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Assessment of Wind Power Potential for Coastal Areas of Pakistan

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Abstract

Selected coastal areas of Pakistan (Karachi, Ormara, Jivani and Pasni) were studied for the possibility of wind energy generation, using available meteorological data. Wind speed pattern, Extractable Wind power, Wind Energy and associated Weibull parameter for these coastal areas have been examined. The analysis also includes seasonal changes in wind speed values. The power output using fast and slow wind machines using different blade diameters have been estimated to explore the possible use for irrigation deep well pumping and small scale power generation. Along with this, 4 KW and 20 KW aero generators were also examined. It was found that, considering maximum location wind speed, Pasni is the best location; and Jivani is the next best location with stable wind throughout the year. The other two locations were found to have similar same properties.

Key Words: Assessment, Coastal areas, Wind power potential, Weibull Distribution.

1. Introduction

There is rising need for alternate and renewable sources of energy, especially in developing countries, whose progress and economic growth may strongly be indexed to its development. With the ever increasing growth in energy consumption and rapidly depleting fossil fuel reserves, it is feared the world will soon exhaust its fossil fuel reserves.

Pakistan is an energy deficient country and each year spends a large amount of its foreign exchange to import oil, to meet its energy requirements [1]. Thus the need to develop alternate energy resources has become inevitable. The oldest and most widely used renewable energy resources are solar and wind, which have shown prospects and potential for efficient utilization. In the recent past, wind energy has emerged as clean, abundant, affordable, inexhaustible and environmentally benign source of energy. This is getting worldwide attention with the development and availability of inexpensive technology that allow its easy conversion into useful energy [2, 3].

Wind energy has the advantage that it can be utilized independently, and deployed locally in rural and remote areas. Thus the location far away from the main grid finds wind suitable for generating electricity and pumping water for irrigation purpose [4]. Unfortunately, at present there is no share of wind energy in the energy mix of Pakistan, whereas countries like Germany, United States, India and China have successfully setup wind energy sources.

Coastal areas and mountains with high wind potential are considered most suitable for wind energy utilization. Therefore this study aims in investigating the prospects of harnessing and useful conversion of wind energy potential for the coastal area of Pakistan.

The coast of Pakistan is about 1,120 kilometer long and has a population of about 10 million people [5]. It is very expensive to connect small villages to the national electric grid because of the huge infrastructure costs involved. According to the experts, WAPDA (Water and Power Development Authority, Pakistan) does not have enough electricity to supply them. The only way many in the coastal areas can be supplied is through the use of wind power, because high wind is always available nearly all year round in these areas. [5] Table 1 lists the geographic locations involved this study; and Table 2 gives the monthly mean, maximum, minimum and annual wind speeds.

Table 1. Location of coastal stations.

Location	Latitude	Longitude
Karachi	24° 53	67° 02
Ormara	25° 12	64° 40
Jivani	25° 02	61° 45
Pasni	25° 16	63° 31

Table 2. Monthly mean, maximum, minimum and annual wind speed for coastal locations of Pakistan. in m·sec^{-1}.

Months	Karachi	Ormara	Jivani	Pasni
January	2.5	3.1	4.2	5.0
February	3.4	3.4	5.0	5.6
March	4.0	5.0	6.0	6.5
April	4.2	6.5	5.3	8.5
May	5.0	5.3	5.3	7.7
June	5.9	5.8	6.2	7.6
July	5.4	5.8	5.3	6.5
August	5.0	4.4	5.9	6.7
September	4.6	4.3	5.2	6.9
October	3.5	3.7	4.3	5.9
November	2.3	3.8	3.8	4.2
December	2.0	3.2	3.5	3.9
Maximum	5.9	5.8	6.2	8.5
Minimum	2.0	3.1	3.5	3.9
Annual average	3.5	3.6	5.0	6.3

This paper gives a preliminary investigation of the potential of wind power generation employing wind speed data of six years (1995–2000) for selected coastal areas of Pakistan. The maximum available and extractable wind power is also calculated employing different blade diameters for slow and fast wind machines. To test the power generation feasibility, two *test* aerogenerators are considered: one having $V_{ci} = 2.5$ m·sec^{-1} and $V_r = 5.3$ m·sec^{-1}; the other having $V_{ci} = 3.5$ m·sec^{-1} and $V_r = 8.5$. Parameters V_{ci} and V_r are the *cut-in speed* and *rated speed* of the wind machine, respectively.

