Design of Magnetically Levitated Vertical Axis Wind Turbine

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Abstract- *Non-renewable sources of energy like coal, crude oil etc. is on the verge of depletion. It also adds to various forms of pollution. To meet an increasing demand of energy it is necessary to innovate new ways to effectively harness renewable sources of energy that are environmental friendly and efficient. One such energy found in abundance is wind. The available technology that is widely used is horizontal axis wind turbine. The HAWT typically depends on location and cannot be used for small scale application. Hence vertical axis wind turbines were introduced. It was not popular due to its high starting torque and less power output due to friction at bearings. In this present work a magnetically levitated vertical axis wind turbine is designed to increase the efficiency of wind power system. Magnetic levitation ensures contactless working thus decreasing the starting torque and removing friction completely. Performance of this design is studied to determine starting torque and power output under different wind speeds. The results obtained are compared with the model of conventional windmill supported on frictional contact bearing.*

Keywords- Vertical axis wind turbine, Magnetic levitation, Renewable sources, savonius wind rotor.

I. INTRODUCTION

The renewable source of energy is both abundant and clean as compared to its counterpart. The increasing demand of electric power has challenged the available technology to constantly innovate such that these sources can be utilised effectively to its fullest. One such widely used form of energy is wind energy. Windmills are used to convert wind energy to rotational energy by means of blades or vanes. This rotational energy generates electricity by means of a generator. Thus, depending on axis of rotation there are two configurations in wind mill: Horizontal axis wind turbine (HAWT) and Vertical axis wind turbine (VAWT).

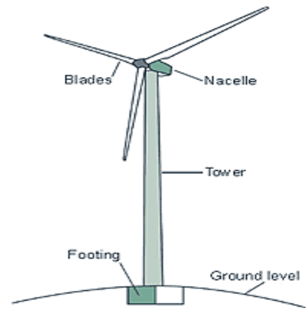

Fig 1 Horizontal axis wind turbine

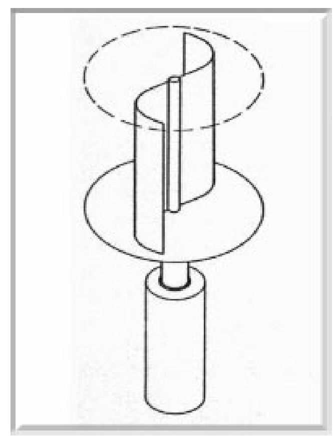
Fig 2 Savonius Vertical axis wind turbine

Recent technological advancements have led to efficient harnessing of wind energy with the use of horizontal axis wind turbine. The disadvantage with HAWT is the sound that it produces and height to which it has to be installed for its high starting torque. Hence, VAWT is gaining popularity since it doesn't require yaw mechanism i.e. it can catch winds from all directions, gearbox and generator are positioned on ground thus making it easy for maintenance, lower wind velocity for starting, lower noise etc. With the use of VAWT inner-city wind power applications can be brought under development since on-land locations are also favourable sites for power applications. However these vertical axis windmills are supported by using axial and radial frictional contact bearings. Entire structural weight is along the gravity and it is supported by thrust bearings. Increase in the structural weight increases the contact friction and hence the efficiency of the windmill reduces. In order to remove the contact, the principle of magnetic levitation can be used.

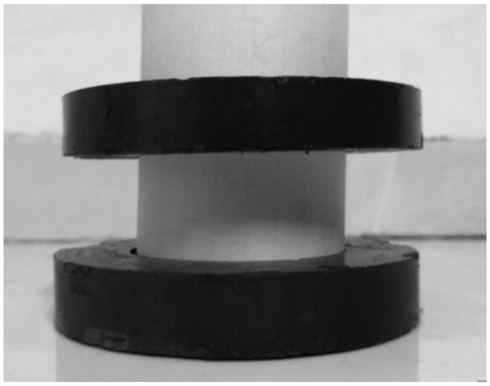

Fig 3 Magnetic levitation using two ring magnets

Magnetic Levitation is method by which an object is suspended by using magnetic fields. Magnetic forces are used to counterbalance gravitational force and levitate the object. Most famous application of this technology can be seen in maglev trains .Magnetic levitation is used in Vertical wind turbine in order to improve its efficiency. Savonius wind turbine requires high starting torque thus starting speed required is high. To overcome these disadvantages magnetic levitation is used. By placing 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. Two Neodymium permanent magnets are used to achieve magnetic levitation. If the efficiency of a wind turbine is increased, then more power can be generated thus decreasing the need for expensive power generators that cause pollution. Since one of the main complaints about wind turbines is the sound they produce, this is a huge advantage over other turbine designs.

