Analysis of Wind Potential for City of Firoozkooh in Iran

M. Kamali, M. Dehghan Manshadi

Abstract**—** There is increasing interest in wind energy investment by both public and private producers in Iran. However, the biggest challenge is the lack of up-to-date site specific data information on wind energy potential across the country. Hence the need for more studies to establish an updated site specific wind data information. In this paper, the 10min period measured wind speed data for years 2002, 2003 at 10m, 30m and 40m heights were analyzed for Firoozkooh city (latitude of 35°43′ N, longitude of 52°44′E and altitude of 1976m) in Iran County approximately 120km from Tehran (capital of Iran). The wind speed distribution was modeled using the Weibull probability function; wind density and Monthly wind energy production are estimated. The results show that the monthly value of shape parameter (k) ranges from 1.1054 in October 2002 (h=40m) to 2.6847 in June 2002 (h=10m), while the monthly value of scale parameter (c) varies from 2.9083m/s in January 2002 (h=10m) to 9.4082m/s in June 2002 (h=40m). Values of 232.18 and 169.32w/m^2 are estimated for annual mean power density at height of 30m for years 2002 and 2003 respectively and the wind class was found to be 2 which not being deemed suitable for large machines, although smaller wind turbines may be economical in this area where the value of the energy produced is higher.

Keywords**—** *Firoozkooh; Weibull distribution; Power density; Wind Speed Data*

I. INTRODUCTION

The continuing growth in population and the shift of nations to industrialization has led to the increase in energy demand. However, factors such as energy sustainability and the gradually emerging consciousness about environmental degradation have provoked priority to the use of renewable alternative sources such as solar and wind energies, the wind industry is a growing sector in the global energy market, as it contributes a domestic, clean, and water free source of electricity generation. The variable nature of wind refers to the fluctuations in magnitude and direction, while uncertainty refers to the unpredictability of wind in its exact timing, location, and strength. Taken together, these characteristics add complexity to wind power development. Use of probability density function (PDF) models to describe wind speed variations has attracted extensive research interests in recent years and numerous publications exist in literatures. Luna and Church (1974) attempted to use a universal distribution for wind speed and discovered that lognormal distribution is the most appropriate one [1]. However, it was realized with caution that a universal distribution may not be applicable to different sites due to the differences in climate and topography. This is supported by a recent study by Zhou *et al.* (2009) [2], in which the effectiveness of conventional and non-conventional statistical distributions was investigated and compared for characterizing the wind speed characteristics at multiple North Dakota sites. It was discovered that there does not exist a universal distribution function that outperforms the others for all sites. In general, two-parameter Weibull statistical distribution is by far the most widely adopted for representing the wind speed and a number of publications can be found in literature (Justus (1978) [3], Manwell (2009) [4], Burton *et al.* (2001) [5]). Meanwhile, other conventional probability distribution functions have been proposed for wind speed. They include Rayleigh distribution, which is a special case of Weibull distribution; lognormal distribution, in which the logarithm values of variate follows normal distribution; gamma distribution, which represents the sum of exponentially distributed random variables. In recent years, the concept of maximum entropy principle (MEP) has been also introduced into this field to derive appropriate PDFs for modeling the wind speed distribution (Li and Shi (2009) [6]). In addition, they applied Bayesian model averaging (BMA) to model the wind speed distribution by combining a number of plausible conventional PDFs. Justus *et al.* (1978) examined the characteristics of the Weibull distribution in relation to the surface wind speed distribution. They found that the Weibull was a good model and adequately describes most wind speed distribution. In addition they also used the model to compute the power output from wind generation in the United States [3]. Van der and Auwera *et al.* (1980) successfully fitted the observed wind speed data for Belgium with four statistical distributions [7], IOANNIS *et al.* investigate wind energy potential in two cities of Greece [8, 9], with his results showing that Weibull distribution gives the best fit for wind speed data. They also observed that once the mean of the cube

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of the wind speed has been determined, it is easier to use Weibull distribution to determine the wind power.

There are many regions in Iran which are capable of harnessing wind energy. Alamdari *et al.* (2012) studied wind speed data for 68 sites at different heights in Iran. GIS themes of wind potential were also used in this study [10]. Mostafaeipour *et al.* (2011) investigated wind energy potential for city of Shahrbabak in Iran [11]. This study indicates that this site is not ideal for grid connected applications and small wind turbine projects at the shahrbabak site are feasible. Reiszadeh *et al.* (2011) investigated wind energy potential in Bardekhun station in Bushehr province in Iran [12]. Saeidi *et al.* (2011) presented statistically study of wind at three heights (10m, 30m and 40m) for north and south khorasan provinces in Iran to determine the potential of wind power generation [13]. Mostafaeipour (2010) statistically analyzed wind speed data over a period of almost 13 years between 1992 and 2005 at three heights (10m, 20m and 40m) for eleven cities in yazd province in Iran [14]. The results show that most of the stations have annual average wind speed of less than 4.5 m/s which is considered as unacceptable for installation of the large-wind turbines. This study useful for implement of small wind turbines for water pumping and also will provide a strong base for harnessing wind in yazd. Mirhosseini *et al.* (2011) presented statistically study to determine wind energy potential at five towns (Biarjmand, Damghan, Garmsar, Semnan and Shahrood) in province of Semnan in Iran using Weibull model. This study indicates Damghan has better potential for using wind energy in the province [15]. Keyhani *et al.* (2010) statistically analyzed wind speed data over a period of almost 11 years between 1995 and 2005 at height of 10m for the capital of Iran, Tehran based on the Weibull model [16]. Their study indicates this site is inappropriate for installation of the large-wind turbines but wind energy potential of the region can be adequate for small wind turbines in non-grid connected.

II. POTENTIAL & WIND ENERGY IN IRAN

Iran geographical latitude is 25.2-39.2 degree northern hemisphere and its longitude is 44-63.6 degree east. Iran covers a total area of about 1.65 million km². About 52 % of the country area consists of mountains and deserts and some 16% of the country has an elevation of more than 2000m above sea level [17].

The climate of Iran is one of great extremes due to its geographic location and varied topography. Annual rainfall ranges from less than 50mm in the deserts to more than 1600mrn on the Caspian Plain. The average annual rainfall is 252mm and approximately 90% of the country is arid or semiarid. Overall, about two-thirds of the country receives less than 250 mm of rainfall per year [17].

Iran is exposed to the continental streams from Asia, Europe, Africa, Indian and Atlantic Pacific, the ministry of energy has serious programs for the evaluation of the wind energy potential in the country [18].

