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Full Length Research Paper

Statistical evaluation of wind speed and energy potential for the construction of a power plant in Baladeh, Nur, Northern Iran

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Renewable energy does not pollute the environment and it has an endless and free primary source and save fossil fuel reserves for future generations. Finding and confirming the appropriate potential areas for installing wind turbines is the first and the most important step for constructing wind power plants. Hence, installing a standard anemometer station and checking wind flow regime is essential. In this paper, statistical characteristics of wind speed and direction and the parameters of Weibull function probability distribution were determined and then the potential and density of the wind power were calculated in Baladeh. The results showed that this place was classified in second power class under world classification and it has a relatively good condition for the installation of wind turbines, especially in warm seasons.

Key words: Baladeh, Weibull distribution function, wind energy potential.

INTRODUCTION

Increasing energy needs and limited fossil resources, increasing environmental pollution caused by burning these resources, global warming and the effects of the phenomenon of greenhouse, acid rain, and the necessity of balancing the release of CO_2 all requires the preservation of fossil fuels and the double attention to the use of renewable energy sources. Among renewable energy, wind energy is one of the most economic electricity production methods that doesn't result in environmental pollution and isn't terminable. According to existing statistics, the production of each kWh of electrical energy from wind can prevent about 1 kg of CO_2 emissions compared with fossil fuel power plants (Keyhani, 2010). Although most of the country's electricity is generated using fossil fuels and the cost of investing in wind power plants is higher than fossil power plants, but with advances in the technology of building wind turbines and considering social and environmental costs of energy the country has reached the stage economically. Lack of pollution and helping preserve the environment, free use of wind energy, non-use of fossil fuels for electricity, the installation time, saving oil reserves for next generations, employment creation and industrial development are among the benefits of using wind energy as new energy in the country. In Initial study, the generation of more than 10,000 MW of electric energy from wind is certain to happen, and the capacity is predicted to reach more than this figure if studies continue. Yet according to the climate of Iran, the wind speed and the dispersion of its blowing, wind turbines can be installed in most parts of the country (Anonymous, 2002). Installed capacity of wind power plants in the country until the first half of 2008 is about 128 MW. With this capacity, 185,000,000 kWh of electrical energy is generated in the country which is low compared to the total electricity production in the country. Based on the goals of the fourth development plan of the country, the share of electricity produced from renewable sources to total electricity production in the country should increase by one percent until the end of the fourth development plan (Year 2010). This requires the installation of more power plants and the generation of 500 MW. Now Iran as one of the countries located in

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the Middle East has the ability to build wind turbines with the capacity 660 kW. These turbines can be built by the private sector. According to Article 62 of the law of the third plan, the government must purchase the electricity generated from renewable sources. Hence the modification of the base price to buy electricity from renewable power plants that is very effective in attracting private investors. Whereas, the government issued the license and contract of manufacturing a 600 MW wind power plants by the private sector (Anonymous, 2002; Weisser, 2003).

Few studies on the potential of different regions and wind atlas have been done by the country's atomic energy organization in the past and by new energy organization in recent years. Since the construction of wind farms requires understanding the wind potential of the area under study, installing modern wind poles and recording the precise meteorological values are the major potential studies. The Weibull distribution function is one of the most common distribution function that is used in the statistical study of wind speed and wind energy potential distribution functions of wind speed and wind energy potential (Keyhani, 2010; Canale et al., 2009). In this article wind potential in Baladeh was studied using Weibull distribution, recorded weather data and the software windographer.

The results indicate that this region has relatively good and reasonable conditions for installing wind turbines.

The specifications of the Baladeh region and the data used

Baladeh is located in the province of Mazandaran and in the geographical area 36.12 degrees north and 51.48 degrees east and at the altitude of 2120 m above sea level. Baladeh synoptic weather station was established in 2006. In this article the data wind speed and direction during the statistical period of 2006 to 2009 recorded at the interval of 3 h at altitude of 10 m were used.