In the present work vertical axis windmill is designed and the magnetic levitation principle is used to support the windmill structure both axially and radially without any physical contact. Permanent magnets are used to avoid the requirement of electricity. Performance of this design is compared with the conventional windmill supported on frictional contact bearings.

II. LITERATURE REVIEW

Mahmood et al. has studied different geometries of Savonius wind turbine 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 rotor with end plates gives higher efficiency than those of without end plates. Double stage rotors have higher performance compared to single stage rotors. The rotors without overlap ratio are better in operation than those with overlap. The results show also that the power coefficient increases with raising the aspect ratio. Model was built in order to verify the above summarized results of this work.

Dhareppagol and Konagutti, (2014) has described a new model of wind turbine which uses magnetic levitation to reduce the internal friction of the rotor which is considered as a revolution in the field of wind technology, producing 20% more energy than a conventional turbine, at the same time decreasing operational costs by 50% over the traditional wind turbine. Designing of rotor and no. of blades by using analytical method is done in this paper. The no of blades used for this turbine is 6 which are placed such that the angle between two adjacent blades is 60 degree. Each blade is fixed between the two discs with 30 degree deviated from each other. The length to diameter ratio is kept as 1 for better performance of the turbine. Comparison between a Horizontal axis wind turbine and Regenedyne Maglev Wind turbine is done. The technology is expected to create new opportunities in low-speed areas, with starting speed as low as 1.5m/s & cut in speed of 3m/s. It is configured to capture wind from any direction and convert wind to energy at very high efficiency. Magnetic levitation reduces the friction & eliminates need of bearings. Major components are located at ground level. It requires less maintenance as no lubrication is required. Maglev wind turbines have long life span. They are able to deliver clean green-power for less than one cent per kilowatt hour. This new technology is remarkably cheap with low operating cost. Less noise compared to existing conventional wind turbines. Today wind turbines are considered to be the most developed form of renewable energy technology. Advantages and disadvantages of Regenedyne Maglev Wind turbine is shown.RPM v/s voltage curve is plotted according to the results obtained. The system can provide electricity at a rate lower than coal and nuclear. Thus we believe this technology has the capacity to completely displace current technology in use for wind farm.

Jafar et al., (2014) has focused on the development of a permanent magnet generator for a vertical axis wind turbine thus solving the high starting torque problem of vertical axis wind turbine. Magnetic levitation was used to resolve this problem. Magnetic levitation reduced the wind turbine weight acted by the gravitational force. The prototypical structure on customize design was analysed on its geometry and output voltage were measured. The author had divided the project in three components that is savonius wind turbine, base and Permanent magnet generator. Savonious blade was made up of two semi-circular cylinders. Geometrical arrangement of the prototype was done. Model analysis was done and it was divided in two parts Rotational speed analysis and generator analysis. By using Rotational speed analysis graph for rotational speed v/s wind speed was plotted. Comparison between theoretical and actual voltage was done in generator analysis. Half wave rectification circuit was used which was able to convert half positive AC voltage to pulsating DC voltage. The prototyping model showed that a small designed Savonius blade is also able to rotate at low wind speed. In order to achieve higher rotational speed the author advised us to improve tip speed ratio. Future improvement and optimization are needed in order to achieve better efficiency. The project is planned to be applied to the highway streetlight as fast moving vehicle is believe to beable to create an amount of wind speed which is enough to rotate the Savonius rotor.