2. Data and Methodology

The data for this study was obtained from Pakistan Meteorological Department, Karachi. The data consisted of six years duration (1995 to 2000): monthly average wind speed measured at a height of 10 meters.

Generation of power from a windmill requires continuous flow of wind at a rated speed. This is difficult to accomplish because wind by its very nature is not constant and does not prevail at a steady rate, but in fact fluctuates over short periods of time. The speed of wind is also dependent on height above the ground. In order to estimate the wind speed at any height, we employ the Hellmann exponent law [6]:

$$V(h)/V_{10} = (h/10)^{\alpha}, \tag{1}$$

where $V(h)$is the wind speed at height h, and V_{10} is the wind speed at 10 m height and α is the Hellmann exponent. For flat and open areas, $\alpha \approx\tilde{}\ 1/7$. The available power in the wind per unit area at any wind speed may be estimated as [7]

$$P \;=\; 1/2\rho V^3, \tag{2}$$

where ρ is the air density, which was assumed to be 1.225 Kg·m^{-3}and V^{3}is monthly mean wind speed in m·sec^{-1}. This available power can not be totally extracted by any wind machine. The maximum extractable power from any wind machine is limited by the Betz relation [8], which assigns the power coefficient $C = 16/27$ for the maximum performance of a wind machine.

Maximum extractable power per meter is given as

$$P_{max} = 1/2\rho C_p V^3 W m^{-2} \tag{3}$$

2.1. Statistical models

For the prediction of energy output of a wind energy conversion system, among the most important of data is the wind speed frequency distribution. Among the statistical models developed so far, Weibull function gives good fit to the observed wind speed data [9]. Wentink [9], after comparing the Weibull function with other distribution, such as Rayleigh distribution, Planck's frequency distribution, and Gamma function, concluded that Weibull distribution gave the best fit to the wind speed data. Other investigators, Justus et al. [10], Peterson et al. [11] and Rehman [12] also confirmed the superiority of Weibull distribution function over others by testing it for a number of stations in U.S.A. and Saudi Arabia.

2.2. Weibull distribution function

Weibull distribution function is a two-parameter function expressed as

$$P(V) = k/c(v/c)^{k-1}\exp\{-(v/c)^k\}, \tag{4}$$

where k is the shape factor, c is the scale parameter and v is the average wind speed.

There are several methods to calculate these parameters as reported by Stevens and Smulders [13]. They employed five different methods (method of energy pattern factor, the maximum likelihood method, Weibull distribution function, percentiles, etc.) for the purpose and obtained the same results in each case. The method adopted in this paper is due to Hennessey [14], for being simple and easily available, employing the values of mean wind speed v and standard deviation σ. Using v and σ via the relation

$$k = (\sigma/v)^{-1.086}, \qquad (5)$$

one obtains the **s**hape factor k, from which scale parameters c is calculated as

$$c = v/\Gamma(1 + 1/k), \qquad (6)$$

where Γ is the gamma function.

3. Results and Discussion

Since the second half of the 19^{th} century, multi-bladed low speed wind turbines have been used in Europe and North America. In this type of machine, the number of blades varies from 12 to 24 and it covers the whole face of the wheel, and equipped with a tail vain to keep the machine facing the wind. Slow wind machines (SWM) are well adapted to low wind speed. They start easily with wind speeds ranging from 2 to 3 m sec^{-1}; however, the starting torque is relatively high. SWM is most often used for the extraction of water from deep wells. The optimal rotational speed N (in rotations per m^{-1}) is $19V/D$ where V is the wind speed in m·sec^{-1} and D is the diameter [15].

An 18 bladed horizontal axis slow wind turbine having blade diameters 5 to 10 m was selected for the study. The maximum power likely to be produced by this type of machine can be calculated via the equation

$$P \ = \ 0.15D^2 \quad V^3 \qquad (7)$$

where P is power in watts, D is diameter in meters and V is in m·sec^{-1}.

