Electricity Generation by Micro Wind Turbine

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Abstract - *Now a day, people start to use renewable sources like solar energy, wind energy, Tidal Energy etc. This is because renewable sources are easily and freely available. It is pollution free compare to non-renewable sources. It makes an interconnected system to reduce the loading on conventional sources. Sun is a primary source of wind energy. Wind is generated due to temperature difference and wind always flows from low temperature to high temperature. The kinetic energy of wind is converted into mechanical energy using turbine, then this mechanical energy is converted into electrical energy by generator. Block diagram of energy conversion is given as Kinetic Energy-> Mechanical Energy-> Electrical Energy.*

Large wind turbines are popular and are mostly responsible for the continued steady growth of wind technology in the past decade. These MW scale, grid connected turbines are installed in wind farms and in areas with high wind speeds. Small scale wind turbines on the other hand are different: they are mostly used for off-grid applications in remote areas. They also differ from large wind turbines in size, power rating, and types of generators and speed regulation used.

Key Words: **Wind energy, wind charger, green energy, Wind mill, renewable energy source, Free energy source**.

CHAPTER 1. INTRODUCTION

Nowadays, use of Non-conventional Energy sources like solar and wind is increasing. We use solar and wind to produce the electricity but at MW level which farm are to big and so require more space. We also use rooftop solar plates which convert solar energy in electricity and other use at our home. Same as our project is also based on wind energy but for small level. We want to use wind turbine at small level nearly at 1KW to 5KW at high building's rooftop to generate Electricity which can be used in our house or offices and it can also be store in any battery. Here we use direct driven wind turbine so losses are also decrease.

1.1 Objective

Our main object is to generate electricity by using wind energy at our house or office buildings. Which energy can be used in our household or office to run small load.

1.2 Problem Specification

Requirement of this is because in large wind turbine, space is requiring more and also, they require gear system due to which efficiency of turbine decrease. And we get less output.

CHAPTER 2. Design Approach

There are a number of approaches that can be taken towards wind turbine design. This section outlines the steps in one approach.

The key design steps include the following:

1) Determine application
2) Select topology
3) Preliminary loads estimate
4) Develop tentative design
5) Predict performance
6) Evaluate design
7) Estimate costs and cost of energy

1. Determine Application: -

The first step in designing a wind turbine is to determine the application. The application will be a major factor in choosing the size of the turbine, the type of generator it has, the method of control, and how it is to be installed and operated.

In India, our electric utility infrastructure is based on a system of large power plant feeding power to consumers through long transmission and distribution system. it is collectively known as a grid. So dispersed generation is a concept where small and highly efficient power can be produced close to the end-user consumers. It will reduce the burden on large conventional power plants.

Our application is based on small scale power generation from wind energy at domestic level. So small scale wind turbines know as micro wind turbine is installed within the built environment and that is known as micro generation technology.

Such concept of micro wind turbine may soon become a commercial reality in the India as a result of advancement in technology and new financial incentives provided by the government and this technology have the potential to reduce the CO2 emissions and reduce the electricity cost of consumers.

2. Aim: -

Our aim of this project is to design small wind turbine that can generate electricity form wind energy at domestic level. This process directs us to think about various aspects like cost, Noise, efficiency, etc. which leads us to analyses the overall system.

3. Geographical analysis of Wind: -

Wind turbine generates the electricity by gaining the energy from the wind energy; it is a free energy source on our earth. In earth circulation system winds are created by its magnetic poles and the difference of the temperature gradient its various latitudes.

There are mainly two origins of wind.

1) Planetary wind
2) Local wind

1. **Planetary wind:** Earth completes one rotation around its polar axis in one day. So, it causes unequal solar heating between the earth surface near the equator and the northern or southern poles.

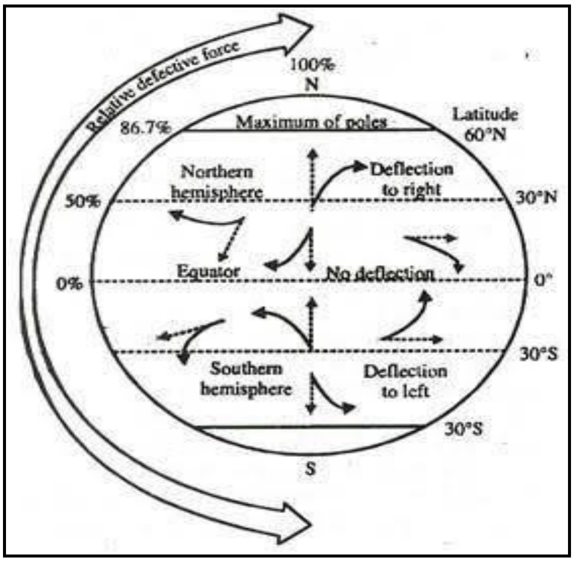


Figure 1. Planetary wind

2. **Local wind:** It is produced by uneven heating of the earth surface by the sun. Surface of the earth is made from various lands and water formations and due to this geographical diversification, there is unequal heating and winds are created.

