Chapter 2

Wind Power Generation Unit Model

2.1 Introduction

The electrical power grid is an extensive, interconnected network to serve electricity among all end users. Power generation is the initial stage of this integrated power grid. The advancement in power generation technology proliferates from convectional sources to renewable sources. The augmentation of wind power has attracted researchers to do novel things in favor of the power grid, keeping wind power as a center. The better wind power technology at the megawatt scale, higher fuel costs, and global warming challenges have livened up the countable interest in wind power generation. The use of onshore and offshore wind power has increased worldwide. The state laws of various countries worldwide have driven the demand for wind power. Globally, installed wind power was 7.5 GW in 1996 and 564 GW in 2018. This data is received from the International Renewable Energy Agency (IRENA). The rapid growth of wind power throughout the world reduces greenhouse gas emissions associated with conventional energy generation. The wind potential is very high in many parts of the world. The tremendous potential of wind power is available offshore. The kinetic energy produced by air in motion is transformed into electrical energy using wind turbines and wind energy converters.

Integration of wind generation units into any power network imposes many issues on the operation of the power system. Many researchers have proposed feasible solutions to various challenges regarding the penetration of wind power units in power transmission and distribution networks. The higher penetration of wind power motivates researchers to develop an accurate methodology for different power grid issues like frequency control, synchronization, optimal placement, size, voltage stability, reliability, loss minimization, etc. The development of methodology for evaluating actual and more benefits of wind power must be considered given the uncertain nature of wind. To deal with uncertainties of wind power sources, the first step is to forecast wind speed accurately and estimate the output power or capacity factor of wind turbine units. For estimation of the output power of wind turbines and deciding capacity factor, many researchers have proposed various statical models with their advantages. Today's smartgrid is developed with smart controlling and measuring devices and bi-directional current flow in the feeder. So, the placement of distributed energy sources requires more accuracy. Wind power generation is widely regarded as the most promising distributed energy source in microgrid throughout the world. The smart grid demand is to develop more widely applicable methods for integrating wind power generation units and evaluate the benefits of incorporating them into microgrids. To maximize the benefits of the wind power unit with its intermittent nature is a very baroque process. This needs a more precise estimation of the power output of a specific wind generation unit provided on-site. Estimating the power output of a specific wind turbine depends on wind turbine characteristics and the model of wind speed behavior. Wind speed data analysis and proper wind power potential assessment are necessary for the efficient development of wind power applications and are highly site-dependent [71]. As a result, knowledge of the statistical properties of wind speed is essential for predicting the energy output of wind generation units. Weibull PDF has usually been considered the most qualified function for statistical analysis of wind speed data due to its simplicity and high accuracy [72]. For decades, researchers involved in wind speed analysis have almost unanimously used the Weibull PDF, and it has also been extensively used in wind power analysis. [73]. According to International Standard IEC 61400-12 and other recommendations as per [74], [75],[76], the two-parameter Weibull probability density function is the most appropriate distribution function for modeling of wind speed uncertainty. It fits the observed wind speed data both at the surface and in the upper atmosphere. This chapter introduces the basic concept of wind power and describes the computation method to estimate wind power generation based on the two-parameter Weibull distribution. The wind speed data analysis has been carried out for the site near the Bay of Cambay, Gujarat. The computational procedure is described here to estimate the probable output power of a wind-based Natural Power Distributed Source (NPDS) by considering the discrete value of the Weibull parameter for a specific time.

Weibull parameters according to mean wind speed and standard deviation and four states of wind speed are introduced for specific time laps. The obtained results are discussed and concluded.

2.2 Wind System

In earlier days, as recorded history, the people used wind power to grind the grain and pump the boat by using a windmill machine. The conversion of wind's kinetic energy to electrical power using a windmill was introduced in 1887 in Scotland. Afterward, people use the following terminology: "wind generator," "wind-driven generator," "wind turbine," "wind energy conversion system" (WECS), "wind-turbine generator" (WTG), and "wind power generation unit" for the system which produces electricity from wind energy. Several wind turbine-generator systems in various configurations have been built to produce electrical power generation by harnessing wind potential. The main way to classify wind turbines is in terms of the axis around which the blades rotate, which are horizontal wind turbines and vertical wind turbines. The rotor blades convert the kinetic energy of wind into mechanical energy to spin the generator. A very small wind turbine with battery storage to store electrical energy has a DC generator. The grid-connected wind generation unit is set up with a synchronous generator or induction generator.

