International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Analysis of Vertical Axis Windmill Turbine for Electricity Generation on Highways

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Accepted 01 Oct 2016, Available online 05 Oct 2016, **Special Issue-6 (Oct 2016)**

Abstract

In today's life the demand on electricity is much higher than that of its production, the main objective is to produce electricity by using the force of air created by the moving vehicle in highways, Electricity can be generated by using the VERTICLE AXIS HIGHWAY WINDMILL. This is a new unique method of power generation. In this method the windmill blade is designed in a vertical direction and it is kept at the middle of the highway divider by a series combination. The force in the middle portion is higher than the side of the road .This force will rotate the vertical turbine blade and this blade is coupled with the generator which produces electricity. In this method one additional generator is coupled to increase the efficiency. The vertical axis wind turbines are not readily available in the market and not found in India but the horizontal axis wind turbine is found. Most of the research is on experimental side on determination of mechanical power and power coefficients. Various design configurations give different power performance outputs which again depend on the wind velocity. Hence the experimental study using wind tunnel is necessary to generate the data for different wind speeds. The selection of rotor parameters plays an important role to achieve the power performance. It is also important to study the effect of combinations of rotor for different aspect ratio and number of stages to achieve maximum power performance coefficient. This research aims to develop a savonius type Vertical Axis Wind Turbine capable to run on lower wind conditions in India.

Keywords*: Aspect ratio, horizontal axis wind turbine, power coefficients vertical axis wind turbine, and wind velocity*

1. Introduction

Developed modified Savonius wind rotors and electrical power generated was measured. The experimentation was carried out at different locations such as in the city and on the beach. In the findings with optimum design chosen generates 13.2 volt and 0.380 mille-ampere current at 4.96 m/s wind velocity with central shaft rotation about 68 rpm. The material used for rotors was galvanized sheets which may cause the effect on power performance. The study was carried out for only one type of rotor design and experiment was carried out in open atmosphere not with the wind tunnel. With the experiment at open to atmosphere the exact wind speed is not possible to set (VinayP. V.,*et al*, 2012).

His study basically deals with the conception of a small Savonius rotor for local production of electricity. Design, development and ultimately fabricating a prototype, as a complete electromechanical system were studied. An optimized configuration was chosen for the geometry of the present prototype. The building data were calculated on the basis of the nominal wind velocity V=10 m/s. Particular care was necessary to choose the appropriate generator, which was finally a rewound conventional car alternator. The power performance study required for lower wind speed for such type of wind turbines (J L Menet , *et al*, 2004).

In this work, different geometries of Savonius wind turbine are experimentally studied in order to determine the most effective operation parameters. It was found that, the two blades rotor is more efficient than three and four ones. The rotors without overlap ratio, β are better in operation than those with overlap. The results show also that the power coefficient increases with increasing the aspect ratio (N.H. Mahmoud, *et al*, 2012).

This work conducted with wind tunnel tests on 14 prototypes of Savonius rotor models first time in India. All theturbines are with same overall dimension. The study was performed on variation of number of blades, the number of stages and their respective combinations. Both semicircular and twisted blades have been used in either case. A family of rotor systems was manufactured with identical stage aspect ratio keeping identical the projected area of each rotor. The overlap ratio, being another important geometrical

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parameter has been suggested to be around 20% to 30% for the models. Experiments were carried out to optimize the different parameters like number of stages, number of blades and geometry of the Rotor. Further attempt was made to investigate the performance of two-stage rotor system by inserting valves on the concave side of blade. Velocities of wind speeds were considered between the range of 6 m/s and 11 m/s. Spanning 84 experiments on all these parameters, the 2 stage 2 Rotor Savonius model was considered to be showing the highest value of power coefficient. Among a comparison between the semicircular and the twisted ones, the twisted model was found to be more efficient than the semicircular one. The semicircular Rotor is less costly and easy for manufacturing (U. K. Saha, *et al*, 2006).

In this work new curtain arrangement provided to improve the performance of Savonius wind rotors. The curtain arrangement was placed in front of the rotor preventing the negative torque opposite the rotor rotation. The geometrical parameters of the curtain arrangement were optimized to generate an optimum performance. The rotor with different curtain arrangements was tested out of a wind tunnel, and its performance was compared with that of the conventional rotor. The maximum power coefficient of the Savonius wind rotor is increased to about 38.5% with the optimum curtain arrangement. The experimental results showed that the performance of Savonius wind rotors could be improved with a suitable curtain arrangement (Burcin Deda Altan, *et al*, 2008).

