction [17–20]. The problems faced in the process of the selection of parameters could possibly be resolved by integrating and applying prior knowledge to segregate and remove parameters that are irrelevant. Otherwise, a more sophisticated manner of approach to the above-mentioned problem is to view it as an optimization procedure through the use of genetic algorithms [21].

The objective here is to select the proper explanatory (input) parameters and thereby reduce and minimize the error that exists between the observed values and the model estimations of the explained variables. Among the many neural network system, one of the most used and powerful is the ANFIS; and the ANFIS was employed here, for the purposes of this study, in the variable selection part [22–26].

In order to determine how the four main parameters affect the wind turbine power coefficient: blade pitch angle, rotor speed, wind speed and rotor radius, a parameter search by employing the ANFIS was conducted. The process, which is called *variable selection*, includes a number of ways to discover a subset of the total recorded parameters that show good capability of prediction. ANFIS [27], a hybrid intelligent system that increases the capability of learning and adapting automatically has been used by researchers for many different purposes in a variety of engineering systems such as in modeling [28–31], predictions [32–34] and control [35–39]. This neuro-adaptive learning methodology allows the fuzzy modeling process to obtain information regarding the data gathered [40,41]. This is the foundational idea underlying all neuro-adaptive learning methodologies. The ANFIS methodology aims to organize the FIS (fuzzy inference system) by analyzing the input/output data pairs [42,43]. It gives fuzzy logic the ability to adjust the MF parameters so that it is optimal in allowing the associated FIS to detect and trace the given input/output data [44].

## Wind turbine power

The major components of a typical wind energy system are wind turbine, a generator, and control system. The main part of a wind energy conversion system is the wind turbine transforming the wind kinetic energy into mechanical or electric energy. The system basically is composed of a blade, a mechanical part and an electric engine coupled to each other. The kinematical energy of wind is the function of wind pace, the specific mass of air, the area of air space where the wind is captured and the height at which the rotor is placed. The power available in a uniform wind field can as expressed as

$$P_w = \frac{1}{2}\rho A v^3 \quad (1)$$

where $P_w$ is the power (W) of the wind with air density $\rho$ (kg/m$^3$) and wind speed $v$ (m/s) is passing through the swept area $A$ (m$^2$) of a rotor disk that is perpendicular to the wind flow. The wind turbine can only capture a fraction of the power available from the wind. The ratio of captured power to available power is referred to as the power coefficient

$$C_p = (\beta, \lambda) \quad (2)$$

which is a function of the collective blade pitch angle $\beta$ and the tip-speed ratio $\lambda$. The tip-speed ratio is defined as the ratio of the tangential velocity of the blade tips divided by the effective wind speed, or

$$\lambda = \frac{R\Omega_r}{V_e} \quad (3)$$

where $R$ is the rotor radius, $\Omega_r$ is the rotor speed, and $V_e$ is the effective wind speed perpendicular to the rotor plane. The value of $C_p$ can be expressed according to [45] as:

$$C_p(\beta,\lambda) = 0.5176\left(\frac{116}{\frac{1}{\lambda-0.08\beta}-\frac{0.035}{\beta^3+1}} - 0.4\beta - 5\right)e^{\frac{-21}{\frac{1}{\lambda-0.08\beta}-\frac{0.035}{\beta^3+1}}} + 0.0068\lambda \quad (4)$$

A characterization of the power coefficient $C_p$ for the wind turbine used in this study is shown as contour plot in Fig. 1 for different values of blade pitch angle $\beta$.

Table 1 shows the four the most influential parameters on the wind turbine output energy. These parameters were examined in this study to determine which one has the most influence on the wind turbine output energy. As wind turbine output energy indicator, power coefficient was used as depicted in Table 1. The main goal was to find which of the prescribed input parameters have the largest effect on the power coefficient of the wind turbine.

## Variable selection using adaptive neuro-fuzzy inference system

Generating predetermined input–output subsets requires the construction of a set of fuzzy 'IF THEN' rules with the suitable MFs (membership function). The ANFIS can serve as the foundation for such a construction. The input–output data are converted membership functions. In accordance to the collection of input–output data, the ANFIS takes the initial FIS and adjusts it through a back propagation algorithm. The FIS is comprised of three components, (1) a rule base, (2) a database and (3) a reasoning mechanism. The rule base consists of a choice of fuzzy rules. The database assigns the MFs which are employed in the fuzzy rules. Finally, the last component is the reasoning mechanism and it infers from the rules and input data to come to a feasible outcome. These intelligent systems are a combination of knowledge, methods and techniques from a variety of different sources. They adjust to perform better in environments which are changing. These systems have similar-human intelligence within a specific domain. The ANFIS recognizes patterns and assists in the revision of environments. FIS integrates human comprehension, does interfacing, and makes decisions.

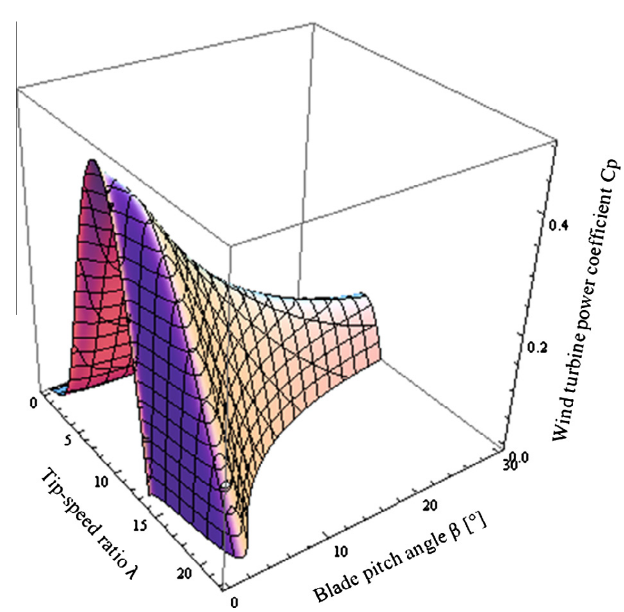


**Fig. 1.** Wind turbine power coefficient $C_p$ as function of tip speed ration $\lambda$ and blade pitch angle $\beta$.