Of fast wind machines (FWM), the number of blade is much more limited, usually varying from two to four. These wind machines are much lighter than SWM, and they need a higher wind speed to start up, usually 4 to 5 m sec^{-1} being necessary. As expected, the rotational speed is much faster than SWM. FWM is usually employed in the generation of electricity. The optimal rotational speed N (revolutions per minute) for FWM is $115V/D$, where V is the wind speed in m·$\text{sec}^{-1}$and D the diameter in meters.

A three-bladed horizontal axis fast wind machine having blade diameters 5 to 10 m has been chosen. The maximum power likely to be produced by this machine can be calculated by using the equation [15]

$$P = 0.20D^2 \quad V^3, \qquad (8)$$

where P is expressed in watts, D is in meters, and V is in m·sec^{-1}. The power output for slow and fast wind machine using different blade diameter for all stations are shown in Tables 3 and 4. The power output has been estimated using maximum and minimum wind speeds per the locations.

Table 3. Power output for slow wind machine using different blade diameters, in KW.

Blade diameter, m	Karachi		Ormara		Jivani		Pasni	
	V=2.5, m·s^{-1}	V=5.9, m·s^{-1}	V=3.1, m·s^{-1}	V=5.8, m·s^{-1}	V=3.5, m·s^{-1}	V=6.2, m·s^{-1}	V=3.9, m·s^{-1}	V=8.5, m·s^{-1}
5	0.05	0.77	1.11	0.73	0.16	0.89	1..48	2.30
6	0.08	1.10	0.16	1.05	0.23	1.28	2.13	3.31
7	0.14	1.50	0.22	1.43	0.31	1.75	2.90	4.51
8	0.15	1.97	0.28	1.87	0.41	2.28	3.79	5.89
9	0.18	2.49	0.36	2.37	0.52	2.89	4.80	7.46
10	0.23	3.08	0.44	2.93	0.64	3.57	5.93	9.2

Table 4. Power output for fast wind machine using different blade dia in KW.

Blade dia in m	Karachi		Ormara		Jivani		Pasni	
	V=2.0 m·sec^{-1}	V=5.9 m·sec^{-1}	V=3.1 m·sec^{-1}	V=5.8 m·sec^{-1}	V=3.5 m·sec^{-1}	V=6.2 m·sec^{-1}	V=3.9 m·sec^{-1}	V=8.5 m·sec^{-1}
5	0.04	1.03	0.15	0.97	0.21	1.19	0.29	15.35
6	.0.05	1.47	0.21	1.40	0.30	1.72	0.43	22.10
7	0.08	2.00	0.29	1.91	0.42	2.33	0.58	30.08
8	0.10	2.62	0.37	2.37	0.54	3.09	0.76	39.29
9	0.13	3.32	0.47	3.15	0.69	3.86	0.96	49.73
10	0.16	4.1	0.59	3.90	8.6	4.76	1.18	61.40

Figures 1 and 2 gives the power curve for 4 KW and 20 KW aero-generators, where the rated wind speed has been estimated using the expression [16]

$$V_{ci} = (0.15)^{1/3} \quad V_r. \tag{9}$$

Here V_{ci} is the cut-in and V_r is rated wind speed of the machine. The rated wind speed for a 4 KW wind machine is 5.3 m·sec^{-1}and for 20 KW wind machine it is 8.5 m·sec $^{-1}$ while the cut-in speed V_{ci} of these machines are 2.5 m·sec $^{-1}$3.5 m·sec $^{-1}$, respectively [16]. The generator will not generate power below V_{ci} and wind machine output will be constant at the rated speed. Shown in Figure 3 is the variation of mean monthly wind speed for the selected coastal areas: Karachi, Ormara, Jivani & Pasni. For Karachi the wind speed is lower during the period November, December and January. It is higher during monsoon months, i.e. June, July, August and September. The maximum value of 5.9 m- sec $^{-1}$ is recorded in June.

