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Evaluation of wind energy potential at Hezarkanian station, west of Iran

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Abstract: As a developing nation of energy-starved people, Iran importune needs new sources of affordable, clean energy. Wind energy is potentially memorable because of its low environmental impact and sustainability. This work aims to investigate the wind power production potential of sites in west of Iran. Wind speed data measured over a tree-year period at a typical site on the west of Iran are presented. Frequency distributions of wind speed and wind power densities at five heights, monthly variations of speed, and estimates of power likely to be produced by Enecron turbine are included. The site investigated is found to be a class 6 wind power site with annual average wind speed of 6.89 m/s and power density of 745 w/m^2 at 50 m height. The site is, therefore, likely to be suitable for wind farms.

Key words: *Wind, Energy, Weibull distribution, turbine*

INTRODUCTION

Iran's geographical location is such that its low air pressures in comparison with high pressures in the north and northwestern regions produce strong air flows over it in general during the summer and winter months. During the winter months it is the difference in the air pressure between the atmospheres over Iran; center Asia as well as the Atlantic Ocean that makes cold winds from north and humid air flows from the Atlantic and Mediterranean from west. When these systems of air maldes collide with the humid air from the Mediterranean, cools down Iran producing snow over the country. During the summer Iran is also affected by winds from the Atlantic Ocean on the northwest and by the winds from the Indian Ocean from the southeast; of the well known winds from the east are the 120 day winds of Sistan and lavas wind: the other local winds in the country include the north winds on the Persian golf and Khoch a bad winds in the Gorgon plain, deez wind between Mashad and Nayshabour and sham winds in Khuzestan. On the other hand, this country located in middle east Asia is rich in fossil fuel supplies such as oil, gas, etc. which make up the basis of its national economy and taking into account the population growth rate energy consumption is quite substantial which could possibly cut down the export rates of fossil fuels. Usage of renewable energy sources in Iran began a decade ago and it is still in its initial stages of development. In this article, the feasibility of instructing wind turbines to take advantage of wind power in Hezarkanian region is discussed. (Keyhani, A. 2010). the number of installed wind power plants is increasing every year and many nations have made plans to make large enterprise in wind power in the near future. The factors influencing the energy produced by a Wind Energy Conversion Systems (WECS) at a given location over a period are: (1) the power response of the turbine to different wind velocities, (2) the strength of the dominant wind regime and (3) the distribution of wind velocity within the regime. The total energy generated by the turbine over a period can be computed by adding up the energy corresponding to all possible wind speeds in the regime, at which the system is operational. Hence, along with the power characteristics of the turbine, the probability density corresponding to different wind speeds also comes into our energy calculations. Knowing the wind speeds of a certain region is important in determination of specification speeds of the turbine which are its cut-in velocity, rated velocity, and the cut-out velocity. Also, the effective utilization of wind energy entails a detailed knowledge of the wind characteristics at the particular location (Seguro, J.V. and TW. Lambert, 2010). 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 (Keyhani, A. 2010; Pallabazzer, R. and A. Gabow, 1991) to the use of such functions for analyzing the wind speed data and wind energy economics (Sherlock, R.H. 1951; Weisser,). The first statistical studies of wind speed as a discrete random variable began 50 years ago, with the Gamma distribution. Over this period, different distribution functions have been suggested to represent wind speed, including those of Pearson, Chi-2, Weibull, Rayleigh and Johnson functions. Several non-normal distributions have been suggested as appropriate models for wind speed (inverse Gaussian, log-normal, Weibull (Sherlock, R.H. 1951; Tchinda, R. and E. Kaptouom, 2003) and squared normal). Among these, the Weibull distribution function is the most commonly used in applications. The variation of wind velocity often described using the Weibull two parameter density functions. To date, this statistical method is widely accepted for evaluating local wind load probabilities and can be considered almost a standard approach. Wind energy potential is not easily estimated because, against to solar energy, it depends on the site

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specifications and topography to a large degree, as wind speeds is influenced strongly by local topographical phenomenon. The classification and characterization of an area as of high or low wind potential requires significant effort, as wind speed and direction present extreme transitions at most sites and demands detailed study of spatial and temporal variations of wind speed values. Before determining the wind farm site, the hourly and monthly mean wind speed, wind speed distributions as well as the wind power densities should be analyzed carefully (Weisser,; Kelleher, J. and J.V. Ringwood, 2009).

