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The Analysis of Wind Power Potential in Kerman Synoptic Stations, Iran -An Estimation Using the Weibull Density Function

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Abstract

In the current research, wind energy potential at Kerman synoptic stations which contain wind data with 20 years statistic period and beyond, including Kerman synoptic station (30°.15'N, 56°.58'E, 1753.8 M high), 1951-2011; Kahnooj (27.58'N, 57°.42'E, 469.7 M high), 1989-2011; Bam (29°.06'N, 58°.21'E, 1066.9 M high), 1956-2011; Baft (29°.14'N, 56°.35'E, 2280 M high), 1986-2011; Anar (30.53'N, 55°.15'E, 1408.8 M high), 1986-2011; Shahrbabak (30°.06'N, 55°.08'E, 1834.1 M high), 1987-2011; Sirjan (29°.28'N, 55°.41'E, 1739.4 M high), 1985-2011; Miandeh-Jiroft (28°.35'N, 57°.48'E, 601 M high), 1989-2011 and Rafsanjan (30°.25'N, 55.54'E, 1580.9 M high), 1992-2011 has been studied. Wind data were obtained from the recorded data at Tehran meteorology organization. This data was recorded at an interval of 3 hrs at 10 m height above the ground level.

Using weibull distribution function, discontinuous wind data were substituted. This substitution has been applied through least square feet after computing weibull parameters C & K. Wind date were changed at 10 m height to 50 m by applying one seventh power law (50 m is the most height of turbines axis) and characteristics of both wind speed and wind power in each height has been computed.

Due to wind power density equals 292.63 and 583.29 w/m^2 at 10 and 50 m height respectively, average wind speed equals 17.42 m/s at 50 m height, wind existence equals 7438.5 h/y, probability of wind blowing in the wind existence hours with speeds between 3 to 25 m/s equals 0.95, most probability of wind speed equals 7.77 m/s, the result show that Rafsanjan synoptic station is an ideal place having high wind energy potential. Application of wind energy at this synoptic station with automatic turbines working at the speed of 3 m/s at 50 m height axis and above has been economically efficient.

Keywords: Wind energy potential; Wind turbine; Weibull distribution function; Wind power density; One seventh power law; Kerman province

Introduction

The worldwide concern and environmental awareness of air quality created a move towards pollution free energy production such as solar and wind energies. Wind is an abundant resource available in nature that can be utilized by mechanically converting wind power to electricity. Wind turbines are especially meant for this purpose.

The gradual increase in the earth population and the increasing demand for energy from natural resources have been the major causes for man to search for an appropriate substitution for the sources of energy. Having been aware of the decrease of the earth's energy resources, scientists have cautioned against the surplus use of energy. Moreover, environmental pollutions resulting from the burning of fossil fuels in the power stations have led to energy loss. This phenomenon is a threat to every living creature on the earth. Thus, the appropriate use of energy and the involvement of new sources of energy have been the focus of study for a long time. An appropriate solution to lower the impact of energy loss is the substitution of renewable forms of energies such as wind.

World winds hold almost around 2700 TW potential energy -25% of this energy occupies an environment of 100 meters above the ground level. It is noteworthy that 10% of this energy, i.e. 4 TW exceeds the capacity of the world's total water energy [1].

Although Iran has been a pioneer in the use wind energy, we have yet to witness the applications of wind energy which have been extremely limited. But the remnants of the numerous windmills all over the country support our claim that undoubtedly wind energy must have been of importance.

This project attempts to discover not only potential power of wind energy but also the feasibility of using wind power at Kerman synoptic stations in Iran.

Moreover, in the process of this study, a new formula, has been obtained that can be applied for computing wind existence hours at an area.

Material and Methods

Since wind is a vector quantity having direction and speed, it is subject to topographical and atmospheric changes. It is impossible to make an estimation of wind direction and wind speed at intervals in which wind speed is not reported. Moreover, this estimation is not error free. To reduce the impact of this error, the researcher took raw data from Tehran Meteorology Organization for a period of at least 20 years. The data reported wind direction and wind speed at Kerman synoptic stations for the consecutive years. Then wind data were converted from Knot to m/s (1 Knot=0.514 m/s).

All the graphs, tables and data in the project were analyzed

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by applying Excel and SPSS 17. In order to process the data the mathematical model Weibull Probability Distribution Function is used. Probability Distribution Function is the most applicable strategy to the study and calculation of wind statistics at a specific location. After the calculation of the components of this function, some parameters relating to the calculation of wind energy can be estimated.

Theory of Analysis

There are several mathematical functions called probability density functions that can be applied to model the wind speed frequency curve. In wind power studies, Weibull and Rayleigh probability density functions are commonly used and widely adopted [2]. Herein Weibull distribution is used since the Rayleigh distribution is only a subset of it.

Weibull distribution function of wind speed

Wind power is proportionate to the cubic power of the wind speed and rotor's diameter square root power [3]. Thus, wind speed is one of the most significant factors in the optimum use of wind energy.

In the calculation of wind energy, wind speed is considered a random variable which can take every quantity in a specific distance. However, practically wind speed data recorded every 3 hours at synoptic stations. The function of which is a disconnect function. In other words, the frequency distribution should be first replaced by the connected distribution function. For this purpose Weibull probability distribution function is reliable and is the most frequently used model to describe the distribution of the wind speed [4].

Weibull distribution function is a derivative of Gamma distribution and has a higher flexibility in comparison with Rayleigh distribution. It can be defined as follows:

$$P(V) = \frac{k}{C} \cdot \left[\frac{V}{C}\right]^{K-1} \exp\left(-\left[\frac{V}{C}\right]^{K}\right) \tag{1}$$

where V [m/s] is the wind speed, K [–] is the Weibull shape parameter describing the dispersion data and C [m/s] is the Weibull scale parameter.

Values of the two parameters, K and C, can be calculated by using the least square fitting of the data [5] i.e.

$$Y = A + B \cdot X \tag{2}$$

Where

$$Y = \ln\left(-\ln\left(1 - P\left(V_i\right)\right)\right) \tag{3}$$

And

$$X = \ln v_i \tag{4}$$

where v_i is the mean of wind speed classes, $P(V_i)$ is the accumulative probability of the frequency of every mean speed classes. By quantities of X and Y, the values of A and B can be calculated using the following equation:

$$A = \frac{n \cdot \sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n \cdot \sum_{i=1}^{n} x_i^2 - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} x_i} \tag{5}$$

$$B = \frac{1}{n}\sum_{i=1}^{n} y_i - \frac{A}{n}\sum_{i=1}^{n} x_i \tag{6}$$

Here, A is the gradient of the equation of a straight line Y=AX+B, B is the width of the intersection of the line by the Y axis. In this equation, the relationship between A and B and the Weibull parameters K and C is as follows [6]:

$$K = A \quad \text{and} \quad C = \exp\left(\frac{-B}{A}\right) \tag{7}$$

A brief presentation of the observations and measurements of wind speed at Kerman synoptic stations are shown in Tables 1-9.

Considering equations (3) and (4), v_i and $P(V_i)$ are substituted with X and Y, so that A and B quantities can be calculated by liner regression equation or least square line of X and Y values. These values are shown in Tables 10-18.

