International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 10 | Oct 2021 www.irjet.net p-ISSN: 2395-0072

Design, Analysis and Simulation of a Darrieus (Eggbeater type) Wind Turbine

Dhaval S. Shah[1] and Shivprakash B. Barve[2]

[1,2]School of Mechanical Engineering, Dr. Vishwanath Karad MIT World Peace University, Maharashtra, India.

---***---

Abstract - *The principal objective of this project is design, modelling and simulation of a Darrieus rotor Vertical Axis Wind Turbine. Wind Energy is a clean and renewable source of energy that is an enticing alternative to non-conventional sources of energy. Due to rapid increase in global energy requirements, renewable forms of energy are gaining importance in current period. Unlike nuclear power or tar sand oils, wind energy does not leave a long-term toxic effect. Considering multiple design theories, various airfoils have been designed and analyzed using Q-blade and Solidworks. The wind turbine has been modelled using Solidworks and analyzed using ANSYS Workbench. The Multi-body dynamic analysis has been done with the aid of Q-blade software. Flow simulation has been done on Solidworks and various parameters have been extracted like the flow trajectory of velocity of wind. Following the design and analysis, the most efficient airfoil shape and a Darrieus wind turbine design has been determined.*

Keywords*: Darrieus, Q-blade, Solidworks, ANSYS Workbench*

1.INTRODUCTION

Wind power is a popular sustainable, renewable source of power that has a much smaller impact on the environment compared to burning fossil fuels [1]. Wind is caused by differences in atmospheric pressure. The evolution of wind energy production over the past decade has exceeded all expectations. From a mere production of 159 GW in 2009 to a gargantuan leap of 651 GW in 2019, renewable energy has become the epitome of clean energy and is well on the way to replace fossil fuels. India specifically added 2.4 GW of wind power in 2019. The principal objective of this project is design and analyse a Darrieus Wind turbine to generate 1kW/hr wind energy. Vertical Axis Wind Turbine (VAWT) is selected over a Horizontal Axis Wind Turbine (HAWT) as it is more compact. The wind turbine is designed to generate electricity adequate for domestic use. This project emphasizes on electrification of isolated areas with lowest possible cost. Fossil fuels have been overexploited and have caused enough damage to the planet beyond repair. A small, hybrid wind turbine can generate 1KW/h of power at reasonable wind speeds. This power is sufficient for a domestic household to reduce their lighting and cooling energy usage by 100% and still be able to be in a surplus of energy. Installing a source of harnessing clean energy demoralizes usage of fossil fuels. The objectives of this project are to provide electricity in rural areas, to generate enough power for 1 domestic house, compact design for easy installation, cost effective, to keep the noise emitted from the windmill to a minimum. The scope of this project is excessive testing to be carried out for assurance of working capability, fabrication of the turbine, testing of the fabricated model, comparative analysis of the different types of Vertical Axis and Horizontal Axis Wind Turbines.

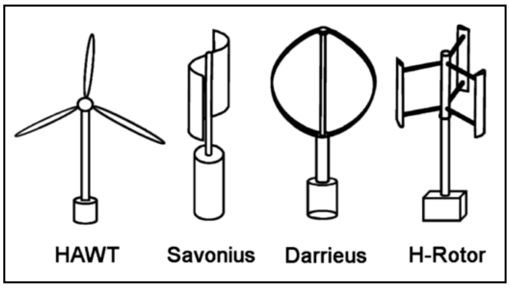


Figure 1: Types of VAWT [2]

A Darrieus Wind Turbine has various components like,
Rotor (blades and connection items)- It produces aerodynamic efficiency.
Braking system- It stops the rotor motion in poor weather conditions.
Control system- It controls the function of the aerogenerator according to the different working requirements.
Tower- It withstands the action of wind and the weight of the blades.

