SJIF Impact Factor 2021: 8.013| ISI I.F.Value:1.241| Journal DOI: 10.36713/epra2016 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)
Volume: 6 | Issue: 11 | November 2021 - Peer Reviewed Journal

PARAMETRIC STUDY AND DESIGN OPTIMISATION OF MAGNETIC LEVITATION VERTICAL AXIS WIND TURBINE

Naveen Krishna P[1], Kishor C[2], Nithin Nandakumar[3], Sanjay Kumar S[4], Vinayak AS[5]
[1,2,3,4]*Research Assistants in Department of Mechanical Engineering College of Engineering Adoor*

[5]*Professor in Mechanical Engineering, College of Engineering Adoor, Kerala, India*

ABSTRACT
The primary goal of the paper is to design a windmill that does not require a generator or ball bearings and produces the maximum amount of power. One of the oldest methods of harnessing renewable energy is the use of wind energy for energy generation. Renewable energy is a necessary component of socioeconomic development and growth. Magnetic levitation technology optimises the performance of a vertical axis wind turbine (VAWT). The system makes use of the permanent magnet's nature as a replacement for ball bearings to levitate the turbine component and thus reduce energy losses while rotating. Furthermore, the system can be suited in use for more rural and urban areas of low speed regions. The effects of various parameters on wind turbine performance, such as altitude, blade angle, and tip speed ratio, will be discussed. Power will then be generated with an axial flux generator, which incorporates the use of permanent magnets and a set of coils.

INTRODUCTION

According to the Global Wind Report, 743GW of wind generating capacity would be added globally by 2020, implying a net growth rate of more than 21% each year [1]. The goal of this project is to research and develop a magnetically levitated vertical axis wind turbine system that can function in both high and low wind speeds. Unlike ordinary horizontal axis wind turbines, this one is levitated vertically on a rotor shaft using maglev (magnetic levitation). This maglev technology, which will be discussed in depth, can be utilised to replace ball bearings in traditional wind turbines and is often implemented with permanent magnets. Between the spinning shaft of the turbine blades and the base of the entire wind turbine system, this levitation will be used. We hope to harness enough wind for power generation using an axial flux generator made of permanent magnets and copper coils once the necessary mechanisms are in place. The magnets will be arranged in such a way that an effective magnetic field will be created, and the copper coils will aid in voltage capture when the magnetic field changes.

LITERATURE REVIEW

2.1. TURBINE STUDY

The introduction and use of wind turbines appear to have been directed more by the serendipity of enthusiasts than by government encouragement around the world during the last 2000 years. As a result, although though wind is a significant power source, it is still underutilised. In 1984, P. D. Fleming and S. D. Proben [2] investigated the possibilities of wind energy and explained how wind turbines evolved. In 1983, Otto De Vries [3] published a review of the aerodynamic features of horizontal axis wind turbines for wind energy conversion. In 2007, Scott J.

Schreck and Michael C. Robinson [4] published Experiments and Modeling on Horizontal Axis Wind Turbine Blade Aerodynamics. A detailed study on vertical axis wind turbine and its historical development was discussed by Yan Li [5] in 2019.

2.2 PARAMETRIC STUDY

Fabrication of wind energy systems has become a critical area of concern as industry's energy demand develops tremendously. The relationship between wind energy parameters and subsequent relative energy has been studied using wind energy parameters. R. K. Tyagi [6] investigated the wind energy impacting parameters (types of gas, velocity of gas, diameter of blades, etc.) in 2012 using a combination of characteristics. C. Marimuthu and V. Kirubakaran created a mathematical model to analyse the parameters that affect the electrical power generated by wind turbines in 2014 [7]. Jayanna Kanchikere [8] developed a MATLAB model to explore the aerodynamic parameters that affect wind turbine power generation in 2012, and this Simulink model is valid for a wide range of wind turbines. Jianyang Zhu and Changbin Tian [9] investigated the effect of rotation friction ratio on the power extraction performance of a passive rotation H-type vertical axis wind turbine in a systematic numerical analysis published in 2019. (H-VAWT). M. H. El-Ahmar et al. [10] investigated the most critical parameters that determine the wind system's energy output in 2017. Also, a mathematical model is presented for wind power & investigates the influence of such parameters on the electrical power generated by the wind turbine.

