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Wind speed and power characteristics of Kalasin province, Thailand

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Abstract. This paper presents a wind energy assessment of Kalasin province in the Upper North-Eastern region of Thailand. Four year wind data were recorded continuously from January 2012 to December 2015 at different heights of 60, 90 and 120 m above ground level (AGL). The mean wind speeds were found to be 3.14, 3.63 and 3.94 m/s at 60, 90 and 120 m AGL, respectively. The majority of wind directions for this region are distributed from the East to South directions. The highest wind power density was observed in the summer season, followed by winter and rainy seasons, in order. Four commercial wind turbines were selected to estimate energy yield output using the WAsP 10.0 software application; the results show that VESTAS with rated power of 2.0 MW was estimated to give 2,747 MWh/year with the highest capacity factor of 15.68%.

1. Introduction

Currently, the energy demand of the world is increasing rapidly [1]-[3], especially energy from fossil resources such as crude oil, natural gas and coal. The use of fossil energy causes environment damage and concern about global warming effects from carbon dioxide emission [2], [4]. Renewable energy sources, such as wind, solar and biomass energy are alternatives to replace the fossil energy demand [5]. Wind energy is the one clean and free energy which can reduce energy imports and carbon dioxide emission [6], [7]. Nowadays, wind energy is studied and developed in many countries of the world, with a total installed wind capacity increasing from 23,900 MW to 486,790 MW during the period of 2000-2016. At the end of 2016, China maintained a leadership position, with total installation of 168,690 MW, followed by USA, Germany and India which were 82,184, 50,018 and 28,700 MW [8], respectively.

Regionally, wind energy potential was studied in Hong Kong by Z.R. Shu et al. [9]. The 6- year wind data statistics were used to analyse 4 different meteorological stations; the annual Weibull scale and shape parameter varied from 2.85 to 10.19 m/s and 1.65 to 1.99, respectively. A stationary rooftop wind mast and mobile Light Detection and Ranging (LiDAR) were used to measure wind data from 3 sites in Singapore by B.R. Karthikeya et al. [10]. The offshore west coast of Taiwan was studied for wind farm installations using mesoscale and excellent wind performance was also found by Hsin-Fa Fang [11]. Wind speed and economic analysis in the central region of Thailand [12] was studied, and it was found that the annual mean wind speed was between 3 m/s and 5 m/s along the direction of tropical monsoons, which is suitable for small-scale wind turbine application. W. Huang et al. [13] used the CMO (Cell Membrane Optimization) method to place wind turbine positions in a square 2x2 km wind farm; the results show that it can reduce wake loss in the wind farm.

This paper presents micro siting of wind energy resource assessment in Kalasin province of Thailand. The 4-year mean wind speeds by season, month and day and the wind directions were analyzed.The selected wind turbines were used to estimate energy output for this region.

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2. Location of wind measurement site.

Kalasin province (K site) is one wind energy resource assessment site in the upper north-east Thailand project. The distance from Bangkok to the measurement site is approximately 450 kilometers and it is located at 16.900°N, 103.329°E and 175 meter above sea level (ASL) as illustrated in Figure 1. The 4-year wind data were recorded continuously by sampling intervals of 10 min from January 2012 to December 2015. The 120 meter NRG tower mast was installed and wind measurement accessories such as the 3-cup anemometers and wind guide vanes were mounted on the mast with different heights of 60, 90 and 120 meters above ground level (AGL) as shown in Figure 2 and Table 1.

Figure 1. Wind measurement site (K)

Figure 2. Installation of wind mast and devices

Table 1. Equipment specification

Equipment	Details	Manufacturer
120 m mast tower	Guyed Lattice Mast	
NRG#40C	3-cup type, Measuring range 1-96 m/s	NRG System
Wind Vane NRG#200P	Measuring range 0-360 degree, -55 to 60 degree C	

3. Results and Discussion

3.1. Wind speed characteristics, Annual, Monthly and Daily wind speed

The annual mean wind speed in the time series chart from 2012 to 2015 of the K site at different heights of 60, 90 and 120 m AGL is illustrated in Figure 3. From the data we observe that the wind speed has not much variation over all seasons in a year. Figure 4 reveals the daily wind speed; a higher wind speed at the K site was observed at night time between 18:00 and 7:00 of the next day. The maximum wind speed was 5.01, 4.48 and 3.61 m/s at 21:00 while the minimum wind speed was 2.89, 2.74 and 2.56 m/s at 8:00 for the heights of 120, 90 and 60 m AGL, respectively. Figure 5 shows that the monthly wind speed did not fluctuate much over all seasons and all heights above ground level. The highest mean wind speed was observed in December to be 4.29 m/s and the lowest in September to be 3.32 m/s at 120 m AGL and similar trends were also observed at 90 and 60 m AGL. The annual mean wind speeds at 60, 90 and 120 m AGL were 3.14, 3.63 and 3.94 m/s respectively, as presented in Table 2. The seasons of Thailand are classified to be 3: Rainy is from June to October; Winter is from November to January and Summer is from February to May.

