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The Potential of a Small Scale Environmentally Friendly Renewable Hybrid Photovoltaic and Wind Energy Generation System at Terengganu State Coastal Area

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Abstract – *This paper presents a study of data on solar radiation and wind resources used to generate the renewable electrical power in the Terengganu state coastal area. This study utilized the data collected from the University Malaysia Terengganu Renewable Energy Research Station (UMTRERS) and Kuala Terengganu International Airport (KTIA) for years 2004, 2005 and 2006. The generated power analysis was conducted using MATLAB, based on the power produced from the Unisolar U.S 64 photovoltaic module with an area of 1 m^2 and the BWC.XL wind turbine with a blade area of 4.9 m^2. The statistical method of the Weibull distribution was used to analyze the wind data to determine the potential of wind energy. Moreover, extrapolation of the 23 m data, using the power law, was used to determine the wind data at heights of 30, 40, 60, 80, 100 and 120 m. A wind turbine with a capacity of 1 to 50 kW was used to estimate the power generated. Furthermore, a general study was implemented based on the power produced from both sources for supplying renewable electricity for the basic utilization of households in the Terengganu coastal area habitation. The results showed that the average annual energies from the photovoltaic module and wind turbine were 95.18 kWh/m^2yr and 339.09 kWh/m^2yr, respectively. In addition the ideal height for continuously powering a household was higher than 50 m for the wind turbine size of over 50 kW for the UMTRERS site.*

Keywords – Coastal area, photovoltaic, renewable energy, Terengganu state, wind turbine.

1. INTRODUCTION

Human population growth and development activities increase the demand for energy. In Malaysia, the electrical energy demand for 2004 grew at rate of 7.5 percent compared to the state economic growth of 7.1 percent. Meanwhile, the hydro source of energy, which is included in the main categories of electricity generation has an annual energy output potential of about 10 million GWh [1]. Hydro capacities, however, tend to be only 2 to 6 percent of the commercial energy supply in Malaysia. The natural gas supply to industries through pipe line is predicted to rise at mean rate of 4.3 percent annually reaching 2647 million standard cubic feet per day (mmcsfd) in 2010 [2].

Owing to the present day's energy crisis, the growing environmental concern and the constantly escalating cost of fossil fuels, the country have to make every effort to supplement our energy base with renewable sources. Malaysia has accepted the target that 10 percent of energy resources be based on the renewable resources by year 2010 [3]. Therefore, this study is an initial step to achieve the above-mentioned target.

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In the last decade, few studies have been carried out by Malaysian researchers on the development of the wind and solar energy particularly on the issues of data banking and promoting the utilization of renewable energy [4]–[6]. Among them, none have produced the recommended sizing of the wind and solar system applicable for the Malaysian climate condition. Hence, this study focuses on the data analysis and suggests the optimum sizing for the renewable energy system especially for the coastal area of Terengganu.

The UMT Renewable Energy Research Station (UMTRERS) located in Universiti Malaysia Terengganu, Kuala Terengganu at the latitude of 4° 13.557'N and longitude of 103° 26.048'E was chosen as the location to set up the station. The data for the Kuala Terengganu International Airport (KTIA) located at latitude 5° 23'N and longitude 103° 06'E with 10 m height above the ground level, was obtained from the Malaysia Meteorological Department to compare the potential of the wind energy at these two locations. The distance between the both stations is approximately 3 km.

Figure 1 shows the location of the UMT research station. The station is near the coastline where land and sea breezes may influence the wind regime [7]. The renewable energy system that has been set up at UMTRERS is a hybrid system that combines photovoltaic and wind turbine sources to optimize the rate of power generation.

The hybrid application of two energy sources maximizes the rate of energy production compared to the stand-alone energy system as the strength of one source can overcome the weakness of the other during a certain period of time [7].

The wind distributions are classified into 3 categories: (i) northeast monsoon season (November, December, January, February and March), (ii) transition period between two monsoon season (April and October) and (iii) southwest monsoon season (May, June, July, August and September). During the northeast monsoon season, the wind potential is better than during the southwest monsoon season. This is due to the fact that two apparent seasonal conditions exist in this state, which will affect the performance of electrical power production from both resources.

Consequently, this paper also discusses the potential of both sources to acquire steadiness in supplying renewable electrical power to the Terengganu state, especially for the basic utilization of households in the coastal area habitation.

Fig. 1. Research location of the measurement station.

2. METHODOLOGY

The data used in the analysis were wind speed data, v and global radiation, G collected throughout the years of 2004, 2005 and 2006. Wind speed data were recorded by the NRG Symphonie Data Retriever every 10 minutes, everyday.

The Weibull distribution with two parameters was used to characterize the wind regimes in terms of the probability density. Patel [8] has claimed that this is the best method to predict future wind speed variation and to evaluate the wind potential in different zones. The Weibull Distribution with two parameters is given by the following equation [9]:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \qquad (1)$$

where k is dimension shape parameter and c is scale parameter. From the available wind data, the graph of the frequency distribution vs. the wind speed was plotted. The peak of the graph indicates the most frequent wind speed in the studied location.

The k and c values were determined using the graphical method, and the value of [- ln [1 – F (V)]] was plotted vs. the value of *ln V,* forming a linear graph. The value of v is a mean for each range. The y-intercept of the graph indicates the c value, while the k value can be obtained from the slope. The k value is indicative of the wind uniformity, as the uniformity of wind at the site increases with k. The c value indicates when the wind speeds at certain months are higher than at other month [10].

A simplified simulation was done using MATLAB to acquire the performance results for both sources. The simple coding was executed to produce the power generation of both the wind and photovoltaic sources. Then, the power output graphs were plotted by the MATLAB function.