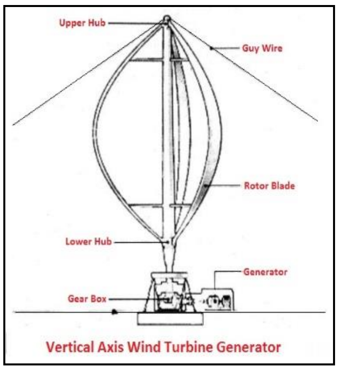


Figure 2: Components of a Darrieus Wind Turbine [2]

Material selection with the help of calculations for drag and lift forces. Results for diameter and length of shaft, dimensions of radial arm and Airfoil coordinates for H-Darrieus VAWT. [3-6]

Design of a Vertical Axis Wind Turbine with Design of blades and shaft dimensions of the windmill were discussed [7-10].

Wind speed data is manually measured at various places to get real time value of the velocity of wind in that area. The average of the velocity of wind measured is used further for calculation purpose.

Table 1: Velocity of wind at different locations

Observations	
Bopdev Ghat (928m)	10.27 m/s
Vetal Tekdi (790m)	9.9 m/s
Society Terrace (600m)	5 m/s

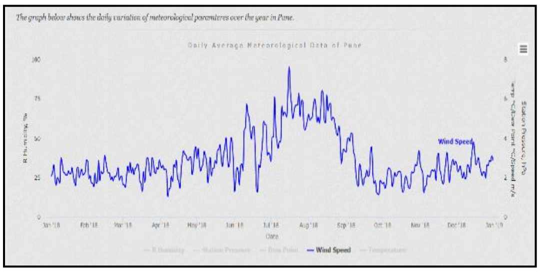


Figure 3: Daily variation of meteorological parameters over the year in Pune [2]

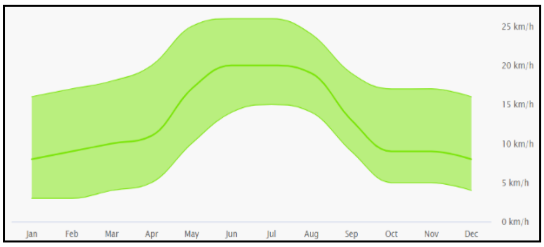


Figure 4: Speed of Wind during each month of the year in Pune [2]

Figure 5: Reading of wind speed using Anemometer.

The designed wind turbine is compact in design as compared to the traditional wind turbine. The efficiency of energy transformation of the turbine is also more. Moreover, due to the compact design the overall weight of the turbine is less which is suitable for installation in domestic households. The turbine generates 1 kW/hr of power with taking up much less space than a traditional wind turbine.

2. MATERIALS AND METHODOLOGY

The total weight of the designed assembly is calculated using Solidworks Software. The total weight of the assembly is used to calculate the force acting on the tower due to the weight.

Total Weight:

215.27 kg

Force due to weight of assembly:

= (1.5) mg

= 3217.5 N

≈ 5000 N.

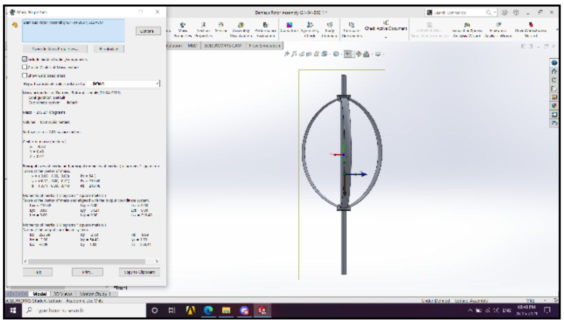


Figure 6: Total mass of the Assembly

3. DESIGN OF DARRIEUS (EGGBEATER TYPE) WIND TURBINE

Power

$P = Cp * \eta mech * \frac{1}{2} * \rho * A * V^3$

$1000 = 45\% * 85\% * 0.5 * 1.225 * A * 9^3$

$A = 7.48\ m \approx \mathbf{7.5\ m}$

Wind Power

$P_w = \frac{1}{2} * \rho * A * V^3$

$Pw = 0.5 * 1.225 * 7.5 * 9^3$

$Pw =$ **3348.84 W**

Blade Power

$Pb = Cp * Pw * \eta mech$

$Pb = 0.45 * 2658.63 * 0.85$

$Pb =$ **1016.92 W**

Efficiency of Energy Transformation

$\eta = \frac{Pb}{Pw}$

$\frac{1016.92}{3348.84} = 30.36\%$

Angular Speed

Considering a tip speed ratio of 5 (TSR is 4-7 for 3 blade turbines)