The mean wind speed (U_m) and standard deviation (σ) are expressed as

$$U_m = \frac{1}{N}\left[\sum_{i=1}^{N} U_i\right] \tag{1}$$

$$\sigma^2 = \frac{1}{N-1}\left[\sum_{i=1}^{N} (U_i - U_m)^2\right] \tag{2}$$

where U_m is the mean wind speed, U_i is the wind speed which is averaged over the time interval, N is the number of wind data points and σ is the standard deviation.

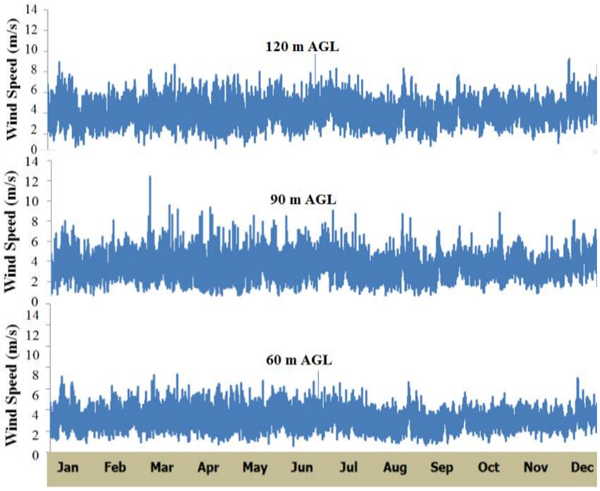

Figure 3. Wind speed in the time series

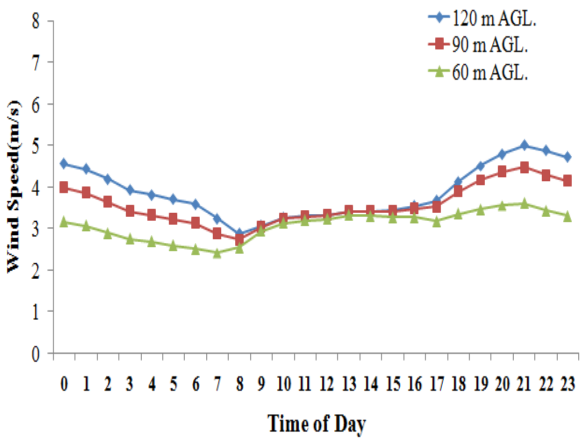

Figure 4. Daily wind speed variation

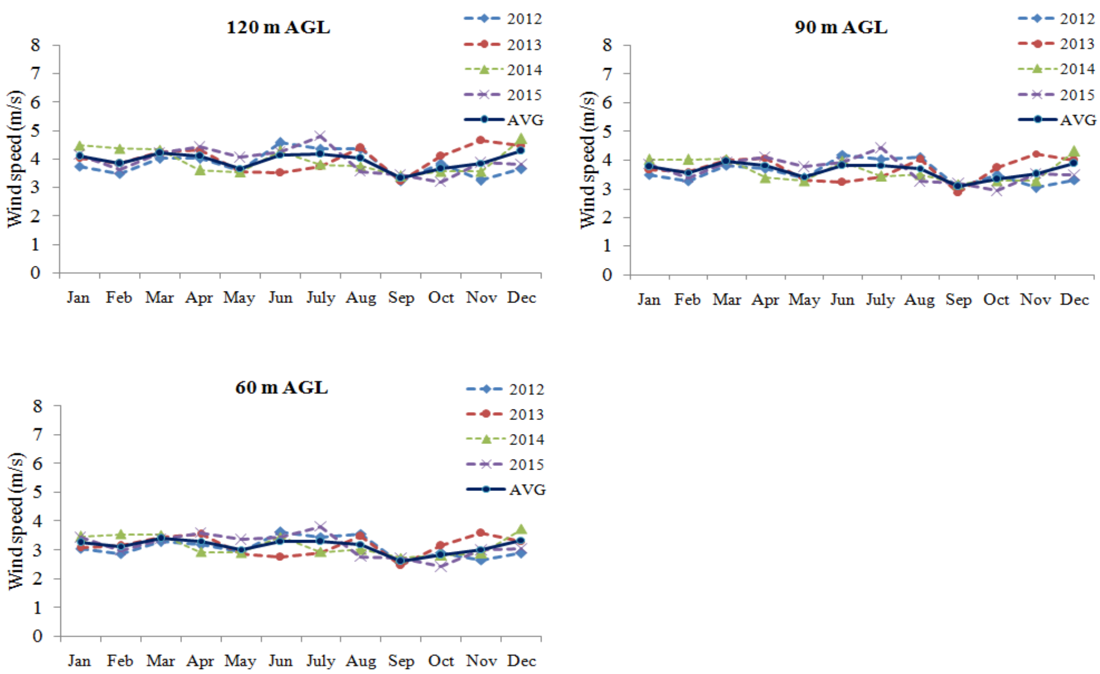

Figure 5. Monthly wind speed variation

3.2. Weibull distribution function analysis and wind direction

The 2 parameters of the Weibull distribution function were used to characterise wind data behavior [5], [9]. This paper presents interval bins of 1 m/s and the Weibull probability function is expressed as [9]

$$f(u)=\left(\frac{k}{c}\right)\left(\frac{U}{c}\right)^{k-1}\exp\left[-\left(\frac{U}{c}\right)^{k}\right]\quad(u>0;k,c>0) \tag{3}$$

$$k=\left(\frac{\sigma}{U_m}\right)^{-1.086}\quad(0\le k\le 10) \tag{4}$$

$$c=\frac{U_m}{\Gamma(1+1/k)} \tag{5}$$

where k is the dimensionless shape parameter, c is the scale parameter (in units of m/s) and Γ is the Gamma function.