The power output from the wind system is known to be [11]:

$$P = \frac{1}{2}\rho.A.C_P.V^3 \quad \text{(W)} \qquad (2)$$

where ρ = air density (~1.225 kg/m^3 at temperature of 15 °C and pressure of 1013 hPa at sea level), A is the area of the wind blade in m^2, C_P is the potential coefficient (0.35 for the finest design). This power output determination of the wind turbine is subject to the rated wind speed, 2.5 m/s. For the photovoltaic system, the power output may be calculated based on the following equation [12]:

$$I_{pv} = I_{ph} - I_o\left(e^{\frac{qv_{pv}}{kT}} - 1\right) \qquad (3)$$

where I_{ph} is the photo current (A), I_o the diode reverse saturation current (A), q is the electron charge = 1.6×10^{-19} (C), k is the Boltzman constant = 1.38×10^{-23} (J/K), and T is the cell temperature (K). The power output of the solar module is given as:

$$P_{PV} = V_{PV} I_{PV} \qquad (4)$$

where I_{PV} is the output current of the solar cell (A), V_{PV} is the solar cell operating voltage (V), and P_{PV} is the output power of the solar cell (W).

In addition, the input energy to the photovoltaic module is solar radiation, and the total solar radiation on an inclined surface is estimated by [13]:

$$G_R = I_b R_b + I_d R_d + (I_d + I_b)R_r \qquad (5)$$

where I_b and I_d are the direct normal and diffuse solar radiations and R_b, R_d and R_r are tilt factors for the beam, diffuse and reflected part of the solar radiations, respectively.

Therefore, the power output from the photovoltaic modules with an area A_{PV} (m^2), and an average global radiation (Wh/m^2) on the photovoltaic surface, is given by:

$$P_{PV} = G_R \eta A_{PV} \qquad (6)$$

where η is photovoltaic efficiency. The correlation between the wind turbine and wind velocity must be established before further work is done on setting up the turbine in a certain location. The wind speed data measured at a height of 23 m above a sea level was referred to as a reference wind speed at UMTRERS.

Whereas, the velocities at the heights of 30 m, 40 m, 60 m, 80 m, 100 m and 120 m above a sea level were estimated by the following formula [14]:

$$\frac{V_2}{V_1} = \left(\frac{h_2}{h_1}\right)^{\alpha} \tag{7}$$

where, V_1 is the reference wind speed measured at a height h_1 and V_2 is the wind speed at the required or extrapolated height h_2. The power law exponent is expressed as α. This value varies with parameters such as height, time of day, season, terrain characteristics, wind speed, temperature and a mixture of mechanical and thermal parameters. The equation to acquire the α value is [15]:

$$\alpha = \frac{0.37 - 0.08 \ln(v_1)}{1 - 0.08 \ln\left(\frac{h_1}{10}\right)} \tag{8}$$

Thus, the correlation between the wind turbine height and the different wind velocities is obtained and studied in terms of the power output.

An analysis on the relation between the monthly power output for different wind turbines at different heights and the power output estimated from different type of capacity Bergey wind turbines was executed. Wind turbine with capacities of 1, 1.5, 10, and 50 kW were used for the above analysis. Table 1 shows the wind turbine specifications.

In addition, the power output graph for the same wind turbine capacity at different heights was also plotted. This study is useful in that it gave important data for choosing the optimum wind turbine size for use in a Terengganu coastal area household prior to starting the wind and photovoltaic hybrid system. The household is furnished with basic equipment, such as a fluorescent lamp, a refrigerator, a television set, a washing machine and a ceiling fan, to serve as a basic electrical load.

3. RESULTS AND DISCUSSIONS

The Weibull parameters, *c* and *k*, found from wind data for the UMTRERS and KTIA sites, for each year are shown in Table 2. The *k* values for UMTRERS site vary from 1.04 to 1.9. The highest *k* value is 1.91 and occurs in May 2006. The curve has a wider span and a flatter peak at 1.5 m/s. Meanwhile, the lowest *k value* is 1.04, and it occurs in December 2005. There the plot tends to have a steep slope and a narrow peak at a wind speed of 1.5 m/s as well. The *k* values for the KTIA state vary between 0.15 and 3.78 m/s. The *k* values that are acceptable occur in the range $1.5 \leq k \leq 3.0$, as they demonstrate that the wind regime is good at a certain location [16].

The *c* values for the UMTRERS site vary from 1.2 m/s to 4.95 m/s. The highest *c* value was 4.95 m/s, and it occurred in February 2006. The lowest value was 1.2 m/s, and occurred in August 2006. Meanwhile, for the KTIA, the maximum *c* value was 2.03 m/s, and it occurs in December 2006. The lowest value was 0.04 m/s, and it occurred in both February 2005 and October 2006.

Table 1. Wind turbine specification.

Wind Turbine	Rated Power (W)	Cut-In Speed (m/s)	Rated Speed (m/s)	Cut-Out Speed (m/s)
1 kW	1000	2.5	11	13
1.5 kW	1500	3.6	12.5	N/A
10 kW	10000	3.4	13.8	N/A
50 kW	50000	2.5	11	N/A

Table 2. Monthly *c* and *k* values.

Month	UMT Renewable Energy Research Station (23 m)						Kuala Terengganu International Airport (10 m)					
	c (m/s)			k			c (m/s)			k		
	2004	2005	2006	2004	2005	2006	2004	2005	2006	2004	2005	2006
January	3.49	2.69	3.32	1.89	1.65	1.54	1.89	1.50	1.62	3.78	1.41	1.38
February	2.58	2.06	4.95	1.52	1.34	1.32	0.16	0.04	2.01	0.33	0.15	1.68
March	2.31	2.62	1.95	1.12	1.34	1.67	1.42	1.40	1.86	1.27	1.37	0.17
April	1.97	2.03	1.93	1.51	1.41	1.62	1.23	1.05	0.44	1.55	1.77	0.81
May	1.51	1.38	1.53	1.52	1.22	1.91	1.18	1.07	0.46	1.48	1.45	0.90
June	1.39	1.39	1.58	1.44	1.44	1.68	0.93	1.03	1.24	1.37	1.15	1.42
July	1.65	1.55	1.54	1.43	1.63	1.31	1.20	1.03	1.24	1.38	1.44	0.18
August	1.29	1.49	1.2	1.26	1.48	1.08	0.92	1.15	0.44	1.41	1.54	0.90
September	1.49	1.66	1.5	1.52	1.54	1.66	1.08	1.16	1.25	1.55	1.55	1.83
October	2.17	1.91	1.57	1.18	1.38	1.55	1.56	0.97	0.04	1.16	1.34	0.26
November	1.39	2.28	1.53	1.18	1.10	1.27	1.19	1.14	1.05	1.46	1.12	1.53
December	3.71	2.42	3.63	1.43	1.04	1.05	2.00	1.41	2.03	1.41	1.25	1.35

