
# Wind Power Estimation from Forecast Wind Data

**S.N.M.Deros, A. Asmat and S. Mansor**
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Name of the Presenter: Siti Noratiqahbinti Mohamad Deros

**Abstract**

Efficient wind power production forecasting requires wind speed pattern study. Monthly wind data is insufficient to derive the pattern of wind speed. Long-term study of wind data was presented in this study to model the wind pattern. This study aims to estimate wind power from forecast wind data. Ten years of daily wind speed data set in Langkawi was used to retrieve the pattern of wind. Qualitative analysis used to study the annual characteristic of the wind. Several of time series models were tested with penalty function criteria method to identify the suit model. Forecast wind speed was derived from the model and thus wind power capacity was estimated by using kinetic energy formulation. Mean of annual data is 2.306 m/s and categorized as low wind speed with standard deviation 0.657 which means the wind speed was self-consistent. The suit model identified was Seasonal Autoregressive Integrated Moving Average (SARIMA) (1,1,3)×(1,1,1). Wind energy forecasted at Langkawi shows that the energy in Northeast monsoon is highest with average of9.61 Watts per second in a meter square.

**Key words**: Long-term Forecasting, SARIMA Model, Time Series, Wind Power and Wind Speed

## 1. Introduction

The increasing trend was forecasted by Azizul*et al.*, (2010) in their study on future scenario of Malaysian energy consumption from 29016850MWh (Megawatt hour) in 2008 to 51137110MWh by 2020. This consuming trend will lead to the running out of Malaysia's energy sources. The exhaustion of main energy sources, 57.6% from natural gas and 38.8% coalwas predicted to occur in 2017.Thus, Malaysia made an effort to explore renewable energy from various sources since 2001.Among all renewable energy sources, wind can be reliable and cost-effective energy sources compared to solar, biomass, hydro and many more. However, the study of wind behavior is a must to forecast the power capacity in one regional area and optimize the energy generation.

According to Battacharya (2011), wind speed is a parameter that highly influenced wind power capacity. Wind speed in Malaysia depends on geographical and meteorological factor. Location of Malaysia near to the Earth equator inducing four climatic seasons experienced throughout the year. Consist of two monsoons and inter-monsoon respectively,their impact on windcreates seasonal pattern of wind speed. According to Siti et al., (2011) in their evaluation on potential wind energy in Malaysia, Northeast monsoon occurred from November to March gives highest wind speed each year that can reach 15 m/s compared to Southwest monsoon and inter-monsoon. Lightest wind averagely 1-2 m/s occurred in April each year during Northeast monsoon transition to Southwest monsoon.Long distance traveled by wind from Indian Ocean to Langkawi reduces the wind speed during Southwest monsoon. This happens due to large frictional force on wind with water surface thus forming large waves. This explains the reason of high wind speed during Northeast monsoon in Langkawi despite its West Coast location.

Short term study by LiangLanzhen and ShaoFan (2010) using every 10 minutes data for 30 days is useful to explain next few days wind condition. However, such study fails to show the trend pattern of wind along the year. This paper carried out long-term study to identify wind trend pattern for accurate wind speed forecast.

Wind is very high at dry air, high temperature and less friction force from hills, trees and buildings.This supported by Archer and Caldeira (2009) findings in their high-altitude wind power assessment where the wind speed at 10,000 m height produces of five the power of wind at altitude of 1000 m. Such characteristics best describe remote and near coast area especially an island, along the beach such as PulauLangkawi, Malaysia and on top of the hill.

According to kinetic energy principle, Edelstein *et al.*, (2003) concluded that wind power production is pertaining to the cube of the wind speed that moves the turbine’s blade. This is the reason why the study of wind is a vital process before any decision to construct wind-generated energy technology is made. Apart of designing an appropriate wind turbine, the estimation of power output is necessary to produce effective and productive technology. To estimate wind power capacity, long term wind data is required to forecast wind speed distribution by considering its seasonality factor.

This study aims to estimate wind power production by using kinetic energy function based on forecast wind data derived from Seasonal ARIMA model.