Modified forms of the conventional Savonius rotors in an effort to improve the coefficient of power and to obtain uniform coefficient of static torque. To achieve these objectives, the rotors are being studied with and without central shaft between the end plates. Tests in a closed jet wind tunnel on modified form of the conventional Savonius rotor with the central shaft were to have a coefficient of power of 0.32. They studied the effect of geometrical parameters on the performance of the rotors in terms of coefficient of static torque, coefficient of torque and coefficient of power. The parameters studied are overlap ratio, Rotor arc angle, and aspect ratio and Reynolds number(M.A. Kamoji ,*et al*,2009).

Study of 2, 3, 4, 5 and 6 Rotor Savonius rotor is carried out for aerodynamic performance. It is concluded that six bladed vane type rotors provides more power than other two, three, four and five bladed vane type rotor but power coefficient is rather low and measured about 0.16 (Shamsun Nahar, *et al*, 2011).

Wind Turbine Classification

a) Horizontal Axis Wind Turbines (HAWT)

Horizontal-axis wind turbines (HAWT) get their name as per their axis of rotation which is horizontal. The random nature of wind distribution and speed needs the requirement of a gear system connected with the rotor and the generator. The gear system makes a constant speed of rotation to the generator thus enables constant frequency electrical power generation.

Advantages

1) Higher efficiency, better performance.
2) Variable Rotor pitch, which gives the turbine blades the optimum angle of attack.
3) More commercially viable.
4) As wind energy increases with height, the tall tower in the HAWT gives access to higher wind speed.

Disadvantages

1) Due to inherent large structures, construction costs are very high and transportation costs.
2) Production of noise due to wind turbine operation.
3) In case of VAWT's (downwind) the regular turbulence produced leads to structural failure.
4) HAWT's requires an additional yaw control mechanism to turn the blades toward the wind which leads more constructional cost.

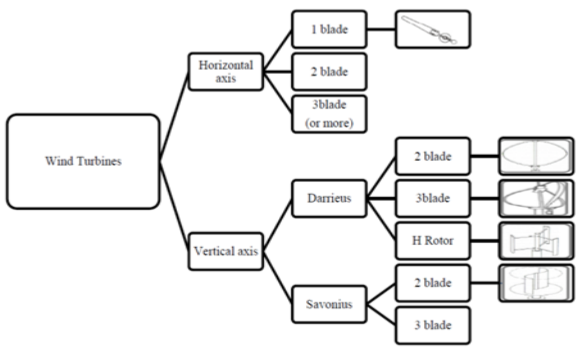

Fig.1 Wind Turbine Classification

b) Vertical Axis Wind Turbines (VAWT)

Vertical-axis wind turbines (VAWT) have the main rotor shaft arranged vertically as the plane of rotation is vertical to the earth's surface. Blades are also vertical in this arrangement. The biggest advantage of VAWT is, it don't require a yaw control mechanism to be faced into the direction of wind. So VAWT don't require a taller tower structure and can be placed on a ground enabling access to electrical components. Some drawbacks are the low efficiency of wind production and the fact that large drag is created for rotating the blades in a vertical axis.

Advantages

1) A massive tower structure is not required, as are mounted on the ground and hence easier for maintenance.
2) No requirement of yaw mechanisms.

3) Can be located closer to the ground Lower startup speeds than their horizontal counterparts.
1) Can be stalled - on rooftops, along highways, in parking lots.
2) Do not kill birds and wild - life - slow moving and highly visible.
3) Can be significantly less expensive to build due to inherent simpler structure.

Disadvantages

1) VAWTs' have lower efficiency as compared to HAWT's.
2) Even though VAWTs' are located on the ground, the equipment now resides at the bottom of the turbines structure thus making it inaccessible.
3) Because of their low height they cannot capture the wind energy stored in higher altitudes.