2.3 MAGNETIC LEVITATION

Magnetic levitation is a technique for suspending an object using just magnetic fields as a support. In 1998 [11], Richard.F. Post and Walnut Creek discovered that repelling magnetic forces are used to levitate high-speed objects. P.Suster and A.Jadlovska investigated the control algorithm design for nonlinear simulation mode magnetic levitation in 2010 [12]. V.Bojarevics, A.Roy, and K.A.Pericleous reported in 2010 that full levitation of liquid metal requires careful adjustment of electromagnetic force for generating tangential flow [13]. Ikbal M.M.Hassan and Abdelfatah. M.Mohamed published the results of stability against parameter perturbations in 2001 [14].

2.4 DESIGN AND OPTIMIZATION

The development of appropriate VAWT design will create new options for the large-scale acceptance of these machines. Vertical Axis Wind Turbine (VAWT) is very straightforward to deploy in urban settings on ground or/and building-roofs. In 2018, Sahishnu R [15] et al used MATLAB simulation to create a mathematical model that included wind power coefficient, tip speed ratio, mechanical, and electrical subcomponents. The goals were to evaluate turbine blade designs, build a mathematical method, and determine the new curved shape design's techno-economic performance. In 2018, Abdolrahim Rezaeiha et al [16] presented the impact of solidity and number of blades on the aerodynamic performance of the turbine to provide a deeper knowledge and to assist designers and manufacturers with this part of the design. A review of various works involving rotor design and testing of both lift and drag Vertical Axis Wind Turbines (VAWTs) is presented in a study conducted by David MacPhee and Asfaw Beyene [17] in the year 2012.Benefits of vertical axis wind turbines in small scale and off grid wind power generation is summarized in the study.

Ghulam Ahmad and Uzma Amin [18] built a small scale vertical axis wind turbine (VAWT) with an axial flux permanent magnet (AFPM) generator and employed the magnetic levitation approach to improve the efficiency of this type of wind turbine in 2017. The planned generator produces three phase output, which is converted to direct current and used to charge the batteries using a three-phase rectifier. The proposed prototype's performance is also put to the test in an experimental setting. According to the findings, the planned wind turbine functions ideally and efficiently, just as the created design procedure expected.

2.5 SUMMARY

The maglev technology can be used to build a wind turbine system that can perform at low wind speeds, according to the literature studies conducted. The aerodynamic shape of the turbine blades, wind speed, friction or drag force that affects the turbine's rotation, altitude, and other factors all influence performance. Different wind turbines are compared, with the maglev wind turbine having a larger potential at low wind speeds of less than 4m/s. Also, when utilised in conjunction with solar cells, it has a greater potential for utilisation, and this technology can be employed at roadside locations to capture energy from fast-moving vehicles. The design is less complicated than the existing VAWT or HAWT. The cost of production is low because the construction is simple and the parts are

SJIF Impact Factor 2021: 8.013| ISI I.F.Value:1.241| Journal DOI: 10.36713/epra2016 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)
Volume: 6 | Issue: 11 | November 2021 - Peer Reviewed Journal

inexpensive. It can be erected on a house's terrace. Wind energy can be extracted by using a large number of these turbines arranged at appropriate distances.

METHODOLOGY

This chapter includes the basic working of the maglev turbine and details of the step-by-step procedures for the completion of this project. It describes the plan and strategy adopted for the completion of the same. The methodology steps include literature review, study of parameters and design of the turbine.

3.1 WORKING OF MAGLEV WIND TURBINE

Considering a VAWT the winds energy is converted to rotational motion of the turbine. But due to the effect of friction no conversion took place at low wind speeds and also losses are took place even if the turbine rotates. If we are able to reduce the friction experienced in VAWT due to the bearings, we can use this turbine to extract energy from low wind speeds and can reduce the frictional losses. For this we can employ magnetic levitation technique in which the bearings can be avoided. Magnetic levitation is a technique by which an object is suspended in air so the effect of gravity on that object reduces significantly with no support other than magnetic fields. Here magnetic pressure is used to mainly counteract the effects of the gravitational forces. Magnetic levitation is an extremely effective system for wind energy. At the bottom one magnet is placed. It repels the other magnet which is welded to the shaft of the generator. The shaft contains the vertically oriented blades of the wind turbine. Now due to this repulsion power between the magnets the upper magnet attached to the shaft is suspended and is air suspended. For this levitation full permanent rare earth magnets made from neodymium are used. Due to this no energy loss through friction occurs in the generator. This also helps in decreasing the maintenance cost and increases the lifespan of the wind generator. The working of magnetic levitation is shown in fig.3.1

