A PROGNOSIS OF WIND ENERGY POTENTIAL AS A POWER GENERATION SOURCE IN BASRA CITY, IRAQ STATE

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Abstract

In this study, wind energy potential of Basra, one southern Iraqi cities, was analyzed for the period of five years from 2004 – 2008. The statistical data of five years' wind speed measurements of this city are used to find out the wind energy potential. Behind the meteorological data, Weibull distribution method is assessed to evaluate wind characteristics. Based on these data, it was indicated that the numerical values of the shape and scale parameters for Basra varied over a wide range. The yearly values of k (dimensionless Weibull shape parameter), ranged from 1.684 to 4.276 with a mean value of 2.9, while those of C (Weibull scale parameter), were in the range 3.5–8.509 m/s with a mean value of 4.862 m/s. Corresponding values for monthly data of whole year were found to be within the range 2.383–3.116 and 4.425–5.719 m/s, respectively related to k and C Weibull parameters. Results revealed that the highest and the lowest wind power potential are in June and December, respectively. It was also concluded that the site studied is not suitable for electric wind application in a large-scale. It was found that the wind potential of the region can be adequate for non-grid connected electrical and mechanical applications.

Keywords: Wind power potential, Weibull distribution function, Basra, Iraq

Introduction

Renewable energy sources, wind, solar, geothermal, hydro, biomass and ocean thermal energy have attracted increasing attention from all over the world due to their almost inexhaustible and non-polluting characteristics. Wind energy as one of these important sources is perhaps the most suitable, most effective and inexpensive sources for electricity production as a result, it is vigorously pursued in many countries[1]. Human beings have been putting the wind to useful work for a very long time. Sailing vessels provided the primary means of intercontinental travel until only a few hundred years ago. Stationary machines that converted the wind's energy into mechanical force were first developed in the Near East. As early as 1700 BC, Hammurabi employed windmills to water the plains of Mesopotamia[1] . Evidence of other early windmills exists in Iran, Afghanistan, and China. All of the earliest windmills utilized a vertical axis and were used for milling grains or pumping water. As such, this technology played a major role in the widespread cultural shift from nomadic, hunter-gatherer cultures to permanent, agricultural settlement. The horizontal-axis windmill was developed significantly later, circa 1100 AD. "As the most important driving engine eapart from the water wheel, it spread from England and France via Holland, Germany (1200s) and Poland to Russia(1300s)"[2]. The basic design of the horizontal-axis windmill underwent numerous iterations, culminating in the Dutch "Smockmill" in the 1700s and 1800s, which saw very widespread use throughout much of Europe. The wind speed probability distributions and the functions representing them mathematically are the main tools used in the wind related literature. Their use includes a wide range of applications, from the techniques used to identify the parameters of the distribution functions[3,4&5] to the use of such functions for analyzing the wind speed data and wind energy economics[6,7]. The first statistical studies of wind speed as a discrete random variable began 50 years ago, with the Gamma distribution[8]. Over this period, different distribution functions have been suggested to represent wind speed, including those of Pearson, Chi-2,Weibull, Rayleigh and Johnson functions[9–12].

The aim of the present study is to analyze wind speed at Basra city due to the important of statistical analysis of wind data to predict the power density in this area.

Theoretical Analysis and Formulation

Weibull probability density function:

The wind speed data in time series format is usually arranged in the frequency distribution format since it is more convenient for statistical analysis, therefore the available time-series data were translated into frequency distribution format [13]. The probability density function of the Weibull of wind speed being $v,\ f(v)$ during any time interval is given, as following[15,16]:

$$f(v) = \frac{k}{c}\left[\frac{v}{c}\right]^{k-1} e^{\left[-\left(\frac{v}{c}\right)^{k}\right]}, (k > 0, v > 0, c > 1) \qquad (1)$$

Where C (m/s) is the Weibull scale parameter and k is the dimensionless Weibull shape parameter. The Weibull parameters k and c, characterize the wind potential of the region under study. Basically, the scale parameter, c, indicates how 'windy' a wind location under consideration is, whereas the shape parameter, k, indicates how peaked the wind distribution is, Once the mean, $\bar{v}$, and the variance, σ^2, of the data are known, the following approximation can be used to calculate the Weibull parameters c and k:

$$k = \left[\frac{\sigma}{\bar{v}}\right]^{-1.086} \quad (1 \leq k \leq 10) \qquad (2)$$

$$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \qquad (3)$$

where the average wind speed $\bar{v}$ is:

$$\bar{v} = \frac{1}{n}\sum_{i=1}^{n} v_i \qquad (4)$$

the variance, σ^2, of wind velocity recordings is:

$$\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n}(v_i - \bar{v})^2 \qquad (5)$$