Iran is an energy rich country and one of the world's main oil exporters and its economics has been highly dependent on energy revenues for a long time, Like most countries, Iran is faced with the challenge of how to meet the foreseeable increase in energy demand in the world. According to the International Energy Agency's Reference Scenario, global primary energy demand is expected to grow by 40% in the years between 2007 and 2030.

Iran Renewable Energy Organization (SUNA) has been attending to prepare national model of country's wind atlas, wind atlas of Iran for elevation of 60m is shown in Fig. 1 as presented in [19].

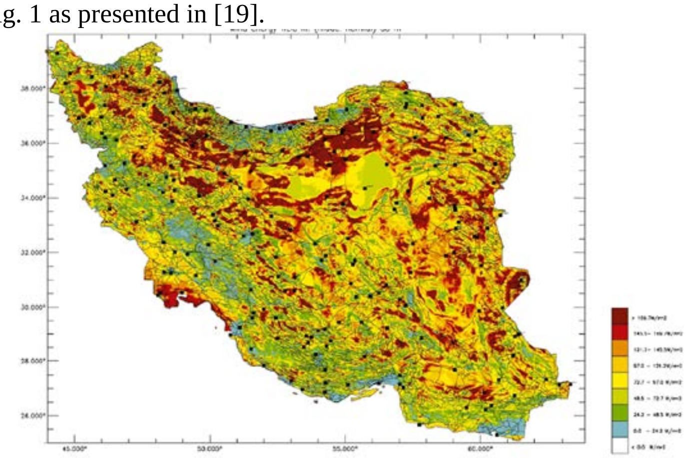


Fig. 1. Wind atlas of Iran for elevation of 60m above the ground [19]

III. FIROOZKOOH

Firoozkooh is located in the north-east of Tehran Province (capital of Iran) (latitude of 35°43′N, longitude of 52°44′E and altitude of 1976m), the city is located on the central part of the Alborz Mountains and thus has much ruggedness. The city has a relatively cool and windy climate. Firoozkooh city is frosty for about 170 days during a year. Firoozkooh region with a total precipitation of 282.4mm and mean annual temperature of 9.6°C is regarded as a region with cold and dry climate.

IV. DATA ANALYSIS PROCEDURE

Wind speed and direction data gathered during two years, 2002 and 2003 in the period of 10min for site. The meteorological tower with 40m height was installed in appropriate location by SUNA Organization. The data logger used, includes 3 velocity sensors at 10m, 30m and 40m heights and also 2 direction sensors at 10m and 40m heights.

A. Weibull distribution

The Weibull distribution is closely related to the exponential distribution. This distribution has two main parameters in terms of wind speed assessment, the shape parameter, c and the scale parameter, k [20]. In the wind speed distribution there is a higher frequency of lower wind speeds than the mean wind speed. This results in a curve with a peak on the lower end of the distribution and a tail on the higher end. From the peak the shape parameter can be determined. It is the shape parameter that determines how stable the mean wind speed is at a site. If the shape parameter is equal to 1, the distribution is called the exponential distribution; if equal to 2, the Rayleigh distribution and if equal to or greater than 3, it converges towards the Gaussian distribution [4, 21].

The two-parameter Weibull distribution function can be expressed mathematically by [22, 23, 24]:

$$f(v) = \frac{k}{c}(\frac{v}{c})^{k-1}\exp[-(\frac{v}{c})^k] \quad (1)$$

Where;

$f(v)$ is the probability of observing wind speed (v)

$k > \circ$ is a shape parameter (dimensionless) and $c > \circ$ is a scale parameter (m/s)

While the corresponding cumulative distribution is [22, 23, 25]

$$F(v) = 1 - \exp[-(\frac{v}{c})^k] \quad (2)$$

It has been found that from Weibull distribution the variance is given by [22, 23]

$$\sigma^2 = \bar{v}^2\left[\frac{\Gamma(1+\frac{2}{k})}{\Gamma^2(1+\frac{1}{k})} - 1\right] \quad (3)$$

Where the mean wind speed ($\bar{v}$) is

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

And the gamma function of (x) (standard formula) is

$$\Gamma(x) = \int_{\circ}^{x} \exp(-u)\, u^{x-1}\, du \quad (5)$$

calculated as

The mean wind speed and the two Weibull parameters are related through the relationship given in equation 6 obtained from the Weibull distribution [22, 23, 3].

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

For estimating the parameters of the shape and scale parameter several numerical methods are used. The method of maximum likelihood (Harter and Moore (1965a), Harter and Moore (1965b), and Cohen (1965)) is a commonly used procedure because it has very desirable properties [26, 27].

In this method weibull parameters are determined according to the following equations

$$k = \left[\frac{\sum_{i=1}^{N} v_i^k \ln(v_i)}{\sum_{i=1}^{N} v_i^k} - \frac{\sum_{i=1}^{N} \ln(v_i)}{N}\right]^{-1} \quad (7)$$

$$c = \left(\frac{1}{N}\sum_{i=1}^{N} v_i^k\right)^{\frac{1}{k}} \quad (8)$$

Where N is the number of observations and v_i is the measured wind speed at the interval i [28].

A number of other approximations have been found to provide good calculations for the same. Justus, (1978) provided a more straight forward formula for evaluating the shape parameter. This is as below [3, 24];

$$k = (\frac{\delta}{\bar{v}})^{-1.086} \quad (9)$$

With equation 6, it is possible to determine the mean wind speed provided the two parameters are available. Equally, it is possible to evaluate the value of the scale parameter from the calculated values of the shape parameter and mean speed. Lysen, (1983) simplified equation 6 and obtained a simpler formula for determining the scale parameter, this is as follows [29];

$$c = \bar{v}\,(0.568 + \frac{0.433}{k})^{-\frac{1}{k}} \quad (10)$$

V. Air density

Monthly air density (ρ) is a function of temperature and pressure both of which vary with height and can be calculated by applying the ideal gas law which as expressed in equation 11 [30];

$$\bar{\rho} = \frac{\bar{P}}{R_d \bar{T}} \quad (11)$$

Where:

$\bar{\rho}$ = density (Kg/m3)

$\bar{P}$ = average monthly air pressure in Pa

R_d = gas constant for dry air, $287.05\frac{J}{Kg-K}$

$\bar{T}$ = average monthly air temperature in Kelvin (K)

VI. Wind Power and wind energy density function

The wind power density through a blade sweep area A is analyzed based on a Weibull probability density function which can be derived as follows [31, 32]:

$$P(v) = \frac{1}{2}\rho v^3 \quad (12)$$

Where ρ is air density at sea level with a mean temperature of $15^{\circ}C$ and a pressure of $1atm$ $(1.225\frac{kg}{m^3})$ and v is mean wind speed ($\frac{m}{s}$)

The energy potential per second varies in proportion to the cube (the third power) of the wind speed, and is proportional to the density of the air. Multiplying the power of each wind speed with the probability of each wind speed obtained from the Weibull curve, then the results gives the distribution of wind energy at different wind speeds (the power density) [4, 16, 31].