MATERIAL AND METHODS

Kurdistan is both a vast and mountain province. It is composed of the slopes of the Zagros Mountain. The Hezarcanian station considered is located at 35- 46 N and 46- 48 E, and its elevation is about 1894 m above sea level. At this station, the wind is measured by an anemometer and weather cock label, placed at 10 m above the ground. If we accept that the climate is a very important factor in the development and progress of the country, it is important that it should be recognized and understood in any planning and policy decisions. Kordestan enjoys considerable climatic diversity, which is subjected to various seasons in different parts of the province, in a way that in some areas the cold of the winter and the heat of the summer can be seen simultaneously. A terrain map of Kordestan is shown in (Figure. 1)

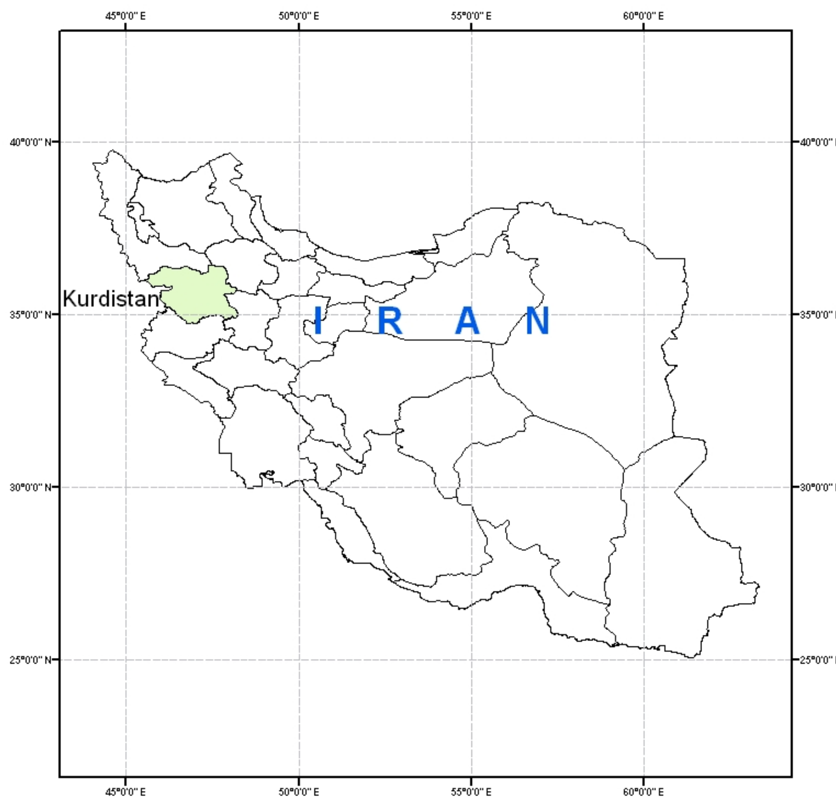

Fig. 1: Location of Kurdistan province in Iran country

Wind speed and direction were averaged over tree-hour periods. These measurements are available from 2005 to 2007. The wind speed data were recorded in English knots. For the needs of the statistical processing, the units were converted to SI (m/s) system. The resulting sequences of six-hourly wind data consist of fast random fluctuations superimposed on trend variations. The random fluctuations and trend variations are caused by atmospheric turbulence and geotropically circulation, respectively.

