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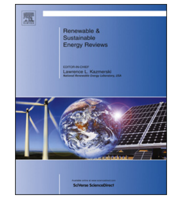

A review of estimation of effective wind speed based control of wind turbines

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ABSTRACT

This paper provides a comprehensive literature review on the estimation of effective wind Speed (EEWS), and EEWS based control techniques applied to wind turbine (WT). Several numbers of good publications have reported the EEWS based control of wind turbine. Wind speed is a driving force for the wind turbine system. In general wind speed measurement is carried out by anemometer which is located at the top of the nacelle. The optimal shaft speed is derived from the exact measurement of wind speed to extract the optimal power output at below rated wind speed. The wind speed provided by the anemometer is measured at a single point of the rotor plane which is not the accurate effective wind speed. At the same time anemometer increases the overall cost, maintenance and reduce the reliability of the overall system. So an accurate EEWS based control technique is required for WT systems to get the optimal power output. In this paper, a detailed description and classification of EEWS and some EEWS based control techniques have been discussed which is based on control strategy and complexity level of WT system. All most all previous work estimates the wind speed using EEWS techniques such as Kalman filter (KF), extended Kalman filter (EKF), neural network (NN) etc., and then different control techniques are applied. In the last section of this paper integral sliding mode control (ISMC) of a WT at below rated speed region is considered. Operating points are determined by proper estimation of effective wind speed, and modified Newton Raphson (MNR) is employed to estimate this. Finally simulation results are presented with a comparison between proposed ISMC, sliding mode control (SMC) and classical controllers such as aerodynamic torque feed forward (ATF) and indirect speed control (ISC).

Contents

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1. Introduction

The burning of fossil fuels has the significance influence on global climate change [1]. Wind energy is one the fastest growing and environment-friendly renewable energy sources. Past two decades the sizes of the wind turbines have been developed from 20 kW to 2 MW, even large wind turbines are also designed and tested [2]. Wind energy is playing an important role in future national energy scene [3–5]. Greenpeace states that, about 10% electricity can be supplied by the wind by the year 2020. Wind turbines convert the kinetic energy of the wind to electrical energy by rotating the blades. Modern wind turbines are classified into two types, i.e. fixed speed and variable speed wind turbine. Compared with fixed speed WT, variable speed WT are more reliable. Measurement of exact wind speed is required to control the variable speed WT (VSWT) at below rated wind speed for maximum power extraction. Generally a number of anemometers are placed at some distance to measure the wind speed at different points. The effective wind speed is defined as the spatial average of the wind field over the rotor shift area with the wind stream being unaffected by the wind turbine. WT anemometer cannot measure the exact shift area wind speed, due to which the overall performance of the system reduces. The other demerit is that the initial cost and maintenance of the anemometer is high. Exact estimation of effective wind speed is required to control the WT at above and below the rated wind speed which cannot be measured by using the anemometer. Several EEWS and control are reported in the literature [6–50]. In this review, an attempt has been made to compare the EEWS and control techniques on the basis of their advantages, disadvantages, control strategy, types of generator and operation of the WT at different regions. This paper provides a comparative review on most of the EEWS and control techniques. The contribution of this paper is the approximation of aerodynamic torque power coefficient to a 5^{th} order polynomial and estimation of the wind speed using MNR. Based on this estimated wind speed proposed ISMC based controller was found suitable in terms of the maximum power capture and reduced transient load compared to existing ATF, ISC, and SMC.

This paper is organized as follows. Section 2 explains polynomial based EEWS, Section 3 describes the NN based EEWS, Section 4 describes the nonlinear estimation with Newton Raphson (NR), Section 5 describes the unknown input based estimation, Section 6 describes the iterative algorithm/estimator based EEWS, Section 7 describes the nonlinear observer based EEWS, Section 8 describes the nonlinear estimation without NR, Section 9 describes the particle filter based EEWS, Section 10 describes the statistical model based EEWS, Section 11 describes the data fusion based EEWS, Section 12 describes the EEWS based fault diagnosis and finally Section 13 describes the proposed EEWS and comparison of various control performances. Finally, a conclusion is drawn in Section 14.

2. Polynomial based estimation

2.1. First- and second-order polynomial

When the generator is operated in speed control mode (below rated speed) the wind speed is estimated from the turbine output power (P_{wt}) by using the second order polynomial given in Eq. (1) [6].

$$\hat{\omega}_{s,low} = a_1 + a_2 P_{wt} + a_3 P_{wt}^2 \tag{1}$$

$\hat{\omega}_{s,low}$ is the estimated wind speed at below rated wind speed.

a_1, a_2, a_3 are the coefficient of the second order polynomial of Eq. (1).

When the wind speed is above the rated speed, pitch angle is used for estimating the wind speed by using first order polynomial given in Eq. (2).

$$\hat{\omega}_{s,high} = b_1 + b_2 \beta \tag{2}$$

$\hat{\omega}_{s,high}$ is the estimated wind speed at above rated wind speed, and b_1 and b_2 are the coefficient of the first-order polynomial. Then the estimated wind speed is low pass filtered as given in Eq. (3).

$$\begin{aligned}\frac{d\hat{\omega}_s}{dt} &= \alpha_{\omega_s}((1-k_{tr})\hat{\omega}_{s,low} + k_{tr}\hat{\omega}_{s,high} - \hat{\omega}_s) \\ &= \alpha_{\omega_s}\left((1-k_{tr})(a_1 + a_2 P + a_3 P^2) + k_{tr}(b_1 + b_2\beta) - \hat{\omega}_s\right)\end{aligned} \tag{3}$$

where $\hat{\omega}_s$ estimated wind speed, α_{ω_s} is the bandwidth of the estimator and k_{tr} is a transition parameter.

2.2. nth-Order polynomial

In [7,8] based upon the shaft speed and power output of the turbine, the wind speed is estimated by using the nth order polynomial. The characteristic of the power coefficient of the wind turbine is normally expressed in terms of tip speed ratio λ given as

$$C_P(\lambda) = C_{P0} + C_{P1}\lambda + C_{P2}\lambda^2 + \cdots + C_{Pn}\lambda^n \tag{4}$$