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Estimation of Wind Power Potential and Turbine Rating Selection

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A B S T R A C T

This work is an analysis of wind characteristics of wind site Motha, near Chikhaldara, district Amaravati in the state of Maharashtra during. One windmast of 25 m height located on the site recorded the wind speed data and wind direction for this region. The main emphasis of this research work is to study the average wind power density (WPD), mean annual wind speed, most frequently observed wind speed, rated wind speed, wind energy density, rated wind power density and the capacity factor of the site. Energy analysis method was used out to find out these parameters. It was found that mean average wind speed of the site came to 5.85 m/s, with the average wind power density nearly 191 W/ m^2. Wind energy density was found 1693.23 kwh/ m^2. Rated power generation capacity of the site was found to be 686.58 W/m^2 at which rated wind speed was 10.39 m/s. The most prominent factor in the wind potential analysis i.e., capacity factor of the wind site evaluated to be 28.15 per cent. The Weibull factor of the frequency distribution shape factor (k) and scale factor (c) came to be 1.17 and 6.27 respectively.

Introduction

Interest in wind power lagged, however, when cheap and plentiful petroleum products became available. The day of cheap and plentiful petroleum were drawing to an end and people began to realize that world's oil supplies would not last forever and that remained supplies should be conserved for petroleum industries. Inspite of higher costs than those for coal or nuclear power, wind power may become a major source of energy because of the basic environmental problems of coal and nuclear power. Wind power has attracted great attention worldwide due to its techno-commercial viability and environmental friendly nature. Therefore, it is popularly known as "Green Power". States with high wind power potential are Tamil Nadu Gujarat, Andhra Pradesh, Karnataka, Kerala, Madhya Pradesh and Maharashtra. Total capacity of 401.2 MW wind power is installed in Maharashtra, which is next to Tamil Nadu (MNES, 2004). During last three years capacity addition in Maharashtra has been largest in the country. The most interesting feature of the wind sites in Maharashtra is their location in South-West-diagonally opposite to thermal power stations. Availability of large number of substations created for wind power projects shall ensure better rural electrification besides immense social benefit effects.

The Centre for Wind Energy Technology (C-WET), Chennai has carried out studies of the wind potential assessment of India. These studies have been developed through measurement programs in various locations throughout country. Currently, only about 45000 MW wind potential of the country has been assessed. Based on the studied that have been done, some projection have indicates that it is possible to supply close to 10 per cent of the forthcoming demand of the country of electricity generation capacity with wind energy (MEDA, 2001).

Anemometry studies have been carried at 71 stations in Maharashtra and 28 sites have wind potential above the minimum required level of 150 W/m^2 at 30 m height. To instil confidence in the technology, demonstration project of 6.53 MW were installed in Maharashtra with support from Ministry of Non-conventional Energy Sources. Technical viability of demonstration projects and investor friendly policy announced by Government of Maharashtra has facilitated private investment of more than Rs. 2000 Crores in the wind sector. Nearly 400 MW of private wind power projects have been installed in the state. Asia's largest wind farm of 250 MW has been installed at Vankunvade Plateau of Satara district (MEDA, 2002). India now ranks fifth in the world with 1628.2 MW of installed wind power capacity. Maharashtra has second largest installed capacity (MNES, 2004) within the country.

In this paper an analysis of the wind characteristics have been carried out for proper selection of the wind turbine.

Materials and Methods

Theory of analysis

The data were observed on the 25 m wind mast. The data was made available through Maharashtra Energy Development Agency (MEDA), Pune. Generally wind turbine have the hub height of 60 m, therefore this data has been shifted to the turbine hub height for the exact quantification of wind potential. The methods were used for the energy analysis have been given in the following term.

Mean wind speed

Mean wind speed (MWS) is the most commonly used indicator of wind production potential. A mean annual wind speed (MAWS) of about 4 m/s at 10 m height is considered economically viable for a utility-scale wind farm (Rosen, 1998). This mean wind speed can be calculated as below;

$$MWS = \frac{1}{N} \times \sum_{i=1}^{N} vi \quad (1)$$

where, N is the sample size and *v*i is the wind velocity recorded for the i^{th} observation.