MATERIALS AND METHODS

Theory analysis

Probability distribution function

Considering the random nature of wind with long measurements in different time range, we used Weibull probability density distribution function to calculate wind energy (Kelleher and Ringwood, 2009).

$$f(v)=\frac{k}{c}\left(\frac{v}{c}\right)^{k-1}\exp\left(-\left(\frac{v}{c}\right)^{k}\right),(k\rangle 0, v\rangle 0, c\rangle 1) \quad (1)$$

The cumulative distribution function

$$F(v)=1-e^{-\left(\frac{v}{c}\right)^{k}} \quad (2)$$

Where V is wind speed, C and K are the scale and shape parameters respectively. These parameters can be calculated by Maximum likelihood method using the following equations (Seguro and Lambert, 2000)

$$k=\left(\frac{\delta}{\bar{v}}\right)^{-1.086} \quad (1\leq \kappa \leq 10) \quad (3)$$

$$c=\frac{\bar{v}}{\Gamma\left(1+\frac{1}{\kappa}\right)} \quad (4)$$

Where the average wind speed is:

$$\bar{v}=\frac{1}{n}\sum_{i=1}^{n} v_i \quad (5)$$

And the Variance of the wind speed recorded is calculated from the following relationship:

$$\delta^2=\frac{1}{n-1}\sum_{i=1}^{n}\left(v_i-\bar{v}\right)^2 \quad (6)$$

Vi is the wind speed in the time range I, and n is the number of non-zero wind speed. The following relationships can be obtained using Weibull parameters:

$$\bar{v}=c\Gamma\left(1+\frac{1}{k}\right) \quad (7)$$

$$\delta^2=c^2\left[\Gamma\left(1+\frac{2}{k}\right)-\Gamma^2\left(1+\frac{2}{k}\right)\right] \quad (8)$$

Finally, the mathematical function of Gamma (standard formula) is calculated as follows:

$$\Gamma(\chi)=\int_{\circ}^{\infty} e^{-u} u^{x-1} du \quad (9)$$

Calculating the wind energy potential wind energy power has a direct relationship with the cubic wind speed:

Table 1. Statistical parameters and characteristic values of Weibull distribution function at a height.

Month	Average speed (m/s)	Standard deviation	k	c
Jan	2.9	2.4	3.3	4.72
Feb	3.3	2.7	1.7	4.03
Mar	4.3	3.4	1.6	5.11
Apr	4.6	3.7	1.5	5.45
May	5.1	3.9	1.4	5.83
Jun	5.6	4.2	1.5	6.43
Jul	5.7	4.2	1.5	6.60
Aug	5.4	4.1	1.4	6.14
Sep	4.9	3.9	1.4	5.58
Oct	4.3	3.4	1.5	5.08
Nov	3.4	2.9	1.6	4.87
Dec	3.0	2.7	2.9	4.70

$$p(v) = \frac{1}{2}\rho v^3 \quad (10)$$

In which ρ is the standard air density at sea level with an average temperature 15℃ and an atmospheric pressure (1.225) and $\overline{v}$ is the average wind speed. Monthly corrected air density calculated from the relationship is:

$$\rho = \frac{\overline{p}}{R_d \overline{T}} \quad (11)$$

In which p⁻ is the average monthly air pressure and $\overline{T}$ is average monthly temperature according to K, R_d is the gas constant for dry air. The Power of wind energy calculated in relation to the height of 10 m is as follows. To estimate the wind speed at higher elevations, we use either equation 12

$$\frac{v_z}{v_z} = \left(\frac{z}{z_{10}}\right)^a \quad (12)$$

In which Vs is the wind speed at height z and Vz is the actual speed at the height of 10 m or the relationship $V = V_0\left(\frac{Z}{Z_0}\right)^a$ ‹ and a is calculated as follows:

$$a = \frac{[0.37 - 0.088\ln V_{10}]}{[1 - 0.088\ln(z_{10}/10)]} \quad (13)$$

The average intensity of wind power in a windy period is calculated as follows:

$$WPD = \frac{\sum_{i=1}^{N} 1/2\, p v_i^{\,3}}{N} \quad (14)$$

Where i wind speed calculated for 3 h and N total data samples for each year. In addition, the intensity of wind power based on the measured wind speed can be calculated using Weibull distribution analysis according to the Equation (15):

$$\frac{P}{A} = \int_0^\infty \frac{1}{2}\rho V^3 f(V)dV = \frac{1}{2}\rho c^3 \Gamma\left(\frac{k+3}{k}\right) \quad (15)$$

