Performance Analysis of Time Series Forecasting Models for Short Term Wind Speed Prediction

Alper Kerem[1], Ismail Kirbas[2], Ali Saygin[33]

Abstract

Being incontrollable and variability of wind power can lead to problems in terms of power quality, production-consumption balance and power system reliability in the networks with high wind power. Wind speed forecasting methods with high accuracy are an effective tool that can be used to minimize these problems. In this study, 63m wind measurement station has been assembled with corresponding wind sensors in Mehmet Akif Ersoy University campus and the system has been engaged. From the recorded data total 4464 wind data of March 2014 have been studied and 8 different models (random walk, linear trend, quadratic trend, simple moving average, ARIMA (1,0,2), ARIMA (2,0,1) ,ARIMA(2,0,2) ,NARX) have been developed by using time series forecasting methods. Performance analyses have been carried out by using Root Mean Square Error (RMSE) method and comparison of model performances of developed models have also been carried out. The developed models make wind speed estimations when two consecutive wind speed data is entered. According to the results it has been seen that the most successful model is Nonlinear Autoregressive with External Input (NARX) obtained with the use of artificial neural network and as a result of running of this model regression coefficient has been found as 97.82%, RMSE value has been found as 0.80. Consequently, the results show that the developed NARX model is quite effective for short term wind speed prediction.

Keywords: *ARIMA, NARX, time series analysis, wind speedforecasting, wind speed prediction*

1 INTRODUCTION

The wind energy is fast growing among all the renewable energy sources because of its high efficiency and low pollution. The power created by the wind energy transformation systems directly depends on wind speed and atmosphere meteorology. However, the untidy behaviour of wind is a great challenge to the steadiness and consistency of power system. The fluctuations of the power generation can cause operating expenses for the electricity, and places potential risks to the reliability of electricity supply. For this reason, wind speed forecasting is helpful for unit assurance, economic dispatch and power system operations [1].

The wind power system workers have to forecast variations of the wind power production to accomplish the grid processes, and to plan the spinning backup capacity. In order to increase the wind power penetration and shrink the reserve capacity, more precise predicting of wind speed is an essential need [2].

Moreover, wind speed forecasting is important because it has a significant role in the allocation of balancing power. In addition, wind speed estimating is used for transaction of electricity and the day-ahead scheduling of conventional power plants [3].

2 DATA ACQUISITION

First of all, in order to obtain real-life data about the potential of wind power generation in the Istiklal campus of Mehmet Akif Ersoy University, a wind measurement station was settled [4]. Before the settlement, coordinate determination works have carefully been performed in the campus for the construction of wind measurement station in the campus. For this purpose, different points in the field have been visited at different times and wind speeds were observed. Based on the criteria in the literature, the most appropriate point at the field has been identified as UTM E 263254 and N 4173479 coordinates at 1313m altitude. Wind measurement station has been constructed to detected coordinates, wind speed sensor, wind direction sensor, temperature and humidity sensor, pressure sensor and data

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logger has been assembled. System has been engaged and data has been tracked. Schematic illustration of the measuring stations is given in Figure 1.

