DESIGN AND DEVELOPMENT OF MVAWT (Maglev Vertical Axis Wind Turbine)

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Abstract: The principal benefit of a vertical axis wind turbine using magnetic levitation in which the rotor is floating in the air due to levitation force which is generated using magnetic repulsion so that mechanical friction is totally eliminated. This new design comprises magnetic levitation phenomenon using rare earth permanent magnets between both rotors to reduce the losses. In the levitated generator design bearings and gears are absent which provides the frictionless flow of energy minimizing noise and hence friction losses are also reduced. At the same time the soft running of some moving component ensures minimum material wear, which reduce the maintenance cost. A VAWT rotor has two types such as savonius and darrieus. Savonius wind turbine produces high torque compare to other which is useful in self-starting. In other hand darrieus rotor has high tip speed ratio useful for electrical generation. So the combination of both type rotors are used over the individual savonius or darrieus rotor would have many advantages. so they are able to operate with starting speeds as low as 1.5 m/s. Also, they can operate at winds speed exceeding upto 40 m/s. That makes the rotation possible in very low wind speeds. The use of magnetitic levitation phenomenon in the VAWT reduces the vibration around 36% to 38%. Also it is conclude that the power generated with maglev system is increase by 30% compare to the normal wind turbine.

Keywords- wind turbine, magnetic levitation, savonius and Darrius rotor, neodymium magnet, power generation

1. INTRODUCTION

Renewable energy is generally energy supplied from sources such as wind power, solar power, geothermal energy, hydropower and various forms of biomass. These sources have been coined renewable due to their continuous replenishment and availability for use over and over again. The demand of renewable energy has increased at high rate in recent times due to the depletion of conventional power generation methods and increasing realization of its adverse effects on the environment. It is estimated that renewable sources might contribute about 20% – 50% to energy consumption in the former part of the 21st century. Wind is a natural power source that can be economically used to generate electricity. The way in which wind is created is the uneven heating of the sun, rotation of the earth and the rockiness of the earth's surface, winds are formed. Wind power is used to generate the electricity by means of using turbine which converts the kinetic energy of wind power into mechanical energy. This mechanical energy also can be used for pumping water or grinding grains further this mechanical energy converted into electrical energy by the generator. The wind strikes on blades which turns the blades of the rotor. Rotor is mounted on the shaft which spin a shaft, which connects to a generator and produce electricity. World Wind Energy Association estimates that the 250GW of wind power capacity is expected to be installed worldwide by 2020 which involves an expected net growth rate of more than 30% per year. Maglev Wind turbine has consist of permanent magnets which is instead of bearings and shafts so there is no mechanical linkages, no friction etc. Which minimize the noise and frictional losses. By reducing the damping in the magnetic levitation wind turbine, which makes the wind turbine start up with low wind speed and work with breeze. The Maglev wind turbine, which was first revealed at the Wind Power Asia exhibition in Beijing, is expected take wind power technology to the next level with magnetic levitation. Efficiency of turbine is directly proportional to increase in power generation. So that which leads the decreasing the need for expensive power generation processes that cause pollution.

2. MAGNETIC LEVITATION WIND TURBINE

PRINCIPLE: Magnetic levitation, maglev, or magnetic suspension is a method by which an object is suspended above another object with no support other than magnetic fields. The electromagnetic force is used to counteract the effects of the gravitational force.
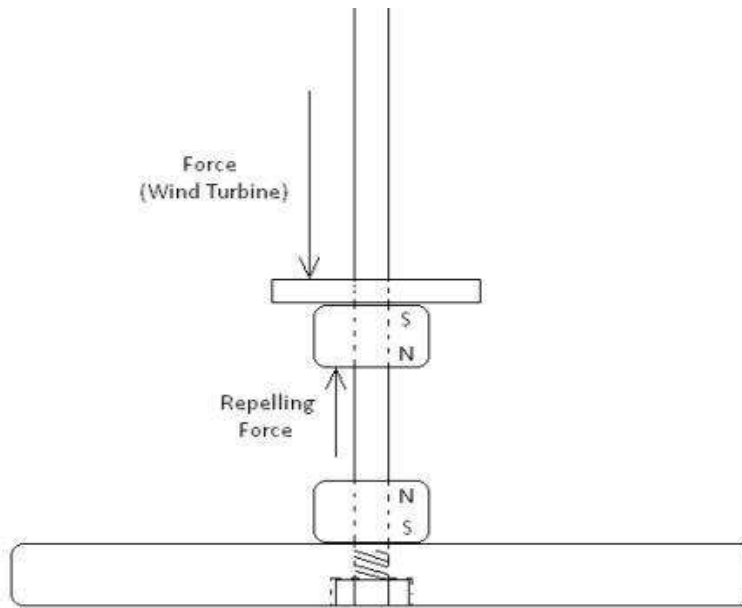
Fig.no.1 principle of maglev