After computing X and Y quantities, A and B quantities related to shape and scale parameters of Weibull function can be determined. Then, we are able to draw a line Y=AX+B which is the line nearest to points, when compared with X and Y

There is a sample of least square line for x and y which are related to Rafsanjan's synoptic station in Figure 1.

The numerical values of A=K, B and C obtained from Kerman synoptic stations are presented respectively as follows: Kerman: 1.5271, -2.6023 and 5.4963; Kahnooj: 2.4894, -5.3718 and 8.6524; Bam: 1.4619, -2.1969 and 4.494; Baft: 2.3471, -4.6212 and 7.1625; Anar: 1.9472, -3.4531 and 5.8906; Shahrbabak: 2.3925, -4.8376 and 7.553; Sirjan: 2.1545, -3.8827 and 6.0624; Miandeh-jiroft: 1.7545, -2.8968 and 5.2125; Rafsanjan:

Weibull probability function quantities (P_w) are presented in Tables 1-9. These quantities are computed using Weibull scale and Form parameters. Also, v_i numerical values, in these Tables (mean of wind speed classes) were computed through equation 1.

With the help of Weibull distribution function, the computation quantities for wind speed occurrence and factual wind speed occurrence over Kerman synoptic station has been drawn in Figures 2-10. Numerical representations of wind speed are distributed in the graphs and are connected by the continuous line drawn with the help of Weibull function. By comparing them, the wind speed disconnected quantities substituted in a curve Contiguous can be observed.

Calculation of efficacious parameters in wind energy potential estimation

As the scale and shape parameters have been calculated, two meaningful wind speeds for wind energy estimation, i.e. the most probable wind speed and the wind speed carrying maximum energy, can be simply obtained. The most probable wind speed denotes the most frequent wind speed for a given wind probability distribution and is expressed as follows [7]:

$$V_{MP} = C\left(\frac{K-1}{K}\right)^{1/K} \tag{8}$$

The wind speed carrying maximum energy represents the wind speed which carries the maximum amount of wind energy, and is expressed as follows [6]:

$$V_{MaxE} = C\left(1 + \frac{2}{K}\right)^{1/K} \tag{9}$$

The average wind speed (V) and wind speed standard deviation (σ) can be calculated through the following equations [7]:

$$V = C\Gamma\left(\frac{K+1}{K}\right) \tag{10}$$

I	Wind speed classes v[m/s]	Mean of wind speed classes v_i[m/s]	Frequency f_i	Probability ($_i$v)p	Accumulative probability ($_i$v)P	Probability in Weibull model $P_w(v_i)$
1	0.5-1.5	1	116	0.004278548	0.004278548	0.0597024
2	1.5-2.5	2	4599	0.169629684	0.173908233	0.1051664
3	2.5-3.5	3	6671	0.246053408	0.419961641	0.1333364
4	3.5-4.5	4	4830	0.178149897	0.598111537	0.1430981
5	4.5-5.5	5	3632	0.133962821	0.732074358	0.1368364
6	5.5-6.5	6	2471	0.091140454	0.823214813	0.1193128
7	6.5-7.5	7	1675	0.061780761	0.884995574	0.0960548
8	7.5-8.5	8	1209	0.0445928	0.929588374	0.0719434
9	8.5-9.5	9	326	0.012024196	0.94161257	0.0503812
10	9.5-10.5	10	724	0.026704042	0.968316613	0.0331025
11	10.5-11.5	11	103	0.003799056	0.972115668	0.0204583
12	11.5-12.5	12	343	0.012651225	0.984766893	0.0119159
13	12.5-13.5	13	96	0.003540868	0.98830776	0.0065506
14	13.5-14.5	14	125	0.004610505	0.992918265	0.003403
15	14.5-15.5	15	97	0.003577752	0.996496017	0.0016721
16	15.5-16.5	16	32	0.001180289	0.997676306	0.0007778
17	16.5-17.5	17	19	0.000700797	0.998377102	0.0003428
18	17.5-18.5	18	19	0.000700797	0.999077899	0.0001432
19	18.5-19.5	19	1	0.000037	0.999114783	0.0000567
20	19.5-20.5	20	18	0.000664	0.999778696	0.0000213
21	21.5-22.5	22	1	0.000037	0.99981558	0.0000026
22	22.5-23.5	23	2	0.000074	0.999889348	0.0000008
23	24.5-25.5	25	3	0.000111	0.999999	0.0000001
Total			27112	1		

Table 1: Arrangement of the measured three hourly time-series data in frequency distribution format for 1986-2011 and the probability density distributions calculated from the Weibull function at Anar synoptic station.

i	Wind speed classes v[m/s]	Mean of wind speed classes v_i[m/s]	Frequency f_i	Probability ($_i$v)p	accumulative probability ($_i$v)P	Probability in Weibull model $P_w(v_i)$
1	0.5-1.5	1	9	0.000326	0.000326	0.0228712
2	1.5-2.5	2	2665	0.096642	0.096968	0.0558927
3	2.5-3.5	3	5415	0.196366	0.293335	0.0891254
4	3.5-4.5	4	6664	0.241659	0.534994	0.1158754
5	4.5-5.5	5	4213	0.152778	0.687772	0.1313352
6	5.5-6.5	6	3085	0.111873	0.799645	0.1334372
7	6.5-7.5	7	959	0.034777	0.834421	0.1231778
8	7.5-8.5	8	2133	0.077350	0.911771	0.1040348
9	8.5-9.5	9	266	0.009646	0.921417	0.080687
10	9.5-10.5	10	1301	0.047179	0.968596	0.0575692
11	10.5-11.5	11	23	0.000834	0.96943	0.0378135
12	11.5-12.5	12	409	0.014832	0.984262	0.0228657
13	12.5-13.5	13	33	0.001197	0.985458	0.0127242
14	13.5-14.5	14	133	0.004823	0.990281	0.0065115
15	14.5-15.5	15	141	0.005113	0.995395	0.0030617
16	15.5-16.5	16	35	0.001269	0.996664	0.0013214
17	16.5-17.5	17	12	0.000435	0.997099	0.000523
18	17.5-18.5	18	38	0.001378	0.998477	0.0001895
19	18.5-19.5	19	1	0.000036	0.998513	0.0000628
20	19.5-20.5	20	32	0.001160	0.999674	0.000019
21	21.5-22.5	22	1	0.000036	0.99971	0.0000013
22	23.5-24.5	24	1	0.000036	0.999746	0.0000001
23	24.5-25.5	25	5	0.000181	0.999927	0
24	27.5-28.5	28	2	0.000073	0.99999	0
		Total	27576	1		

Table 2: Arrangement of the measured three hourly time-series data in frequency distribution format for 1986-2011 and the probability density distributions calculated from the Weibull function at Baft synoptic station.