2.2.1 Average Power in Wind

Theoretically, the power available in the wind is expressed as;

$$P_w = \frac{1}{2}\frac{m}{t}v^2 \ watt \tag{2.1}$$

Where, an air packet of mass 'm' moving through the turbine rotor blades area A in time 't' second. The mass of air is given by $m = \rho A v$. and v is the wind speed measured in m/s. Actually, the wind speed is not constant, but it can be represented by instantaneous speed "$v(t)$" using a wind speed time curve, the instantaneous power in the wind would be expressed by;

$$P_w(t) = \frac{1}{2}\rho A v^3(t) \tag{2.2}$$

Practically, due to the uncertain nature of the wind, it is normally more interesting to represent the average power in the form of average wind speed over the specified period.

$$P_{w_{avg}} = \frac{1}{2}\rho A(v)^3_{avg} \tag{2.3}$$

The basic mathematical model for the mechanical power output of a wind turbine system is:

$$P_{w_{avg}} = \frac{1}{2}C_p\rho A(v)^3_{avg} \tag{2.4}$$

Where, C_p is the power coefficient of the wind turbine, which is the main function of wind turbine radius and angular speed. The average value of the cube of velocity - $(v)^3_{avg}$ is calculated with the help of some required statistics [76]. It is given by;

$$(v)^3_{avg} = \frac{[\sum_i (v_i)^3 \cdot hours@v_i]}{\sum hours} \tag{2.5}$$

in probability terms $(v)^3_{avg} = \sum_i (v_i)^3 \cdot probability(v = v_i)$

2.2.2 Wind Speed Distribution Function

Mainly following statistical model has been used for characterised wind speed uncertainty:

- Normal Distribution Function (NDF)
- Probability Distribution Function (pdf)
- Cumulative Distribution Function (cdf)

The simplest way to represent information on the wind speed variation is in the form of a discrete wind speed histogram. This information is frequently represented as a continuous function, which is called a probability distribution function (pdf). The wind probability distribution function is shown in Fig: 2.1 [75]. The fetchers of the pdf is shown in the fig are as follows :

- The area under the curve is equal to unity.
- The area under the curve between wind speed $v_1 \quad and \quad v_2$ equals the probability that the wind is between those two speeds.

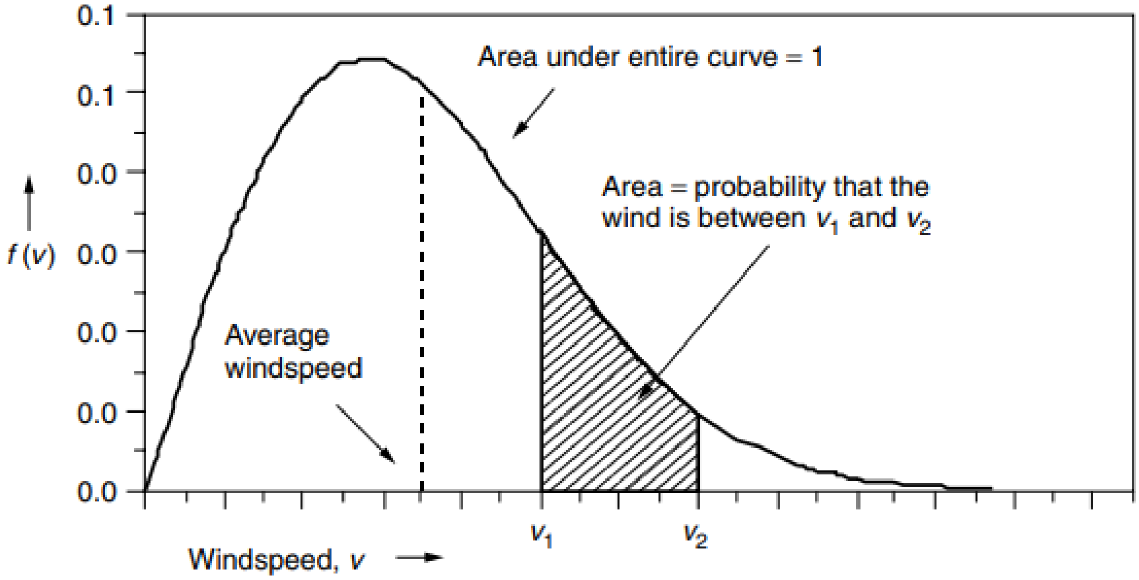

Figure 2.1: Wind probability distribution function

The fetchers of pdf are expressed mathematically as given below:
$f(v)$ = wind speed probability density function
where probability $(v_1 \leq v \leq v_2) = \int_{v_1}^{v_2} f(v)\, dv$

probability $(0 \leq v \leq \infty) = \int_0^\infty f(v)\, dv = 1$
Hence, the average value of wind speed and an average value of the cube of wind speed can also be computed using a pdf of wind speed as in the equation 2.6

$$v_{avg} = \int_0^\infty (v) f(v)\, dv; \qquad (v)^3_{avg} = \int_0^\infty (v)^3 f(v)\, dv \tag{2.6}$$