Wind probability distribution

Where the sample size is large, it is useful to group the wind speed data into intervals to create a histogram of the wind speed distribution (NWCE, 1997). The probability of the observed wind speed being within an interval can be written as

$$f(v) = \frac{\Delta t}{t_0} \quad (2)$$

where, $f(v)$ is the probability distribution function, Δt is wind speed duration in hours available in the wind speed v (m/s), t_0 is the total hours during the year.

The mean wind speed can then be calculated as

$$MWS = \Sigma f(v)v \quad (3)$$

Wind direction

Wind direction is usually described in terms of degrees, where North is 360^0, South is 180^0, East is 90^0 and West is 270^0. In assessing wind resource potential, wind direction frequency distributions are typically calculated for 8, 12 or 16 direction intervals. The probability that the wind will blow from within a given direction intervals (Rosen, 1998).

$$P(Dj) = \frac{nj}{N} \quad (4)$$

Where, Dj is the medium value of the j^{th} interval. Results are often displayed on a wind rose, which is a radar graph where direction (degrees) is plotted on the circular X-axis and frequency (%) is plotted on the Y-axis.

Wind shear law (Power law index)

For vertical estimation of wind speed power law model were usually preferable. Winds are slowed by friction at the earth's surface, so that wind speeds tend to be greater at higher elevations. The standard height for wind speed observations is 10 m (Pillai, 2003). Since wind turbine hub heights are typically between 20 and 50 m, extrapolation of wind speeds to the planned hub height is usually required to estimate wind potential. For regions with relatively level terrain and little vegetation, the method most commonly used to obtain this extrapolation is the 1/7 power-law model (Pillai, 2003).

The equation of the 1/7 power-law model is

$$\frac{v(z)}{v(z_0)} = (z/z_0)^{1/7} \quad (5)$$

Where, z is the height at which the wind speed is to be estimated, v(z) is the wind speed to be estimated and z_0 and $v(z_0)$ are the reference height and wind speed, respectively.

Wind power

$$WP = 0.5\, \rho A\, v^3 \quad (6)$$

Wind power density

The equation for wind power density (WPD) is simply the wind power divided by the area.

$$WPD = 0.5\, \rho\, v^3 \quad (7)$$

Wind energy

The quantity of energy that is captured by wind turbine depends on the power in wind speed and the wind speed distribution at the site. The average energy generated (ΔE) during Δt duration is given as:

$$\Delta E = P.\, \Delta t \quad (8)$$

The expression for annual energy generated (E) will be,

$$E = t_o.\int_{v_{cut-in}}^{v_{cut-out}} P.\, f(v)\, dv \quad (9)$$

where, v_{cut-in} is the cut-in wind speed of the wind site and $v_{cut-out}$ is the cut-out wind speed of the wind site.

Capacity factor/ plant load factor

The capacity factor (CF) is a parameter often used to describe the energy production performance of the wind site. The capacity factor is a measure of the annual energy production from the site. It is defined as the ratio of the (actual or estimated) energy produced to the energy production that would result from rated power capacity of the site for energy hour of the year.

$$CF = \frac{\text{Energy density } (kwh/m^2)}{(\text{Rated Power Capacity}) \times \text{duration}} \times 100 \quad (10)$$

The Weibull distribution

The statistical analysis was carried out by using the Weibull probability distribution function for the data collected at the site. Based on the probability for the wind speed occurring in the region the Weibull probability function allows to model the available wind energy at the site (Pillai, 2003).

The equation of the cumulative Weibull distribution ($P(v)$, $F(v)$) is as follows

$$P(v) = \Delta t_c / t_0$$
$$F(v) = 1 - P(v) = \exp[-(v/c)^k] \quad (11)$$

The non-cumulative Weibull probability distribution function ($f(v)$) is

$$= k/c\, (v/c)^{k-1} . \exp[-(v/c)^k$$

where, v is the velocity of wind, k is the shape parameter and c is the scale parameter. To estimate the k and c values, the following procedure is used. Taking the logarithm of equation of cumulative Weibull distribution, yields,

$$-(v/c)^k = \ln[1-P(v)] \quad (12)$$

Again taking natural logarithm gives,

$$k \ln(v) - k \ln(c) = \ln\{-\ln(1-P(v))\} \quad (13)$$

Now let $Xi = \ln(v)$, $Yi = \ln\{-\ln(1-P(v))\}$

In this way equation (13) will have a linear form $y = Ax+B$, then, $A = k$ and $B=-k \ln(c)$, which calculates c as $\exp(-B/A)$. Therefore, the Weibull parameters (k and c) are related to the parameters A and B of the line. A is the slope of the line and B is the intersection point on ordinate i.e the y-axis.