## 2. Data and Material

The data contains daily mean wind speed data acquired from anemometer in meter per second (m/s) unit starting January 2000 to December 2010. The anemometer was mounted at 6° 20' N Latitude and 99° 44' E Longitude by Malaysian Meteorological Department (MMD). The height of an anemometer above Mean Sea Level (MSL) is 6.4 meter with the tower height is 10 meter from the ground.

## 3. Research Methodology

### 3.1 Wind speed Modeling and Forecasting

The monthly mean data was plotted to identify wind behavior and to determine the seasonality factor of wind speed pattern. Zuhaimi and Khairil (2005) stated that the time taken of data to repeat its pattern for next period is seasonality span, $T$ that determined in month. In this study, the seasonality span identified from the plot is $T=12$.

Forecasting model fitting will involve four process; identification, estimation, diagnostic checking and forecasting.SARIMA model can be expressed as SARIMA $(p,d,q)\times(P,D,Q)$ form. This model consist of non-seasonal and seasonal windthat represented by degree $p$, $q$, $P$ and $Q$ as shown in Equation 1. Seasonal integration order represented as $D$ while non-seasonal integration order represented by $d$.

$$\Phi_P(L^s)\phi_p(L)\Delta_s^D\Delta^d y_t = \Theta_Q(L^s)\theta(L)\varepsilon_t \quad (1)$$

Parameter$\Delta_s^D$is defined as the seasonal difference $(1-L^s)^D$and $\Delta^d$as the non-seasonal difference $(1-L)^d$ and$\Phi$is the parameter for non- seasonal autoregressive (AR), $\phi$is the seasonal autoregressive (SAR) parameter, $\Theta$ is the parameter for seasonal moving average (SMA)and$\theta$is the parameter for non-seasonal moving average (MA).

All significant $p$, $q$, $P$ and $Q$ were considered as possible model. The fit model was examined by using penalty function criteria method based on two penalty function statistic, Akaike Information Criterion (AIC) and Schwarz/Bayesian Information Criterion (BIC) (Zuhaimi and Khairil, 2005).

The forecast method is the out-of-sample method by dividing 80% of data to in-sample dataset and 20% is the out-of-sample dataset. Five year forecast, $h$=5 of wind speed distribution was estimated. To validate the forecast wind speed, Mean Absolute Error (MAE), Root Mean Squared Error (RMSE) and Mean Absolute Percentage Error is used. The smaller value of error indicates the accuracy of forecasted wind speed data.

**3.2 Wind Power Estimation**

To estimate wind power wind power production (in Watts), kinetic energy function is used as in Equation 2 (Siti *et al.*, 2011).

$$Wind\ Power\ (Watts) = \frac{1}{2}\rho v^3 \quad (2)$$

Equation 2 explained the relationship between air density, wind speed and wind power production. The density of air, ρ at standard temperature 0°C and pressure 1 atmosphere is equal to 1.2929kg/m³. This standard was defined by IUPAC.

## 4. Result

### 4.1 Wind speed Modeling and Forecasting

Monthly mean of wind speed from year 2000 to 2010 is 2.306 meter per second (m/s) while the standard deviation is 0.657 m/s which means the data is self-consistent. The monthly mean used to plot the graph of wind speed versus month shows that the wind speed in Langkawi has various wind speed pattern. This variation influence by Southwest monsoon occurred in May to September, transition between two monsoon in October, Northeast monsoon in November to Mac and second inter-monsoon in April each year.

Four types of SARIMA have been applied as tabulated in Table 1. AIC and BIC value works by controlling the possible error and fit the measure using maximum likelihood method. From the table, it shows that SARIMA (1,1,3)×(1,1,1) has produced the smallest error.

| SARIMA | AIC | BIC |
|---|---|---|
| **(1,1,1)×(1,1,1)** | 0.703544 | 0.747660 |
| **(1,1,2)×(1,1,1)** | 0.707552 | 0.751668 |
| **(1,1,3)×(1,1,1)** | 0.275654 | 0.319770 |
| **(1,1,4)×(1,1,1)** | 0.702883 | 0.746999 |

**Table 1: AIC and BIC value of ARIMA model**

The result of the forecast data produced low error with 0.3186 root mean squared error (RMSE), 0.265 mean absolute errors (MAE) and 11.644% mean absolute percentage error (MAPE). This shows the accuracy of SARIMA (1,1,3)×(1,1,1) model to represent the wind speed data.