2.2.3 Wind Generation Unit

This cubic relationship is not enough for wind energy generated at any location for the given wind turbine. The energy captured in the wind depends on turbine characteristics, topography, obstructions, surface roughness, the velocity of wind, and timing. The actual energy generation by a single turbine generator unit is lower than the power in the wind due to energy conversion losses that consist of mechanical losses associated with bearings and gearbox, copper and iron losses of the generator, and electromechanical characteristics of the wind system unit. The output power generation in terms of wind speed probability has been modeled based on the wind turbine performance curve or standard curve fitting technique. In some cases, power output has been computed by wind turbine generator specification or modeling capacity factor that follows wind pdf statistics. The estimation of wind generator power through the linear interpolation of the values of the data provided by the manufacturer can be expressed as [47].

$$P_w(v) = \begin{cases} 0, & v \leq v_i \text{ or } v \geq v_i; \\ a_1 v + b_1, & v_i < v \leq v_1; \\ a_2 v + b_2, & v_1 < v \leq v_2; \\ ..... & \\ a_n v + b_n, & v_{\texttt{n-1}} < v \leq v_n; \\ P_r, & v_r < v > v_0 \end{cases} \tag{2.7}$$

Here, $P_w(v)$ is the output power of the wind generator at wind speed v. The cut-in wind speed, cut-out wind speed, and rated speed are indicated by v_i , v_0 and v_r respectively. The P_r is the rated power of the wind turbine generator, n is the number of interpolation functions, and a and b are the polynomial coefficients of the interpolation functions that depend on the type of the wind turbine generator. Duong in [47] has calculated capacity factor co-efficient: a_0, a_1 ,a_2 ,a_3 using standard curve fitting technique such as 'polyfit' routine in Matlab. The power output has been estimated by the equation: 2.8

$$P_{w_0}(v) = \begin{cases} 0, & 0 \leq v \leq v_{c_i}; \\ a_0 + a_1 v + a_2 v^2 + a_3 v^3, & v_{c_i} \leq v \leq v_r; \\ P_{\text{rated}}, & v_r \leq v \leq v_{c_o}; \\ 0, & v_{co} \leq v; \end{cases} \tag{2.8}$$

Where v_{c_i}, v_r,and v_{c_o} are cut in, rated and cut out speed of the wind turbine respectively; P_{rated} is the rating of wind turbine; In [61] simplified wind model has been obtained for wind power output curve. The WTG power $P_i(i = 1, 2, 3 - - - - - Nb)$ has been estimated for simulated wind speed $S_{wb_i}(i = 1, 2, 3 - - - - - Nb)$ of number of interval steps of distribution - Nb using expression;

$$P_i = \begin{cases} 0, & 0 \leq S_{w_{b_i}} < v_{c_i}; \\ P_r \left(A + B \times S_{w_{b_i}} + C \times S^2_{wb_i} \right), & v_{ci} \leq S_{wb_i} < V_r; \\ P_r, & v_r \leq S_{wb_i} \leq V_c o; \\ 0, & v_{co} < S_{wb_i}; \end{cases} \tag{2.9}$$

In the equation: (2.9) A,B, and C are constants, which are the function of v_{c_i} and v_r The mathematical model of the wind power generation unit can be developed based on the modification of any expression discussed above, followed by the wind distribution function. The basic model that is expressed as per equation:(2.10) has been used here to obtain probable wind power generation.

$$p_{wg}(v) = \begin{cases} p_{sr}, & v_{sr} < v \leq v_o; \\ P_{sr} \frac{v - v_i}{v_{sr} - v_o} & v_i < v \leq v_{sr}; \\ 0, & v \leq v_i \text{ or } v \geq v_o; \end{cases} \tag{2.10}$$

The wind power generation model has been developed by considering the probability of wind speed within the range around the mean speed and power generation at that mean wind speed. The probability function is discussed in the next section.