i	Wind speed classes v[m/s]	Mean of wind speed classes v_i[m/s]	Frequency f_i	Probability $p(v_i)$	accumulative probability $P(v_i)$	Probability in Weibull model $P_w(v_i)$
1	0.5-1.5	1	2869	0.036216059	0.036216059	0.1453942
2	1.5-2.5	2	17502	0.220931847	0.257147906	0.1647792
3	2.5-3.5	3	12974	0.163773842	0.420921749	0.1551221
4	3.5-4.5	4	17059	0.215339754	0.636261503	0.1326244
5	4.5-5.5	5	9521	0.120185814	0.756447317	0.1061931
6	5.5-6.5	6	8499	0.107284869	0.863732185	0.0808406
7	6.5-7.5	7	3283	0.041442078	0.905174264	0.0590278
8	7.5-8.5	8	4178	0.052739873	0.957914137	0.0415805
9	8.5-9.5	9	989	0.012484379	0.970398516	0.0283729
10	9.5-10.5	10	1517	0.019149446	0.989547962	0.0188115
11	10.5-11.5	11	131	0.001653644	0.991201606	0.0121472
12	11.5-12.5	12	408	0.00515028	0.996351885	0.007654
13	12.5-13.5	13	78	0.000984612	0.997336498	0.0047134
14	13.5-14.5	14	85	0.001072975	0.998409472	0.0028405
15	14.5-15.5	15	78	0.000984612	0.999394085	0.001677
16	15.5-16.5	16	9	0.000113609	0.999507694	0.0009709
17	16.5-17.5	17	8	0.000100986	0.99960868	0.0005517
18	17.5-18.5	18	10	0.000126232	0.999734912	0.0003079
19	18.5-19.5	19	1	1.26232E-05	0.999747535	0.0001689
20	19.5-20.5	20	11	0.000138856	0.999886391	0.0000911
21	20.5-21.5	21	3	0.000038	0.999924261	0.0000484
22	23.5-24.5	24	1	0.000013	0.999936884	0.0000066
23	24.5-25.5	25	1	0.000013	0.999949507	0.0000033
24	29.5-30.5	30	1	0.000013	0.99996213	0.0000001
25	31.5-32.5	32	1	0.000013	0.999974754	0
26	34.5-35.5	35	1	0.000013	0.999987377	0
27	35.5-36.5	36	1	0.000013	0.9999999	0
		Total	79219	1		

Table 3: Arrangement of the measured three hourly time-series data in frequency distribution format for 1956-2011 and the probability density distributions calculated from the Weibull function at Bam synoptic station.

i	Wind speed classes v[m/s]	Mean of wind speed classes v_i[m/s]	Frequency f_i	Probability $p(v_i)$	accumulative probability $P(v_i)$	Probability in Weibull model $P_w(v_i)$
1	0.5-1.5	1	2	0.0000991	0.0000991	0.0115117
2	1.5-2.5	2	794	0.039336141	0.039435224	0.0316365
3	2.5-3.5	3	1459	0.072281397	0.111716621	0.0552975
4	3.5-4.5	4	2796	0.138518702	0.250235323	0.0787512
5	4.5-5.5	5	4478	0.221847907	0.47208323	0.0984773
6	5.5-6.5	6	3842	0.190339361	0.662422591	0.1115778
7	6.5-7.5	7	1619	0.080208075	0.742630666	0.1163125
8	7.5-8.5	8	2597	0.128659896	0.871290562	0.1124491
9	8.5-9.5	9	175	0.008669804	0.879960367	0.1012525
10	9.5-10.5	10	1589	0.078721823	0.95868219	0.0850939
11	10.5-11.5	11	38	0.001882586	0.960564776	0.0668046
12	11.5-12.5	12	350	0.017339609	0.977904384	0.0489959
13	12.5-13.5	13	14	0.000693584	0.978597969	0.0335557
14	13.5-14.5	14	41	0.002031211	0.98062918	0.021443
15	14.5-15.5	15	281	0.013921229	0.994550409	0.0127725
16	15.5-16.5	16	14	0.000693584	0.995243993	0.0070833
17	16.5-17.5	17	1	0.000050	0.995293535	0.0036526
18	17.5-18.5	18	20	0.000990835	0.99628437	0.001749
19	19.5-20.5	20	67	0.003319297	0.999603666	0.0003193
20	20.5-21.5	21	1	0.000050	0.999653208	0.0001214
21	21.5-22.5	22	2	0.000099	0.999752291	0.0000426
22	23.5-24.5	24	1	0.000050	0.999801833	0.0000041
23	27.5-28.5	28	1	0.000050	0.999851375	0
24	29.5-30.5	30	1	0.000050	0.999900917	0
25	37.5-38.5	38	1	0.000050	0.999950458	0
26	39.5-40.5	40	1	0.000050	0.999999	0
		Total	20185	1		

Table 4: Arrangement of the measured three hourly time-series data in frequency distribution format for 1989-2011 and the probability density distributions calculated from the Weibull function at Kahnooj synoptic station.

i	Wind speed classes v[m/s]	Mean of wind speed classes v_i[m/s]	Frequency f_i	Probability ($_i$v)p	accumulative probability ($_i$v)P	Probability in Weibull model $P_w(v_i)$
1	0.5-1.5	1	4203	0.047056584	0.047056584	0.1050749
2	1.5-2.5	2	8235	0.092198661	0.139255245	0.1317106
3	2.5-3.5	3	21770	0.243735865	0.38299111	0.1358068
4	3.5-4.5	4	9611	0.10760429	0.490595401	0.1269828
5	4.5-5.5	5	15893	0.177937258	0.668532659	0.1112482
6	5,5-6.5	6	6284	0.07035536	0.738888018	0.0927607
7	6.5-7.5	7	6155	0.068911082	0.8077991	0.0742786
8	7.5-8.5	8	5122	0.057345664	0.865144764	0.0574524
9	8.5-9.5	9	3947	0.044190421	0.909335184	0.043097
10	9.5-10.5	10	4270	0.047806713	0.957141897	0.0314463
11	10.5-11.5	11	701	0.007848362	0.96499026	0.0223699
12	11.5-12.5	12	998	0.01117356	0.976163819	0.0155425
13	12.5-13.5	13	681	0.007624443	0.983788262	0.0105627
14	13.5-14.5	14	295	0.003302806	0.987091068	0.0070302
15	14.5-15.5	15	685	0.007669227	0.994760295	0.0045872
16	15.5-16.5	16	94	0.001052419	0.995812714	0.002937
17	16.5-17.5	17	56	0.000626973	0.996439687	0.0018467
18	17.5-18.5	18	114	0.001276338	0.997716026	0.001141
19	18.5-19.5	19	23	0.000257507	0.997973533	0.0006932
20	19.5-20.5	20	89	0.00099644	0.998969972	0.0004144
21	20.5-21.5	21	47	0.00052621	0.999496182	0.0002438
22	21.5-22.5	22	8	0.0000896	0.99958575	0.0001413
23	22.5-23.5	23	12	0.000134351	0.999720101	0.0000806
24	23.5-24.5	24	5	0.000056	0.999776081	0.0000454
25	24.5-25.5	25	10	0.000112	0.99988804	0.0000252
26	25.5-26.5	26	4	0.000045	0.999932824	0.0000138
27	26.5-27.5	27	1	0.000011	0.99994402	0.0000074
28	27.5-28.5	28	2	0.000022	0.999966412	0.000004
29	29.5-30.5	30	2	0.000022	0.999988804	0.0000011
30	34.5-35.5	35	1	0.000011	0.9999999	0
		Total	89318	1		

Table 5: Arrangement of the measured three hourly time-series data in frequency distribution format for 1951-2011 and the probability density distributions calculated from the Weibull function at Kerman synoptic station.

