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Wind Turbine Output Estimation using Windographer Software

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Abstract—Wind Resource assessment is the first step in wind power development at pre-investment stage. In this paper, using Windographer software, the capacity factor of the site is esti- mated by considering different wind turbine models. The input used for estimation are time-series wind speed and technical specifications of wind turbine models. In addition to the capacity factor, wind power density is also estimated and it is found that the site is having enough potential for wind power generation.

***Index Terms**—Wind resource assessment, windographer, power curve, capacity factor, wind power density.*

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I. INTRODUCTION

Energy is one of the crucial inputs for socio-economic development. The rate at which energy is being consumed by a nation often reflects the level of prosperity that it could achieve. Global population is increasing day by day. The population growth is more rapid in developing countries than the industrialized nations. As a result of this, overall energy de- mand is also increasing. The global energy demand is met with range of energy sources. Fossil fuels are the main source in supplying global energy demand. However, fossil fuel reserves are limited and also this usage has negative environmental im- pacts. The conventional energy sources, including coal, fossil fuels, and nuclear fuels produce emissions and by-products, such as airborne particulate, carbon monoxide, hydrocarbons, hydrochloric acid, solid ash and waste, ionizing radiation and trace elements which are harmful to the environment.

Renewable energy sources are known to provide solution to the aforementioned problems. Among the renewable energy sources, wind energy source has rapidly matured as source for power generation. Wind energy has emerged as clean, affordable, inexhaustible and environment friendly source of energy.

Wind power is harnessed by converting the kinetic energy in the wind to mechanical energy and then to electrical energy. The blade of wind machines derives its rotational energy from the kinetic energy of the wind and moves a prime- mover involving gear system, thus converting the wind energy to mechanical energy. The shaft torque drives a generator to produce electric power. It has been claimed that efficiency of conversion of kinetic energy of wind to mechanical energy is reported as 59.3 % [1], [2].

II. STATUS OF INSTALLED WIND POWER GENERATION CAPACITY

Globally installed capacity of wind turbine generators (WTGs) has crossed 432.883 GW [3]. Indian energy industries have a total installed capacity of 284.404 GW of electricity generation as on 31 December, 2015 of which about 38.41
GW [4] is from all renewable energy sources, and about
25.055 GW is from wind energy [5]. India ranked fourth in the world in the installed wind power generation capacity, with China as the leading nation with the installed capacity of
145.362 GW. Table I lists the top five countries in the wind power generation [3].

TABLE I: Installed capacity of wind power generation as on Dec 2015 [3]

S.No.	Country	Installed capacity (GW)
1	China	145.362
2	USA	74.471
3	Germany	44.947
4	India	25.055
5	Spain	23.025

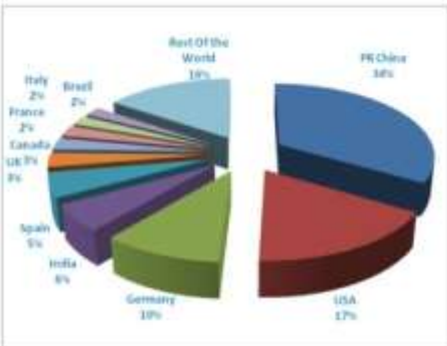

Fig. 1: Status of installed wind power generation capacity in the world [5].

Fig. 1 shows the contribution of different countries in the world in installed wind power generation capacity. The wind-power programme in India was started at the end of the sixth five year plan, in 1983-84 by the Government of India. A market-oriented strategy was adopted from inception, which has led to the successful commercial development of the wind-power programme in the country [6]. The programme includes wind resource assessment, implementation of demonstration projects to create awareness, opening up of new sites, involvement of utilities and industry, development of infrastructure capability, installation, operation and maintenance of wind turbine generators and policy support. The wind resource assessment programme has been implemented through the state nodal agencies (SNAs) by the field research unit of Indian Institute of Tropical Meteorology (IITM-FRU), Bengaluru, India. National Institute of Wind Energy (NIWE), Chennai, India is conducting re-assessment of wind resources in India.

In India, the installed capacity of WECS has reached about 25.055 GW at the end of the year 2015, against the estimated wind power potential of 49.130 GW at 50 m above ground level (AGL) [5]. The corresponding re-assessed wind power potential at 80 m (AGL) is 102.788 GW [5]. It is important to continue to re-assess available wind resource at wind farms for various reasons including likely modification of topography of certain regions and climate change in future.