The months in the northeast monsoon season have higher *c* values than the months in the southwest monsoon season. This condition can be explained by the wind velocities during the northeast monsoon season that promise more power production. The monthly frequency distributions of wind speeds for both locations are presented in Figures 2 to 4. The highest peak for each probability density curve shows the most frequent wind speed in a particular wind regime.

For the southwest monsoon season, northeast monsoon season and transition period, the UMTRERS recorded peak probability densities of 0.8 at 1.5 m/s, 0.54 at 1.5 m/s and 0.44 at 0.5 m/s. Meanwhile, for the above three seasons, the KTIA shows peak probability densities of 0.78 at 0.5 m/s, 0.7 at 0.5 m/s and 0.73 at 0.5 m/s.

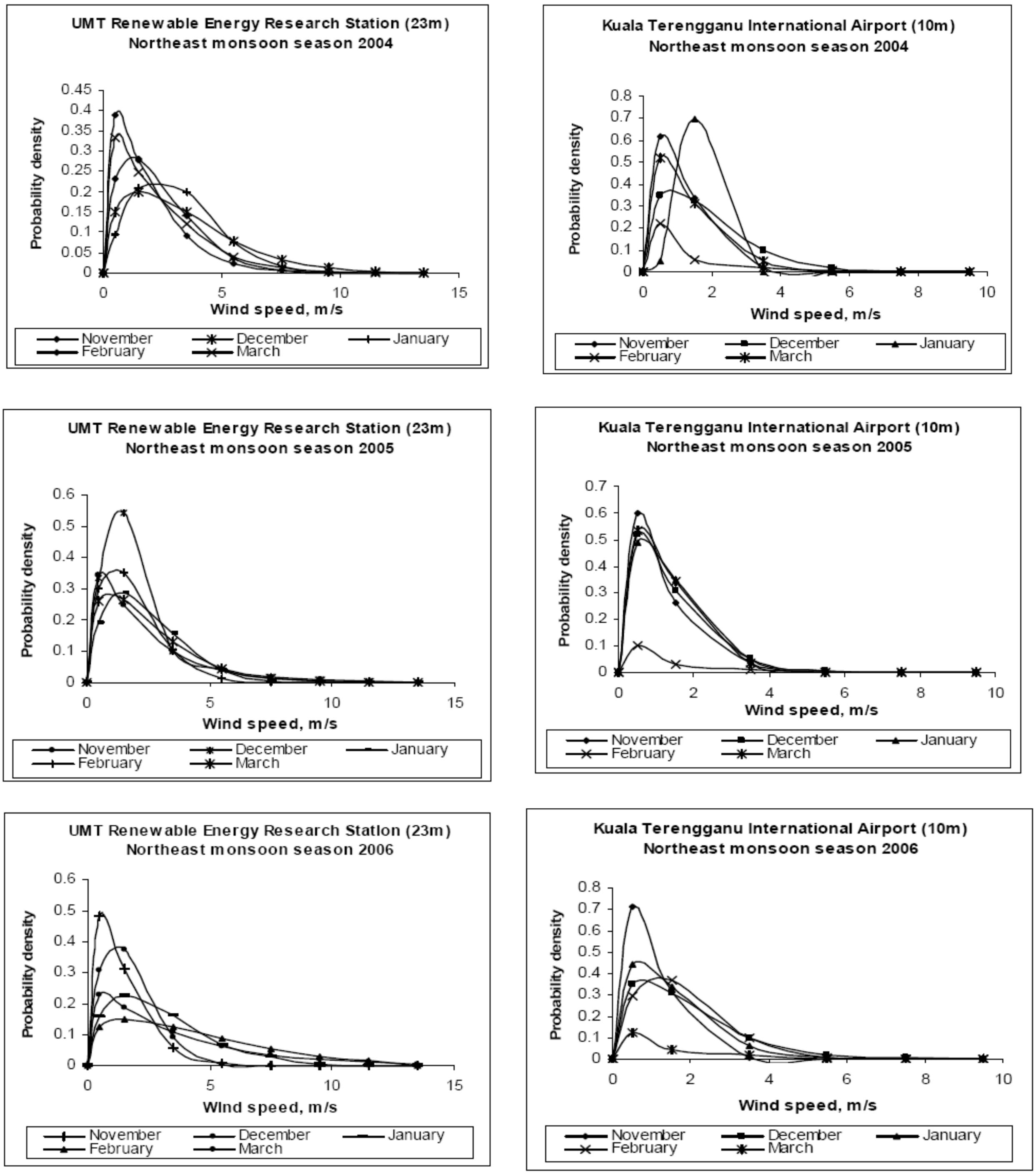

Fig. 2. The monthly frequency distribution of wind speeds (northeast monsoon season, 2004, 2005, and 2006).

