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Estimation of Wind Power Potential employing Weibull distribution and finding trade off of appropriate Wind Turbine: Mumbai, India

Sabbir Reza Tarafdar[1 *], Member, IEEE , Santanu Thandar [2], Tushnik Sarkar[3]

[1]Dr. B. C. Roy Engineering College, Jemua Road, Fuljhore, Durgapur-713209, India, Email: sabbir.tarafdar@bcrec.ac.in

[2]The Durgapur Projects Ltd, Dr. B.C. Roy Avenue,.Durgpur-713201, India, Email: thandar.santanu@gmail.com

[3] Dr. B. C. Roy Engineering College, Jemua Road, Fuljhore, Durgapur-713209, India, Email: tushnik.sarkar@bcrec.ac.in

Abstract — Characteristics of the wind speed and wind power potential of Mumbai, India have been studied in the current work. The daily average wind speed signal at Mumbai, India for the span of 01/01/2000 to 31/12/2010 (collected from the website of the National Centres for Environmental Information (NCEI) of the NOAA) has been taken as a sample of wind speed. Weibull distribution has been employed to characterize signals. This analysis suggests that the period between July and September (Monsoon) may be considered the most active for the wind in Mumbai, India. In the second fold of the study, a comparison among several wind turbine performances on the basis of site characteristics has been carried out to choose the appropriate wind turbine for the particular site. This study is significant as a decisive method of important investment in a wind electricity project.

Keywords — ***Wind speed, Wind power, Weibull distribution, Wind Turbine Generator***

1. INTRODUCTION

The Electricity expenditure of the developing nations is rising annually. However, growing adverse impacts of fossil fuel burning on the atmosphere in addition to its restricted stock have enforced many nations to investigate environment-friendly renewable alternatives to maintain the rising energy requirement of the society. The authorities are planning to lessen the greenhouse gas release as well as to reduce electricity consumption by raising the quantity of renewable energy and improving energy efficiency respectively. Shifting to renewable resources and the accomplishment of effective preservation strategies would guarantee sustainability. The solar, wave, wind, bio-energy and geothermal belong to the renewable energy resources. If these ample renewable energy sources are widespread, they can deliver total protection to energy generation. The present scenario of installed electricity capacity from different sources in India is shown in Fig.1 [1].

*Corresponding author: Sabbir Reza Tarafdar, sabbir.tarafdar@bcrec.ac.in

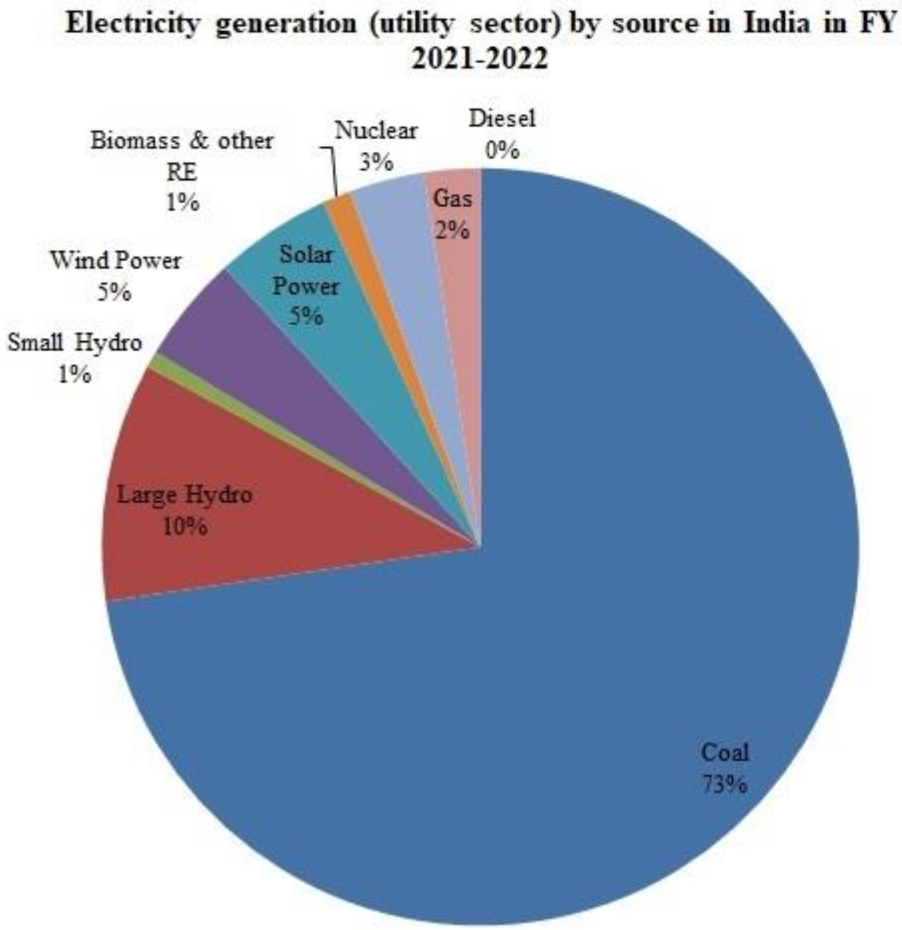

Fig.1: Electricity generation (utility sector) by source in India in FY 2021-2022

Presently, one of the greatest emergent renewable energy resource technologies around the world is wind energy. Wind energy is a fresh energy resource compared to fossil fuel, that makes dirty the bottom layer of the environment. It has the benefits of being appropriate to be used in the vicinity of remote and rural regions. As wind energy is renewable and pollution-free, it is very lucrative. Wind speed analysis presents significant information to researchers concerned with renewable energy studies [2]. Awareness of the statistical behaviours of the wind speed is necessary for foreseeing the energy production from a wind power conversion process. The energy that can be obtained by windmills is very much reliant on the local characteristics of wind speed. In current years lots of efforts have been taken to build a satisfactory model of the frequency distribution of wind speed [3-5]. The production of wind turbine generators (WTG) on a specific location can be evaluated by studying the local wind speed probability distribution and the respective WTG power curve. Fig.2 shows a graph to illustrate how power production from a wind turbine depends on wind speed.