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

$$\omega = 5 * \frac{9}{1.5}$$

$$\omega = 30 \text{ rad/s}$$

Rotor Speed

$$\omega = \frac{2\pi N}{60}$$

$$34 = \frac{2 * \pi * N}{60}$$

$$N = 286.47 \text{ RPM} \approx 290 \text{ RPM}$$

Torque

$$\tau = \frac{30}{\pi} * \frac{P_{out}}{N}$$

$$\tau = 29.38 \text{ N-m}$$

Each component of the Darrieus wind turbine is designed on Solidworks. The dimensions of each component were decided through basic calculations.

Rotor Blade

NACA 4424 Airfoil is used for the rotor blade. The length and diameter of the blade is determined through calculations.

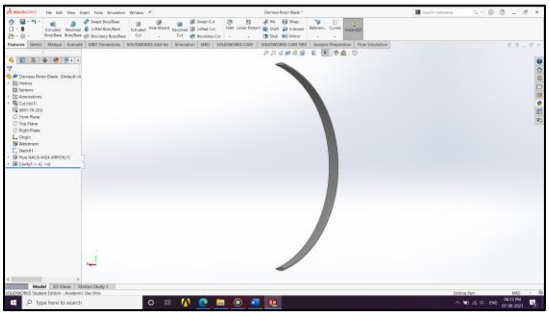


Figure 7: Rotor Blade design

Hub

A hub is designed to provide support to the blades and a connection point for all the three blades. The hub would rotate along with the blades. The material used for the hub is **Al 6061-T6.**

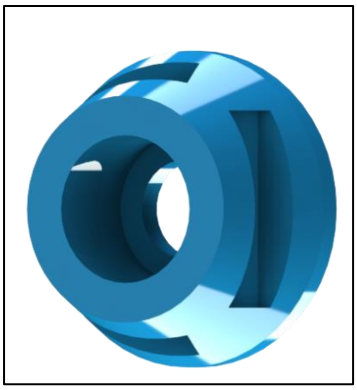


Figure 8: Hub Design

Full Assembly

The full assembly of the wind turbine is done on Solidworks. The tower height considered is **8.5m** with the outer diameter **100mm** and the inner diameter **90mm.**

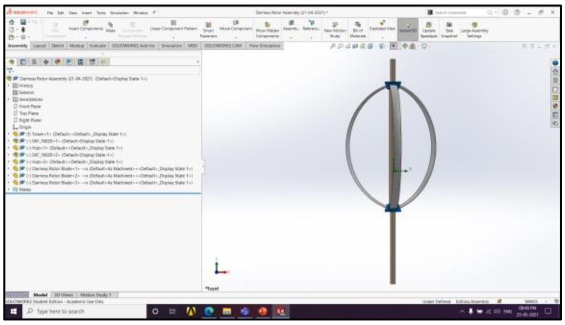


Figure 9: Full Assembly Design

4. ANALYSIS OF DARRIEUS (EGGBEATER TYPE) WIND TURBINE

Static structural analysis of each component is done using ANSYS Workbench to check the strength of the components for different conditions. Airfoil analysis is done on Q-blade Software to determine the most efficient Airfoil.

For static structural analysis, for pre-processing, initially a mesh is generated. The mesh type used is **hex dominant** with the mesh size of **5mm**.

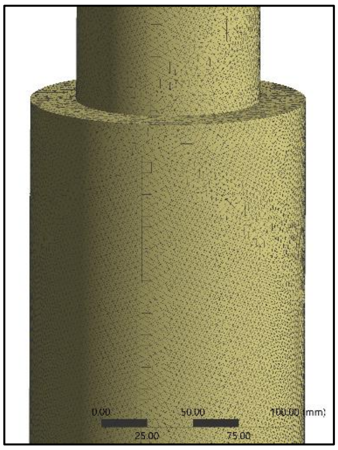


Figure 10: Tower Mesh

The types of analyses performed are-

Tower (Compressive)

The material of tower is Al 6061-T6. Compressive strength of the tower is checked by fixing the lower face of the tower and applying a vertically downward force on the upper face. From the results acquired, the maximum stress on is **9.67 MPa** with a deformation of **0.03 mm**.