Since wind power production is dependent on the wind, the output of a turbine and wind farm varies over time under the influence of meteorological fluctuations. These variations occur on all time scales: by seconds, minutes, hours, days, months, seasons, and years. Understanding and predicting these variations is essential for successfully integrating wind power into the power system and to use it most efficiently. Wind power as a generation source has specific characteristics, which include variability and geographical distribution. These raise challenges for the integration of large amounts of wind power into electricity grids. To integrate large amounts of wind power successfully, a number of issues need to be addressed, including design and operation of the power system, grid infrastructure issues, and grid connection of wind power.

III. Importance of Wind Resource Assessment

Wind resource assessment (WRA) helps wind farm devel- opers to determine the technical and economic feasibility of wind farm deployment at pre-investment stage. WRA involves measuring and analyzing the wind speed and other mete- orological data, namely, temperature, pressure, and relative humidity at a site. Other characteristics of the site which need to be determined are the distribution of wind speed, wind direction, wind power density, wind shear, and turbulence in- tensity. The annual energy production and capacity factor, the two important parameters which determine economic viability of the wind farm project are also to be estimated [7], [8].

Wind Resource assessment is time-wise extensive and ex- pensive process. The campaign is, therefore, is supported by Government in several countries. The availability of detailed data at several sites has generated confidence among wind power development. The basic steps in WRA at a site involve setting up meteorological mast for anemometer, wind vane and measuring instruments for measuring ambient temperature, pressure and humidity, with programmable data logger facil- ity. Usually, detailed time-series data on wind speed, direction at 20 m, 50 m or 80 m height above ground and data on ambient air temperature, pressure and humidity at about 3 m above ground at a prospective wind farm site.

The WRA is an extensive exercise, therefore prior to un- dertaking campaign for detailed WRA, efforts should be made to analyze available wind data for the region and estimate the wind power potential in the region. For the successful operation of a wind farm, a reliable wind resource assessment is a prerequisite . Such an analysis may consider short term data recorded over a period up to one year. The results of the analysis will be useful for defining scope for re-assessment of wind resource at the site. Wind speed data are the most important indicator of a sites wind energy resource. Also the wind direction frequency information is important for identifying preferred terrain shapes and orientations and for optimizing the layout of wind turbines within a wind farm.

A. Standard Procedure for Determining Characteristics of Wind Resource

The characteristics of wind resource can be determined on the basis of detailed wind climate data at the site. The detailed time series wind climate data can be measured at the site for a minimum period of one year as per the standard procedure [9], [10]. Alternatively, such data can also be obtained from NIWE, Chennai for certain sites. Under National wind resource assess- ment programme, Ministry through National Institute of Wind Energy, Chennai and state nodal agencies had installed and monitored 794 dedicated wind monitoring stations of height ranging from 20 m to 120 m throughout the country. Fig. 2 shows the wind energy density map of India. It is observed that high wind concentration is mainly in the states of Tamilnadu, Maharastra, Karnataka, Gujarat and Andhra Pradesh.

IV. Description of Wind Climatological Data

The site represents grid integrated wind farm in India situated at Periyapatti, TamilNadu (Lat.$10^\circ\, 45^0\, 18.5^{00}$ N , Long.
$77^\circ 15^0 11.0^{00}$E), altitude 327 m mean sea level. The site is located approximately 22 km from Udumalpet, Coimbatore, TamilNadu. The site provides detailed wind climatological data measured for a period of one year from 1 January 2011 to 31 December 2011. The wind climatological data includes wind speed and wind direction measured at 50 m height AGL. In addition, the data include air temperature measured at 6 m AGL is used for the analysis.

A. Introduction to Windographer Software

Windographer is a software package for analyzing wind resource data, whether measured by met tower, SoDAR, or LiDAR. It imports raw data files quickly, displays the data in sophisticated interactive graphics, provides powerful quality control capabilities and performs comprehensive statistical analyses, and creates high-quality output. The raw hourly time-series measured data is processed using Windographer, Ver 3.3 [11]. The measured data is represented as graphical