2.1. Types Of Wind Turbine

Many types of turbines exist today and their designs are usually inclined towards one of the two categories: horizontal-axis wind turbines (HAWTs) and vertical-axis wind turbines (VAWTs). As the name pertains, each turbine is distinguished by the orientation of their rotor shafts. The HAWTs are the more conventional and common type everyone has come to know, while the VAWTs due to its seldom usage and exploitation, is quiet unpopular.
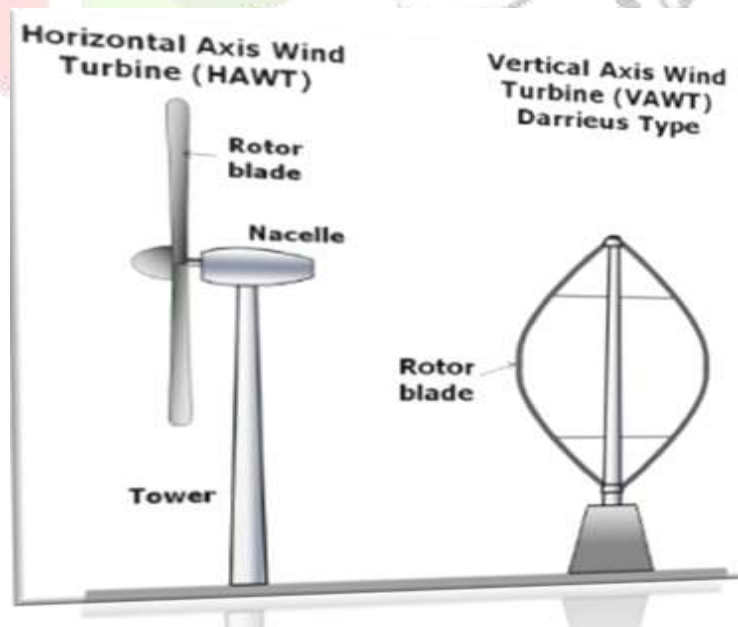
Fig.no. 2 Types of Wind Turbine

2.2.1. Horizontal Axis Wind Turbine

The axis of rotation of a HAWT is parallel to the ground. The HAWTs usually consist of two or three propeller-like blades attached to a horizontal and mounted on bearings the top of a support tower. When the wind blows, the blades of the turbine are set in motion which drives a generator that produces AC electricity. For optimal efficiency, these horizontal turbines are usually made to point into the wind with the aid of a sensor and a servomotor or a wind vane for smaller wind turbine applications.