i	Wind speed classes v[m/s]	Mean of wind speed classes v_i[m/s]	Frequency f_i	Probability ($_i$v)p	accumulative probability ($_i$v)P	Probability in Weibull model $P_w(v_i)$
1	0.5-1.5	1	6	0.000186875	0.000187	0.0188125
2	1.5-2.5	2	701	0.021833245	0.02202	0.0477558
3	2.5-3.5	3	7817	0.243467157	0.265487	0.0784585
4	3.5-4.5	4	12135	0.377954963	0.643442	0.1050525
5	4.5-5.5	5	3734	0.116298626	0.759741	0.1228575
6	5.5-6.5	6	2957	0.092098296	0.851839	0.1291674
7	6.5-7.5	7	1032	0.032142523	0.883982	0.1237958
8	7.5-8.5	8	1993	0.062073691	0.946055	0.108938
9	8.5-9.5	9	172	0.005357087	0.951412	0.0883471
10	9.5-10.5	10	834	0.025975644	0.977388	0.0661495
11	10.5-11.5	11	28	0.000872084	0.97826	0.0457582
12	11.5-12.5	12	358	0.011150216	0.98941	0.0292414
13	12.5-13.5	13	9	0.000280313	0.989691	0.0172542
14	13.5-14.5	14	143	0.004453857	0.994145	0.0093932
15	14.5-15.5	15	51	0.001588439	0.995733	0.0047133
16	15.5-16.5	16	55	0.001713022	0.997446	0.0021774
17	16.5-17.5	17	6	0.000186875	0.997633	0.000925
18	17.5-18.5	18	33	0.001027813	0.998661	0.0003609
19	18.5-19.5	19	1	0.000031	0.998692	0.0001291
20	19.5-20.5	20	30	0.000934376	0.999626	0.0000423
21	21.5-22.5	22	6	0.000186875	0.999813	0.0000035
22	23.5-24.5	24	1	0.000031	0.999844	0.0000002
23	24.5-25.5	25	2	0.000062	0.999907	0
24	27.5-28.5	28	1	0.000031	0.999938	0
25	29.5-30.5	30	1	0.000031	0.999969	0
26	34.5-35.5	35	1	0.000031	0.99999	0
		Total	32107	1		

Table 6: Arrangement of the measured three hourly time-series data in frequency distribution format for 1987-2011 and the probability density distributions calculated from the Weibull function at Shahrbabak synoptic station.

i	Wind speed classes v[m/s]	Mean of wind speed classes v_i[m/s]	Frequency f_i	Probability $(_iv)p$	accumulative probability $(_iv)P$	Probability in Weibull model $P_w(v_i)$
1	0.5-1.5	1	122	0.003856244	0.003856	0.0434674
2	1.5-2.5	2	4049	0.127983058	0.131839	0.0901226
3	2.5-3.5	3	4860	0.1536176	0.285457	0.1266384
4	3.5-4.5	4	5996	0.189524923	0.474982	0.1461868
5	4.5-5.5	5	6226	0.196794892	0.671777	0.1470099
6	5.5-6.5	6	4021	0.127098018	0.798875	0.1320683
7	6.5-7.5	7	2163	0.068369314	0.867244	0.1073469
8	7.5-8.5	8	2019	0.063817682	0.931062	0.0795051
9	8.5-9.5	9	611	0.01931283	0.950375	0.0538804
10	9.5-10.5	10	913	0.028858615	0.979233	0.0334964
11	10.5-11.5	11	85	0.002686728	0.98192	0.0191326
12	11.5-12.5	12	287	0.009071657	0.990992	0.01005
13	12.5-13.5	13	65	0.002054556	0.993046	0.0048574
14	13.5-14.5	14	86	0.002718336	0.995764	0.0021607
15	14.5-15.5	15	96	0.003034422	0.998799	0.0008847
16	15.5-16.5	16	12	0.000379303	0.999178	0.0003334
17	16.5-17.5	17	4	0.000126434	0.999305	0.0001156
18	17.5-18.5	18	12	0.000379303	0.999684	0.0000369
19	18.5-19.5	19	1	0.000032	0.999716	0.0000108
20	19.5-20.5	20	6	0.000189651	0.999905	0.0000029
21	21.5-22.5	22	2	0.000063	0.999968	0.0000002
22	23.5-24.5	24	1	0.000032	0.99999	0
		Total	31637	1		

Table 7: Arrangement of the measured three hourly time-series data in frequency distribution format for 1985-2011 and the probability density distributions calculated from the Weibull function at Sirjan synoptic station.

i	Wind speed classes v[m/s]	Mean of wind speed classes v_i[m/s]	Frequency f_i	Probability $(_iv)p$	accumulative probability $(_iv)P$	Probability in Weibull model $P_w(v_i)$
1	0.5-1.5	1	47	0.003856252	0.003856252	0.0916441
2	1.5-2.5	2	3572	0.293075156	0.296931408	0.1356201
3	2.5-3.5	3	3564	0.292418773	0.589350181	0.1518182
4	3.5-4.5	4	2460	0.201837873	0.791188054	0.1470365
5	4.5-5.5	5	1119	0.091811618	0.882999672	0.1287542
6	5.5-6.5	6	602	0.049392845	0.932392517	0.1040692
7	6.5-7.5	7	154	0.012635379	0.945027896	0.0785591
8	7.5-8.5	8	276	0.022645225	0.967673121	0.0557984
9	8.5-9.5	9	43	0.00352806	0.971201181	0.0374827
10	9.5-10.5	10	165	0.013537906	0.984739088	0.0239034
11	10.5-11.5	11	10	0.000820479	0.985559567	0.0145131
12	11.5-12.5	12	64	0.005251067	0.990810633	0.0084085
13	12.5-13.5	13	6	0.000492287	0.991302921	0.0046575
14	13.5-14.5	14	14	0.001148671	0.992451592	0.0024702
15	14.5-15.5	15	40	0.003281917	0.995733508	0.0012561
16	15.5-16.5	16	9	0.000738431	0.99647194	0.0006131
17	16.5-17.5	17	4	0.000328192	0.996800131	0.0002875
18	17.5-18.5	18	4	0.000328192	0.997128323	0.0001297
19	18.5-19.5	19	1	0.000082	0.997210371	0.0000563
20	19.5-20.5	20	23	0.001887102	0.999097473	0.0000235
21	20.5-21.5	21	2	0.000164096	0.999261569	0.0000095
22	21.5-22.5	22	3	0.000246144	0.999507713	0.0000037
23	24.5-25.5	25	6	0.000492287	0.9999999	0.0000002
		Total	12188	1		

Table 8: Arrangement of the measured three hourly time-series data in frequency distribution format for 1989-2011 and the probability density distributions calculated from the Weibull function at Miandeh-Jiroft synoptic station.