As showed in Fig. 2:

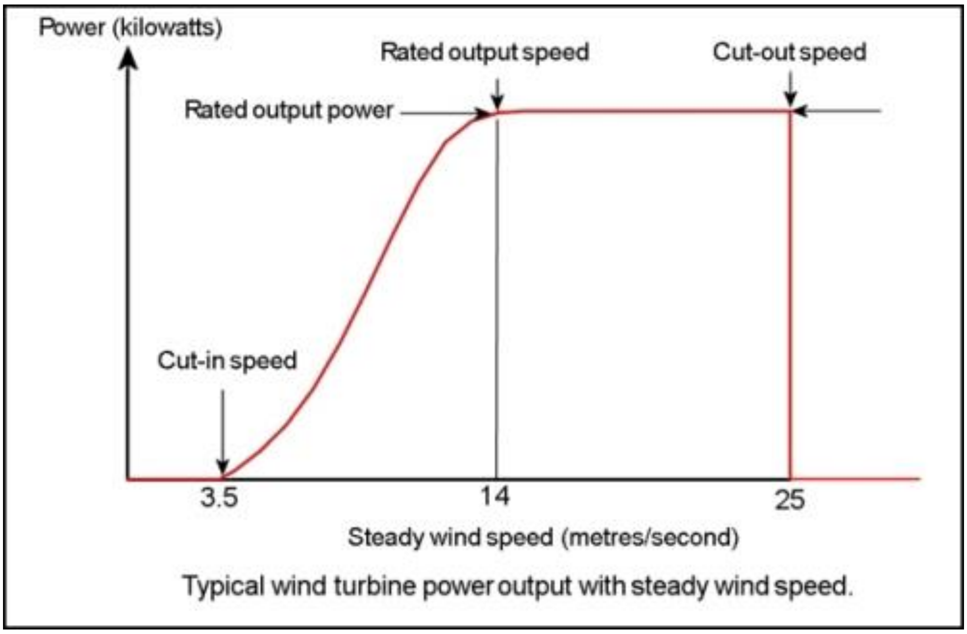

Fig. 2: Output power vs. wind speed curve of a typical wind turbine.
(Courtesy: http://www.wind-power-rogram.com/turbine_characteristics.htm)

(a) *Cut-in speed*: The minimum speed of wind at which the turbine first begins to rotate and produce power is known as cut-in speed and is usually between 3m/s-4m/s.

(b) *Rated output power and rated output wind speed*: With the increase of wind speed beyond the cut-in speed, the amount of electrical power output also rises in cubic proportion to the wind velocity. Usually, somewhere between 12 m/s-17 m/s, the output power attains the limit at which an electrical power generator is competent. This output power limit of the generator is known as the output power ratting and the corresponding wind speed is referred as the rated wind speed. Above this wind speed, the turbine's construction is designed to restrict the power at this highest stage by some control mechanism without any further increase in power output.

(c) *Cut-out speed:* The velocity of the wind beyond which the rotating parts of the wind generator may get damaged due to large wind force is known as cut-out speed or furling speed. Above this speed, the wind turbine is not allowed to run to avoid the risk of damage. The typical value of this speed is around 25m/s.

Once the power curves of the WTG are identified, the crucial information required is the wind flow probability distribution to approximate wind energy production at a particular site for the given curve. So, obtaining an appropriate wind flow probability distribution is essential in wind energy utilization.

The daily average wind speed (meter per second) data series at Santacruz wind station (Station Index: 430030), Mumbai, India has been taken into account in this work,. Mumbai is situated on the west coast (Latitude: 19˚ 04'N, Longitude: 72˚52' E) of India. The span of wind speed data series is considered from the year 2000 to 2010 (i.e. 11 years). The source of Wind Speed data series is NOAA's National Centres for Environmental Information (NCEI).The wind speed profile of Mumbai, India, has been analysed here using most popular Weibull distribution method. Wind power generation is very much reliant on the velocity of the wind observed at a location. Precise estimation of wind power potential for a given region necessitates an overall understanding of wind patterns of the site and turns a difficult quest because of the extremely unexpected character of the wind. In numerous applications of wind power, a suitable function that can closely characterize the wind velocity data, is frequently required. For any site, the velocity of wind changes arbitrarily and its fluctuation in a particular area for a given time period can be expressed by nemours probability distribution functions (PDFs) [6]. For wind speed analysis, the widely adopted PDFs are Weibull and Rayleigh functions [7-8]. Weibull distribution is a versatile, simple, accurate PDF immensely applied for almost all wind regimes available in nature [9]. Weibull distribution function is described by shape parameter and scale parameter. It is regarded as a standard way of assessing local wind load probabilities [3][10-13]. The function of Weibull distribution is applied to explain the frequency distribution wind velocity in this work.