Figure 1 shows the plot of mean wind speed data versus 2002 to 2015 during Southwest monsoon.The forecasting starts after the first period of the sample. Only 2002 and ahead of the forecast data produced after adjustment to get the dynamic forecast.

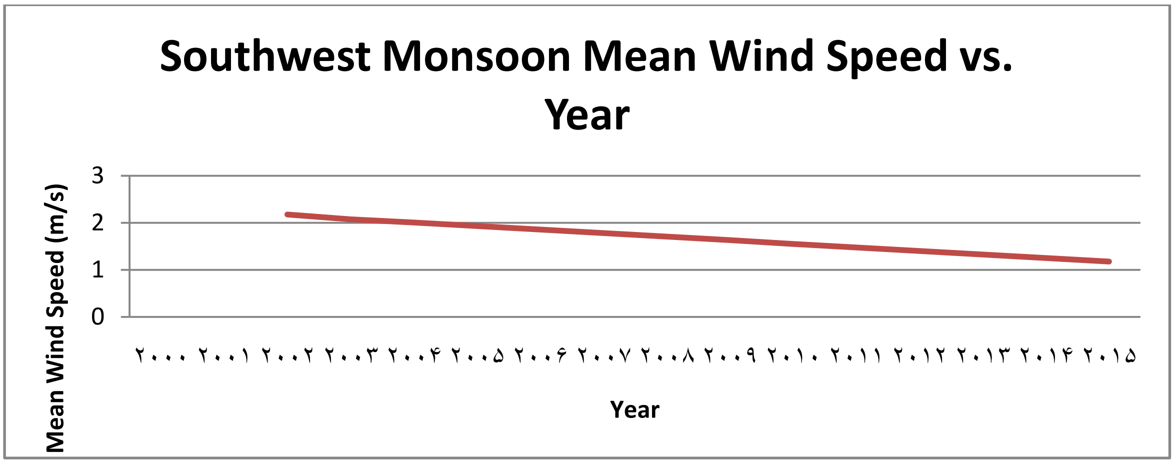


**Figure 1: Plot of Southwest Monsoon Mean Wind Speed versus Year 2002-2015**

Figure 1 depicts the speed of wind during Southwest monsoon decreases by year. Mean wind speed in Southwest monsoon atLangkawi ranged between 2.17 m/s to 1.17m/s from year

2002 to 2015. The range of the wind speed is considered as low (Siti et al., 2011). Although Langkawi facing directly to the Indian Ocean, the long journey of wind was affected by large friction force especially the waves that lower the wind speed(). The inter-monsoon occurred in October each year between two monsoons also affect the wind speed pattern in Langkawi. Figure 2 is the plot of October inter-monsoon by year.