Direction and the speed of the wind get affected by the landscape and geometry of the location. The wind energy generates lift or drag force as a result of pressure difference.

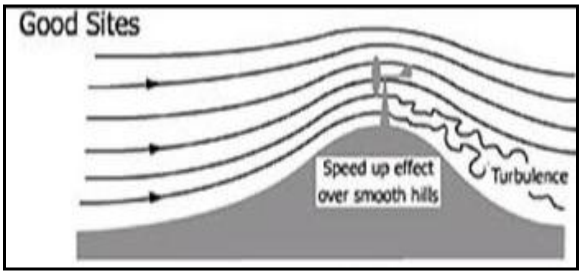


Figure 2. Good Sites

Figure (2) shows the behavior of wind over the hills. At the hill wind turbine gets the enough energy due to absence of turbulence. So, height of the wind turbine should not be too much high. That is good site.

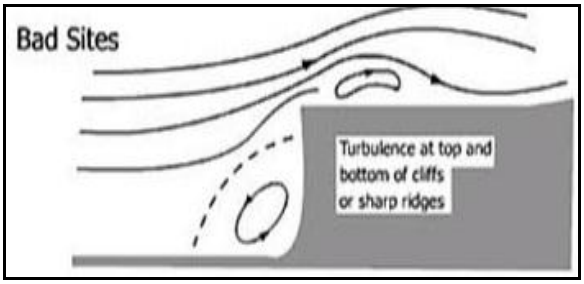


Figure 3. Bed Sites

Figure (3) shows the behavior of wind near the cliff. So, turbulence is formed at top and bottom of cliff. It causes adverse effect on the speed of turbine. So that is bad site.

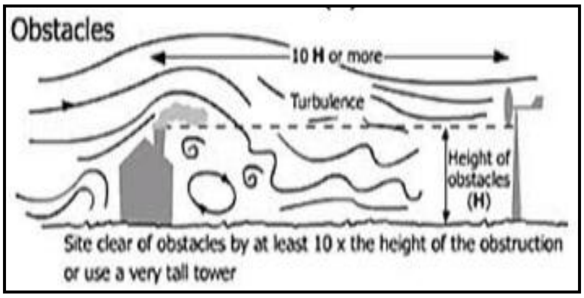


Figure 4. Obstacles

Figure (4) shows the behavior of wind due to obstacles (like houses, building) in direction of wind. Due to the obstacle's turbulence are created but the effect of the turbulence is reduced by selecting the proper height of wind turbine and distance from the obstacles.

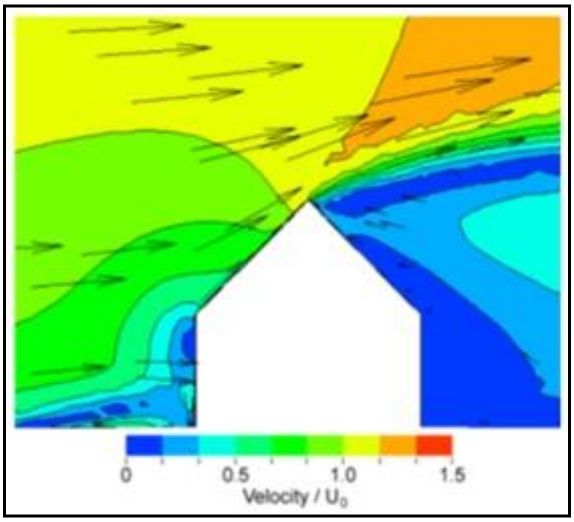


Figure 5. For Isolated Area

Figure (5) shows the behavior of wind over the house rooftop in isolated area. In isolated area, there are no other obstacles before the house rooftop. So, there is a less turbulence in the opposite direction of the wind so wind turbine is installed at the top of the house rooftop.