2. THEORY

A. Weibull distribution function & Weibull parameters

In the theory of statistics and probability, the Weibull distribution function is one of the continuous probability distribution. The Weibull distribution offers a close estimation of the probability rules of numerous physical phenomena. The Weibull function is being broadly employed to describe wind speed characteristics [14]. In current times, lots of attention has been paid on this function for the study of wind velocity variation due to its flexibility, and excellent fitting property to wind speed profile [15]. The Weibull function composes of two-parameters. This function has a unique property that it carries no particular characteristic pattern but can adapt the nature of other known distributions depending upon the values of the shape parameter. Mathematically [12][16] Weibull probability density function (PDF) is represented as:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left(-\left(\frac{v}{c}\right)^{k}\right) \tag{1}$$

Here f(v) indicates the probability of getting wind velocity to be v. k and c are the Weibull shape parameter and scale parameter respectively. The parameter k is dimensionless. The parameter, k, is also called the Weibull slope because k represents the line slope in a probability plot. The value of k characterizes the crest of the distribution at a location. On the other hand, c is described in the units of wind velocity (m/s), and it displays the windiness of the place. Increasing the value of c and keeping k unchanged, the PDF is stretched out. Usually, the scale parameter offers information of the mean wind velocity profile, whereas the shape parameter indicates that how far the wind velocity values deviate from the average as well as the attributes of the PDF. It could be noticed that Weibull distribution becomes relatively higher and narrower as the shape parameter raises. The crest of the density function goes towards the higher values of wind velocity with the increase of the shape parameter. The Weibull function appears like a hyper-exponential distribution while the shape parameter is lower than one; the distribution becomes exponential while the shape parameter reaches to one. If the shape parameter is equal to two, then Weibull distribution becomes same as Rayleigh distribution. It becomes a normal distribution if this parameter value is 3.4, for the parameter value close to 4 it is an approximately normal distribution. The effect of variation in shape parameter (k) on the curve of Weibull PDF is demonstrated in Fig. 3(a) by considering three different PDF with three different k values (for k=0.5, 1, 3) while c is kept unchanged. Similarly, the effect of the change in scale parameter c on Weibull PDF is shown in Fig. 3(b) while k-parameter remains unchanged. In Fig.3 (b) three Weibull PDFs are represented for c=30, 60, 90 respectively where k=3 for all three PDFs.

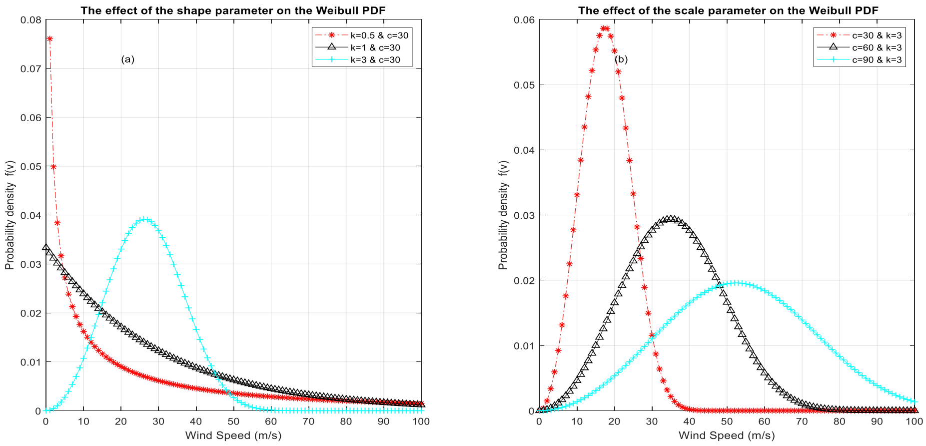

Fig. 3: (a) Weibull PDF at different k, (b) Weibull PDF at different c

So from Fig.3 (a), it is apparent that:

(a) for k<1, f(v) goes to infinity while v tends to zero, i.e. hyper-exponential curve

(b) for k=1 the f(v) vs v curve is monotonically decreasing exponential curve, f(v) approaches to zero as v goes to infinity

(c) for k>1, f(v) is zero at v equals to zero then f(v) increases up to a certain value with the increase of v then f(v) starts to fall towards zero as v increases further, i.e. Weibull PDF approaches to resemble with the normal distribution.

From Fig.3 (b) it is observed that

If c-parameter is increased, while k-parameter is kept constant, the distribution gets extended out to the right and its height reduces while preserving its shape.

While c-parameter is decreased and also k-parameter kept unchanged, the distribution moves towards the left (i.e., towards its beginning or 0), and its peak rises.

The consequent cumulative probability distribution function (CDF) of the Weibull distribution is expressed as:

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

If double logarithm is obtained at both side of Equation (2), this will provide:

$$\ln\left[-\ln\left(1 - F(v)\right)\right] = k\ln(v) - k\ln(c) \quad (3)$$

Equation (3) is an equation of straight line where 1n(v) is independent and 1n [–1n(1 – F(v))] is dependent variable, k is the straight line gradient and – kln(c) is the intercepting point on the 1n[–1n(1 – F(v))] axis. So if 1n[–1n(1 – F(v))] vs 1n(v)graph is obtained then from this graph k and c can be found out.