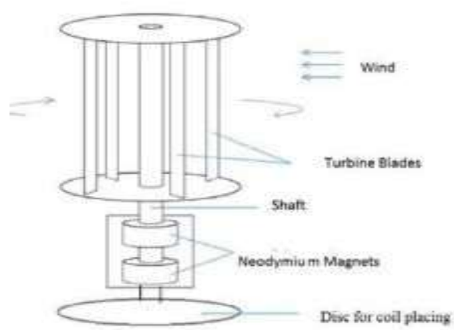

Fig. 3.1 Working Principle of Maglev Turbine [19]

3.2 MODELING

The magnetic levitated wind mill consists of

- Base
- Central shaft about which the turbine rotates
- Two large magnets which provides the levitation
- Some small magnets which produces magnetic flux
- Copper windings in which the EMF is generated
- Turbine blades
- Turbine end plates

The base plate distributes the entire load to the ground. It is preferably flat so as the load is uniformly distributed to the ground. On the central shaft the main stress encountered are the torsional stress and bending stress caused by the wind. The diameter for the shaft is determined using the equation [22],

$$D_o = \left[\frac{32M^2}{\Pi\sigma_{max}} \times \left(\frac{1}{1-K^4}\right)\right]^{\frac{1}{3}} \tag{3.1}$$

SJIF Impact Factor 2021: 8.013| ISI I.F.Value:1.241| Journal DOI: 10.36713/epra2016 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)
Volume: 6 | Issue: 11 | November 2021 - Peer Reviewed Journal

Here D_o=Outer diameter of the shaft

τ_{max} =Maximum shear stress
M=Bending moment
T=Torsional moment
K=Outside inside diameter ratio

The large magnets used in order to levitate the turbine should carry the weight of the turbine and also there should be some clearance between the magnets, so that some small angular displacements that may be caused by the wind on the turbine is adjusted. The design for these magnets is done by equating the weight of the turbine to the magnetic repulsive force.

Weight of the turbine=Magnetic repulsive force

Weight of the turbine is calculated by taking the volume of the components and multiplying it with the density of the materials used.
And magnetic repulsive force is given by the equation [24],

$$F_m = \frac{\mu_o h_1 h_2}{4\pi r^2} \tag{3.2}$$

Here , μo = Magnetic permeability in vacuum
h_1, h_2 = Magnetic field strength

Copper conductors are winded on soft iron core and is sticked to the base. When the turbine rotates the magnet sticked to it also rotates. The copper windings then cut the magnetic flux made by the moving magnets. An emf is generated on the conductor by faraday's law of magnetic induction, the smaller magnets attached below the turbine provide the magnetic flux. The number of coils and number andpower of small magnets can be found out from the equation [23],

$$E = \frac{PZN\varphi}{60A} \tag{3.3}$$

Here , E = EMF induced
P = Number of poles
Z = Number of conductor turns
N = Speed of rotation in rpm
φ = Flux per pole in Weber.
A = Number of parallel paths in the armature winding.
The number of poles and flux per pole gives us the number and power of magnets required.

The turbine blades have to be designed so as the maximum wind is intercepted on the turbine and smooth flow should take place without backflow. The swept area is calculated by Equating the wind power with required power after applying the betz limit.

Power Required=0.593*½*ρAs V ^{3} (3.4)

Here, ρ=Density of air
A s =Swept area
V=Velocity of air
The turbine end plates can be made using light materials, no much load is applied on the system. So complicated designs are eliminated.

RESULTS AND DISCUSSION

4.1 PARAMETRIC STUDY

The different parameters that affect the performance of the wind turbine are discussed in this section. The parameters that taken into account are the altitude, tip speed ratio and blade angle. The study about the parameters helped for the design of the maglev wind turbine i.e., for fixing the number of blades, blade angle etc.