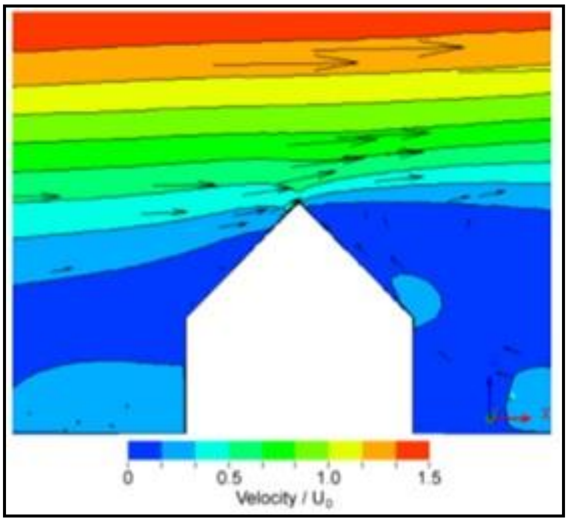


Figure 6. For Urban area

Figure (6) shows the behavior of wind over the house rooftop in urban area. There is a large turbulence near the house as compared to isolated area. So, wind turbine is installed at the top of house rooftop with sufficient height.

4. Wind speed and direction data of India and Gujarat: -

The weather changes with time along with various climate conditions and various seasons. Indian Meteorological Department (IMD) provides some average data on mean speed and maximum speed of wind at various regions of India and Gujarat. This data will help us to identify the speed limit of wind turbine while designing small scale wind turbine for domestic use. Below figure shows the data of wind speed in India and Gujarat.

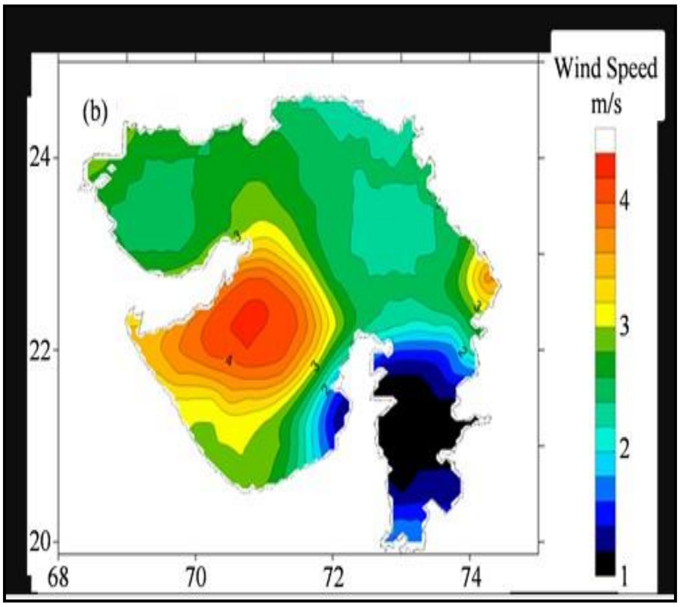


Figure 7. Wind Speed of Gujarat

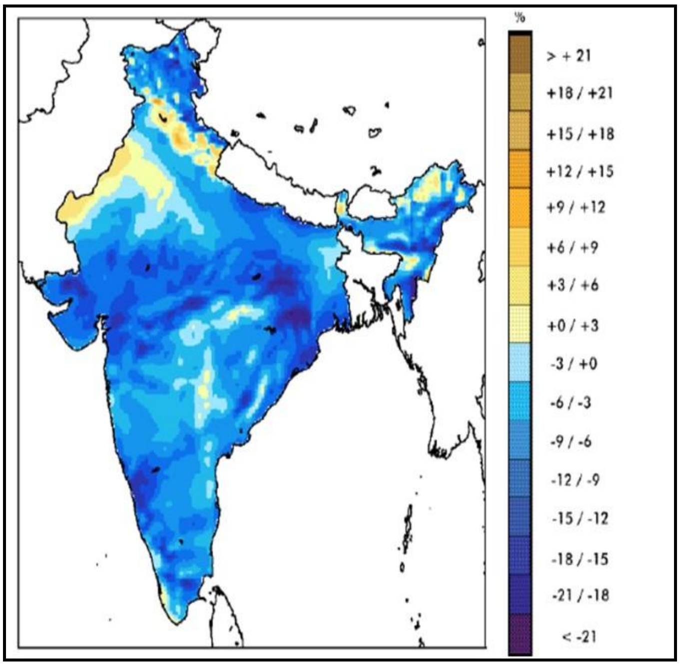


Figure 8. Wind Speed of India

Months	Mean Speed (KMPH)	No of days Wind Speed 10-19 KMPH
January	6.2	25
February	6.4	22
March	7.1	25
April	8.3	26
May	11.3	28
June	12.3	26
July	10.7	27
August	9.1	26
September	7.4	25
October	4.8	20
November	4.7	20
December	5.4	23

Table 1. Wind Speed data

From above figures we can say that wind speed is high enough near the coastal area of India and Gujarat. There is enough speed of wind for small scale wind turbine in various region of Gujarat like Kutch, Saurashtra, etc. In the coastal area of Gujarat like Somnath, etc. Large wind mills are already installed to produce large amount of electrical power. In the regions like Kutch and Saurashtra small scale wind turbine can be used in rural areas to produce electric power from wind energy freely.