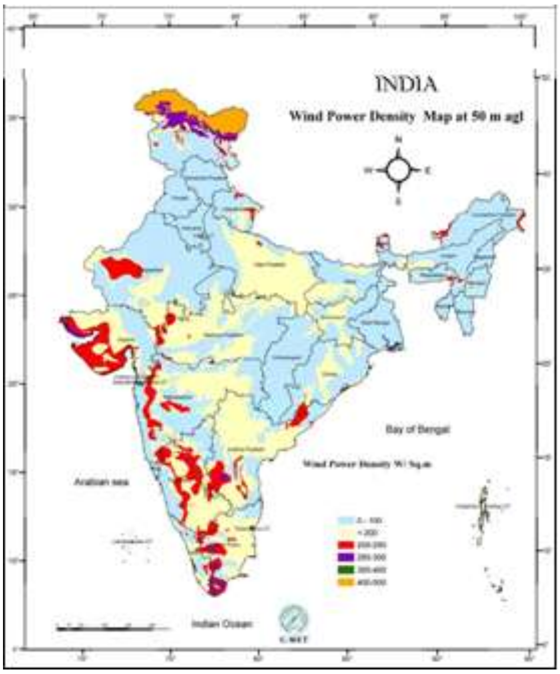

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Fig. 2: Wind power density map at 50 m height (India) [5].

time-series data and measured wind direction data is repre- sented as wind-rose diagram for the site.

Fig. 3 shows month-wise daily variation of average wind speed measured at 50 m (AGL). It is observed that the daily average wind speed varies between a minimum of 1.35 m/s and a maximum of 12.4 m/s occurring on 2 November and 1 August, respectively in 2011.

Fig. 4 shows the wind rose diagram for the site. It is observed that prevalent direction of wind during the year is from west to east for most part of the year. It is observed that the predominant wind direction varies from month to month and the site mostly experiences wind from West (55 %).

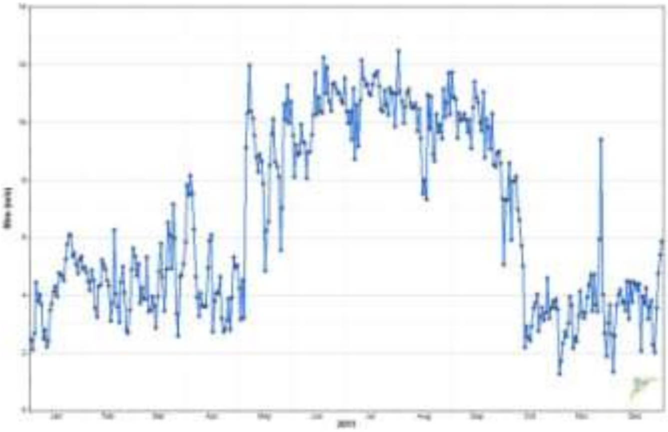


Fig. 3: Time series wind speed at the site

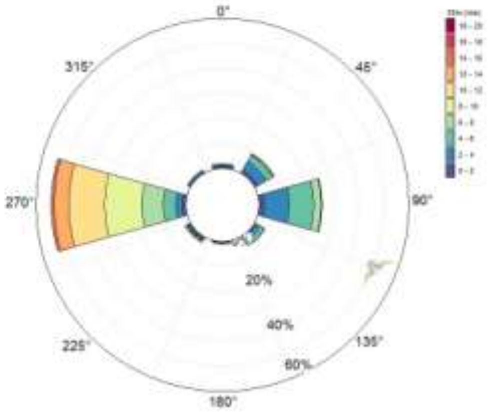


Fig. 4: Wind Rose diagram at the site

the corresponding measurement interval. The average value is calculated using equation below [12]:

$$V_m = \frac{1}{N}\sum_{i=1}^{N} V_i \qquad (1)$$

Also, then month-wise variation of wind direction is shown in Fig. 5. From the figure, it is observed that the predominant direction in the most of months in the year is west direction. The windographer software is further used to find out the distribution of wind speed in the year. The Fig.6 shows the frequency of occurrence of wind speed at a particular time period.

B. Estimation of wind power density using Windographer Software

Using the hourly wind data, the statistical parameters (av- erage wind speed and wind power density) are obtained using Windographer software, for each month and year of measurement. These are explained in this section.

1) Average Wind Speed: The average value of wind speed is calculated using instantaneous values recorded as time- series data over a measurement interval of five

minutes or ten minutes. The average value of wind speed is taken to be representing value of instantaneous wind speed at the end of