4.1.1 Altitude vs Wind Speed or Power

The amount of wind power available is mostly determined by the density of the air, wind obstacles, and the pressure differential that causes the wind. Because the earth's gravity draws the air towards its center, the density of the air drops as altitude increases. This is because the heavier gases settle to the bottom. Due to viscous forces and impediments, the energy of the wind reduces as it blows. The wind is obstructed mostly by the massive trees and structures that confine it to the surface. When a result, as height rises, wind power rises to a certain point. Wind is the passage of air from a high-pressure area to a low-pressure one. The differential heating of the earth's surface causes the pressure difference. Here, the oceans and land surface play a major role, as the land heats up quicker than the oceans during the day and cools down faster than the oceans at night. This creates a pressure difference, which is the wind's pushing power. This is most noticeable near the ground; as height rises, the pressure differential decreases, and the wind slows down. The relationship between height and wind speed, as well as altitude and wind power, is represented in fig. 4.1. In the graph it can be seen that as altitude increases in the rate of increase in wind speed decrease this is due to the fact that the pressure difference decreases when altitude increases. The power of the wind is proportional to the density and cube of the speed of wind

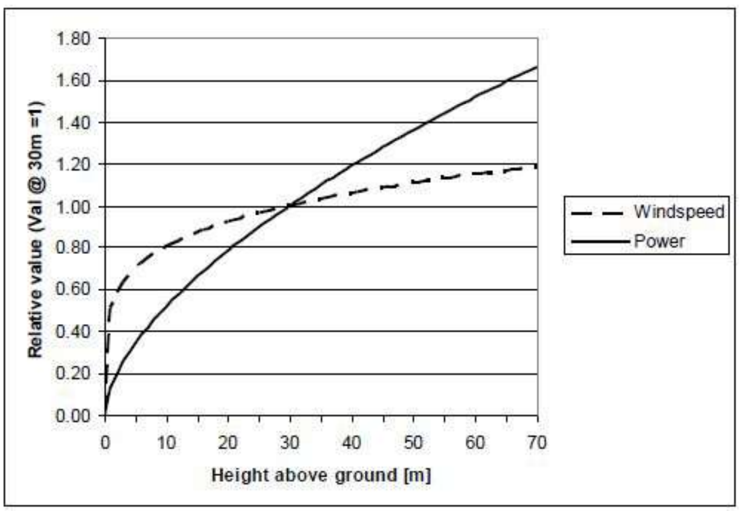

Fig.4.1 Altitude vs Wind Speed or Power

4.1.2 Power Coefficient vs Tip Speed Ratio

The power coefficient is the ratio of the power available in the wind to the power that can be collected from it. The tip speed ratio is the ratio of the turbine's speed at the outer end of the blade to the available wind speed. The results of experiments conducted by Qing'an Li et al. [19] comparing the power coefficient and tip speed ratio at different numbers of blades are displayed in fig. 4.2. On varying numbers of blades, there is an ideal tip speed ratio where a maximum power coefficient is obtained, as shown in the figure. In modern turbines, features like as pitching and yawing ensure that the tip speed stays close to the optimal value. The power coefficient increases when the tip speed ratio increases, as seen in the graph, which can be associated with the turbine starting. Even when the wind blows, it takes some time for the blades' velocity to reach the rated number. Similarly, at high tip speed ratios, the wind captured by the turbine blades diminishes the power coefficient because the high-speed blades generate turbulence, which causes extra losses. The tip speed ratio's ideal value falls as the number of blades increases. Even though the tip speed ratio is inversely related to the wind speed, the blade tip speed is also dependent on the wind speed in practise, hence 5 blades are advised at lower wind speeds. This can also be put in other terms: when the wind speed

SJIF Impact Factor 2021: 8.013| ISI I.F.Value:1.241| Journal DOI: 10.36713/epra2016 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)
Volume: 6 | Issue: 11 | November 2021 - Peer Reviewed Journal

is high, a larger number of blades generates turbulence and drags, yet when the wind speed is low, a larger number of blades is advised to intercept more wind and extract more power.

