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ESTIMATION OF WIND ENERGY POTENTIAL AND CHARACTERISTICS

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ABSTRACT

The project was carried out in order to study the wind energy resources for wind production in Akola district. The mean hourly wind velocity and air density of the selected site has been observed to be 1.42 m/s and 1.14 kg/m^3 respectively. The standard deviation of the annual wind speed data was observed to be 0.61 at which turbulence intensity was 0.42. It was observed that the turbulence in the wind speed was high at which there is no possibility to harvest wind energy for the commercial power generation. The estimated rated wind power density and energy generation at 10 m height was observed to be 44 W/m^2 and 12.60 kWh /m^2 respectively at 4.25 m/s wind speed. The total wind energy generation for turbine swept area of 4.9 m^2 was observed to be 285.6 kWh at 10 m height. The increased in rated wind speed at 40 m and 70 m height was observed to be 23.52% and 58.8 % over 10 m height. It is found that the assessed site of wind energy is feasible for the household type wind energy generation.

KEY WORDS
Wind energy
Wind power density (WPD)
Turbulence intensity

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INTRODUCTION

The use of energy in the human development is increased and which playing the key infrastructural role. The use of traditional energy sources viz coal based power is now depleting due to the scare in the natural resources (Anon, 2014). The major concern to harvest the clean energy is trending towards the wind resources. The conversion of the kinetic energy to electrical energy by aero-generator is possible with high efficiency (MNRE, 2014). Worldwide development activities now a day have been concentrated on to replicate and use alternative energy sources from mega watts power structures to individual. Non-conventional energy sources have been utilized in various forms according to the nature of application. Wind energy has got importance in sustainable modern economy. Most of the wind energy in world has been harvested in mega scale project with huge amount of investment. The total installed power generation from the wind resources is around to be 360 GW by the end of year 2014 (Oluseyi *et al.*, 2013).

In Indian context wind is rapidly growing power sector component (Pandey 2002). Indian boundaries have a potential to harvest about 45 000 MW wind power. As on end of 2014, the installed wind power capacity is 21136 MW and still more path has to go ahead to harvest wind energy potential in the country (Singh & Singh, 2014). The technology to harvest the energy from wind is so much matured in the country (Khambalkar *et al.*, 2007). The turbine capacity of from kilo-watt to mega-watts is available for the various hub heights (Paul 2009). The wind potential available in the country is found in hilly region of various terrains, pleatus, on high elevation and the desert zone especially. A very amount of potential is available in residential regions and the urban side (Singh & Singh, 2014). The attempt has been made to evaluate potential of wind energy in urban area for feasibility study of power generation for domestic purpose.

MATERIALS AND METHODS

The data of wind speed regarding the availability according to the wind monitoring station has been used for the analysis. In the present work wind energy potential viz, various wind speed determination, energy , wind power density, the generation hours determination, power law and wind resistance, wind distribution has been examine for the one year duration data.

Wind speed data

The data regarding the wind speed with the temperature, humidity has been collected from the University monitoring station of meteorology. In the present data average wind speed per day has been available. The wind speed data from January 2008 to December 2008 is to be collected for the entire project work. The wind monitory station installed at 10 m height as per world meteorological organization requirements (Nasir, *et al.*, 1994).

The wind distribution

Once the data of the station has been received, it has been reshuffle in to the frequency distribution over the study periods. The wind speed data has rearranged according to the availability in the one-year duration. The distributed wind speed in entire duration was used to find out various characteristics of site (Lopez *et al.*, 2008).