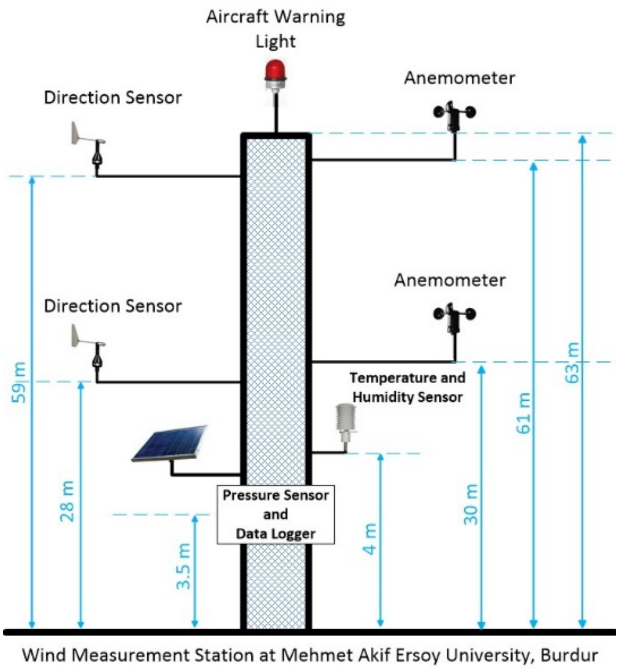

Figure 1. Schematic illustration of the wind measuring station

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For this study, wind speed measurement was carried out in 10 minute intervals at the wind measurement station during the month of March 2014. A total of 4464 pieces of data are obtained and converted into a time series for further analysis of this data. Figure 2 depicts daily based average wind speed measurements.

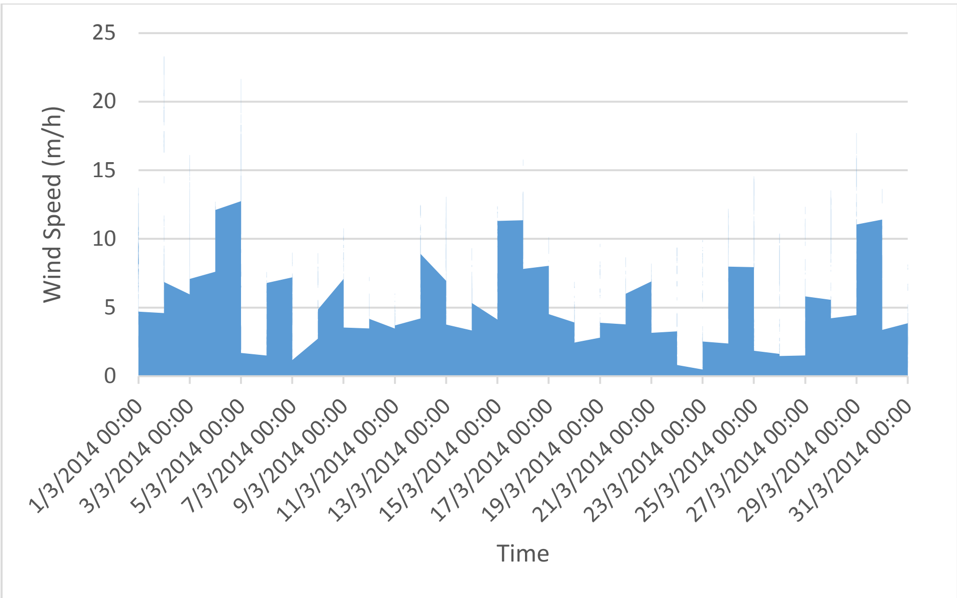

Figure 2. Daily based average wind speed measurements in March 2014

Table 1 also gives some fundamental statistical information about collected data.

Table 2. Statistical results for wind speed measurement.

Statistical Calculation	Value
Average	6.424

Standard Error	0.055
Standard Deviation	3.740
Median	5.926
Variance	13.989
Skewness	0.340
Kurtosis	0.701
Range	23.310
Maximum	23.310
Minimum	0
Total	28677.409
Quantity	4464

Measurements were made has a volatile results as shown in Figure 2 and table 1 respectively. For short term wind speed prediction, eight different methods are investigated and compared in the rest of the paper.

3 TIME SERIES FORECASTING MODELS

Statistical methods purpose discovering the relationship of the gathered data. The historical data of the wind speed can be used for a statistical model easily. Statistical models are low-cost to develop compared to other models and useful to model. Principally, statistical approach is reliable especially for short time periods. The main disadvantage of the approach is that the forecast error rises as the estimation time rises [1].

Statistical methods mainly contain the auto regressive (AR), auto regressive moving average (ARMA), auto regressive integrated moving average (ARIMA), grey predictions and Bayesian approach. These techniques can be used to answer the questions in finance, natural sciences and engineering that have countless data where the observations are inter-reliant [1].