2. Savonius Vertical Axis Wind Turbine

Savonius wind turbines are drag based VAWTs that operate on the theory and principle of a paddle propelling a boat through water. It was invented by a Finnish engineer, Sigurd Johannes Savonius in 1922. If no slip exists between the paddle and water, the maximum speed attained will be the same as the tangential speed of the paddle. Similarly, in a drag based VAWT, the speed at the tip of the Rotor can seldom exceed the speed of the wind. In other words, the drag can also be described as the pressure force or the thrust on the blades created by the wind as it passes through it. Various types of drag based VAWTs have been developed in the past which use plates, cups, buckets, oil drums, etc. as the drag device. The Savonius rotor is an S - shaped cross section rotor which is predominantly drag based, but also uses a certain amount of aerodynamic lift.

Drag based VAWTs have relatively higher starting torque and less rotational speed than their lift based counterparts. Furthermore, their power output to weight ratio is also less .Because of the low speed, these are generally considered unsuitable for producing electricity, although it is possible by selecting proper gear trains. Drag based windmills are useful for other applications such as grinding grain, pumping water and a small output of electricity. A major advantage of drag based VAWTs lies in their self-starting capacity.

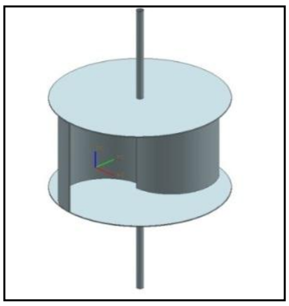

Fig. 2 Savories VAWT

3. Basic equations used in wind energy conversion system

3.1 Swept area (A)

The swept area is the section of air that encloses the turbine in its movement, the shape of the swept area depends on the rotor configuration

$$A = 2\,R\,H \quad (1)$$

Where
A = swept area (m^2)
R = rotor radius (m)
H = Height of rotor (m)

3.2 Power (P_{rotor}) and power coefficient (C_p)

$$P_{rotor} = \tfrac{1}{2}\,\rho A V^3 \quad (2)$$

Where
V = velocity of the wind (m/s)
ρ = air density (kg/m3);
Reference air density used its standard sea level value (1.225 kg/m^3 at 15ºC)

$$C_p = \frac{Pm}{protor} \qquad \text{Where } P_{m=} \left(\frac{2\pi NT}{60}\right) \quad (3)$$

C_p represents the part of the total available power that is actually taken from wind

3.3 Tip speed ratio (λ)

The tip-speed ratio, λ for wind turbines is the ratio between the tangential speed of the tip of a rotor and the actual velocity of the wind *V*

$$\lambda = \frac{\text{Tip speed of blade}}{\text{Wind speed}}$$

Where Ω is the rotor rotational speed in radians/second, and *R* is the rotor radius in meter.

3.4 Solidity (σ)

Solidity is defined as total Rotor area divided by the swept area. The solidity could also have been changed by changing the Rotor chord.

$$\sigma = \frac{nc}{2\pi r} \quad (4)$$

Where,
n = Rotor number
c= chord length at that element
r= radius at that element

3.5 Cut-in Speed ($V_{cut\text{-}in.}$)

Cut-in speed is the minimum wind speed at which the wind turbine will generate usable power. This wind speed is typically between 3 and 5 m/s.

3.6 Rated Speed (V_{rated})

The rated speed is the minimum wind speed at which the wind turbine will generate it designated rated power. Rated speed for most machines is in the range of 11 to 13 m/s.

3.7 Rated power (P_{rated})

Power produced at the rated speed is called rated power which is also called installation capacity of wind turbine. At wind speeds between cut-in and rated, the power output from a wind turbine increases as the wind increases.

3.8 Cut-out Speed ($V_{cut\ out}$)

At very high wind speeds, typically between 15 and 25 m/s, most wind turbines cease power generation and shut down. The wind speed at which shut down occurs is called the cut-out speed. Having a cut-out speed is a safety feature which protects the wind turbine from damage.

4. Design considerations

This Design of wind turbine aims to

1) Develop Savonius type vertical axis wind turbine capable to run on lower wind speed conditions in India
2) To Design a wind turbine to recapture wind energy from vehicles on the highway
3) Design Wind Turbine in Cities and to make use of wind energy
4) To harvest a maximum amount of non-conventional wind energy as it is clean and reliable

5. Experimental set up

Experimentation is done to find the effect of variation in wind velocity and respective power output at that velocity. Following are the steps followed to conduct experimentation.