The parameters of the Weibull distribution function can also be evaluated after the mean value v_m & the variance σ^2 of the wind velocity fluctuation are obtained [9] by the Empirical method which depends on the moment method. The relations among Weibull parameters, the average value of wind velocity & the variance of the velocity are given by Equation (4) and Equation (5) [17]:

$$k = \left(\frac{\sigma}{v_m} \right)^{-1.086} \qquad 1 \le k \le 10 \tag{4}$$

$$c = \frac{v_m}{\Gamma\left(1 + \frac{1}{k}\right)} \tag{5}$$

where Γ(.) denotes gamma function. Gamma function is mathematically represented as

$$\Gamma(x) = \int_0^\infty t^{x-1} e^{-t} dt \tag{6}$$

The average & the variance of the wind flow fluctuation are evaluated as Equation (7) and Equation (8) respectively:

$$v_m = \frac{1}{n}\left[\sum_{i=1}^{n} v_i\right] \tag{7}$$

$$\sigma^2 = \left[\frac{1}{n-1}\sum_{i=1}^{n}(v_i - v_m)^2\right] \tag{8}$$

B. Power contained in Wind

The extent of power present per perpendicular unit area to the wind stream under the wind flow at a speed v can be represented as [18]:

$$P_a = 0.5\rho v^3 \tag{9}$$

Here Pa represents the total available power as per theory. ρ denotes the air density (kg/m3). But wind energy is low-quality energy because the motion of air molecules is highly disordered although there exists statistically a mean velocity of wind speed in one direction. As a result of that energy conversion from wind energy is not very efficient. The Betz limit (16/27 = 0.593) decides the utmost extractable power from the flow of wind. In 1919 the German physicist Albert Betz showed that the maximum conversion capacity of any wind turbine is 16/27 (59.3%) times the kinetic energy of the wind to mechanical energy to turn a rotor. So the capacity factor of power that can be obtained is roughly 59.3 % of the total power present within the wind stream which is mathematically expressed as [19].

$$P_m = 0.5 \times 0.593 \rho v^3 \tag{10}$$

C. Probabilistic estimation of density of wind power by Weibull distribution parameters

The average value of power present within the wind stream is expressed [17] by

$$P_{avg} = \frac{1}{2}\rho A \int_{0}^{\infty} v^3 f(v) dv \qquad (11)$$

'A' denotes the swept surface in m^2 perpendicular to the direction of wind, ρ is the density of air in kg/m^3, the value of ρ is considered to be $1.225 kg/m^3$ in the work. If the expression of f(v) from Equation (1) is substituted in Equation (11) then P_{avg} can be written as follows:

$$P_{avg} = \frac{1}{2}\rho A v_m^3 \left| \frac{\Gamma\left(1+\frac{3}{k}\right)}{\Gamma^3\left(1+\frac{1}{k}\right)} \right| \qquad (12)$$

The expression of P_{avg} can also be written in terms of c i.e. Weibull scale parameter [20-21]. Equation (13) is developed by substituting Equation (5) in Equation (12). It shows P_{avg} as:

$$P_{avg} = \frac{1}{2}\rho A c^3 \Gamma\left(1+\frac{3}{k}\right) \qquad (13)$$

The density of power P_d is computed as $P_d = P_{avg} / A$. From these parameters, k & c, the most frequent wind pace (v_{mf}) and the wind velocity at which the extreme power is available (v_{max} (m/s)), could also be obtained [22] respectively as:

$$v_{mf} = c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \qquad (14)$$

$$v_{max} = c\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \qquad (15)$$

D. Deviation of Wind flow with altitude

There exists variation in wind velocity as height changes from the ground. Typically, the velocity of the wind rises with the altitude from the earth surface. This is primarily because of the diminished effect of the obstructions and roughness near the earth's surface as the height rises [23]. Commonly used relation that is accepted to evaluate the wind speed at some different height from the height at which the speed is measured is given by a power law [24] as:

$$\frac{v}{v_o} = \left(\frac{h}{h_o}\right)^{\alpha} \qquad (16)$$

Here v represents the wind velocity at some required altitude h, v_0 is the wind velocity at a particular observed elevation h_0. The factor α which rely on surface irregularity and environmental stability is referred to as coefficient of surface roughness. Frequently, the typical value of $\alpha = 0.14$ is adopted [22] which is referred as a one-seventh power law [25].

E. Selection of Wind Turbine

Wind profile for a given site plays the key roll to select appropriate wind turbine. The operating range of wind turbine could be estimated by Nigim & Parker [26] when the maximum wind speed (v_{max}) and its probability is known. It is expressed as

$$
\begin{aligned}
&v_{\max} \le v_F \le (2\ to\ 4)\, v_{\max} \\
&(1.5\ to\ 3)\, v_{mp} \le v_R \le v_F \\
&0.3 v_{mp} < v_c \le 0.8\, v_{mp}
\end{aligned}
\tag{17}
$$

Where v_F denotes furling speed, v_R denotes the velocity at which turbine is rated, v_c represents the cut in velocity. v_{max} is the maximum velocity of the wind and v_{mp} is the highest probable velocity of the wind at the particular location.

Although the wind turbine's power generation curve has a typical structure as shown in Fig.2, but it is not unique for all turbines. The power output of a wind turbine can be simulated using the following widely suggested [17] equation

$$
P_w(v) = \begin{cases} P_R \dfrac{v^k - v_c^k}{v_R^k - v_c^k} & (v_c \le v \le v_R) \\ P_R & (v_R \le v \le v_F) \\ 0 & (v \le v_c \ \&\ v \ge v_F) \end{cases}
\tag{18}
$$

3. RESULTS & DISCUSSIONS

A. Evaluated Weibull parameters with respective PDFs & CDFs

Table:1 shows Monthly & yearly Weibull scale and shape parameters for daily averaged wind speed data of the time duration from 2000 to 2010 at Mumbai, India. Table 1 is computed from the data series by employing Empirical methods as mentioned in section 2.1. After a decimal point, two digits are considered here. From Table.1, it is found that the two Weibull parameters, namely shape and scale parameters vary monthly as well as annually. It is to be noted that the average value of k is highest (6.84) for May while for c it is maximum (8.70 m/s) in July. On the opposite hand the minima of the parameters k and c are in September (3.19) and December (3.87 m/s) respectively. So, the shape parameter suggests that the magnitude of the wind speed generally used to stay very high in May and it calms down in September. The scale parameter c advocates that month of July used to remain turbulent with winds of different speeds and then it transforms to a weather of gentle breeze in December. Hence it is evident that large variation in the wind speed is prevalent in between July and September. If we now scrutiny the yearly figures, shape (k) & scale (c) factors scales from 1.86 (in 2006) to 3.62 (in 2010) and from 4.98 m/s (in 2000) to 6.84 m/s (in 2009) respectively.

