Wind Potential Assessment and Optimization of Wind Turbine Blade for Coastal Area of Jiwani Balochistan Pakistan

Liaquat Ali Lehri, Syed Mushtaq Ahmed Shah, Bashir Ahmed Leghari, and Muhammad Ishaque Tareen

***Abstract*—The coastline of Pakistan extends 1,050 km (650 miles), with an high wind energy potential in areas of Jiwani and Pasni. This high potential wind energy may be efficiently utilized if it is properly assessed and optimization techniques are applied. The present work is related to the assessment of wind potential for the coastal area of Jiwani Balochistan and consequently steps are suggested to optimize the wind turbine blade for effective utilization of the available wind energy through numerical modeling and simulation.. The aim of the research work is to focus on the wind conditions in Jiwani coastal site and to assess the requirement for a small scale wind turbine and perform the design optimization of the turbine blades to produce power at even low wind speeds. Four years wind data (i.e. 2006, 2007, 2008 and 2009) of the Jiwani was collected and based upon the available data wind turbine blade was designed and optimized for maximum power output for that area. This study addresses the method of wind turbine blade optimization through Blade Element Momentum (BEM) theory and results were confirmed through CFD software COSMOS flow works 2009. The work was carried out on a three blade horizontal axis wind turbine by considering the performance of its blades and effect of changing the airfoil sections of the blade along its length. The best blade shape was obtained from BEM theory calculations with maximum coefficient of performance (CP). The design parametric studies were conducted for six sections of blade including angle of twist, length of blade, chord and found the significant effect over the coefficient of performance (CP). It was shown that the efficiency of wind turbine may be improved and power output can be enhanced through the change in design of blade as well as by the angle of twist.**

***Index Terms*—Air foil, blade element momentum theory, co-efficient of performance, computational fluid dynamics, wind turbine, wind speed, wind blade.**

I. Introduction

Many developing countries in Asia have experienced high rate of economic growth during the past few decades. The advanced technological nations of the world have been engaged in the race of energy and resources that has also brought us in to the position of energy crisis. Pakistan is an energy-deficient country that spends Billions US dollars every year to import oil, in order to meet the domestic need of the country. The prospects for meeting this demand and avoiding crises in supply would be improved, if new and alternative energy sources could be developed. It is now widely recognized that fossil fuels and other conventional resources, presently used in generation of electrical energy, may not be either sufficient or suitable to keep pace with the ever-increasing world demand for electrical energy. The other direction is the research and development being made in the area of "Economical and Efficient Usage of energy" [1]. The current government of Pakistan is working on the utility of renewable energy and initializing many projects, such as a wind speed measurement program the establishment of big wind farms on different locations that have been appraised as suitable projects [2].

Balochistan, Pakistan's one the four provinces; is the largest province of Pakistan, mostly with barren hills and mountains and a large area is without electricity. Underground water is available for usage and cannot be used for irrigation due to un-availability of electricity to pump water to the surface. The population of the area is scattered and expanded over large and remote areas. Whereas, the power supply from the main grid station is high in cost and not bearable for everyone. The use of oil (Diesel/Petrol) engine is limited due to the maintenance, Transportation and heavy expenses [3]. The Jiwani town is situated in district Gawadar and located near Iran border, having geographical coordinates 25.30O N and 61.44O E. Jiwani is at about 34 km away from the boarder of Iran. The majority of population is depended upon fishing, and there are many fish freezing plants related to export oriented fishes [4]. Keeping in view the feasible conditions and the wind potential for installation of windmills for electricity production, the assessment for the requirement of a small scale wind turbine was made initially. Based on the wind data of that area, the design optimization of the turbine blades to produce power at even low wind speeds was then performed.