The rate of wind energy density in one location can be obtained from the following relationship:

$$\frac{E}{A} = \frac{1}{2}\rho c^3 \Gamma(\frac{k+3}{k})\mathrm{T} \quad (16)$$

RESULTS AND DISCUSSION

Necessary calculations on the data of wind speed and direction in a four-year period was performed for the primary estimation of attainable energy from the wind flow in Baladeh. Statistical specifications and the parameters from Weibull distribution function in different months and the whole year is summarized in Table 1. The data in Table 1 indicates that this area will have maximum production in summer month, which are peak hours of consumption, if wind turbines are installed and this is an advantage for the construction site of the wind farm.

Figure 1 shows the dominant wind direction that is an important parameter in the installation and arrangement of wind turbines and construction fields, and this figure shows that the dominant wind direction and maximum energy extraction was for North (0-90°), which was

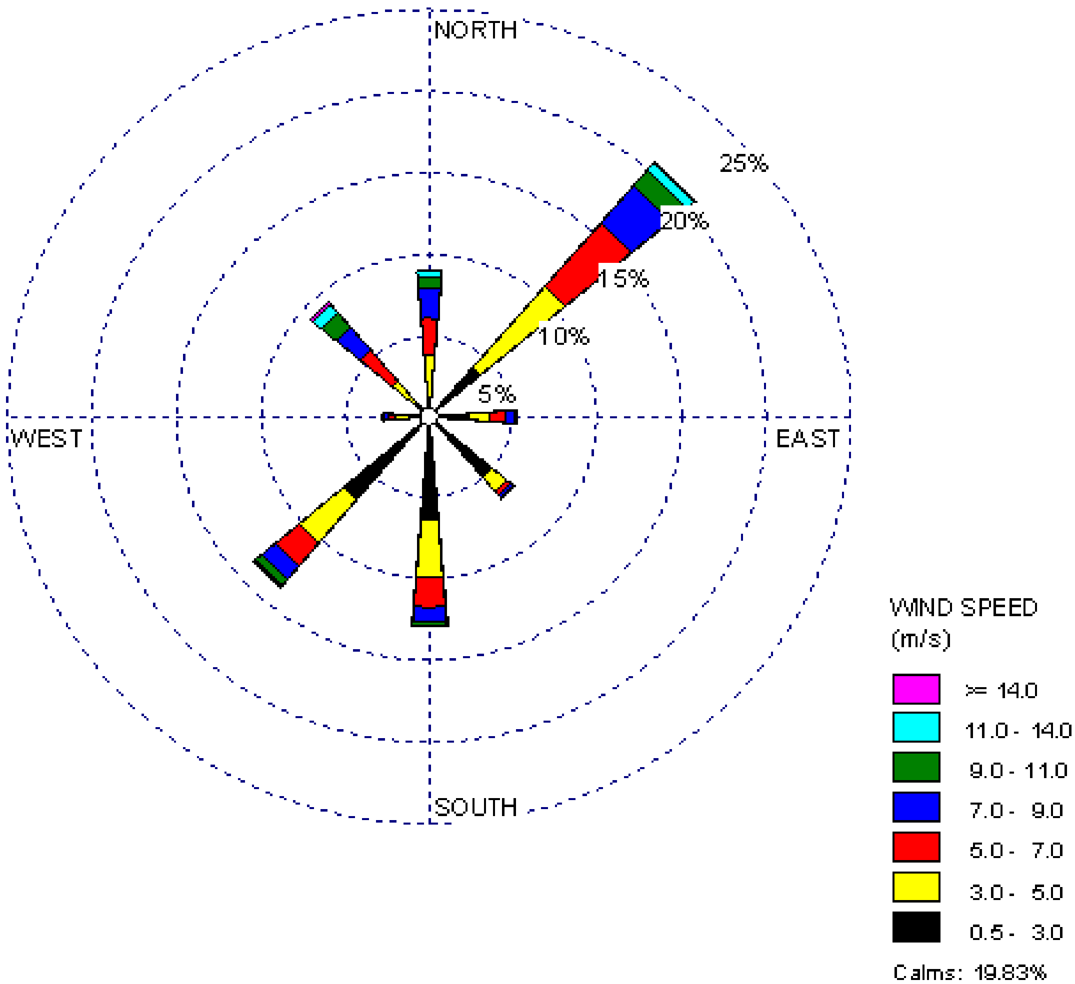

Figure 1. Windrose diagram of Baladeh.