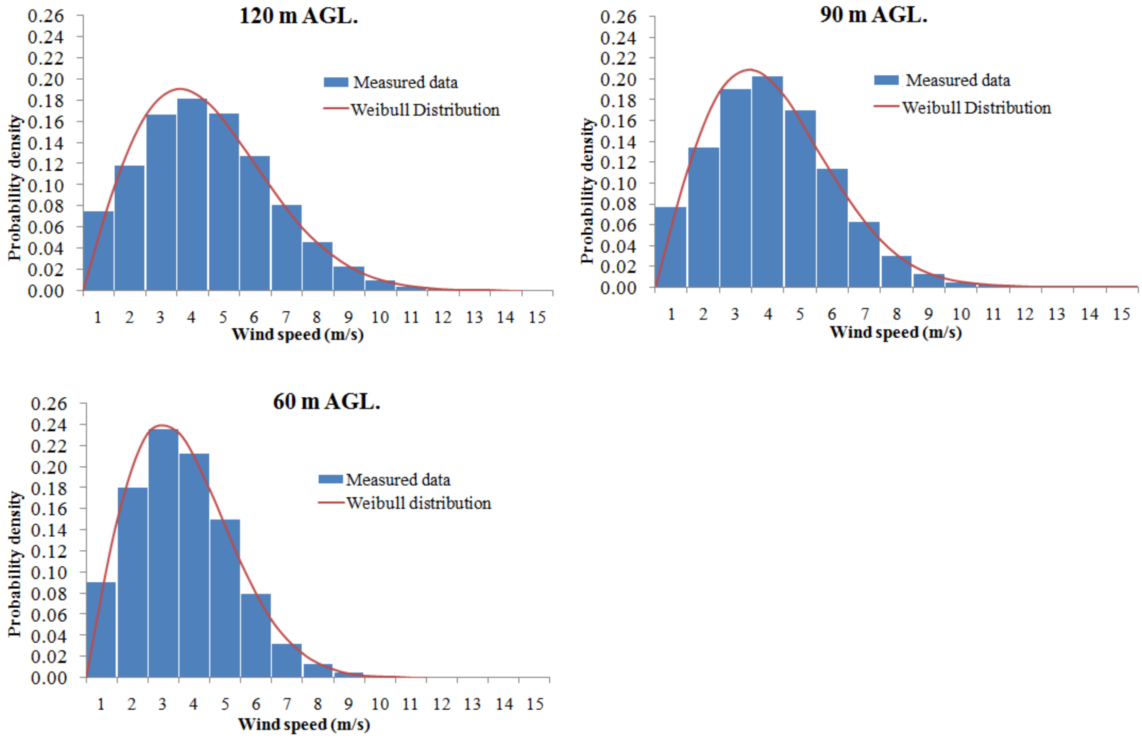

Figure 6. Actual wind speed frequency distribution and Weibull curve

Figure 6 shows the actual wind speed frequency distribution and the Weibull curve at 120, 90 and 60 m AGL. There is good correspondence between the 2 parameter Weibull curves and the actual wind speed bins. Generally, the cut in wind speed for the wind turbine is 3.0 m/s and from the Weibull curve we can estimate the percentage of wind frequency distribution above 3.0 m/s. The results show that 49%, 59% and 63% at 60, 90 and 120 m AGL respectively are above the threshold. Moreover, from the Weibull curve comparison in each season at 120 m AGL as presented in Figure 7, the shape parameters were 2.22, 2.08 and 1.93 in the winter, rainy and summer seasons, respectively. Table 2 presents a summary of the mean wind speed (U), Weibull shape parameter (k) and scale parameter (c). The maximum wind speed is shown in the winter to be 4.04 m/s at 120 m AGL. The value of the scale parameter (c) increases with height and is highest in the winter at 4.70 m/s at 120 m AGL, and the highest value of the shape parameter (k) was observed in winter. The wind rose at level

120 m AGL for this region was presented in Figure 8. The greatest frequency was observed in East to South, and similar results were also observed at 90 and 60 m AGL.

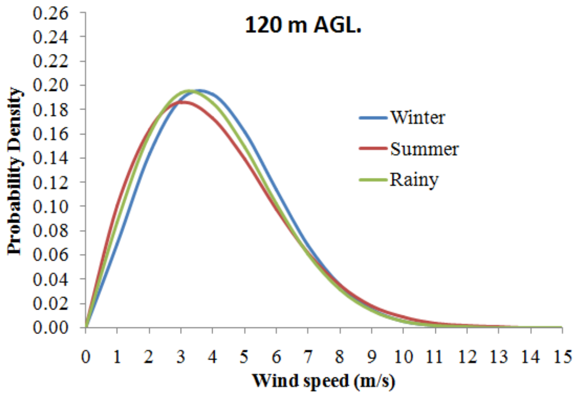

Figure 7. Weibull curve of the seasonal

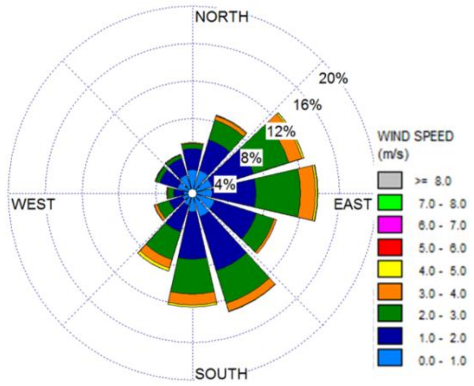