II. Data and Methodology

This study depends upon the data obtained by the Pakistan Meteorological Department, Karachi for period of four year (2006 to 2009). The speed of wind was measured on the monthly average speed at the height of 10 meters. Windmill requires a continuous wind at rated speed, for generation of power; but it is very difficult to maintain the steady state conditions due to the fluctuations in the wind speed [5]. In order to overcome this situation the wind speed at any height can be measured through the Hellmann exponent law as given below:

$$\frac{V(h)}{V_{10}} = \left(\frac{h}{10}\right)\alpha \; \frac{V(h)}{V_{10}} = \left(\frac{h}{10}\right)\alpha \qquad (1)$$

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where *V (h)* is the wind speed at the height, and V10 is the speed of wind at 10m, while α is the Hellmann exponent constant having value α = 1/7. The wind has a kinetic energy because of its speed; the maximum power from the wind extractable and usable. This maximum power can be computed from the following equation:

$$P_{wind} = 0.5\, \rho\, A\, V^3 \qquad (2)$$

III. Statistical Models

The statistical models were developed for the prediction of output for wind energy conversion system; over the data of wind speed frequency distribution. The basic knowledge about wind speed and its frequency distribution was very much important to analyze the wind potential for the location. The Weibull distribution was used as appropriate case of popularized gamma distribution function for wind speed data and expressed as:

$$f(v) \frac{k}{c} \left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^{k}\right] \qquad (3)$$

The two parameters *K* and *C* of Weibull distribution are derived by using mean wind speed standard deviation method in this study. The wind power that flows at speed *V* directly on a blade swept area *A* that increases the cubic of its velocity and is presented by using the following equation:

$$P(v) = \frac{1}{2}\, \rho A \bar{v}^{\,3} \qquad (4)$$

where ρ mean air density, v^3 mean value of the third power of the wind speed and *A* for swept area. The mean wind power density of the site based on Weibull probability density function can be expressed as:

$$P_m = \frac{1}{2}\, \rho \bar{v}^{\,3}\, \frac{\Gamma\,(1+3/k)}{[\Gamma\,(1+1/k)]^{\,3}} \qquad (5)$$

Furthermore, for a height of less than 100 m, the power density for the wind speed above ground level was given by:

$$P_h = P_{10} \left(\frac{h}{10}\right)^{3\alpha} \qquad (6)$$

where P_{10} was the corrected power available in the wind at a height of 10 *m* and α for the roughness factor, usually in the range of 0.05–0.5. Wind speed data were guess by using following power law formula

$$\frac{v_1}{v_2} = \left(\frac{h_1}{h_2}\right)^{\alpha} \qquad (7)$$

While v_1 & v_2 were the wind velocities at heights h_1 and h_2 [6].

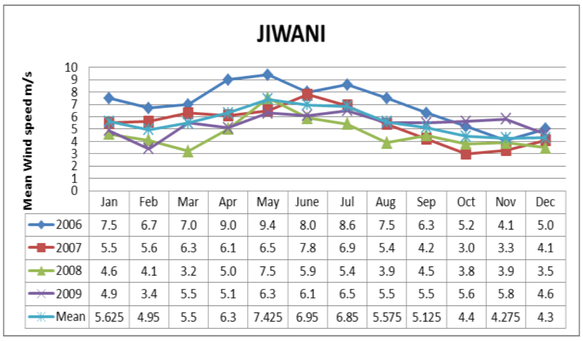

Fig. 1. Monthly mean wind speeds of the site for the years 2006-2009

IV. Mean Wind Speed

The monthly mean wind speeds in the Jiwani site for the years 2006, 2007, 2008 and 2009. It can be seen in the Fig.1.

The mean wind speed varies between 3.0 *m/s* and 9.4 *m/s*. The maximum value of the mean wind speed was in the month of May while the minimum value was in the month of October as shown in Fig. 2 and Fig. 3 respectively.