Corrected available wind power at elevation of 10m is [4, 16, 31]

$$P_{10} = \frac{1}{2}\rho A v_{10}^3 \quad (13)$$

If the wind speeds are known, then the average wind power or average wind energy per unit area can be estimated for any convenient time period, usually months, seasons, or year. When more than 1 year of data are available, then the year data or month data are averaged to obtain annual values by year or month. The wind power per area is referred to as the wind power potential or wind power density [33, 34]:

$$WPD = \frac{P_{avg}}{A} = \frac{\sum_{j=1}^{N} \frac{P_j}{A}}{N} = \frac{\sum_{j=1}^{N} \frac{0.5\rho_j v_j^3 A}{A}}{N} = \frac{\sum_{j=1}^{N} 0.5\rho_j v_j^3 A}{N} \quad (14)$$

Where N is the number of observations.

Air density at sea level can be used to calculate an average density and then the average power/area can be calculated for the available wind speed data. The result will be fairly accurate since the pressure and temperature will not vary over the month or year nearly as much as the wind speeds [16, 33, 34].

$$WPD = \frac{P_{avg}}{A} = \frac{0.5\rho}{N} \sum_{j=1}^{N} v_j^3 \quad (15)$$

The average power/area can be calculated from wind speed distribution by [16, 33, 34]:

$$\frac{P_{avg}}{A} = \int_{\circ}^{\infty} \frac{1}{2}\rho v^3 f(v)\,dv = \frac{1}{2}\rho c^3 \Gamma(1+\frac{3}{k}) \approx \frac{1}{2}\rho \bar{v}^3 \quad (16)$$

Similarly, the wind energy density per unit area for a given extended time period $N\Delta t$ long is given by:

$$\frac{E_{avg}}{A} = (\frac{P_{avg}}{A})(N\,\Delta t) = \frac{1}{2}\rho c^3 \Gamma(1+\frac{3}{k})(N\,\Delta t) \quad (17)$$

Where N is the number of measurement period [16, 33].

Considering the effect of the Betz limit whose value is 0.593, the maximum extractable power approximately 59.3% of the theoretical power density. So the maximum extractable power from the wind is given by [16]:

$$\frac{P_{\max}}{A} = \frac{16}{27}\frac{P_{avg}}{A} \quad (18)$$

VII. TWO MEANINGFUL WIND SPEEDS

When the power conversion efficiency is constant, the wind speed, denoted v_{opt}, for which the maximum energy is obtained from the condition [33, 34]

$$\frac{d}{dv}[v^3 \ f(v)] = \circ$$

Which, using the Weibull distribution, results in [33, 34]

$$v_{opt} = c(1+\frac{2}{k})^{\frac{1}{k}} \quad (19)$$

On the other hand, the most probable wind speed, v_{mp} corresponds to the peak of the probability density function denotes the most frequent wind speed for the wind probability distribution of given site, can be deduced from the condition [32, 33, 34]:

$$\frac{d}{dv}[v\ f(v)] = \circ$$

as

$$v_{mp} = c(1-\frac{1}{k})^{\frac{1}{k}} \quad (20)$$

The pair (v_{mp}, v_{opt}) calculated for a given site by using the weibull distribution.

VIII. RESULTS AND DISCUSSION (14)

A. *Mean wind speed*

Table 1 shows the variation of monthly and annual mean wind speed for years 2002, 2003 at different elevations. As shown in Table 1, the monthly mean wind speed varies between 3.1 in January 2003 and 8.2 m/s in June 2002 for height of 40m and varies between 3 in January 2003 and 8m/s in June 2002 for height of 30m and varies between 2.6 in January 2002 and 6.8 m/s in June 2002 for height of 10m. For year 2002 the biggest value of wind speed for heights of 40m, 30m and 10m observed in September, (27.3, 27 and 24.3m/s respectively) and for year 2003 the biggest value of wind speed for heights of 40m and 30m observed in March, (23.6 and 22.8m/s respectively) and for height of 10m observed in June (20.5m/s). Monthly mean wind speed that in Table 1 shown in Fig. 2 as graphically. A graphical presentation of hourly average wind speed variation provided a diurnal wind speed distribution pattern for years 2002, 2003 at different elevations are presented in Figs. 3 and 4.

TABLE I : Monthly and annual mean wind speed (m/s) at different height

	2002 $h=40$	2003 $h=40$	2002 $h=30$	2003 $h=30$	2002 $h=10$	2003 $h=10$
Jan.	3.3	3.1	3.2	3	2.6	2.8
Feb.	4.1	3.8	3.8	3.7	3.4	3.3
Mar.	5	4.4	4.8	4.3	3.9	3.8
Apr.	5.7	4.9	5.3	4.7	4.5	4
May.	6.5	6.4	6.1	5.8	5.3	4.7
Jun.	8.2	7.7	8	7.6	6.8	6.6
Jul.	7	6.7	6.5	6.6	5.6	5.7
Aug.	6.4	6.2	6.2	5.7	5.1	4.8
Sep.	5.6	5.3	5.4	5	4.7	4.3
Oct.	3.9	3.8	3.7	3.5	2.8	2.8
Nov.	4.7	4.7	4.6	4.4	3.9	3.7
Dec.	4.5	4.2	4.3	3.9	3.6	3.5
Whole year	5.4	5.1	5.2	4.9	4.4	4.2