Firat et al. [5] suggested a new statistical process using independent component analysis and AR model. According to acquired results, the projected technique noticeably provides higher precision compared with direct forecasting.

Erdem and Shi [6] projected 4 methods based on ARMA method for the forecasting of the wind direction and speed. The outcomes revealed that the component model is much better at forecasting the wind direction than the traditional-linked ARMA model, although the contradictory is detected for wind speed predicting.

Palomares-Salas et al. [7] used an ARIMA model for time-series forecast including wind speed measurements. Their work grants the method of model validation with a regression analysis. The obtained results confirm that ARIMA model is superior to back propagation neural network for short time-intervals.

In recent times, various new techniques for wind speed and power forecast have been developed with the advance of artificial intelligence. The new developed methods embrace fuzzy logic methods, neuro-fuzzy network, artificial neural network (ANN), support vector machine (SVM), and evolutionary optimization algorithms and adaptive neuro-fuzzy inference system (ANFIS).

ANN could handle complex and non-linear problems in terms of forecasting or classification. ANN based method is a suitable way to apply into the problem to predict the wind speed.

Chang [8] offered a technique using RBF neural network to forecast wind speed. Zeng and Qiao [9] projected a SVM-based technique to predict wind power.Guo et al. [10] studied a modified empirical mode decomposition based on feed-forward neural network. Sfetsos [11] introduced an ANN technique for the predicting of mean hourly wind speed data by means of time series analysis. Yang et al. [12] proposed an ANFIS method to interpolate the invalid and missing data. Chang [13] suggested a wind speed predicting approach based on back propagation neural network.

In this study, we have used 7 different statistical time series forecasting models. Table 2 shows model abbreviations from A to G and their model names respectively.

Table 2.Model abbreviations and model names.

Model Abbreviations	Model Name
A	Random walk
B	Linear trend = 7.24416 + -0.000367306 t
C	Quadratic trend = 9.31918 + -0.00315506 t + 6.24356E-7 t^2
D	Simple moving average
E	ARIMA(1,0,2)
F	ARIMA(2,0,1)
G	ARIMA(2,0,2)

Statistical methods can be modelled effortlessly and it is inexpensive compared to other techniques. They process the former wind data to estimate the present over the next few hours. This approach are successful especially for short time periods. The main weakness of the statistical method is error value growths with the forecast time. These approaches are mainly used to forecast up to six hours in advance.

The auto regressive moving average (ARMA) is a recognised model which is based on time series analysis. The main purpose of the ARIMA method is to predict the future value of time series, benefiting from its past values and the past forecast errors. It is popular because it can handle any series, with or without seasonal elements. ARIMA model has three parts as auto regressive, integrated, and moving average. At the same time, the model is also known as Box-Jenkins approach and can give the reliable predicting outcomes within 1 to 2 hours. Equation (1-4) define 4 different ARIMA models as following.

$$ARIMA(1,0,0)y_t = a_1 y_{t-1} + \varepsilon_t \quad (1)$$

$$ARIMA(2,0,0)y_t = a_1 y_{t-1} + a_2 y_{t-2} + \varepsilon_t \quad (2)$$

$$ARIMA(2,0,1)y_t = a_1 y_{t-1} + a_2 y_{t-2} + b_1 \varepsilon_{t-1} \quad (3)$$

$$ARIMA(2,1,0)\ \Delta y_t = a_1 \Delta y_{t-1} + a_2 \Delta y_{t-2} + \varepsilon_t\,,\ \ where\ \Delta y_t = y_t - y_{t-1} \quad (4)$$

In literature, there are many statistical evaluation method to evaluate the developed models. In this study we choose mean error (ME), mean absolute error (MAE), mean squared error (MSE), root mean squared error (RMSE), Akaike information criterion (AIC), Hannan–Quinn information criterion (HQC) and Schwarz-Bayesian information criterion (SBIC). As the root mean squared error method is preferred as the main evaluation criteria, each model has been evaluated using the model evaluation methods given in Table 3.

