DESIGN OF MAGLEV WIND TURBINE

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Abstract: The increased need to overcome the global energy crisis as well as the environmental ill-effects of traditional fossil fuels used, developed the demand for the use of renewable sources of energy. Renewable energy such as wind energy, solar energy, tidal energy is available in plenty and can reduce the dependency on fossil fuels. The increased concern for environment now-a-days steered to the research for more environment friendly sources of energy. The use of wind for the generation of energy is the most environment friendly solution to the increasing energy crisis and pollution problems. There are various wind turbines available for harnessing wind such as Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT). As the name implies, the wind turbines are classified according to the orientation of the rotor. The HAWT are most widely used turbines and are used in large scale applications and require more space and more installation and maintenance costs. The VAWT, however, are smaller in sizes and can be installed at smaller land spaces and even on buildings, highways and places where low wind speeds are available and have low installation cost and servicing. The VAWT are further classified as Darrieus and Savonius depending on its rotor blades. The Magnetic Levitated (Maglev) VAWTs incorporate the use of magnets instead of the mechanical bearings used in conventional HAWTs. The use of magnets significantly reduces the friction coefficients thereby reducing mechanical wear and tear due to bearings in the conventional turbines. The Maglev wind turbine works on the principle of repulsion of like poles of a magnet. This paper includes a detailed and systematic study on the aerodynamics and performance characteristics of Savonius rotor and the constructional aspects of Maglev wind turbine. The aim of the paper is to provide the design of Maglev VAWT and to analyze its future scope.

Index Terms: Maglev Wind Turbine, Magnetic Levitation, Wind Power, Neodymium Magnet, Savonius Rotor.

I. INTRODUCTION

Wind is a natural power source that can be economically used to generate electricity. The wind is created due to the sun causing areas of uneven heating on the earth’s surface. Along with the uneven heating of the sun, and the rockiness of the earth’s surface winds are formed. Wind energy or wind power describes the process by which the wind is harnessed to generate electricity or mechanical power. The kinetic energy of the wind is converted into mechanical power by using wind turbines. This mechanical power can be converted into electric power with the help of a generator. The wind rotates the blades which in turn spins the shaft to which they are connected; which connects to a generator and converts the rotations into electric energy.

The Maglev wind turbine design is a vast departure from conventional propeller designs. Its main advantages are that it uses frictionless bearings and a magnetic levitation design and it does not need to vast spaces required by more conventional wind turbines. It also requires little if any maintenance. The Maglev wind turbine was first unveiled at the Wind Power Asia exhibition in Beijing 2007. The unique operating principle behind this design is through magnetic levitation. Magnetic levitation is supposedly an extremely efficient system for wind energy. The vertically oriented blades of the wind turbine are suspended in the air replacing any need for ball bearings. [1]

II. MAGNETIC LEVITATION

Also known as maglev, this phenomenon operates on the repulsion characteristics of permanent magnets. This technology has been predominantly utilized in the rail industry in the Fareast 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 and is strong enough to balance the weight of an object depending on the threshold of the magnets. In this project, we expect to implement this technology form the purpose of achieving vertical orientation with our rotors. [2]

Permanent magnet bearing has the advantages of low power consumption, no mechanical contact and suitable for severe adverse environment. In recent years, with the rapid development of permanent magnet material, the technology of permanent magnetic levitation has been expanded to wind turbine applications. This has greatly reduced the cost and stringency of wind power. Specifically, the application of magnetic levitation to wind turbines has achieved the following advantages:

1. Starting wind speed is reduced by magnetic levitation due to reduced bearing friction and power output of wind turbine is increased for the same wind speed.
2. Magnetic levitation has largely changed the traditional wind turbine rotor system design using special rolling-element or oil-film bearings. These traditional bearings depend on careful lubrication and sealing for long service life, impact resistance, and high reliability. The magnetic levitation not only reduces the cost of the bearings and their maintenance, but also reduces the down time of the wind turbine and therefore, improves the over-all efficiency of the system.