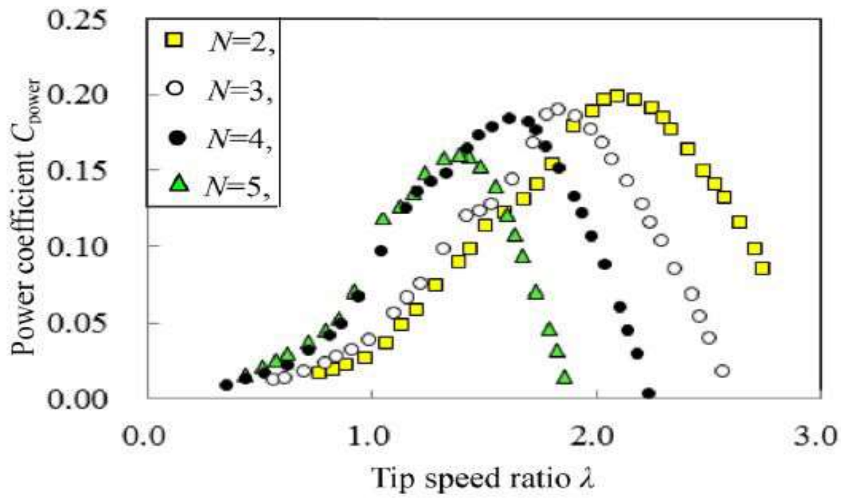

Fig.4.2 Power Coefficient vs Tip Speed Ratio [19]

4.1.3 Turbine Speed vs Blade Angle at Different Wind Speeds

In the design of turbine blades, blade angle is a critical factor. Aravind CV et al. [20] tested different blade angles at varying wind speeds on both maglev and conventional bearing supported wind turbines, and observed turbine speeds at various times. Figure 4.3 depicts their findings. They tested at three different wind speeds: 2.5 m/s, 4 m/s, and 5 m/s. They conducted testing on maglev turbines at 2.5 m/s, according to the report. The reason behind this is that bearing friction cannot be overcome at lower wind speeds, while maglev turbines can work even at such low speeds. The speed of the maglev turbine is also faster than that of regular bearing-supported turbines at greater wind speeds. The turbine's speed indicates the amount of energy extracted. It should also be mentioned that the turbines' speeds in the experiments were higher at over 30° blade angles.

SJIF Impact Factor 2021: 8.013| ISI I.F.Value:1.241| Journal DOI: 10.36713/epra2016 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)
Volume: 6 | Issue: 11 | November 2021 - Peer Reviewed Journal