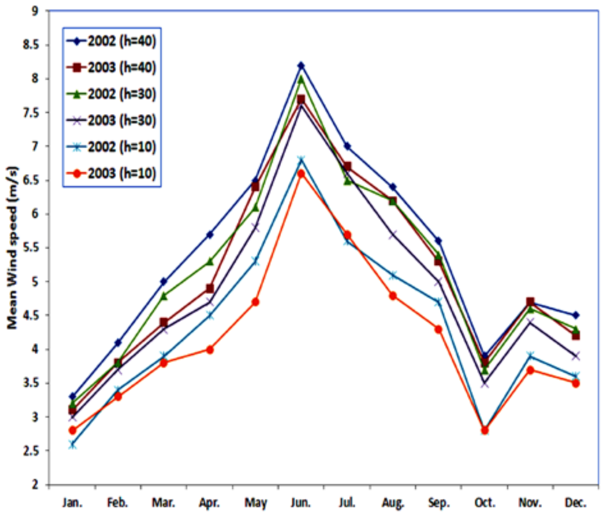


Fig .2. monthly mean wind speed

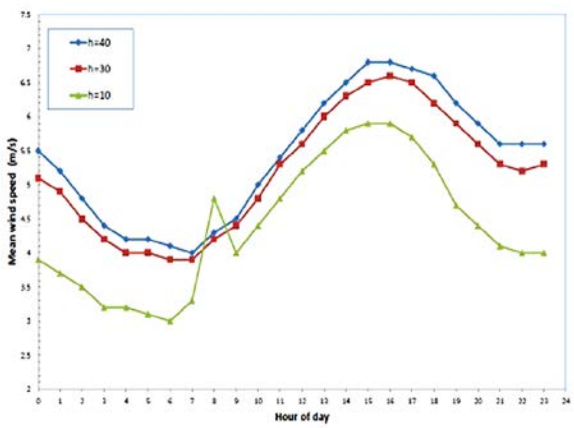


Fig . 3. Diurnal variation of wind speed for city of Firoozkooh, 2002

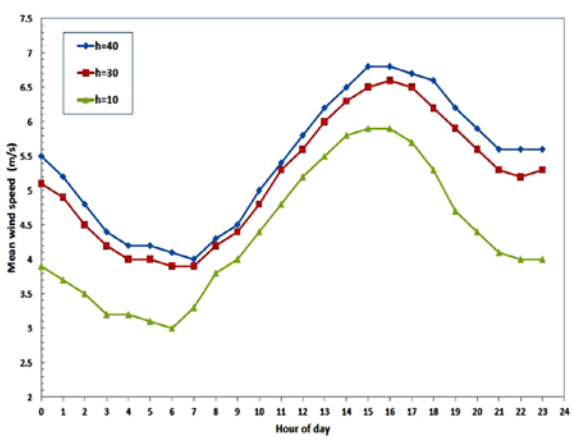


Fig. 4. Diurnal variation of wind speed for city of Firoozkooh, 2003

As shown in Figs. 3 and 4, the wind speed increases at around 9 AM and the peaks around 4 PM, it can be found that the daytime from 11 AM to 11 PM, is windy for all years, This is typical of diurnal pattern where wind speeds increase during the day with wind speeds lowest during the hours from midnight to sunrise, it can be seen, that the minimum average is at around 8 AM and the maximum is at around 4 PM.

B. Weibull distribution

Tables 2, 3 show monthly and annual values of weibull parameters (scale parameter c (m/s) and shape parameter k (dimensionless)) and characteristic speeds (v_{mp}, v_{op} *and* $\bar{v}$) calculated from wind data of Firoozkooh (based on likelihood method). Shape parameter is very important parameter in wind energy prediction since it tells how peaked the distribution is, meaning it determines the shape of the Weibull distribution and hence it determines the wind speed variation. Its value normally lies within the range of 1.5 and 3.0 and the scale parameter, is used to indicate how windy the site is. From the calculations; the monthly value of the shape parameter varies from 1.1054 (October 2002, h=40m) to 2.6847 (June 2002, h=10m). These values are within the acceptable range. Monthly value of scale parameter varies from 2.9083 (January 2002, h=10m) to 9.4082 (June 2002, h=40m). Results indicate that scale parameter c has much bigger variation than the shape parameter k.

TABLE II : monthly and annual weibull parameters and characteristic speeds for different elevations, 2002

	k	c	v_{mp}	v_{op}	$\bar{v}$ (calculated)
Jan. ($h=40$)	1.4904	3.6848	1.75	6.52	3.68
Jan.($h=30$)	1.5652	3.4853	1.82	5.90	3.49
Jan.($h=10$)	1.4922	2.9083	1.38	5.14	2.91
Feb. ($h=40$)	1.8468	4.7120	3.09	7.01	4.71
Feb. ($h=30$)	1.9035	4.3161	2.92	6.29	4.32
Feb. ($h=10$)	1.8808	3.8184	2.55	5.61	3.82
Mar. ($h=40$)	1.2815	5.3650	1.64	11.17	5.37
Mar. ($h=30$)	1.3255	5.1375	1.78	10.28	5.14
Mar. ($h=10$)	1.2233	4.1036	1.02	9.06	4.10
Apr. ($h=40$)	1.7557	6.3498	3.93	9.79	6.35
Apr. ($h=30$)	1.7696	6.0053	3.75	9.21	6.01
Apr. ($h=10$)	1.8088	5.0132	3.21	7.57	5.01
May ($h=40$)	1.7966	7.3214	4.66	11.10	7.32
May($h=30$)	1.9215	6.8452	4.67	9.92	6.85
May ($h=10$)	2.0425	5.8786	4.23	8.21	5.88
Jun. ($h=40$)	2.5023	9.4082	7.67	11.90	9.41
Jun. ($h=30$)	2.5955	9.1534	7.59	11.41	9.15
Jun. ($h=10$)	2.6847	7.7244	6.49	9.50	7.72
Jul. ($h=40$)	1.7387	7.9812	4.88	12.40	7.98
Jul. ($h=30$)	1.6479	7.2468	4.11	11.74	7.25
Jul. ($h=10$)	1.6704	6.1909	3.58	9.92	6.19
Aug. ($h=40$)	1.3937	7.0806	2.86	13.41	7.08
Aug. ($h=30$)	1.3873	6.7462	2.69	12.84	6.75
Aug. ($h=10$)	1.3290	5.6699	1.98	11.31	5.67
Sep. ($h=40$)	1.8126	6.3228	4.06	9.53	6.32
Sep. ($h=30$)	1.7868	6.0990	3.85	9.28	6.10
Sep. ($h=10$)	1.8816	5.3168	3.55	7.81	5.32
Oct. ($h=40$)	1.1054	4.1075	0.49	10.46	4.11
Oct. ($h=30$)	1.1968	3.9618	0.87	9.00	3.96
Oct. ($h=10$)	1.2665	3.2395	0.94	6.84	3.24
Nov. ($h=40$)	1.9260	5.4382	3.71	7.87	5.44
Nov. ($h=30$)	2.0347	5.3560	3.84	7.50	5.36
Nov. ($h=10$)	2.2802	4.4286	3.44	5.84	4.43
Dec. ($h=40$)	1.7651	5.0864	3.17	7.81	5.09
Dec. ($h=30$)	1.8077	4.8139	3.08	7.27	4.81
Dec. ($h=10$)	1.8811	4.0158	2.68	5.90	4.02
Annual($h=40$)	1.4113	6.0401	2.52	11.29	6.04
Annual($h=30$)	1.5008	5.7461	2.76	10.10	5.75
Annual($h=10$)	1.4382	4.8107	2.10	8.82	4.81