i	Wind speed classes v[m/s]	Mean of wind speed classes v_i[m/s]	Frequency f_i	Probability $(_iv)p$	accumulative probability $(_iv)P$	Probability in Weibull model $P_w(v_i)$
1	0.5-1.5	1	9	0.00022686	0.00022686	0.0157413
2	1.5-2.5	2	2582	0.065083686	0.065310546	0.0432486
3	2.5-3.5	3	5095	0.128428111	0.193738657	0.0746244
4	3.5-4.5	4	8599	0.216752369	0.410491026	0.1035553
5	4.5-5.5	5	9577	0.241404517	0.651895543	0.1243828
6	5.5-6.5	6	4775	0.120361968	0.772257512	0.1332449
7	6.5-7.5	7	2619	0.066016334	0.838273846	0.1290849
8	7.5-8.5	8	2586	0.065184513	0.903458359	0.1138468
9	8.5-9.5	9	570	0.014367816	0.917826175	0.0916788
10	9.5-10.5	10	1787	0.045044364	0.962870538	0.0674697
11	10.5-11.5	11	86	0.002167776	0.965038314	0.0453634
12	11.5-12.5	12	753	0.018980641	0.984018955	0.0278356
13	12.5-13.5	13	47	0.001184715	0.98520367	0.0155644
14	13.5-14.5	14	165	0.004159105	0.989362775	0.0079161
15	14.5-15.5	15	246	0.006200847	0.995563622	0.0036548
16	15.5-16.5	16	41	0.001033474	0.996597096	0.0015285
17	16.5-17.5	17	18	0.000453721	0.997050817	0.0005777
18	17.5-18.5	18	38	0.000957854	0.998008671	0.0001969
19	19.5-20.5	20	43	0.001083888	0.999092559	0.0000166
20	20.5-21.5	21	6	0.00015124	0.999243799	0.0000041
21	21.5-22.5	22	10	0.000252067	0.999495866	0.0000009
22	22.5-23.5	23	1	0.000025	0.999521073	0.0000002
23	23.5-24.5	24	8	0.000201654	0.999722726	0
24	24.5-25.5	25	11	0.000277274	0.99999	0
		Total	39672	1		

Table 9: Arrangement of the measured three hourly time-series data in frequency distribution format for 1992-2011 and the probability density distributions calculated from the Weibull function at Rafsanjan synoptic station.

i	$Y = \ln(-\ln(1-P(V_i)))$	$X = \ln V_i$
1	-5.451998424	0
2	-1.655223178	0.693147181
3	-0.607591621	1.098612289
4	-0.09257517	1.386294361
5	0.275391193	1.609437912
6	0.54975009	1.791759469
7	0.771396588	1.945910149
8	0.975840664	2.079441542
9	1.044034537	2.197224577
10	1.238942994	2.302585093
11	1.275276299	2.397895273
12	1.431335631	2.48490665
13	1.492641127	2.564949357
14	1.599435321	2.63905733
15	1.732337582	2.708050201
16	1.802468091	2.772588722
17	1.859969691	2.833213344
18	1.944316865	2.890371758
19	1.950140884	2.944438979
20	2.130131358	2.995732274
21	2.151563788	3.091042453
22	2.209276046	3.135494216
23	2.779942594	3.218875825

Table 10: The numerical values of liner equations, between X and Y, for the determination of A and B, in relation to Weibull parameters K and C in Anar synoptic station.

i	$Y=\ln(-\ln(1-P(V_i)))$	$X=\ln V_i$
1	-8.027313323	0
2	-2.28280494	0.693147181
3	-1.057859329	1.098612289
4	-0.266957784	1.386294361
5	0.151880829	1.609437912
6	0.474781312	1.791759469
7	0.586846379	1.945910149
8	0.886994051	2.079441542
9	0.933581229	2.197224577
10	1.241504457	2.302585093
11	1.249252285	2.397895273
12	1.423507429	2.48490665
13	1.442376843	2.564949357
14	1.533358734	2.63905733
15	1.682783913	2.708050201
16	1.740977015	2.772588722
17	1.76518865	2.833213344
18	1.869805029	2.890371758
19	1.873512873	2.944438979
20	2.082870223	2.995732274
21	2.09743611	3.091042453
22	2.113696938	3.17805383
23	2.254607761	3.218875825
24	2.779942594	3.33220451

Table 11: The numerical values of liner equations, between X and Y, for the determination of A and B, in relation to Weibull parameters K and C in Baft synoptic station.

i	$Y=\ln(-\ln(1-P(V_i)))$	$X=\ln V_i$
1	-3.29986526	0
2	-1.213153752	0.693147181
3	-0.604554675	1.098612289
4	0.011256491	1.386294361
5	0.345305963	1.609437912
6	0.689707825	1.791759469
7	0.856844048	1.945910149
8	1.153114169	2.079441542
9	1.258441321	2.197224577
10	1.517532754	2.302585093
11	1.554598557	2.397895273
12	1.725182385	2.48490665
13	1.779706003	2.564949357
14	1.863101286	2.63905733
15	2.002664493	2.708050201
16	2.030305104	2.772588722
17	2.06000184	2.833213344
18	2.108447887	2.890371758
19	2.114354815	2.944438979
20	2.206376666	2.995732274
21	2.250050184	3.044522438
22	2.269083482	3.17805383
23	2.291895875	3.218875825
24	2.320558515	3.401197382
25	2.359610234	3.465735903
26	2.423028715	3.555348061
27	2.779942594	3.583518938

Table 12: The numerical values of liner equations, between X and Y, for the determination of A and B, in relation to Weibull parameters K and C in Bam synoptic station.

i	$Y=\ln(-\ln(1-P(V_i)))$	$X=\ln V_i$
1	-9.219498309	0
2	-3.213046365	0.693147181
3	-2.133142223	1.098612289
4	-1.244809084	1.386294361
5	-0.448137813	1.609437912
6	0.082464789	1.791759469
7	0.305455532	1.945910149
8	0.717936294	2.079441542
9	0.751384632	2.197224577
10	1.158911095	2.302585093
11	1.173440145	2.397895273
12	1.338252638	2.48490665
13	1.346583584	2.564949357
14	1.372192261	2.63905733
15	1.651004846	2.708050201
16	1.676787512	2.772588722
17	1.678743455	2.833213344
18	1.721910324	2.890371758
19	2.05837794	2.995732274
20	2.075281009	3.044522438
21	2.116647862	3.091042453
22	2.143167311	3.17805383
23	2.176350754	3.33220451
24	2.221325997	3.401197382
25	2.293816262	3.63758616
26	2.779942594	3.688879454

Table 13: The numerical values of liner equations, between X and Y, for the determination of A and B, in relation to Weibull parameters K and C in Kahnooj synoptic station.

i	$Y=\ln(-\ln(1-P(V_i)))$	$X=\ln V_i$
1	-3.032401402	0
2	-1.897404888	0.693147181
3	-0.728003987	1.098612289
4	-0.393764793	1.386294361
5	0.09914463	1.609437912
6	0.294761391	1.791759469
7	0.500298871	1.945910149
8	0.694922304	2.079441542
9	0.87571284	2.197224577
10	1.147358186	2.302585093
11	1.209595653	2.397895273
12	1.3181629	2.48490665
13	1.416343272	2.564949357
14	1.470138096	2.63905733
15	1.658511849	2.708050201
16	1.700320581	2.772588722
17	1.729512885	2.833213344
18	1.805307006	2.890371758
19	1.824784955	2.944438979
20	1.92835259	2.995732274
21	2.02726573	3.044522438
22	2.052717669	3.091042453
23	2.101824476	3.135494216
24	2.128734679	3.17805383
25	2.207985715	3.218875825
26	2.26261678	3.258096538
27	2.281414612	3.295836866
28	2.332274569	3.33220451
29	2.433609699	3.401197382
30	2.779942594	3.555348061