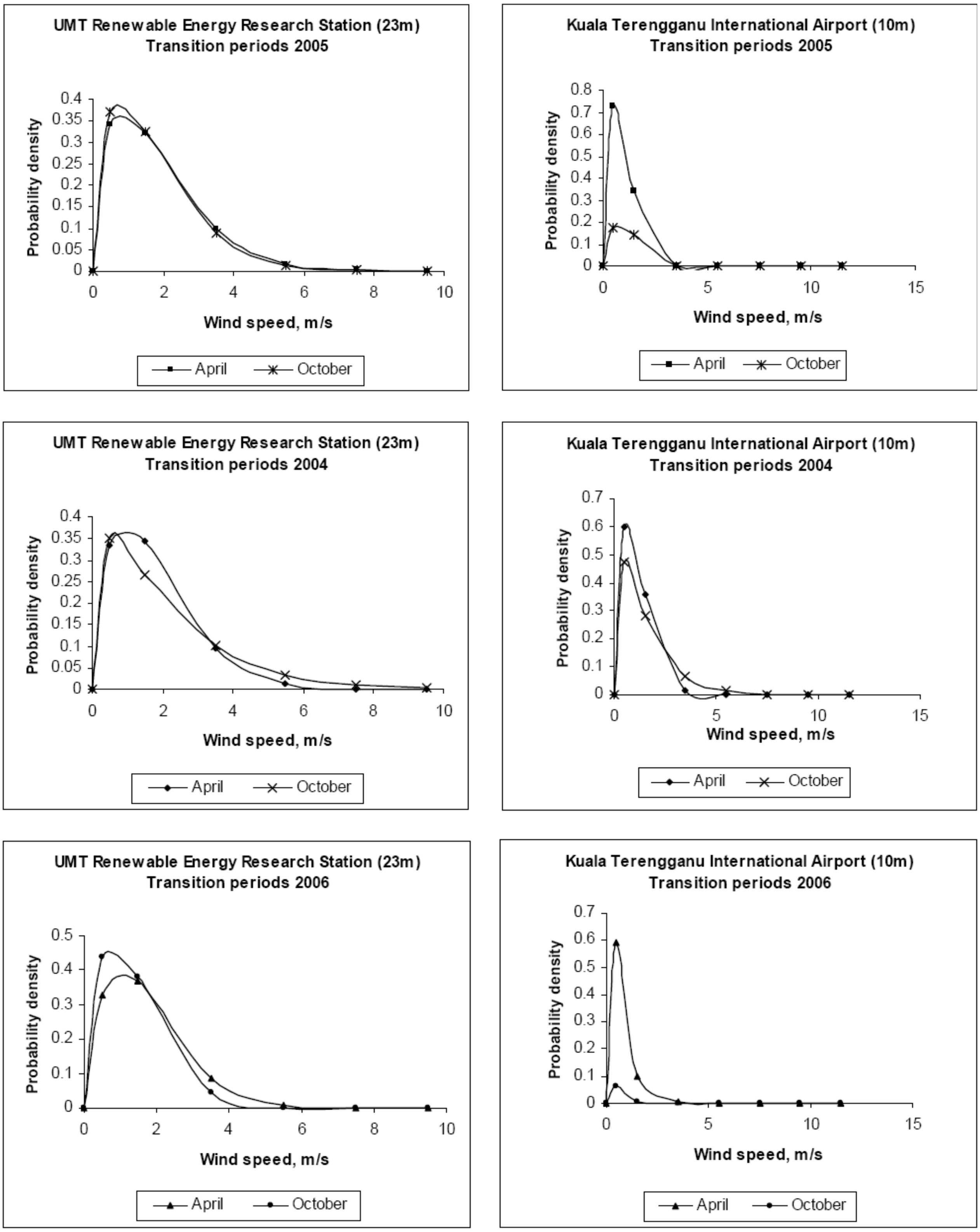

Fig. 3. The monthly frequency distribution of wind speeds (Transition periods, 2004, 2005, and 2006).