2.2.2 Vertical Axis Wind Turbine

The axis of rotation of VAWT is perpendicular to the ground. The major difference is the orientation of the rotors and generator, which are all vertically arranged, and usually on a shaft for support and stability. This also results in a different response of the turbine blades to the wind in relation to that of the horizontal configurations. Their design makes it possible for them to utilize the wind power from every direction unlike the HAWTs that depend on lift forces from the wind similar to the lift off concept of an airplane. Vertical axis wind turbines are further subdivided into two major types namely the Darrius model and the Savonius model.Darrius Model was named after designer and French aeronautical engineer, Georges Darrius. The form of this design is best described as an eggbeater with the blades, two or three of them bent into a c-shape on the shaft. It has the high tip speed.
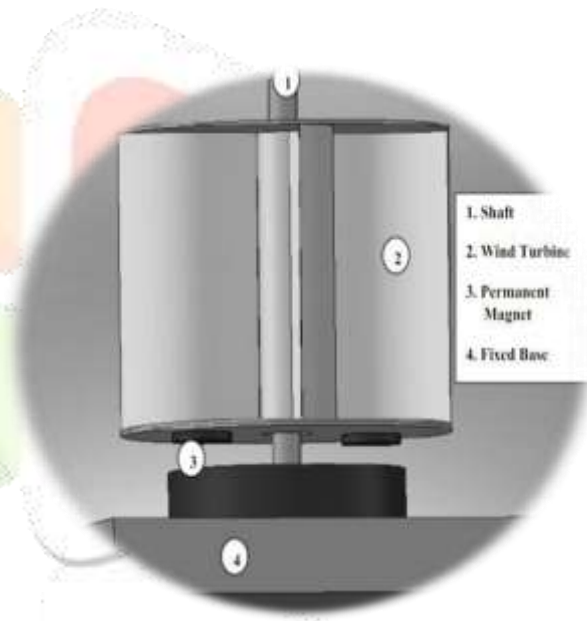

Fig.no.3 Darrius VAWT   Fig.no.4 Savonius VAWT

Finnish engineer Sigurd Savonius invented the Savonius model. The functioning of this model is dependent on drag forces from the wind. This drag force produced is a differential of the wind hitting by the inner part of the scoops and the wind blowing against the back of the scoops. Like the Darrius model, the Savonius turbines will work with winds approaching in any direction and also work well with lower wind speeds due to their very low clearance off the ground. It can produce high torque.

3. WIND POWER GENERATION

As mentioned earlier the effective functioning of a wind turbine is dictated by the wind availability in an area and if the amount of power it has is sufficient enough to keep the blades in constant rotation. The wind power increases as a function of the cube of the velocity of the wind and this power is calculated with respect to the area in which the wind is present as well as the wind velocity. When wind is blowing the energy available is kinetic due to the motion of the wind so the power of the wind is related to the kinetic energy.

We know,

$$\text{Kinetic Energy} = 1/2 \ MV^2$$

The volume of air passing in unit time through an area A, with speed V is AV and its mass M is equal to the Volume V multiplied by its density ρ so:

$$M = \rho AV$$

Substituting the value of M in above equation we get:

$$\text{Kinetic Energy} = 1/2 \ \rho AV^3$$

To convert the energy to kilowatts, a dimensionless proportionality constant k is introduced where,

$$K = 2.14 \times 10^{-3}$$

Therefore,

$$\text{Power in KW (P)} = 2.14 \rho AV^3 \times 10^{-3}$$

Where:

Air Density (ρ) = 1.2 kg/m^3

Area (A) = Area swept by the blades by the turbine

Velocity (V) = wind speed in m/s

With the above equation, the power being generated can be calculated, however one should note that it is not possible to convert all the power of the wind into power for generation. The power harnessed from the wind cannot exceed 59% of the overall power in the wind. Only a portion can be used and that usable portion is only assured depending on the wind turbine being used and the aerodynamic characteristics that accompany it.

4. WORKING OF MAGLEV WIND TURBINE

It is the vertical axis wind turbine working on the principle of magnetic levitation effect i.e bearings are replaced by permanent magnets which reduces the frictional losses and allows turbine to rotate on low wind speed.
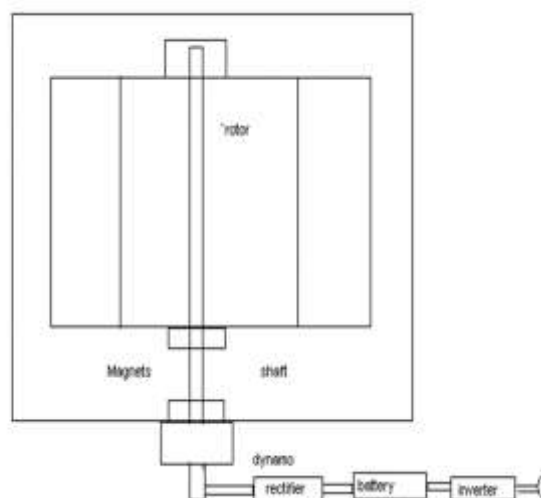