Average wind speed and the variance of wind velocity can be calculated on the basis of the Weibull parameters as given below[13]:

$$\bar{v} = c\Gamma(1 + \frac{1}{k}) \qquad (6)$$

$$\sigma^2 = c^2\left[\Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2(1 + \frac{2}{k})\right] \qquad (7)$$

Where the gamma function of (x) standard formula is:

$$\Gamma(x) = \int_0^{\infty} e^{-u}\, u^{x-1}\, du \qquad (8)$$

Wind power density function

The evaluation of the wind power per unit area is of fundamental importance in assessing wind power projects, it is well known that the power of the wind at speed V through the blade sweep area A increases as the cube of its velocity and is given by[17,18].

$$P(v) = \frac{1}{2}\rho A v^3 \qquad (9)$$

Where ρ (kg/m3) is the mean air density, the value 1.069 kg/m^3 is used in this work [19]. This depends on altitude, air pressure and temperature.

The expected monthly or annual wind power density per unit area of a site based on a Weibull probability density function can be expressed as follows[20]:

$$P_w = \frac{1}{2}\rho c^3 \Gamma\left(\frac{k+3}{k}\right) \qquad (10)$$

Wind power density, expressed in Watt per square meter (W/m^2), takes into account the frequency distribution of the wind speed and the dependence of wind power on air density and the cube of the wind speed. Therefore, wind power density is generally considered a better indicator of the wind resource than wind speed[14]. The average wind power density in terms of wind speed is calculated as:

$$WPD = \frac{\sum_i^N \frac{1}{2\rho v_i^3}}{N} \qquad (11)$$

where i is the measured three-hourly wind speed and N is the total sample data used for each year.

The errors in calculating the power densities using the distribution model (Weibull) in comparison to values of the Probability density distributions derived from measured values can be found using the following formula[15,16]

$$Error\% = \frac{P_{w-}P_p}{P_p} \quad (12)$$

Where $P_w(W/m^2)$ is the mean power density calculated from the Weibull function, and P_p is the wind power density for the probability density distribution, derived from measured values which serves as the reference mean power density.

Estimated Wind power by using wind turbine

Wind turbines work by converting the kinetic energy in the wind into rotational kinetic energy in the turbine and then electrical energy that can be supplied, via the national grid. It is well known that the power of the wind at speed V through the blade sweep area A increases as the cube of its velocity and is given by Eq.(9). A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. The theoretical maximum power efficiency of *any* design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). This is called the “power coefficient”. Also, wind turbines cannot operate at this maximum limit. The *Cp* value is unique to each turbine type and is a function of wind speed that the turbine is operating in. Once we incorporate various engineering requirements of a wind turbine - strength and durability in particular – the real world limit is well below the *Betz Limit* with values of 0.35-0.45 common even in the best designed wind turbines.

So, the power coefficient needs to be factored in equation (9) and the extractable power from the wind is given by:

$$P_{output} = \frac{1}{2}\rho A v^3 C_P \quad (13)$$

The sweep area of the turbine can be calculated from the length of the turbine blades using the equation for the area of a circle:

$$A = \pi\, r^2 \quad (14)$$

where the radius is equal to the blade length as shown in the Fig.(1):

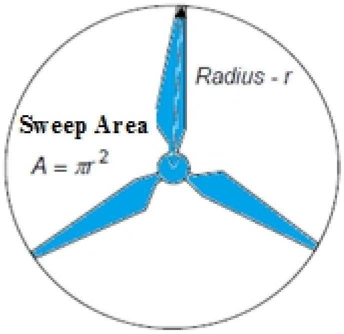


Figure (1): Sweep Area for wind turbine

Results and discussion

Data for wind speed in the present calculation were obtained during the period 2004 to 2008 taken from the meteorological directorate center of Basra. The main results obtained from the present study can be summarized as follows.