2.3 Weibull Probability Distribution Function

The Probability Distribution Function approach to modeling the random nature of wind speed is known as the parametric approach, in which shape index and scale index can be calculated using wind speed statistics such as mean and standard deviation (SD). Another method for wind speed modeling is the autoregressive time series model, which has been used in[77],[78]. Some non-parametric approaches for wind speed modeling and forecasting have been reviewed in [79]. In this thesis, the two parameters of Weibull pdf have been applied to modeling the random behaviour of wind speed. The empirical method, which is the case of the moment method, has been used to estimate Weibull pdf parameters to fit available wind speed distribution. The Weibull probability distribution function of wind speed is characterised by the equation: (2.11) [47], [53], [76];

$$F_w(v) = \frac{k}{c} \left(\frac{v}{c} \right)^{\mathtt{k-1}} \exp \left[- \left(\frac{v}{c} \right)^k \right] \tag{2.11}$$

The shape parameter (k) and scale parameter (c) are estimated based on mean wind speed and the standard deviation of wind speed for the specified time laps. The mean wind speed - (v_m) m/s^2 and the standard deviation (v_{sd}) of specified time laps are considered based on historical meteorological data and area. The high value of the shape parameter (k) indicates variation in wind speed around the mean wind speed in the region for the specified period. As the name implies, the shape of the Weibull pdf changes with the variation in shape parameter (k).

2.3.1 Estimation of value of k and c

The Weibull factors k and c are estimated from the mean wind speed (v_m) and standard deviation (v_{sd}) of wind data. The wind data may be historical data or forecasting data. Generally, for the Weibull parameter, past data measured using an anemometer located 10 m above the ground is used to estimate the average wind speed. The hub height of the wind turbine may be 50 m, 80 m, and 110 m above ground level. The wind speed at this height will be estimated using the expression;

$$v_H = v_{10} \left(\frac{\frac{\ln(H_{hub})}{z}}{\frac{\ln(H_{10})}{z}} \right) \tag{2.12}$$

In this thesis, primarily the Moment Method (MM) is applied to determine shape and scale parameters by the following equations:

$$c = \left(\frac{v_m}{(\Gamma(1 + \frac{1}{k})} \right) \tag{2.13}$$

where,the gamma function is given by:

$$\Gamma = \int_0^\infty t^{(x-1)} \exp(-t) dt \tag{2.14}$$

This method is used to do wind analysis on the basis of scale parameter (c), which is the function of mean wind speed and shape parameter (k). When the variation in wind speed around mean wind speed is fairly consistent, the value of k can be considered two or nearer to 2. When k=1 for the same value of scale parameter, the shape of the pdf looks like an exponential decay function. It means most of the time, wind speed variation is very high around the mean wind speed in the regime. Again, keeping the scale parameter (c) value constant and for k = 3, the function resembles the familiar bell-shaped curve, and the site would be one where the steady wind is always blowing and doing so at a fairly constant speed around the mean wind speed. The Weibull with varying shape parameter k = 1, 2, 3 for fixed value scale parameter c can be obtained as shown in Fig: 2.2 which is presented in [75]. Looking at this would lead researchers to assume k=2, which is realistic

