Manufacturing Technology and Research (An International Journal)| Volume 15 | Number 1 | Month Jan-June(2022) ISSN: 0973-0281

Design, Analysis and Simulation of a Darrieus H-type Vertical Axis Wind Turbine

Omkar R. Jigjini[a], Dr. Shivprakash B. Barve[b]

[a] School of Mechanical Engineering Dr. Vishwanath Karad MIT World Peace University Pune, Maharashtra, India
[b] Professor, School of Mechanical Engineering Dr. Vishwanath Karad MIT World Peace University Pune, Maharashtra, India

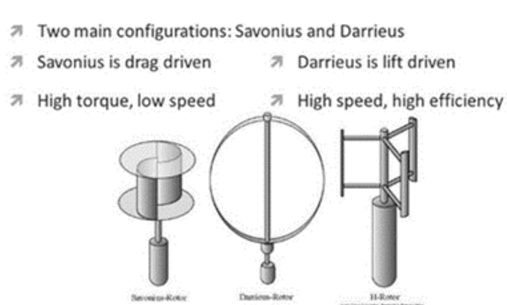
Abstract

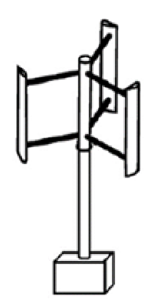
This project aims at design, modelling, optimization & analysis of h-type darrieus vertical axis Wind Turbine. Wind Energy is a fresh source of energy that is an appealing alternative to non-conventional sources of energy. By reducing the use of fossil fuels, hence reducing pollution and toxic waste, also due to rapid increase in global energy requirements, renewable forms of energy are gaining importance. VAWTs can be fitted in small wind speed areas for small-scale generation of power. The turbine design presented here is a VAWT with straight blades and is named an H-rotor. This is a portable and efficient system that can be used to produce small amounts of electricity. The turbine is designed in Solidworks and by considering multiple design theories, aerofoils have been designed and analysed using Software's like Q-blade and Solidworks. The wind turbine has been analysed using Solidworks Flow simulation and ANSYS Workbench. The dynamic analysis and simulation have been done with the help of Q-blade software. Validation of analytical results has been done by using software's like q-blade and Solidworks flow. According to the following design and analysis most efficient airfoil is been selected. Our aim is to construct small VAWT wind turbine capable of generating 1KW/h power at fluctuating or unsteady wind speeds, for household purposes in rural areas for lightning and cooling purposes. Electrification of the domestic households with minimum costs and leading to the sustainable future.

Keywords: Wind Energy, Wind Turbine, Renewable, Sustainable, VAWT, Simulation.

1. Introduction

Wind power uses the air to deliver mechanical power over blow-off turbines to turn electric originators for electric power. Air energy or power is a renewable power has a much smaller or no impact on the atmosphere compared to fiery fossil fuels. Wind power is a source of renewable energy. It doesn't contaminate, it is inexhaustible and cuts out the use of fossil energies, which are the source of greenhouse fumes that roots global warming. Conversion of Wind's kinetic energy in electrical power is done by wind turbine. The wind Turbines can be seen into 2 types which produces electricity from wind energy they are VAWTs and HAWTs. VAWTs have vertical shaft: vertical to the ground, whereas shaft of H.A.W.T. is horizontal: parallel to the ground. Vertical axis wind turbine is further classified as: Darrieus wind turbine using lift forces and Savonius wind





turbine using drag forces. Vertical axis wind turbines can generate electricity at relatively low & fluctuating speeds.

Fig. 1. Savonius and Darrieus

Fig. 2. VAWT

In h-type VAWT the rotor-blades are vertically straight blades as no any specific geometry is present. VAWT can accomplish noteworthy high efficiency. They produce energy or work also in fluctuating wind speeds and are suitable for rural and small-scale applications for power generation. Basically, turbine's strength relies on number of blades, rotor diameter. The power constant rests on rotor solidity and TSR. The TSR is ratio of speediness of the tips of turbine blades to speediness of the wind. It is denoted as 'λ'. The goal in the project process stands by maximize aerodynamic capability and annual energy production. We can see two types of VAWTs in figure 1 with their configurations. Figure 2 consists of straightforward H-type turbine. The efficiency of our design for 3-blade turbine is more than the traditional wind turbine, also it is compact in size than the traditional wind turbine which will be easy for installation. For turbine's generating 1KW/h, our turbine requires less space for installation purpose.

1.1. Objectives and Scope

To improve efficiency of the turbine. To design compact, economical turbine for household purposes in rural areas. To reduce the usage of the fossil fuels and to rely more on sustainable/renewable energy. To provide a constant flow of electricity for household purposes in rural areas, especially during the times of load-shedding. To add savings for household purposes by reducing or eliminating the electricity bills. By providing a clean wind energy with no fossil fuels and thus eliminating or reducing harm to environment.

