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Wind characteristics influencing wind energy

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Abstract

Usually the wind speed for a particular site is given at a standard reference height of 10 m. However, in the context of wind turbines, the hub height is a natural choice for estimating the power potential. The wind speed distribution is a function of roughness parameter. In this paper, wind speeds at various heights are estimated for different configurations which will help in the estimation of power potential. It has been observed that for a particular site, the average velocity has been decreasing continuously over a number of years. The parameter corresponding to this change has been evaluated. Wind turbines located on shore are subjected to winds blown from open sea and also from land. The power potential when the wind blows from the sea and when the wind blows from land has been estimated for this site with a mean wind velocity of 6.1 m/s.

Keywords

Wind energy potential; Roughness length; Mean velocity at 10 m height.

Introduction

Wind energy has become a techno-economically viable renewable energy resource. In recent years, we have seen a steady growth of utilization of wind energy in power production. The understanding of the wind and its characteristics will help to accurately assess the potential of wind energy available at a given site. Wind speeds can vary over a period of time and some years may be windy and others calmer. The surrounding terrain and height above ground will influence wind speed. Usually the wind speed for a particular site is given at a standard reference height of 10 meters. However, in the context of wind turbines, the hub height is a natural choice for estimating the power potential at a given site. The objective of this paper is to determine and look into the effect of upstream condition towards the contribution of power available at a location.

The wind speed distribution can be described by a logarithmic function based on experiments [1,2,3] and is given below,

$$\frac{V(z)}{V(10)} = \frac{\ln\left(\dfrac{z}{z_0}\right)}{\ln\left(\dfrac{10}{z_0}\right)} \tag{1}$$

where V(10) is the wind speed at 10 meters above ground level, z is the height above ground level in meters and z_0 is the roughness length.

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The roughness lengths can be related to the roughness classes by the following equations [3].

$$Roughness\ class = 1.699823015 + \ln(roughness\ length) / \ln(150) \quad (2)$$

when the roughness length is less than or equal to 0.03, and

$$Roughness\ class = 3.912489289 + \ln(roughness\ length) / \ln(3.3333333) \quad (3)$$

when the roughness length is greater than 0.03.

For each different roughness length and roughness class, there exist a corresponding type of terrain [1,2,3], for example roughness length of 0.0002 corresponds to open sea.

The power of a wind turbine can be estimated using the equation [1,2,3],

$$P = 0.5 \times \rho \times V^3 \times A \times C_p \quad (4)$$

where ρ is the density of air, V is the wind speed at a particular height, A is the area and C_p is the coefficient of performance. The maximum C_p for all types of wind turbines is governed by Betz limit [1,2,3]. Betz limit states that the maximum C_p value which can be achieved is about 59% for all types of wind turbines.

Calculation Methodology

Wind speed profile and equivalent available power

A theoretically assumed wind speed of 5.50 m/s at 10 m above ground has been used for various roughness lengths. From the velocity profiles obtained, power potential at various heights have been estimated. Another calculation was made by assuming a constant roughness length (z_0=0.002) and for various wind speeds at 10 m above ground. From the velocity profiles obtained, the power potential at various heights have been estimated.

The roughness lengths and roughness classes

A study made to estimate the wind energy potential of Malaysia using data collected from 1982 to 1991 has concluded that Mersing has the greatest potential [4]. From a recent observation by Mr M. A. Bawadi [5], the mean annual wind speed at a particular site has reduced for the data.

To analyse this particular type of problem, it has been assumed that the annual mean wind speeds in m/s are 6.1, 5.8, 5.8, 5.3, 4.5 and 4.4 respectively for the year I to VI at a reference height of 10 m. The roughness length, z_0 can be determined by using equation (1) and the corresponding roughness classes by using either equation (2) or (3). It is assumed that this variation is not due to climate and the effects are due to changes in the upstream condition. The assumed value of 6.1 m/s for year I was used as a reference point. The relevant upstream condition for this year is open sea (z_0=0.0002). From this, the wind speeds at different heights above ground are calculated. From the assumption, if the wind speed reaches a constant velocity at a certain height, we can determine the value of z_0 by using the wind speed data at two elevations (at 10 meter from measured

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wind speed and the wind speed at a height above ground when surrounding terrain has negligible affect on the wind velocity).

