

A Review of Wind Speed Estimation for Wind Turbine Systems Based on Kalman Filter Technique

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Article Info

Article history:

Received Mar 3, 2016

Revised May 15, 2016

Accepted May 30, 2016

Keyword:

Kalman Filter
Review
Speed Estimation
Wind Turbine

ABSTRACT

This paper presents a review of wind speed estimation based on Kalman filter technique applied to wind turbine systems. Generally, wind speed measurement is performed by anemometer. The wind speed provided by the anemometer is measured at a single point of the rotor plane which is not the accurate wind speed. Also, using anemometer increases the system cost, maintenance, complexity and reduces the reliability. For these reasons, estimation of wind speed is needed for wind turbine systems. In this paper, the several wind speed estimation methods based on Kalman filter method used for wind turbine systems are reviewed.

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1. INTRODUCTION

Wind energy is playing a significant role in future energy scene. About 10% electricity can be supplied by the wind energy by the year 2020. Wind energy is one the fastest increasing and environment friendly renewable energy sources. Wind turbines convert the kinetic energy of the wind to electrical energy [1]-[5].

Generally, wind turbines are categorized into two types, fixed and variable speed wind turbines which variable speed wind turbine is more reliable. To control the variable speed wind turbines, the measurement of wind speed is required. For this, anemometers are placed to measure the wind speed. Wind turbine anemometer cannot measure the exact shift area wind speed. Moreover, using anemometer increases the overall cost, size and reduces the reliability of the system. Another disadvantage of using anemometer is that the cost and maintenance of the anemometer is high. In this case, the sensorless strategies can guarantee the performance of control system. In the literature, several speed estimation techniques are reported as an alternative method for anemometers [6]-[39]. These techniques are based on Kalman filter [9]-[24], neural network [25]-[27], adaptive neuro fuzzy inference systems [28]-[30], extreme learning machine [31], [32], support vector machine [33], [34] and etc [35]-[39].

Concerning the estimation of the speed, there have been a number of researches that presented different techniques for this purpose. While the estimation technique based on observer approximately depends to the accuracy of the model; the Kalman filter is one of the most general model based estimator [8]. The Kalman filter algorithm introduced by R. E. Kalman represents an efficient method for the recursive data processing.

The main contribution of this research is to review the presented techniques for wind speed estimation based on Kalman filter method. Based on this, in this paper, several numbers of good publications have reported the wind speed estimation methods applied for wind turbine systems are discussed. The paper is organized as follows: After introduction in Section 1, the Kalman filter methodology is presented in Section 2. Section 3 discusses the different methods of speed estimation based on Kalman filter and finally the paper concludes at Section 4.

2. KALMAN FILTER

Kalman filter is the statistically sequential estimation procedure for dynamic systems. Observations are recursively combined with recent forecasts with weights that minimize the corresponding biases. This algorithm can be formulated as following equations [40], [41].

$$x_t = F_t \cdot x_{t-1} + w_t \quad (1)$$

$$y_t = H_t \cdot x_t + v_t \quad (2)$$

$$x_{t/t-1} = F_t \cdot x_{t-1} \quad (3)$$

$$P_{t/t-1} = F_t \cdot P_{t-1} \cdot F_t^T + W_t \quad (4)$$

$$x_t = x_{t/t-1} + K_t (y_t - H_t \cdot x_{t/t-1}) \quad (5)$$

$$K_t = P_{t/t-1} \cdot H_t^T (H_t \cdot P_{t/t-1} \cdot H_t^T + V_t)^{-1} \quad (6)$$

$$P_t = (I - K_t \cdot H_t) P_{t/t-1} \quad (7)$$

3. WIND SPEED ESTIMATION BASED ON KALMAN FILTER

In the literature, different techniques for wind speed estimation based on Kalman filter including linear, extended and unscented and etc. Kalman filter, have been presented. In Ref. [10], a hybrid Kalman filter-artificial neural network model was proposed based on an Auto-Regressive Integrated Moving Average (ARIMA) model to further improve the forecasting accuracy of wind speed. The framework of the study used in [10] is shown in Figure 1.



Figure 1. The framework of the study used in [10]

In [11] the comparison between Kalman filter and Takagi–Sugeno observer methods for wind speed estimation has been presented. In this paper, the Kalman filter and Takagi–Sugeno observer techniques are compared based on reduced-order models of a reference wind turbine with different modelling details. In [12], unscented Kalman filter is incorporated with Support Vector Regression (SVR) based state-space model in order to accurately update the short-term estimation of wind speed sequence. In the presented method, support vector regression is used to formulate a nonlinear state-space model and then unscented Kalman filter is adopted to achieve dynamic state estimation. Schematic diagram of the used SVR-unscented Kalman filter method for wind speed estimation is shown in Figure 2.