Fig.no.5 Block Diagram of Maglev Windmill

Figure gives an idea of Maglev Wind Turbine. This phenomenon operates on the repulsion characteristics of permanent magnets. This technology has been predominantly utilized in the rail industry in the Far East to provide very fast and reliable transportation on maglev trains and with ongoing research its popularity is increasingly attaining new heights. Using a pair of permanent magnets like neodymium magnets and substantial support magnetic levitation can easily be experienced. By placing these two magnets on top of each other with like polarities facing each other, the magnetic repulsion will be strong enough to keep both magnets at a distance away from each other. The force created as a result of this repulsion can be used for suspension purposes ands strong enough to balance the weight of an object depending on the threshold of the magnets. Power will then be generated with an axial flux generator, which incorporates the use of permanent magnets and a set of coils. The generated power is in form of DC, stored in battery, this can be used to directly supply the DC loads and can also be converted to AC using inverter to supply AC loads. It can be used as OFF grid and ON grid as shown in above figures. Wind power is a proven and highly effective way to generate electricity. Maglev technology is the most efficient means of transferring kinetic energy to generate electricity. The vertical axis wind turbine platform floats on a magnetic cushion with the aid of permanent- magnet suspension and a companion linear synchronous motor. This technology eliminates nearly all friction and delivers maximum wind energy to the downstream linear generator. Vent which allows for a different type of rotational support rather than the conventional ball bearing system found in horizontal wind turbines. This figure shows a basic rendition of how the maglev will be integrated into the design. If the magnets where ring shaped then they could easily be slid tandem down the shaft with the like poles facing toward each other. This would enable the repelling force required to support the weight and force of the wind turbine and minimize the amount of magnets needed to complete the concept.

5. COMPONENT DESCRIPTION

5.1. Model of Turbine Blade:

We selected ABS Polymer for 3-D printing to reduce weight and minimise bearing friction and tap maximum possible   power and appropriate results for our designed prototype.

Diameter of blade, $d_b = 62\ mm$

Height of blade, H=127 mm

Thickness of blade, t=0.80 mm

Material: ABS (Acrylonitrile Butadiene Styrene) Polymer

Density of ABS Polymer, ρ_b = 925 kg/m3

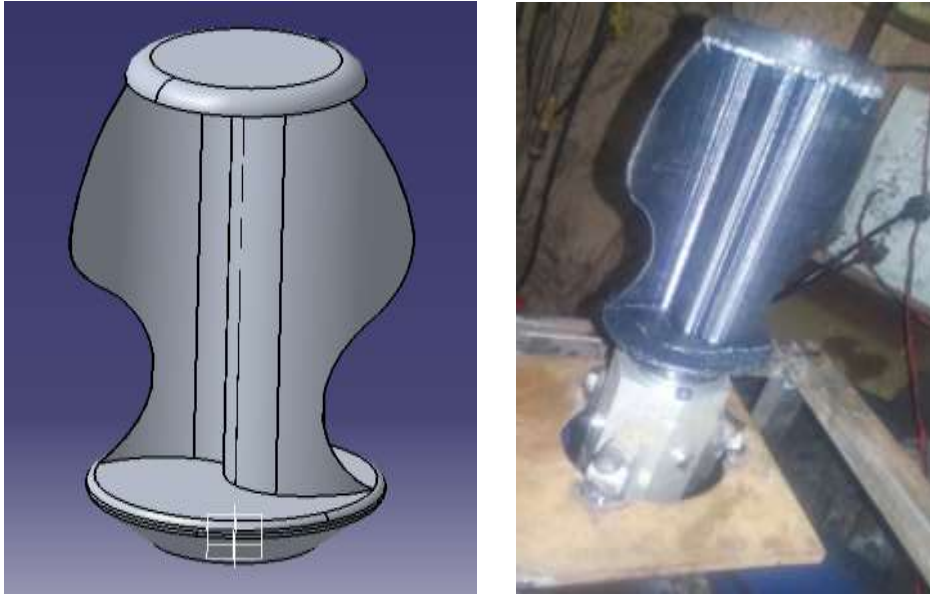Operating Temp. Range, T = -20 $°C$ to 80 $°C$

