ASSESEMENT OF WIND ENERGY POTENTIAL IN FOUR CITIES OF GUJRAT, INDIA

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The four cities of Gujrat namely Surat, Ahmadabad, Vadodara and Rajkot were analyzed using Weibull distribution and other statistical tools to assess the wind energy potential for generating electricity at an altitude of 10 m above ground. On the basis of the wind data of twenty-two years duration, the two parameters of the Weibull distribution were computed. The scale(K) and shape parameter(C) was found to be in the range $3.14 \leq K \leq 4.52$ and $1.78 \leq C \leq 4.45$, respectively. The outcomes recommend the use of small scale wind turbine to effectively extract the wind energy at an altitude of 10 m above ground.

Keywords: Gujrat, Weibull distribution, Wind speed, Wind turbine, electricity.

1. Introduction

Fossil fuels, the key source of energy worldwide is also the reason for land air, and water contamination. Not only that, the fossil fuels like coal, petroleum, natural gas etc. used for electricity generation in power sector will disappear in near future due to its extensive use [1,2]. Owing to climate change, greenhouse gas emission and global warming, counties has switched to non-renewable to renewable energy-based power generation. Hence, the demand for clean and renewable energy sources has increased enormously in the last few decades [3]. The fuel used in renewable energy-based power generation are wind energy, ocean wave energy, firewood, solar energy, tidal energy, geothermal energy, biomass, etc. The renewable energy is inexhaustible, readily available, stable and clean to use as compared to fossil fuels. Among the various renewable energy sources available, the use of wind energy for power generation has increased manifold throughout the globe [4,5]. The energy carried by the wind are being continuously converted into electricity with the help of wind turbine mechanism. Today, wind turbine industry benefit from well-established wind energy forecasting method. Wind resource assessment is an essential and basic requirement for selection and deployment of

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wind turbines [6]. Wind speed values over the years are the primary input data that help to forecast the wind energy potential available at any location. In order to efficiently harvest the available wind energy at any location, the assessment of wind potential and accordingly proper selection of wind turbine are the decisive steps [7,8]. Hence, the assessment of wind resource must be carried out religiously and precisely as it determines the parameters, based on which wind turbine is installed.

The electricity demand in India is mostly fulfilled by the burning of fossil fuels-based power generator and Gujrat is not exception at all. Therefore, the use of renewable energy is gaining pace gradually in Gujrat, due to climate change and scarcity of fossil fuels in near future. In spite of huge potential of renewable energy resources available in different parts of Gujrat in the form of solar energy, biomass and wind energy, only a marginal part is being used for electricity generation [9]. In 1993, Gujrat was the first state in India to come with Wind Energy framework to reduce the dependence on fossil fuels and cut the emission of greenhouse gases [10]. As per Gujrat government report, the installed capacity of wind energy-based power generation has increased from 2694 MW to 5318.38 MW during 2012 to 2017. Table 1 shows the fuel wise installed capacity of Gujrat in MW (March 2012 to March 2017). Of which wind energy contributed only 19.65 percent of total installed power plant in the state of Gujrat. Thus, there is a huge scope for wind energy-based power generation in the state of Gujrat. Due to diverse geographical and climatic conditions, the wind energy resource is not same throughout the Gujrat.

Table 1

Fuel wise installed capacity of Gujrat in MW (Source: State Load Dispatch Centre, Gujrat)

Period	Fossil fuel-based power generation(MW)			Renewable energy-based power generation(MW)				Total
	Thermal	Gas	Nuclear	Hydo	Solar	Wind	Biomass	
As on 31-03-12	9649.25	3821.07	559.00	785.00	554.40	2694.00	31.20	18093.92
As on 31-03-13	12426.17	3821.01	559.00	785.00	856.81	3087.40	31.20	21566.59
As on 31-03-14	13188.09	4203.51	559.00	787.56	860.80	3351.95	31.20	22982.11
As on 31-03-15	13188.09	4906.37	559.00	787.56	973.54	3541.68	41.10	23997.34
As on 31-03-16	13781.54	4806.37	559.00	787.56	1015.86	3932.73	41.10	24924.16
As on 31-03-17	14188.44	4933.53	559.00	787.56	1229.60	5318.38	41.10	27057.60

The four cities of Gujrat – Surat, Ahmadabad, Vadodara and Rajkot are investigated for evaluating the wind to electricity generation capacity. The feasibility of extracting wind energy with the help of small or large-scale wind turbine totally depends upon the availability of wind power at that location.

