EXPERIMENTAL INVESTIGATION, OPTIMIZATION AND PERFORMANCE PREDICTION OF WIND TURBINE(S) FOR COMPLEX TERRAIN

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Abstract

Man has been doing business with Winds since a very long period of time; the wind power has been used as long as humans have put sails into the wind. For more than two millennia wind powered machines have ground grain and pumped water. This affiliation of man and wind is inexhaustible which makes Wind Energy a very significant and rapidly developing renewable energy sources in all over the world. But when it comes to electricity generation by harnessing the wind energy, indeed, it requires more technicality, since it requires a great need for correct and reliable installations of new wind turbines in a more optimized way for smooth operations and electricity productions, and for that, a precise knowledge of wind energy regime is a prerequisite for the efficient and optimized extraction of power from the wind. The main purpose of this paper is to present, in brief, wind potential and to perform an investigation on wind flow characteristics at RGPV Hill Top. In this work the recorded time series wind data for a period of five months as from july-2013 to November-2013 at the heights of 20 meters and 40 meters was fetched and analyzed for studying the observed wind climate, which was recorded by the NRG Symphonie Data logger wind mast installed at Energy Park, RGPV campus with an fixed averaging interval of 10 minutes, the analyzed data which was worked upon comprises of wind speed data in meter per second and its direction of flow in degrees. As a part of this work, the Wind Atlas Analysis and Application Program (WAsP) was employed to predict average mean-wind speeds for all directions for some desired sites. The influences of roughness of the terrain, for the area were also taken into consideration, followed by the vector map of the area. These data were analyzed using WAsP software and regional wind climate of the area was determined, leading to a wind resource map of the whole site, providing crucial details which helped in selecting the proposed turbine sites. Also, the AEP for the two already installed turbines was calculated.

Keywords: *WAsP, AEP, Wind resource, Wind Rose*

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1. INTRODUCTION

Limited reserves of fossil fuels and their negative impacts on the environment lead institutions, organizations and governments to find out more efficient technologies and new and renewable energy resources to produce energy in the natural environment. Recently, wind energy is the growing energy source in the world and wind power is one of the most widely used alternative sources of energy. The effective utilization of the wind energy entails having a detailed knowledge of the wind characteristics at the particular location. The distribution of wind speeds is important for the design of wind farms, power generators and agricultural applications such as the irrigation. It is not an easy task to choose a site for a wind turbine because many factors have to be taken into account [1].

By knowing the wind characteristics in any region will help greatly in identifying windy sites which is crucial for the successful installation and operation of wind turbines. The suitable windy sites are necessary in order to assess the maximum possible electricity that could be generated by a wind turbine at that particular site at the minimum cost [2]. For the commencement of any wind energy project, the first essential step is the identification of suitable sites and prediction of the economic viability of the wind project. So, the analysis of wind characteristics and the prediction of the climate in any specified region could greatly help in identifying areas with maximum power density which further allows the best possible installations and operations of wind turbines.

2. APPLICATION OF WASP ON RGPV HILL TOP

WAsP Wind software is a tool for evaluating the wind conditions of a specific site, taking into consideration the local influences, by applying the wind data of a suitable reference point to this site [3]. Provided with the time series wind data which was recorded by the wind mast installed inside the campus at Energy Park, the data was analyzed and processed accordingly to the standard file as required by the WAsP. And by utilizing the SRTM data the vector map of the specified area was developed to study the orography and roughness of the terrain. To be able to predict the wind climate and eventually the wind potential of the site, the 'observed wind climate' of the area was developed using WAsP and by taking into account the influence of roughness of the terrain, obstacles nearby the site and the topography, now also, this study allows further research to calculate annual energy prediction at any specific desired location. Therefore, eventually the AEP for two already installed turbines was also calculated which are installed at the RGPV hill site.

3. OBJECTIVES OF THE STUDY

1. Acquisition and analysis of time series data.
2. Preparation of vector map of the RGPV hill including the nearby area.
3. Classification of terrain features and roughness description along with a roughness map
4. Determining the observed wind climate at the mast site
5. Preparation of Generalized wind climate for the site
6. Estimation of AEP of installed turbines
7. Selection of feasible locations for turbine sitting.