The values of Xi and Yi are generated from Δv, Δt and $f(v) = \Delta t/to$ values. The analytical calculation of A and B is possible with the help of the least squares methods (LSQM) (Jafri *et al.*, 1989). The formulae to find out the values of A and B with the help of the LSQM are:

$$A = \frac{\sum_{i-1}^{N} (Xi-X)(Yi-Y)}{\sum_{i-1}^{N} (Xi-X)^2} \text{ and } B = Y - AX \quad (14)$$

where X and Y are means of Xi and Yi, which have to be determined considering the frequency $f(v)$ information.

$$X = \Sigma f(v).Xi$$

The simple correlation coefficient and the R^2 value of the observed wind speed data can be calculated from the following equation.

$$R^2 = \frac{[\Sigma (Xi-X)(Yi-Y)]^2}{\Sigma (Xi-X)^2 . \Sigma (Yi-Y)^2} \quad (15)$$

Results and Discussion

Wind energy assessment means the determination of wind characteristics i.e., wind energy potential of the site for the wide range with the time. This magnitude of the wind characteristics mainly incorporates the wind potential of the site. The assessment of the wind potential was analyzed by the using the tabular wind energy analysis and the also using the Weibull parameter. The recorded anemometer data were used for the energy prediction which was on the sensor height 25 m with the wind speed distribution of the site. This wind speed distribution data were collected from the site over the period of one year.

Vertical wind profile of the site

The wind data used was shifted for the 60 m height using the wind shear power law model The vertical estimation of the wind speed was carried out and has been tabulated in the table 1. The data obtained for the extrapolated height, which indicated that average wind speed change for a given wind interval. The original wind interval at 25 m was 0.55 m/s, after extrapolating the data on 60 m the wind interval has been change which was 0.6295 m/s. Average wind speed for the particular wind class is also changed. Wind class and average wind speed of the potential site increases on the extrapolated height (Table 1).

Wind potential characteristics

Wind energy analysis was carried out as consideration of theory for determination of potential of the site. The Wind power density, wind energy density and the Mean wind speed, rated wind speed and mostly frequently observed wind speed of the site were calculated (Table 1). The air density was considered for power calculation as 1.225 kg/m^3. Capacity factor was also determined by using the energy generated from frequency distribution and the energy generated at the rated wind power of the site for the year (Deb, 2002).

Table 2 reveals the information of the wind energy analysis of the site on the 60 m height. Mean and most frequently observed wind speed are calculated to be 5.85 m/s and 4.09 m/s respectively. Energy density was maximum on wind speed 10.39 m/s, is the rated wind speed and this energy density was used determination of power generation capacity of wind site. The power density at maximum energy density comes to 686.58 W/m^2.

Wind speed distribution

Resulted presented here represent wind speed values at 60m height; however this referred the hub height of the turbine. Energy analysis method describes the nature of wind speed in the wind potential. Table 2 presented the results of the analysis of Motha wind speed data. Mean average wind speed of site was computed using the frequency distribution of wind available in one year duration which found to be 5.84 m/s. The rated wind speed most frequently observed wind speed also were determined. The rated wind speed 10.39 m/s is for duration of 237 hours. Most frequently observed wind speed was found to be 4.09 m/s at which the wind duration was 730 hours.

Wind power

Wind power density obtained in the analysis at wind speed of 10.39 m/s referred as rated wind power density is 686.58 W/m^2. Energy generation was found maximum at this wind power density. Therefore, this power density called rated wind power density of the site. It was observed that wind power density increased with the increase in wind speed. This wind power density and time duration of this class wind speed used for calculating useful wind energy generation of the site. The annual average wind power density comes to 193 W/m^2.