Vertical wind shear exponent

The wind shear is the change in horizontal wind speed with a change in height. The wind shear exponent (α) should be determine for each site, because it's magnitude is influenced by site-specific characteristics. The power law index is given as, (Jamil, *et al.*, 1995).

$$\alpha = \frac{\log_{10}[v_2 / v_1]}{\log_{10}[z_2 / z_1]} \quad \text{Eq. (1)}$$

Where, α = Wind shear exponent

V_2 = the wind speed at height Z_2 and V_1 = the wind speed at height Z_1

Turbulence intensity

Wind turbulence is the rapid disturbance or irregularities in the wind speed, direction, and vertical component. It is an important site characteristic, because high turbulence levels may decrease power output and cause extreme loading on wind turbine component. The most common indicator of turbulence for sitting purposes is the standard deviation (σ) of wind speed (Fegbenle *et al.*, 2011 and Rehman *et al.*, 2008).Nomaliizing this value with the mean wind speed gives turbulence intensity this value allows for an overall assessment of sites turbulence. It is relative indicator of turbulence with low levels indicated by less than or equal to 0.10, moderate levels to 0.25 and high levels greater than 0.25.

$$T1 = \frac{(\sigma)}{V} \quad \text{Eq. (2)}$$

Where,âσ = Standard deviation of the wind speed

V = the mean wind speed.

Wind power density

The wind power density is the function of wind speed available at site. The power density is express as below. It is a truer indication of a sites wind energy potential than wind speed alone. Its value combines the effect of site wind speed distribution and its dependence on air density and wind speed. (Lawis, 1986: Nasir *et al.*, 1994).

$WPD = ½\rho v^3$ Eq. (3)

Where,

WPD is the wind power density, W/m^2

ρ is the air density in kg/m^3 and *v* is the wind speed , m/s

Wind energy

Wind power is the function of wind speed and the swept area of the turbine. Generally, wind power is expressed as below; (Lawis, 1986).

$WP = ½\rho v^3 A$ Eq. (4)

Where ,

WP is the wind power in Watts

A is the turbine swept area in m^2

Wind energy the function of the wind power density and the duration at which the wind speed is available. The wind energy generally is determined by the following equation;

$WE = WPD \times \Delta t$ Eq. (5)

Where

Δt is the wind speed distribution in the wind ranges in hours

The meteorological characteristics like shape and scale factors have been determined by using the weibull distribution of the wind speed. The least square statistical analysis method was used to predict the topographical factor.

Energy estimation

The basic wind data of hourly mean wind velocity is recast into number of hours in the years or which wind speed equal or exceed each particular value. The energy estimation has been computed by considering the wind turbine of model BERGEY XL1 having rotor diameter 2.5 m. (Gips, 2009; Pandey, 2002; Khambalkar *et al.*, 2007).

RESULTS AND DISCUSSION

The study involves the collection of wind speed data and evaluating the wind energy resources. After processing the data, the size of the wind aero generator has been selected based on available data at the site for household. The wind energy analysis was used to find out the optimum sizes of the wind turbine. The wind speed distribution and the characteristics for the wind turbine under consideration can be combined to predict the energy output from the machines at a particularly location for various hub height. The monthly or weekly pattern of energy production through out the year and the calm distribution are used to size the wind turbine.

Wind speed distribution

The wind speed distribution data collected at the site 10 m height of wind monitoring station at meteorological department of university Dr. PDKV, Akola of recorded for the period of January to December 2008. The monthly variation of wind speed at 10 m height is depicted in Table 1.

The wind speed data of the site have been analyzed in HOMER for find out the various meteorological aspects of wind energy. The annual variation of high and low wind speed is presented in Fig. 1. It has been observed that from May to August months is the most favourable wind speed than other months.

Table 1: Mean hourly average wind speed at 10 m height monitoring station

Months	Wind Speed (m/s)
January	0.54
February	0.80
March	0.74
April	1.30
May	3.47
June	2.88
July	2.56
August	2.26
September	0.99
October	0.51
November	0.47
December	0.47