Fig.no.6 Turbine Rotor model

5.2 Neodymium Magnet

A neodymium magnet (also known as Nd-Fe-B, Nib or Neo magnet), the most widely used type of rare-earth magnet, is a permanent magnet made from an alloy of neodymium, iron and boron to form the Nd2Fe14B tetragonal crystalline structure. Neodymium magnets are metal, and they are colored silver, like most other metals. Neodymium magnets are graded according To their maximum energy product. Higher values indicate stronger magnets and range from N35 up to N52. This is the most powerful permanent magnet humans have discovered so, per unit of size, Nd-Fe-B magnets provide the strongest magnetic field available without the use of an electro-magnet. A neodymium magnet can lift more than any other type of magnet of the same size.

Fig.no.7 Disc Type Neodymium Magnet

5.3 Generator

Dynamo is an electrical generator that produces direct current with use of commentator. The electric dynamo uses rotating coils of wire and magnetic field to convert mechanical rotation into a pulsing direct electric current. A dynamo machine consist of a stationary structure called the stator which provides constant magnetic field and a set of rotating windings called the armature which turn within that field.According to Faraday's law of induction the motion of the coil within the magnetic field creates an electromotive force which pushes on the electrons in the metal, creating an electric current in the wire.

Fig.no.8 Generator

6. BASIC DESIGN CONSIDERATIONS

6.1 Estimation of Wind Power

For an airstream flowing through an area A, the mass flow rate is ρAV, and therefore the power is given by

$$P_w = \rho A_s V_W \times \frac{1}{2} V_w^2 = \frac{1}{2} \rho A_s V_w^3 \qquad \text{- (eq.no.1)}$$

$$P_w = \frac{1}{2} * 1.225 * 0.003017 * 12^3 = 3.19376 \, W \qquad \text{(eq.no.2)}$$

Where, ρ is the air density (kg/m^3), V is the wind speed (m/s) and P_w is the power (watts). The power is also known as the energy flux or power density of the air. The ratio of shaft power (P_s) to the power available in the wind (P_w) is known as the power coefficient (C_p), and this indicates the efficiency of conversion. Thus,

$$C_p = \frac{P_s}{P_w} \qquad \text{- (eq.no.3)}$$

In the present investigation, A is the projected area of rotor (m^2), and V is the airspeed (m/s) at the blower exit. The shaft power (P_s) is calculated from actual voltage and current output.

6.2 Power and Torque Calculations

The maximum power of a Savonius rotor is given by

$$P_{max} = 0.36 \text{kg m}^{-3} \text{h.r.} V_w^3 \qquad \text{- (eq.no.4)}$$

Where, h and r are height and radius of rotor and V_W is the wind speed.

The angular speed of a rotor is given by

$$\omega = \frac{\lambda V_W}{r}$$ - (eq.no.5)

Where, λ is a dimensionless factor called the tip-speed ratio. The value of tip-speed ratio for a Savonius rotor is typically around 1.

Torque of Savonius rotor can be calculated as

$$P = T_q \omega$$ - (eq.no.6)

6.3 Design of Shaft

According to maximum stress theory, the maximum shear stress in the shaft

$$\tau_{max} = \frac{1}{2}\sqrt{(\sigma_b{}^2 + 4\tau^2)}$$ - (eq.no.7)

Since power is transferred through vertical shaft we have to design shaft for torsional shear stress and diameter of shaft can be obtained by the following equation.

$$\frac{\pi}{16}\tau_{max}d^3 = \sqrt{(M^2 + T^2)}$$ - (eq.no.8)

Where, T is twisting moment, τ is shear stress for material used and d is the diameter of shaft.

According to maximum normal stress theory, maximum normal stress in the shaft

$$\sigma_{b(max)} = \frac{32}{\pi d^3} x \frac{1}{2}(M + \sqrt{M^2 + T^2})$$ - (eq.no.9)

Maximum diameter from the above two will be considered for the shaft design.