Table 14: The numerical values of liner equations, between X and Y, for the determination of A and B, in relation to Weibull parameters K and C in Kerman synoptic station.

i	$Y = \ln(-\ln(1-P(V_i)))$	$X = \ln V_i$
1	-8.58497644	0
2	-3.804686255	0.693147
3	-1.175877981	1.098612
4	0.030780418	1.386294
5	0.354899419	1.609438
6	0.646818834	1.791759
7	0.767329932	1.94591
8	1.071514184	2.079442
9	1.106708841	2.197225
10	1.332175853	2.302585
11	1.342501879	2.397895
12	1.514662012	2.484907
13	1.520543523	2.564949
14	1.637128445	2.639057
15	1.696871412	2.70805
16	1.786765371	2.772589
17	1.799412777	2.833213
18	1.889434916	2.890372
19	1.89298541	2.944439
20	2.065839794	2.995732
21	2.150024635	3.091042
22	2.171039321	3.178054
23	2.227669402	3.218876
24	2.270442219	3.332205
25	2.339575374	3.401197
26	2.779942594	3.555348

Table 15: The numerical values of liner equations, between X and Y, for the determination of A and B, in relation to Weibull parameters K and C in Shahrbabak synoptic station.

i	$Y = \ln(-\ln(1-P(V_i)))$	$X = \ln V_i$
1	-5.556130329	0
2	-1.956314973	0.693147181
3	-1.090310948	1.098612289
4	-0.43955606	1.386294361
5	0.108012043	1.609437912
6	0.472392871	1.791759469
7	0.702722588	1.945910149
8	0.983778837	2.079441542
9	1.099695602	2.197224577
10	1.354390446	2.302585093
11	1.389525039	2.397895273
12	1.549601582	2.48490665
13	1.603108938	2.564949357
14	1.698225558	2.63905733
15	1.905757044	2.708050201
16	1.960656044	2.772588722
17	1.983899355	2.833213344
18	2.086851211	2.890371758
19	2.099839338	2.944438979
20	2.226078742	2.995732274
21	2.33815324	3.091042453
22	2.779942594	3.17805383

Table 16: The numerical values of liner equations, between X and Y, for the determination of A and B, in relation to Weibull parameters K and C in Sirjan synoptic station.

i	$Y = \ln(-\ln(1-P(V_i)))$	$X = \ln V_i$
1	-5.556128307	0
2	-1.043269862	0.693147181
3	-0.116517582	1.098612289
4	0.448729692	1.386294361
5	0.763409231	1.609437912
6	0.991040667	1.791759469
7	1.065031178	1.945910149
8	1.23310129	2.079441542
9	1.266220837	2.197224577
10	1.430899702	2.302585093
11	1.444026131	2.397895273
12	1.545370378	2.48490665
13	1.557042547	2.564949357
14	1.586459635	2.63905733
15	1.696892485	2.708050201
16	1.731125675	2.772588722
17	1.748268203	2.833213344
18	1.766930273	2.890371758
19	1.771870763	2.944438979
20	1.947382189	2.995732274
21	1.97560522	3.044522438
22	2.030310076	3.091042453
23	2.779942594	3.218875825

Table 17: The numerical values of liner equations, between X and Y, for the determination of A and B, in relation to Weibull parameters K and C in Miandeh-Jiroft synoptic station.

i	$Y = \ln(-\ln(1-P(V_i)))$	$X = \ln V_i$
1	-8.39106291	0
2	-2.695021344	0.693147181
3	-1.53550301	1.098612289
4	-0.637778064	1.386294361
5	0.053780247	1.609437912
6	0.391731043	1.791759469
7	0.599852896	1.945910149
8	0.849202123	2.079441542
9	0.91585802	2.197224577
10	1.191903617	2.302585093
11	1.210005324	2.397895273
12	1.419814234	2.48490665
13	1.438264252	2.564949357
14	1.513674665	2.63905733
15	1.689711412	2.708050201
16	1.73750146	2.772588722
17	1.76236962	2.833213344
18	1.827601577	2.890371758
19	1.946607333	2.995732274
20	1.97230216	3.044522438
21	2.027183131	3.091042453
22	2.033916048	3.135494216
23	2.102975637	3.17805383
24	2.779942594	3.218875825

Table 18: The numerical values of liner equations, between X and Y, for the determination of A and B, in relation to Weibull parameters K and C in Rafsanjan synoptic station.

Citation: Tezerjani MD, Omidvar K, Mazidi A (2015) The Analysis of Wind Power Potential in Kerman Synoptic Stations, Iran -An Estimation Using the Weibull Density Function. J Climatol Weather Forecasting 3: 125. doi:10.4172/2332-2594.1000125

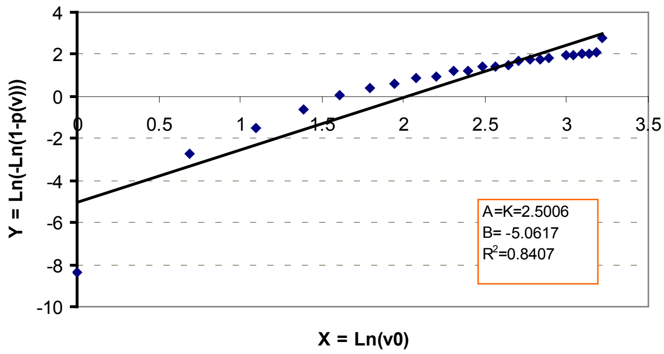

Figure 1: Least square line for Rafsanjan synoptic station, through which the parameters K and C are estimated.

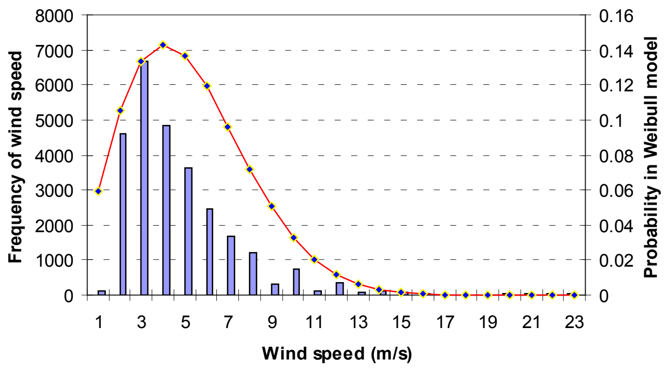

Figure 2: Wind speed frequency with fitted Weibull distribution for Anar synoptic station at 10 m height.

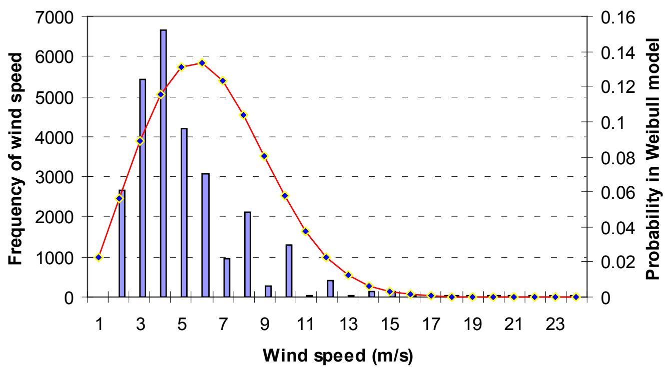

Figure 3: Wind speed frequency with fitted Weibull distribution for Baft synoptic station at 10 m height.

$$\sigma = C\sqrt{\left[\Gamma\left(\frac{K+2}{K}\right) - \Gamma^2\left(\frac{K+1}{K}\right)\right]} \qquad (11)$$

where Γ denotes the Gamma function.