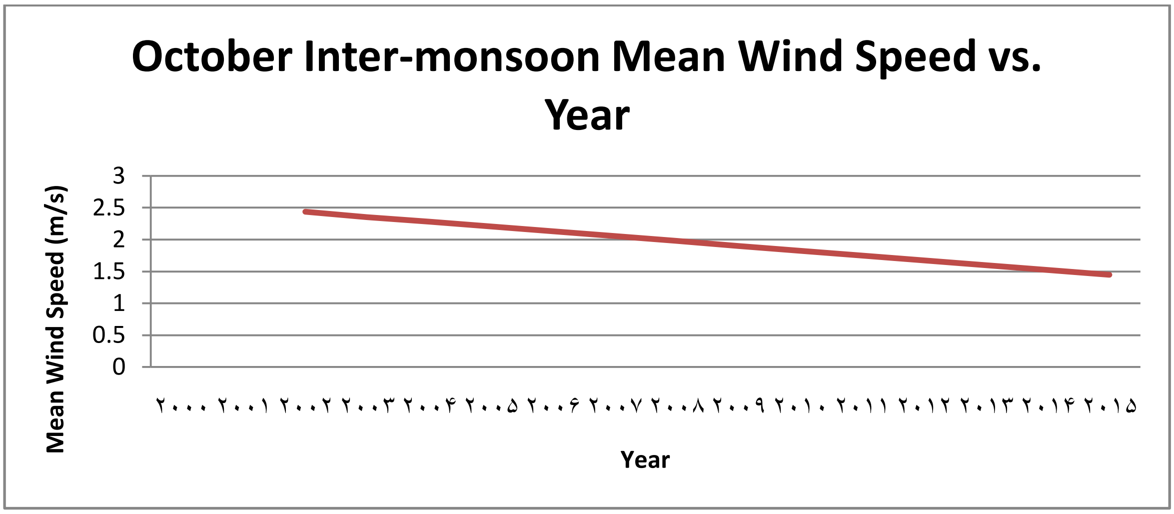


**Figure 2: Plot October Inter-monsoon Mean Wind Speed versus Year 2000-2015**

In October inter-monsoon, wind direction changes from Southwest to its opposite direction, northeast. In this inter-monsoon period, low wind speed in Southwest monsoon is slightly increases. However, from 2002 to 2015, the plot of mean wind speed in October inter-monsoon reduces significantly from 2.43 m/s to 1.47 m/s.

Hence, Northeast monsoon takes place and bring very wet climate to affected area. In Malaysia, Northeast monsoon mainly affect the east coast area. Figure 3 represents annual mean wind speed in Northeast monsoon from 2002 to 2015.

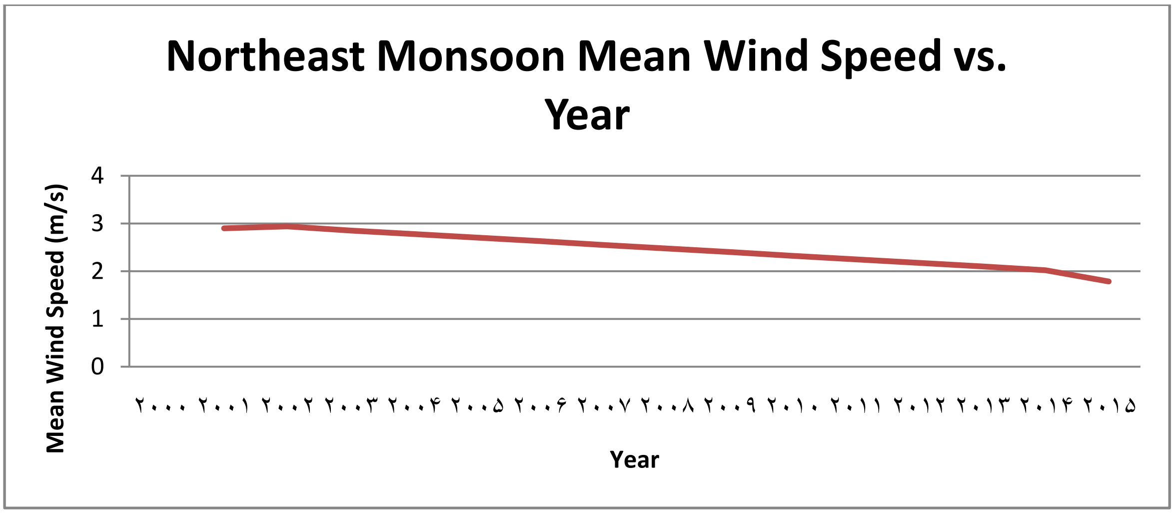


**Figure 3: Plot of Northeast Monsoon Mean Wind Speed versus Year 2002 -2015**

Wind speed in Northeast monsoon shows in Figure 3 categorized as low and medium wind speed. This monsoon produces highest wind speed among all monsoons and inter-monsoon. Wind speed in year 2002 at 2.93 m/s is the highest wind speed compared to other years. Similar with Southwest monsoon, the wind speed at Northeast monsoon decreases by year. The transition period of Northeast monsoon to Southwest monsoon occurred in April each year and the annual mean wind speed is represents by Figure 4.