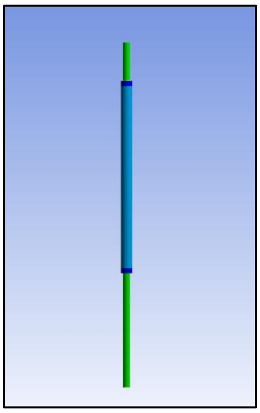


Figure 11: Maximum Stress on Tower (Compressive)

Tower (Torsional)

Torsional strength of the tower is checked by fixing the lower face of the tower and applying a torque on the upper face. From the results acquired, the maximum stress on is **12.32 MPa** with a deformation of **1.12 mm.**

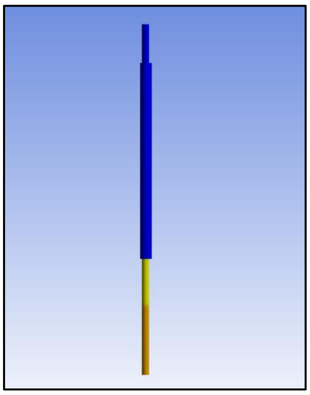


Figure 12: Maximum Stress on Tower (Torsional)

Hub (Compressive)

The material of hub is Al 6061-T6. Compressive strength of the hub is checked by fixing the lower face of the hub and applying a vertically downward force on the upper face. From the results acquired, the maximum stress on is **11.68 MPa** with a deformation of **0.54 mm.**

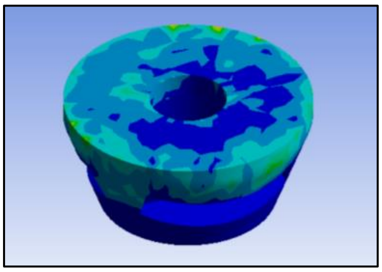


Figure 13: Maximum Stress on Hub (Compressive)

Full Assembly (Compressive)

Lastly, the compressive strength of the full assembly is checked to see the interaction of the components with each other and to find out the point with the maximum stress. For this analysis, the lower face of the tower is fixed, and a vertically downward force is applied on the upper face. From the results acquired, the maximum stress on is **7.89 MPa** with a deformation of **0.03 mm.**

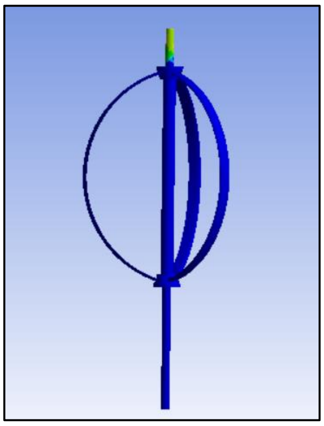


Figure 14: Maximum Stress on Full Assembly

Airfoil Analysis

Airfoil analysis is performed on the Q-blade software to find out the Cl/Cd ratio i.e., the glide ratio for the airfoils. The most efficient Airfoil is determined through this analysis. After the analysis, the Airfoil selected is **NACA 4424** as the Cl/Cd graph for that Airfoil is more linear compared to the other airfoils.

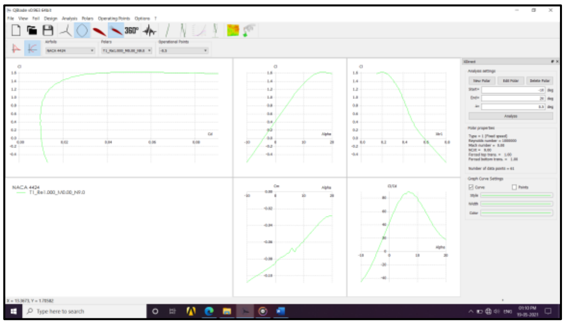


Figure 15: Airfoil Analysis on Q-blade

Evaluation of Coefficient of Power

The coefficient of power of the Darrieus wind turbine is evaluated with the help of the simulation performed in the Q-blade Software. From the results, the value of coefficient of power came out to be 0.41 which is close to the value considered for calculations.