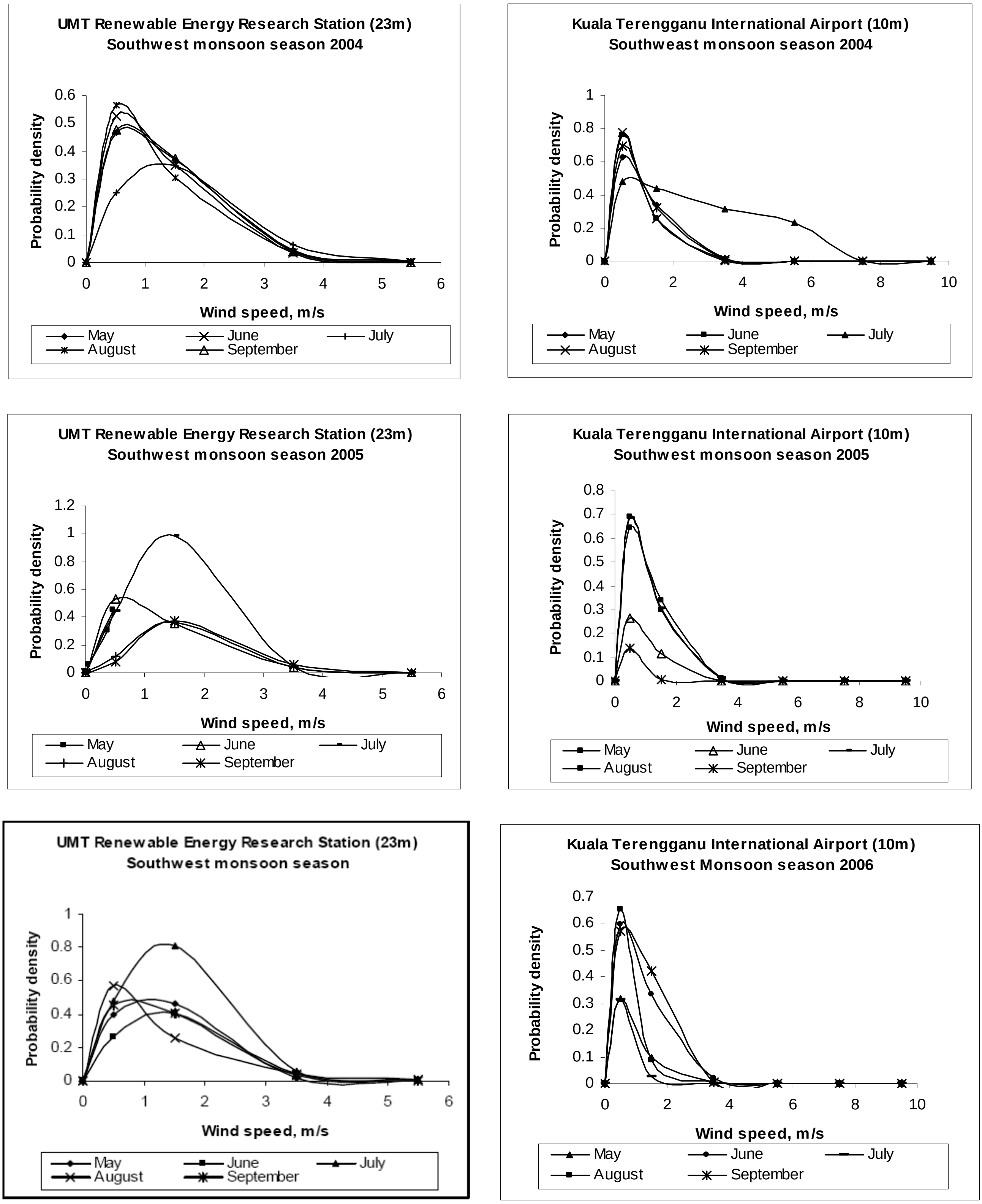

Fig. 4. The monthly frequency distribution of wind speeds (Southwest monsoon season, 2004, 2005, and 2006).

Table 3 shows the seasonal frequencies of wind speeds in number of hours per season for the ranges of wind speed for both locations. From the study, it was found that the highest wind speed recorded at the UMTRERS was 13 m/s and occurred during the northeast monsoon season, while, at KTIA was 11.5 m/s and also occurred during the northeast monsoon season.

The analysis shows that the wind speed during northeast monsoon season is more promising than during the southwest monsoon season. This study is sufficient to assess the availability of wind sources for evaluating the wind energy for electricity power generation.

The power outputs from solar radiation and wind speed were obtained based on the area of the wind turbine and the solar module. The area of a 1 kW wind turbine is 4.909 m^2 with a radius of 1.25 m. Meanwhile, the area of the solar module is 0.96 m^2 with a length of 1.36 m and width of 0.7 m. Figures 5 and 6 presented a comparison of both sources in 2005 and 2006.

Most of the northeast monsoon season has the potential to produce more power from wind than from solar radiation. March and December 2005 produced 12.42 W/m^2 and 16.92 W/m^2 solar power with mean solar radiations of 260.10 W/m^2 and 354.4 W/m^2. December and January 2006 produced 20 W/m^2 and 26.42 W/m^2 with mean solar radiations of 432.22 W/m^2 and 550.5 W/m^2, respectively. In addition, in November and December 2005, the mean wind speed was between 3.13 m/s and 3.51 m/s resulting in more power being generated (91.32 W and 117.94 W, respectively). December and February 2006 demonstrated the two highest wind power outputs, obtaining 185.92 W and 142.9 W at mean wind speeds of 4.72 m/s and 4.43 m/s respectively.

For the southwest monsoon season, wind speeds in May to September 2005 were 2 m/s and produced 3 to 7 W of power. The inverse situation occurred for solar radiation with radiation values of 542.6 W/m^2 occurring in June 2005 and 642.9 W/m^2 occurring in September 2005 that produced power outputs of about 25.9 W and 31.2 W respectively. The pattern for 2006 is similar to 2005 with almost all of the months in this season producing more solar power output than the other months of the year.

For the transition seasons, April and October, the amount of solar radiation and wind velocities, and the power outputs associated with those are moderate. Mean wind speed and solar radiation for April 2005 are 2.6 m/s and 769.70 W/m^2 with power outputs of 15.90 W and 36.80 W, respectively. October 2005 had a wind speed of 2.36 m/s and a solar radiation of 507.30 W/m^2 with power output of 10.02 W and 24.70 W respectively. For 2006, the mean wind speed and solar radiation for April were 2.43 m/s and 709.25 W/m^2 with power outputs of 8.9 W and 34.04 W respectively. Meanwhile, October 2006 had a wind speed of 2.13 m/s and a solar radiation value of 596.21 W/m^2 with power outputs of 2.92 W and 28.62 W respectively.

Table 3. The seasonal frequency of the wind speeds for years 2004-2006 in hours.

Wind Speed (m/s)	UMT Renewable Energy Research Station (23 m) (hour)			Kuala Terengganu International Airport (10 m) (hour)		
	2004	2005	2006	2004	2005	2006
Northeast monsoon						
1 – 2.9	147	405	139	239	228	230
3 – 4.9	111	75	82	73	37	75
5 – 6.9	59	31	47	13	4	14
7 – 8.9	25	14	26	2	1	3
9 – 10.9	9	7	26	-	-	1
Transition period (October)						
1 – 2.9	199	243	283	211	108	3.8
3 – 4.9	77	67	35	49	0.15	-
5 – 6.9	24	11	2	9.5	-	-
7 – 8.9	7	1.5	-	1.4	-	-
9 – 10.9	2.2	-	-	0.2	-	-
Transition period (April)						
1 – 2.9	248	231	266	260	243	71
3 – 4.9	68	72	64	10	0.6	5
5 – 6.9	9	13	5	0.1	-	0.4
7 – 8.9	0.7	1.4	-	-	-	-
9 – 10.9	-	-	-	-	-	-
Southwest monsoon						
1 – 2.9	324	255	303	259	224	602
3 – 4.9	234	7.2	3.3	48	42	44
5 – 6.9	171	-	-	3.7	5.2	4.5
7 – 8.9	-	-	-	-	-	-
9 – 10.9	-	-	-	-	-	-

From Figures 5 and 6, it was found that the photovoltaic and wind systems have the potential to accommodate the power requirement at certain times of the year, particularly when one source can overcome the weakness of the other. Hence, the production of power can be optimized without facing any problems such as climate or lack of power supply.