So, 2009 and 2010 can be considered to be stormier compared to the other years which is also evident from the PDF and CDF represented in Fig. 4 and Fig.5 respectively.

Table 1: Monthly shape parameters (k) and scale parameters c (m/s) (2000 - 2010)

	Parameters	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
JAN	K	5.50	4.01	6.74	5.70	3.76	4.14	2.72	6.07	3.86	9.07	8.05
	C	4.17	3.12	4.98	4.78	3.31	4.29	2.89	3.14	3.68	4.28	5.03

FEB	K	5.62	5.19	3.96	7.26	4.96	3.92	5.50	5.55	3.47	7.33	8.14
	C	3.90	3.22	4.03	5.51	4.19	4.99	3.01	3.98	4.37	5.10	5.32
MAR	K	5.29	5.26	3.92	6.74	3.98	4.29	4.94	4.44	6.71	10.90	9.98
	C	4.24	4.27	4.30	5.94	3.81	6.03	4.30	4.94	4.32	6.09	5.93
APR	K	6.46	4.27	6.94	9.08	7.47	4.85	7.32	6.65	7.53	10.23	3.93
	C	5.09	5.26	4.18	6.55	4.32	5.34	4.53	4.67	5.36	6.73	6.03
MAY	K	6.96	4.07	4.79	8.54	5.73	9.98	5.04	5.37	6.40	11.26	7.07
	C	5.32	7.66	6.27	7.17	6.75	6.20	5.81	6.14	6.85	7.74	7.82
JUN	K	2.65	4.60	3.34	6.17	7.16	4.20	3.81	3.94	4.76	6.90	7.73
	C	6.54	9.36	6.21	6.43	8.87	7.55	6.29	8.09	9.55	8.41	7.10
JUL	K	2.44	6.17	6.95	4.14	3.03	3.40	7.11	3.36	3.91	4.91	4.55
	C	8.31	8.95	8.55	7.16	6.76	8.05	10.89	9.42	9.63	10.20	7.82
AUG	K	3.58	3.97	2.99	3.62	5.49	2.95	5.57	3.19	2.44	4.11	2.87
	C	6.62	7.83	6.57	6.94	8.93	7.32	9.86	9.39	7.81	8.80	7.47
SEP	K	3.62	4.69	3.06	2.73	2.52	2.15	2.71	2.06	1.79	6.24	3.53
	C	5.18	5.78	3.65	5.55	3.18	6.47	4.70	5.67	5.64	5.98	5.81
OCT	K	4.47	4.30	4.22	8.60	3.31	3.77	3.46	3.94	4.62	5.70	5.05
	C	3.14	5.57	4.61	4.31	3.46	2.68	3.33	3.81	4.40	5.34	4.49
NOV	K	3.10	10.98	7.65	6.42	6.13	4.35	5.45	3.61	6.13	5.04	5.20
	C	2.89	4.55	4.67	3.41	3.71	2.76	3.50	3.89	4.88	5.42	5.20
DEC	K	2.66	9.91	5.73	5.14	6.33	3.59	5.79	3.41	7.41	8.55	5.43
	C	2.91	4.40	4.89	3.57	3.57	3.03	3.01	4.01	4.03	4.78	4.42
Yearly	K	2.29	2.53	2.98	3.43	2.18	2.30	1.86	2.13	2.32	3.40	3.62
	C	4.98	6.05	5.40	5.78	5.26	5.52	5.38	5.74	6.06	6.84	6.19

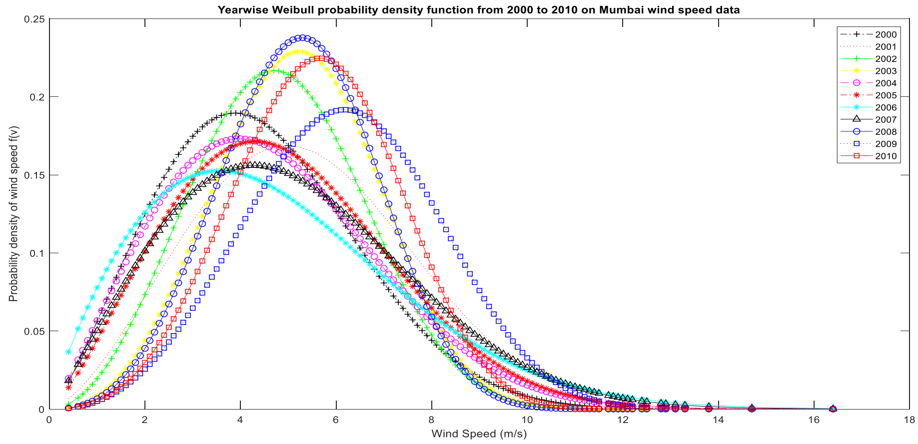

Fig.4: PDF showing the annual variations in wind speed (2000–2010)