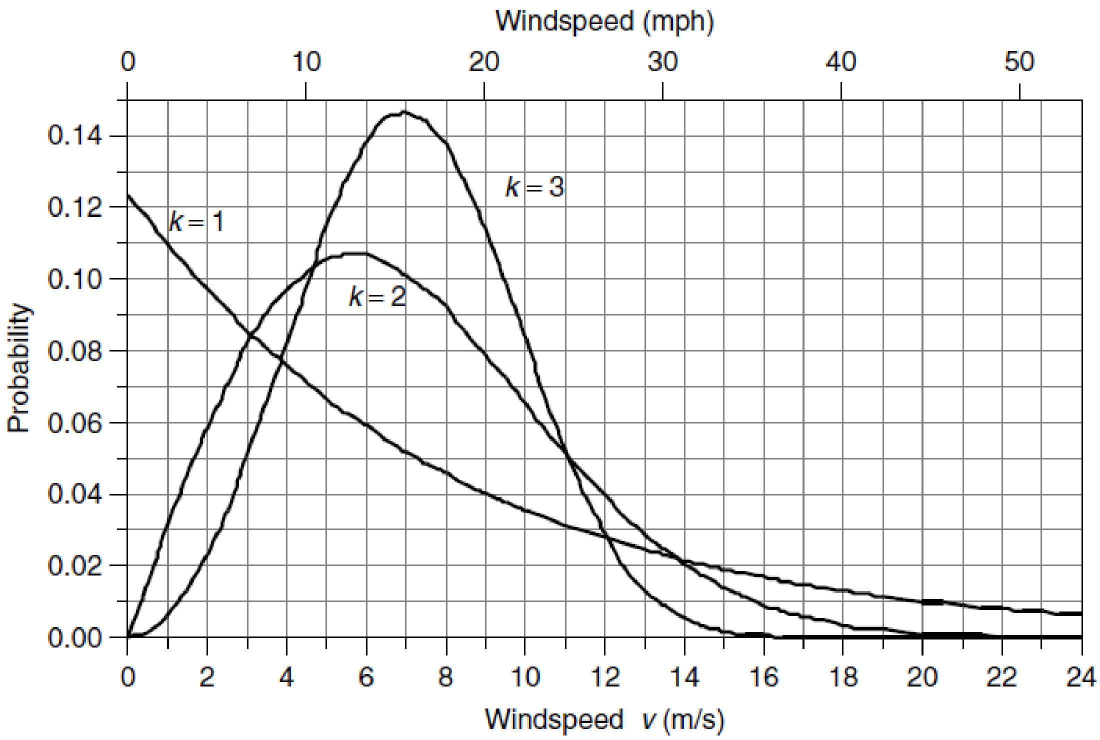

Figure 2.2: Weibull probability distribution function with shape parameter k =1,2,3,(c-constant, say=8)

for a good wind site, and model the wind power generation for power grid application. When K is equal to 2, the pdf is called rayleigh distribution [19] [53] . There are many methods to calculate the shape and scale parameters to fit wind speed distribution. The empirical method is a special case of the moment method. In this, the shape parameter is computed by the equation:

$$k = \left(\frac{v_{sd}}{v_m}\right)^{-1.089} \tag{2.15}$$

The next section presents wind data analysis using Weibull pdf and an hourly estimated power generation computation model. The power generation model has been developed in two ways. In the first case, a simple mathematical model based on commutative probability from the Weibull pdf has been used, and wind turbine output power has been estimated. In the second case, the model has been developed by dividing the wind speed distribution into four states of wind speed range around the mean speed of specified time laps.

2.4 Wind Power Analysis

2.4.1 Data Source

The wind speed data in hourly time-series format over a period of 3 years (2014 - 2016) has been collected and statistically analyzed. The wind speed data were recorded at the height of 10 m, by an anemometer at the site near the seashore town of Khambhat, Gujarat [`www.worldweatheronline.com/lang/en-in-Khambhat-weather-history/gujarat/in.aspx`] and (`http://niwe.res.in`). The motivation behind the selection of this site for the potential wind analysis is data given in [80]. The estimated wind power potential in Gujarat is 35071MW at 80 m above sea level. The installed capacity of wind power in Gujarat was 4227.31MW up to 2016. Wind power assessment in Gujarat using the WLF model has been introduced and determined the potential of wind in five different stations. A wind speed map of Gujarat for every month is published in this paper. It is stated that the average wind speed near the bay of Khambhat is 6 to 7 m/s per year. The Table:2.1 contains the geographical coordinates of the chosen site for analysis.

Table 2.1: Geographical co-ordinates of the Khambhat

Latitude:	22.317
Longitude :	72.622
Anemometer hieght:	10 m
Elevation:	15 m

2.4.2 Wind Speed Statistics and Power Generation Model

The wind speed data for the three years (2015-2017) have been collected from the site [`www.windworldwide.com`]. The month-wise daily data are available on this site which is every three-hour interval per day. The wind analysis has been carried out for each time slot, which consists of three hours per day. The yearly wind power generation has been estimated by integrating quarterly wind power generation. This time-series data has been recorded by the anemometer at the height of 10m. These wind speed data are adjusted at the height of 80m hub height using the equation: (2.12). The mean wind speed and standard deviation have been computed and noted for each slot per day /quarter. Here, one quarter is considered three months. The following steps have been executed to obtain the Weibull pdf for each slot/day/quarter and analyze the potential of a site for power generation. The matlab platform has been used to carry out this task.

- Load the wind speed data sheet in which wind speed per each slot/day/quarter has been recorded.
- The weibull shape parameter and scale parameter have been computed using equations: (2.13, 2.15).
- The weibull probability distribution has been obtained through matlab code.
- Wind potential of each item has been analyzed on the basis of Weibull pdf.
- The power production at a steady mean wind speed has been calculated as an expression;

$$p_{wg}(v_m) = \begin{cases} p_{sr}, & v_{sr} < v_m \le v_o; \\ P_{sr}\frac{v_m - v_i}{v_{sr} - v_o} & v_i < v_m \le v_{sr}; \\ 0, & v_m \le v_i \text{ or } v_m \ge v_o; \end{cases} \tag{2.16}$$