approximately 28% wind blown in Baladeh. 19.38% of the air in the region during the year was quiet and no wind blowing. In fact, wind blow is about 80% of the year in the region. This is a positive feature of the region.

Figure 2 shows the average monthly wind speed in the whole year in the form of time series. It shows that the average speed is higher in summer months. Among different months and seasons of the year in Baladeh, the average maximum wind velocity was in July (4.6 m/s) and the lowest was in winter in January (2.3 m/s).

According to Figure 3, the most wind speed values have occurred in the range of 3 to 5 m/s, which are in the speed range of turbines. Also, Weibull distribution parameters (c, k), calculated by the maximum probability distribution are 1.44 and 4.09 m/s respectively. The diagram suggests that the frequency of speeds over 3 m/s is more than the other speeds, which can be one of the relatively good characteristics of a suitable location for constructing a power plant. Wind speed is proportional to changes in height and the energy output of wind turbine power is proportional to the third power of wind speed, so a one percent error in measuring wind speed reflects a three percent error of the energy output. The amount of energy available in each location can be converted to electrical energy by the turbines. Wind power density is determined and classified by two factors, namely wind speed and height Energy density of 50 m in height is almost twice the energy density of 10 m in height. Figure 4 shows that wind power density increases with height in Baladeh. Wind software analysis, according to the position of the region showed that the wind energy density at an altitude of 10 m is about 100 w/m^2, 30 m in height, approximately 120 w/m^2 and 50 m in height approximately 140 w/m^2 respectively.

According to the height of the turbines used in the region and benefiting from the atlas American Wind Energy Association (11), is placed in the class 2 (medium) from Table 2.

Wind turbine power output curve of the electrical energy as a function of wind speed is shown in Figure 5. Software analysis shows that optimal energy production in Baladeh and warm seasons Baladeh is approximately

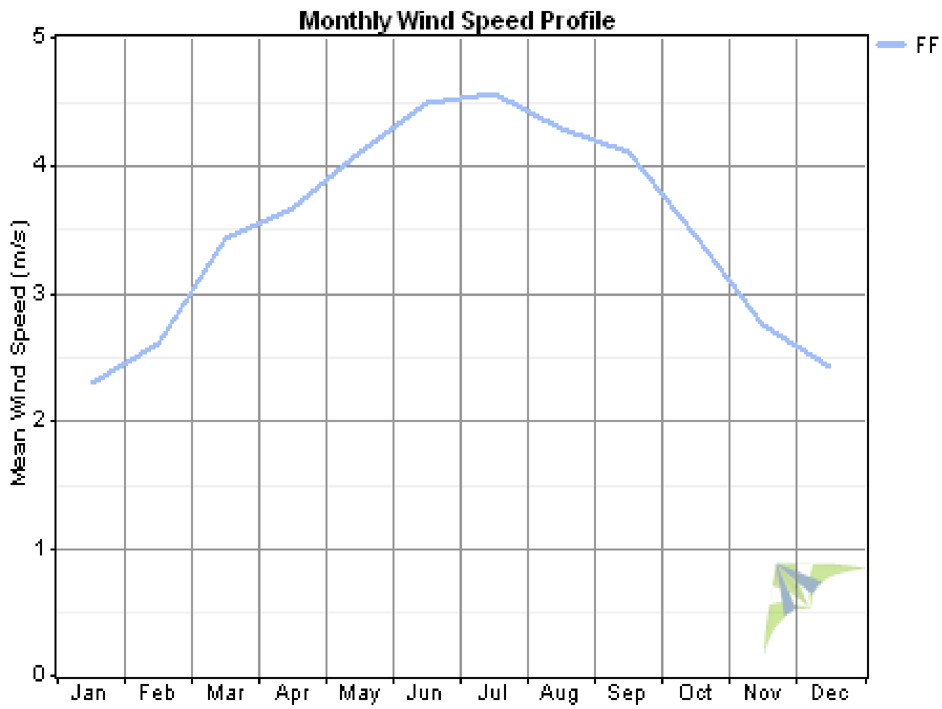

Figure 2. Average monthly wind speed statistics during the statistical period at the height of 10 m in Baladeh Station.