In big cities like Ahmedabad, Surat, Vadodara etc. small-scale wind turbines can be installed at big buildings of apartment, malls and complex on its rooftop. This can reduce cost of electricity consumed from utility and reduce the burden on the conventional power sources.

5. Wind Turbine Design: -

Today there are two basic types of wind turbines available in the market. Most commonly used in wind energy systems are the traditional farm styled, horizontal-axis turbines. Vertical turbine is relatively new design that's gaining market share rapidly. They both have their advantages and disadvantages.

1) Horizontal Axis Wind Turbine (HAWT): -

Figure 9. Horizontal Axis Wind Turbine

Horizontal axis wind turbine(HAWT) have the main rotor shaft an electric generator at the top of the tower and may be pointed into or out of the wind.

- **Advantages of Horizontal Axis Wind Turbines**

i. Variable blade pitch, which gives the turbine blades the optimum angle of attack. Allowing the angle of attack to be remotely adjusted gives greater control, so the turbine collects the maximum amount of wind energy for the time of day and season.

ii. The tall towers allow access to stronger wind in sites with wind shear. In some wind shear sites, every ten meters up, the wind speed can increase by 20% and the power output by 34%.

iii. High efficiency, since the blades always moves perpendicularly to the wind, receiving power through the whole rotation. In contrast, all vertical axis wind turbines, and most proposed airborne wind turbine designs, involve various types of reciprocating actions, requiring aerofoil surfaces to backtrack against the wind for part of the cycle. Backtracking against the wind leads to inherently lower efficiency.

- **Disadvantages of Horizontal Axis Wind Turbines**

  i. Stronger tower construction is required to support the heavy blades, gearbox, and generator.

  ii. Mast height can make them obtrusively visible across large areas, disrupting the appearance of the landscape and sometimes creating local opposition.

  iii. They require an additional yaw control mechanism to turn the blades toward the wind.

  iv. Taller masts and blades are more difficult to transport and install. Transportation and installation can now cost 20% of equipment costs.

2. Vertical Axis Wind Turbines (VAWT): -

Figure 10. Vertical Axis Wind Turbine

Vertical axis wind turbine (VAWT) is a type of wind turbine where the main shaft is set transverse to the wind while the main component is located at the base of the turbine.

- **Advantages of Vertical Axis Wind Turbines**

  i. Ability to effectively capture turbulent winds which are typical in urban settings, especially in built-up areas.

  ii. No need for a yaw mechanism to face the blade rotor into veering wind directions; VAWTs therefore have higher efficiency and no orientation parts to maintain.

  iii. Operation at lower rotational speeds, thereby reducing or eliminating turbine vibration and noise.

  iv. Durability and reliability working in multi-directional wind.

  v. Easier and less expensive repair and maintenance with generator on rooftops.

  vi. Lower noise and vibration.

CHAPTER 3. Design Parameters

The wind turbine parameters considered in the design process are:

1) Swept area
2) Power and power coefficient
3) Tip speed ratio
4) Number of blades
5) Initial angle of attack

1. Swept area: -

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, this way the swept area of an HAWT is circular shaped while for a straight-bladed vertical axis wind turbine the swept area has a rectangular shape and is calculated using:

$$S = 2RL$$

where S is the swept area [m^2], R is the rotor radius [m], and L is the blade length [m].

The swept area limits the volume of air passing by the turbine. The rotor converts the energy contained in the wind in rotational movement so as bigger the area, bigger power output in the same wind conditions.

2. Power and power coefficient: -

The power available from wind for a vertical axis wind turbine can be found from the following formula:

$$P_W = \frac{1}{2}\rho S V_0^3$$

where Vo is the velocity of the wind [m/s] and ρ is the air density [kg/m3], the reference density used its standard sea level value (1.225 kg/m^3 at 15ºC), for other values the source can be consulted. Note that available power is dependent on the cube of the airspeed.

The power the turbine takes from wind is calculated using the power coefficient:

$$C_P = \frac{Captured\ mechanical\ power\ by\ blades}{Available\ power\ in\ wind}$$

Cp value represents the part of the total available power that is actually taken from wind, which can be understood as its efficiency.

There is a theoretical limit in the efficiency of a wind turbine determined by the deceleration the wind suffers when going across the turbine. For HAWT, the limit is 19/27 (59.3%) and is called Lanchester-Betz limit. For VAWT, the limit is 16/25 (64%).

These limits come from the actuator disk momentum theory which assumes steady, inviscid and without swirl flow. Making an analysis of data from market small VAWT, the value of maximum power coefficient has been found to be usually ranging between 0.15 and 0.22.