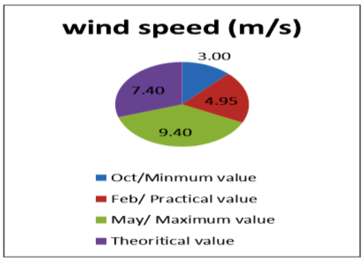

Fig. 2. Minimum and Maximum wind speed of Jiwani

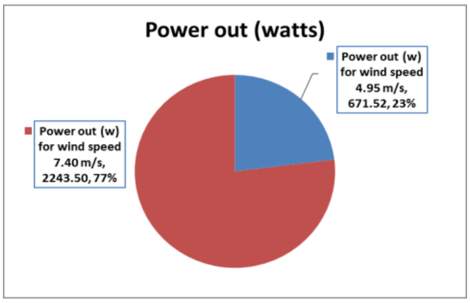

Fig. 3. Power Output at Minimum and Maximum wind speed of Jiwani

V. Optimization Model

The blade shape has an important role in determining the aerodynamic efficiency of wind turbine. In the present work, the optimization model for designing of rotor blades which refers to wind speed distribution for the selected sites; with objective to meet the annual energy requirement [7] as seen in the Fig. 4.

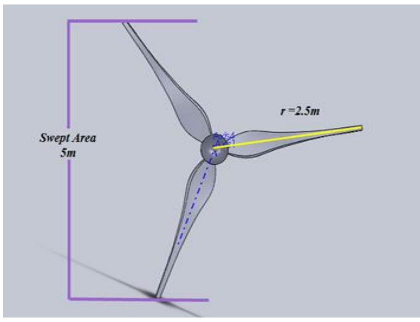

Fig. 4. Blade with hub

In this study (a) Blade element Momentum theory (BEM) and (b) Computational Fluid Dynamics (CFD) were used to improve the power output and efficiency of the system and finally concluded that the results were efficient and approximately similar. The blade shape of the structural design of a 2.5 m long was examined at six sections for modeling and simulation purpose; and equal concentration was given over the angle of twist, variable chord wind turbine blade also calculated through BEM theory. The final efficiency value was obtained through CFD Method, as and integral of all the sections that made the complete blade design as shown in Fig. 5. Maximum power coefficient was found in the month of February about design of wind turbine blade.

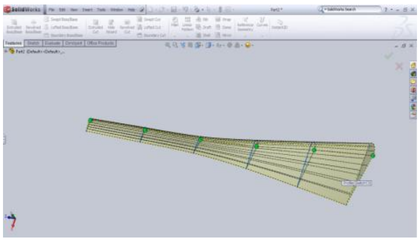

Fig. 5. Blade Geometry.

VI. Blade Element Momentum Theory Calculations

Blade Element Momentum theory was used to obtain the results shown in the Table I. The BEM theory for wind turbine blade analysis and design has been described in details in [8]. Here the details are omitted.

TABLE I: Calculation of Maximum Power Output for Each Month Blade Shape

Months	Wind Speed [m/s]	Blade Radius r[m]	Pturbine Watts	Energy Kwh
January	5.6	2.5	11276.48	40595.33
February	4.95	2.5	**12831.17**	**46192.21**
March	5.5	2.5	8192.084	29491.5
April	6.3	2.5	7506.044	27021.76
May	7.4	2.5	6403.033	23050.92
June	6.95	2.5	5110.092	18396.33
July	6.85	2.5	9357.31	33686.32
August	5.5	2.5	10938.42	39378.31
September	5.1	2.5	7900.64	28442.3
October	4.4	2.5	8282.337	29816.41
November	4.275	2.5	5920.841	21315.03
December	4.3	2.5	7786.054	28029.79

For the month of February Blade parameters were calculated from BEM Theory equations and also maximum wind energy turbine (coefficient of performance CP) were obtained for the month with wind speed 4.95 *m/s* as shown in Table III. The maximum power for the whole year was 12831.1 Watts for the month of February blade shape.