Figures from (2) to (13) study the wind regime of Basra, one southern Iraqi cities. The historical wind data for the period from 2004 - 2008, as supplied by the Meteorological centre, are used to determine the potential of wind energy in this part of the world. Basra is situated at47°50'E Longitude, 30°30'N Latitude. For getting a perfect impression about the wind regime of a place, diurnal wind velocity recording is essential since wind velocity on a particular day of a month may vary from year to year. Figures (2) - (13) show the variations of diurnal wind velocity from January to December of the period 2004 - 2008.

The monthly mean wind values estimated from the available data for the overall and individual Five years are presented in Table (1). It is seen in Table (1) that the highest wind speeds 7.611 m/s occurs in June at 2005. While lowest wind speed 2.558 m/s occur in February in year 2008. The variation of wind speeds often described using the Weibull two-parameter density function. This is statistical method which widely accepted for evaluation local wind local probabilities and considered as a standard approach.

Table (2) shows the yearly values of the two Weibull parameters; the scale parameter c (m/s) and shape parameter k (dimensionless). The values of k and c are determined using Eq.(2) and Eq.(3). It is obvious that the parameter k has a much smaller, temporal variation than the parameter c. The yearly values of k range between 2.383and 3.116with an average value of 2.7812. The lowest value of the scale parameter c is 4.425m/s and is found in year 2007, while the highest value is 5.719, which occurred in the year2004. Its average value is 5.121m/s for the same period.

Figures (14 to 18) show the average annual variation of Weibull wind speed frequencies in Basra for the five years, It can be clearly seen that the highest frequencies happened in 2007 which reached to about (0.27), while the lowest frequencies happened in 2008 which reached to about (0.18).

The power densities calculated from the measured probability density distribution, which mention in eq.(9) are shown in Figure (19). The power density shows a large month to month variation, the minimum power densities occur in the October and November (2007) with 16.41 and 22.88 w/m^2 respectively, it is interesting to note that the highest power density value occur in the June (2004) with the maximum value of 278.7 W/m^2 respectively. The power densities in the remaining moths are between these two groups of low and high values.

Fig.(20) explains the generated power which got from wind turbine accourding to different length of blade. This power depand on the average yearly wind speed, and it is clear that the maximum power accoured at 2004 and 2005. And the lowest values of power accoured at 2008.

Fig.(21) shows the comparession between the power generated from this study and the power generated from Búrfell, Iceland.The wind speed for Búrfell, Iceland, which reach to about (25 m/s) explained the highest values of power generated from the wind turbine[21]. It is clear that the two carves are increaced accourding to increasing in raduis of sweep area.

The Errors in calculating the power densities using the distributions of Weibull model in comparison to those using the measured probability density distributions are presented in Figure (22). The annual analysis shows that the highest error value using the Weibull model occur at 2006 with 12 %, whereas the smallest error in the power density calculation using Weibull model is 9% at 2008.

Table (1):- Yearly mean wind speeds and standard deviations in Basra, Iraq

Month	Param-eter	2004	2005	2006	2007	2008
Jan.	$\bar{v}$	3.817	4.552	4.498	2.885	3.118
	ρ	2.242	1.665	2.369	1.534	1.29
Feb.	$\bar{v}$	4.272	4.416	4.483	3.171	2.558
	ρ	1.998	2.300	1.911	1.91	2.713
Mar.	$\bar{v}$	5.018	5.466	5.556	3.557	3.118
	ρ	1.939	1.714	2.147	1.895	1.29
Apr.	$\bar{v}$	5.111	5.324	4.176	4.185	3.130
	ρ	2.140	2.292	1.976	1.521	1.311
May	$\bar{v}$	5.305	5.027	3.719	4.471	3.118
	ρ	1.795	1.508	1.633	1.241	1.29
Jun.	$\bar{v}$	7.250	7.611	4.759	6.000	3.917
	ρ	1.886	2.682	2.094	1.724	2.040
Jul.	$\bar{v}$	5.636	7.007	5.663	5.959	4.479