2. Methodology

Four cities, namely Surat, Ahmadabad, Vadodara and Rajkot of Gujrat were selected for the study because there has been rapid rate of development in these cities and will necessitate renewable power in future. The location map of the four cities are shown in Figure 1. The wind data of twenty-two years interval from 1983 to 2004 of four cities of Gujrat, obtained from RETScreen plus database are statistically analyzed using Weibull distribution to forecast the availability of wind to electricity generation [11]. Table 2 presents the information like geographical coordinates, air density and altitude from sea level of four cities of Gujrat under investigation.

Fig. 1. Location of the cities used in this study (Source: locations on google map)

2.1 Weibull Distribution

Characterizing the wind speed at a specific location or area is extremely important to assess its energy potential. Among the several statistical distributions available, the researchers in past unanimously used Weibull probability distribution, as it best describes the wind speed distribution and remained to be most consistent and henceforth taken into account for investigating wind resource of four cities of Gujrat – Surat, Ahmadabad, Vadodara and Rajkot [12,13]. Also, the two parameter Weibull statistical distribution is found to be more precise and accurate than corresponding three parameters Weibull distribution [14]. The equations (1)

and (2) separately represent the probability density function, f(u) and cumulative density function, F(u) in terms of wind speed (u), shape parameter (C) and scale parameter (K) as.

$$f(u)=\left(\frac{K}{C}\right)\left(\frac{u}{C}\right)^{K-1}\exp.\left[-\left(\frac{u}{C}\right)^{K}\right] \quad (1)$$

$$F(u)=1-\exp.\left[-\left(\frac{u}{C}\right)^{K}\right] \quad (2)$$

Table 2

Details of four cities of Gujrat

City	Latitude (N)	Longitude (E)	Elevation (m)	Air Density (kgm^{-3})
Surat	21.2	72.8	12	1.150
Ahmadabad	23.1	72.6	55	1.152
Vadodara	22.3	73.2	137	1.135
Rajkot	22.3	70.8	138	1.154

The values of two Weibull parameter K(dimensionless) and C(m/s) plays a key role to harvest the potential of wind energy available at any site under consideration [15].

The statistical variables used in this analysis like mean (u_m) and variances (σ^2) of wind data of four cities of Gujrat are evaluated using the equations (3) and (4) individually.

$$u_m=\frac{1}{n}\sum_{i=1}^{n}u_i \quad (3)$$

$$\sigma^2=\frac{1}{n-1}\sum_{i=1}^{n}(u_i-u_m)^2 \quad (4)$$

The values obtained from equation (3) and (4) are substituted in equations (5) and (6) to estimate the two Weibull parameters K and C.

$$K=\left(\frac{\sigma}{u_m}\right)^{-1.086} \quad (5)$$

$$C=\frac{u_m}{\Gamma\left(1+\frac{1}{K}\right)} \quad (6)$$

Where, Γ is the gamma function.