Using the data from 2005, several studies on the generation of wind power were conducted.

The percentages of days of each month that are able to produce power from wind energy for the year 2005 are presented in Figure 7 based on a power generating wind speed of 2.5 m/s. From the graph, it is obviously seen that the power production ability is related to the season. The months of the year that include many days that are unable to meet the power standard are mostly in the southwest monsoon season, where the months where many days meet the power standards occur mostly during the northeast monsoon season.

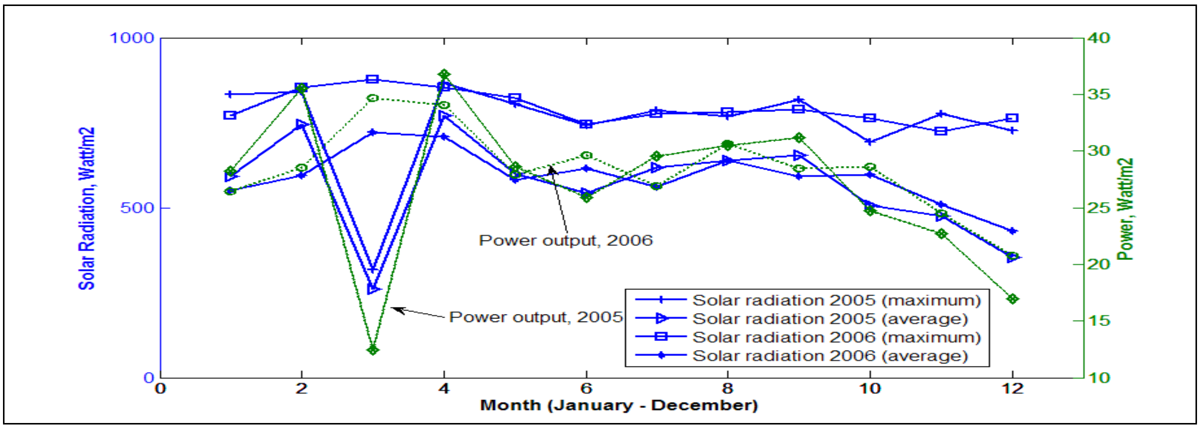

Fig. 5. Comparison of solar radiation and annual power output (2005 and 2006).

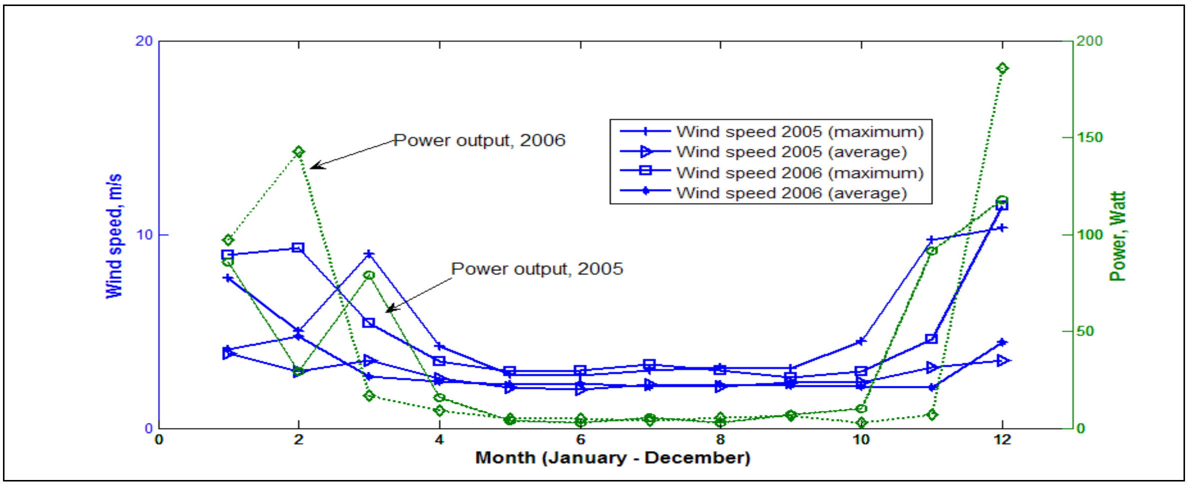

Fig. 6. Comparison of wind speed and annual power output (2005 and 2006).

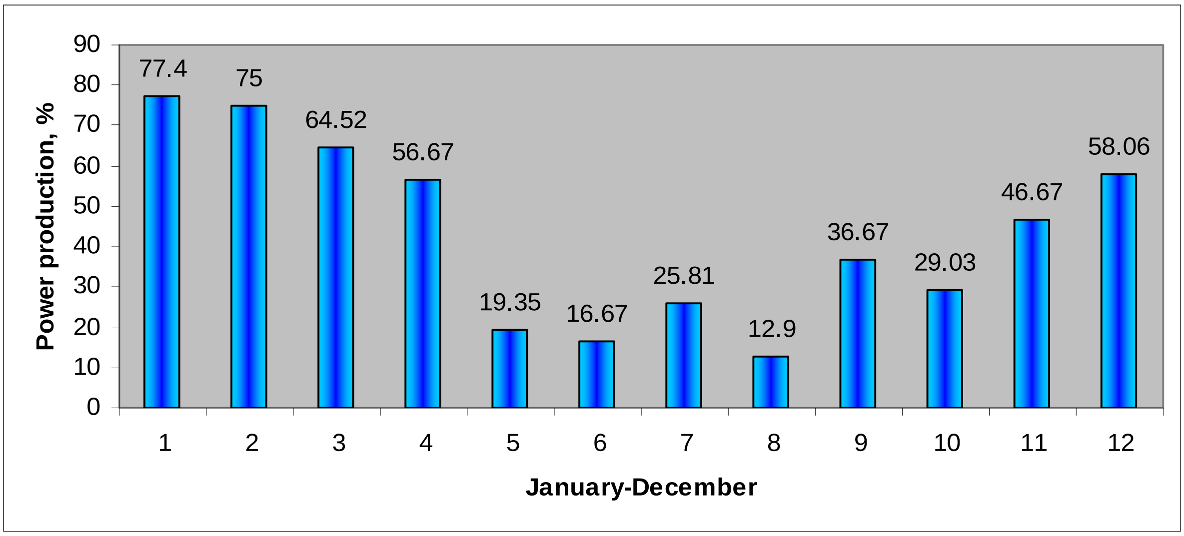

Fig. 7. Percentage of monthly wind power output (2005).