Table 2: Analysis of wind data at 10 m height

ΔV	V(avg)(m/s)	Δt (hr)	F(v)	F(v)v	WPD (kW/m²)	ΔEsite (kWh/m²)	ΔE Turbine energy (kWh)
0-0.5	0.25	2688	0.31	0.08	0.0000	0.02	0.117
0.5-1	0.75	2016	0.23	0.17	0.0002	0.48	2.375
1-1.5	1.25	888	0.10	0.13	0.0011	0.99	4.844
1.5-2	1.75	720	0.08	0.14	0.0031	2.20	10.777
2-2.5	2.25	648	0.07	0.17	0.0065	4.21	20.615
2.5-3	2.75	576	0.07	0.18	0.0119	6.83	33.457
3-3.5	3.25	432	0.05	0.16	0.0196	8.45	41.419
3.5-4	3.75	384	0.04	0.16	0.0301	11.54	56.558
4-4.5	4.25	288	0.03	0.14	0.0438	12.60	61.749
4.5-5	4.75	72	0.01	0.04	0.0611	4.40	21.552
5-5.5	5.25	48	0.01	0.03	0.0825	3.96	19.399
5.5-6	5.75	24	0.00	0.02	0.1084	2.60	12.743
		8784	1.00	1.41		58.29	285.609

Table 3: Wind energy at 40m height

ΔV	V(avg) (m/s)	Δt (hr)	F(v)	F(v)v	WPD (kW/m²)	ΔE site (kWh/m²)	ΔE Turbine energy (kWh)
0-0.5	0.25	1584	0.18	0.05	0.00001	0.0141	0.0691
0.5-1	0.75	2064	0.23	0.18	0.00024	0.4963	2.432
1-1.5	1.25	1176	0.13	0.17	0.00111	1.3092	6.4152
1.5-2	1.75	600	0.07	0.12	0.00305	1.8329	8.9812
2-2.5	2.25	432	0.05	0.11	0.00649	2.8048	13.7437
2.5-3	2.75	528	0.06	0.17	0.01185	6.259	30.6692
3-3.5	3.25	576	0.07	0.21	0.01957	11.2706	55.226
3.5-4	3.75	360	0.04	0.15	0.03006	10.8211	53.0234
4-4.5	4.25	240	0.03	0.12	0.04376	10.5015	51.4575
4.5-5	4.75	384	0.04	0.21	0.06109	23.4578	114.9431
5-5.5	5.25	336	0.04	0.2	0.08248	27.7135	135.7964
5.5-6	5.75	168	0.02	0.11	0.10836	18.2049	89.2039
6-6.5	6.25	168	0.02	0.12	0.13916	23.3789	114.5566
6.5-7	6.75	48	0.01	0.04	0.1753	8.4145	41.231
7-7.5	7.25	48	0.01	0.04	0.21721	10.4263	51.0889
7.5-8	7.75	48	0.01	0.04	0.26533	12.7357	62.4047
8.8.5	8.25	24	0	0.02	0.32006	7.6815	37.6395
		8784	1	2.05		177.32	868.88

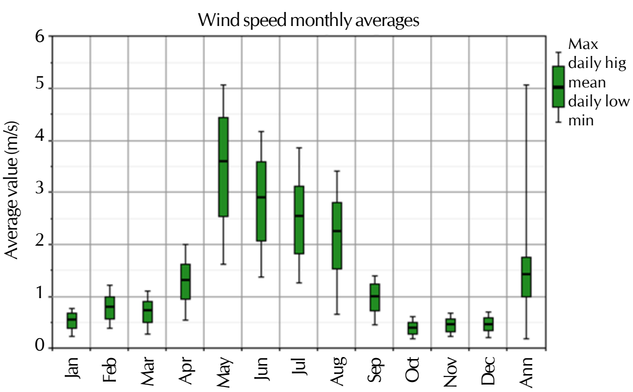

Figure 1: Annual variation of wind speed by HOMER

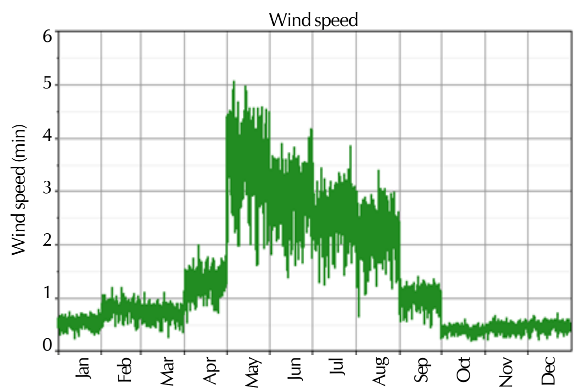

Figure 2: Hourly distribution of wind speed

It has been observed that the wind speed of more than 2 m/s has found in the month of May to August which may be useful for harnessing the wind energy. The maximum wind speed has been observed in the month of May of near about 4.40 m/s. The annual mean wind speed was observed to be 1.42 m/s. Oluseyi *et al.*, 2013, has worked out the wind speed for North-Western Nigeria.