The most probable wind speed (u_{mp}) represents the most frequent wind speed while the maximum energy carrying wind speed ($u_{Emax.}$) represents the wind speed at which the wind carries the maximum amount of wind kinetic energy [16]. In order to assess the wind energy resource of any site the above two statistical variables are important to evaluate and related to two Weibull parameters K and C as per equations (7) and (8) separately.

$$u_{mp}=C\left(\frac{K-1}{K}\right)^{1/K} \quad (7)$$

$$u_{Emax.}=C\left(\frac{K+2}{K}\right)^{1/K} \quad (8)$$

2.2 Wind Power Density

To measure the wind resource available at any site, the best way is to calculate the wind power density [17]. Depending upon the value of wind power density, a site is categorized into fairly decent, decent and poor site for wind to electric power generation [18]. Thus, it is inevitable to evaluate the wind power density of any city under consideration for setting up the wind energy conversion system [19]. The last step of the analysis is to evaluate the value of wind power density using equation (9) as:

$$P(u)=\frac{1}{2}\rho c^3\left(1+\frac{3}{k}\right) \quad (9)$$

Here, ρ is the air density in (kg/m^3).

3. Result and Discussion

Table 3 shows the wind data of twenty-two years duration of four cities of Gujrat namely Surat, Ahmadabad, Vadodara and Rajkot. Statistical investigation of measured wind speed data has been used widely to evaluate wind potential of different regions in different countries. These wind data were measured at an altitude of 10 m from the surface. The comparison among four cities of Gujrat in terms of average wind speed data for throughout the year is shown in figure 2.

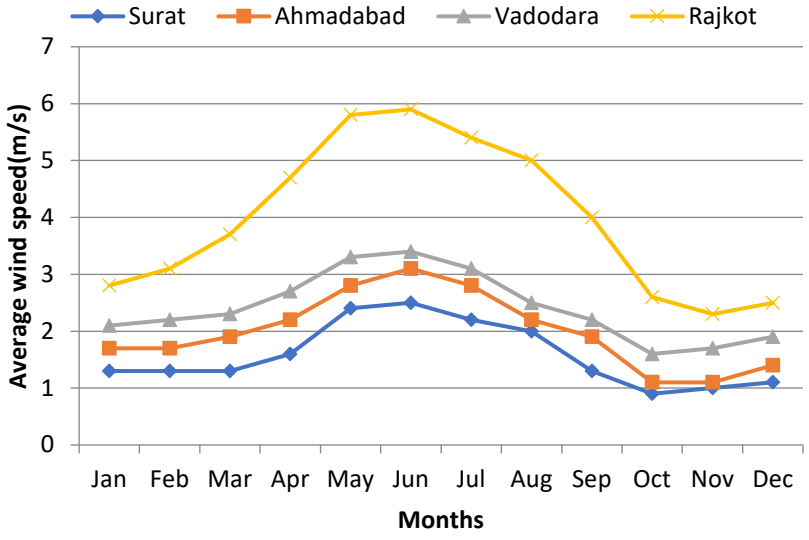

Fig. 2. Comparison among the four cities in terms of average wind speed data.

It clearly shows that Rajkot surpasses the other three cities of Gujrat with respect to wind speed available throughout the year. After going through the table 3, the wind data lies between 0.9 to 2.5 m/s for Surat, 1.1 to 3.1 m/s for Ahmadabad, 1.6 to 3.4 m/s for Vadodara and 2.3 to 5.9 m/s for Rajkot during a year. Figure 3 to 6 shows the seasonal variation of wind speed for four cities of Gujrat and it undoubtedly varies from season to season. In the winter time (Dec., Jan, and Feb.) the monthly average wind data is lower than the annual average of all cities under investigation. While in summer time (Jun., Jul., and Aug.) the monthly average wind data is higher than the annual average of all cities under consideration. During the rest two seasons i.e. spring time (Mar., Apr., and May.) and autumn time (Sep., Oct., and Nov.), there is a mixed variation of wind speed for four cities of Gujrat under consideration. Thus, the figures 3 to 6 envisage the seasons of highest and lowest possibility of extracting wind power to convert it into electricity for the four cities of Gujrat throughout a year. The evaluated statistical variables obtained from equations (3) – (9) along with two parameters of Weibull distributions of four cities of Gujrat are represented via table 3. With the help of figure 7, the two Weibull parameters are explicitly shown for four cities of Gujrat under investigation.

Table 3

Wind data of four cities of Gujrat during 22 years duration.