Magnetic levitation technology applied to wind turbine is an emerging technology; the development of maglev magnetic wind turbine is just beginning. Although there claimed many maglev wind turbine products have been developed, relevant published studies are rare. [3]

III. WIND POWER

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 calculable with respect to the area in which the wind is present as well as the wind velocity [4]. 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:

$$\text{Kinetic energy} = \frac{1}{2}MV^2 \qquad \text{…Eq. 1}$$

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

$$M = \rho AV$$

Substituting the value of M in Equation 1 we get:

$$\text{Kinetic energy} = \frac{1}{2}(\rho AV)V^2 \qquad \text{… Eq. 2}$$

$$\text{Kinetic energy} = \frac{1}{2}\rho AV^3 \qquad \text{… Eq. 3}$$

To convert the energy to kilowatts, a non-dimensional proportionality constant k is introduced where,

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

Therefore

$$\text{Power in kW (P)} = 2.14\ \rho AV^3\ \times 10^{-3} \qquad \text{… Eq. 4}$$

Where:
Air density (ρ) = 1.2 kg/ m^3 / 2.33 x 10^{-3} slugs / ft^3
Area (A) = area swept by the blades of the turbine
Velocity (V) = Wind speed in mph

With equation 4 above, 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. [5]

Hence, from equation 3, the power can be defined as:

$$P = \frac{1}{2}\rho AV^3 \qquad \text{…Eq. 5}$$

A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. To this day, this is known as the Betz Limit or Betz' Law.

The theoretical maximum power efficiency of any design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). This is called the “power coefficient” and is defined as:

$$C_{p\ max} = 0.59$$

Also, wind turbines cannot operate at this maximum limit. The C_p value is unique to each turbine type and is a function of wind speed that the turbine is operating in. Once we incorporate various engineering requirements of a wind turbine - strength and durability in particular - the real world limit is well below the Betz Limit with values of 0.30-0.45 common even in the best designed wind turbines. By the time we take into account the other factors in a complete wind turbine system - e.g. the gearbox, bearings, generator and so on - only 10-30% of the power of the wind is ever actually converted into usable electricity. Hence, the power coefficient needs to be factored in equation 5 and the extractable power from the wind is given by:

$$P = \frac{1}{2}\rho AV^3 C_p\ [6] \qquad \text{…Eq. 6}$$

3.1 GLOBAL STATUS OF WIND POWER

More than 52GW of clean, emissions-free wind power was added in 2017, bringing total installations to 539 GW globally. With new records set in Europe, India and in the offshore sector, annual markets will resume rapid growth after 2018. [7]

A historical record of 4,331 MW of new offshore wind power was installed across nine markets globally in 2017. This represents an increase of 95% on the 2016 market. Overall, there are now 18,814MW of installed offshore wind capacity in 17 markets around the world. [8]

Wind power is present today in more than 90 countries. There are now 30 countries with more than 1,000 MW installed and 9 countries with more than 10,000 MW installed. This interactive infographic shows the cumulative installed wind power capacity per country, continent and the world as a whole from 1982 to 2017. [9]

3.2 WIND IN NUMBERS

Table No. 1: Wind in numbers [10]

1,155,000	Jobs created by the global wind industry at the end of 2016.
55.6	The record number of 55.6GW of wind power installed in 2016, bringing the total installed global capacity to 486.8GW at the end of 2016.
637	In 2016, wind power avoided over 637 million tons of CO2 emissions globally.
341,320	The number of wind turbines spinning around the world at the end of 2016.
14,384	The amount of offshore wind power installed globally at the end of 2016 in megawatts.
3.7	The percentage of global electricity supplied by wind power in 2015.
17	The cost of integrating large, conventional power plants onto the power system in Texas is more than 17 times larger than the cost of reliably integrating wind energy.