Weibull probability density function:

The wind speed probability density function can be calculated as Eq. 1:

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

Where f (v) is the probability of observing wind speed v, c 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 (i.e. if the wind speeds tend to be very close to a certain value, the distribution will have a high k value and is very peaked) (Weisser,). Once the mean, v, and the variance, σ^2 , of the data are known, the following approximation can be used to calculate the Weibull parameters k and c Eq. 2 , Eq. 3:

$$k = \left(\frac{\delta}{\bar{v}}\right)^{-1.086} (1 \le \kappa \le 10) \quad (2)$$

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

Where the average wind speed is Eq. 4 :

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

The variance, σ^2 , of wind velocity recordings is Eq. 5 :

$$\delta^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(v_i - \bar{v}\right)^2 \quad (5)$$

Average wind speed and the variance of wind velocity can be calculated on the basis of the Weibull parameters as given Eq.6, Eq. 7:

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

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

And the gamma function of (x) (standard formula) is calculated as Eq. 8:

$$\Gamma(\chi) = \int_{\circ}^{\infty} e^{-u} u^{x-1} du \quad (8)$$

In circumstances where k is equal to 2, the Weibull distribution is referred to as Rayleigh distribution. Often wind energy conversion turbine manufacturers provide standard performance figures for their turbines using this special case of the Weibull distribution (Seguro, J.V. and TW. Lambert, 2010). The main limitation of the Weibull density function is that it does not accurately represent the probabilities of observing zero or very low wind speeds (Tchinda, R. and E. Kaptouom, 2003). However, for the purpose of estimating wind potential for the commercial use of wind turbines, this is usually unnecessary as the energies available at low wind speeds are negligible (i.e. wind energy is proportional to the cube of wind velocity) and below the operating range of wind turbines (i.e. the cut-in wind speed is usually between 2.5 and 3.5 m/s (Anonymous. 2002)).

Wind power density:

The power of the wind that flows at speed $\bar{v}$ through a blade sweep area A , increases with the cube of the wind speed and the area, that is Eq. 9:

$$p(v) = \frac{1}{2}\rho v^3 \quad (9)$$

Where ρ the standard air density is at sea level with a mean temperature of 15 ^0C and a pressure of 1 atm (1.225 kg/m^3) and $\bar{v}$ is the mean wind speed (m/s). Then the corrected monthly air density ρ (kg/m^3) is calculated as Eq. 10:

$$\rho = \frac{\bar{p}}{R_d \bar{T}} \quad (10)$$

Where: $\bar{P}$ is the monthly average air pressure (Pa); $\bar{T}$ is the monthly average air temperature (K); R_d is the gas constant for dry air ($R_d = 287\ J/kgK$).

The corrected power available in wind at a height of 10 m, can be calculated as Eq. 11:

$$P_{10} = \frac{1}{2}\overline{\rho v^3}(W/m^2) \quad (11)$$

The average wind power density in terms of wind speed is calculated as Eq. 12:

$$WPD = \frac{\sum_{i=1}^{N} 1/2\, pv_i^{\,3}}{N} \tag{12}$$

where i is the measured three-hourly wind speed and N is the total sample data used for each year. Besides, calculation of wind power density based on the wind speed provided by field measurements can be developed by Weibull distribution analysis using the following form Eq. 13 :

$$\frac{P}{A} = \int_0^\infty \frac{1}{2}\rho V^3 f(V)\,dV = \frac{1}{2}\rho c^3 \Gamma\left(\frac{k+3}{k}\right) \tag{13}$$

Wind energy density:

Once wind power density of a site is given, the wind energy density for a desired duration, T, can be calculated as Eq. 14:

$$\frac{E}{A} = \frac{1}{2}\rho c^3 \Gamma\left(\frac{k+3}{k}\right)\mathrm{T} \tag{14}$$

This equation can be used to calculate the available wind energy for any defined period of time when the wind speed frequency distributions are for a different period of time.

RESULTS AND DISCUSSION

In this study, wind speed data for the Hezarkanian station, over a three-year period from 2005 to 2007 were analyzed. Based on these data, the wind speeds analyzed were processed using the software Windographer [14].