Figure 8. Wind direction at 120 m AGL

Table 2. Summary of Weibull parameters of the K site from 2012-2015

Period	Parameter	Height above ground level		
		120 m	90 m	60 m
Annual	U (m/s)	3.94	3.63	3.14
	k	1.97	2.00	1.99
	c (m/s)	4.45	4.10	3.54
Winter	U (m/s)	4.04	3.68	3.17
	k	2.22	2.24	2.18
	c (m/s)	4.70	4.20	3.60
Summer	U (m/s)	3.95	3.68	3.22
	k	1.93	1.97	1.97
	c (m/s)	4.50	4.20	3.70
Rainy	U (m/s)	3.87	3.55	3.05
	k	2.08	2.06	1.94
	c (m/s)	4.50	4.10	3.50

3.3. Wind power density and wind shear coefficient

The average of the wind power density for this area can be expressed as [12]

$$P_{av} = \int_0^{\infty} P(u) f(u) du \tag{6}$$

In terms of shape (k) and scale (c) parameters, the average wind power density can be determined as

$$P_{av} = \frac{\rho c^3 \Gamma(1+3/k)}{2} \tag{7}$$

Where P_{av} is the wind power density based on an air density (ρ_{air}) of $1.225\, kg/m^3$ .The following equation was used to estimate the wind shear coefficient (WSC), α

$$\alpha = \frac{\ln(U_2) - \ln(U_1)}{\ln(Z_2) - \ln(Z_1)} \tag{8}$$

where U_1 and U_2 are the wind speeds at heights Z_1 and Z_2, respectively.
Figure 9 presents the wind power density for this region; the value increases with the height and the maximum value is found in the summer season to be 78 W/m^2, and to be 75 and 69 W/m^2 in the winter and rainy season at 120 m AGL, respectively. A similar trend is also observed at 90 and 60 m AGL. However the wind power density for this region can be classified in the poor condition [5].