8	The largest wind turbine in the world is the Vestas 8 MW turbine with a rotor diameter of 164 meters.
88.4	The world’s longest wind turbine blade is LM Wind Power’s 88.4 meters long blade.
2	A 10 MW wind farm can easily be built in two months. A larger 50 MW wind farm can be built in six months. The Butendiek 288 MW offshore wind farm with 80 turbines in the North Sea was built in just 16 months and now supplies clean power to 370,000 households.
520,000	The number of people expected to be employed by the wind industry in the EU by 2020.
17	Wind power farms generate between 17 and 39 times as much power as they consume, compared to 16 times for nuclear plants and 11 times for coal plants.
29	Amount of countries having more than 1,000 MW of wind power installed across the world; 9 countries have installed more than 10,000 MW.
387	The amount of million cubic meters of water use avoided by wind energy in the EU, equivalent to the average annual household water use of nearly 7 million EU citizens (source: EWEA).
2,000	The amount of water in liters that wind power can save per MWh against other energy sources (source: US Department of Energy).

IV. WORKING PRINCIPLE

The basic working principle of a wind turbine is when air moves quickly, in the form of wind, the kinetic energy is captured by the turbine blades. The blades start to rotate and spin a shaft that leads from the hub of the rotor to a generator and produce electricity. The high speed shaft drives the generator to produce electricity. The low speed shaft of wind turbine is connected to shaft of high speed drives through gears to increase their rotational speed during operation. Using the effects of magnetic repulsion, spiral shaped wind turbine blades will be fitted on a rod for stability during rotation and suspended on magnets as a replacement for ball bearings which are normally used on conventional wind turbines. The energy that can be extracted from the wind is directly proportional to the cube of the wind speed. The power converted from the wind into rotational energy in the turbine can then be calculated using the equation:

$P_{avail} = 0.5\ \rho\ AV^3\ C_p$

Where, P_{avail} is output power available in watts.
ρ is density of air in kg/m3.
A is area swept by blades.
V is velocity of wind.
C_p is the power coefficient called Betz limit… $C_{p\ max} = 0.59$ [11]

V. MAGNET SELECTION

Some factors need to be assessed in choosing the permanent magnet selection that would be best to implement the maglev portion of the design. Understanding the characteristics of magnet materials and the different assortment of sizes, shapes and materials is critical. There are four classes of commercialized magnets used today which are based on their material composition each having their own magnetic properties. The four different classes are Alnico, Ceramic, Samarium Cobalt and Neodymium Iron Boron also known Nd- Fe-B. Nd-Fe-B is the most recent addition to this commercial list of materials and at room temperature exhibits the highest properties of all of the magnetic materials. It can be seen in the B-H graph shown in Figure 3.1 that Nd-Fe-B has a very attractive magnetic characteristic which offers high flux density operation and the ability to resist demagnetization. This attribute will be very important because the load that will be levitated will be heavy and rotating a high speeds which will exhibit a large downward force on the axis.

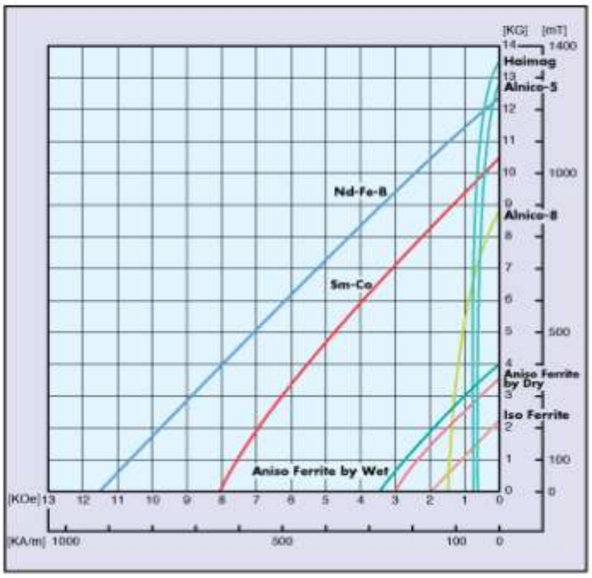


Fig.1: B-H Curve of Various Magnetic Materials

The next factor that needs to be considered is the shape and size of the magnet which is directly related to the placement of the magnets. It seems that levitation would be most effective directly on the central axis line where, under an evenly distributed load, the wind turbine center of mass will be found as seen in Figure 3.2. 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. [12]