Monthly Mean Wind Speeds:

The monthly mean wind speed is presented in Figure 2 for Hezarkanian, 2005–2007. Most of the monthly mean speed wind values are between 5.00 and 6.00 m/s, but some are over 6.00, while only a few are under 5.00 m/s. While June showed the highest mean wind speed value with 7.00 m/s, March showed the minimum mean wind speed value of 3.9 m/s. Hezarkanian, therefore, has good potential for developing wind energy sources.

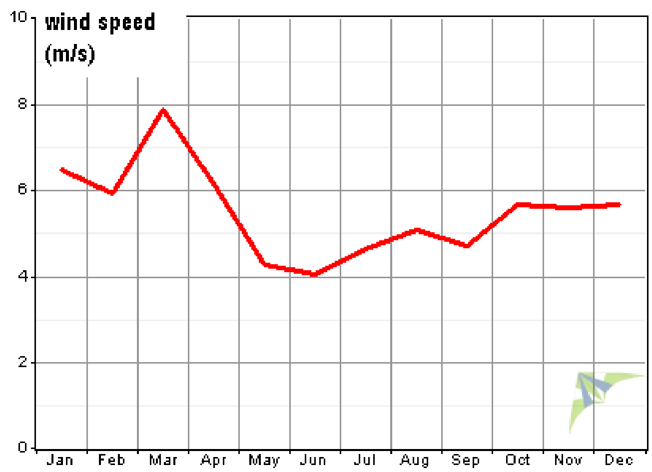

Fig. 2: Monthly mean wind speed in Hezarkanian station from 2005 to 2007

Weibull distribution:

Figure 3 shows the yearly values of the two Weibull parameters, the scale parameter c (m/s) and shape parameter k (dimensionless), calculated from the long term wind data for the site studied. The values of k and c were determined using the method described in section above. It is obvious that the parameter k has a much smaller, temporal variation than the parameter c. The value of k is 1.28, while the value of the scale parameter c is 6.19 m/s for the same period.

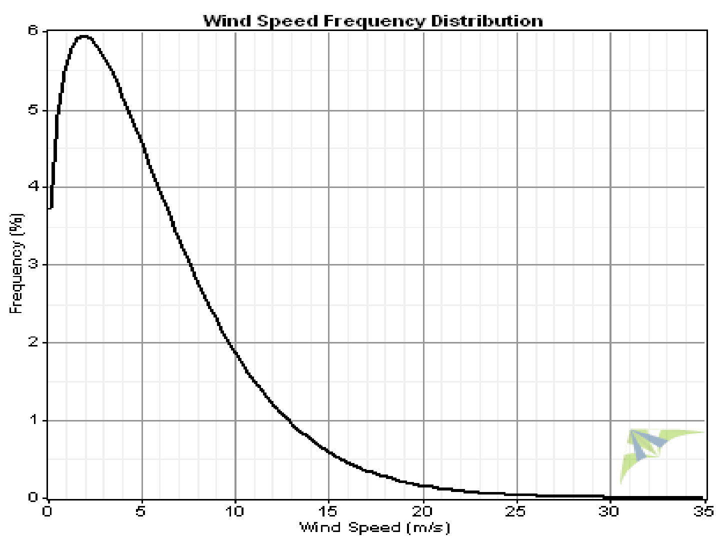

Fig. 3: Weibull distributions of wind speeds for 10 m height at Hezarkanian

Calculation Of Wind Power Density And Energy:

The wind power and energy density are evaluated, respectively, by Eqs. (12) , (13) and (14) and are shown in Figure 4 and Table 1. The actual power a particular turbine is expected to produce at this site depends on turbine rotor area, hub height, and capacity factor of the turbine. Given the power curve of a turbine (i.e., the experimentally determined relation between wind speed and turbine power output, PW (U)) and the wind speeds, as an example, the power generation potential of Enercon E33 has been calculated. Table 2 shows the parameters of turbine (Anonymous. 2002; www.mystaya.ca), including the rated power, the rotor diameter, the hub height, the rated wind speed, and the cut-in and cut-out speeds. Table 2 shows the average power produced, total energy output over the year, and capacity factor of each turbine for this site. The capacity factor is defined as the turbine energy output divided by the theoretical out put with the turbine running constantly at its rated power. For Hezarkanian, the average power density available over the period time is found to be 745 W/m^2 at 50 m height, which translates into total available yearly energy of 831 MWh of rotor area.