$\overline{P}/A < 100\ W/m^2$ is poor, $\overline{P}/A \approx 400\ W/m^2$ is good and $\overline{P}/A > 700\ W/m^2$ is excellent.

Wind Shear Coefficient (α) for this region was calculated based on daily wind speed between 60 - 90 m, 90 - 120 m and also 60 - 120 m AGL. The value started increasing from 15:00 till midnight and was quite stable until 06:00, and then suddenly decreased within 3 hours from 06:00 to 9:00, and then was quite stable again from 09:00 until 15:00 as presented in Figure 10. The average value of wind shear coefficient for this region was 0.35, 0.26 and 0.31 for between 60-90, 90-120 and 60-120 m AGL, respectively. Wind shear coefficient is used to predict the wind speed profile in the vertical direction from the ground which is suitable for the hub height of the wind turbine.

3.4. Wind turbine selected and energy output
The annual energy production (AEP) and plant capacity factor (CF) can be calculated as:

$$AEP = 8760 \int_{U_{ci}}^{U_{co}} p_t(u) f(u) du \tag{9}$$

$$CF = \frac{AEP}{P_r x 8760} \tag{10}$$

where U_{ci} and U_{co} are the cut in and cut out speed of the wind turbine while P_t and P_r are the power curve and rated power of the wind turbine, respectively.

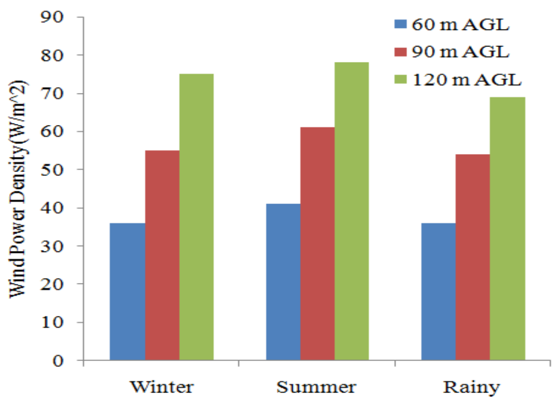

Figure 9. Wind Power Density

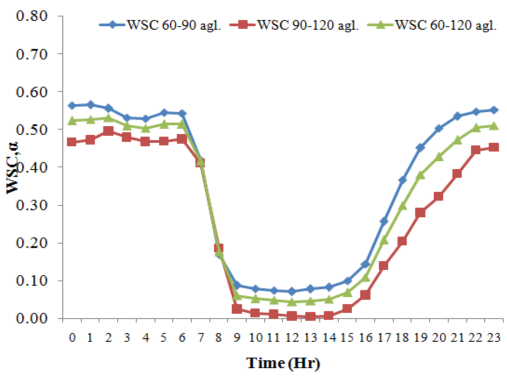

Figure 10. Wind Shear Coefficient

For this study, WAsP 10.0 software licensed by Khon Kaen University was used to estimate the energy yield output of the wind turbine plant. The selected wind turbines and technical data are presented in Figure 11 and Table 3; most wind turbines have a cut in speed of 3.0 m/s. Annual Energy Production (AEP) output and Capacity Factor (CF) of selected wind turbines are shown in Figure 12. The maximum AEP of 3,255 MWh/year can be achieved from the VESTAS 3.3 MW wind turbine, followed by VESTAS 2.0 MW, BONUS 1.3 MW and Nordex N43 wind turbines with the values of 2474, 319.1 and 248.3 MWh/year, respectively. However the capacity factor of the wind turbines have values of 15.68%, 11.16%, 4.72% and 2.80% for VESTAS 2.0 MW, VESTAS 3.3 MW, Nordex N43 and BONUS 1.3 MW, respectively. The Capacity Factor of the wind turbine was calculated based on the actual energy output in a year and the energy output at rated speed (maximum energy output) of the wind turbine. It can be used to consider the wind turbine plant installation and grid connection. However, for this region the capacity factor of selected wind turbines were quite low, so it should be recommended as a small scale wind turbine application or local application, combined with solar energy [12].