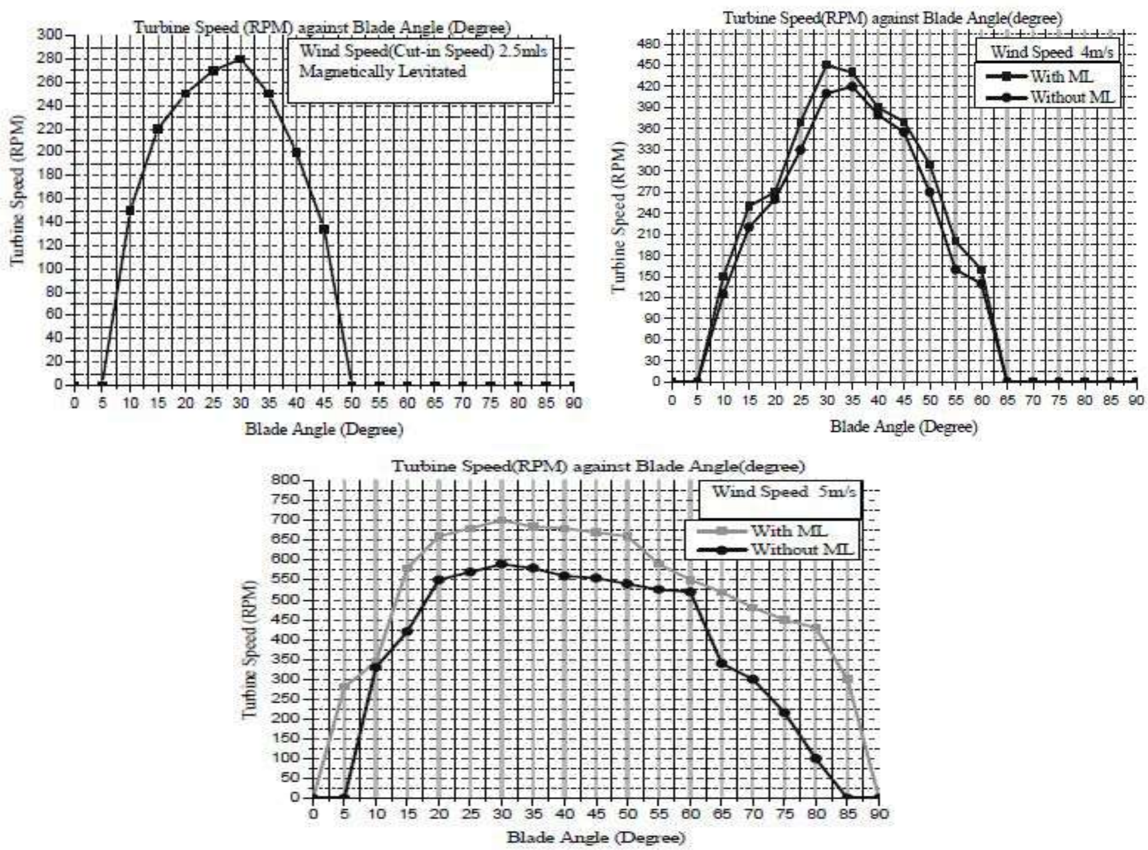

Fig.4.3 Turbine Speed vs Blade Angle at Different Wind Speeds [20]

4.2 CALCULATIONS

4.2.1 Wind Speed

The wind speed of the place where the wind turbine is installing is calculated using the wind speed data available from the website www.ventusky.com. The proposed place is at College of Engineering Adoor. Analysing the wind data of the place it is found that the speed of the wind varies from 2-4 m/s and most of the time wind speed is almost 4m/s. So, for the design purpose wind speed is taken as 4m/s

4.2.2 Swept area of the turbine

For calculating the wind speed, we fixed the power to be generated as 20W.Substituting this in the equation for power generated from the wind turbine after applying the Betz limit and applying the density of the air as $1.275kg/m^3$ by equation 3.4 we get,

$$\textbf{Power Required}=0.593*\tfrac{1}{2}*\rho A_S V^3$$

$$20=0.593*\tfrac{1}{2}*1.275*A_S*4^3 \quad A_S=0.83m^2$$

Taking the aspect ratio as 1:0.83, the length is taken as 1m and breadth is taken as0.83m.

4.2.3 Number of blades of the turbine

From the study conducted by Qing'an Li et.al [19], it is concluded that at higher velocities of wind 2 blades are preferred considering the frictional losses and flowseparation. But at low wind speeds 5 blades are preferred for better wind capture and higher annual generating capacity.

4.2.4 Weight of the turbine

The weight of the turbine is calculated by taking the product of density and volume of the components. For the blades the blade material is chosen as PVC due to its low mass and easy manufacturing and its density is 900 kg/m^3. For 1m long, 2 mm thick and 150 mm aperture blade the volume is $3*10^{-4}$ m^3. For 5 blades it is $1.5*10^{-3}$ m^3.

Mass of the blades =900*1.5*10^{-3}=0.7 kg

For the end plates the diameter is 0.83 m and thickness is 3 mm, the volume of 2 plates is $3.3*10^{-3}$ m^3. The density of the material is 690 kg/m^3

Mass of the plates =690*3.3*10^{-3}=2.7 kg

The total mass of the turbine =3 kg
The total weight of the turbine is approximately 30 N

4.2.5 Strength of Levitating Magnets

To levitate the turbine the repulsive force of the magnets should be equal to the weight of the turbine. The magnetic field strength of the magnets are took equal and the magnetic permeability of vacuum is taken as 4□*10^{-7} H/mA levitation clearance of 40 mm is given between the magnets. Then by equation 3.2,

Weight of the turbine = $(\mu_0 H_1 H_2)/ 4\square r^2$

$$30=(4\square*10^{-7}*H^2)/(4\square(0.04)^2)$$

Magnetic Strength Required, H=500 Am

4.2.6 Shaft Design

The maximum wind speed in the proposed area is found as 4m/s and density is taken as 1.275 kg/m^3 Maximum force exerted by the wind on the wind turbine area of 0.83 m^2 can be calculated by,

$$F = \rho A_S V^2 = 17 \text{ N}$$

Considering the shaft as a cantilever beam of length 1.2m and the force exerted by the wind is of uniformly applied, the bending moment,

$$M_S = F_S*L/2 = 17*1.2/2 = 10.2 \text{ Nm}$$

Taking the material of the shaft as stainless steel with yield stress 215 MPa and a FOS of 8[21]. Then the design stress is 26.875 MPa and take the ratio of inside to outside ratio as 0.8. Then by equation 3.1,

$$D_o = \left[\frac{32M^2}{\Pi\sigma_{max}} \times \left(\frac{1}{1-K^4}\right)\right]^{\frac{1}{3}}$$