Similarly the hourly distribution of wind speed has been presented in Figure 2. The air density at 307.415 m of mean sea level was observed to be 1.14 kg/ m³. The standard

Table 4: Wind energy at 70 m height

Δv	V(avg) (m/s)	Δt (hr)	F(v)	F(v)v	WPD (kW/m$^{2)}$	ΔE site (kWh/m^2)	ΔE Turbine energy (kWh)
0-0.5	0.25	1344	0.153005	0.038251	0	0.012	0.0587
0.5-1	0.75	1944	0.221311	0.165984	0.0002	0.4675	2.2906
1-1.5	1.25	1176	0.13388	0.16735	0.0011	1.3092	6.4152
1.5-2	1.75	648	0.07377	0.129098	0.0031	1.9795	9.6997
2-2.5	2.25	480	0.054645	0.122951	0.0065	3.1165	15.2707
2.5-3	2.75	432	0.04918	0.135246	0.0119	5.121	25.093
3-3.5	3.25	408	0.046448	0.150956	0.0196	7.9833	39.1184
3.5-4	3.75	504	0.057377	0.215164	0.0301	15.1495	74.2327
4-4.5	4.25	360	0.040984	0.17418	0.0438	15.7523	77.1863
4.5-5	4.75	264	0.030055	0.14276	0.0611	16.1272	79.0234
5-5.5	5.25	288	0.032787	0.172131	0.0825	23.7545	116.3969
5.5-6	5.75	288	0.032787	0.188525	0.1084	31.2084	152.9209
6-6.5	6.25	216	0.02459	0.153689	0.1392	30.0586	147.2871
6.5-7	6.75	192	0.021858	0.147541	0.1753	33.6579	164.9239
7-7.5	7.25	120	0.013661	0.099044	0.2172	26.0657	127.7221
7.5-8	7.75	24	0.002732	0.021175	0.2653	6.3678	31.2023
8.8.5	8.25	48	0.005464	0.045082	0.3201	15.3631	75.279
8.5-9	8.75	48	0.005464	0.047814	0.3819	18.3291	89.8124
		8784	1	2.31694		251.8232	1233.933

Table 5: Comparison of Energy Analysis at 10 m, 40 m and 70 m height

Hub Height (m)	Rated Wind Seed (m/s)	Mean Wind Speed(m/s)	Rated WPD (kW/m^2)	Rated Wind Energy (kWh/m^2)	Total wind Energy (kWh/m^2)	Rated Turbine Energy (kWh)	Total Turbine Energy (kWh)
10	4.25	1.41	0.043	12.60	58.28	61.74	285.6
40	5.25 (23.5%)	2.05 (45.39%)	0.082 (86.6%)	27.71 (119.9%)	177.32 (204%)	135.8 (119.9%)	868.8 (204%)
70	6.75 (58.8%)	2.31 (63.38%)	0.175 (306.9%)	33.65 (167%)	251.82 (332%)	164..92 (167%)	1233.93 (332%)

deviation of the wind speed data has found to be 0.60. The pattern of wind speed distribution and the occurrence of wind speed have mainly affect due to the turbulence intensity of the wind speed. The turbulence intensity of the site was observed to be 0.42. Higher value represent that the site is uneconomical for harnessing the wind energy and not feasible for commercial power generation. The wind characteristics data was coupled with the household wind aero-generator to evaluate the energy generation.

The average mean hourly wind speed distribution over a height above ground level is presented in the figure 3. It is observed that the average wind speed increases as the height increases which shows the wind speed distribution pattern i.e. wind flow is influenced by the geographical feature of area.