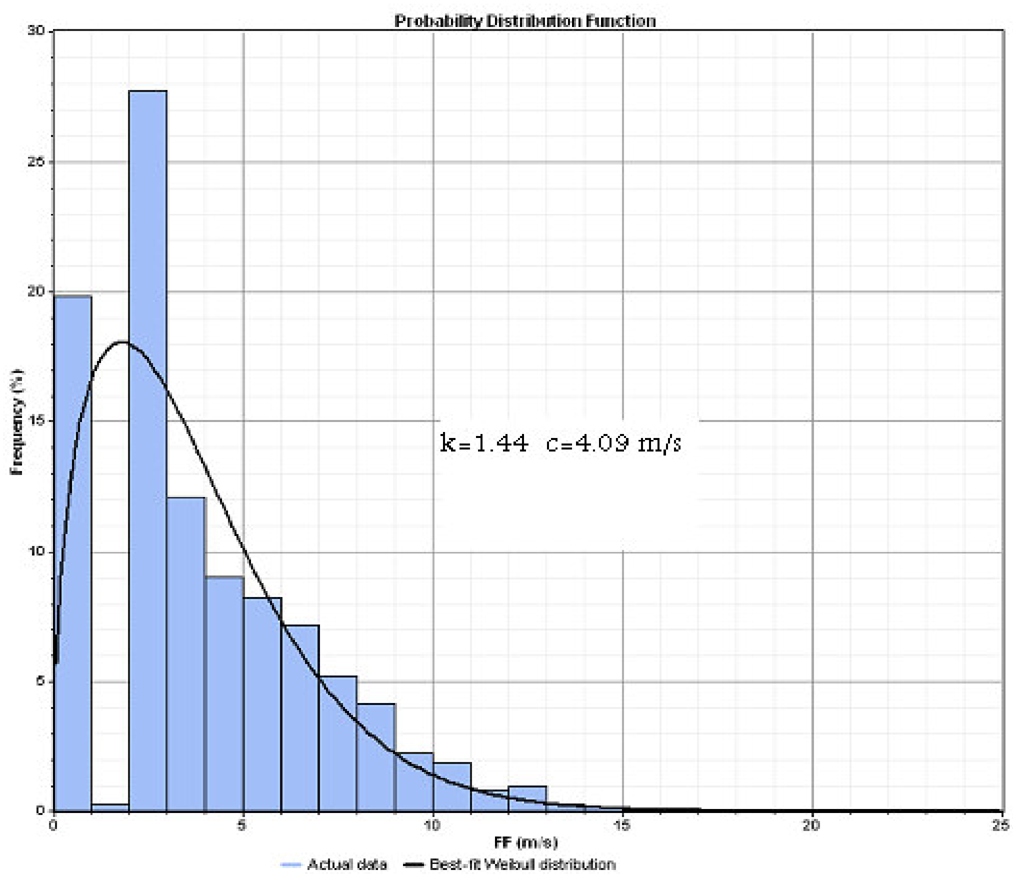

Figure 3. Frequency histogram and Weibull distribution curve diagram in Baladeh Station.