- The probable power power production per one slot with variable speed between cut in speed and cutout speed around mean wind speed has been computed by:

$$p_{wg} = p_{w_{avg}}(v_m) \int_{v_{ci}}^{v_{co}} f(v)\, dv \tag{2.17}$$

- The estimation of energy generation per day has been done by expression

$$E_{wg} = \sum_{i} \sum_{j}^{h} p_{wg_{ij}} \tag{2.18}$$

where, i = no of slots per day and j = no of hours per one slot

2.5 Result and Discussion

The shape index (k) and scale index(c) of each slot/day/quarter have been computed using the recorded mean wind speed and standard deviation, as shown in Table:2.2 to 2.5 and Weibull pdf for each slot has been obtained as per shown in Fig: 2.3. The pdf curve of all slots of the October to December quarter is right-skewed, and the average mean wind speed per day of that quarter is 4.3 m/S. The standard deviation error is 2.1 meters per second. As a result, the power potential of this period is extremely low. When the pdf curves of all the slots of the April to June quarter are near to normal distribution, the average mean wind speed is 5.58 m/S, and the standard error is 2.23 m/s. Looking towards the curves of July to September, the pdf curves of slots 2, 3, and 4 are right-skewed. So, power generation potential is very low. The average mean wind speed is 6 m/s, and the standard deviation error is 2.7. In the case of pdf curves of quarter 1, the curve of slot 6,7 is left-skewed, which means during that period of the day, power production is low. The average mean wind speed is 4.95 m/s and the standard is 2.9 m/s for the period from January to March. From the wind speed statistics and the Weibull pdf, it is proved that in the periods- April to June and July to September, the possibility of power production using wind turbine units is good. In the paper [80], the map of wind potential has been shown, in which quarterly mean wind speed was estimated. It is almost matched with this analysis.

Table 2.2: Wind statistics of the Quarter January to March

Time slot no	slot/day	(v_m) m/s	v_{sd} m/s	k	c
1	00 to 3:00	5.386	3.515	1.59160	6.00445
2	3:00 to 6:00	5.687	3.759	1.5696	6.33155
3	6:00 to 9:00	5.7463	3.569	1.67977	6.43482
4	9:00 to 12:00	5.187	3.489	1.47552	5.51293
5	12:00 to 15:00	4.832	3.137	1.60069	5.38984
6	15:00 to 18:00	3.678	3.042	1.2296	3.93368
7	18:00 to 21:00	4.163	3.851	1.60069	4.2992
8	21:00 to 24:00	5.786	3.102	1.97166	6.5267

Table 2.3: Wind statistics of the Quarter April to June

Time slot no	slot/day	(v_m) m/s	v_{sd} m/s	k	c
1	00 to 3:00	6.823	3.812	1.88505	7.68702
2	3:00 to 6:00	5.926	2.635	2.41717	6.68396
3	6:00 to 9:00	5.491	3.147	1.83345	6.18007
4	9:00 to 12:00	4.728	3.257	1.500600972	5.23762
5	12:00 to 15:00	4.925	3.777	1.158979647	5.360253
6	15:00 to 18:00	5.092	2.421	2.247145205	5.7491249
7	18:00 to 21:00	5.235	3.632	1.489023156	5.79349
8	21:00 to 24:00	6.233	3.023	2.199014175	7.03816

Table 2.4: Wind statistics of the Quarter July to September

Time slot no	slot/day	(v_m) m/s	v_{sd} m/s	k	c
1	00 to 3:00	5.142	4.763	1.110223745	7.68702
2	3:00 to 6:00	5.736	4.215	1.370828345	6.68396
3	6:00 to 9:00	5.443	5.213	1.5599	6.18007
4	9:00 to 12:00	4.821	4.294	1.134356	5.45010395
5	12:00 to 15:00	5.631	3.952	1.470462	6.22293
6	15:00 to 18:00	7.542	2.421	2.0227	5.217244
7	18:00 to 21:00	7.123	3.634	1.8348	5.79349
8	21:00 to 24:00	6.345	3.543	2.13936	7.03816

Here, a sample wind turbine of the following specification has been chosen for estimation of power generation as per equation: 2.17. The probable power generation for the period of each time slot per one quarter is presented in the Fig:2.4.

- Rated power: 1000 KW,
- cut in speed:3.5 m/s,
- rated speed :12m/s

Table 2.5: Wind statistics of the Quarter October to December

Time slot no	slot/day	(v_m) m/s	v_{sd} m/s	k	c
1	00 to 3:00	4.846	1.944157471	2.70367	5.4492
2	3:00 to 6:00	5.0251	1.871823212	2.93123	5.6328
3	6:00 to 9:00	5.008	1.783131937	3.0789	5.60178
4	9:00 to 12:00	5.334	2.937709103	1.91469	4.46559
5	12:00 to 15:00	4.2607	2.225679081	2.02823	4.808916
6	15:00 to 18:00	3.5615	2.043609313	1.83107	4.00799
7	18:00 to 21:00	3.8217	1.833386023	2.2253	4.31489
8	21:00 to 24:00	4.3908	1.787964011	2.66018	4.94014