Step 1 Development of an Experimental Set Up

a) Rotor blade
b) Mild steel chassis to support
c) Dynamo for conversion of mechanical energy into Electrical.
d) Electrical arrangement for output.

Step 2 Experimentation & Measurement

a) Experimentation on savories rotor with available source of wind velocity and calculating different RPM of rotor.
b) Experimentation on different highways to calculate average range of wind velocity with the help of anemometer.
c) Calculated respective output power.
d) Measuring the rotational speed of the central shaft using tachometer.
e) Measurement of voltage and current through alternator using multi meter.

Step 3 Experimental set up

Completing an experimental set up is a challenging task of gathering the fabrication technique, angle bar welding and sheet metal work together.

Fig.3 Experimental set up

The rotor supported vertically in steel housing, Chassis. This chassis fabricated with mild steel angle bars which are welded suitably to withstand the weight of Savonius rotor which is being rotated at higher wind velocity. This chassis plays an important role of support and needed essentially to take accurate readings while testing on Savonius rotor.

6. Design calculations

From the measured values of mechanical torque and rotational speed, the mechanical power can be estimated at each wind speed as

$$P_m = \omega \mathrm{T}(\mathrm{Watt}) \quad (5)$$

Where, '**T**' is the mechanical torque and '**ω**' is the angular speed.
The angular speed is defined in **rad/s** as

$$\omega = \frac{2\pi \mathrm{N}}{60} \quad (6)$$

Where, '**N**' is the shaft rotational speed in rpm which is measured with the help of digital tachometer.
The power coefficient 'C_p' can be determined from the following equations

$$C_p = \frac{Pact}{\mathrm{Protor}} \quad (7)$$

Where 'P_{rotor}' is theoretical power calculated from the equation.

7. Fabrication

Rotor

The Rotor is single stage. There is only single orientation of the Rotor throughout the height of 550 mm. Rotor is as shown in the following fig.4 Only two plates are attached at its end to increase the power performance

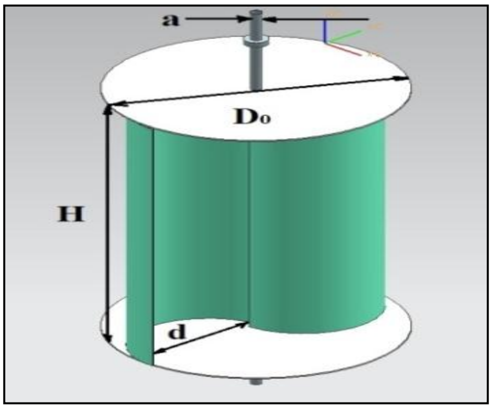

Fig.4 Rotor

The followings are the dimensions of the blades used for Rotor.

Dimensions – Rotor

Table 1 The performance at the (MMIT workshop with an tempt of 290c and density of air is 1.18kg/m3)

Dimensional parameter	Abbreviation	Rotor
Total height of the rotor	H	420 (mm)
Nominal diameter of the blade	d	210 (mm)
Diameter of the shaft	A	16 (mm)
Diameter of the rotor	D	420 (mm)
Diameter of the end plate	D_o	450 (mm)
Aspect ratio	AR	≈ 1
Swept area of the rotor	A = HD	0.16 (m^2)
Nominal velocity of the wind	V	1-5 (m/s)

Table 2 The performance at the (Old Mumbai-Pune Highway with an temperature of 380c and density of air is 1.20kg/m)

V (m/s)	N (RPM)	Pact (W)	Pth (W)	T (N-M)	Cp
1.25	2.65	3.01555	4.154	5.022	6.01
7.30	8.98	9.032	10.267	11.026	12.0
13.35	14.115	15.0766	16.425	17.035	18.0
19.40	20.160	21.134	22.634	23.037	24.0
25.45	26.180	27.201	28.903	29.047	30.0

Table 3 The performance at the (Nashik Highway with a temperature of 360c and density of air is 1.20kg/m3)

V (m/s)	N (RPM)	Pact (W)	Pth (W)	T (N-M)	Cp
1.24	2.64	3.01	4.14	5.02	6.0
7.40	8.16	9.14	10.64	11.03	12.0
13.24	14.63	15.01	16.13	17.0	18.0
19.15	20.20	21.00	22.03	23.01	24.0
25.4	26.16	27.24	28.83	29.04	30.0