3. Tip Speed Ratio: -

The power coefficient is strongly dependent on tip speed ratio, defined as the ratio between the tangential speed at blade tip and the actual wind speed.

$$TSR = \frac{Tangential\ speed\ at\ the\ blade\ tips}{Actual\ wind\ speed} = \frac{R\,\omega}{V_0}$$

where ω is the angular speed [rad/s], R the rotor radius [m] and Vo the ambient wind speed [m/s]. Each rotor design has an optimal tip speed ratio at which the maximum power extraction is achieved.

4. Number of blades

The number of blades has a direct effect in the smoothness of rotor operation as they can compensate cycled aerodynamic loads. For easiness of building, four and three blades have been contemplated.

5. Initial angle of attack

The initial angle of attack is the angle the blade has regarding its trajectory, considering negative the angle that locates the blade's leading edge inside the circumference described by the blade path.

CHAPTER 3. Betz Limit

Wind machine performance is described by Betz's theory which applies to horizontal axis wind machines. However, the efficiency of vertical axis wind machines is also estimated relative to the maximum power calculated by Betz's formula.

Assumptions

The wind rotor is assumed to be an ideal energy converter, meaning that:

1) It does not possess a hub.
2) It possesses an infinite number of rotor blades which do not result in any drag resistance to the wind flowing through them.
3) Uniformity is assumed over the whole swept area by the rotor and the speed of the air beyond the rotor is consider to be axial.

Conclusion

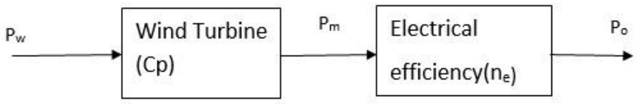
The maximum or optimal value of performance coefficient (Cp) becomes 59.26%, which is referred to Betz's limit. It applies to all wind energy conversion designs. And it is a theoretical power fraction extracted from an ideal wind stream.

Modern wind machines operate at a slightly lower practical non ideal performance co-efficient and it is generally in the range of 40 to 45 percentages.

CHAPTER 4. Electrical power Output

The actual mechanical power in the rotation of the rotor blades is:

$$P_m = C_p 0.5 \rho S V_0^3$$



The actual electrical power generation given by below equation:

$$P_m = C_p \eta_e P_w$$

Graph of Power output (P_m) Vs Wind Speed(V_0):

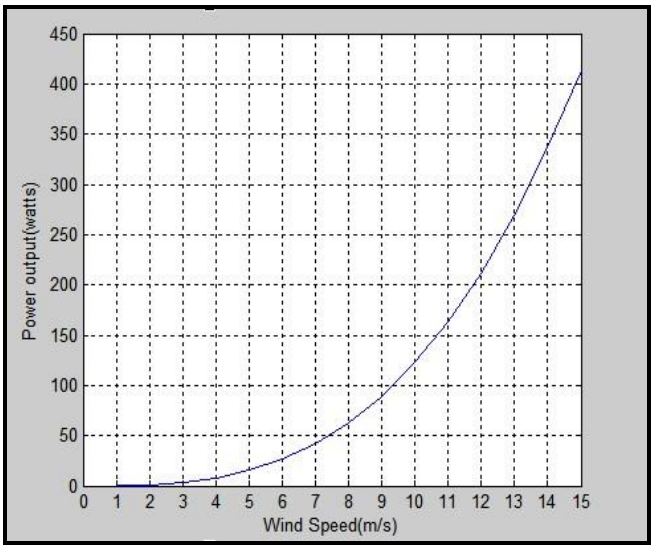


Figure 11. Graph of Power output (Pm) Vs Wind Speed(V0)

For constant power coefficient and swept area power output is directly proportional to cube of wind speed. As wind speed is more power output will be more.