Month	Mean Wind Speed(m/s)			
	Surat	Ahmadabad	Vadodara	Rajkot
Jan.	1.3	1.7	2.1	2.8
Feb.	1.3	1.7	2.2	3.1
Mar.	1.3	1.9	2.3	3.7
Apr.	1.6	2.2	2.7	4.7
May	2.4	2.8	3.3	5.8
Jun	2.5	3.1	3.4	5.9
Jul.	2.2	2.8	3.1	5.4
Aug.	2.0	2.2	2.5	5.0
Sep.	1.3	1.9	2.2	4.0
Oct.	0.9	1.1	1.6	2.6
Nov.	1.0	1.1	1.7	2.3
Dec.	1.1	1.4	1.9	2.5
Annual	1.6	2.0	2.4	4.0

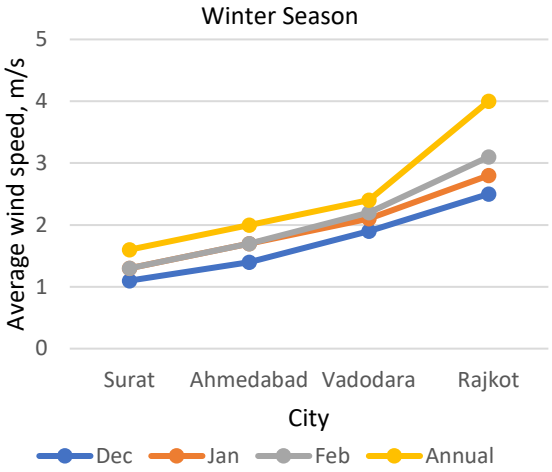

Fig. 3. Monthly Vs annual average wind speed variation during winter season

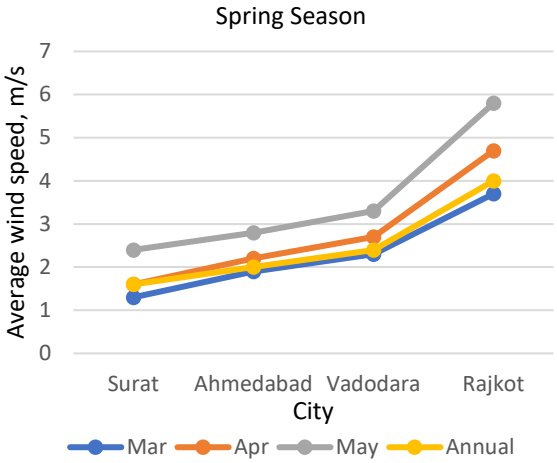

Fig. 4. Monthly Vs annual average wind speed variation during spring season

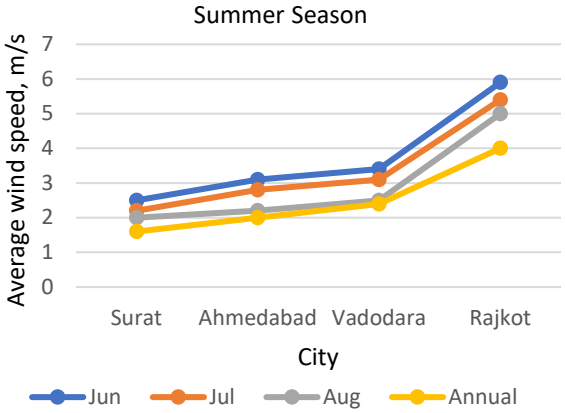

Fig. 5. Monthly Vs annual average wind speed variation during summer season

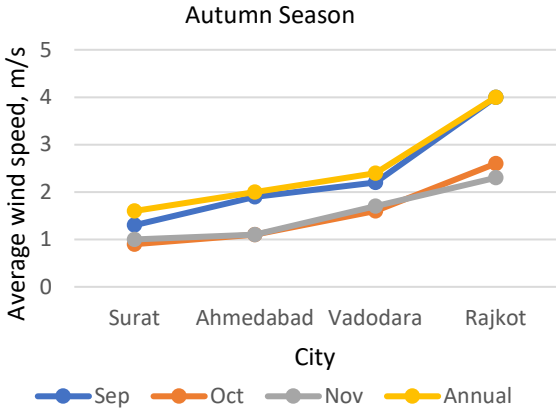

Fig. 6. Monthly Vs annual average wind speed variation during autumn season

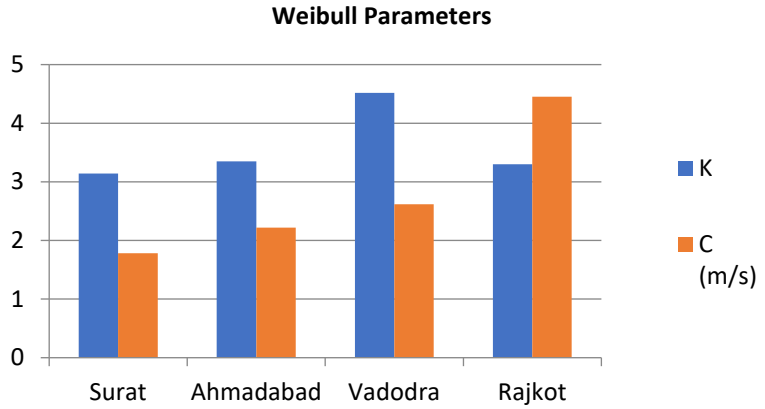

Fig. 7 Weibull parameters for four cities of Gujrat

Likewise, the values of most probable wind speed are 1.57, 1.99, 2.47, and 3.98 m/s whereas the values of wind speed carrying maximum energy are 2.08, 2.55, 2.84 and 5.13 m/s correspondingly for the four cities under consideration. It was further shown that the wind power density of four cities of Gujrat are 6.31 W/m^2 for Surat, 11.90 W/m^2 for Ahmadabad, 16.94 W/m^2 for Vadodara and 97.06 W/m^2 for Rajkot separately. The outcomes obtained of the Weibull statistical investigation for the four cities of Gujrat namely Surat, Ahmadabad, Vadodara, and Rajkot are summarized in table 4.

Wind energy-based power generation uses wind as the only resource, and their output, therefore, depends on the kinetic energy of wind present onsite. A wind resource assessment for a site is the starting point for all wind energy-based power generation projects [20].