Power comparison between two different upstream conditions

Here the two different conditions are z_0=0.0002 (open sea) and z_0=0.03 (open country without significant buildings). The wind velocity profiles for each condition are calculated using equation (1) and the corresponding power for different heights are also calculated. ρ is taken as 1.225 kg/m^3 for all heights because the changes are small for the ranges of heights that are being considered. The area, A is taken as 1 m^2 and the C_p as 0.59.

Results and discussions

Wind profile and equivalent available power

Figures 1 and 2 show the wind speed profile for different upstream conditions and their equivalent power potential at various heights above ground. From the graphs plotted, the wind speed profile and available power changes more if z_0 has a higher value. For z_0 of 0.0002 (open sea), the wind speed changes from 5.50 m/s at 10 m to 6.67 m/s at 100 m and with the equivalent power at 10 m of 60.12 watts to 107.26 watts at 100 m. When z_0 is equal to 0.4 (forests and suburban areas) the wind speed changes from 5.50 m/s at 10 m to 9.43 m/s at 100 m and the equivalent power of 60.12 watts at 10 m to 303.46 watts at 100 m.

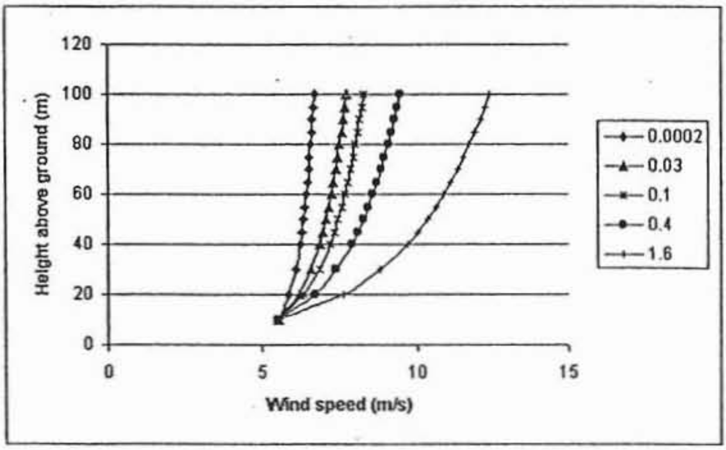

Figure 1. Wind profile for different z_0 with same wind speed at 10 m.

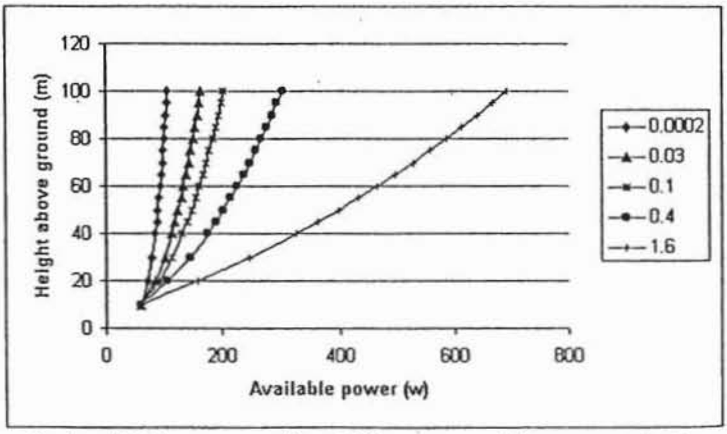

Figure 2. Available power for different z_0 with same wind speed at 10 m.