After standardizing the values,

$$D_o = 20 \text{ mm and } D_i = 16 \text{ mm}$$

4.2.7 Number of Small Magnets and Coils

The total circumference of the end plate is 2.6m. In order to avoid interference and uniform magnetic field, the number of magnets is set as 8 and are arranged 32 cm apart. The number of armature slots is also set as 8 and 10 conductors in each slot with a total of 80 conductors.

4.3 CAD DRAWING

Fig.4.4 CAD Model

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

The project work helped in attaining an in-depth idea about wind energy harvesting techniques and the vast potential in the field. The major notion at the beginning was to design a wind turbine, which is efficient in terms of low energy loss. Considering the increasing pollution rates, alarming phenomena like global warming and other environmental hazards, the need and urgency for developing a sustainable and environmental friendly energy production system was of paramount importance. Also, the model was supposed to be domestic in operation and can even operate at lower wind speeds. Another striking factor was the inconsideration in the area for developing localised energy producing units, the transmission losses are one of the major energy losses. Still little or no concentration is given to this area. The background study and research led us to the implementation of Magnetic levitation principle. This simple concept has the potential to revolutionise the wind energy sector. The study of wind parameters and comparison between the presently existing models helped greatly in the development of the proposed design. The reason for the selection of VAWT model was explained earlier. The design was made so, in order for its smooth operation in lower wind speeds and requires less or no maintenance.

5.2 RECOMMENDATIONS

The simple principle of magnetic levitation can improve the efficiency and reduce the wind speed requirement, this itself is a huge breakthrough for the upcoming research. The proposed model is for domestic or small-scale production of electricity only. The model can be designed for a large apparatus, which will make it a viable option for large scale generation of electricity. The model can be incorporated with solar panels and converted into a hybrid system, which can in turn generate more energy. Considering the ever-increasing demand for non-conventional renewable energy sources this can be a real contender in the future. Also, the territory can be further expanded for off-shore wind energy production that is considered as an asset for future.

SJIF Impact Factor 2021: 8.013| ISI I.F.Value:1.241| Journal DOI: 10.36713/epra2016 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)
Volume: 6 | Issue: 11 | November 2021 - Peer Reviewed Journal