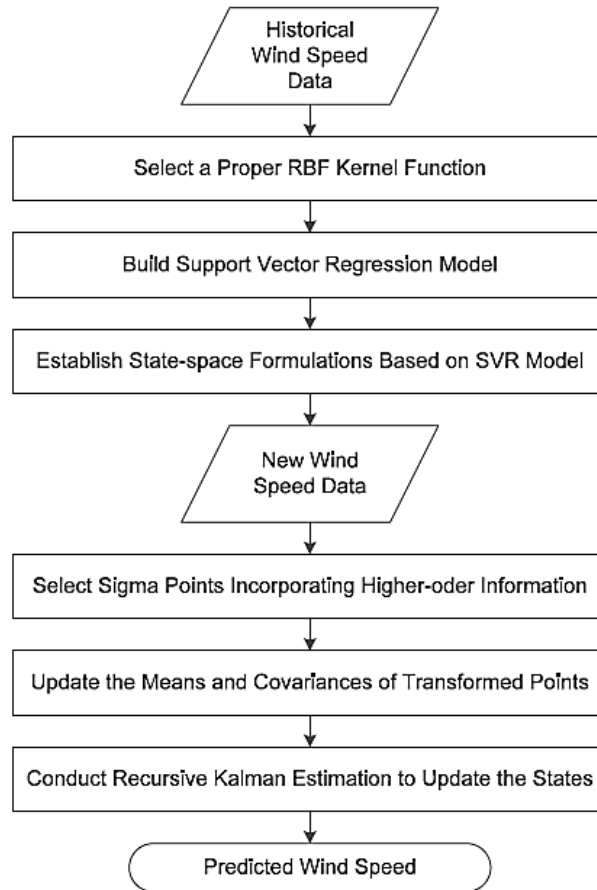


Figure 2. Schematic diagram of the SVR-unscented Kalman filter method for wind speed estimation [12]

In [13], a method for wind power prediction has been proposed using physical and statistical modeling. In [13], the Kalman and Kolmogorov–Zurbenko filters, have been used to adopt local area characteristics and to eliminate possible systematic errors. In [14], an adaptive Kalman filter has been developed and applied to 2-metre temperature and 10-metre wind-speed forecasts in Iceland. The presented method consists of adding two strategies to the conventional Kalman filter algorithm that adaptively estimate the noise statistics individually.

In [15], a comparison of three one-step-ahead forecasting techniques for wind speed data based on robust Kalman filtering has been presented. The author showed that the weighted robust Kalman filter [42] and robust statistics Kalman filter [43] yield better performances than the standard Kalman filter and the thresholded Kalman filter [44] in terms of the sample skewness, sample kurtosis and residual error.

In [17], two hybrid methods (hybrid ARIMA-artificial neural network model and hybrid ARIMA-Kalman model) for wind speed prediction have been proposed and their performances have been compared. The framework of the proposed hybrid models used in [17] is shown in Figure 3.

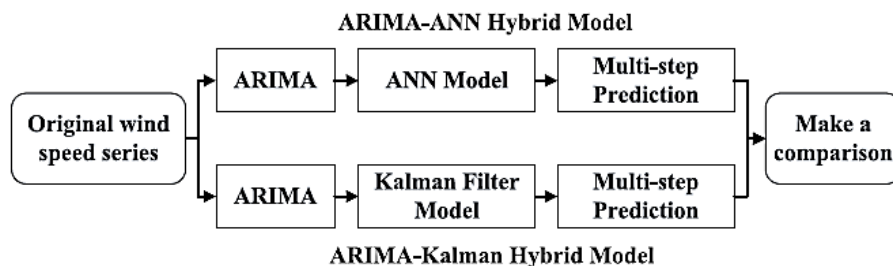


Figure 3. The framework of the proposed hybrid models in [17]

Paper [18] presented a technique for the estimation of the wind speed in order to be used for the control of a variable speed stall regulated wind turbine. The algorithm in [18] consists of a Kalman filter for estimation of states such as rotor speed and Newton-Raphson method for estimation of wind speed (see Figure 4). In this paper, the Kalman filter is improved with adaptive algorithms that estimate the unknown covariances of the process and measurement noises.

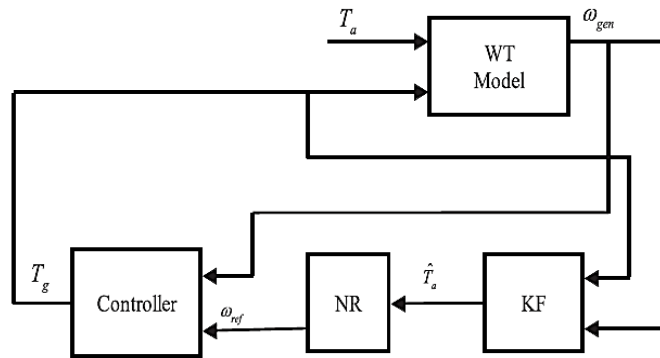


Figure 4. Control scheme used in [18]

In Ref. [19] rotational speed reference is determined by aerodynamic torque estimation using Kalman filter. Adaptive optimal fuzzy system for rotational speed control is presented basis of mechanical and electrical parts of wind turbine equations.