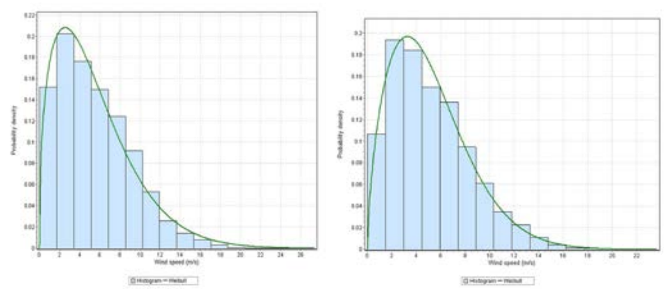
TABLE III : monthly and annual weibull parameters and characteristic speeds for different elevations, 2003

	k	c	v_{mp}	v_{op}	$\bar{v}$ (calculated)
Jan. ($h=40$)	1.3609	3.4466	1.30	6.70	3.16
Jan.($h=30$)	1.4454	3.2796	1.45	5.98	2.98
Jan.($h=10$)	1.6020	3.0615	1.66	5.08	2.74
Feb. ($h=40$)	1.3183	4.3138	1.47	8.69	3.97
Feb. ($h=30$)	1.3315	4.0914	1.44	8.15	3.76
Feb. ($h=10$)	1.3776	3.6417	1.42	6.98	3.33
Mar. ($h=40$)	1.5600	4.8176	2.50	8.18	4.33
Mar. ($h=30$)	1.4625	4.7772	2.17	8.61	4.33
Mar. ($h=10$)	1.7937	4.2054	2.70	6.39	3.74
Apr. ($h=40$)	1.5629	5.4721	2.85	9.27	4.92
Apr. ($h=30$)	1.6070	5.2494	2.86	8.68	4.70
Apr. ($h=10$)	1.9357	4.4751	3.07	6.46	3.97
May ($h=40$)	2.5726	7.2247	5.97	9.03	6.42
May($h=30$)	2.4447	6.6056	5.33	8.44	5.86
May ($h=10$)	2.5006	5.3029	4.32	6.71	4.71
Jun. ($h=40$)	2.2234	8.7359	6.68	11.46	7.74
Jun. ($h=30$)	2.2282	8.5680	6.56	11.42	7.59
Jun. ($h=10$)	2.2828	7.4628	5.80	9.83	6.61
Jul. ($h=40$)	2.6052	7.5797	6.29	9.43	6.73
Jul. ($h=30$)	2.6237	7.4127	6.17	9.20	6.59
Jul. ($h=10$)	2.6506	6.3586	5.32	7.86	5.65
Aug. ($h=40$)	2.0170	7.0271	5.00	9.89	6.23
Aug. ($h=30$)	1.9856	6.4759	4.55	9.20	5.74
Aug. ($h=10$)	2.0394	5.3247	3.83	7.44	4.72
Sep. ($h=40$)	1.6881	5.8741	3.45	9.33	5.24
Sep. ($h=30$)	1.8274	5.5890	3.62	8.38	4.97
Sep. ($h=10$)	2.0087	4.8039	3.40	6.78	4.26
Oct. ($h=40$)	1.8004	4.2340	2.70	6.41	3.77
Oct. ($h=30$)	1.9317	3.9569	2.71	5.72	3.51
Oct. ($h=10$)	2.0006	3.0881	2.18	4.37	2.74
Nov. ($h=40$)	1.7791	5.3220	3.35	8.13	4.74
Nov. ($h=30$)	1.8118	4.9376	3.17	7.44	4.39
Nov. ($h=10$)	2.0378	4.1683	2.99	5.83	3.69
Dec. ($h=40$)	1.7318	4.9230	2.99	7.67	4.39
Dec. ($h=30$)	1.6707	4.4039	2.55	7.05	3.93
Dec. ($h=10$)	1.7626	3.9022	2.43	6.00	3.47
Annual($h=40$)	1.6403	5.7650	3.25	9.37	5.16
Annual($h=30$)	1.6333	5.4269	3.04	8.85	4.86
Annual($h=10$)	1.7640	4.6365	2.89	7.12	4.13

Wind data and best fitted weibull distribution at different heights are shown in Figs. 5-7, table 4 shows the probability of a wind speed happen upper than different speeds base on weibull distribution. Figs. 8-10 give the cumulative distribution function of the wind speeds. These curves represent the time fraction or probability that the wind speed is smaller than or equal to a given wind speed.

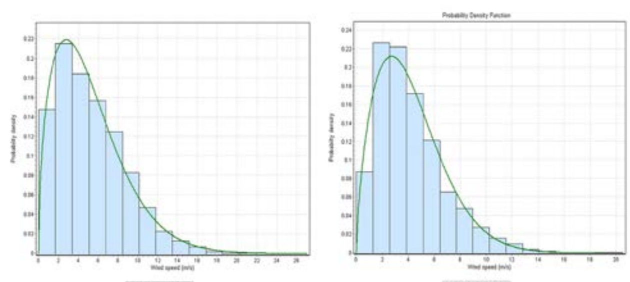
TABLE IV : statistical parameters of Firoozkooh

	10m	30m	40m
2002			
f(v>4.66m/s)	34.49%	48.20%	50%
f(v>4.50m/s)	40.32%	50%	51.67%
f(v>3.73m/s)	50%	59.30%	60.28%
f(v>5m/s)	34.75%	44.41%	46.49%
2003			
f(v>4.61m/s)	37.15%	46.48%	50%
f(v>4.34m/s)	41.13%	50%	53.43%
f(v>3.77m/s)	50%	57.65%	60.80%
f(v>5m/s)	31.91%	41.70%	45.31%



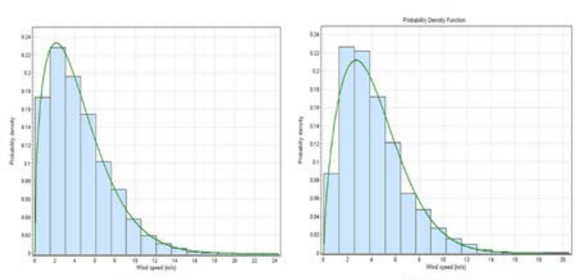
(a) (b)

Fig. 5. wind speed distribution at 40m, (a) for 2002
And (b) for 2003.



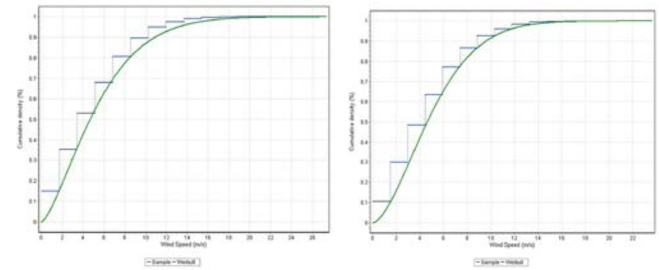
(a) (b)

Fig. 6. wind speed distribution at 30m, (a) for 2002
And (b) for 2003.