Wind energy generation

Wind energy generation at 10 m height.

The collected data has been analysed in the excel spreadsheet at 10 m height of weather monitoring station, Dr. PDKV, Akola shown in Table 2. The occurrence of wind speed has been found from the observed data by converting daily average wind speed to hourly distribution throughout the year. The mean hourly average wind speed (MHAWS) was observed to be 1.41 m/s at 10 m height. The rated wind speed of the site was observed to be 4.25 m/s at which rated wind power density was found to be 43.76 W/m^2. Fegbenle *et al.,* 2011, has worked out wind powr based on Weibull analysis. The energy generation calculation was carried out for the turbine swept area of 4.9 m^2. The rated wind energy generation at 10 m height was observed to be 12.6 kWh/m^2. The total yearly wind energy generation was found to be 58.29 kWh/m^2. When these energy densities values were coupled with the turbine of 4.9 m^2 swept area wind energy generation during the one year was observed to be 285.61 kWh.

The details regarding the calculation of wind speed at 10m height is tabulated in table 2. This wind data has been coupled for the wind turbine of BERGEY XL1 (assessed at www.wind–works.org). The turbine rotor swept area was 4.9 m^2 of diameter 2.5 m. The actual energy generated with this turbine was found to be 285.6 kWh throughout the year. The observed distribution of the wind speed of 10 m height is presented in Fig 4 and Fig 5 represent the wind power density and wind speed distribution at 10 m height.

Wind energy generation at 40 m height.

The calculated data has been analysed in excel spreadsheet at 40 m height shown in table 3 The mean hourly average wind speed (MHAWS) was observed to be 2.05 m/s. The rated wind speed of the site was observed to be 5.25 m/s at which rated wind power density was found to be 82.48 W/m ^{2}. Bagiorgas *et al.*, 2012 has determined wind power density. The rated wind energy generation at 40 m height was

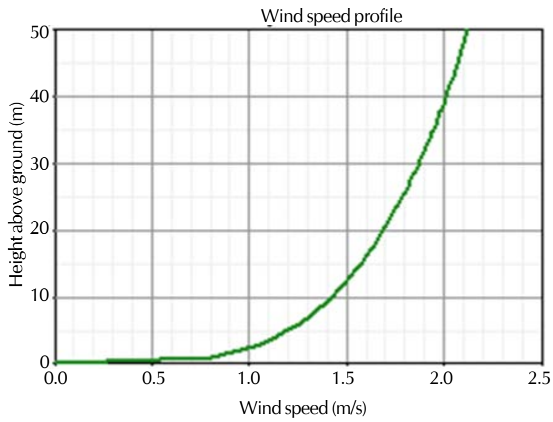

Figure 3: Average wind speed distribution with height

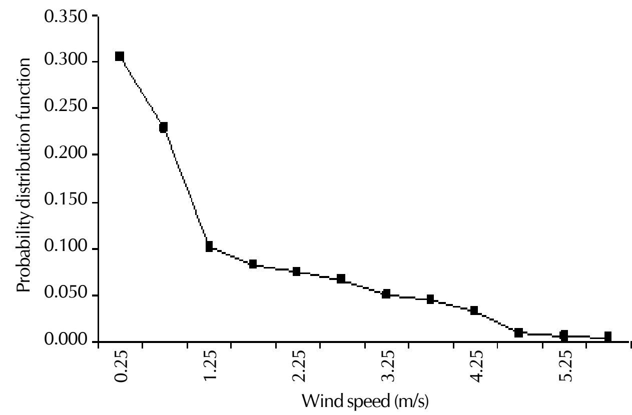

Figure 4:Probability distribution of wind speed at 10 m height.