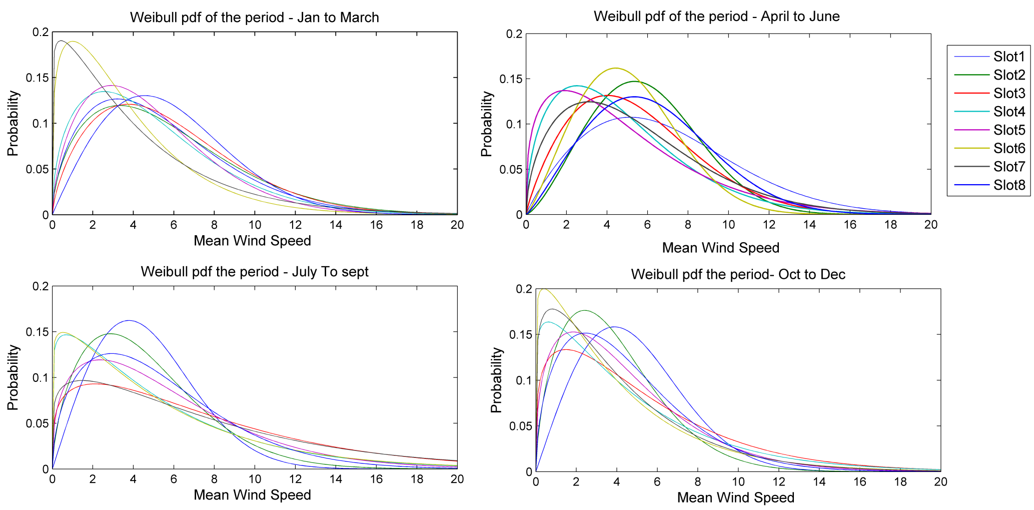

Figure 2.3: Weibull probability distribution function for the period of four Quarters, slotwise

- cut out speed: 20 m/s
- Assume: windmill blades move as-per wind direction

The power generation for the specified wind turbine is computed using the expression 2.17. This calculation is done on the basis of slot-wise wind statistics and wind probability. The probable wind power production per slot on the basis of mean wind speed and a fixed value of shape parameter (k=1.6) for all timeslots/day/ quarter has also been computed.

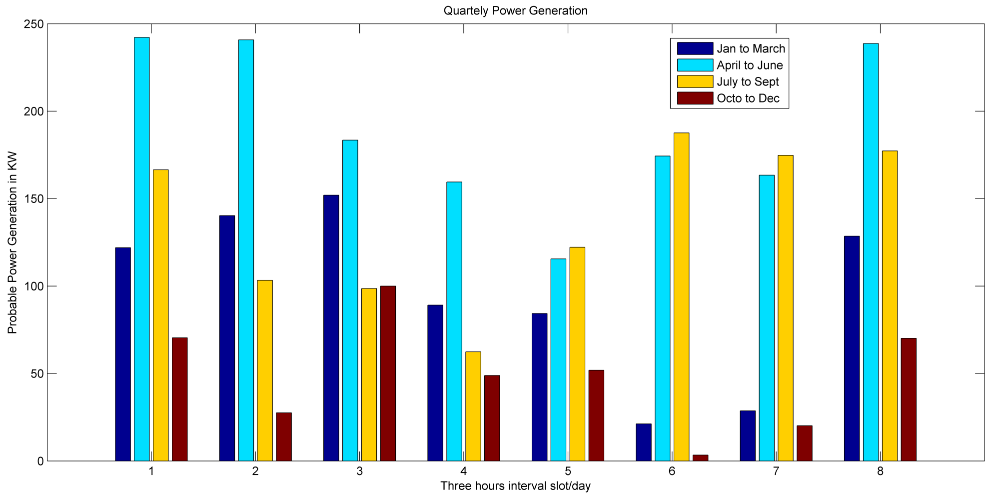

Figure 2.4: Probable power production for the period of four Quarters, slotwise

The result of both the methods has been compared here in Table: 2.6. This computation result is helpful to the modified wind power generation model. The probability of energy production per day/quarter/year has been estimated as per equation: 2.18 and is shown in Table:2.7. This probable power production is on the wind turbine side.