In [21] two mass model based estimation of effective wind speed have been proposed. In this paper the generator torque as shown in Figure 5 is controlled with nonlinear static and dynamic state feedback. The estimator used is the Kalman filter.

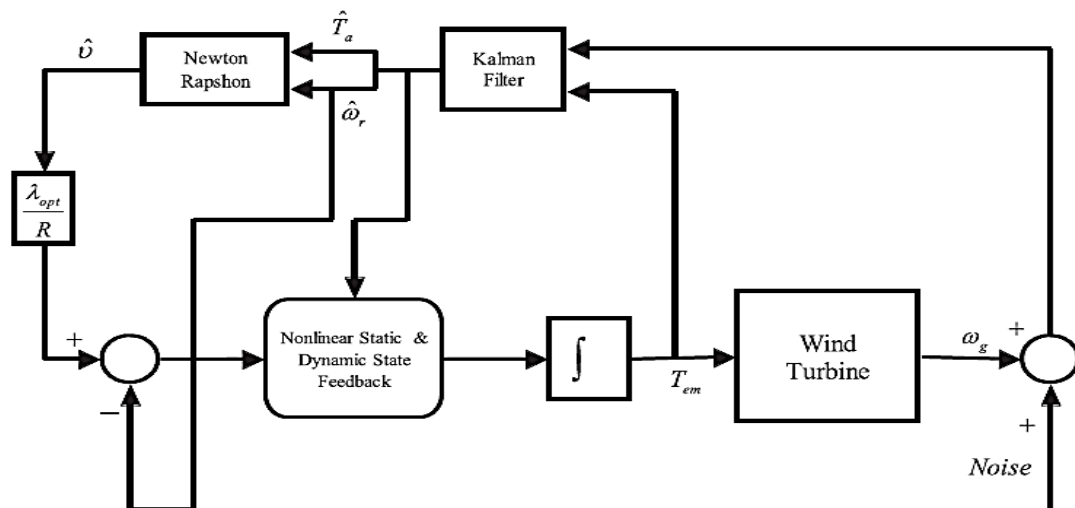


Figure 5. Control scheme used in [21]

In [22], a Higher Order Wavelet Neural Network (HOWNN) trained with an extended Kalman filter is proposed to solve the wind forecasting problem. In this paper, a Kalman filter algorithm is used to update the synaptic weights of the wavelet network. In paper [23], wind turbine state and parameter based on a dual Kalman filter theory have been estimated. The dual Kalman filter scheme is shown in Figure 6. The results in [23] show that the wind speed and rotor speed in below and above rated wind speed can be estimated with a high quality.

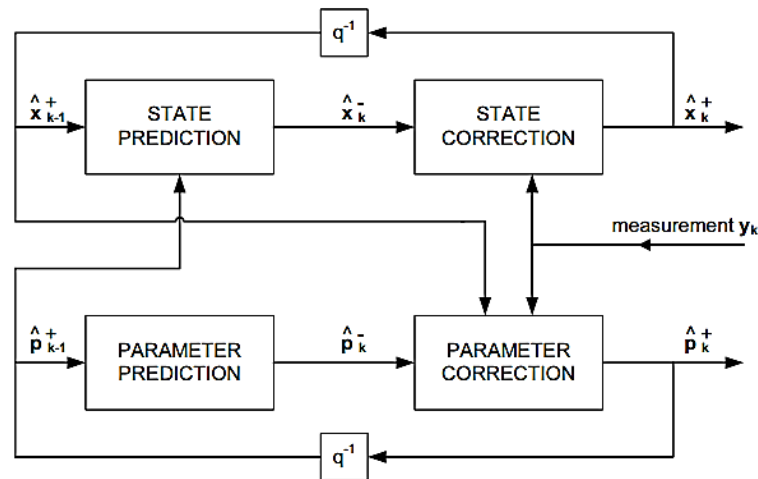


Figure 6. Dual Kalman filter scheme [23]

4. CONCLUSION

To control the variable speed wind turbines, the wind speed measurement is required. Normally, the wind speed provided by the anemometer. Using anemometer increases the system cost, maintenance, complexity and reduces the reliability. Accurate wind speed estimation found to be useful in terms of growth in energy capture. In this research, a review has been done on the effective estimation of wind speed. Practically all the important wind speed estimation techniques based on Kalman filter applied to wind turbines have been carefully discussed.

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