Table 4 The performance at the (Nagar Highway with an temperature of 300c and density of air is 1.20kg/m3)

V (m/s)	N (RPM)	Pact (W)	Pth (W)	T (N-M)	Cp
31.53	32.2	33.4	34.15	35.06	36.03
37.55	38.2	39.4	40.13	41.05	42.03
43.55	44.2	45.4	46.14	47.05	48.03
49.83	50.3	51.1	52.48	53.14	54.85
55.43	56.1	57.1	58.66	59.03	60.28

V (m/)	N (RPM)	Pact (W)	Pth (W)	T (N-M)	Cp
61.7	62.305	63.12	64.356	65.111	66.0
67.1	68.2	69.76	70.20	71.07	72.0
73.5	74.2	75.5	76.14	77.05	78.0
79.5	80.2	81.5	82.15	83.06	84.0
85.4	86.2	87.2	88.75	89.02	90.0

8. Results

a) MMIT workshop with an tempt of 290c and density of air is 1.18kg/m3 (Fig.5)

Graphical representation of velocity vs coefficient of performance based on the practical performance in workshop

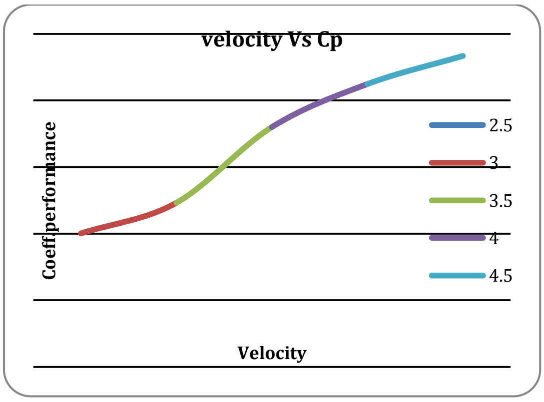

Fig.5 Velocity Vs cp

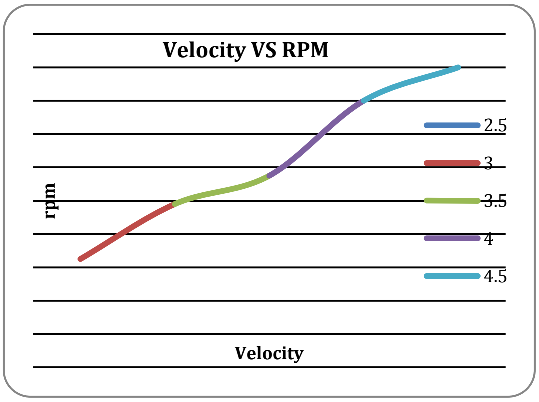

Fig6. Velocity vs. rpm

Cp shows an increase in value with the increasing Velocity

It is seen in the above graph RPM of the rotor increases with increase in wind velocity.

b) Old Mumbai-Pune Highway with an temperature of 38^{0}c and density of air is 1.20kg/m^3

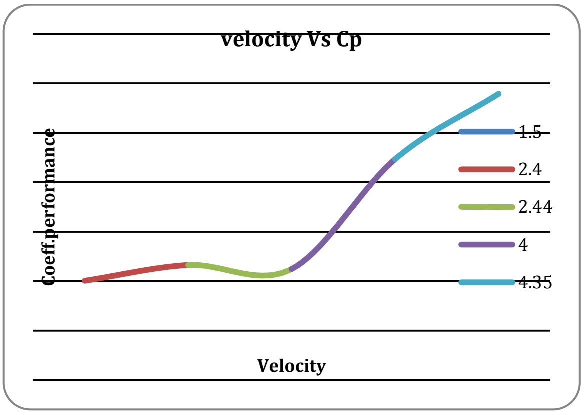

Fig.7 Velocity vs. Cp

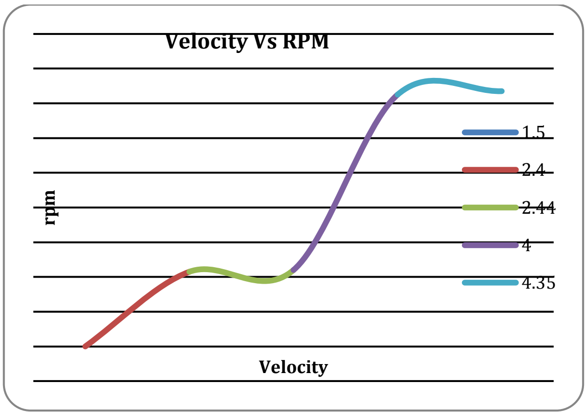

Fig. 8 Velocity vs. rpm

It is seen in the above graph RPM of the rotor increases with increase in wind velocity