Table.1 Conversion of wind speed from 25 m height to 60 m by using the wind power law model

SN.	Δ*v* km/h		*v* km/h	Δt hr	Δ*v* km/h)		*v* km/h	Δ*v* m/s		*v* m/s	Δt/tc =*f*(*v*)
	25 m sensor height				60 m extrapolated height						
1	0.00	2.00	1.00	93.00	0.00	2.27	1.13	0.00	0.63	0.31	0.01
2	2.00	4.00	3.00	194.00	2.27	4.53	3.40	0.63	1.26	0.94	0.02
3	4.00	6.00	5.00	336.00	4.53	6.80	5.67	1.26	1.89	1.57	0.04
4	6.00	8.00	7.00	559.00	6.80	9.07	7.93	1.89	2.52	2.20	0.06
5	8.00	10.00	9.00	685.00	9.07	11.33	10.20	2.52	3.15	2.83	0.08
6	10.00	12.00	11.00	730.00	11.33	13.60	12.47	3.15	3.78	3.46	0.08
7	12.00	14.00	13.00	737.00	13.60	15.87	14.73	3.78	4.41	4.09	0.08
8	14.00	16.00	15.00	711.00	15.87	18.13	17.00	4.41	5.04	4.72	0.08
9	16.00	18.00	17.00	674.00	18.13	20.40	19.26	5.04	5.67	5.35	0.08
10	18.00	20.00	19.00	679.00	20.40	22.66	21.53	5.67	6.30	5.98	0.08
11	20.00	22.00	21.00	533.00	22.66	24.93	23.80	6.30	6.93	6.61	0.06
12	22.00	24.00	23.00	538.00	24.93	27.20	26.06	6.93	7.55	7.24	0.06
13	24.00	26.00	25.00	384.00	27.20	29.46	28.33	7.55	8.18	7.87	0.04
14	26.00	28.00	27.00	358.00	29.46	31.73	30.60	8.18	8.81	8.50	0.04
15	28.00	30.00	29.00	315.00	31.73	34.00	32.86	8.81	9.44	9.13	0.04
16	30.00	32.00	31.00	257.00	34.00	36.26	35.13	9.44	10.07	9.76	0.03
17	32.00	34.00	33.00	**237.00**	36.26	38.53	37.40	10.07	10.70	10.39	0.03
18	34.00	36.00	35.00	193.00	38.53	40.80	39.66	10.70	11.33	11.02	0.02
19	36.00	38.00	37.00	150.00	40.80	43.06	41.93	11.33	11.96	11.65	0.02
20	38.00	40.00	39.00	109.00	43.06	45.33	44.20	11.96	12.59	12.28	0.01
21	40.00	42.00	41.00	83.00	45.33	47.60	46.46	12.59	13.22	12.91	0.01
22	42.00	44.00	43.00	47.00	47.60	49.86	48.73	13.22	13.85	13.54	0.01
23	44.00	46.00	45.00	40.00	49.86	52.13	51.00	13.85	14.48	14.17	0.00
24	46.00	48.00	47.00	30.00	52.13	54.39	53.26	14.48	15.11	14.79	0.00
25	48.00	50.00	49.00	22.00	54.39	56.66	55.53	15.11	15.74	15.42	0.00
26	50.00	52.00	51.00	13.00	56.66	58.93	57.79	15.74	16.37	16.05	0.00
27	52.00	54.00	53.00	11.00	58.93	61.19	60.06	16.37	17.00	16.68	0.00
28	54.00	56.00	55.00	10.00	61.19	63.46	62.33	17.00	17.63	17.31	0.00
29	56.00	58.00	57.00	5.00	63.46	65.73	64.59	17.63	18.26	17.94	0.00
30	58.00	60.00	59.00	8.00	65.73	67.99	66.86	18.26	18.89	18.57	0.00
31	60.00	62.00	61.00	5.00	67.99	70.26	69.13	18.89	19.52	19.20	0.00
32	62.00	64.00	63.00	5.00	70.26	72.53	71.39	19.52	20.15	19.83	0.00
33	64.00	66.00	65.00	3.00	72.53	74.79	73.66	20.15	20.78	20.46	0.00
34	66.00	68.00	67.00	3.00	74.79	77.06	75.93	20.78	21.41	21.09	0.00
35	68.00	70.00	69.00	2.00	77.06	79.33	78.19	21.41	22.03	21.72	0.00
36	70.00	72.00	71.00	1.00	79.33	81.59	80.46	22.03	22.66	22.35	0.00
				tc=8760							