	ρ	1.84	1.957	1.970	1.706	2.089
Aug.	$\bar{v}$	6.891	4.857	3.531	4.104	4.283
	ρ	1.808	1.950	1.494	1.208	2.00
Sept.	$\bar{v}$	4.917	3.435	2.722	3.778	4.759
	ρ	2.283	1.381	1.683	0.814	2.094
Oct.	$\bar{v}$	3.961	4.812	3.584	2.778	4.695
	ρ	1.277	1.757	1.738	0.811	2.087
Nov.	$\bar{v}$	4.676	4.407	3.120	3.074	4.617
	ρ	1.612	1.561	1.205	0.875	2.031
Dec.	$\bar{v}$	4.444	3.952	2.805	3.539	4.700
	ρ	1.357	1.703	1.630	1.438	1.507
Yearly	$\bar{v}$	5.108	5.072	4.051	3.958	3.874
	ρ	1.848	1.873	1.821	1.390	1.812

Table 2: the yearly values of the two Weibull parameters

years		$\bar{v}$	v_{max}	K	C	P_w	P_p
1	2004	5.108	6.769	3.017	5.719	81.63	71.24
2	2005	5.072	6.774	2.95	5.684	79.92	69.74
3	2006	4.051	5.902	2.383	4.57	40.72	35.53
4	2007	3.958	5.188	3.116	4.425	37.98	33.14
5	2008	4.617	6.655	2.44	5.207	60.28	53.08

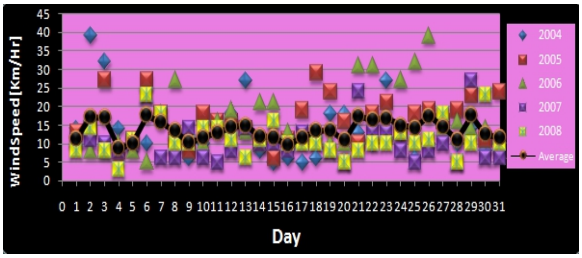


Figure (2): Variation of wind velocity over 24 h in January for the period 2004-2008.

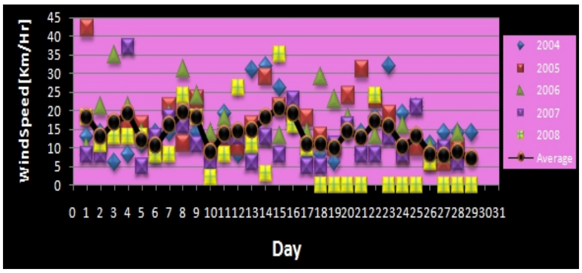


Figure (3): Variation of wind velocity over 24 h in February for the period 2004-2008.

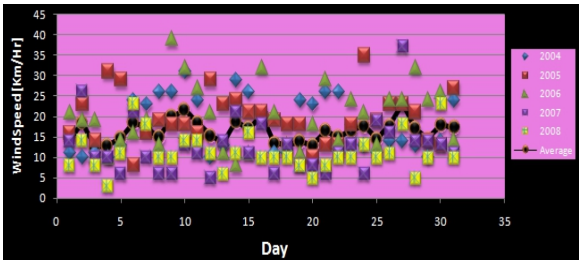


Figure (4): Variation of wind velocity over 24 h in March for the period 2004-2008.

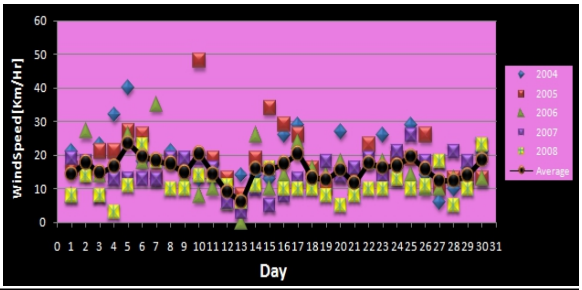


Figure (5): Variation of wind velocity over 24 h in April for the period 2004-2008.

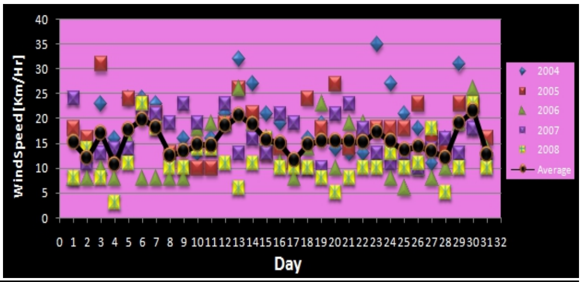


Figure (6): Variation of wind velocity over 24 h in May for the period 2004-2008.