4. DESCRIPTION OF THE SITE

The study site is located inside the Rajiv Gandhi Proudyogiki Vishwavidyalaya campus, with a geographical coordinates at 23.307° Lat and 77.363° Lon, which is an isolated hill. The institution is near Gandhi Nagar on the outskirts of the city, 3 km from the airport on the Gwalior bypass road. The campus is spread over 241.14 acres (0.9759 km2). The campus has instruction blocks, workshop, library block, nanotechnology block, School of Energy and Environment block and Administrative block [4].

5. DESCRIPTION OF THE MONITORING SITE

The wind data for the purpose of study was recorded by the NRG Symphonie data logger which is installed inside the Energy Park and the wind data was fetched for a period of five months at two mast heights of 20 and 40 meters with a geographical location of East 077' 21.668 and North 23' 18.720 and the elevation of mast base is 591 meters.

The mast is shown in figure 1, it is a 3 cup type anemometer with measuring heights of 20 and 40 meters and two wind vanes at the heights of 38 and 20 meters. It also provides the measurements for Temperature, relative humidity, atmospheric pressure and rain gauge.

A data logger was connected with all sensors on the mast to collect data in time series. , and the data logger was Symphonie data logger which has a fixed averaging interval of 10 minutes. Each of the 12 channels' averages, standard deviations, minimum and maximum values are calculated from continuous 2 second data samples. Data intervals are calculated every 10 minutes, time stamped with the beginning time of each interval and written to the Multimedia Card (MMC) at the top of each hour.

Fig 1- Wind mast at Energy Park, RGPV

5.1 Topography of RGPV Hill and Nearby Area

Topography of any specified area is essential in describing the elevation also known as orography and land cover also known as surface roughness of the area surrounding the calculation sites such as meteorological stations, reference sites, turbine sites or the sites in a resource grid. For this purpose WAsP uses vector maps to get information about the elevation (orography) and land cover (roughness) characteristics of the landscape in which the modelling is being done [5].

Fig 2 - Satellite image of the Area

Mortensen et. Al., have reported that it is possible to obtain accurate assessment of stable wind speed which are close to the measured values with maps of 8 x 8 sq. Km and the influence of contour interval on the accuracy of wind speed prediction [7].

This study includes the vector map of the site which covers an area spread about 28 sq. Kms having width of 6.7 km and height of 4.1 km. The map used in this study has 143 elevation contour lines and the map was transformed to the Universal Transverse Mercator (UTM) projection with the datum of WGS 1984. The area falls in Zone 43 with the central meridian of +75° E, with elevation ranging from a low of 450 m to a high of 546 m.

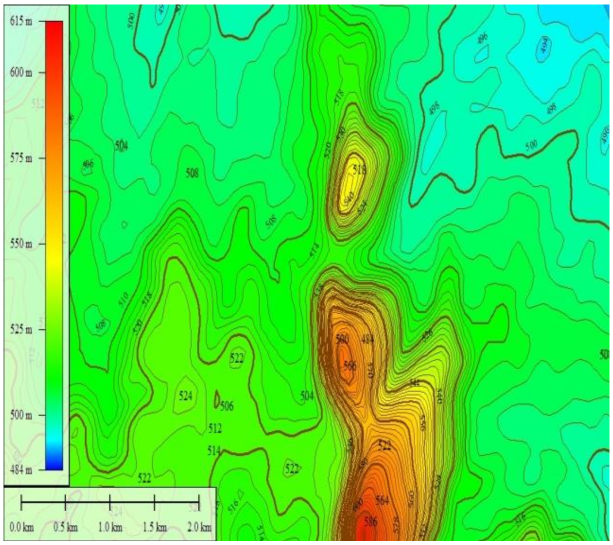

Fig. 3 -Vector map of RGPV hill showing elevation contours

5.2 Obstacles near the Measuring Site

Obstacle groups are used to describe objects in the vicinity of one or more calculation sites (met. station, turbine site or reference site) which might affect the behaviour of the wind at the site. Examples of sheltering obstacles include buildings, shelter belts and groups of trees. Each obstacle present near the measuring site affect the wind data collected and it depends upon porosity and roughness of the terrain [5].