The equation of the 1/7 power law model (Wind Shear law) is:

$v\,(z)/v\,(z_o) = (z/z_o)^{1/7}$

$v\,(z)/(1)) = (60/25)^{1/7}$

$v\,(z) = (60/25)^{1/7} \times (1) =$ **0.31 m/s**

Table.2 Wind energy calculations for 60m at wind mast height

Sr. No.	Δ*v* m/s	*v* avg m/s	Δt hr	*f*(*v*) = $\Delta t/t_0$	*v* f(*v*)	WPD W/m^2	ΔE =WPDxΔt kWh/m^2	WPD useful W/m^2	ΔE useful kWh/m^2
1	0.00-0.63	0.31	93	0.0106	0.00	0.02	0.00	0.00	0.00
2	0.63-1.26	0.94	194	0.0221	0.02	0.52	0.10	0.00	0.00
3	1.26-1.89	1.57	336	0.0384	0.06	2.39	0.80	0.00	0.00
4	1.89-2.52	2.20	559	0.0638	0.14	6.55	3.66	0.00	0.00
5	2.52-3.15	2.83	685	0.0782	0.22	13.93	9.54	13.93	9.54
6	3.15-3.78	3.46	723	0.0825	0.29	25.43	18.56	25.43	18.56
7	3.78-4.41	4.09	730	0.0833	0.34	41.97	30.93	41.97	30.93
8	4.41-5.04	4.72	725	0.0828	0.38	64.48	45.84	64.48	45.84
9	5.04-5.67	5.35	674	0.0769	0.41	93.86	63.26	93.86	63.26
10	5.67-6.30	5.98	673	0.0768	0.46	131.04	88.98	131.04	88.98
11	6.30-6.93	6.61	539	0.0615	0.40	176.93	94.30	176.93	94.30
12	6.93-7.55	7.24	538	0.0614	0.44	232.45	125.06	232.45	125.06
13	7.55-8.18	7.87	384	0.0438	0.34	298.52	114.63	298.52	114.63
14	8.18-8.81	8.50	358	0.0409	0.35	376.04	134.62	376.04	134.62
15	8.81-9.44	9.13	315	0.0360	0.33	465.95	146.77	465.95	146.77
16	9.44-10.07	9.76	257	0.0293	0.29	569.16	146.27	569.16	146.27
17	10.07-10.70	10.39	237	0.0271	0.28	686.58	162.72	686.58	162.72
18	10.70-11.33	11.02	193	0.0220	0.24	819.13	158.09	686.58	132.51
19	11.33-11.96	11.65	150	0.0171	0.20	967.72	145.16	686.58	102.99
20	11.96-12.59	12.28	109	0.0124	0.15	1133.29	123.53	686.58	74.84
21	12.59-13.22	12.91	83	0.0095	0.12	1316.73	109.29	686.58	56.99
22	13.22-13.85	13.54	47	0.0054	0.07	1518.98	71.39	686.58	32.27
23	13.85-14.48	14.17	40	0.0046	0.06	1740.94	69.64	686.58	27.46
24	14.48-15.11	14.79	30	0.0034	0.05	1983.53	59.51	686.58	20.60
25	15.11-15.74	15.42	22	0.0025	0.04	2247.68	49.45	686.58	15.10
26	15.74-16.37	16.05	13	0.0015	0.02	2534.29	32.95	686.58	8.93
27	16.37-17.00	16.68	11	0.0013	0.02	2844.29	31.29	686.58	7.55
28	17.00-17.63	17.31	10	0.0011	0.02	3178.59	31.79	686.58	6.87
29	17.63-18.26	17.94	5	0.0006	0.01	3538.11	17.69	686.58	3.43
30	18.26-18.89	18.57	8	0.0009	0.02	3923.76	31.39	686.58	5.49
31	18.89-19.52	19.20	5	0.0006	0.01	4336.46	21.68	686.58	3.43
32	19.52-20.15	19.83	5	0.0006	0.01	4777.14	23.89	686.58	3.43
33	20.15-20.78	20.46	3	0.0003	0.01	5246.70	15.74	686.58	2.06
34	20.78-21.41	21.09	3	0.0003	0.01	5746.07	17.24	686.58	2.06
35	21.41-22.03	21.72	2	0.0002	0.00	6276.15	12.55	686.58	1.37
36	22.03-22.66	22.35	1	0.0001	0.00	6837.88	6.84	686.58	0.69
Total			t_o= 8760		Σ *v f* (*v*) = 5.85				ΣΔE = 1693.23