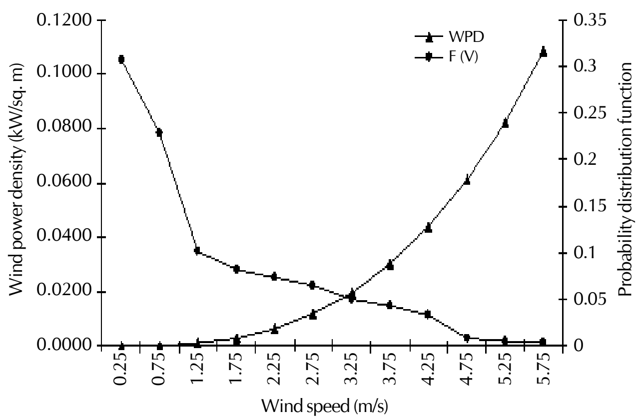

Figure 5: Wind power density and wind speed distribution at 10 m height

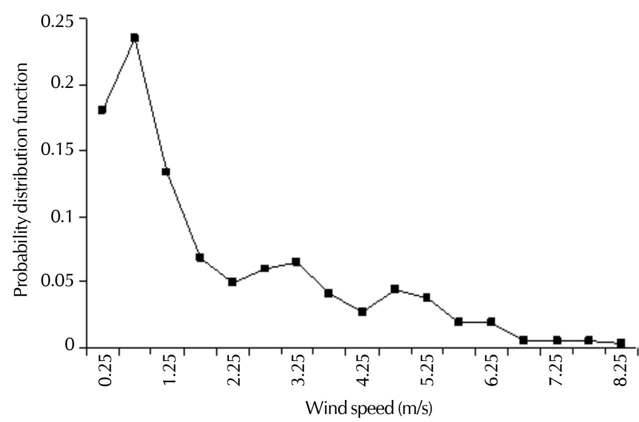

Figure 6: Probability distribution of wind speed at 40 m height

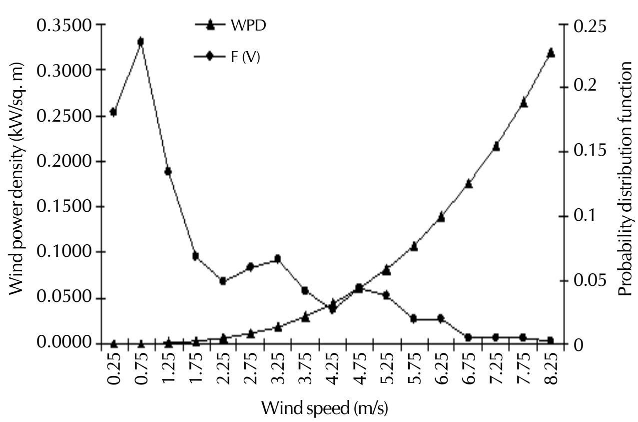

Figure 7: Wind power density and wind speed distribution at 40 m height

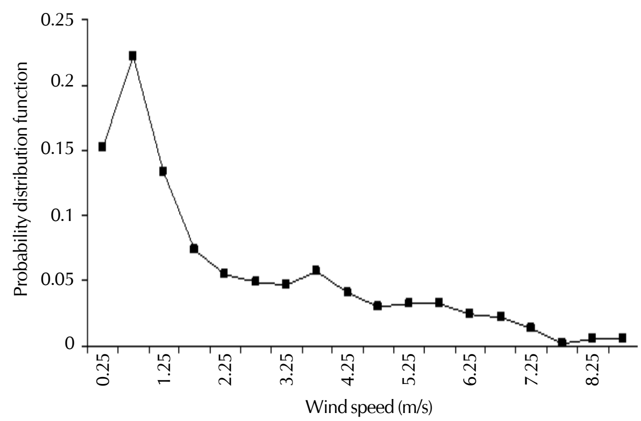

Figure 8: Probability distribution of wind speed at 70 m height

observed to be 27.73 kWh /m^2. The annual wind energy generation was found to be 177.32 kWh/m^2. Fig 6 and Fig 7 represent probability distribution and density of wind speed at 40m height

Wind energy generation at 70 m height.