Power in the wind,

$$P_W = 3.19376W$$ - (from eq.no.1)

$$P_W = F \times V_W$$ - (eq.no.11)

$$= 3.19376 = F \times 12 \Rightarrow F = 0.26614 \text{ N}$$

Moment, M = 0.26614 x 0.300=0.079844 N-m

Torque, T_q = 0.04921 N-m

σ_u=250 MPa,

$\tau_u = 115 \, MPa$,

$FOS = 5$

M = 0.079844 x 10^3 N-mm,

T = 0.04921 x 10^3 N-mm

$$\sigma_b = \frac{\sigma_u}{FOS} = \frac{250}{5} = 50 \, N/mm^2$$ - (eq.no.12)

$$\tau = \frac{\tau_u}{FOS} = \frac{115}{5} = 23 \, N/mm^2$$ - (eq.no.13)

Let, d=diameter of shaft in mm

A/c to maximum shear stress theory, equivalent twisting moment (T_e)

$$T_e = (\sqrt{M^2 + T^2})$$ - (eq.no.14)

$$=2.559 \times 10^3 = \pi/16\tau d^3 \qquad \text{- (from eq.no.8)}$$

d=8.2750 mm

A/c to Maximum normal stress theory, equivalent bending moment (M$_e$)

$$M_e = 0.5(M+(\sqrt{M^2 + T^2})) = 2519.94 \, N.mm \qquad \text{- (eq.no.15)}$$

Now, equivalent bending moment M$_e$

$$2.519 \times 10^3 = \frac{\pi}{32}\sigma_b \times d^3 = d = 8.007 \, mm \qquad \text{- (from eq.no.9)}$$

6.4 Designed Dimensions of Project:

- Diameter of the shaft, $d_s = 10 \, mm$
- Diameter of blade, $d_b = 62 \, mm$
- Diameter of endplate, $d_o = 50 \, mm$
- Height of blade, H=127 mm
- Thickness of endplate & blade, t=0.80 mm
- Density of ABS polymer, ρ_b=925 kg/m^3
- Mass of turbine rotor = 0.301279478 kg
- Mass of shaft $= \pi r^2 l \times \rho$
    $=3.14 \times 0.005^2 \times 0.010 \times 7850$

    =6.1622 gm

- No. of turns of spring = 15
- Compressed length of spring = 20 mm
- Free length of spring = 24 mm
- Elongated length of spring = 30 mm
- Inner diameter of spring = 10 mm
- Outer diameter of spring = 12 mm

7. FINAL FABRICATION MODEL

the final structure of the prototype is shown in the figure below which is designed and fabricated by using above consideration of dimension and calculations.

Fig.no.9 final prototype model

8. EXPERIMENTAL PROCEDURE AND RESULTS

1) Wind Velocity Measurement

- First we calculated the wind speed using pressure gradient method. In this method we measure the pressure difference between two points and the differential when multiplied with a constant gives wind velocity.
- Note down each reading of wind speed.

2) RPM Measurement of Rotor

- Start the blower and adjust the speed to get the start up speed of the turbine.
- Then as turbine starts rotating, note down reading when turbine rotates at constant speed.
- Take five readings for different wind blower velocities.

8.1. Observations :

Rotor diameter, D: 62 mm

Rotor height, H: 127 mm

Swept area, A_s= 2*2000 mm^2 = 4000mm^2

Table No. (1) Observation table for maglev VAWT

Sr. No.	Wind Velocity (V_w)	Voltage (V)	Current (Amp.)	Speed RPM (N)
1	6	6.3	0.015	90
2	8	10.4	0.035	230
3	10	14.2	0.055	412
4	12	22.4	0.084	620
5	14	29.3	0.01	818