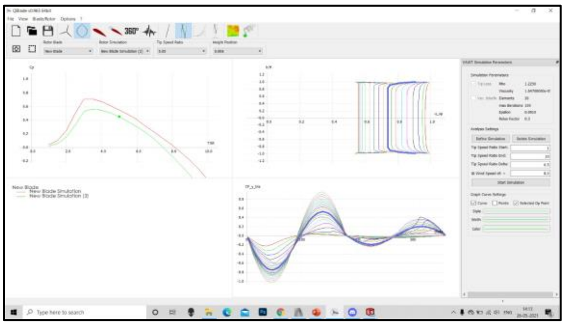


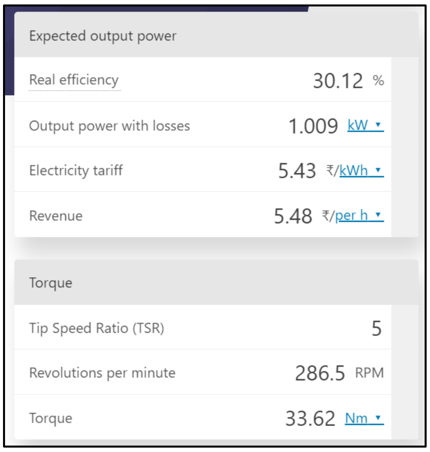
Figure 16: Evaluation of Coefficient of Power on Q-blade

5. RESULTS

The quantification of results is done through Omni Calculator, Simulations in Q-blade, and Flow simulation in Solidworks.

Omni Calculator

The parameters that were calculated were verified with the use of Omni Calculator. From the results the values of the parameters calculated like power output, rotor rpm and torque were the same as the calculated values. Hence the calculations were verified.



Expected output power	
Real efficiency	30.12 %
Output power with losses	1.009 kW
Electricity tariff	5.43 ₹/kWh
Revenue	5.48 ₹/per h
Torque	
Tip Speed Ratio (TSR)	5
Revolutions per minute	286.5 RPM
Torque	33.62 Nm

Figure 17: Results from Omni Calculator

Q-blade Simulation

A simulation is performed on Q-blade software to find out the power output of the wind turbine in actual conditions. The value of power output from the results is approximately **1600 W**, which is close to the calculated power output.

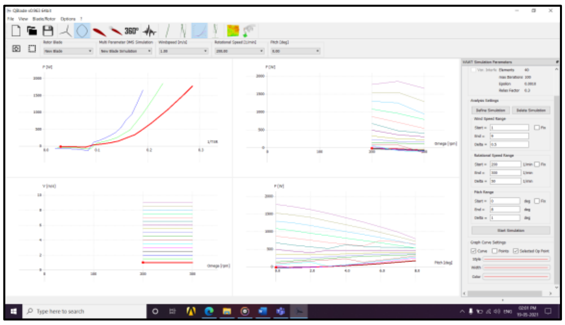


Figure 18: Simulation for Power Output on Q-blade

Solidworks Flow Simulation

Flow simulation is done on Solidworks to find out the parameters like force, velocity, pressure etc. acting on the wind turbine.