The calculated data has been analyzed in excel spreadsheet at 70 m height depicted in Table 4. The mean hourly average wind speed (MHAWS) was observed to be 2.31 m/s. The rated wind speed of the site was observed to be 6.75 m/s at which rated wind power density was found to be 175.30 W/m^2. The rated wind energy generation at 70 m height was observed to be 33.67 kWh /m^2. The total yearly wind energy generation was found to be 251.82 kWh/m^2. The probability distribution and wind density at wind speed of 70 m height is shown in Fig. 8 and Fig. 9.

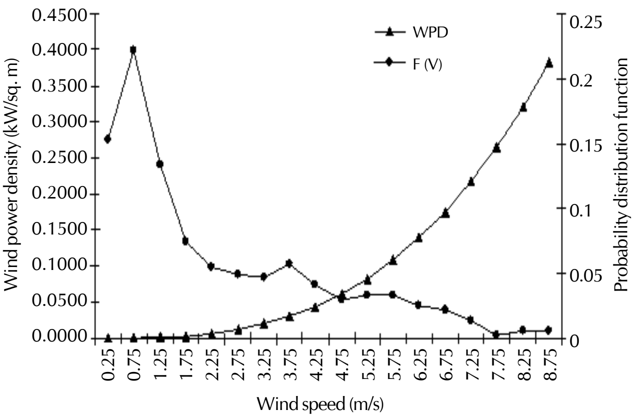

Figure 9: Wind power density and wind speed distribution at 70 m height

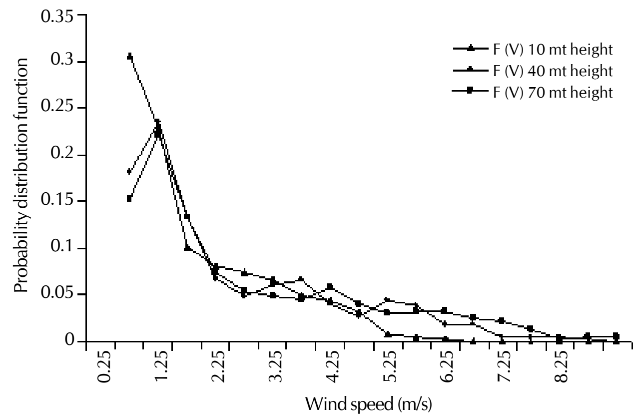

Figure 10: Wind probability distribution at 10 m, 40 m and 70 m height

Comparison of wind energy analysis at 10 m, 40 m and 70 m height

The probability distribution of wind speed at height 10 m, 40 m and 70 m is shown in Fig 10. The rated wind speed increases with increase in height.

The comparison of energy analysis at 10 m, 40 m and 70 m height are shown in Table 5. The rated wind speed at 10 m, 40 m, and 70 m were observed to be 4.25 m/s, 5.25 m/s and 6.75 m/s respectively. The observed mean wind speed at 10 m, 40 m and 70 m was found to be 1.41 m/s, 2.05 m/s and 2.31 m/s respectively.

The wind speed data have been analysed for the wind power density and energy density at 10 m, 40 m and 70 m hub heights. It was found that rated wind power density at 40 m and 70 m height increases 86.6 % and 306.9 % over 10 m height respectively.

Similar trend in the wind energy at rated wind speed was observed. The yearly energy generation at 10 m, 40 m and 70 m have been calculated. It was observed that, at 10 m, 40 m and 70 m height total wind energy is found to be 58.28 kWh/m^2, 177.32 kWh/m^2 and 251.82 kWh/m^2 respectively. The energy is increased at 40 m and 70 m height of 204 % and 332 % over 10 m height respectively. By considering the turbine of 1.2 kW capacity, the energy generation throughout the year for 10 m, 40 m and 70 m was observed to be 285.6 kWh, 868.8 kWh and 1233.93 kWh respectively. The total energy generation increases by considering the 1.2 kW capacity turbine at 40 m and 70 m was 204 % and 332 % over 10 m height respectively.

Weibull analysis of wind speed by HOMER

The wind speed data have been analysed by using the HOMER software and analysed for determination of the shape (k) and scale factor(c) of the site. The wind speed probability distribution curve of the HOMER analysed is seen in fig.11

The k and c value of the site was found to be 1.35 and 1.56 m/s respectively. It has been observed from the figure 11 that the maximum wind distribution has occurred 0 to 1.2 m/s wind speed bin.

