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Wind turbine power curve estimation based on cluster center fuzzy logic modeling

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Abstract

Wind energy applications and turbine installation at different scales have been increased for last decade. Technically wind turbine capacity has been improved at high levels. However, electricity could not be generated at all stages of wind speed and so there are some limits related to cut-in and cut-out data. One of the main problems in wind engineering is to estimate output data of wind turbines depends on wind speed and system values. Wind speed problematic values, that are less than cut-in and greater than cut-out, take the most important role for estimating wind power curve models. All wind turbines have different cut-in and cut-out limits and generating of electricity could be achieved in a certain interval that could be called as affective interval. Fuzzy logic that is a new and novel verbal logical approach has many applications in the field of engineering. Cluster center fuzzy logic modeling is also a new and the effective method in this scientific area. In this paper, the first power curve of a wind turbine is modeled by least square methodology. After that depending on the fuzzy logic approach a new application is realized. It is seen that, this curve type could be well represented and modeled by the clustering center fuzzy logic modeling than classical least square methodology. It is estimated that four or five cluster centers are enough for representing wind turbine power curve by running proposed method.

Keywords: Cluster; Fuzzy logic; Power curve; Wind; Wind power

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1. Introduction

Energy is available in two different alternatives, nonrenewable (coal, fuel, and natural gas) and renewable (solar, wind, hydro, and wave) sources. Especially, after the industrial revolution in the nineteenth century, first coal and then fuel oil are used as primary energy sources for the needs of modern communities. As it is known, fossil fuels have limited potential, and at the current rates exploitations they are expected to be depleted within the next centuries. This is one of the reasons why clean, sustainable, and environmentally friendly alternative energy resources are currently sought.

Wind energy can be utilized for a variety of functions ranging from windmills to pumping water and sailing boats. With increasing significance of environmental problems, clean energy generation becomes essential in every aspect of energy consumption. Wind energy is very clean, but not persistent for long periods of time. There are many scientific studies in the wind energy domain, which have treated the problem with various approaches (Justus, 1978; Cherry, 1980; Troen and Petersen, 1985).

Generally, strong wind speeds are described as risk values, but low wind speeds also have important risk potentials for desired electricity generation. These values are known as out of cut-in and cut-out wind speeds. Wind turbines produce electricity approximately between 3 and 25 m/s wind speeds interval, and the highest generations are evaluated after 10–12 m/s values. Each turbine has cut-in and cut-out values depending on design rule with magnitude and each wind turbine power curve that indicates the amount of the electrical power output versus different wind speeds. The wind turbine technology development also led to improve performance. Wind turbine rotor efficiency increased from 35% to 40% in the early 1980s to 48% in the mid-1990s. Moreover, the technical availability increased up to 98% (DTI, 1992; Karnøe and Jørgensen, 1995; Gipe, 1995; Neij, 1999). The swirl losses reduce the maximum power coefficient, $C_{P,\ max}$, to approximately 0.42 and C_p is a nonlinear function of factors such as blade radius, pitch angle, tip-speed ratio (TSR), etc. The development in wind engineering and turbines is given by Ackerman and Soder (2000), Şahin (2004).

In addition to this, ability of a wind turbine to extract power from varying wind is a function of three main factors, namely, the wind power availability, the power curve of the machine, and the ability of the machine to respond to wind fluctuations. In contrast to conventional power generation where input energy can be scheduled and regulated, wind energy is not a controllable resource, due to its intermittent and stochastic nature (Milborrow, 2002).

In order to determine power estimation, it is necessary to simultaneously consider the frequency of wind velocities and the power curves of the wind turbines (Şen, 1997; Şen and Şahin, 1998). When selecting this design parameter, a careful study should be made in order to determine best model, which fits the power curve of the wind turbine. The feasibility of wind turbines depends largely on a suitable selection of their characteristics so that they match those of the wind at the location. In order to develop theoretical design trade-off studies, the use of useful analytic expressions containing parameters that can be systematically varied to determine some maximum is convenient. Different wind turbine power curve models also were taken into consideration by different authors (Petersen et al., 1981; Pallabazzer, 1995; Powel, 1981; Garcia et al., 1998; Torres et al., 2003).

Wind energy conversion systems depend on aerodynamic drag and lift. The early Persian vertical axis wind wheels utilized the drag principle. Drag devises have a low power coefficient with $C_{P,\ max}$ around 0.16 (Gasch, 1982).