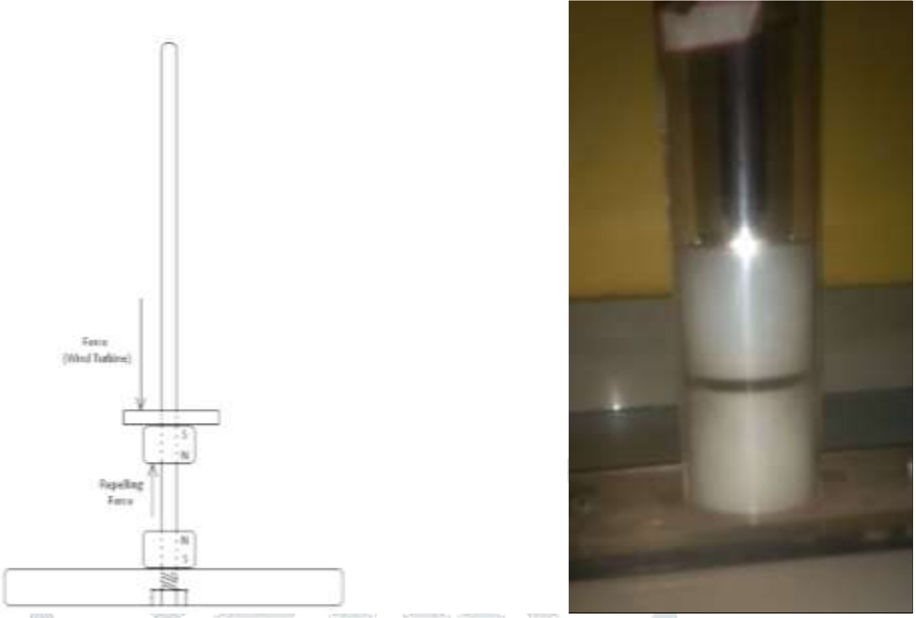


Fig.2: Basic Magnet Placement

The permanent magnets that were chosen for this application were the NX8CC-N42 magnets from K&J Magnetics. These are Nd-Fe-B ring shaped permanent magnets that are nickel plated to strengthen and protect the magnet itself.

VI. CONSTRUCTION

6.1 BLADE DESIGN: Various Blade designs for VAWTs are available from which the Conventional Savonius Rotor is selected in the present prototype. Savonius wind rotor is a vertical axis wind machine. It is a drag type rotor and its basic configuration consists of an ‘S’ shape formed by two semicircular blades with a small overlap between them. This structure has the ability to accept wind from any direction. The design of this rotor is very simple and economical. It has very high starting torques. The Savonius rotor is a drag type rotor, i.e., the main driving force on the rotor is the drag force acting on its blade. Figure 3 shows the structure of a conventional Savonius rotor. The semicircular plates are held in place with the help of two flanges as shown in the figure. There are several performance parameters associated with the Savonius Rotor. They have been defined in the following section.

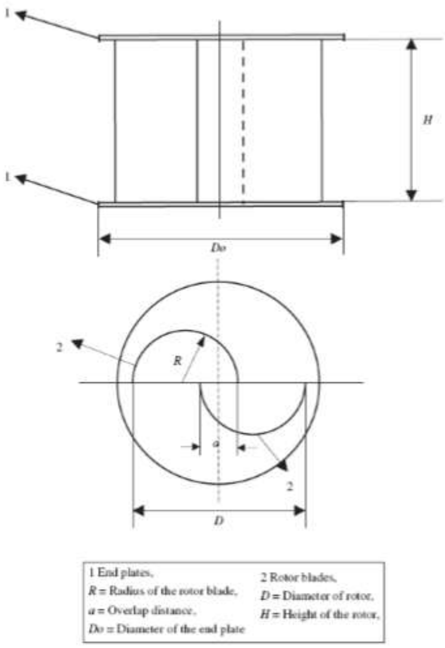


Fig.3: Conventional Savonius rotor

Several performance parameters govern the performance of a Savonius rotor. These parameters enable the comparison between different rotors.