Table 3. Model evaluation methods.

The mean error (ME)	$ME = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)$
The mean absolute error (MAE)	$MAE = \frac{1}{n}\sum_{i=1}^{n}\lvert y_i - \hat{y}_i\rvert$
The mean squared error (MSE)	$MSE = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2$
The root mean squared error (RMSE)	$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$
Akaike information criterion (AIC)	$AIC = 2k - 2\ln(L)$
Hannan–Quinn information criterion (HQC)	$HQC = -2 \cdot L_{max} + 2k \cdot log \log n$
Schwarz-Bayesian information criterion (SBIC)	$SBIC = -2 \cdot \ln \hat{L} + k \cdot \ln(n)$

The results obtained from the statistical model evaluation criteria are shown in Table 4.

Table 4. Statistical model evaluation results.

Model	***RMSE***	***MAE***	***ME***	***AIC***	***HQC***	***SBIC***
A	0.834294	0.579629	-0.00118642	-0.362339	-0.362339	-0.362339
B	3.71065	3.04828	9.58115E-16	2.62331	2.62432	2.62618
C	3.59325	2.9544	1.41705E-13	2.55946	2.56098	2.56376
D	0.940994	0.658987	-0.00171022	-0.12119	-0.120684	-0.119755

E	0.831831	0.577612	0.0385374	-0.366909	-0.365392	-0.362605
F	0.832543	0.577968	0.0404928	-0.365198	-0.36368	-0.360894
G	0.832559	0.57791	0.0402586	-0.364711	-0.362688	-0.358973

Artificial neural networks (ANN) are known as the best solution for predicting the time series. Artificial neural networks modelling motivation was specified by human intelligence. So there is a solid relation between organic neurons and artificial neural networks.

The Nonlinear Autoregressive with External Input (NARX) neural network model, which is developed in MATLAB software, is shown in figure 3.

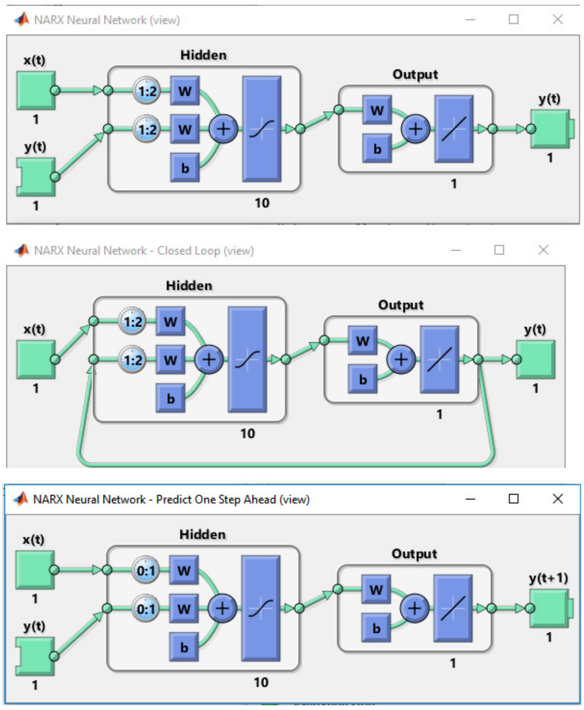

Figure 3. The Nonlinear Autoregressive with External Input (NARX) neural network model developed in MATLAB software.

NARX networks can learn to forecast one time series given past values of the same time series. These networks can be expressed as Equation 5 wherein given d past values of $y(t)$ and another series $x(t)$.

$$y(t) = f(x(t-1), \dots, x(t-d), y(t-1), \dots y(t-d)) \quad (5)$$

The developed network model has 10 neurons in hidden layer and 1 neuron for output layer. For network training, 3124 pieces of data were selected randomly, then the network model was validated with 670 measurement values. Finally, the trained network was tested with 670 different data. Obtained results and error values can be seen in Table 5.