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Table 1 shows the wind speed profile and available power for the same upstream condition but with different wind speeds measured at 10 meters as in ref. [5]. Average wind speed at reference height has changed from 6.1 m/s in year I to 4.4 m/s in year VI. The maximum power that can be extracted by wind turbine as we move up from ground level will increase most rapidly near the ground (<40 m). As the height above ground increased, the additional increase of power will decrease. An example of power potential increase of 10.91 watts when the comparison is made at 30 m above ground (118.04 watts) and 40 m above ground (128.95 watts), but the increase of power potential of only 4.87 watts when the comparison is made at 90 m above ground (163.29 watts) and 100 m above ground (168.16 watts) for the upstream condition of z_0 =0.002 (open sea with waves) and wind speed of 6.10 m/s measured at 10 m above ground. The higher wind speed at measured height above ground (10m) will give a larger increase of available power as the height increases from 10 m.

Table 1. Wind profile and available power for different wind speeds with same z_0.

Height (m)	Wind speed (m/s)	Power (W)	Wind speed (m/s)	Power (W)	Wind speed (m/s)	Power (W)	Wind speed (m/s)	Power (W)	Wind speed (m/s)	Power (W)
10	6.10	82.03	5.80	70.51	5.30	53.80	4.50	32.93	4.40	30.78
20	6.60	103.73	6.27	89.16	7.57	68.03	4.87	41.64	4.76	38.93
30	6.89	118.04	6.55	101.46	5.98	77.42	5.08	47.39	4.97	44.30
40	7.09	128.95	6.74	110.85	6.16	84.58	5.23	51.77	5.12	48.39
50	7.25	137.86	6.90	118.51	6.30	90.43	5.35	55.35	5.23	51.74
60	7.38	145.45	7.02	125.02	6.41	95.40	5.45	58.39	5.33	54.58
70	7.49	152.07	7.13	130.72	6.51	99.74	5.53	61.05	5.41	57.07
80	7.59	157.97	7.22	135.79	6.59	103.61	5.60	63.42	5.47	59.28
90	7.67	163.29	7.30	140.36	6.67	107.10	5.66	65.56	5.54	61.28
100	7.75	168.16	7.37	144.55	6.73	110.29	5.72	67.51	5.59	63.11

The roughness lengths, z_0 and roughness classes determination

Table 2 shows the roughness lengths and the corresponding roughness classes calculated. The year I has been taken as reference and the known z_0 of 0.0002 has been applied. The upstream condition has shown changes from years I to VI. The upstream condition values in years I, II and III have values ranging from 0.0 to 0.6 that corresponded to terrain with open water areas and few surface features. From years IV to VI, the roughness class values have increased from 1.0 to 3.6. From the roughness class values obtained, for the years I to III show that the upstream condition has relatively no surface features and the wind blow over open water. From years IV to VI, the upstream condition has changes to a terrain that has more surface features (buildings, trees or farmland).

Table 2. Equivalent roughness length and roughness class in bracket.

Year	I	II	III	IV	V	VI
Wind speed, (m/s) Height, (m)	6.1	5.8	~~5.8~~	5.3	4.5	4.4
50	0.0002 (0.0)	0.0044 (0.6)	0.0044 (0.6)	0.0677 (1.7)	0.5566 (3.4)	0.6614 (3.6)
60	0.0002 (0.0)	0.0036 (0.6)	0.0036 (0.6)	0.0527 (4.5)	0.4555 (3.3)	0.5453 (3.4)
70	0.0002 (0.0)	0.0031 (0.5)	0.0031 (0.5)	0.0435 (1.3)	0.3890 (3.1)	0.4684 (3.3)
80	0.0002 (0.0)	0.0028 (0.5)	0.0028 (0.5)	0.0374 (1.2)	0.3421 (3.0)	0.4136 (3.2)
90	0.0002 (0.0)	0.0025 (0.5)	0.0025 (0.5)	0.0331 (1.1)	0.3071 (2.9)	0.3726 (3.1)
100	0.0002 (0.0)	0.0023 (0.5)	0.0023 (0.5)	0.0298 (1.0)	0.2801 (2.9)	0.3407 (3.0)
150	0.0002 (0.0)	0.0018 (0.4)	0.0018 (0.4)	0.0209 (0.9)	0.2029 (2.6)	0.2490 (2.8)

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