Figure 8 describes the typical diurnal variation of the southwest monsoon season wind speeds as it occurred on 29 September 2005. The diurnal variation plot shows more power production in the daytime, which is suitable for human activities that need more energy during the daytime than during the night time. The highest wind speed was 4.2 m/s with a power production of 78 W and the lowest wind speed was 0.6 m/s which not sufficient to produce any power.

For the northeast monsoon season the diurnal variation is shown in Figure 9 for 22 December, 2005. This plot shows extreme wind speeds that vary continually through the day. The maximum wind speed was 13.1 m/s, which produced 2365.8 W of power and the minimum wind speed was 7.7 m/s, which produced 480.4 W of power. This kind of wind speed is very good for power production but seldom occurs in the areas studied. This situation is one reason why the hybrid system of wind and solar energy should be implemented.

The presence of terrain characteristics has a tremendous affect on the rate of power production, because the economic value of an entire project depends mainly on the correct selection of a site. In theory, wind velocity at the surface is zero, and it is greater than zero at a certain height. Hence, the estimation of the relation between the wind velocity and the height is essential before starting a wind project. Wind turbine position must be at a suitable height to acquire potential wind velocity.

The wind speeds estimated using Equation 7 are presented in Figure 10, and they describe the wind velocity increase that occurs when the height increases. The maximum wind speed is 5.8 m/s at 120 m in March, whereas, the minimum wind speed is 2 m/s in June at UMTRERS.

The blade diameters of the four wind turbines stated in Table 1 (1 kW, 1.5 kW, 10 kW, and 50 kW), are 2.5 m, 3.2 m, 7 m and 14 m, respectively [17]. The larger area increases the rate of power production as the power is proportional to the swept area of wind that passes the turbine.

Figure 11 describes the output power of the four wind turbines at a height 23 m. The power outputs of the 1 kW and 1.5 kW turbines are not very different because both had a small blade diameter. The power output of the 10 kW turbines does differ from the 1 kW, turbine, with the 10 kW turbine, whose diameter is 4.5 m more than the 1 kW turbine, showing a power output that is almost twice that of the 1 kW turbine. For the 50 kW turbine, the power output was about fourteen times that of the 1 kW turbine, due mostly to the fact that the diameter was 11.5 m larger for the 50 kW turbine than for the 1 kW turbine.

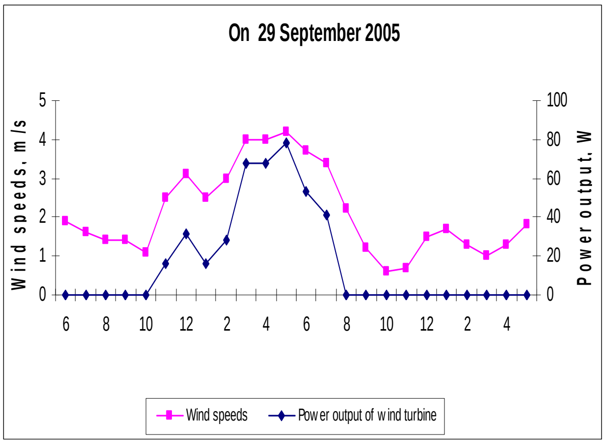

Fig. 8. Diurnal wind speeds variation (Southwest Monsoon season).

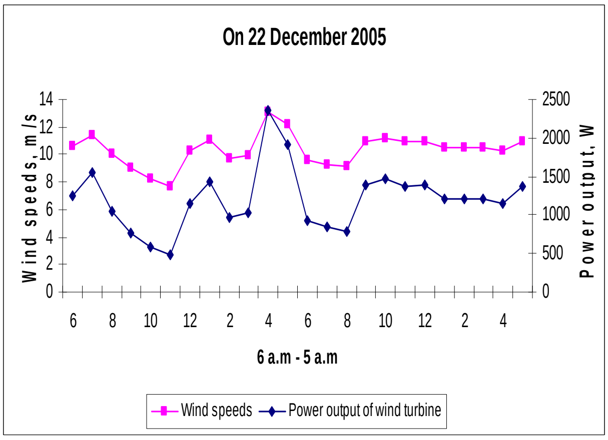

Fig. 9. Diurnal wind speeds variation (Northeast Monsoon season).

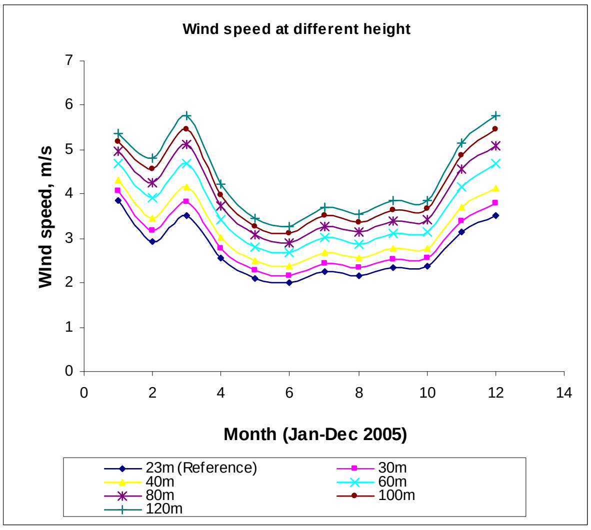

Fig. 10. Wind speed at different height.