CHAPTER 5. Simulation

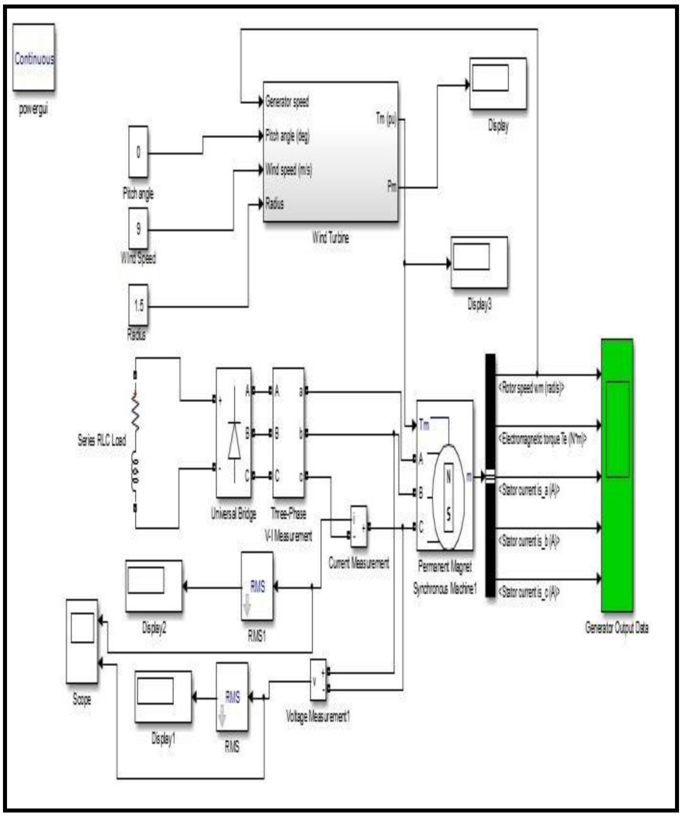


Figure 12. Simulation model

In this model we basically work on four inputs. This model is work on equation of mechanical power of wind turbine which is given below.

$$P_m = C_p 0.5 \rho S V_0^3$$

In equation we require the cube of wind speed so we made cube block and wind speed also used to find lambda. Here lambda is product of radius generator speed and which is divided by wind speed. Lambda is known as nominal speed. To find Cp we use lambda and pitch angle which equation is given below.

This Cp is multiplying with Rho which is taken 1.125 constant. And then that output is given to product block. Here area of blades is $3.14r^2$. Now the product of Cp, wind speed cube and area of blade give mechanical output. Form this output we find torque by dividing it by generator speed. And that mechanical torque is given to PMSG which is show in simulation circuit diagram.

$$c_p(\lambda, \beta) = c_1(c_2/\lambda_i - c_3\beta - c_4)e^{-c_5/\lambda_i} + c_6\lambda,$$

Here we use Permanent Magnate Synchronous Generator (PMSG). In place of this machine we can also use DC Generator. But the problem is DC Generator has commutator and brushes on its rotor part which add loose in machine so the efficiency and output of machine is become low. So, to reduce that difficulty we use Permanent magnate Synchronous Generator.

This machine construction is same as synchronous generator. It has also one field winding and another armature winding but its field winding on rotor and armature winding on its stator part. It has two type rotors one is Permanent magnate and another is salient pole. But we use Permanent magnate Rotor.

In this machine permanent magnate is embedded on rotor which has constant magnetic field. And when rotor rotates it cutes the conductors of stator windings. And due to faraday's law the emf induced in the stator windings and when load is connected the current flow through the line.

But in this machine synchronous speed is required to get required output. But in wind turbine, wind speed is variable in nature so the output of generator has different frequency. So for that we use this generator for domestic and office purpose only for low power generation from 1KW to 5KW.

Here due to variable frequency of output the generated voltage is converted in DC output and then it can be stored in battery, or can be again converted in AC voltage by using inverter to use in our home appliances.

We give the output in simulation to rectifier and then that DC voltage is given to RL Load of 1KW.

Here we take some waveform for this simulation:

Figure 13. No Load Output

This is no load output of PMSG which has 210 V(rms) at line to phase voltage at Generator Terminal.

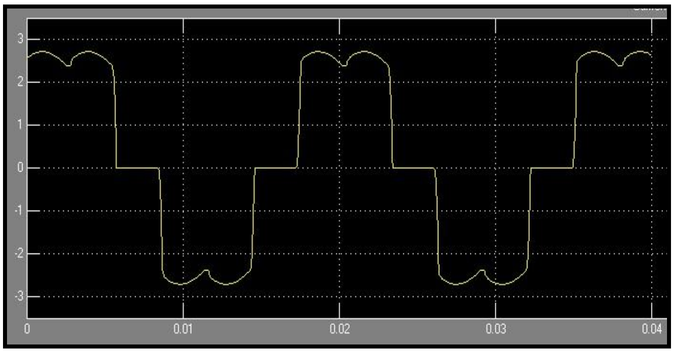


Figure 14. 1 Kw Load Output

This is output of Current waveform at 1KW Load with Rectifier at Line to Phase current at Generator terminal.