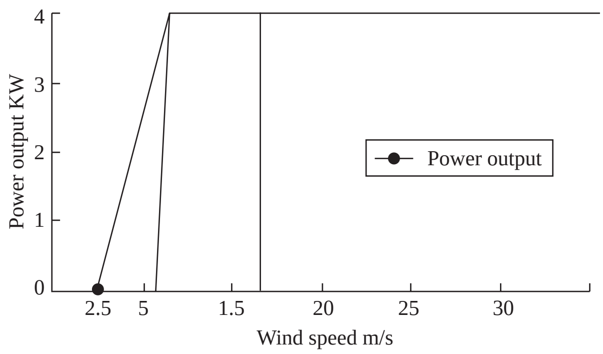

Figure 1. Power curve for 4 KW selected Wind Machine.

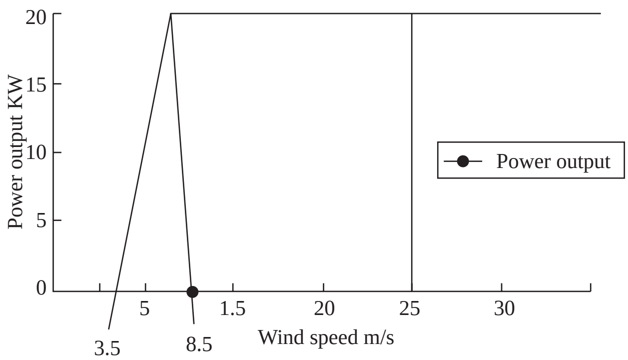

Figure 2. Power curve for 20 KW selected Wind Machine.

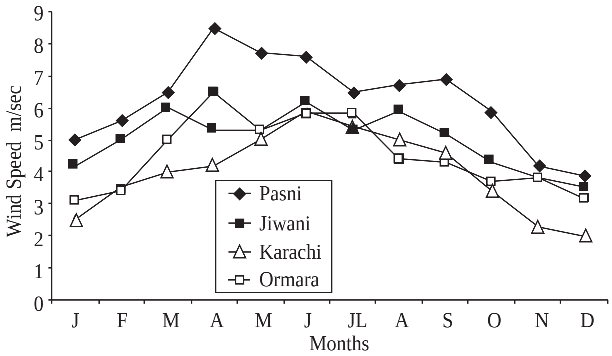

Figure 3. Monthly Wind Speed for Coastal Stations of Pakistan.

The wind speed pattern for Karachi and Ormara is nearly identical. It is observed that the wind speed at Jivani is higher during the period of March to August, when it ranges from 5.3 m·sec^{-1} to 6 m·sec^{-1}; and at Pasni the peak months are April, May and June [17] as these months show the maximum wind speed of 8.5 m·sec^{-1} whereas annual average is 6.3 m·sec^{-1} and the lowest observed value is 3.9 m·sec^{-1}. The coastal areas exhibit strong variations during their seasonal cycle: the wind speed being lower during September to January, and high from February to August. This trend is peculiar for the coastal locations as also shown by Rehman [18] and Ramachandra et al. [4] for coast of Saudi Arabia and Southern India. The annual wind speed pattern is shown in Figure 4. Among annual averages, Pasni shows higher value of wind speed, and thus can be rated a better choice for wind energy utilization in comparison to other coastal sites such as Ormara, Jivani and Karachi. Table 5 shows the shape and parameters k and c for these stations under study, whereas Figure (5) shows the monthly variation of k for all these coastal stations. From figure it is apparent that for Karachi, Ormara and Pasni the shape factor k does not remain stable through out the year. The fluctuation is high. For Karachi, the minimum k is 3.1 in the month of January and maximum value is 17.4 for August. For Ormara the minimum is 2.2 in December and the maximum is 8.4 in June while for Pasni minimum is 6.7 in March and maximum is 12.6 in June. For Jivani the wind speed remains smooth through out the year. The minimum k is 2.6 in March and maximum is 4.6 in April. From Figures (6) and (7) It is observed that a 4 KW wind machine can work efficiently for all the coastal stations whereas 20 KW wind machine will only be useful for Pasni and Jivani since the wind speed for Karachi and Ormara is below the cut-in speed of the machine.