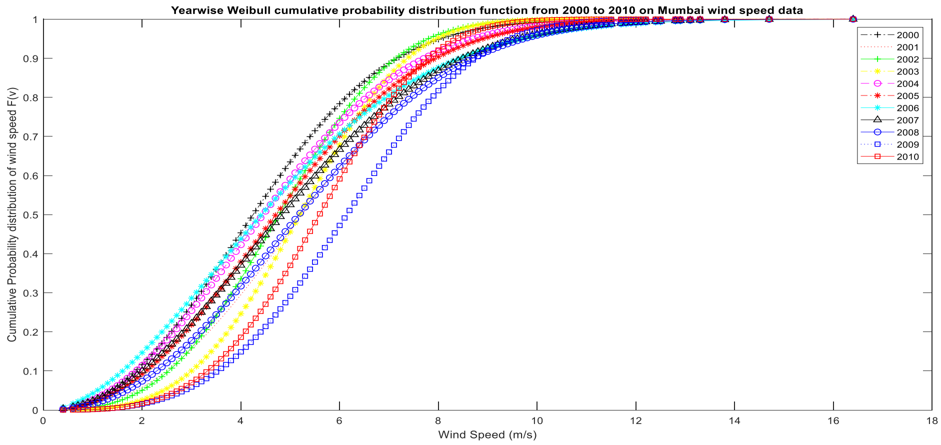

Fig.5: Yearly wind speed CDF for each of the years (2000–2010)

The Weibull scale & shape parameters for different prominent seasons throughout the entire period (i.e. from 2000 to 2010) have been obtained in Table.2. The department of Indian meteorology considers the four climatological seasons with few regional adjustments according to international standard: summer (March to May), monsoon season (June to September), post-monsoon period (October to November), & winter (December to February).

It is evident from Table.2 that the magnitude of scale parameter c is maximum (7.55) in monsoon whereas the shape parameter (k) is highest (3.94) in summer. This implies that summer is mostly populated with high-speed storms, but monsoon remains substantially windy with the wind speed of various speeds. This advocates the earlier claim.

Table. 2: Seasonal shape parameter (k) and scale parameter c (m/s) (2000–2010)

	Parameters	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Mean
Summer	k	5.45	3.01	3.62	6.98	3.24	5.17	4.53	4.56	4.39	7.86	4.80	3.94
	c	4.92	5.85	5.01	6.60	5.12	5.91	4.94	5.30	5.65	6.95	6.71	5.79
Monsoon	k	2.58	3.75	2.61	3.64	2.47	2.98	2.65	2.71	2.60	3.89	3.68	2.84
	c	6.72	8.10	6.41	6.57	7.18	7.39	8.25	8.23	8.28	8.52	7.13	7.55
Post-monsoon	k	3.66	5.07	5.31	5.78	4.19	4.06	4.19	3.80	5.12	5.39	4.87	3.45
	c	3.02	5.13	4.65	3.92	3.60	2.72	3.42	3.85	4.65	5.38	4.86	4.18
Winter	k	3.59	4.16	4.85	4.27	4.39	3.13	4.02	4.10	4.16	7.40	6.24	3.75
	c	3.71	3.68	4.69	4.68	3.71	4.12	2.99	3.73	4.05	4.73	4.94	4.14

The wind velocity PDF for different seasons over the entire years (2000-2010) which has been depicted in Fig.6 is also in agreement with the above argument.

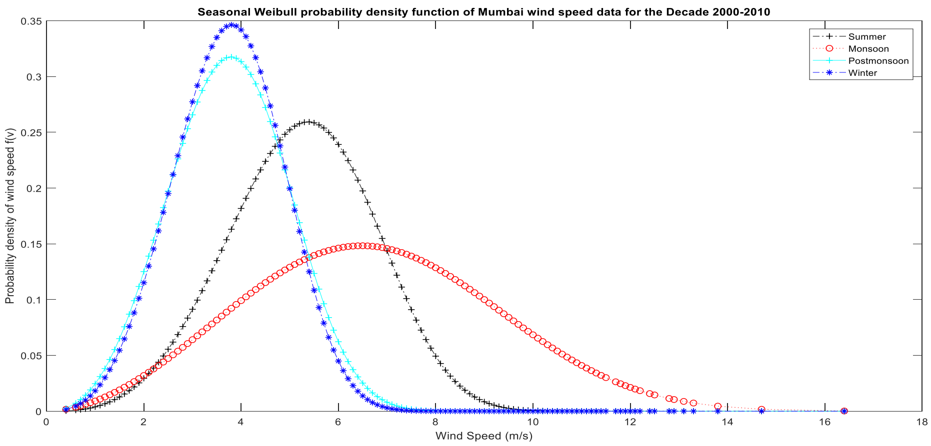

Fig.6: PDF of the seasonal variations in wind speed for the duration of 2000-2010

Now, to study the variation of the wind velocity distribution in the monsoon for different years, the PDF for monsoon seasons of each year (from 2000-2010) has been developed. Fig.7 (a) and Fig. 7 (b) is produced to depict the wind speed PDF in the monsoon for different years from 2000 to 2005 and from 2006 to 2010 respectively.

From Fig.7 (a) and (b), it can be said that the monsoons of 2003, 2009 and 2010 are tormented mostly with powerful storms compared to the other monsoons. The variations of the wind speed are ample for the three consecutive years of 2006, 2007 and 2008.