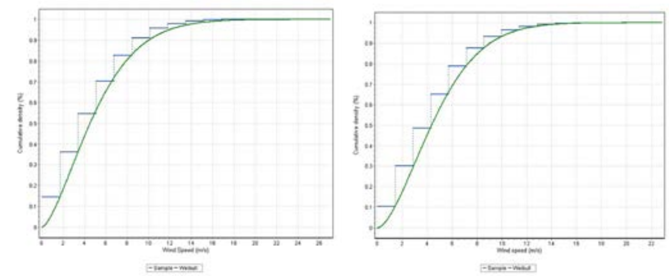
(a) (b)

Fig. 7. wind speed distribution at 10m, (a) for 2002
And (b) for 2003.



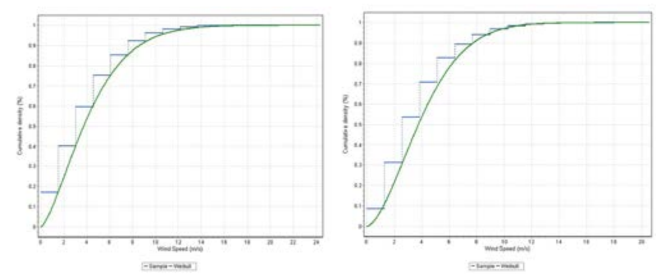
(a) (b)

Fig. 8. The Weibull cumulative frequency curve at 40m, (a) for 2002
And (b) for 2003.



(a) (b)

Fig. 9. The Weibull cumulative frequency curve at 30m, (a) for 2002
And (b) for 2003.



(a) (b)

Fig. 10. The Weibull cumulative frequency curve at 30m, (a) for 2002
And (b) for 2003.

From the Figs. 8-10, approximately 30% of the wind speeds recorded will be below the wind speed 3 m/s.

C. *Mean wind power density*

Figs. 11-16 illustrate the monthly and annual empirical and calculated power density of the site, by using equations 15-18, values of 304.07 and 201.62w/m^2 are estimated for annual mean power density at height of 40m for years 2002 and 2003 respectively. As shown maximum monthly power density for each figure is related to June and values of 561.65 and 491.04 w/m^2 at height of 40m for years 2002 and 2003 respectively. Considering the effect of the Betz limit whose value is 0.593, the maximum extractable power approximately 59.3% of the theoretical power density. For this site, the maximum extractable power by a system of unit area operating at its optimum efficiency at height of 40m is:

Year 2002: $304.07 \times 0.593 = 180.31 \frac{W}{m^2}$

Year 2003: $201.62 \times 0.593 = 119.56 \frac{W}{m^2}$

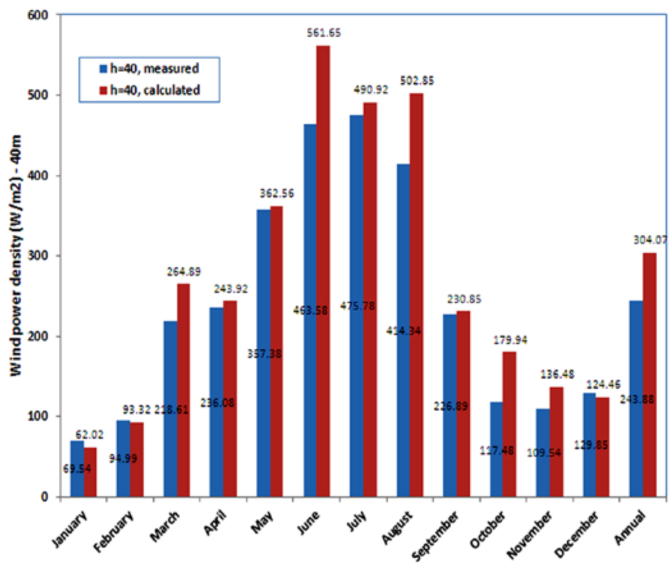


Fig. 11. Wind power density at height of 40m, 2002

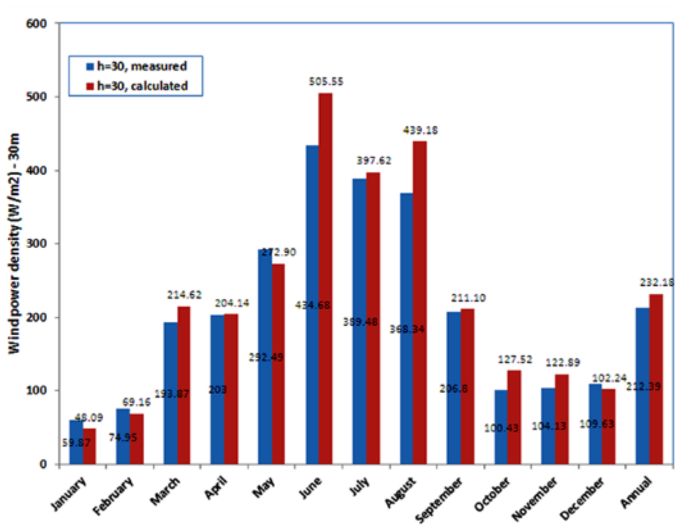


Fig. 12. Wind power density at height of 30m, 2002

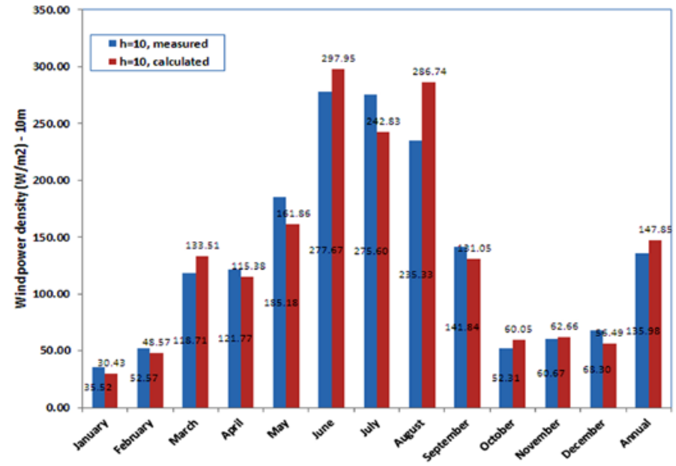


Fig. 13. Wind power density at height of 10m, 2002

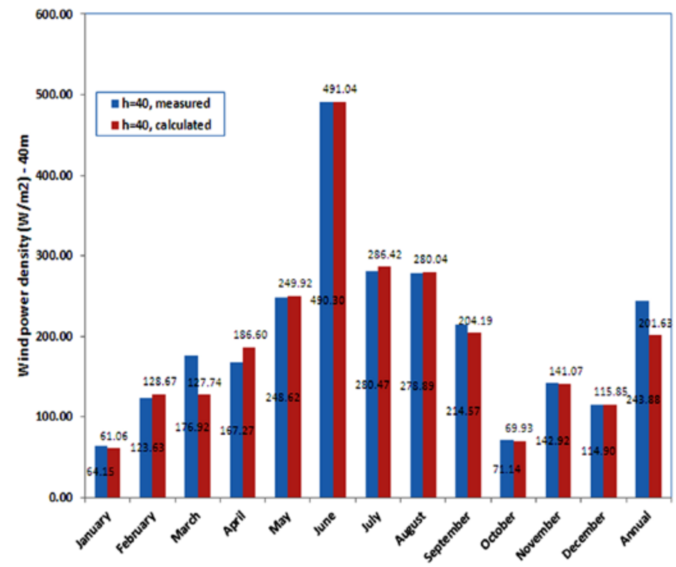


Fig. 14. Wind power density at height of 40m, 2003

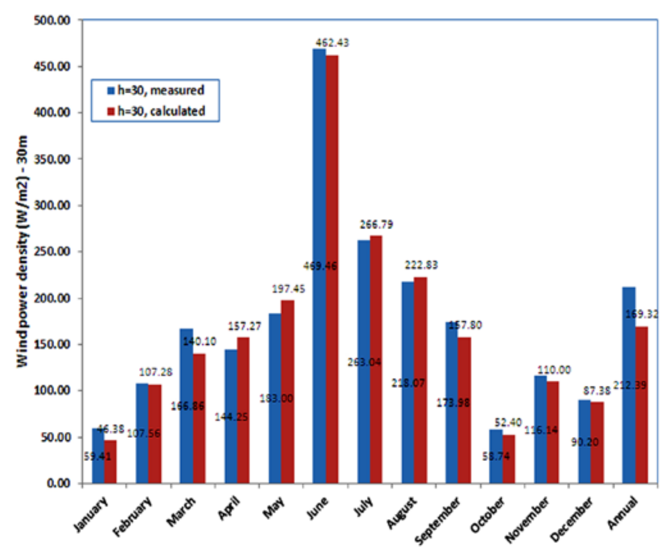


Fig. 15. Wind power density at height of 30m, 2003

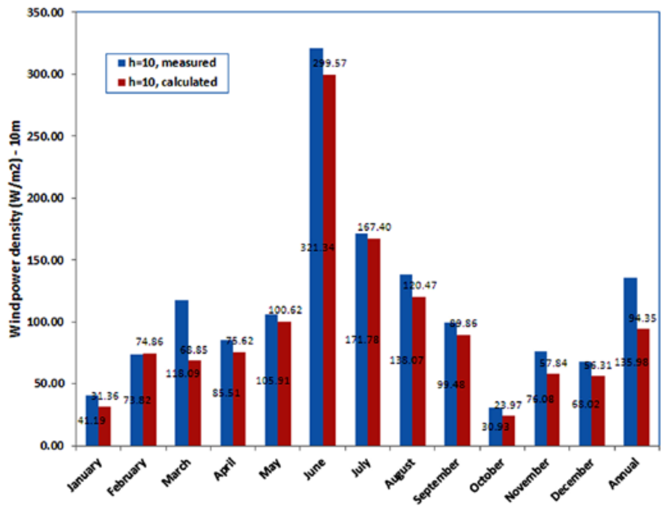


Fig. 16: Wind power density at height of 10m, 2003

Estimates of wind resource are expressed in wind power classes ranging from class 1 to 7 (Table 5). Areas designated class 4 or greater are compatible with existing wind turbine technology. Power class-3 areas may become suitable with future technology. Class-2 areas would be marginal and class-1 areas unsuitable for wind energy development [35].

TABLE V : Wind Energy Resource Classification with Wind Classes of Power Density [35]

Wind class	Wind power density at 30m (w/m^2)	Wind speed at 30m (m/s)
1	0-160	0-5.1
2	160-240	5.1-5.9
3	240-320	5.9-6.5
4	320-400	6.5-7.0
5	400-480	7.0-7.4
6	480-640	7.4-8.2
7	640-1600	8.2-11.0

From the average power density was calculated and shown in Figs. 14 and 17, For Firoozkooh city, the wind class was found to be 2, class 1 and class 2 areas are not being deemed suitable for large machines, although a smaller wind turbine may be economical in this area where the value of the energy produced is higher. Figs. 17 and 18 show the Distribution of wind speed classes for years 2002 and 2003 at height of 40m.

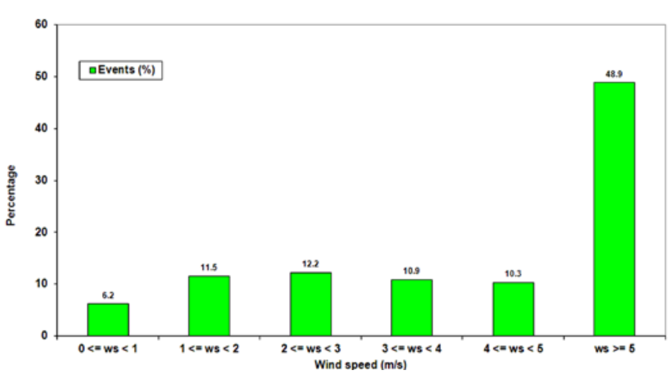


Fig. 17. Distribution of wind speed classes, h=40m, 2002

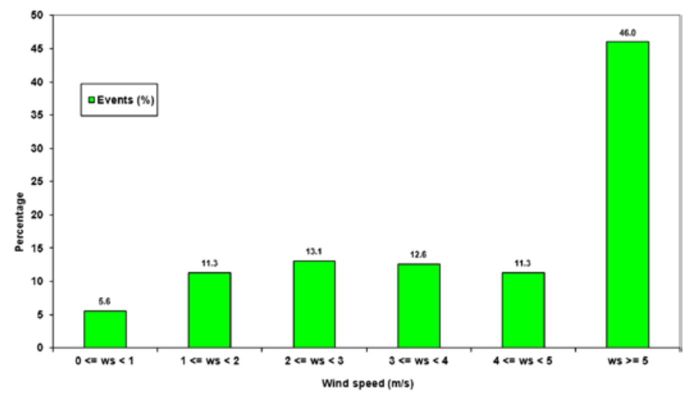


Fig. 18. Distribution of wind speed classes, h=40m, 2003

D. *Wind direction analysis*

Information on the velocity and direction of wind, in a combined form, can be presented in the wind roses. The wind rose is a chart which indicates the distribution of wind in different directions. The chart is divided into 8, 12 or even 16 equally spaced sectors representing different directions. The site's wind rose diagrams at height of 40m are presented in Figs. 19-20.