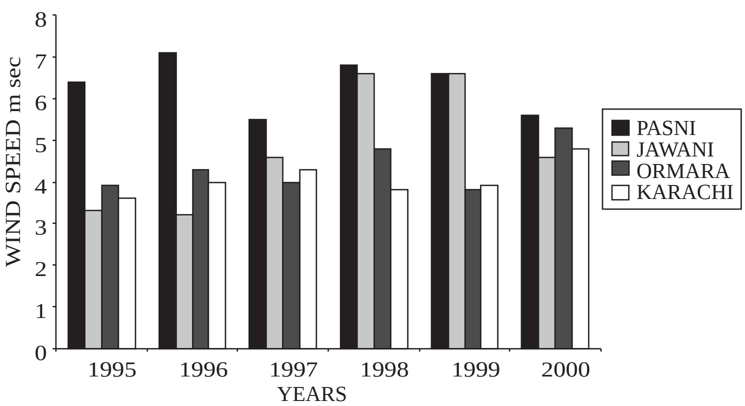

Figure 4. Yearly Wind Speed for Coastal locations.

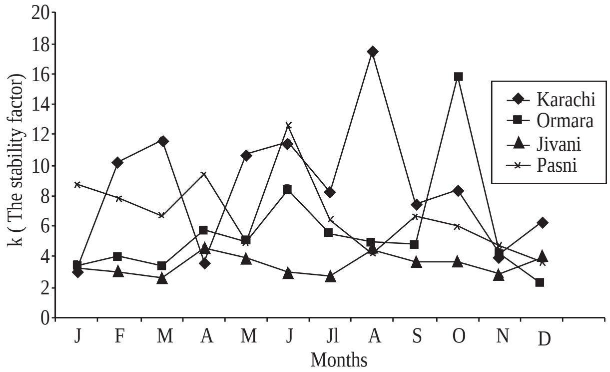

Figure 5. Weibull Parameter k.

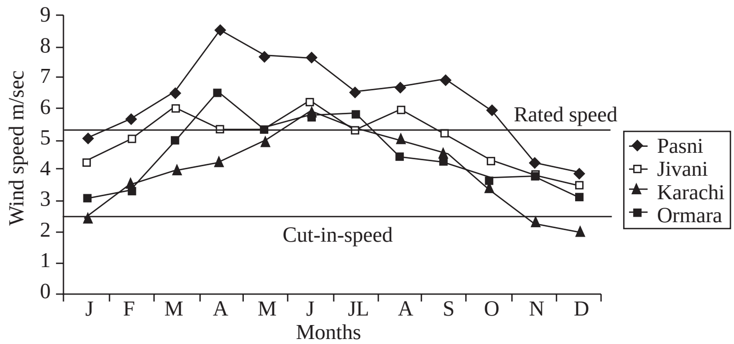

Figure 6. Monthly Wind Speed with cut-in and rated speed for a 4 KW wind machine.

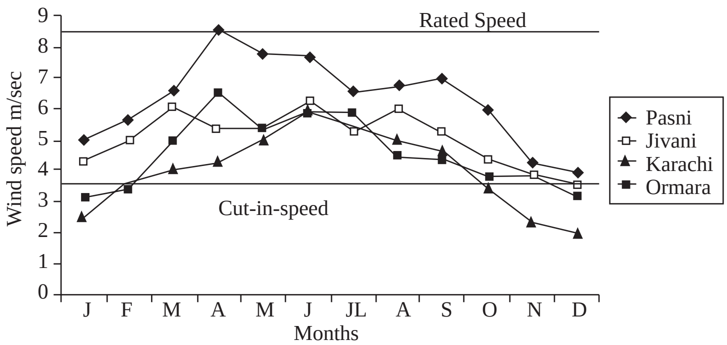

Figure 7. Monthly Wind Speed with cut-in and rated speed for a 20 KW wind machine.

Table 5. Weibull Parameter c and k for Coastal Locations of Pakistan.