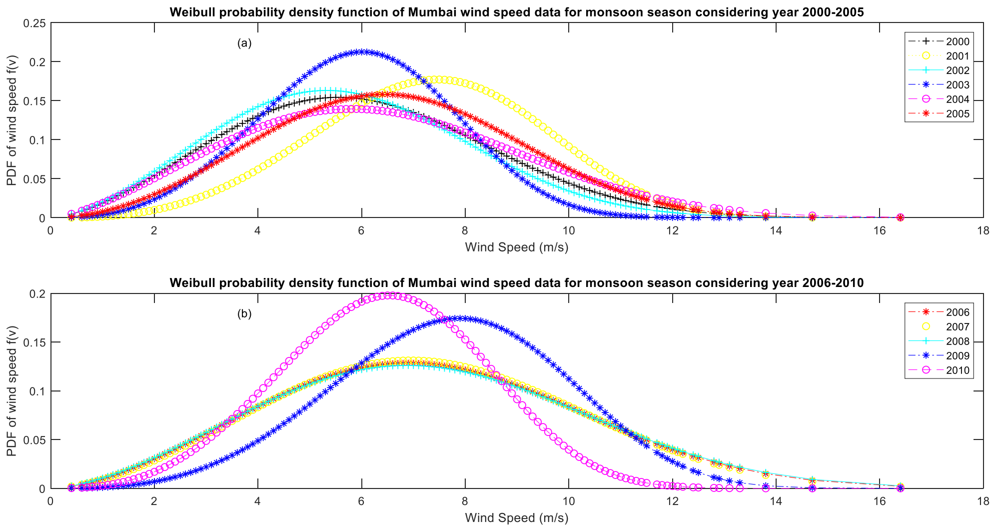

Fig.7: (a) PDF of wind speed for the monsoon season for 2000-2005,

(b) PDF of wind speed for the monsoon season for 2006-2010

B. Wind power densities in Mumbai, India

Monthly mean density of wind power (W/m2) as discussed and obtained in Section 2.3 is tabulated in Table.3 below.

Table .3: Monthly average wind power density (W/m2) for the year 2000-2010

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Jan	39.52	17.15	66.82	59.40	20.69	44.11	15.42	16.82	28.33	43.01	69.31
Feb	32.31	18.18	36.89	90.86	40.27	70.03	14.89	34.37	48.72	72.06	81.85
Mar	41.70	42.37	44.84	113.68	31.22	121.95	43.66	66.71	43.74	124.84	114.67
Apr	71.48	80.90	39.68	153.88	43.66	83.66	50.47	55.12	83.89	168.12	123.60
May	81.83	252.33	135.13	201.53	166.80	131.14	107.20	125.91	174.11	256.26	259.28
Jun	182.11	451.80	140.71	144.39	378.87	240.03	141.36	298.93	478.59	322.63	194.79
Jul	393.65	389.04	339.00	205.50	187.99	305.20	700.76	490.42	504.77	581.48	264.15
Aug	167.25	270.18	174.10	192.60	387.35	242.22	522.01	494.89	326.57	381.46	259.93
Sep	77.96	111.85	28.90	107.93	22.23	198.88	65.65	139.47	160.40	115.41	111.95
Oct	16.75	89.95	55.97	42.80	23.99	10.79	20.93	31.42	48.11	82.41	48.88
Nov	17.87	52.20	55.45	21.69	27.21	11.35	22.75	33.28	62.99	86.19	76.51
Dec	12.71	46.72	63.85	24.82	25.20	16.43	15.22	38.32	34.87	59.35	46.45

The density of the wind power starts to shoot up from May and reaches its peak in July in general which is observed from Table.3. The month between June and August, i.e. monsoon season is found to have substantial power in the wind compared to the other months. This can be better realized from Fig. 8 and 9. The variations in the mean densities of wind power over seasons are shown in Fig.9.

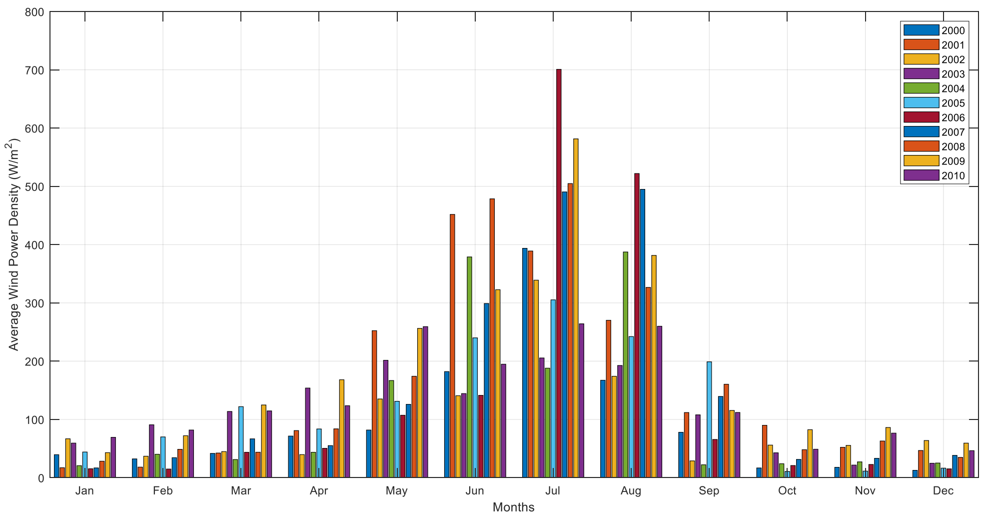

Fig. 8: Plot of monthly variations in wind power densities (2000–2010)