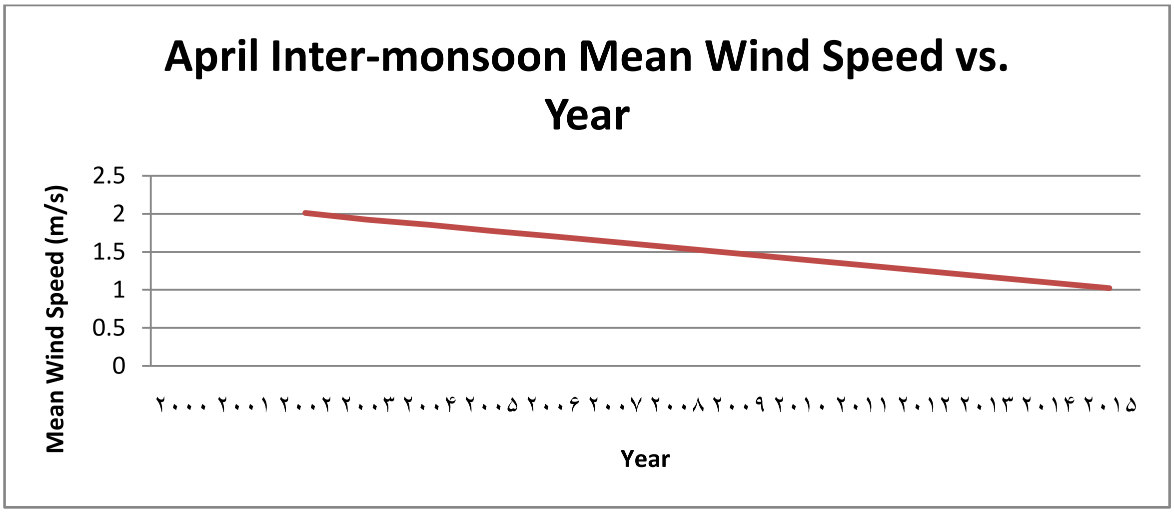


**Figure 4: Plot of April Inter-monsoon Mean Wind Speed versus Year 2002-2015**

Mean wind speed in April inter-monsoon ranged from 2.01 m/s in 2002 and reduce significantly to 1.02 m/s in 2015. These wind speed is categorized as low wind speed.

Langkawi was shielded by Titiwangsa Range from wet climate in Northeast monsoon (Jamaludin et al., 2010). However, according to the result, Northeast monsoon produces low andmedium wind speed, the highest wind speed compared to other monsoon and inter-monsoon period. The lowest wind speed observed in April inter-monsoon.

As observed through the years, wind speed decreasing from year to year. There are three possible reasons in decreasing of wind speed includes climate change, the increase of vegetation grow and urban development (Michael, 2009). Global warming that affects other area hence changing the high-altitude atmosphere circulation caused the decreasing of temperature in Langkawi. The decreasing of temperature results in the decreasing of wind speed. The increasing in vegetation and urban development, in other hands increase the friction that slower the wind speeds.

### 4.2 Wind power estimation

The average power recorded in Table 2 is the estimation of wind power production generated from one wind turbine based on seasonal mean wind speed in meter per second respectively.The average potential wind power derived from forecast wind speed per square meter area in one second shows in Table 2.

| Period | Average wind speed (m/s) | Average power (Watts) | R-squared |
|---|---|---|---|
| Southwest Monsoon | 1.667454 | 2.99 | 0.9717 |
| April inter-monsoon | 1.514476 | 2.25 | 0.9692 |
| Northeast monsoon | 2.4586139 | 9.61 | 0.9952 |
| October inter-monsoon | 1.938564 | 4.71 | 0.9808 |

**Table 2: Average wind power estimation by monsoon period**

The highest wind power production was predicted to occur in Northeast monsoon each year with average 9.61 Watts in a second at a squared meter power production. In Northeast monsoon, one wind turbine in Langkawi can generate the total wind power 124.5456 Megawatts (MW) with average of 0.83 MW each day. The second highest average wind power is in October inter-monsoon at 4.71 Watts. Along October inter-monsoon, the total wind power is 12.20832 MW. The Southwest monsoon produces averagely 2.99 Watts and April inter-monsoon 2.25 Watts wind power per second.

R-squared values of all monsoons and inter-monsoons respectively are very close to the value of 1. This indicates that the wind speed can perfectly predict the value of wind power production in any monsoon or inter-monsoon period.