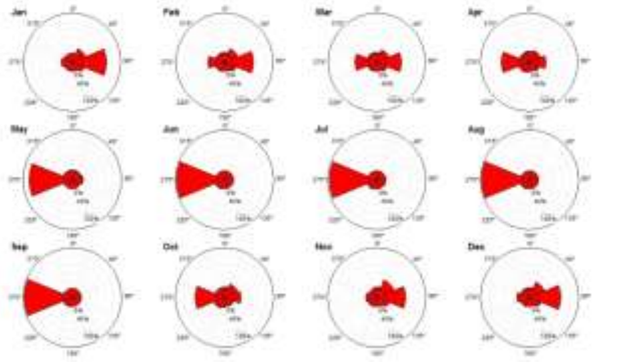


Fig. 5: Month-wise variation of wind direction at the site

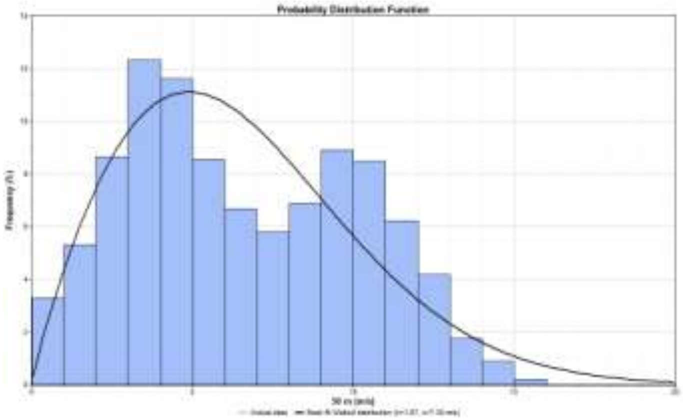


Fig. 6: Frequency distribution of wind speed (Histogram)

where, V_i, is instantaneous value of wind speed, V_m is the average value of wind speed and N is the total number of observations during ten minutes interval. The above equation can also be used to calculate hourly/ monthly/ annual average wind speed etc.

2) Wind Power Density: The measured wind speed data has been used to estimate power (P_W) in the wind (in watts), as follows [12]:

$$P_W = \frac{1}{2}\rho A V_i^3 \tag{2}$$

The instantaneous values of wind speed (Vi) and air density (ρ), 1.225 kg/m3 are used to determine wind power density using following equation [12].

$$WPD = \frac{1}{2}\rho V_i^3 \tag{3}$$

where WPD is the measured wind power density in W/m2, A is the swept area and ρ is the air density.

The month-wise variation of wind speed and wind power density are listed in Table II. It is seen from the table that the monthly average wind speed, Vm varies between minimum of 3.481 m/s occurring in month of November 2011 to maximum of 10.804 m/s occurring in July 2011, in the year. The annual average wind speed is found to be 6.583 m/s.

The windographer software uses air density (ρ), to be constant as 1.225 kg/m3. Further, this air density is used to estimate the wind power density. Thus using constant air density (ρ =1.225 kg/m3), the wind power density is calculated. From the table it is found that the wind power density varies from a minimum of 50.5 W/m2 to a maximum of 841.1 W/m2. The The annual average wind power density is found to be 336.1 W/m2.

TABLE II: Month-wise variation of statistical characteristics of the site

Month Year	V_m (m/s)	WPD (W/m^2)
Jan 2011	4.215	69.4
Feb 2011	4.232	73.8
Mar 2011	4.633	106.8
Apr 2011	4.604	118.8
May 2011	8.245	463.5
Jun 2011	10.209	741.1
Jul 2011	10.804	841.1
Aug 2011	10.137	719.4
Sep 2011	9.863	654
Oct 2011	4.696	122.7
Nov 2011	3.481	54.2
Dec 2011	3.704	50.5
Annual	6.583	336.1

V. ESTIMATION OF ANNUAL ENERGY PRODUCTION AND CAPACITY FACTOR

In this section, Windographer estimates the energy output of a wind turbine in the measured wind regime by using the selected hub height wind speed and air density in each time step to estimate the gross power output of the wind turbine in each time step. Windographer assumes that the gross turbine power output (before accounting for losses) depends on three factors: the turbine's power curve, the wind speed at hub height, and the air density. To calculate the gross power output in a particular time step, Windographer first chooses the appropriate power curve. Often the wind turbine properties comprise only one power curve, in which case no choice must be made.

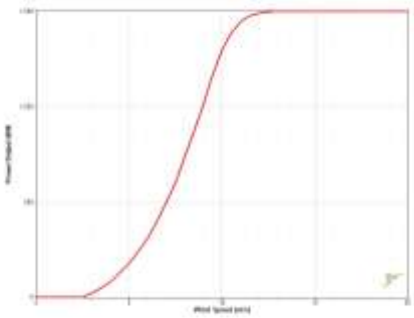
The technical specifications of different wind turbine models used to estimate annual energy production and capacitor factor are listed in Table III. In all these models considered, the wind turbine have the rated power (PR), rotor diameter and hub height are 1500 kw, 82 m and 80 m, respectively. The power curves of the different wind turbine models are shown in Fig.7.