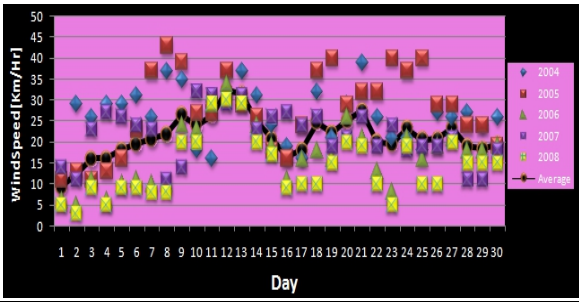


Figure (7): Variation of wind velocity over 24 h in June for the period 2004-2008.

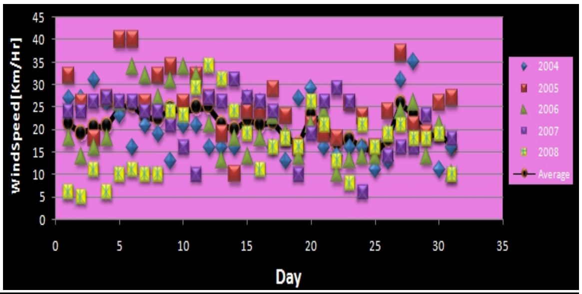


Figure (8): Variation of wind velocity over 24 h in July for the period 2004-2008.

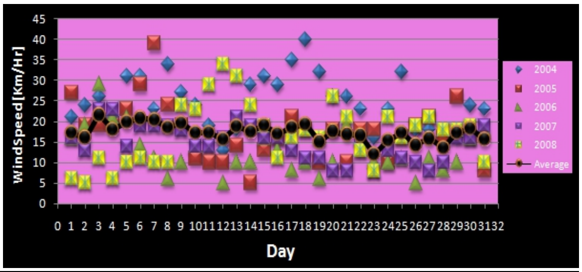


Figure (9): Variation of wind velocity over 24 h in August for the period 2004-2008.

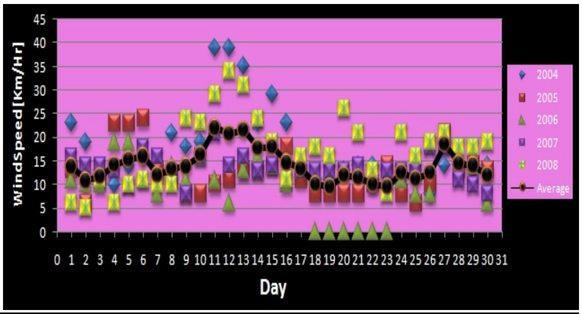


Figure (10): Variation of wind velocity over 24 h in September for the period 2004-2008.

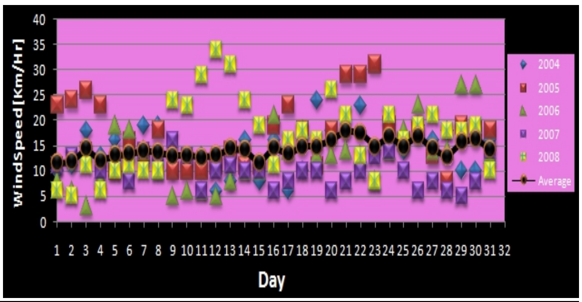


Figure (11): Variation of wind velocity over 24 h in October for the period 2004-2008.

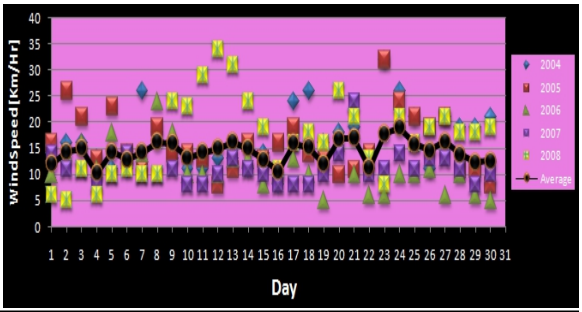


Figure (12): Variation of wind velocity over 24 h in November for the period 2004-2008.