Table.3 Weibull Distribution Factor calculation for 60m extrapolated height

Δ*v* m/s	***v avg* (m/s)**	**Δt (hr)**	***f* (*v*) =Δt/ t_o**	**P (*v*) = tc/ t_o**	**1-P (*v*) =F (*v*)**	**Xi ln (*v*)**	**Yi=ln(-ln(F (*v*))**	**Δt $_{cal}$**	***f*(*v*) $_{cal}$**
0.00-0.63	0.31	93	0.0106	0.0106	0.989	-1.1559	-4.5400	177.28	0.0202
0.63-1.26	0.94	194	0.0221	0.0328	0.967	-0.0573	-3.4019	375.45	0.0429
1.26-1.89	1.57	336	0.0384	0.0711	0.928	0.4536	-2.6067	511.21	0.0584
1.89-2.52	2.20	559	0.0638	0.1349	0.865	0.7900	-1.9314	603.72	0.0689
2.52-3.15	2.83	685	0.0782	0.2131	0.786	1.0414	-1.4284	660.02	0.0753
3.15-3.78	3.46	723	0.0825	0.2957	0.703	1.2420	-1.0484	685.38	0.0782
3.78-4.41	4.09	730	0.0833	0.3790	0.619	1.4091	-0.7415	684.85	0.0782
4.41-5.04	4.72	725	0.0828	0.4618	0.538	1.5522	-0.4789	663.48	0.0757
5.04-5.67	5.35	674	0.0769	0.5387	0.461	1.6773	-0.2566	626.24	0.0715
5.67-6.30	5.98	673	0.0768	0.6155	0.383	1.7886	-0.0451	577.78	0.0660
6.30-6.93	6.61	539	0.0615	0.6771	0.323	1.8887	0.1225	522.33	0.0596
6.93-7.55	7.24	538	0.0614	0.7385	0.261	1.9796	0.2936	463.50	0.0529
7.55-8.18	7.87	384	0.0438	0.7823	0.217	2.0630	0.4218	404.30	0.0462
8.18-8.81	8.50	358	0.0409	0.8232	0.176	2.1400	0.5496	347.04	0.0396
8.81-9.44	9.13	315	0.0360	0.8591	0.140	2.2114	0.6729	293.41	0.0335
9.44-10.07	9.76	257	0.0293	0.8885	0.111	2.2781	0.7855	244.52	0.0279
10.07-10.70	10.39	237	0.0271	0.9155	0.084	2.3406	0.9047	200.98	0.0229
10.70-11.33	11.02	193	0.0220	0.9376	0.062	2.3995	1.0201	163.03	0.0186
11.33-11.96	11.65	150	0.0171	0.9547	0.045	2.4551	1.1295	130.56	0.0149
11.96-12.59	12.28	109	0.0124	0.9671	0.032	2.5077	1.2282	103.28	0.0118
12.59-13.22	12.91	83	0.0095	0.9766	0.023	2.5577	1.3231	80.72	0.0092
13.22-13.85	13.54	47	0.0054	0.9820	0.018	2.6053	1.3901	62.36	0.0071
13.85-14.48	14.17	40	0.0046	0.9865	0.013	2.6508	1.4603	47.63	0.0054
14.48-15.11	14.79	30	0.0034	0.9900	0.010	2.6943	1.5262	35.98	0.0041
15.11-15.74	15.42	22	0.0025	0.9925	0.007	2.7360	1.5868	26.88	0.0031
15.74-16.37	16.05	13	0.0015	0.9939	0.006	2.7760	1.6307	19.87	0.0023
16.37-17.00	16.68	11	0.0013	0.9952	0.004	2.8144	1.6753	14.54	0.0017
17.00-17.63	17.31	10	0.0011	0.9963	0.003	2.8515	1.7249	10.53	0.0012
17.63-18.26	17.94	5	0.0006	0.9969	0.003	2.8872	1.7548	7.55	0.0009
18.26-18.89	18.57	8	0.0009	0.9978	0.002	2.9217	1.8138	5.36	0.0006
18.89-19.52	19.20	5	0.0006	0.9984	0.001	2.9550	1.8624	3.76	0.0004
19.52-20.15	19.83	5	0.0006	0.9990	0.001	2.9873	1.9287	2.62	0.0003
20.15-20.78	20.46	3	0.0003	0.9993	0.001	3.0185	1.9860	1.81	0.0002
20.78-21.41	21.09	3	0.0003	0.9997	0.001	3.0488	2.0769	1.23	0.0001
21.41-22.03	21.72	2	0.0002	0.9999	0.000	3.0782	2.2058	0.83	0.0001
22.03-22.66	22.35	1	0.0001	1.0000	0.000	3.1068	2.4435	0.56	0.0001
Total		**ΣΔt =t_o = 8760**	**Σ *f* (*v*)= 1.000**			ΣX=**76.69**	ΣY=**18.723**	**ΣΔt $_{cal}$ =t_o 8760.901**	**Σ *f*(*v*) $_{cal}$ =1.001**