The probability of wind speeds between v_1 and v_2 is given by [8]:

$$P(v_1 \langle v \langle v_2) = \exp\left[-\left(\frac{v_1}{C}\right)^k\right] - \exp\left[-\left(\frac{v_2}{C}\right)^K\right] \qquad (12)$$

Wind turbines are designed with a cut-in speed, or the wind speed at which it begins to produce power, and a cut-out speed, or the wind speed at which the turbine will be shut down to prevent the drive train from being damaged. For most wind turbines, the range of cut-in wind speed is 3_4.5 m/s, and the cut-out speed can be as highly as 25 m/s [8].

Wind characteristics at the height of 10 m above ground level are shown in Table 19.

Wind power density

The evaluation of wind power density per unit area is of fundamental importance in assessing wind power projects. Wind power density,

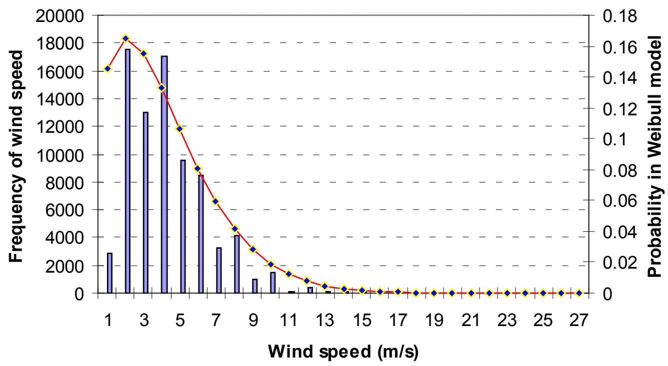

Figure 4: Wind speed frequency with fitted Weibull distribution for Bam synoptic station at 10 m height.

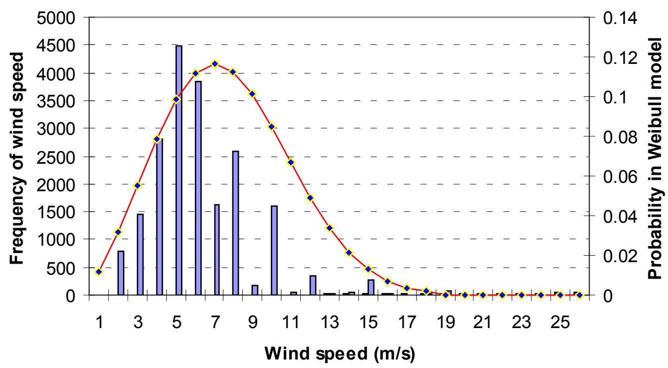

Figure 5: Wind speed frequency with fitted Weibull distribution for Kahnooj synoptic station at 10 m height.

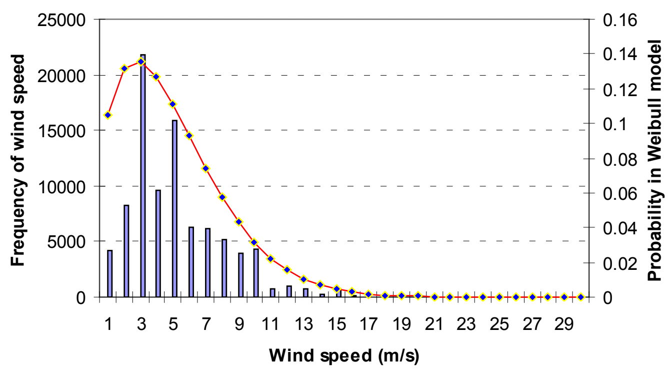

Figure 6: Wind speed frequency with fitted Weibull distribution for Kerman synoptic station at 10 m height.

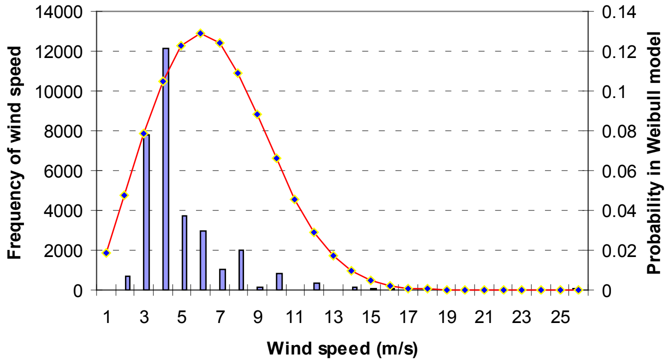

Figure 7: Wind speed frequency with fitted Weibull distribution for Shahrbabak synoptic station at 10 m height.

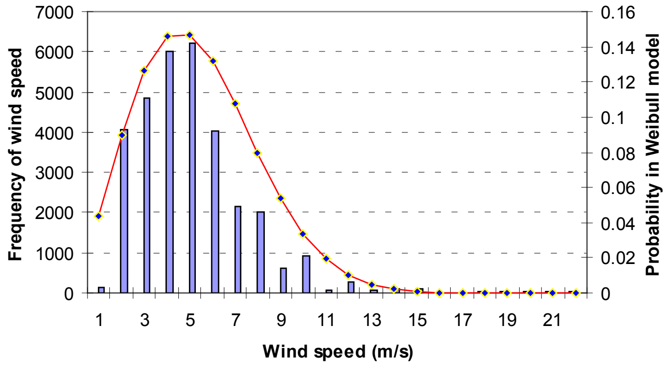

Figure 8: Wind speed frequency with fitted Weibull distribution for Sirjan synoptic station at 10 m height.

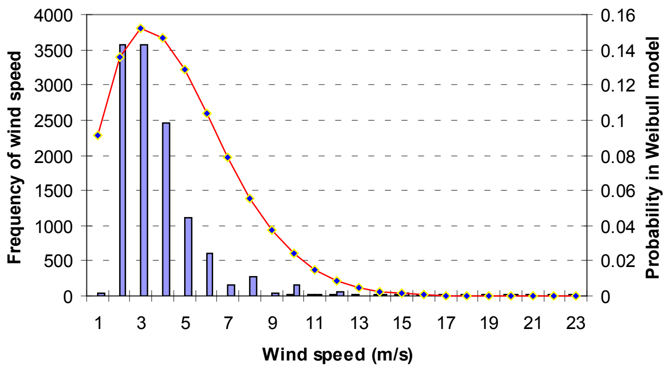

Figure 9: Wind speed frequency with fitted Weibull distribution for Miandeh-Jiroft synoptic station at 10 m height.

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 [9]. Therefore, wind power density is generally considered a better indicator of the wind resource than wind speed. Wind power density of a site based on a Weibull probability density function can be expressed as follows [10]:

$$\frac{P}{A}=\frac{1}{2}\rho C^3\Gamma\left(\frac{K+3}{K}\right) \tag{13}$$

where ρ is the mean air density (usually taken as equal to 1.225 kg/m^3 which depends on altitude, air pressure, and temperature) [11], and Γ denotes the Gamma function. Once wind power density of a site is given, the wind energy density for a desired duration (a month or a year) can be expressed as [12]:

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

where T is the time period (or duration), for example, T is 720 hr for monthly duration.