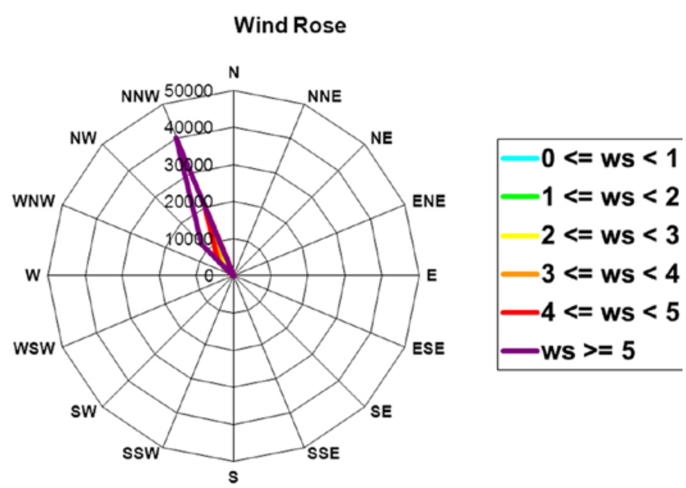


Fig. 19. Wind rose diagram from the measured data at 40m height, 2002

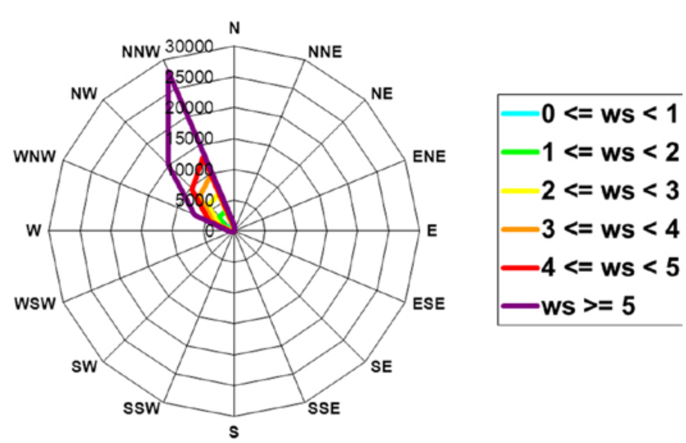


Fig. 20. Wind rose diagram from the measured data at 40m height, 2003

From Fig. 19, it is evident that a large frequency of wind at this site blows from the NW and NNW directions (2002) and From Fig. 20, the wind blows mainly from the WNW, NW and NNW directions (2003). Distribution of wind directions are shown in Figs. 21 and 22.

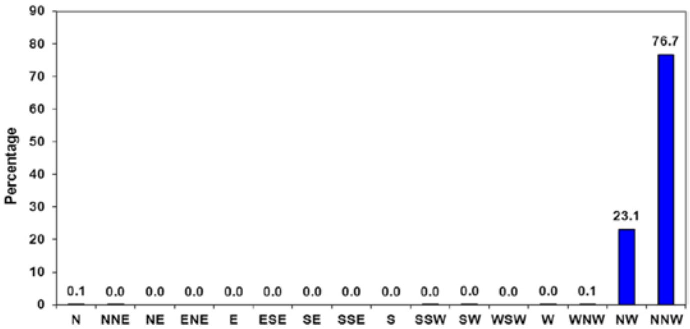


Fig. 21. Distribution of wind directions from the measured data at 40m height, 2002

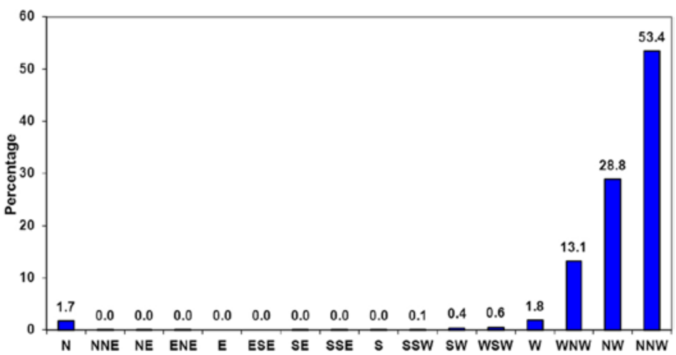


Fig. 22. Distribution of wind directions from the measured data at 40m height, 2003

IX. CONCLUSION

In this paper, the 10min period measured wind speed and direction data for years 2002, 2003 at 10m, 30m and 40m heights have been analyzed for city of Firoozkooh in Iran County. The wind speed distribution was modeled using the 2-parameter Weibull distribution function. The main contributions and conclusions of this research are as follows:

- Monthly and annual mean wind speeds for years 2002, 2003 at different elevations are investigated. The monthly mean wind speed varies between 3.1m/s in January 2003 and 8.2m/s in June 2002 for height of 40m and varies between 3m/s in January 2003 and 8m/s in June 2002 for height of 30m and varies between 2.6m/s in January 2002 and 6.8m/s in June 2002 for height of 10m.
- For year 2002 the biggest value of wind speed for heights of 40m, 30m and 10m observed in September, (27.3m/s, 27m/s and 24.3m/s respectively) and for year 2003 the biggest value of wind speed for heights of 40m and 30m observed in March, (23.6m/s and 22.8m/s respectively) and for height of 10m observed in June (20.5m/s).
- Monthly and annual values of weibull parameters (scale parameter c (m/s) and shape parameter k (dimensionless)) calculated from wind data of Firoozkooh, From the calculations; the monthly value of the shape parameter varies from 1.1054 (October 2002, h=40m) to 2.6847 (June 2002, h=10m). These values are within the acceptable range. Monthly value of scale parameter varies from 2.9083 (January 2002, h=10m) to 9.4082 (June 2002, h=40m). Results indicate that scale parameter c has much bigger variation than the shape parameter k.
- From calculations, values of 304.07 and 201.63w/m^2 are estimated for annual mean power density at height of 40m for years 2002 and 2003 respectively. Maximum monthly power density is related to June and values of 561.65 and 491.04 w/m^2 at height of 40m for years 2002 and 2003 respectively.
- From the average power density was calculated For Firoozkooh city at height of 30m, the wind class was found to be 2 which not being deemed suitable for large machines, although a smaller wind turbine may be economical in this area where the value of the energy produced is higher.
- From plotted wind roses, it is evident that a large frequency of wind at this site blows from the NW and NNW directions during the year 2002 and the wind blows mainly from the WNW, NW and NNW directions during the year 2003.

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