Patel and Nasiruddin, (2012) has designed a magnetically levitated vertical axis wind turbine for reducing frictional losses. The paper presents the idea of designing axial flux generator with dual rotors that are levitated via passive magnetic levitation vertically on stator plate. It has spiral shaped blades and axial flux (disc shaped) permanent magnet machine yielding low speed and high torque operation. The design has a dual rotor assembly for maximum flux concentration Analytical modelling method instead of FEA, number of phase, coils and magnetic pairs are defined. Also, frictional losses during electrical transmission are taken into account. The paper studies the graph between No load line voltage v/s rpm that has an increasing nature. Thus power output depends on input kinetic energy of wind which is effectively harvested. Friction between rotors and stator has been made minimal using passive magnetic levitation in AFPM generator. Moreover, the design helped to reduce the noise and vibration which has been a big issue by AFPM generators in residential area. Additionally, bearing less design reduces the maintenance cost and enhances the life span of the system. Savonius type model of VAWT has been presented for AFPM generator which is very simple design and can run at low wind speed according to power coefficient vs. tip speed ratio graph. The uniqueness of the proposed work is the dual rotor levitating turbine, which is more efficient than the few existing single rotor levitating turbines. Maximum power output strategies and magnetic properties due to Curie temperature has not been discuss. Also, FEA and CFD analysis has not been carried out.

Aravind et al., (2012) has proved the need to define a correct tip speed ratio. The tip speed ratio is governed by the wind speed and generator starting torque. Hence with this idea number of the blades is optimized. One has to keep in mind the effect of tip speed ratio on parameters like height of the blade. The values were then used to calculate the blade angle thus giving maximum power output. These parameters were used to calculate the generated voltage and turbine speed at various speeds. The paper failed in understanding the problems of cogging and magnetic pull.

III. DESIGN CONSIDERATIONS

A windmill has to be designed according to maximum conversion of mechanical energy into its electrical form. The design not only should sustain drag forces but also should generate minimum power under different operating wind speeds.

a) Calculation of wind power

The concept of effective conversion lies to the fact that the wind should be able to provide continuous rotation to blades. Thus, the blades should have greater area, such that more power can be generated. Also, the kinetic energy of the wind depends upon cube of velocity of the wind. Therefore, it can be said from the output point of view, more area and wind velocity will enhance more output in the wind power system.
The kinetic energy of the wind is given as,

Kinetic Energy = $\frac{1}{2}MV^2$

where M is mass and V is velocity

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

Available wind Power $P_w = \frac{1}{2}\rho A V^3$

Here $\rho = 1.207$ kg/ m^3 is density of air , A is Area swept by the turbine blade , V is wind velocity.

According to beltz limitation no turbine can capture more than 59.3% of available wind energy. For two bladed savonius wind turbine maximum coefficient of performance is considered to be 0.3.

Wind energy captured $P_s = \frac{1}{2}C_p\rho AV^3$

Where C_p is coefficient of performance for turbine.

In order to convert into kilowatts a non-dimension proportionality constant k is multiplies whose value is 2.14×10^{-3}.

b) Calculations for drag forces on the blade

When the blades of the windmill move slower than the wind velocity, it will absorb energy from the wind. This form of energy is called as the drag developed on the blade by the wind velocity. The drag force F_w on the blade is given by

$$F_w = \frac{C_d A\rho(U_w - U_b)^2}{2}$$

Here U_w is wind speed, U_b is the speed on blade surface and C_d is the drag coefficient (1.9 for rectangular form). It is seen that the wind velocity dominates the wind force as compared to other parameters A, C_d and ρ. As expected, more driving force is effective to rotate the turbine and to gain more electricity. The maximum power is obtained when U_b=U_w/3

c) Calculations for magnetic force between magnets

The repelling force created during magnetic levitation of permanent magnets is given by

$$F_m = \frac{\pi\mu}{4} M^2 R^2 \left[\frac{1}{x^2} + \frac{1}{(x+2h)^2} - \frac{2}{(x+h)^2}\right]$$

Where R is radius of the magnet, h is height of the magnet, M is magnetization, x is he distance between the two magnets.

d) Calculation for tip speed ratio.

Once the wind speed is set, the Tip Speed Ratio (TSR) is computed. TheTSR(λ) of the blade is given by

$$\lambda = \frac{\omega R}{u}$$

Here, ω is the rotational speed of rotor in rad/s and R is the radius tip of motor in m

For savonius wind turbine tip speed ratio is approximately equal to one.