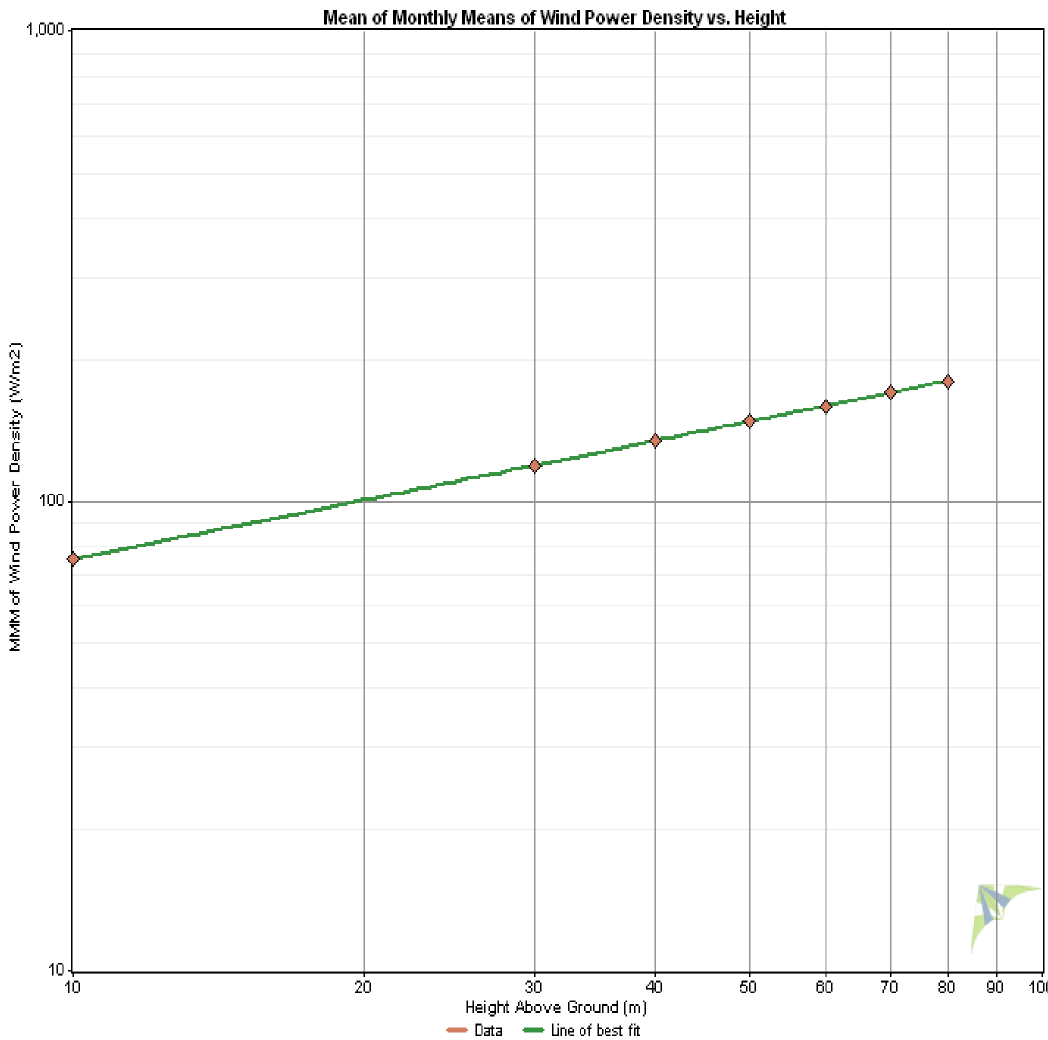

Figure 4. Wind power density curve diagram (w/m^2) according to the height from the ground station, Baladeh.

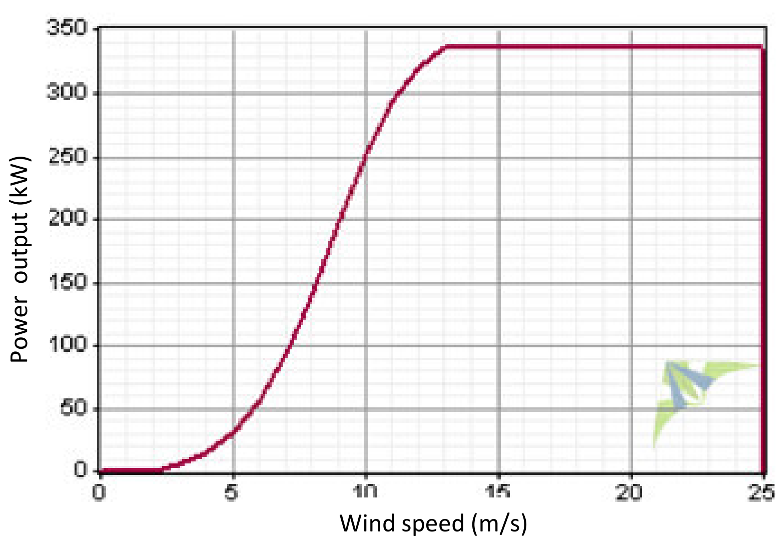

Figure 5. Power curve plotted for Enercon turbine.