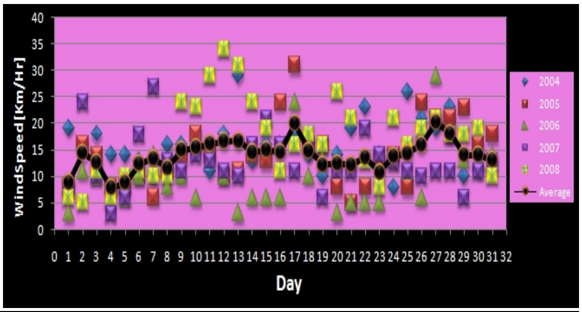


Figure (13): Variation of wind velocity over 24 h in December for the period 2004-2008.

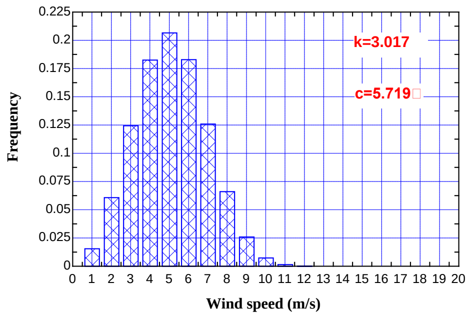


Fig.(14): Average annual variation of Weibull wind speed frequencies in Basra (2004)

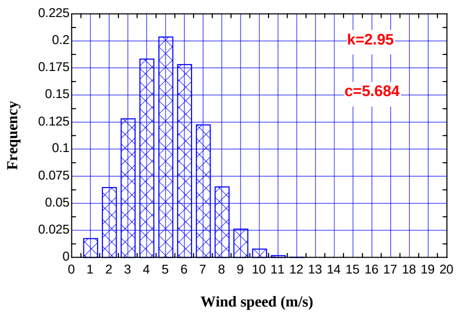


Fig.(15): Average annual variation of Weibull wind speed frequencies in Basra (2005)

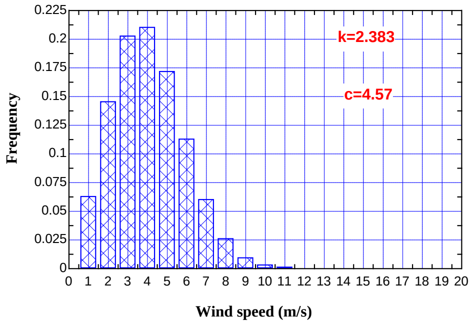


Fig.(16): Average annual variation of Weibull wind speed frequencies in Basra (2006)

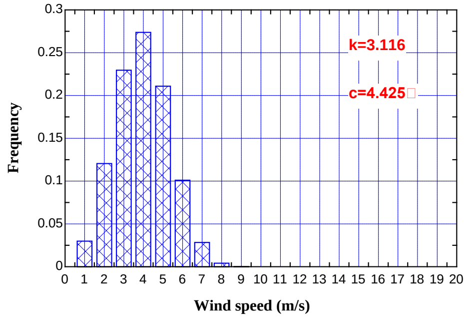


Fig.(17): Average annual variation of Weibull wind speed frequencies in Basra (2007)

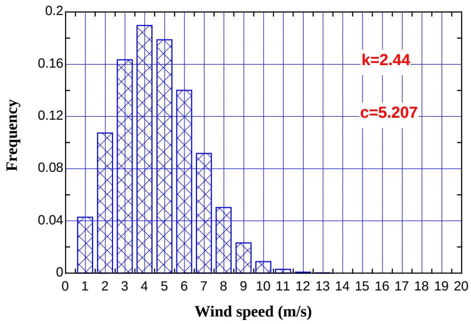
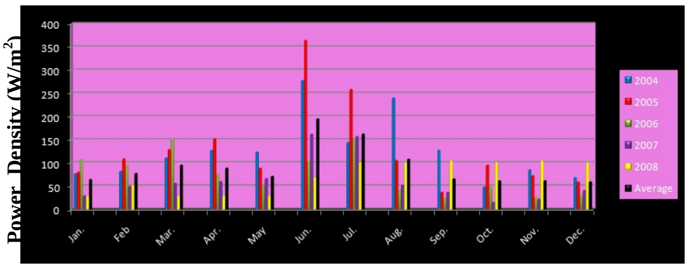