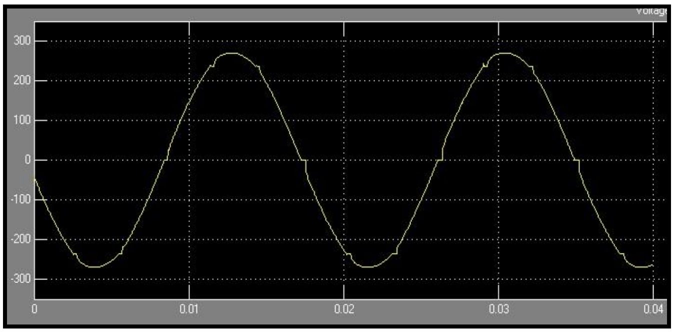


Figure 15. output of Voltage waveform at 1KW Load with rectifier

This is output of Voltage waveform at 1KW Load with rectifier at terminal of generator Line to Phase voltage.

Here we can see that the line to phase voltage is sinusoidal with harmonics. And these harmonics are developed due to nonlinear load. Current waveform contains more harmonics as compare to the voltage waveform.

Summary of Simulation:

Average Wind Speed(m/s)	9 m/s
Radius of Rotor Blades(m)	1.5 m
Pitch Angle(beta)	0
No Load Voltage(V)	210 V(rms)
1KW Load Voltage(V)	188 V(rms)
1KW Load Current(A)	2.087 A(rms)
Mechanical Power at 1KW	0.709 KW

Table 2. Summary of Simulation

As from fig. 13 we can see that, by using PMSG we get sinusoidal output. Here we can see that at no load the output of generator with 9m/s of wind speed and 1.5m rotor blades radius which is given to turbine is 210 RMS Voltage.

As from fig. 9.4 is figure of current at 1KW RL Load which is connected to generator by rectifier so we get the current waveform nearly to square waveform. That output current between two-line terminals of generator is 2.087 Arms. This waveform consists some harmonics due to rectifier.

As from fig.9.5 is figure of voltage at 1KW RL Load, between two terminals of generator, so it is line voltage. Which value is 188 Vrms. This waveform consists some harmonics due to rectifier.

Factors Affecting VAWT:

1. Aspect Ratio:
    - In aerodynamics aspect ratio is ratio between length and breadth.
    - For most wings the length of the chord is not a constant but varies along the wing, so the aspect ratio is defined as blade height and rotor radius.

$$AR = h/R$$

2. No. of Blades:
    - It is affecting the speed and efficiency of turbine. The most commonly used wind turbines use three blades.
    - It is consist two major factors:
        1. Power drawn from each blades. Assume each blade draws certain amount of power then

higher no of blades would draw more energy from wind.

2. The interference effect of each blade on another. Lesser the interference of each blade on another blade higher the efficiency of each blade.

3. Reynold Number

- Reynolds number always affected the performance of vertical axis wind turbine.

$$Re = \frac{cV_0 \lambda_{cpmax}}{v}$$

- Here λcpmax is derived corresponding to Cpmax.
- Cpmax is power coefficient as coefficient change, power coefficient curve also changes which means λcpmax also change so the reynold number also change.

4. Blade Profile:

- The VAWT rotor, comprised of a number of constant cross section blades, is designed to achieve good aerodynamic qualities at various angles of attack.
- Unlike the HAWT where the blades exert a constant torque about the shaft as they rotate, a VAWT rotates perpendicular to the flow, causing the blades to produce an oscillation in the torque about the axis of rotation.
- VAWT blades are designed such that they exhibit good aerodynamic performance throughout an entire rotation at the various angles of attack they experience leading to high time averaged torque.

CHAPTER 6. Rotor Configuration

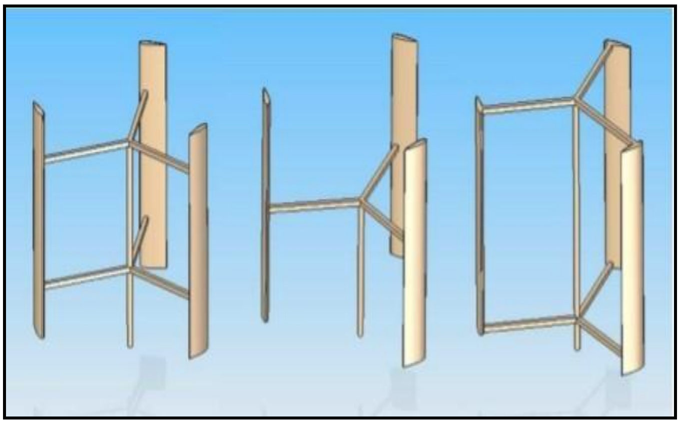


Figure 16. Rotor Configuration

- Three different rotor configurations have been tested and are presented in the following figure.
- In these three configurations, first configuration has low bending strength, second and third has maximum bending strength and lower shear strength.
- Second has also lower exposed area per same strength, so second has more benefits then third so it is chosen.