In this study the obstacles were specified by their position relative to the measuring mast site and the dimensions of each obstacle was assigned along with the porosity of each obstacle. Positions of all the obstacles were specified in a polar coordinate system. Angles (bearings measured with a compass) from the mast to the front side corners of each obstacles are measured and specified in clockwise from north, radial lenghts between the front side corners and the mast was measured and specified.

The list and location of obstacles for the wind monitoring station for incorporation as a WAsP obstacle file is shown in TABLE 2 and the plot shown in FIG.4, TABLE shows the reading for the two Angles from the mast location to the two corners of the obstacle (A1 & A2), Radial lenghts between the mast and the corners (R1 & R2), height, depth, and the porosity of the obstacle.

Table 1: List of obstacles

ID #	A1[]	R1[m]	A2[]	R2[m]	Ht. [m]	D	Por.
1	2.8	106	3	87	10	37	0.50
2	21	126	25	104	10	72	0.50
3	50	159	55	150	10	36	0.50
4	63	188	79	171	10	55	0.50
5	70	130	77	125	10	40	0.50
6	39	69	52	55	10	70	0.50
7	111	39	143	20	10	20	0.50
8	94.2	117	96	45	10	19	0.50
9	94	134	102	126	10	35	0.50

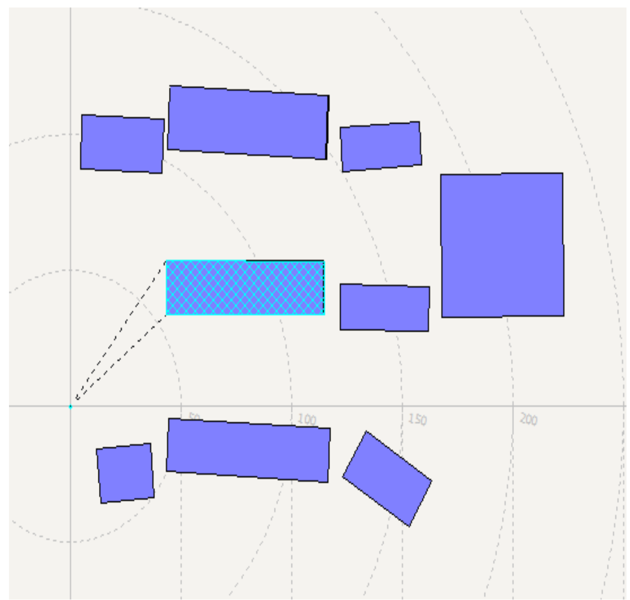

Fig. 4 - Obstaceles group near the measuring site

6. OBSERVED WIND CLIMATE AT ENERGY PARK

The analysis of time series data of meteorological data to obtain the observed wind climate is done by Climate Analyst, and the result of these analyses is the summaries which describes some aspect of the climate. The observed wind climate file contains the frequencies of occurrence of the wind in a number of sectors (the wind rose) and wind speed bins. It further contains the height of observation above ground level and the geographical coordinates (latitude and longitude) of the wind mast [5].

The observed wind climate (OWC) represents as closely as possible the long-term wind climate at anemometer height at the position of the meteorological mast [5], [6]. The discrepancy calculated in the measured and Weibull fitted values of mean wind speed and mean power density for 20 m is shown in Table-I.

Table 2: Discrepancy in mean wind speed & mean power density at 20 m

	Mean wind speed	Mean power density
Measured	2.55 m/s	19 W/m2
Weibull fit	2.58 m/s	20 W/m2
Discrepancy	1.4 %	2.0 %

The values of weibull parameters (A, k), mean wind speed (U), mean power density (P) and frequency of all 12 sectors (0° to 359°) are calculated from WAsP OWC Wizard and recorded in Table-3 for 20 m height.