The surface plot for pressure is generated in which the maximum pressure is **1.0018 atm** and the minimum pressure is **0.9990 atm.**

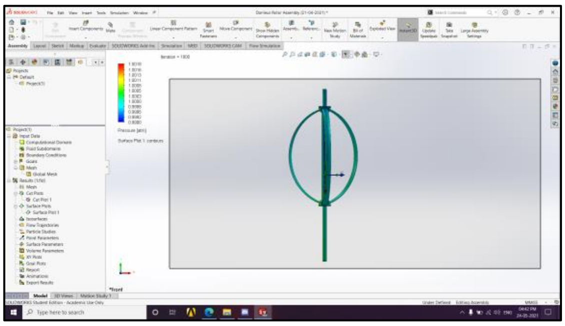


Figure 19: Surface Plot for Pressure on Solidworks

Next, the flow trajectory for the velocity of wind is generated to check flow of velocity of wind with respect to the turbine. From the results, the maximum velocity came out to be **12.180 m/s** and the minimum velocity **0 m/s.**

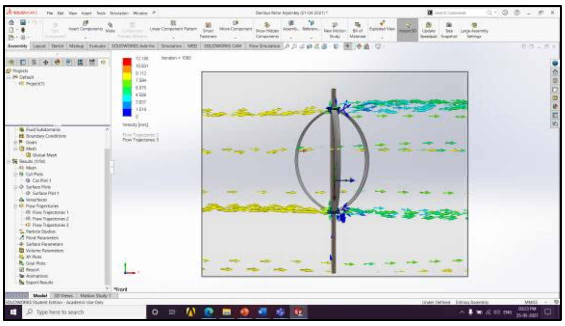


Figure 20: Flow Trajectory of Velocity of Wind

6. CONCLUSION

Strength of each component is checked. Airfoil analysis is done on Q-blade software. Coefficient of performance is evaluated through simulations on Q-blade software. The calculated power output is verified on Omni Calculator. Simulation of the windmill is done on Q-blade software to check the power output. Flow analysis is done in Solidworks to calculate max and min pressure as well as flow trajectory of velocity of wind.

REFERENCES

[1] Wind Energy Explained: Theory, Design and Application by J. F. Manwell, J. G. McGowan, A. L. Rogers, Second Edition, December 2010. DOI:10.1002/9781119994367

[2] Renewable Energy Statistics (2020), International Renewable Energy Agency (IRENA) 2020. ISBN 978-92-9260-246-8

[3] Samir Deshmukh and Sagar Charthal. (2017). Design and Development of Vertical Axis Wind Turbine. IRA-International Journal of Technology & Engineering, Proceedings of the International Conference on Science & Engineering for Sustainable Development, pp 286-194.

[4] Ritesh Sharma, Prof. Brijesh Patel (2015), Design and Simulation of Darrieus (Eggbeater) Type Vertical Axis Wind Turbine using Open Source Software Q Blade IJIRST –International Journal for Innovative Research in Science & Technology, Volume 1, Issue 12, pp 162-169.

[5] Hnin Yu Yu Kyaw, Ei Cho Cho Theik, Khaing Zar Nyunt (2019) Design and Fabrication of H-Darrieus VAWT International Journal of trends in Scientific Research and Development (IJTSRD), Volume 3, Issue 4, pp 1570.

[6] J. Pulfer, W. Meza, F. Mitjans , J.Gonzalez (2018), Energy Efficiency Assessment of Four Designs of Vertical Axis and Drag Differential Wind Turbines, IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), Volume 13, Issue 1, Ver IV, pp 73-81.

[7] Saurabh Arun Kulkarni and Prof. M.R. Birajdar, (2016) Vertical Axis Wind Turbine for Highway Application, Empirical Journal of Interdisciplinary Research (IJIR), Vol 2, Issue 10, pp 1543-1546.

[8] Piyush Gulve and **Dr. S. B. Barve (2014)**, Design and Construction of Vertical Axis Wind Turbine, International Journal of Mechanical Engineering and Technology (IJMET), Volume 5, Issue 10, pp. 148-155.

[9] Bhushan D. Agarkar and **Shivprakash B. Barve (2016)**, A Review on Hybrid solar/wind/ hydro power generation system, International Journal of Current Engineering and Technology', Special Issue-4, pp 188.

[10] Ninad Vaidya and Dr. Shivprakash Barve (2021), Design, Modelling and Comparative Analysis of a Horizontal Axis Wind Turbine, International Research Journal of Engineering and Technology (IRJET), Volume 8, Issue 8, pp 808-815.