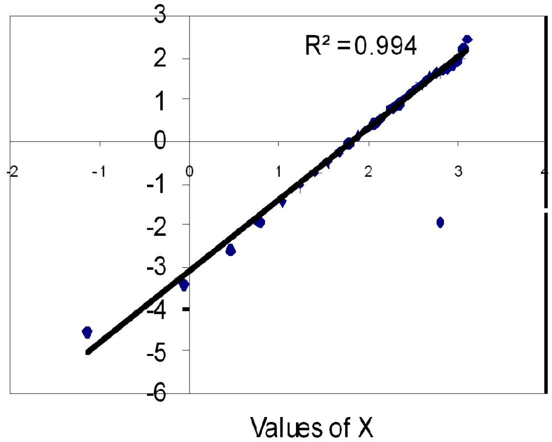

Fig.1 The linearship between X and Y for determination of A and B.

Wind energy density

The analysed value obtained for wind energy density is given in table 2. It was observed that wind energy density maximum wind speed 10.39 m/s and found to be 162.72 kWh/m^2. The total annual energy density was found to be 1693.23 kWh/m^2. It was also observed for the useful power density and energy density as stated earlier for available wind power density and energy density

Rated wind power and energy generation

Wind power generation capacity was found from the wind power density for the Suzlon wind turbine. By considering the wind density at rated wind speed and efficiency of the various stages of the wind turbine (mechanical, electrical 0.85. and 0.95 with power coefficient 0.5) and swept area of 2826 m^2, the rated power generation capacity found comes to 783.30 kW/m^2. This power generation capacity near to the turbine power rating.

The selection of Suzlon 1MW is appropriate. With combinations of three typical efficiencies as stated earlier and wind duration, with regards to distribution, the annual wind energy estimated by annual energy density and the swept area of turbine. Using the annual energy density 1693.23 kWh/m^2 and efficiency as stated earlier, and the swept area of 2826 m^2, the annual energy which can be generated comes to 1.93 MWh (with total available energy generation comes to be 4.78 MWh of Electrical unit).

Capacity factor of the wind site

Capacity factor of the wind of the site was calculated by the expected energy generation of the site to the energy generated at rated power of wind of the site. The calculated capacity factor comes to 28.15 per cent. This calculated expected capacity factor show the very good energy output of the site (WMO, 1996).