TABLE II: February Blade Parameters

Blade Sections	Section radius r[m]	Chord length c [m]	*A*	á	Pitch angle B[°]
1	0.42	0.571	0.8259	0.0576	34.8
2	0.83	0.395	0.7631	0.0452	68.4
3	1.25	0.251	0.5734	0.0210	75.9
4	1.67	0.153	0.4164	0.0144	81.8
5	2.08	0.123	0.3079	0.0028	82.6
6	2.5	0.103	0.2278	0.0010	87.3

TABLE III: Power Output from February Blade Shape

Months	*Wind speed*	*1*	*2*	*3*	*4*	*5*	*6*	P turbine
1	5.6	61.82	113.9	369.11	243.18	151.9	32.258	972.31
2	4.95	42.70	78.69	254.92	167.95	104.9	22.279	671.52
3	5.5	58.57	107.9	349.69	230.38	143.9	30.561	921.15
4	6.3	88.03	162.2	525.55	346.25	216.4	45.931	1384.4
5	7.4	142.6	262.9	851.71	561.12	350.7	74.435	2243.5
6	6.95	118.1	217.8	705.59	464.86	290.5	61.665	1858.6
7	6.85	113.1	208.5	675.57	445.08	278.1	59.041	1779.5
8	5.5	58.57	107.9	349.69	230.38	143.9	30.561	921.15
9	5.1	46.70	86.06	278.81	183.68	114.8	24.366	734.43
10	4.4	29.99	55.26	179.04	117.95	73.72	15.647	471.63
11	4.275	27.50	50.68	164.21	108.18	67.61	14.351	432.56
12	4.3	27.99	51.58	167.11	110.09	68.81	14.604	440.19
								12831
	P turbine	815.9	1505	4871.0	3209.1	2005.7	431.70	
	KW	0.815	1.505	4.8710	3.2091	2.0057	0.4317	

VII. Computational Fluid Dynamics (CFD)

Computational Fluid Dynamics (CFD) is the system of analysis of the fluid flow, heat transfer and combine phenomenon in terms of computer based simulation. The instance of the complication which could be analyzed by using of CFD is the aerodynamics of wind turbine blades. COSMOS floworks is a computational fluid dynamics (CFD) computer code broadly used for flow modeling operations.

VIII. Computational Fluid Dynamics (CFD) Results

COSMOS Floworks simulations were done for CFD analysis to get power output results using February wind speed blade shape design in Solid Works.

TABLE IV: Calculations of Power Output for Each Month in COSMOS Floworks

Months	Wind Speed [m/s]	Blade Radius r[m]	Angular Velocity Ω Rad/sec	Pturbine Watts	Energy Kwh
January	5.6	2.5	13.44	986	3549.6
February	4.95	2.5	11.88	742	2671.2
March	5.5	2.5	13.2	924	3326.4
April	6.3	2.5	15.12	1469	5288.4
May	7.4	2.5	17.76	2013	7246.8
June	6.95	2.5	16.68	2093	7534.8
July	6.85	2.5	16.44	2068	7444.8
August	5.5	2.5	13.2	827	2977.2
September	5.1	2.5	12.24	663	2386.8
October	4.4	2.5	10.56	437	1573.2
November	4.275	2.5	10.26	401	1443.6
December	4.3	2.5	10.32	408	1468.8
			Total	**13031**	**46911**

IX. Comparison of Power Co-Efficient between Computational Fluid Dynamics (CFD) with Blade Element Momentum (BEM) Method

The calculation of blade element momentum for power coefficient is compared with the computational fluid dynamics method. The blade geometry which gives maximum power was in the month of February blade model. The same blade geometry was used to obtain power for every month of wind speed. The CFD results were seems to be in good reliability with those achieved from the BEM theory, for the proven calm wind velocities, ranging from 4.275 *m/s* to 7.4 *m/s* for the Jiwani coastal wind site.

X. Results and Discussion

Calculate Mean wind speed by using the data taken from Pakistan Metrological Department Karachi. The results from Blade Element theory regarding blade parameters, blade design and computational fluid dynamics analysis were compared. Finally angle of twist was investigated through parametric study and the coefficient of performance was evaluated.

XI. Conclusions

1) Modeling and simulation was carried out for design and evaluation for the performance of wind turbine blade; using blade element momentum theory, solid works and cosmos flow. The results from analysis were obtained by BEM theory and CFD method for the improvement of power output through parametric study.