Specification of Prototype Rotor:

Parameters	Values
Radius(R)	0.22m
Height(h)	0.55m
Aspect Ratio (AR)	2.5
Air Density(ρ)	1.225kg/m3
Wind speed(V0)	7 m/s
Power Coefficient (Cp)	0.2
Chord Length(c)	0.06m
Number of Blades (Nb)	4
Solidity(σ)	1.08

Table 3. Specification of Prototype Rotor

- From power output equation and following values of different parameters we get mechanical output is 11.11 W.
- Here if we assume generator efficiency is 0.9 then electrical power output is got 10W.

Calculation of Prototype:

Mechanical Output

$$P = 0.5 * \rho * 2 * R * h * {V_0}^3 * C_p$$

=0.5*1.225*(7)3*0.22*0.55*2*0.2

=11.11W

Electrical Output

$$\eta = \frac{P_o}{P_I}$$

$$P_o = \eta * P_I$$

= 0.9*11.11

= 10W

Solidity

$$\sigma = N_b * c/R$$

= 4*0.06/0.22

= 1.08

Rotation per Minute

$$TSR = \frac{R\omega}{V_0}$$

$$\omega = \frac{TSR * V_0}{R}$$

$$= \frac{1 * 7}{0.22}$$

$$= 31.82\, rad/s$$

$$n_s = \frac{\omega}{2 * \pi}$$

$$n_s = \frac{31.82}{2 * 3.14}$$

$$n_s = 5.07$$

$$N = 60 * n_s$$

$$N = 60 * 5.07$$

$$N = 304.2\, rpm$$

CHAPTER 7. Designing of Prototype

In our project, we found problems related to the speed of the wind turbine and the output of the DC Generator. At first, we couldn't obtain sufficient output with normal speed of the wind turbine. Then we thought about various solutions for this problem.

At first, we try to embed the wind turbine directly on the shaft of DC Generator. But due to direct mounting shaft of Generator and heavy weight of the blades with small diameter of shaft it gets too much stress. Due to which it having problem to rotate at require speed so we can't get require output.

In other solution, we try to rotate shaft with two different methods 1) by using gear mechanism and 2) By using Pulley mechanism. From these two methods we have adopted second one. This was found to be more efficient and more economical for our project.

Figure 17. Designing of Prototype

Above figure shows pulley mechanism used in our project to enhance the speed of the DC Generator. We have used 3:1 ratio in diameters of pulleys. Among them large pulley has diameter of 75 mm and small pulley has diameter of 25 mm and Centre to Centre distance between two pulleys is 140 mm.

So, from this we can say that during one rotation of large pulley make three rotation of small pulley. Which also increase the output of Generator.

We found problem related to solidity and weight of blades. At first try we could not get sufficient rotation for electricity production at moderate wind speed. Then we thought about different size of blades. And found most efficient size of the blades which can generate enough rotation for our prototype.

Prototype:

Figure 18. Prototype

In our prototype, four blades are used to extract wind power from surrounding and to convert into electrical energy with the help of pulley mechanism and DC Generator. These blades are made from ACP material and PVC. And other things are made from Cast Iron.

Specification of Ideal Rotor:

Parameters	Values
Radius(R)	1 m
Height(h)	2 m
Aspect Ratio (AR)	2
Air Density(ρ)	1.225kg/m3
Wind speed(V0)	7 m/s
Power Coefficient (Cp)	0.45
Chord Length(c)	0.3 m
Number of Blades(Nb)	4
Solidity(σ)	1.2
Tip Speed Ratio (TSR)	2

Table 4. Specification of Ideal Rotor

Calculation of Ideal Prototype:

Mechanical Output

$$P = 0.5 * \rho * 2 * R * h * V_0^{\ 3} * C_p$$

=0.5*1.225*(7)3*0.45*1*2*2

=378.15W

Electrical Output

$$\eta = \frac{P_o}{P_I}$$

$$P_o = \eta * P_I$$

= 0.9*378.15

= 340W

Solidity

$$\sigma = N_b * c/R$$

= 4*0.3/1

= 1.2

Rotation per Minute

$$TSR = \frac{R\omega}{V_0}$$

$$\omega = \frac{TSR * V_0}{R}$$

$$= \frac{2 * 7}{1}$$

$$= 14\, rad/s$$

$$n_s = \frac{\omega}{2 * \pi}$$

$$n_s = \frac{14}{2 * 3.14}$$

$n_s = 22$

N $= 60 * n_s$

$N = 60 * 22$

$N = 1320\ rpm$

Main Advantage of this system is Here we are designing a small level wind turbine which can be eliminate use of gear system in large wind turbine and can be used low wind speed to generate require mechanical torque, it can also be implemented at our rooftop of house or large buildings.

References:

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