Table 4

Result of Weibull statistical analysis

City	Unit	Surat	Ahmadabad	Vadodara	Rajkot
u_m	ms^{-1}	1.6	2.0	2.4	4.0
σ	ms^{-1}	0.557	0.657	0.599	1.33
u_{max}	ms^{-1}	2.5	3.1	3.4	5.9
K	No Unit	3.14	3.35	4.52	3.30
C	ms^{-1}	1.78	2.22	2.62	4.45
u_{mp}	ms^{-1}	1.57	1.99	2.47	3.98
u_{Emax}	ms^{-1}	2.08	2.55	2.84	5.13
P(u)	Wm^{-2}	6.31	11.90	16.94	97.06

4. Conclusion

The present study carried out an assessment for measuring the potential of wind power for generation of electric current at ten-meter height for four cities of Gujrat, namely Surat, Ahmadabad, Vadodara, and Rajkot from the wind data obtained from ground stations of past 22 years from RETScreen climate database and validated from Indian Meteorological Department local stations. The aim of the research is to benefit the lives of over 5 million people living in these four cities of Gujrat, India by utilizing the unused wind energy to convert it into electricity. The results obtained from Weibull statistical analysis along with two characteristics K and C are presented in Table 4. Based on the thorough analysis of result obtained, we found that none of the four cities are appropriate for large-scale generation of electricity from wind energy. However, the low speed wind in these locations can be wisely used to generate electricity using small-scale wind turbine or micro wind turbine at an elevation of ten meters or above from the ground. The authors too spent considerable time at the four cities of Gujrat under investigation to better understand the feasibility of wind to electricity generation.

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