The problem of transforming Weibull parameters at the hub heights of the wind turbines can be easily solved with the compatible features of Weibull distribution. Weibull function facilitates the presentation of the wind speed distribution thereby making it possible for the researcher to transform the wind speed distribution at 10 m height to the distribution at any other height. This is done by applying the so called one seventh power law [13]:

$$\frac{C_2}{C_1}=\left(\frac{Z_2}{Z_1}\right)^{1/7} \tag{15}$$

where C_2 and C_1 are the Weibull scale parameters at heights Z_2 and Z_1, respectively. Even if the Weibull shape parameter, k, varies with height, the variation is small, and for the present analysis, the shape factor is assumed to be independent of the height.

Wind characteristics at the height of 50 m above ground level at studied stations are shown in Table 20.

Computing Wind Existence Hours at an Area

In the previous studies, in order to obtain total wind hour existence, wind hours in each speed class throughout a year were computed and then the cumulative quantities were achieved [14].

In the present research, a new equation is obtained which provides a simpler and easier method to estimate wind hour existence at an area. The equation is as follows (Mahdi Dehghan):

$$WE_{(h/y)}=\left(\frac{\sum f_i}{N}\right)\cdot T \tag{16}$$

where WE stands for Wind Existence, (h/y) is the unit of measuring the parameter, hour by year, f_i is the frequency of wind speed classes or the quantities presented in Table 1, column 4. N is the length of the statistical period under study in a year, and T is the time interval between the wind data records in hours.

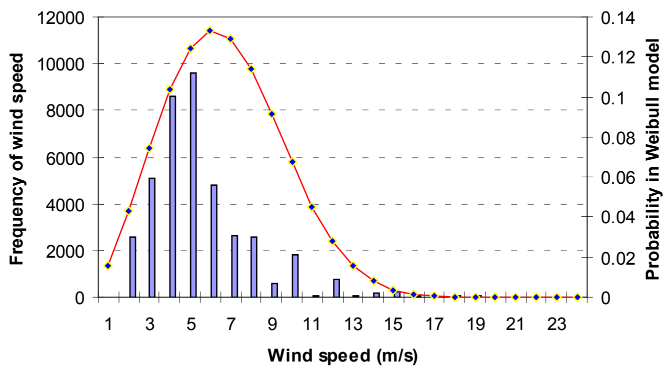

Figure 10: Wind speed frequency with fitted Weibull distribution for Rafsanjan synoptic station at 10 m height.

Station	Scale parameter C(m/s)	Shape parameter k	Mean wind power density P/A (w/m²)	Most probable wind speed V_{MP} (m/s)	Wind speed carrying maximum energy V_{MaxE} (m/s)	Mean wind speed V (m/s)
Kerman	5.4963	1.5271	196.09	2.7388	9.5090	6
Kahnooj	8.6525	2.4894	439.55	7.0393	10.9652	15.69
Bam	4.494	1.4619	116.49	2.0434	8.1047	4.81
Baft	7.1625	2.3472	259.48	5.6538	9.3132	11.74
Anar	5.8906	1.9472	171.24	4.0685	8.4676	7.62
Shahrbabak	7.553	2.3926	299.70	6.024	9.7364	12.78
Sirjan	6.0625	2.1545	168.43	4.5383	8.2227	8.79
Miandeh-jiroft	5.2126	1.7545	135.08	3.2223	8.0421	6.17
Rafsanjan	7.5694	2.5006	292.68	6.1712	9.5747	13.84

Table 19: Wind characteristics at the height of 10 m above ground level at studied stations.

Station	Scale parameter C(m/s)	Shape parameter k	Mean wind power density P/A (w/m²)	Most probable wind speed V_{MP} (m/s)	Wind speed carrying maximum energy V_{MaxE} (m/s)	Probability of wind speeds between 3 and 25 m/s	Mean wind speed V (m/s)
Kerman	6.92	1.5271	391.35	3.4467	11.97	0.76	7.55
Kahnooj	10.89	2.4894	876.33	8.8589	13.8	0.96	19.75
Bam	5.66	1.4619	232.72	2.5717	10.2	0.67	6.06
Baft	9.01	2.3472	516.51	7.1153	11.72	0.93	14.77
Anar	7.41	1.9472	340.86	5.1202	10.66	0.84	9.59
Shahrbabak	9.51	2.3926	598.24	7.5811	12.25	0.94	16.09
Sirjan	7.63	2.1545	335.77	5.7114	10.35	0.87	11.06
Miandeh-jiroft	6.56	1.7545	269.23	4.0553	10.12	0.78	7.67
Rafsanjan	9.53	2.5006	584.1	7.7665	12.05	0.95	17.42

Table 20: Wind characteristics at the height of 50 m above ground level at studied stations.

The total amount of wind hour existence at the synoptic stations under study was in Kerman 4392.69, Kahnooj 2632.81, Bam 4243.87, Baft 3181.85, Anar 3128.31, Shahrbabak 3852.84, Sirjan 3515.22, Miandeh-Jiroft 1589.74 and Rafsanjan 5950.8 hour by a year.

Conclusion

Wind power density is an essential factor in locating places suitable for the installation of wind turbines. At studied synoptic stations, wind power density in Kahnooj, Shahrbabak, Rafsenjan and Baft at heigh of 10 meters from ground level was 439.55, 299.7, 292.68 and 259.48 W/m³ respectively. Meanwhile In the classification of areas suitable for wind turbine installation based on available wind power at 10 meters from ground level, wind power density raging from 200 to 250 W/m³ is considered.

As mentioned above, most efficient wind turbines have been designed for a wind speed of 3 meters per second. Meanwhile lowest most probable monthly wind speeds for studied stations at an altitude of 50 meters (the height of the installation of most wind turbines) at all studied stations except Bam, more than 3 meters per second, can be safely observed in Kahnooj, Rafsanjan,Shahre Babak and Baft stations , respectively 8.86, 7.77 and 7.11 m.

According to equation (12), the probability of a wind speed between 3 and 25 m/s in Kahnooj, Rafsenjan, Shahrbabak, and Baft synoptic stations was respectively 96,95,94 and 93 percent of total wind hour existence that in these places has been respectively 2632.81, 5950.8, 3852.84, and 3181.85 hour by year at the height of 50 m. Therefore, the economical operations for wind turbines in mentioned stations are estimated to be about 2527, 5653, 3621 and 2959 hour by year respectively.

The mean wind speeds in all of studied stations is estimated to be more than 6 m/s. Each of these speeds can be the working speed level for wind turbines.

The difference between the most probable wind speed and the wind speed carrying maximum energy in Rafsanjan, Baft, Sirjan, Shahrbabak, Kahnooj, Anar and Miandeh-Jiroft, annually, are less than 5 which show the trivial difference between the maximum probability of wind speed and the wind speed which provides the highest amount of energy in these places.

Finally, the wind power density at 50 meters above ground level, and other mentioned features, Kahnooj, Shahre Babak and Rafsanjan synoptic stations are obtained the potential for the installation of wind turbines and extraction of wind power.

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