2) The Mean monthly wind speed for the Jiwani coastal wind observation station at a height of 10 m above the ground level for the years 2006, 2007.2008, and 2009 were selected. The values were then used in BEM theory to obtain the power output for each moth over the year. Maximum power of 12831watts was observed in the month of February with the wind speed of 4.95m/s. This power was used to design blade shape and achieved parameters for the blade of the concerned month.

3) The blade shape of the structural design of a 2.5 m long, twisted, variable chord wind turbine blade was calculated through BEM theory. The final efficiency value was obtained through CFD Method, as an integral of all the sections that made the complete blade design. Maximum power coefficient was found in the month of February about design of wind turbine blade.

4) The power output over a year, taken on same given input wind speed and respective month reveals a good similarity. The total power output from CFD simulation result was 13031watts.

5) The Parametric study of the blade design was also done in the COSMOS Floworks software. After changing the twist angle of blade again simulations were carried out, in order to check the overall effect and efficiency of wind turbine. The result shows through analysis that changing of twist angle has significant effect to maximize the power efficiency.

A medium size 2.5 m blade was selected for the assessment and study keeping under consideration of location of site available local resources. Designed blade for wind turbine was proposed in accordance with the logistics and material handling problems. The main advantage of wind turbine was that it can be easily maintained and installed.

XII. Recommendations

Following recommendations were made on the basis of findings and considering the simulation results as under:

1) The proposed designed blade has a capacity of 12.83 KW for the site Jiwani town. If considered that it has a population of 25000 people and having five hundred houses in the town with 5 persons in each house. Assume every house requires 500 watts for electricity; then the total power required for the town was 250 kilowatts. Therefore wind turbine farm can be developed with 20 wind turbines machines to provide local electrification to the remote area of the Jiwani town.
2) Wind speed is not same all the time. Batteries are required to store the energy at maximum wind velocities and then distributed to the houses in case of variable adverse conditions of wind flowing.
3) Wind farm can be connected to the National grid station and extra power could be supplied to the electrical generation companies for generating the funds for the repair and maintenance of wind turbine.
4) Utilization of wind energy potential for the Jiwani coastal site to optimal conversion, using proposed blade shape will be beneficial and economically feasible size for water pumping and power generation.
5) Considering logistic and materials handling problems at least one spare blade of the wind turbine can be included in the project feasibility.
6) CFD simulations can be done for all the months wind speed to check also the best blade shape observed results.

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References

[1] Global Status Report. (2007). Paris: Renewable Energy Policy Network for the 21st century. [Online]. Available: http://www.unep.org/energy/Activities/REN21/tabid/79491/Default.aspx

[2] A. Makkawi and Y. Tham, "Analysis and inter-comparison of energy yield of wind turbines in Pakistan using detailed hourly and per minute recorded data sets," *sciencedirect* , vol. 50, pp. 2340-2350, September 2009.

[3] S. Z. Ilyas and S. Kakac, "The Wind Potential in Coastal Areas of Balochistan, Pakistan," *American-Eurasian Journal of Scientific Research* , pp. 52-54, 2006.

[4] Wind turbine. [Online]. Available: http://en.wikipedia.org/wiki/Wind_turbine.

[5] X. Liu, Y. Chen, and Z. Ye, "Optimization model for rotor blades of horizontal axis wind turbines," *Frontiers of Mechanical Engineering in China* , vol. 2, pp. 483-488, October 2007.

[6] A. Ucar and F. Balo, " Evaluation of wind energy potential and electricity generation at six locations in Turkey,"*Applied Energy*, vol. 86, pp. 1864–1872, 2009.

[7] M. Jureczko, M. Pawlak, and A. Mężyk, "Optimisation of wind turbine blades," *Journal of Materials Processing Technology*, pp. 463-471, 2005.

[8] G. Ingram, *Wind Turbine Blade Analysis using the Blade Element Momentum Method*, version 1, pp. 1, October 2011.

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