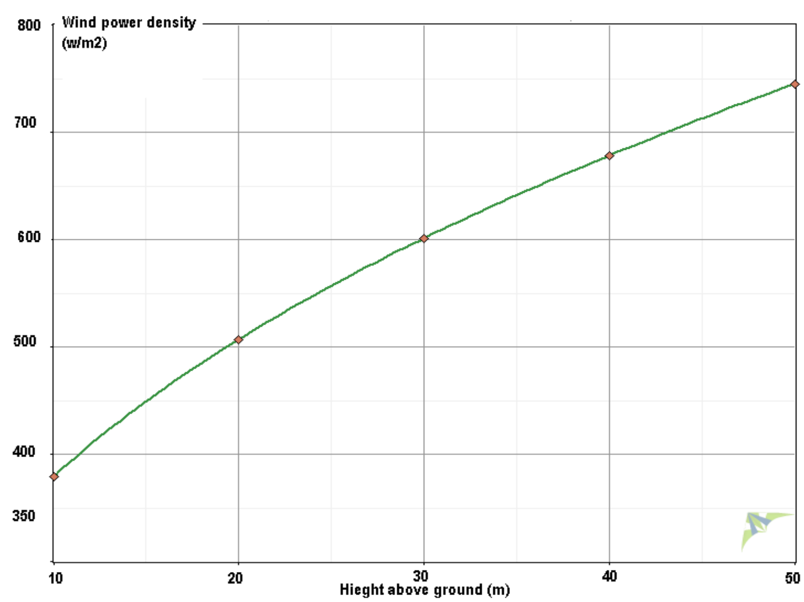

Fig. 4: Mean of monthly means of wind power density at 10 to 50 m heights in Hezarkanian

Table 1: Monthly variation of the Power and Energy output for Hezarkanian station

Month	Wind Speed ($m.s^{-1}$)	Energy Output ($MWh/Year$)	Capacity Factor ($\%$)
Jan	8.1	79	32.2
Feb	7.44	70	31.4
Mar	9.86	102	41.5
Apr	7.71	70	29.4
May	5.34	48	19.6
Jun	5.04	45	19
Jul	5.8	58	23.7
Aug	6.35	71	29.1
Sep	5.91	64	27
Oct	7.1	74	30.3
Nov	6.99	72	30.1
Dec	7.09	78	31.8
all	6.89	831	28.8

Table 2: Parameters of Enercon E33 wind turbine

Rated power (kW)	340
Rotor diameter (m)	33.4
Hub height (m)	50
Cut-in wind speed (m/s)	3
Rated wind speed (m/s)	13
Cut-out wind speed (m/s)	25

Discussion:

The USA wind energy atlas defines seven wind power classes to classify the wind energy resource at a site, ranging from class 1 (least energy) to class 7 (most energy). The 745 W/m^2 average power density at 50 m height put Hezarkanian in class 6, suitable for most wind turbine usage, ranging from small, stand-alone turbines to wind farms. While the large investment required for a wind farm needs a detailed analysis of the costs and profits that is beyond the scope of this paper, a rough economic analysis of a stand-alone system to serve the local community is presented below. Small, off-grid or mini-grid power systems based on renewable energy sources have many benefits. The most important consequence of the study can be summarized as follows: (1) The wind energy potential in the Hezarkanian, is quite promising, because the chances of having wind speeds less than 4 m/s are small but because the wind speed range for electricity generation is within 5–7 m/s, the site studied is suitable for electric wind application in a large-scale. (2) The Weibull distribution presented here indicates a good agreement with the data obtained from actual measurements. (3) Jan, Feb, Mar, Apr are the 4 months that the average wind speeds are the highest all around the year (Canale *et al.*, 2009).

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