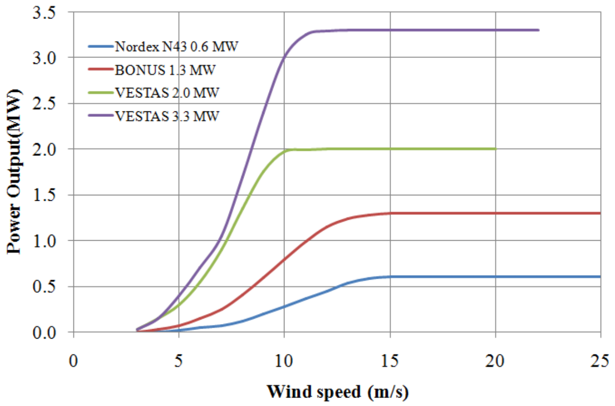

Figure 11. Power curve of selected wind turbines

Table 3. Technical data of selected wind turbines

Selected WTG	Cut-in Speed	Cut-out Speed	Hub Height	Rotor Diameter
Nordex N43 0.6 MW	3	25	78	43
BONUS 1.3 MW	3	25	60	62
VESTAS 2.0 MW	3	20	125	110
VESTAS 3.3 MW	3	22.5	117	126
(Unit)	m/s	m/s	m	m

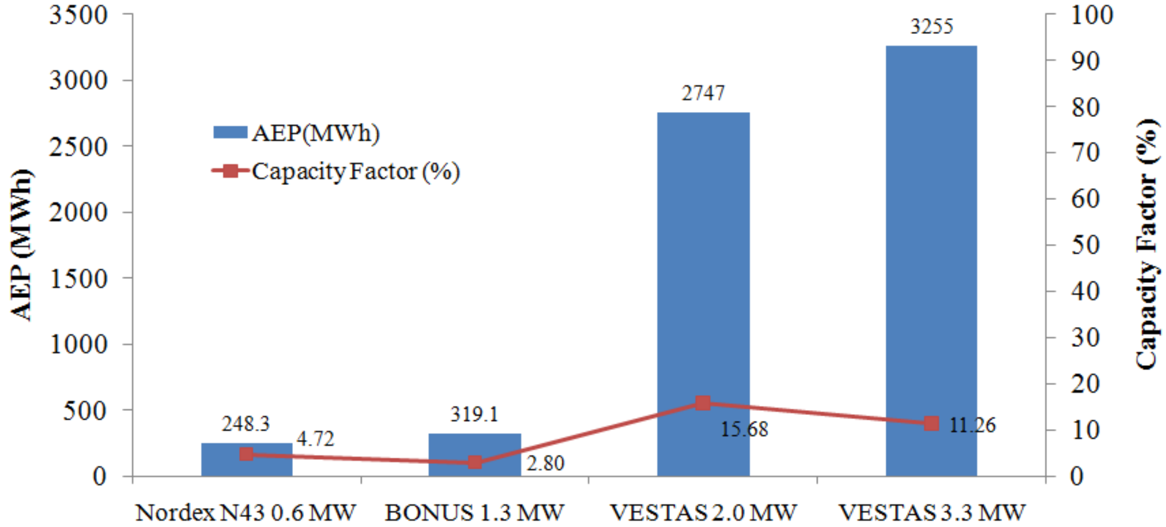

Figure 12. AEP and Capacity Factor of selected wind turbines

4. Conclusion

A wind energy assessment in Kalasin province of Thailand was made with wind data recorded for 4-years from January 2012 to December 2015. The conclusions are as follows.

- The annual mean wind speed is 3.14, 3.63 and 3.94 m/s at 60, 90 and 120 m AGL, respectively.
- Daily wind speed was higher at night time with maximum speed of 5.01 m/s at 21:00.
- Wind frequency distribution above 3.0 m/s from the Weibull curve was 49%, 59% and 60% at 60, 90 and 120 AGL, respectively.
- Wind power density for this region showed a maximum value at 78 W/m^2 at 120 m AGL in the summer season. For this region, it can be classified as a poor condition.
- The average value of the wind shear coefficient for this region was 0.35, 0.26 and 0.31, calculated based on 60-90, 90-120 and 60-120 m AGL, respectively.

- The annual energy production (AEP) from a commercial VESTAS wind turbine with rated power of 2.0 MW was estimated to be 2,747 MWh/year, with the highest capacity factor of 15.68%.
- However, the wind performance for this region was quite low. It should be recommended to be small scale for local application or be combined with solar energy.

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