1. Overlap Ratio (β): It is the ratio of the overlap distance (a) to the diameter of the rotor blade. It gives an indication of the extent of blade overlap for a particular configuration of the blades. It is given by:

$\beta = \frac{a}{2R}$ …Eq. 7

2. Aspect Ratio (α): It is the ratio of the height of the rotor to its diameter. It is a measure of the extent to which the maximum dimension of the rotor differs from the minimum dimension.

$\alpha = \frac{H}{D}$ …Eq. 8

3. Tip Speed Ratio (λ): Tip speed ratio or TSR, is the ratio of the rotational speed of the blade to the actual velocity of the air stream. A higher tip speed ratio is indicative of higher efficiency but is also related to higher noise levels and the need for stronger blades. TSR is quite important in the design of any wind turbine. If the rotor of the wind turbine turns too slowly, most of the wind will pass undisturbed through the gap between the rotor blades. Alternatively if the rotor turns too quickly, the blades appear stationary to the wind. Therefore, wind turbines are designed with optimal tip speed ratios to extract as much power out of the wind as possible.

$\alpha = \frac{\omega D}{2U}$ …Eq. 9

4. Reynolds Number (Re): Reynolds number is the non-quantity that gives a measure of the inertial forces to the viscous forces in a given flow. They are used to perform a dimensional analysis of a given problem. The length scale that is used to obtain the Reynolds number is different in different situations. In each of the cases discussed in the report, the length scale is given by the diameter of the rotor, and the Reynolds number is hence, given by:

$R_e = \frac{\rho U D}{\mu}$ …Eq. 10

5. Torque Coefficient (C_t): Torque Coefficient is the dimensionless torque of the rotor. The normalizing term is the product of the dynamic pressure due to the wind, an area term and a length equivalent of the rotor. The starting torque coefficient (C_{ts}) is another non dimensional quantity associated with the performance of a rotor. It is obtained by replacing the torque in the torque coefficient equation by the starting torque. It is given by:

$C_t = \frac{4T}{\rho U^2 D^2 H}$ …Eq. 11

$C_{ts} = \frac{4T_S}{\rho U^2 D^2 H}$ …Eq. 12

6. Coefficient of Power (C_p): Coefficient of power is the non-dimensional power that is generated in the rotor. It is the ratio of the power produced in the rotor to the total kinetic energy of the air interfaced by the rotor. It is given by;

$C_p = \frac{Power\ produced\ by\ rotor}{Energy\ in\ interfaced\ air} = \frac{P}{(\frac{1}{2}\rho U^3)(DH)} = \frac{2T\omega}{\rho D H U^3} = C_t\ TSR$ …Eq. 13

6.2 CENTER SHAFT: The shaft of the turbine consists of a single rod of steel measuring 20mm diameter. The use of steel over a lighter metal such as cast iron was based on the availability of materials. The solid shaft is assumed to be made of mild steel. The yield strength of a mild steel shaft material (C45) from design data is 360Mpa. [13]

Selecting C45 material, from design data book, $\sigma_{ut} = 360 \frac{N}{mm^2}$, fos = 2

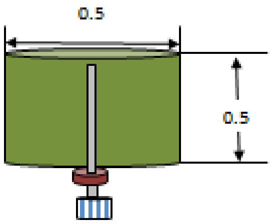
→ $\sigma_t = \sigma_b = \frac{360}{2} = 180 \frac{N}{mm^2}$ …Eq. 14

→ $\sigma_{s\ allowable} = 0.5 \times \sigma_t = 0.5 \times 180 = 90 \frac{N}{mm^2}$ …Eq. 15

The safe load is 150N (Approx 20Kg).The shaft is subjected to bending and torsion stresses.