Table- 3: sector wise parameters at 20m

sectors	A	k	U	P	f
0	2.9	1.78	2.56	22	4.9
30	2.4	2.08	2.09	10	8.6
60	1.9	1.81	1.72	7	13.1
90	2.0	1.83	1.77	7	10.3
120	2.0	2.12	1.76	6	4.5
150	1.6	2.61	1.42	3	1.9
180	2.4	2.10	2.15	11	1.9
210	3.1	2.40	2.72	20	6.5
240	3.3	2.40	2.91	25	11.4
270	3.8	3.00	3.36	33	19.7
300	3.7	3.42	3.33	30	11.9
330	3.3	1.96	2.89	29	5.3

7. WIND ROSE AND HISTOGRAM

Wind direction is one of the wind characteristics. Statistical data of wind directions over a long period of time is very important in the site selection of wind farm and the layout of wind turbines in the wind farm [7].

The wind rose diagram is a useful tool of analyzing wind data that are related to wind directions at a particular location over a specific time period (year, season, month, week, etc.). This circular diagram displays the relative frequency of wind directions distributed among all the directions.

It is noticed that strong winds usually come from a particular direction, hence to show the information about the distributions of wind speeds, and the frequency of the varying wind directions, the Wind Rose diagram has been prepared [8].

The wind rose diagram showing relative frequencies of wind direction for each sector and the histogram graph of the frequencies of wind speeds at 20m mast heights is shown in figure 5.

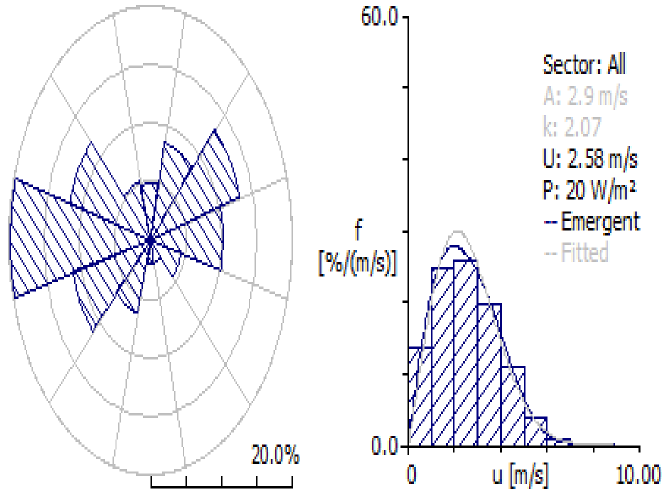

Fig. 5 - Wind Rose and Weibull distribution for 20 m at RGPV Energy Park mast

8. ESTIMATION OF POWER PRODUCTION OF TURBINE

The total energy content or the potential in the wind to produce power is calculated by WAsP. Furthermore, an estimate of the actual, annual mean energy production of a wind turbine can be obtained by providing WAsP with the power curve of the wind turbine in question [5].

The equation used by WAsP for calculating the mean power production of a wind turbine is shown below. With WAsP, the total or Omni-directional power production is calculated as the sum of the sector-wise power productions.

Once the power curve P (u) is measured for a wind turbine, the mean power production can be estimated provided the probability density function of the wind speed at hub height is determined either by measurements or a siting procedure [5]:

$$P = \int_0^\infty \Pr(u)P(u)d(u)$$

For the estimation process, the power curve of the installed wind turbine(s) was developed, namely 10 KW machinocraft wind turbine generator. The power curve was developed by Turbine Editor, which is a utility tool of WAsP. The power curve shown below in the figure 6 is a graph between wind speed in m/s and power in KW along with the thrust coefficient of the wind turbine.