Fig.(18): Average annual variation of Weibull wind speed frequencies in Basra (2008)



Months

Fig.(19) Plot of Monthly Variation of Power Density for the Period 2004-2008

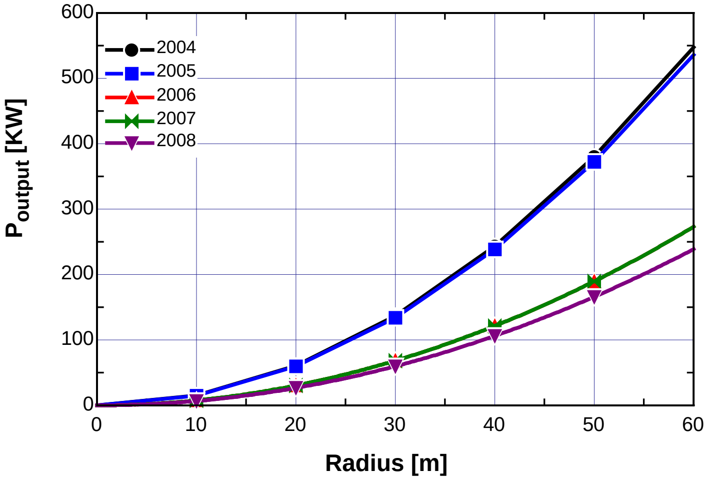


Fig.(20): Rotor Radius vs Generator Capacity for wind Turbine

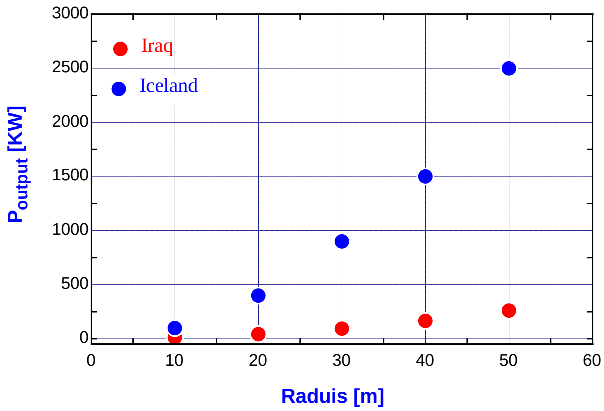


Fig. (21): Comparison of generator capacity for wind turbine between Iraq and Iceland vs. rotor radius

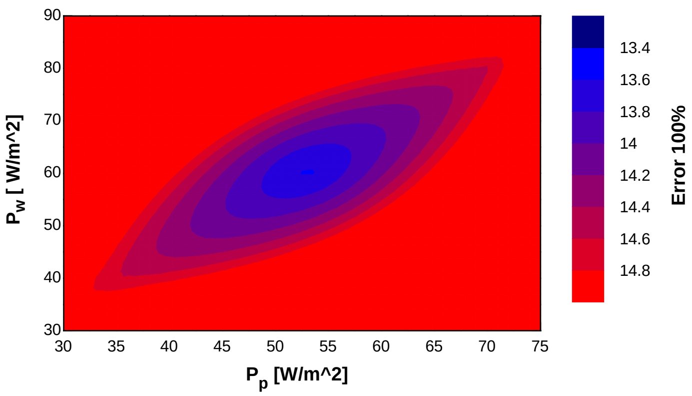


Fig. (22) Error values in calculating the wind power density obtained from the Weibull model in reference to the wind power density obtained from the measured data.

Conclusion

Wind characteristics of Basra have been analyzed statistically, wind speed data were collected for a period of five years (2004-2008). The probability density distributions were derived and the distribution parameters were identified. The wind energy potential of the location has been studied based on the Weibull model. The most important outcomes of the study can be summarized as follows:

- The wind energy potential in one southern Iraqi cities, Basra, is quite promising, because the chances of having wind speeds less than 3 m/s are small but because the wind speed range for electricity generation is within 5–6 m/s, the site studied is not suitable for electric wind application in a large-scale.

- The Weibull distribution presented here indicates a good agreement with the data obtained from actual measurements. That given good impression about studying the wind regime in this area of the world.