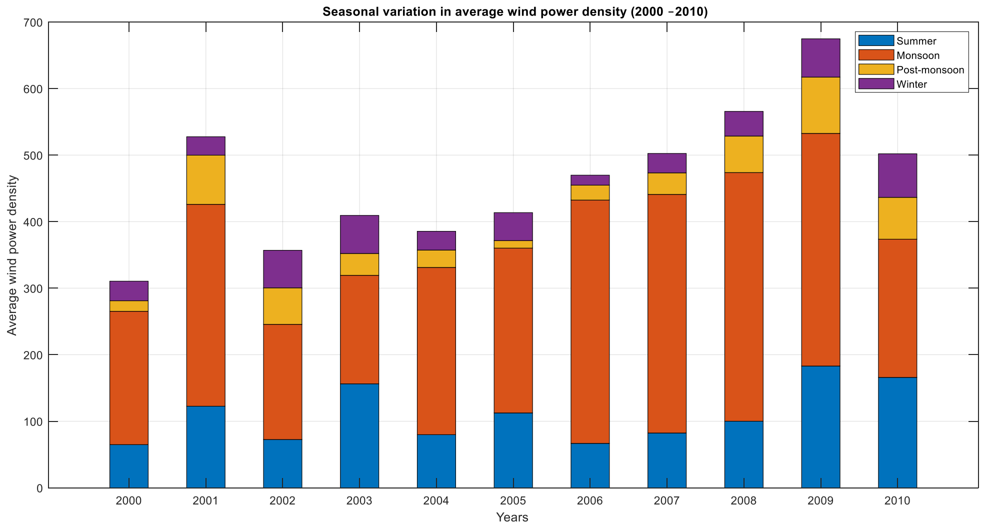

Fig. 9: Seasonal variations in average wind power density (2000–2010)

C. Performance analysis of wind turbines

In the current work, three different wind turbines of different makers have been chosen. The chosen wind turbines models are Siemens SWT-3.6-120 Onshore, W2E Wind to Energy W2E-120/3.5fc, and GE General Electric GE 3.6s. The specifications and their performances on the test site (i.e. Mumbai, India) have been provided at Table.4. Table 4 shows that the three chosen turbines have almost same cut-out speed & rated power. Although they have slightly different cut-in speed and rated speed, the reason behind this choice is to minutely notice the effect of varying cut-in and rated speed on the annual performances of the wind turbines in the test location.

Table .4: Different wind turbine's specification & performances

Wind Turbine Model / Specification & performance			Siemens SWT-3.6-120 Onshore	W2E Wind to Energy W2E-120/3.5fc	GE General Electric GE 3.6s
Rated power (MW)			3.6	3.5	3.6
Cut-in wind speed (m/s)			3	3	3.5
Rated wind speed (m/s)			12.5	13	15
Cut-out wind speed (m/s)			25	25	25
Probability of the turbine being in operation during the 11 year periods (2000-2010) (in %)			92	92	87
Probability of operating at rated power during the 11 year period (2000-2010) (in %)			4.1	3.11	0.473
Capacity factor on (%)	On the year	2010	17.5	15.32	8.97
		2009	25.57	23.12	14.84
		2008	26.92	25.14	18
		2007	25.2	23.76	17.34
		2006	24.64	23.35	17.35

The probable operating period of the turbine during the 11 year periods (2000-2010), the probable span of operation at rated power during the 11 year period (2000-2010) and annual Capacity factor for years 2006-2010 have been computed for three chosen wind turbines. The highest value of the probability while turbine is under operation during the 11 year periods (2000-2010) is 92% which is shared by Siemens & W2E. It is notable that the Siemens turbine shows consistent better result than W2E on the basis of capacity factor. This observation suggests for the test site if rated speed is smaller the working of the wind turbine will be improved.

4. CONCLUSION

Above analysis inferrs that the high-speed wind is prevalent in May-June and it calms down in September. But the deviation of the speed of the wind is prominent in July whereas in December the speed remains nearly constant. So, the period between July and September (Monsoon) may be considered as the most active for the wind. And in the month of May-June (summer), the wind becomes gigantic in power. The current study suggests that for the test site wind turbines having lesser rated wind speed will work more efficiently. This study is equally viable for the surrounding region of the test site as long as the climatic pattern remain unchanged. However, climate change is almost invariably considered a global issue. Indeed, when potential (wind power) sites for wind electricity generation are to be chosen, the climatic shifts of the site should be considered crucially where more sensitive tools can be developed for proper estimation. Once potential location is selected appropriate turbine selection is an inseparable part of successful wind electricity generation.

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Sabbir Reza Tarafdar *(Member, IEEE)* received the B.Tech degree in Computer Science Engineering from MAKAUT(formerly WBUT) ,India in 2006, the M.E. degree in Computer Science Engineering from Anna University ,India in 2008.

He is currently working as Assistant Professor at Dr B.C.Roy Engineering College,Durgapur and pursuing the Ph.D degree in engineering from CMERI under AcSIR,India. His current research interests include medical image processing, deep learning, machine learning ,statistical data analysis ,application of optimization technique.

Santanu Thandar received the B.Tech degree in Electronics and Instrumentation Engineering from University of Kalyani ,India in 2007 and M.E. degree in Electrical Engineering (Control System) from IIEST(formerly BESU, Shibpur),India in 2010.

He is currently working as Manager (Instrumentation) at The Durgapur Projects Ltd (Thermal Power Plant) pursuing the Ph.D degree in engineering from CMERI under AcSIR,India. His current research interests include Power system and Control, optimization technique, and power system cyber-attack, statistical data analysis.

Tushnik Sarkar received the B.Tech degree in Electronics and Instrumentation Engineering from University of Kalyani ,India in 2007 , the M.E. degree in Electrical Engineering from Jadavpur University ,India in 2010 and the Ph.D degree in Engineering from NIT,Durgapur,India in 2019.

He is currently working as Assistant Professor at Dr B.C.Roy Engineering College,Durgapur. His current research interests include statistical data analysis ,application of optimization technique in control system, power system.