The wind speed forecast shows previously decreases by year and this can results in the decreasing of wind power production. However, it can be prevented by identifying the optimum height of turbine tower. Optimum height is the height where the friction or surface roughness is minimum or equal to zero. Compared to the tower to collect the data sample that had been installed at 10 meter height and always influenced by many friction factors, the wind turbine tower should be installed at higher altitude. The determination of optimum height with friction force is zero in Langkawi area is recommended to enhance the wind speed that rotates the turbine blade. Hence, the design of suitable wind turbine with respective monsoon in Langkawi need to be developed to optimizes the production of wind power.

## 5. Conclusion

In this study, the wind speed trend pattern can be represented by SARIMA (1,1,3)×(1,1,1) model. This model development is important to forecast wind speed distribution hence estimate the site-specific wind power capacity for wind energy execution. The analysis of the data proved that Langkawi is the potential site for wind energy project implementation based on the wind speed characteristics.

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**References**

Archer,C.L.andCaldeira, K.(2009). Global Assessment of High-Altitude Wind Power, Energies, 2(2), pp. 307-319

Bari, M.A., Begum,R.A.,Jaafar,A.H.,Abidin, R.Z.R.Z.and Pereira, J.J. (2010).Future Scenario of Residential Energy Consumption and $CO_2$ Emissions in Malaysia, Universiti Malaya Conference, Malaysia.

Bhattacharya, P. (2010).A Study on Weibull Distribution for Estimating the Parameters, Journal of Applied Quantitative Methods. Vol. 5, No. 2, pp. 234-241

Edelstein, W.A., Walcek, C.J., Cox, D.L. and Davis, L.C. (2003). Wind Energy, Panel on Public Affairs (POPA), American Physical Society.

Gokhan, S. (2011). The Efficacy of SARIMA Models for Forecasting Inflation Rates in Developing Countries: The Case for Turkey. International Research Journal of Finance and Economics.(62), pp. 111-142.

Jamaludin, S., Sayang, M.D., Zawiah, W.Z.W. and Aziz, J.A. (2010).Trends in Peninsular Malaysia Rainfall Data During the Southwest Monsoon and Northeast Monsoon Seasons: 1975-2004. SainsMalaysiana. Vol. 39 (4), pp. 533-542

Krohn, S. (2009).The Economics of Wind Energy, The European Wind Energy Association, Denmark.

Lee, K., Yoo, S. and Jin, J.J.(2007).Neural Network Model vs. SARIMA Model in Forecasting Korean Stock Price Index (KOSPI), Issues in Information System Vol. 8 No. 2, pp. 372-378.

LiangLanzhen and ShaoFan. (2010).The Study on Short-time Wind Speed Prediction based on Time Series Neural Network Algorithm, *IEEE*Power and Energy Engineering Conference (APPEEC), 2010 Asia-Pacific, pp. 1-5.

Malaysian Meteorological Department (MMD).Monthly Weather Bulletin. Available at: http://www.met.gov.my

Michael, J.I. (2009). Why is the Wind Speed Decreasing?, Blue Hill Meteorological Observatory, New York.

Sheikh M.R.I. and Haque M.M. (2011).Performance of Governor System on Minimizing Frequency Fluctuations with Wind Power Generation.International Journal of Electrical and Computer Engineering.Vol. 2 (1)

Siti, M.R.S., Norizah, M. and Syafrudin, M.(2011).The Evaluation of Wind Energy Potential in Peninsular Malaysia, International Journal of Chemical and Environmental Engineering. Vol. 2, No. 4, pp. 284-291.

Soebiyanto, R.P., Adimi, F. and Kiang, R.K. (2010).Modeling and Predicting Seasonal Influenza Transmission in Warm Regions Using Climatological Parameters. PLoS ONE Vol. 5 (3).

Tajuddin, A.A. (2010). Securing a Sustainable Energy Future for Malaysia, Energy Commission, Malaysia.

Zuhaimy, H.I. and Khairil,A.M. (2005). SARIMA Model for Forecasting Malaysian Electricity Generated, JabatanMatematikUniversitiTeknologi Malaysia. Vol. 21, No. 2, pp. 143-152.