The wind speed data of the site have been analysed in HOMER for studying the wind power potential characteristics. The wind

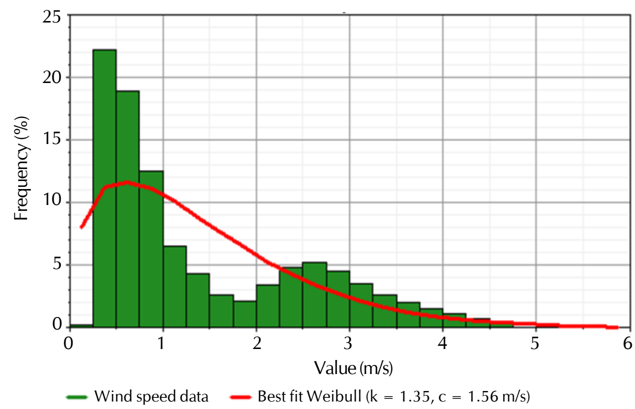

Figure11: Probability distribution curve of wind speed

speeds at different heights have been studied for better understanding of the wind speed characteristics. The wind energy generation at 10 m, 40 m and 70 m heights were calculated in excel work sheet. The various parameters which affect wind power generation like turbulence intensity, wind power density (WPD), air density were calculated. The wind data from meteorological department of university Dr. PDKV, Akola was used for meteorological aspects of wind energy and for wind power potential characteristics by using advance analysis tools such as HOMER software. The mean hourly average wind velocity of the selected site at 10 m, 40 m and 70 m heights has been observed to be 1.42 m/s, 2.05 m/s and 2.3 m/s respectively. The air density was calculated for the site is 1.14 kg/m^3. Ahmed, 2011 reported that wind spped for the site was varies from 8.3 to 9.8 km/s at 10 m and 24.5 m respectively. The standard deviation of annual wind speed data was observed to be 0.61 at which turbulence intensity was 0.42 for 10 m height. It was observed that turbulence in the wind speed was high at which there is no possibility to harness wind energy for the commercial power generation. Oluseyi *et al.*, 2013 reported two Weibull parameters for determining the wind speed and the energy generation. The turbulence intensity at 40 m and 70 m height was found to be 0.29 and 0.26 respectively. The rated wind speed of 4.25 m/s was observed for duration of 288 hours for 10 m height from ground level. At this rated speed the wind power density (WPD) was found to be 43.76 W/m^2 and wind energy at rated speed was observed 12.60 kWh/m^2. The rated energy generation of turbine BERGEY XL1 was found to be 285.6 kWh throughout the year. For 40 m height rated wind speed was found to be 5.25 m/s for duration of 336 hours of a year. The total turbine energy was found to be 868.8 kWh. The rated wind speed of 6.75 m/s for duration of 192 hours was observed at 70 m height The total energy generation of turbine was found to be 1233.9 kWh . The total wind energy generation at 10 m height was found to be 58.28 kWh/m^2. Bagiorgas *et al.*, 2012 reported the variation of wind energy with respect to the height. They also found that around 15-16% higher winds were observed at 10 m compared to that at 3 m. Total turbine energy for the area of 4.9 m^2 turbine was observed to be 285.6 kWh. It was observed that the mean wind speed increases as height changes from 10 m to 70 m. The weibull parameter as shape (k) and scale (c) factor of wind speed data were observed to be 1.35 and 1.56 m/s respectively. The rated wind speed at 40 m and 70 m height increases 23.52% and 58.8% over 10 m height respectively. It was found that rated wind power density at 40 m and 70 m height increases 86.6 % and 306.9 % over 10 m height respectively. Fagbenle et al , 2011 reported that wind power density variation based on the Weibull analysis ranged from 102.54 to 300.15 W/m^2. It was observed that energy availability is increases at 40 m and 70 m height of 204 % and 332 % over 10 m height respectively.

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