REFERENCES

1. ***Mr. Sharangdhar Dehadrai Mr. Anurag Wasnik Mr. Yogesh Gaidhane*** *(2016), Study on Magnetic Levitation for Vertical Axis Wind Turbine and Low Wind Speed, International Journal of Science Technology & Engineering, Volume 2, Issue 10, 459-464*
2. ***P.D.Fleming and S.D.Probert.*** *(1984), The evolution of wind-turbines: An historical review, Applied Energy, 3, 163-177.*
3. ***Otto De Vries.*** *(2003). On the Theory of the Horizontal-Axis Wind Turbine.,Annual Review of Fluid Mechanics, 15, 77-96*
4. ***Schreck, S. & Robinson, Michael.*** *(2007), Horizontal Axis Wind Turbine Blade Aerodynamics in Experiments and Modeling, IEEE Transactions on Energy Conversion, Volume: 22, Issue: 1, 61 - 70.*
5. ***Yan Li.*** *(2019), Straight-Bladed Vertical Axis Wind Turbines:History,Performance, and Applications. RotatingMachinery,doi:10.5772/intechopen.84761*
6. ***RK Tyagi****.(2012), Wind Energy and Role of Effecting Parameters, European Journal of Applied Engineering and Scientific Research, 3, 73-83*
7. ***Muthu, Mari & Victor, Kirubakaran.*** *(2014), A critical review of factors affecting wind turbine and solar cell system power production, InternationalJournal of Advanced Engineering Research and Studies, III.*
8. ***Jayanna Kanchikere****, (2012), Aerodynamic Factors Affecting Wind Turbine Power Generation, International Journal of Engineering Research & Technology (IJERT), Volume 01, Issue 09*
9. ***Zhu, Jianyang & Tian, Changbin****. (2019), Effect of Rotation Friction Ratioon the Power Extraction Performance of a Passive Rotation VAWT, InternationalJournal of Rotating Machinery,1-10, doi:10.1155/2019/6580345.*
10. ***El-Ahmar, Mohamed & El-Sayed, Abou-Hashema & Hemeida, Ashraf.*** *(2017), Evaluation of factors affecting wind turbine output power, Nineteenth International Middle East Power Systems Conference (MEPCON), 19-21 1471-1476, doi:10.1109/MEPCON.2017.8301377.*
11. ***Richard F Post*** *(1998), Magnetic Levitation System For Moving Objects,United States Patent ,Patent Number: 5,722,326,March 3, 1998*
12. ***P. Suster and A. Jadlovska*** *(2010), Modeling and Control Design of Magnetic Levitation System, 10th IEEE Jubilee International Symposium on Applied Machine Intelligence and Informatics, 295-299*
13. ***V. Bojarevics, A. Roy, K.A. Pericleous*** *(2010), Magnetic Levitation of Large Liquid Volume, Magnetohydrodynamics, Vol. 46, No. 4, 317–329*
14. ***Ikbal M.M. Hassan, and Abdelfatah M. Mohamed*** *(2001), Variable Structure Control of a Magnetic Levitation System, Proceedings of the American Control Conference, Vol.5, 3725-3730*
15. ***Shah, Sahishnu & Kumar, Rakesh & Raahemifar, Kaamran****. (2018). Design, Modeling and Economic Performance of a Vertical Axis Wind Turbine,*
16. *Energy Reports, Vol: 4, 619-623, doi: 10.1016/j.egyr.2018.09.007*
17. ***Rezaeiha, Abdolrahim & Montazeri, Hamid & Blocken, Bert.*** *(2018). Towards optimal aerodynamic design of vertical axis wind turbines: Impact of solidity and number of blades, Energy, Vol:165, 1129-1148. doi: 10.1016/j.energy.2018.09.192.*
18. ***MacPhee, David & Beyene, Asfaw.*** *(2012). Recent Advances in Rotor Design of Vertical Axis Wind Turbines, Wind Engineering, Volume: 36 issue: 6, 647-665, doi:10.1260/0309-524X.36.6.647.*
19. ***Ahmad, Ghulam & Amin, Urjit.*** *(2017), Design, Construction and Study of Small Scale Vertical Axis Wind Turbine Based on a Magnetically Levitated AxialFlux Permanent Magnet Generator, Renewable Energy, 286-292. doi: 10.1016/j.renene.2016.08.027.*
20. ***Manoj L, Nithesh J, Manjunath T, Gowreesh S S*** *(2019), Power Generation using Magnetic Levitation Vertical Axis Wind Turbine, International Journal of Engineering and Advanced Technology (IJEAT), Volume-9, Issue-2, 365-369*
21. ***Qing'an Li, Takao Maeda, Yasunari Kamada, Junsuke Murata, Kazuma Furukawa, Masayuki Yamamoto*** *(2015), Effect of number of blades on aerodynamic forces on a straight-bladed Vertical Axis Wind Turbine, Energy,Vol 90, 784-795*
22. ***Aravind CV, R Rajparthiban, R Rajprasad, Wong Y V*** *(2012), A Novel Magnetic Levitation Assisted Vertical Axis Wind Turbine–Design Procedure and Analysis, IEEE 8th International Colloquium on Signal Processing and its Applications, 93-98*
23. ***K.Mahadevan, K.balaveera Reddy****, Design Data Book, CBS Publishers & Distributors Pvt Ltd, 4th edition,2013*
24. ***B.L. Theraja, A.K. Theraja****, A Textbook of Electrical Technology, :Volume 2 AC and DC Machines, S.Chand & Company Pvt Ltd, 2005*
25. ***Mayur Patel1, Aditya Thakur, Angad Singh Thukral, Rahul Yadav, Prof. Vijay Patil*** *(2018), Design, Analysis & Fabrication of Maglev Vertical Axis Wind Turbine, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 7, Issue 4, 3659-3670*