Table 2.6: Comparison of probable power potential of all Quarters in kw with slot wise shape index(k)and fixed shape index(k=1.6)

Time slot no	Jan to March		April to June		July to Sept		Octo to Dec	
	slotwise k	k=1.6	slotwise k	k=1.6	slotwise k	k=1.6	slotwise k	k=1.6
1	121.93	137.16	241.34	260.67	166.52	99.55	70.46	73.41
2	140.2926	149.8294	235.1626	200.1307	103.3036	78.2338	27.5126	79.67
3	152.0031	156.1060	183.2629	173.1022	98.5961	71.3188	100.0053	67.2269
4	89.1433	124.3860	159.4220	155.0048	62.4564	57.8847	48.8449	49.1983
5	84.3070	105.1347	115.4832	128.0915	122.2258	92.3707	51.8587	17.9645
6	21.2391	37.7840	174.1953	137.0062	187.6181	92.3707	3.3879	3.8364
7	28.7075	55.1027	163.1381	173.1022	174.7442	106.8072	20.1472	17.0189
8	128.5144	117.9725	238.9648	217.8933	177.2963	114.0996	70.110	43.4199

Table 2.7: Probable energy generation/day/Quarters in (KWH)

value of k	Jan-March	April-June	July-Sept	Octo-Dec
k is slotwise	2298.4	4553.8	3278.3	1177
$k = 1.6$	6152	8574	4765	2250
$k = 2$	7056	11560	5875	2734

2.5.1 Wind Power Generation Model using Wind States

It is studied from the state- of-the-art that generally, the behavior of wind speed is characterized using Weibull pdf with K=2 (Rayleigh pdf) to allocate wind units in the power grid. But after doing a detailed analysis of the data gathered, it is concluded that there is a 30 to 50 percent variation in the estimation of probable power generation considering the fixed value of shape index (k) and varying with the time slot. This may have an adverse effect on the planning and operation of the power grid with wind-based natural power distributed sources. The slot-wise data collection and analysis require more computational time to include in the power flow analysis of the power grid. So these two reasons lead to developing a model of random wind speed, which should be seasonal/periodically, and estimating power production for each state of wind speed by considering the seasonal mean speed and standard deviation of a large amount of data. The following procedure has been developed to determine the probable power generation of a wind turbine unit.

The seasonal/periodic hourly mean wind speed and standard deviation have been obtained [`http://niwe.res.in/`]. The Weibull pdf for each period has been utilized to know the wind speed probability for each state. Power generation estimation is done by considering the probability of each state and power production at the mean wind speed of that state. The mathematical model has been proposed here as;

$$p_{wg} = \sum_{i}^{st} p_{wg}(v_{mst}) \int_{v_1}^{v_2} f(v)\, dv; \quad v_1, v_2 \geq v_{ci} \quad and \quad v_1, v_2 \leq v_{co} \tag{2.19}$$

where, v_1 is lower limit of wind speed specified wind state; v_2 is upper limit of wind speed the state, v_{mst} is average wind speed of the state;
Here four wind speed states has been considered for estimation of wind power generation unit as shown in Table:2.8.

Table 2.8: Wind speed state

state	v_1	v_2
1	$v_m - 2(v_{sd})$	$v_m - (v_{sd})$
2	$v_m - (v_{sd})$	v_m
3	v_m	$v_m + (v_{sd})$
4	$v_m + (v_{sd})$	$v_m + 2(v_{sd})$

The wind data for the same site has been analyzed from the data sources [`www.windworldwide.com`] and obtained wind mean speed and standard deviation. The Weibull pdf has been plotted, and the average probable power of each state has been computed. The hourly average wind power generation/day/specific period is the sum of the power of all states obtained from equation:(2.19), and wind energy /day has been estimated as equation:(2.18). The result is shown in Table: 2.9

Table 2.9: Wind parameters and energy generated considering wind states

	Time period			
Wind statistics	Jan- march	April-June	July- Sept	Octo- Dec
mean wind speed	5.4	6.45	5.59	4.5
Standard deviation	5.4	4.5	4.07	3.39
Shape parameter(k)	1.02	1.34	1,41	1.3
Scale parameter(c)	5.5455	7.0329	6.1419	4.9146
Energy generated/day(KWH)	2319	4784	3312	1256

2.6 Conclusion

It is obvious from the results that estimating energy generation/day or power production/specific time period by considering wind speed state for that period is nearly equivalent to estimating energy generation/day or power production/specific time period by considering slot wise shape parameter. However, in the case of state-wise probability, the computational steps and time are less. The accurate estimation of the site's wind power potential leads to an optimistic outcome in the case of optimal power grid planning, placement of wind-based DG, and optimal operation and control of microgrids with wind DG penetration. The wind model considering shape parameter K=2 (Rayleigh) is not always applicable to implementing a novel method from a research point of view. As a result, a detailed analysis has been performed, which can be used to plan the optimal installation, operation, and control of the power grid and scheduling of the power plant. This model is also useful for reducing estimation error in wind power forecasting and maximizing natural resource utilization in the power grid.