IV.ANALYTICAL CALCULATIONS

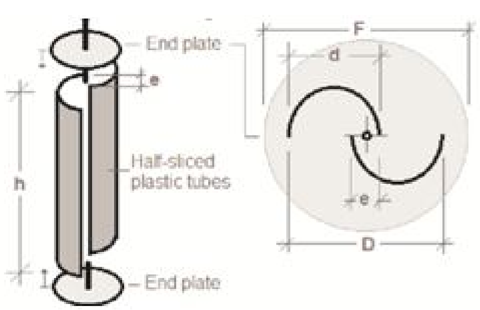

Fig 4 Basic sketch of savonius rotor [2]

a) Calculation for dimensions

A two bladed savonius wind turbine is designed such that it should produce minimum power output of 5W for wind velocity of 5m/s.

Substituting value as required power = 5W, Coefficient of performance = 0.3, Density of air = 1.207 kg/m^3, Velocity of air = 5 m/s in power equation.

Therefore,

Area Swept required (A) = 0.2222m^2

We know, A = h*D

Where D is diameter of rotor blade,h is height of rotor

Taking aspect ratio as 1.5

That is h/D = 1.5

Therefore,

Required h=0.5773 m and D=0.3848 m

Taking h=60 cm and D=40 cm

New swept area = 0.24 m^2

Table 1 Power output for different wind velocities

Wind Velocity	Power Obtained
5 m/s	5.432 W
6 m/s	9.386 W
7 m/s	14.904 W
8 m/s	22.247 W
9 m/s	31.670 W

As we can see power increases cubically with increase in wind velocity.

End plate diameter (F) = 1.2 * D = 48 cm

b) Shaft analysis

For calculation of shaft diameter Maximum shear stress theory was used. Shaft of turbine was considered as a cantilever beam.

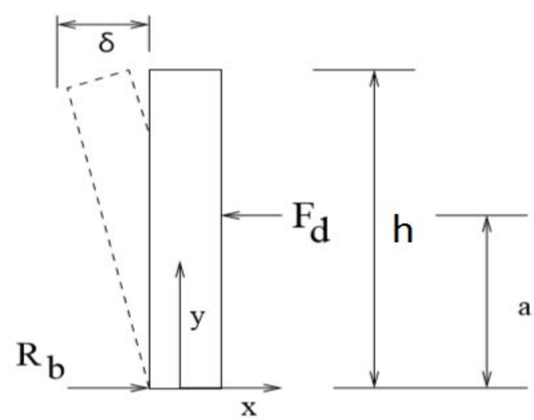

Fig 5 Free body diagram of shaft

As seen in the figure F_d is drag force acting on the blades,$R_b$isthe reaction force absorbed by the bearings,h is height of the turbine and δ is the deflection in shaft of the turbine.

$$F_d = 0.5\rho v^2 C_d A$$

Where C_d is drag coefficient and for rectangular form

C_d = 1.9

$$F_d = 33.974\,N$$

Equation of shaft diameter is :-

$$\text{Shaft Diameter } (d_s) = \left(\frac{32n_s}{\pi S_y}\sqrt{M^2 + T^2}\right)^{\frac{1}{3}}$$

Where n_s is the factor of safety which is taken to be as 3, $S_y$is yeild strength of the material and is 90Mpa for aluminium alloy. M and T are the static moment and dynamic torque, respectively, acting on the shaft.

M = $F_d * a$

M = 10.192 Nm

T = $\frac{P_s}{\omega}$

Where, $P_s = \frac{1}{2} Cp\, \rho A V^3$

For max wind velocity of 40kmph or 11.111m/sP_s = 59.257N and ω = 55.555 rad/s

Thus, T=1.0666Nm

Substituting the values in equation of diameter,

$$d_s = 0.01515\,m = 15.15\text{mm}$$

Diameter of the shaft should be more than 15.15 mm. Available shaft diameters are 16, 18, 20, 25mm.Thus selecting the shaft diameter as 16mm.

c) Number of Blades

Savonius rotor can have multiple numbers of blades. For commercial use mainly we have two, three or four bladed savonius rotor.