Table 5. The evaluation results for NARX neural network model.

	Target Values	MSE	RMSE	R
Training	3124	0.6696	0.8182	0.9757
Validation	670	0.7169	0.8466	0.9740
Testing	670	0.6392	0.7994	0.9782

Figure 4 shows output response of the developed network including the error graph.

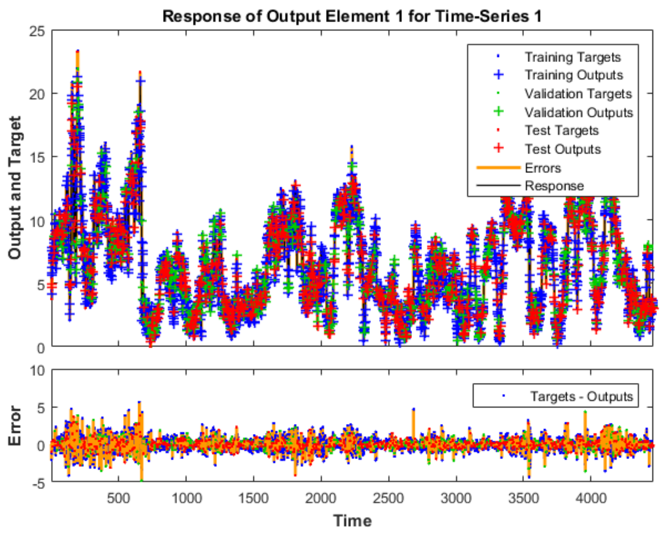

Figure 4. The model evaluation results for NARX model.

Figure 5 also gives a detailed picture and information obtained from training, validation and test phases. Calculated R values are converging to 1 means that the created network model almost exactly fits the problem.

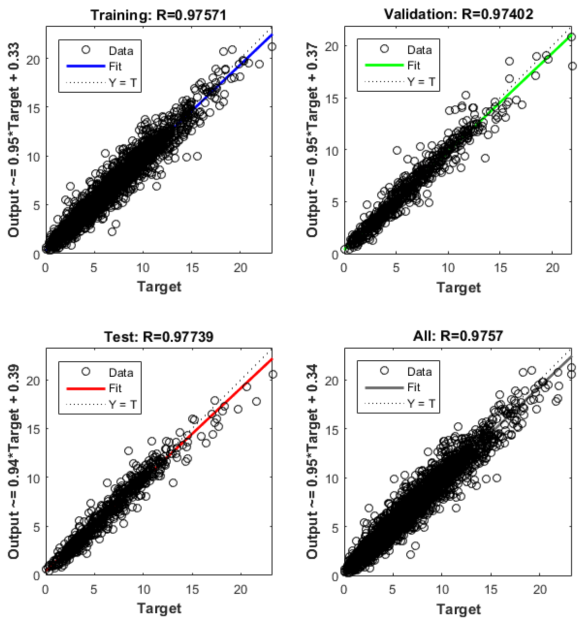

Figure 5. Graphical results for NARX model evaluation.

4 CONCLUSION

In this study, we have established a wind measurement station in in the Istiklal campus of Mehmet Akif Ersoy University to reveal the potential of wind power generation. Well-directed forecasting of wind speed is essential to predict generated electric energy. Thus, we tried to estimate next wind speed values according to past ones accurately as possible. For this reason, eight different methods are investigated and compared according to evaluation criteria such as mean error, mean absolute error, mean squared error, root mean squared error, Akaike information criterion, Hannan–Quinn information criterion and Schwarz-Bayesian information criterion.

In accordance with the results obtained, ARIMA models and NARX neural network model appear more successful than others. If we consider root mean square error values as the main criteria, NARX neural network model has the best RMSE and R values. Three ARIMA models (ARIMA(1,0,2), ARIMA(2,0,1) and ARIMA(2,0,2)) are following it.

This study finds out that NARX neural network model and ARIMA models can be used for short time wind speed prediction in reliable fashion.

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