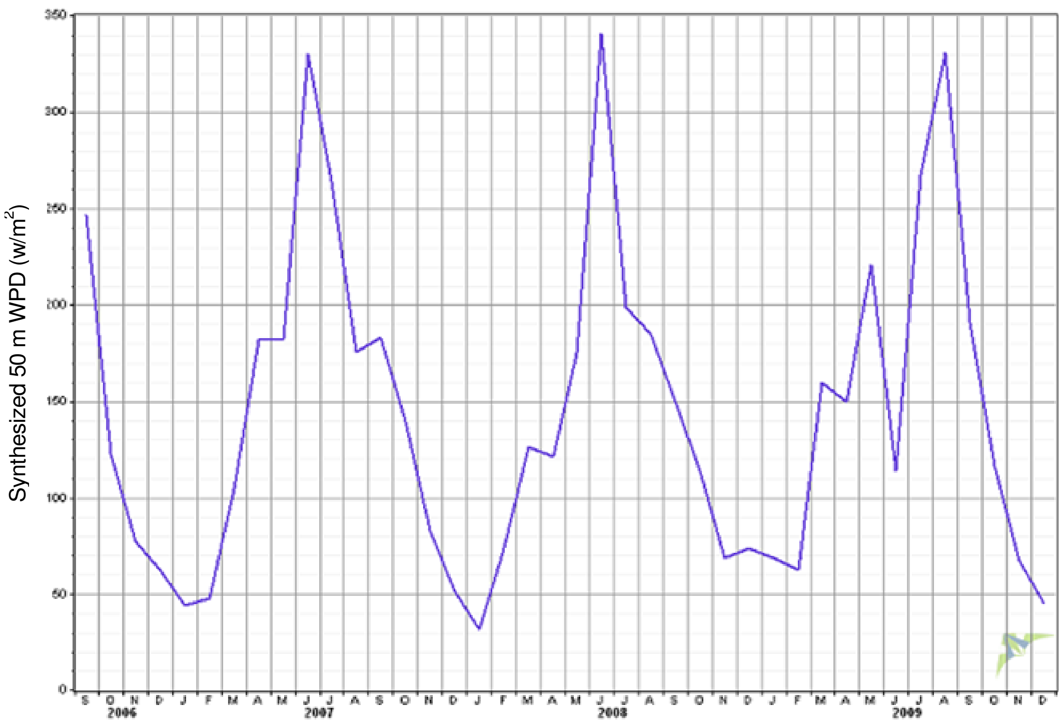

Figure 6. Wind power density diagram for the region of Baladeh at altitude of 50 m during time period.

Table 2. Classification of wind power (Fadai, 2007).

Wind power Class 01	Height=50 m	
	Wind power density (w/m^2)	Speed (m/s)
1	0-200	0-5.6
2	200-300	5.6-6.4
3	300-400	6.4-7.0
4	400-500	7.0-7.5
5	500-600	7.5-8.0
6	600-800	8.0-8.8
7	800-2000	8.8-11.9

330 w/m^2 at the height of 50 m. This is a relatively good condition for installing wind turbines. Also in the summer months which are the peak hours of power consumption, this region will have maximum production if wind turbines are installed. This is an advantage for building a wind farm. The density value of the power in the cold season gets less than 100 w/m^2.

As shown in Figure 6, during the different years from 2007 to 2009, the most wind power density (w/m^2) related to the warm months and months of June and July, which had a power of more than 300 w/m^2 and amounts to 200 w/m^2 levels in early spring. In other words, Baladeh had a moderate to fairly good conditions from early spring to early autumn which are good for installing small and large turbines.

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