Weibull data and analysis

The wind speed behaviour of a region is a function of attitude, season and hours of measurements. The wind energy potential of this region is analysed based on one year of recorded wind data. Using the Weibull model, time series data are analyzed and distributional parameters are estimated for probability distributions on an annual basis given in table 3. In addition, the annual average wind speed, rated wind speed, most frequently observed wind speed, wind power density and wind energy density were analyzed.

Weibull analysis was carried out to find out the shape factor (k) and scale factor(c). These parameters were calculated using the least square method, of curve fitting. Table 3 gives the details of Xi and Yi values and generated using the data of wind speed and the distribution of the wind speed. The data obtained for the Xi and Yi are plotted in figure 1 for finding the value of constant in straight line. Simple correlation coefficient and R^2 value were found 0.9953 and 0.9976 respectively. The constant of straight line y= Ax +B were found to be 1.712506, -3.14598 and using these constant the values of shape factor and scale factor were calculated.

Present investigation is exploring the hypothesis that shape factor related only to the form of local topography and synoptic (general) wind pattern. The shape factor (k) and scale factor(c) were found 1.71 and 6.27 respectively. This values compare favorable to the results obtained by (Twidell and Weir, 1986).

Probability distribution and Weibull analysis

The most important parameter for specific energy calculation is the wind probability distribution. More reliable results were obtained with calculations based on Weibull distributions. The exact quantification of the wind speed distribution done using the Weibull model. Nature of the cumulative frequency distribution function [F(*v*)] and non-cumulative frequency distribution function [P(*v*)] and probability [*f*(*v*)] presented in table 3. Basically this distribution function was used to find out the Weibull parameter as stated above. Observed wind speed frequency distribution and fitted wind speed distribution by using the shape factor (k) and scale factor (c) graphically shown in the figure 1. This figure also indicates the one year duration of wind speed in particular class.

Estimation of wind speed by using Weibull distribution parameters

Most promising thing in the wind potential is that mean wind speed. Weibull factor i.e., shape factor (k) and scale factor (c) were used to find out the mean average wind speed. The mean average wind speed of the site was calculated and fount to be 5.72 m/s.

In this wind speed analysis, rated wind speed also computed by using the Weibull factor. This parameter results the rated wind speed at 10.51 m/s at which wind duration was 230 hours. Rated wind speed referred as the maximum energy generation wind speed of the site. This rated wind speed was found in the wind speed class 10.07-10.70 (m/s).

Most frequently observed wind speed was calculated by using the Weibull parameter i.e. shape and scale factor. This wind speed was found to be 3.48 m/s in wind class 3.15-3.78 (m/s) at which maximum wind duration was 737 hours.

Wind power density and wind energy density

These wind power density and wind energy density were calculated from the shape factor (k) and scale factor (c) with the mean wind speed taken in to consideration. Wind power density found to be 279.86 W/m^2. The values are more because the power up to cut-in are also considered. This wind density is good for the wind energy harvesting. A typical mean wind power density varies from 2 to 80 W/m^2 for utility scale energy production at turbine height. Energy density is the function, which is mostly responsible for the energy generation capacity of the site. Wind energy density of the site found to be 2449.29 kWh/m^2 for the one year using this for the wind turbine area of 2826 m^2. The total energy generation for one year (8760 hr), calculated using the wind energy density was 6.92 MWh of electrical energy unit. This value compares favorably to the results obtained by Sudhir Kumar (2002).

In conclusion, the estimation of wind energy potential was carried out to find out the feasibility of site for power generation. The rated wind speed, power density and the energy generation has been calculated. It was found that mean average wind speed of the site came to 5.85 m/s, with the average wind power density nearly 191 W/ m^2. Wind energy density was found 1693.23 kWh/m^2. Rated power generation capacity of the site was found to be 686.58 W/m^2 at which rated wind speed was 10.39 m/s. The most prominent factor in the wind potential analysis i.e., capacity factor of the wind site evaluated to be 28.15 per cent. The Weibull factor of the frequency distribution shape factor (k) and scale factor (c) came to be 1.17 and 6.27 respectively.

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