C) Nashik Highway with a temperature of 36^{0}c and density of air is 1.20kg/m^3

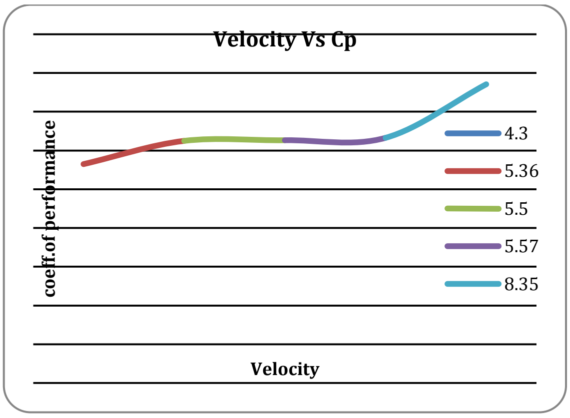

Fig.9 Velocity vs. C_P

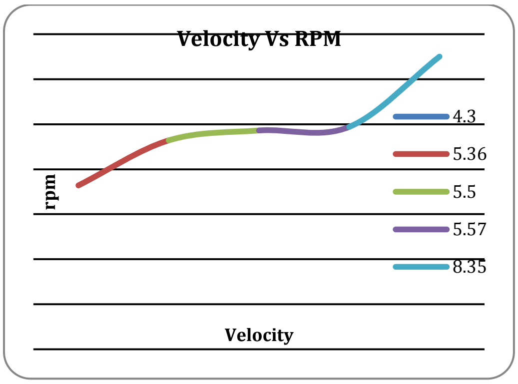

Fig.10 Velocity vs. rpm

The wind velocity up to 8.5m/s was observed and CP up to 0.38.

d) Nagar Highway with an temperature of 30^{0}c and density of air is 1.20kg/m^3

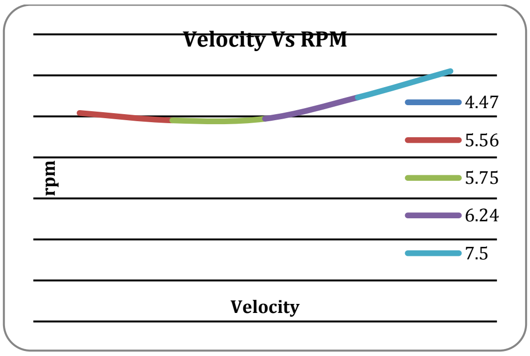

Fig.11 Velocity Vs. rpm

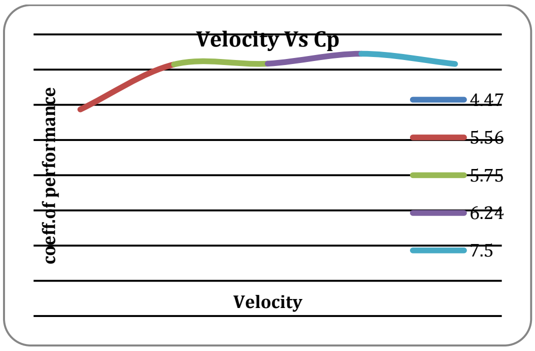

Fig.12 Velocity vs. C_p

The wind velocity at Nagar highway was around 7.5m/s giving an C_P of 0 .40

Conclusions

Following conclusion are summarized from the experimental study.

1) Coefficient of performance (Cp) increases with velocity

2) Rotations per minute (RPM) increases with increase in velocity

3) Wind potential power is higher at Pune-Nashik highway

4) The wind velocity increases consistently with increase in altitude

5) Maximum power rating was found out to be 18.8580W.

6) Wind thus is an reliable source of non-conventional for energy production

7) Utilization of highways for energy production fields can give out high yield potentials.

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