Renewable and Sustainable Energy Reviews 30 (2014) 452–460

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

A comprehensive review on wind turbine power curve modeling techniques

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ARTICLE INFO

Article history:
Received 25 May 2013
Received in revised form
27 August 2013
Accepted 21 October 2013
Available online 14 November 2013

Keywords:
Modeling accuracy
Non-parametric modeling
Parametric modeling
Wind turbine power curve

ABSTRACT

The wind turbine power curve shows the relationship between the wind turbine power and hub height wind speed. It essentially captures the wind turbine performance. Hence it plays an important role in condition monitoring and control of wind turbines. Power curves made available by the manufacturers help in estimating the wind energy potential in a candidate site. Accurate models of power curve serve as an important tool in wind power forecasting and aid in wind farm expansion. This paper presents an exhaustive overview on the need for modeling of wind turbine power curves and the different methodologies employed for the same. It also reviews in detail the parametric and non-parametric modeling techniques and critically evaluates them. The areas of further research have also been presented.

Contents

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1364-0321/$ - see front matter
http://dx.doi.org/10.1016/j.rser.2013.10.030

1. Introduction

The significance of alternate energy sources like solar, wind, biomass etc. has exponentially increased in the recent times due to the ever increasing demand for clean energy. Harvesting of wind energy has hence gathered sufficient momentum in the recent days. Estimation of the technical and economic wind energy potential in various regions have gathered momentum [1]. However, the large scale integration and penetration of wind energy into the power grid can result in significant social, environmental, economical and technical impacts [2]. In order to develop a sustainable power system for the future, these impacts need to investigated and mitigated.

Wind energy definitely holds out a promising respite, but for the uncertainty involved in power produced due to the stochastic nature of wind. A significant penetration of wind in the present day power system can be realized only if accurate and reliable forecasting models are made available. A wind turbine power curve can go a long way in fulfilling this. Fig. 1 shows a wind turbine power curve (WTPC).

The output power of a wind turbine significantly varies with wind speed and hence every wind turbine has a very unique power performance curve. A power curve aids in wind energy prediction without the technical details of the components of the wind turbine generating system [3]. The electrical power output as a function of the hub height wind speed is captured by the power curve. The minimum speed at which the turbine delivers useful power is known as the cut-in speed (u_c). Rated speed (u_r) is the wind speed at which the rated power, which is the maximum output power of the electrical generator, is obtained. The cut-out speed (u_s) is usually limited by engineering design and safety constraints. It is the maximum wind speed at which the turbine is allowed to produce power. Power curves for existing machines, derived using field tests, can be obtained from the wind turbine manufacturers. The approximate shape of the power curve for a given machine can also be estimated using the power characteristics of rotor, generator, gearbox ratio and efficiencies of various components. The conversion of power in the wind into actual power varies non-linearly because of the transfer functions of available generators [4].

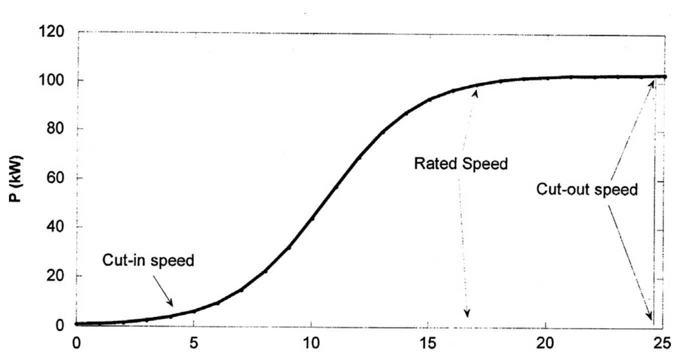

Fig. 1. Typical wind turbine power curve.

The theoretical power captured by the rotor of a wind turbine (P) is given by

$$P = 0.5\rho\pi R^2 C_p u^3 \quad (1)$$

where ρ is the air density, R is the radius of the rotor, C_p is the power coefficient and u is the wind speed [5]. As the air density remains almost constant at hub height, the power captured significantly depends on the power coefficient and wind speed. The power coefficient, which denotes the percentage of power captured by the turbine, essentially depends on the tip speed ratio (λ) and β the blade-pitch angle.

2. IEC power curve

The International Standard IEC 61400-12-1 has been prepared by the International Electrotechnical Commission (IEC) technical committee 88: Wind turbines. The standard methodology for measuring the power performance characteristics of a single wind turbine has been specified here. It is also applicable for testing the performance of wind turbines of varied sizes and types. It can be used to evaluate the performance of specific turbines at specific locations and also aid in comparing the performance of different turbine models or settings [6].

The power performance characteristics of wind turbines are ascertained by the measured power curve and the estimated annual energy production. Simultaneous measurements of wind speed and power output is made at a test site for sufficiently long duration to create a significant database under varying atmospheric conditions. The measured power curve is determined from this database. The annual energy production is calculated, assuming 100% availability, by applying the measured power curve to reference wind speed frequency distributions.

The measured power curve is determined by applying the “method of bins”, for the normalized datasets using the following equations:

$$u_i = \frac{1}{N_i}\sum_{j=1}^{N_i} u_{n,i,j} \quad (2)$$

$$P_i = \frac{1}{N_i}\sum_{j=1}^{N_i} P_{n,i,j} \quad (3)$$

where u_i is the normalized and averaged wind speed in bin i, $u_{n,i,j}$ is the normalized wind speed of dataset j in bin i, P_i is the normalized and averaged power output in bin i, $P_{n,i,j}$ is the normalized power output of dataset j in bin i and N_i is the number of 10 min data sets in bin i. The accuracy of WTPC models have improved by using the profile information available using remote sensing instruments [7]. However, it has been stated in [8], that