❖ Assuming $\rho = 1.2 \frac{kg}{m^2}$, $C_p = 0.3$(for standard Savonius rotor) & $C_p = 0.45$(for maglev wind turbine)

1. Power, $P = 0.5 \times \rho \times A \times V^3 \times C_p = 0.5 \times 1.2 \times 0.5 \times 0.5 \times 5^3 \times 0.3 = 5.625$ Watts …Eq. 16
2. Tip Speed Ratio, $TSR = \frac{V_{tip}}{V_{air}}$
   $\therefore 0.7 = \frac{V_{tip}}{5}$ … For Savonius rotor: $V_{tip} = 0.7$
   $\therefore V_{tip} = 0.7 \times 5$
   $\therefore V_{tip} = 3.5\ {}^{m}/_{s}$ …Eq. 17
3. Velocity, $V_{tip} = \omega \times 2 \times 3.14 \times \frac{r}{60}$
   $\therefore 3.5 = \omega \times 2 \times 3.14 \times \frac{0.25}{60}$
   ∴Angular velocity in rpm = 133 rpm
   ∴Wind turbine speed = 133 rpm
   …Eq. 18



4. Also, Power, $P = \frac{2\pi N T}{60}$
   $\therefore 5.625 = \frac{2\pi \times 133 \times T}{60}$
   $\therefore T = 0.4038\ N - m = 403.8\ N - mm$ …Eq. 19
5. Torque, $T = \frac{\pi}{16} \times f_s \times d^3$
   $\therefore 403.8 = \frac{\pi}{16} \times f_s \times 20^3$
   $\therefore f_{s\ ind} = 0.2571 \frac{N}{mm^2} \quad < 90 \frac{N}{mm^2}$ …Eq. 20

∴Design of shaft is safe.

6. $M = \frac{Wl}{4} = \frac{150 \times 600}{4} = 22500\ N - mm$ …Eq. 21
7. $Z = \frac{bt^2}{6} = \frac{BT^2 - bt^2}{6} = \frac{30 \times 30^2 - 27 \times 27^2}{6} = 46426\ mm^2$ …Eq. 22

8. $F_{b\,ind} = \frac{M}{Z} = \frac{22500}{46426} = 0.48\,\frac{N}{mm^2} \quad < 180\ N/mm^2$ …Eq. 23

∴The diameter of shaft taken (20) mm is safe after testing both bending and torsion.

6.3 GENERATOR: A generator is used to convert mechanical energy into electrical energy. For generation and storage of electricity from the designed wind turbine, a dynamo or a battery can be used.

6.4 BEARINGS: Two bearings are used at the bottom and top of the shaft. Based on the shaft diameter of 20mm, Bearing No. P204 is used in the existing prototype.

VII. RESULTS AND DISCUSSION

Table No. 2: Maglev wind turbine readings at variable wind speeds

Wind Speed (m/s)	Power (Watts)	
	Standard Savonius Rotor	Maglev Windmill
5	5.625	8.4375
6	9.72	14.58
7	15.435	23.1525
8	23.04	34.56
9	32.805	49.2075
10	45	67.5

Thus, it can be observed that a small variation in wind speed can account for an appreciable amount of power generated. With a slight increase in wind speed, the power generated by Maglev wind turbine is much more than the power generated by a conventional wind turbine. With a much greater size of Maglev turbine, more and more power can be generated compared to conventional wind turbines. The efficiency of Maglev wind turbines can be increased by reducing the losses with slight modifications in blade profiles and rotor design.

A small Maglev turbine can be mounted on terraces of buildings and on highways for generation of streetlights. Another modification is mounting a solar panel aside the Maglev wind turbine which can also be called as the Maglev and solar panel wind turbine.

VIII. ACKNOWLEDGEMENT

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