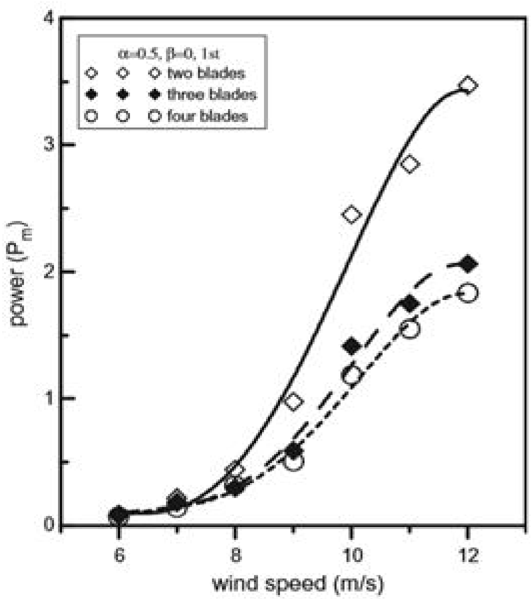

Fig 6 Variation in mechanical power with wind speed for rotors with two, three and four blades [6]

According to Mahmood et al. it was found out that the two bladed rotor gives higher mechanical power compared to three and four blades rotors. The two blades rotor is more efficient also for other aspect ratios and for double stages rotor. It is seen that the two bladedrotor gives higher performance than three and four bladed rotors for all aspect ratios as well as for single or double stages too. Also weight of the setup is reduced as less number of blades are used. This is why we will be using two bladed savonius rotor instead of a three or four bladed.

Result :-

Table 2 Dimensions of the model

Height (h)	600mm
Diameter of Rotor (D)	400mm
Width of blade (d)	250mm
Internal gap between blades (e)	100mm
End plate diameter (F)	480mm
Shaft diameter (d_s)	16mm
Aspect ratio (α)	1.5
Number of blades	2

V. 3D MODEL

CREO parametric was used in order to create a 3D model of the wind turbine.

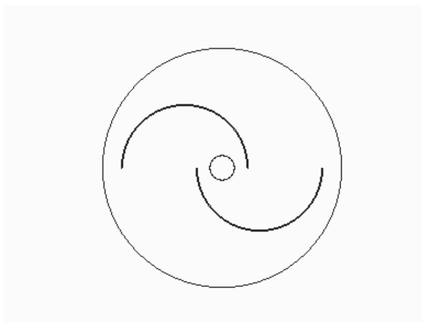

Fig 7Schematic of the two-bucket Savonius rotor with 180° buckets.

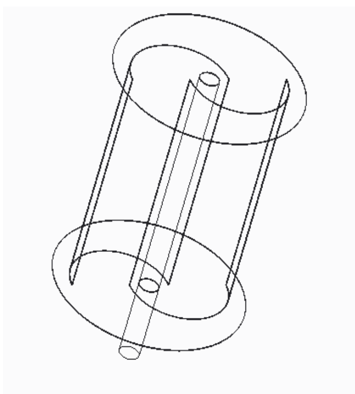

Fig 8 Wireframe view of turbine rotor

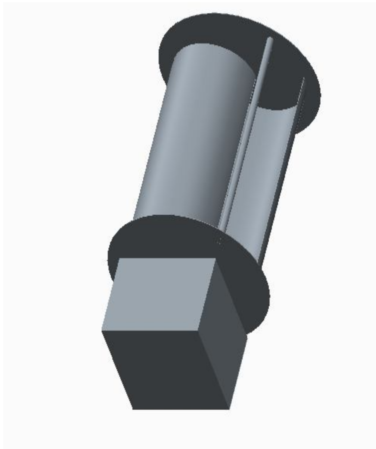

Fig 9 Two bladed savonius vertical axis wind turbine in CREO

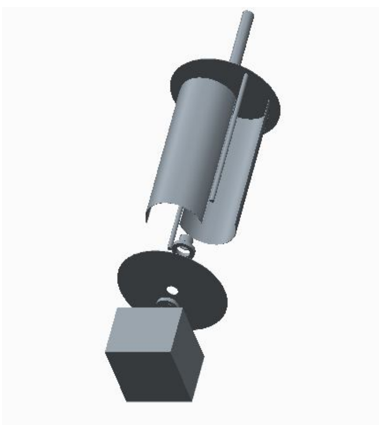

Fig 10 Exploded view of model

VI. CONCLUSION

The efficiency of turbine is increased by using the magnetic levitation. It helps the turbine to spin at much faster rate as it eliminates the stress on the shaft of the turbine. Also the major components are placed at ground level. We can say the maglev turbine can power more output with high efficiency conversion compared to traditional wind turbine.The system will provide electricity at a rate lower than coal and nuclear. As cost is low it can be used for development of rural areas. Thus we believe this technology has the capacity to replace the traditional ways of wind power harnessing.

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