Months	Pasni		Ormara		Jivani		Karachi	
	c	k	c	k	c	k	c	k
January	5.3	8.7	3.4	3.4	4.7	3.3	2.8	3.1
February	5.9	7.8	3.8	4.0	5.6	3.0	3.5	10.2
March	6.9	6.7	5.6	3.4	6.8	2.6	4.2	11.7
April	8.9	9.4	7.0	5.7	5.8	4.6	4.7	3.6
May	8.3	4.9	5.7	5.0	5.8	3.9	5.2	10.7
June	8.2	12.6	6.1	8.4	6.9	3.0	6.1	11.5
July	6.9	6.4	6.3	5.5	5.9	2.7	5.7	8.2
August	7.4	4.2	4.8	4.9	6.5	4.4	5.1	17.4
Sept.	7.4	6.6	4.7	4.8	5.8	3.6	4.9	7.4
Oct.	6.3	6.0	3.8	15.8	4.8	3.6	3.6	8.4
Nov.	4.6	4.7	4.2	4.2	4.2	3.8	2.5	4.1
Dec.	4.3	3.6	3.6	2.2	3.8	3.9	2.2	6.2

4. Conclusion

Start here next From the assessment of wind power potential for four coastal locations of Sindh and Baluchistan (Karachi, Ormara, Jivani and Pasni) it is observed that the annual wind speed pattern in Karachi is same (though on the lower side); and Pasni and Jivani are observed to have the higher wind speeds. The expected power output of slow and fast wind machines is also higher for these stations.

Although a 4 KW wind generator can be used efficiently throughout the year for all locations, there is a limitation for the use of 20 KW generators. This generator can only be used for Pasni and Jivani, as it requires high wind speed for operation. In the final conclusion, Pasni and Jivani are recommended as the most prospective sites for use with a 4 KW and 20 KW wind machines. The locations of Karachi and Ormara can utilize wind power throughout the year using 4 KW wind machines only.

Utilization of wind energy potential for the coastal sites to optimal conversion, using proper wind machine will be beneficial and economically feasible for water lifting and small scale power generation.

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References

[1] Pakistan Energy Year Book, *Ministry of Petroleum & Natural Resources*, Hydrocarbon Development Institute of Pakistan, (Govt. of Pakistan. 2004).

[2] W. E Alnaser and A. Al. Karaglisuli, *Renewable Energy*, **21**, (2000), 247.

[3] W. E Alnaser, *Renewable Energy*, **3(2/3)**, (1993), 185.

[4] T. V. Ramachandra, D.K. Subramanium and N.V.Joshi, *Renewable Energy*, **2**, (1997), 585.

[5] J. A. Khan, *Rehber Publisher*, The Climate of Pakistan, (Pakistan. 1993).

[6] P. J. Musgrove, *Solar and Wind Technology*, **4**, (1987), 37.

[7] M. Rizk, *Solar and Wind Technology*, **4**, (1987), 491.

[8] A. Betz, *Windenergie und Ihre Anwendung Durch Wind Muhler* Vanderhoeck and Ruprecht, (Gottingen. 1942).

[9] Wentink, Final Report, (1976), Report no. NSF/RANN /SE/AER 74-0039 /R-76/1, Geophysical Institute, University of Alaska.

[10] B. Justus, W. R. Hangraves and A. Yaleen, *J. Appl. Meteor.*, **15**, (1976), 673.

[11] F. I. Peterson, I. Frocus, S. Frandsen and K. Hedyard., *Wind Atlas for Denmark*, RISO, (Denmark. 1981).

[12] Shafiqur Rehman, T. O. Halwani and Tahir Hussain, *Solar Energy*, **53**, **6**, (1994), 473.

[13] M. J. Stevens and P. T. Smulders, *Wind Engg.*, **3**, (1979), 132.

[14] J. P Hennessey, *Wind Engg.*, **2**, (1978), 156.

[15] Dessire LE, Gouries *Wind Power Plant*, Theory & Design, (Pergamon Press, New York, U.S.A. 1982), p. 47.

[16] M. M. Pandey and P. Chandra, *Solar & Wind Technology.*, **3**, (1986), 135.

[17] M. Akhlaque Ahmed and Firoz Ahmed, *Journal of Research Science*, **15**, **4**, (2004), BZU, 455.

[18] Shafiqur Rehman and Aftab Ahmed, *Energy*, **29**, (2004), 1105.