8.2. Calculations:

Sample calculation

For Reading 12 m/s,

1. Angular Speed, (ω) = $2\Pi N/60$
   = 0.1046 x 620
   = 64.893 rad/sec

2. Rotor Velocity, (V_R) = ω x (D/2)
   = 2.0116 m/s

3. Tip Speed Ratio, (λ) = V_R/V_W
   = 2.0116/12
   = 0.1676

4. Actual Power, (P_A) = V x I
   = 22.4 x 0.084
   = 1.8816 W

5. Wind Power, (P_W) = ½ x $(\rho A_S V_W^3)$
   = 1/2 x (1.225 x 0.004 x 12^3)
   = 4.2336 W

6. Coefficient of Power, (C_P) = P_A/P_W
   = 1.8816/4.2336
   = 0.4421

7. Efficiency, (η) = (P_A/P_W) x 100
   = 44.21 %

8. Reynolds Number, (R_e) = $(\rho V_W D)/\upsilon$
   = (1.225 x 4 x 0.062)/10^{-5}
   = 91140

8.3. Result Table:

Table no. (2) Result table

Sr. No.	Wind Velocity, (V_W) m/s	Speed RPM (N)	Angular Speed, rad/sec $(\omega) = \frac{2\pi N}{60}$	Rotor Velocity, m/s (V_R) = ω x r	TSR $(\lambda)=\frac{V_R}{V_W}$
1	6	90	9.414	0.2918	0.0486
2	8	230	24.058	0.7457	0.0932
3	10	412	43.095	1.3359	0.1335
4	12	620	64.852	2.0104	0.1675
5	14	818	85.5624	2.6524	0.1834

9. ADVANTAGES

- •A massive tower structure is not required, as VAWT's are mounted closer to the ground.
- •These are located closer to the ground and hence easier to maintain.
- •They don't require Yaw mechanisms.
- •Requires no lubrication.
- •Capable of generating power from wind speeds as low as 1.5 m/s and reported to operate in winds reaching 40 m/s.
- •Producing 20% more energy than a conventional turbine, at the same time decreasing operational costs by 50% over the traditional wind turbine.
- •Accepts wind from any angle.
- •Better answer to rapidly changing winds.
- •Lighter weight towers
- •Virtually silent operation.
- •High Mechanical

10. CONCLUSIONS AND FUTURE SCOPE

10.1 Conclusion

The goal of the project was to test performance characteristics for use in designing a prototype and to confirm the potential power output of Savonius rotor by using Magnetic Levitation to achieve two benefits, first to make it self-start and second to make it work over a wide range of wind speed. The data collected and analysis performed have produced results both accurate and precise enough to significantly contribute to further design efforts and as well as to the general body of knowledge available with regard to rotors from the present investigation the following conclusions can be summarized:

- The Maglev rotor gains self-starting capability i.e.; it doesn't need external power to start.
- The introduction of MAGLEV to VAWT increases the efficiency and reduces the vibration by nearly 30% compared to the HAWT.
- There is no bearing friction and mechanical noise is low. The starting torque, thus the starting wind speed is low. As a result, the wind turbine consumes little power and has a high efficiency using wind power.
- It needs no complicated control mechanism to adjust the blade attack angles.
- Utilization rate of wind power is improved, overall efficiency of wind turbine is enhanced and the production cost as well as maintenance cost is reduced.
- The rotor can operate over wide range of wind speed i.e.; from low to high wind speed safely.
- With overlap Savonius rotor wind turbine have higher power coefficient under the same test. Similarly power coefficients increases up to 0.1758 and then decreases with the increase in wind velocity (V_W).

The power coefficient is a function of the tip speed ratio and varies with different geometries of the Savonius rotor. The maximum C_P of 0.1758 is obtained at a *TSR* of 0.405. During high wind speed there is formation of air pocket so the wind passing through the blades will

10.2 Future Scope

Future work could entail investigation of the effect of following perspectives discussed below on the performance of the present rotor.

- By using aerodynamic blades for Savonius rotor, the torque of the rotor can be increased to produce more power at even low speeds.
- Design related to self-adjustable End Plates can be developed to attract more air to pass through the blades by automatic creation of pressure differential across inlet and outlet.
- Future work in the field of suitable alternator or generator can also be proposed for efficient generation of electricity at lower speeds.
- In this design we can place Solar Plate and can get doubled electricity with the same place in use.

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