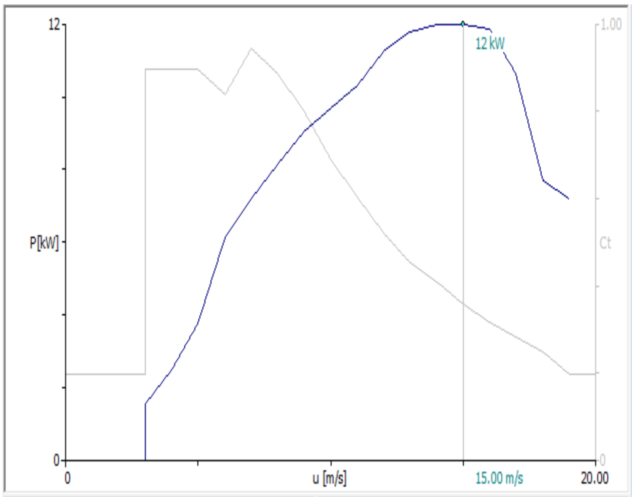

Fig. 6 - Power curve of 10 KW machinocraft wind turbine generator

The result generated by WAsP displayed as a Rose diagram shows the distribution of power density at the turbine sites at a hub height of 20 m.

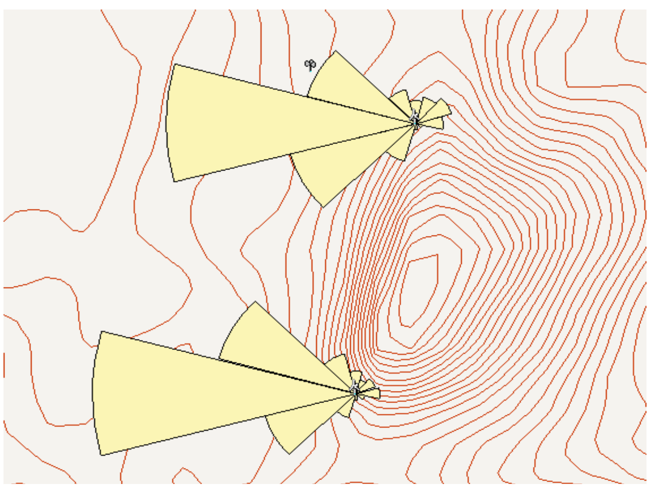

Fig.7 - Power Density Rose at 20 m

Table 4: Turbine Site Results

Site	Turbine site 01	Turbine site 02
Location in UTM [m]	741580.3, 2579111.0	741742.3, 2579906.0
Turbine	Machinocraft 10 KW wind turbine generator	
Elevation [m a.s.l.]	523.3293	522.7935
Height [m a.g.l.]	20	20
Net AEP [MWh]	10.537	11.035
Wake loss[%]	0.24	0.01

9. CONCLUSIONS

The following points are concluded from this study-

1. Wind data was recorded at Energy park wind mast for the duration of five months from July-2013 to November 201, in order to study the prevailing wind climate at the site.
2. Recorded wind data was further analyzed to extract the values for mean wind speed and mean power density at the recording site, and which was found out to be 2.55 m/s and 19 W/m^2 respectively at the height of 20 meters.
3. In order to predict the wind climate at the desired site, 'generalized wind climate' was calculated for reference height of 20 m on the basis of observed wind climate at the recording site.
4. A wind rose diagram was prepared in order to determine the relative frequencies of wind direction for each sector at the wind recording site. And it was observed that the prevailing direction for the wind flow was sector 10 which corresponds roughly towards West at both reference heights.
5. On the basis of observed wind climate report, it was inferred that the minimum wind speed was 0.40 m/s and 9.80 m/s was the maximum value of wind speed at the height of 20 m.
6. Mean power density calculated for the mast location was 19 W/m^2 for the reference height of 20 m.
7. To study the effects of roughness on the wind flow the roughness of the whole area surrounding the site was put into consideration and the area was divided into various roughness classes, and as a result it was observed that roughness is a crucial factor in predicting the wind flow and climate.
8. In order to calculate an estimate for the annual power production by installed wind turbines, the power curve for the 10 KW wind turbine was calculated using Turbine Editor utility tool.
9. The net AEP calculated for the turbines at turbine site 01 and 02 was 10.537 MWh and 11.035 MWh respectively.

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