TABLE III: Technical specification of wind turbine models

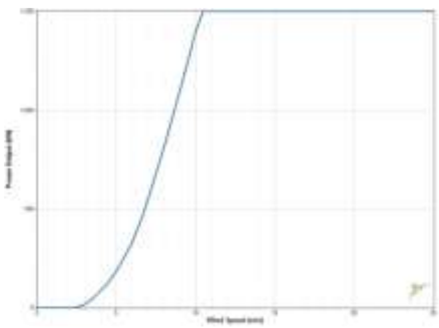
S.No.	Manufacture	Model name	Cut in m/s	Rated speed m/s	Cut out m/s
1	Acciona [13]	AW 82/1500	3	12	25
2	Dongfang[14]	DF 82/1500	3	10.5	25
3	Gold wind[15]	GW 82/1500	3	11	25
4	Sinovel[16]	SL 1500/82	3	10.5	25
5	Suzlon[17]	S82-1.5MW	4	12	20

B. Estimation of Annual Energy production (AEP)

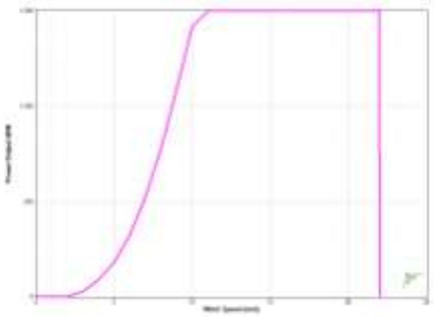
Windographer software calculates the mean net power out- put for each month of the year and for the entire data set, it multiplies these values by the appropriate number of hours to find the turbine's mean net energy output annually and by month.



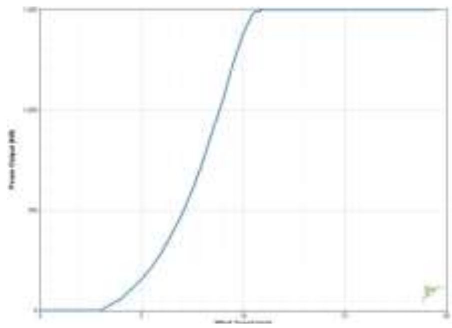
(a) Acciona



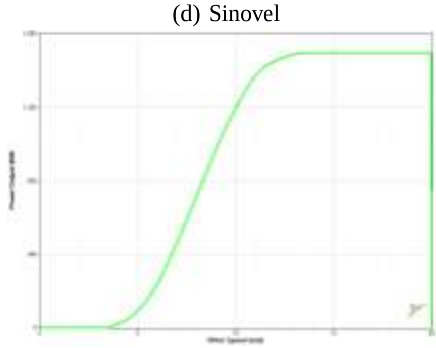
(b) Dongfang



(c) Gold Wind



(d) Sinovel



(e) Suzlon

Fig. 7: Power curves of different wind turbine model

For example, to calculate the mean annual net energy output in kWh/yr, Windographer uses the following equation:

$$AEP = P_{net}.8760 \quad (4)$$

C. Estimation of capacity factor

The capacity factor of wind power is the ratio of average delivered power to theoretical maximum power. It can be computed for a single turbine, a wind farm consisting of dozens of turbines or an entire country consisting of hundreds of farms. Although geographical location determines in great part the capacity factor of a wind farm, it is also a matter of turbine design. The Windographer software calculates the net mean power output for the entire data set and it compares this value to the turbine's rated power to determine the net capacity factor . For example, to calculate the capacity factor (C_f), Windographer uses the following equation:

$$C_f = \frac{P_{net}}{P_R}.100 \quad (5)$$

The annual energy production and capacity factor thus calcu- lated are listed in Table IV. From the table it is found that the maximum capacity factor is found to be 44.5%.

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TABLE IV: Annual Energy production and capacity factor of the site

S.No.	Manufacture	AEP kwh/y	C_f %
1	Acciona	5615047	42.7
2	Dongfang	5862744	44.6
3	Gold wind	5843364	44.5
4	Sinovel	5686587	43.3
5	Suzlon	5204867	39.6

VI. CONCLUSIONS

In this paper, use of industry standard simulation tool, namely, Windographer software to estimate the annual energy production and capacity factor of different wind turbine models is demonstrated. The following conclusions are drawn:

1) The annual average wind speed at mast location is found to be 6.583 m/s.
2) The annual average wind power density is estimated as 336.1 W/m^2 .
3) The maximum AEP and capacity factor of the site are found to be 5862744 kwh/year and 44.6 %, respectively.

VII. ACKNOWLEDGMENT

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