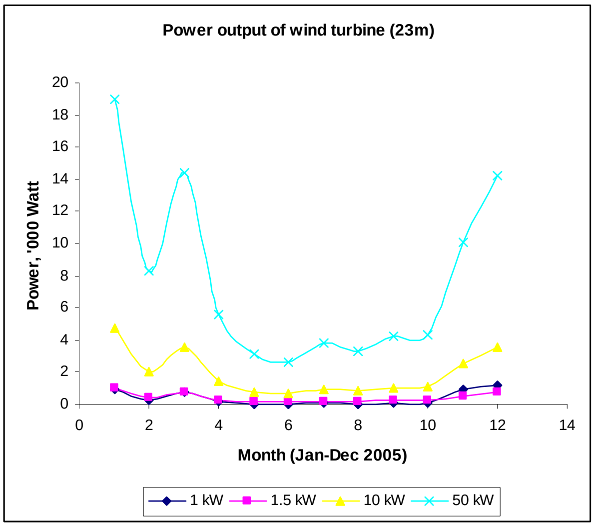

Fig. 11. Power output of wind turbine at 23 m.

Table 4 shows that the energy needed for a household in a year is about 6737.8 kWh. The amounts of energy that can be supplied by the UMTRERS site installed with the wind turbine or photovoltaic modules were only 339.09 kWh/yr and 95.18 kWh/yr respectively. Neither source was able to fulfill the power requirements of a household.

A study of the suitability of a wind turbine at a certain height to supply electricity to a house for a year was made. Table 5 shows that at a height of 23 m only the 50 kW turbine is able to supply enough electricity. Other turbines produce too little energy to meet the needs of the household. At 30 m, 40 m, 60 m and 80 m, the 50 kW turbine is sufficient to meet the needs alone without support from the photovoltaic system. Even if 95.18 kWhr/yr energy from the photovoltaic system was added to the 10 kW turbine, the amount of energy would still be insufficient to supply the household. Therefore, in order to use the 10 kW turbine the area of the photovoltaic module should be increased to achieve an area of 50 m^2 to generate 4759 kWhr/yr which would meet the electricity requirement.

The 50 kW turbine is able to produce electricity unaccompanied for both heights. Whereas, the 10 kW turbine with an energy production of 6923.5 kWh/yr at a height of 120 m is able to generate sufficient power without the help of the photovoltaic system. However, at a height of 100 m the energy production is 5921.2 kWh/yr, and the photovoltaic system with an area addition of 9 m^2 must be used. An addition of 856.7 kWhr/yr makes the total amount of energy 6777.9 kWhr/yr which sufficient to meet the requirement. From the study, it was found that the most suitable height for the wind turbine for the purpose of energy supply are 100 m and 120 m.

The amounts of energy supplied by10 kW turbines every month in the northeast and southwest monsoon seasons at heights of 100 m and 120 m were also estimated, as shown in Table 6.

The energy production of the wind system cannot accomplish the requirement at a height of 100 m during the southwest monsoon season. Hence, a combination with the photovoltaic system is required to achieve an optimum energy supply. Therefore, solar modules with an area of approximately 32 m^2 required to produce energy in the amount of 1250.1 kWh/year are needed to cover the additional energy. Meanwhile, at 120 m, the solar module area must be 36 m^2 and the energy output must be 1447.2 kWh/year to continuously supply energy to the house. As for the northeast monsoon season, wind turbines are able to supply energy autonomously without combination with the photovoltaic system at both heights.

Table 4. Electricity requirement for a house in the coastal area with three rooms.

Appliances	Power (W)	Consumption (h/d)	Daily Energy (kWh/d)	Annual Energy (kWh/yr)
Fluorescent Lamps (6 units)	40	5	1.20	438.00
Ceiling fan (4 units)	84	9	3.02	1102.3
Television	100	5	0.50	182.50
Refrigerator	550	24	13.20	4818.00
Washing machine	1080	0.5	0.54	197.10
Total	1854	50	19.08	6737.8

Table 5. Energy output for wind turbines at different heights.

Height	Energy Output			
	1 kW	1.5kW	10kW	50kW
23	339.2	445.7	1694.5	6747.2
30	411.2	305.3	2129.4	9440.1
40	345.6	566.7	2713.9	10858.5
60	616.6	800.5	3830.2	15317.8
80	1077.1	1021.9	4894.2	19575.6
100	883.0	1237	5921.2	23668.3
120	755.3	1446.3	6923.5	23466.4

Table 6. Energy production of wind turbine 10 kW and photovoltaic module at different season.

Monsoon season	Height (m)	Energy output of wind turbine (kWh/month)	Energy output of photovoltaic module (kWh/month)
Southwest	100	1557.3	40.2
Northeast	100	4061.0	36.9
Southwest	120	1388.9	40.2
Northeast	120	4731.7	36.9

4. CONCLUSION

It was found that a small-scale hybrid renewable energy system has the potential to be implemented in households in the coastal area in the Terengganu state. The average annual energy obtained from the photovoltaic module was 95.18 kWh/m^2.yr. For the wind turbine, the average energy obtained was 339.09 kWh/m^2 yr. The most suitable heights for the application of a standalone renewable energy construction for a particular household in the Terengganu coastal area are larger than 50 m, and the wind turbine capacity is larger than 50 kW. The research revealed that there was a good relationship between both sources, as the strength of one source could overcome the weakness of the other during a certain periods. The power generated from both sources was able to produce power continuously throughout the year.

ACKNOWLEDGEMENT

The acknowledgement goes to Engineering Science Department, Universiti Malaysia Terengganu (UMT), Solar Energy Research (SERI), Universiti Kebangsaan Malaysia (UKM) and Ministry of Science, Technology and Innovation of Malaysia (MOSTI) for providing supervision and financial support.

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