At the end, it worth mentioning that the current work is only preliminary study in order to estimate the wind energy potential analysis Basra, in order to have a comprehensive wind data base and obtain good predictions prior to construction and installation of wind energy conversion systems. In assessing the wind power potential or choosing the suitable type of wind turbine, not only the wind data but also the site circumstances (terrain, different referred height, etc) should be considered that this issue can be addressed for application of new wind energy generation technology.

Reference:

Mahyoub H.Albuhairi, "Assessment and Analysis of Wind Power density in Taiz –Republic of Yemen" Ass. Uni. Bull. Environ. Res.Vol9,No.2,pp, 13-21, October, 2006.

Gasch, R., Twele, J. (2002). *Wind Power Plants.* London: James & James. Page 17-20.

Kelleher J, Ringwood JV. A computational tool for evaluating the economics of solar and wind microgeneration of electricity. Energy 2009; 34:401–9.

Pilavachi PA, Kalampalikas, NG, Kakouris MK, Kakaras E, Giannakopoulos. The
energy policy of the Republic of Cyprus. Energy 2009: 34: 547–554.

Seguro JV, Lambert TW. Modern estimation of the parameters of the Weibull wind speed distribution for wind energy analysis. J Wind Eng Ind Aerodyn 2000;85:75–84.

Pallabazzer R, Gabow A. Wind resources of Somalia. Sol Energ 1991;46(5):313. p. 22.

Pashardes S, Christofides C. Statistical analysis of wind speed and direction in Cyprus. Sol Energ 1995;55(5):405–14.

Sherlock RH. Analysing winds for frequency and duration on atmospheric pollution. Meteorol Monogr Am Meteorol Soc 1951;4:42–9.

Blanchard M, Desrochers G. Generation of autocorrelated wind speeds for energy conversion system studies. Sol Energ 1984;33(6):571–9.

Chou KC, Cortis RB. Simulation of hourly wind speed and array wind power.
Sol Energ 1981;26:199–212.

Corotis RB, Sigl AB, Klein J. Probabilities models of wind velocity magnitude and persistence. Sol Energ 1978;20:483–93.

Conradsen K, Nielsen LB, Prahm LP. Review of Weibull statistics for estimation of wind speed distributions. J Clim Appl Meteorol 1984;23:1173

Jamil M, Parsa S, Majidi M. Wind power statistics and evaluation of wind energy density. Renew Energy 1995;6:623–8.

Al-Nassar W, Alhajraf S, Al-Enizi A, Al-Awadhi L. Potential wind power generation in the State of Kuwait. Renew Energ 2005;30:2149–61.

Mahyoub H.Albuhairi, “A Statistical Analysis of Wind Speed Data and an Assessment of Wind Energy Potential in Taiz-Republic of Yemen”, Ass.Uni.Bull.Environ.Res.Vol9, No.2, pp 21-33, Oct.2006.

Ali Naci Celik,”A Statistical Analysis of Wind power Density Based on The Weibull and Rayleigh Models at the southern Region of Turkey” Renewable Energy Vol.29, pp 593-604,2003.

Mahyoub H.Albuhairi, “A Statistical Analysis of Wind Speed Data and an Assessment of Wind Energy Potential in Taiz-Republic of Yemen”, Ass.Uni.Bull.Environ.Res.Vol9, No.2, pp 21-33, Oct.2006.

Wei zhou, Hongxing Yang, Zhaohong Fang, “Wind Power Potential and Characteristic Analysis of the Pearl River Delta Region, China” Renewable Energy Vol.31, (2006), pp 739-753.

Salahaddin A. Ahmed, "Wind Analysis and Distribution of Wind Energy Potential over Iraqi Kurdistan Region” 2009, PhD Thesis, Univ. of Sulaimani Coll. of Science. O.A.Jaramillo, R. Saldana, U. Miranda, “Wind Power Potential of Baja California Sur, Mexico ” Renewable Energy Vol.29,(2004),pp 2087-2100.

Adrian Ilinca, Ed McCarthy, Jean-Louis Chaumal, Jean-Louis Retiveau Renewable Energy Vol.28, (2003), pp 1881-189.

Samuel Perkin, Deon Garrett, and Pall Jensson, “Optimal wind turbine selection methodology: A case-study for Búrfell, Iceland”. Renewable Energy 75 (2015), pp. 165-172.