- Design and fabrication of the turbine. Analysis and testing of the turbine for the assurance of the efficient working.
- Comparative analysis of all the types of the VAWT with the HAWT.
- By designing the following, new assumptions and constraints may come to light.

1.2. VAWTs over HAWTs

a. Less components- The main rotor shaft is placed vertical rather than horizontal. This causes decrease in components. A HAWT must be aligned in the air pre rotation of blades. Whereas, the blades of VAWT can align in any direction to catch wind. There is no necessity of machineries to control yaw and pitch.
b. Scaling down- This design is possible to rule down and works effective in rural zones or rooftops where other sustainable energy is not achievable. The circumstances of the

VAWT seems encouraging in loss and energy consumption from sources of hydrocarbons.

c. Safety- By avoiding mechanics of rising tall turbine towers makes VAWTs safer substitute. Also, the care costs are declined because generators, gearboxes, & maximum electrical and mechanical parts are at or near ground level unlike HAWTs.
d. As they possess with low-speed blades, it minimizes the danger to person and animals.
e. It functions in unsteady winds and even mountain conditions.
f. It is permissible where taller structures are prohibited.
g. Less noisy in operation.
h. Economical than the HAWTs.
i. Easy installation.

1.3. Basic Principle

Sizes of the turbines according to the rotor diameter. As we can see in figure 3 greater the rotor, the additional energy it can capture. In figure 4 ρ, changes with air temperature and with elevation, more the height of the turbine, more the hike in wind speeds.

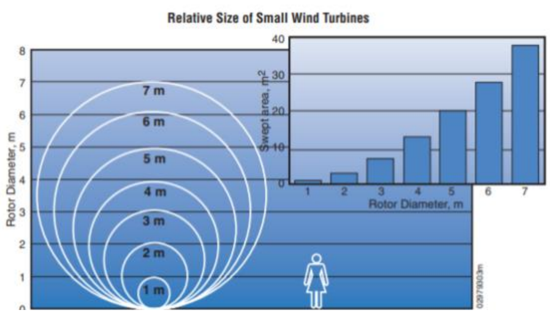


Fig. 3. Rotor Diameter

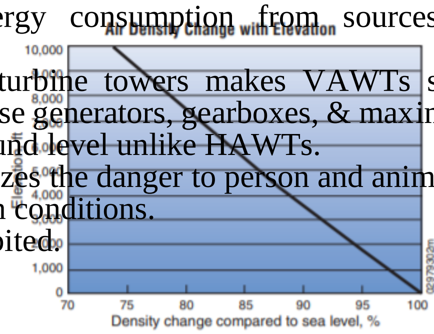


Fig. 4. Air Density vs Elevation

1.4. Problem Statement

Wind power is the cleanest energy available to produce energy, known as renewable form of energy. Over the years, people were reliable on fossil fuels for activities like transportation, cooking, heating, electricity, etc. Acid rain, smog, green house gases and atmospheric emissions are not produced by turbines. Our aim is to design a small VAWT wind turbine having potential of producing 1KW/h power at fluctuating or unsteady wind speeds, for household purposes in rural areas for lightning and cooling purposes.

1.5. Literature Survey

S. Brusca Et. Al.- This paper analysed connection betwixt the dimensional proportions of a VAWT H-type and its capability. Variations in aspect ratio were made which causes variations in Reynolds number which changes the power coefficient and derived how the variations in aspect ratio affect turbine performance. From a geometric point of view, it was observed that as dimensional proportions fall, the Re number rises which improvises wind turbine capacity.[4]

M. Salman Siddiqui Et. Al.- In this paper main approach is to design turbine in offshore rather than land, farms, to eliminate problems like terrestrial procurement and small wind conditions. This work typifies adjustable turbulence intensity stream arena around a rotating VAWT. Complete 3-D arithmetic temporary imitations are executed for disparity of several turbulence stages related with the oncoming air.[3]

R. Hantoro Et. Al.- In this paper turbine arranged in such configuration, known as hydrokinetic turbine array, to meet energy production target.

Teresa Parra Et. Al.- Numerical Simulation is used as to forecast the performance of a VAWT H-Darrieus. Influence of the solidity is tested to get design tendencies.

Lucas Deisadze Et. Al.- This paper calculated the capability for connecting roof-mounted VAWT systems on house roofs. The project considered numerous kinds of VAWT blades with target of increasing the efficiency of a covered turbine. The plan considered top mounting systems for turbines that are meant to scatter vibrations to the rooftop construction. Turbine vibrations were calculated through wind channel trials and in influence trials on a scale-prototypical home.

Kalakanda Alfred Sunny Et. Al.- This paper offers aerodynamic modelling, construction and the performance of VAWT. Aerodynamic construction of VAWT is designed using software tools by considering NACA0012 airfoil. Aluminium material built low weight 3 bladed model of VAWT is designed.

Shivprakash B. Barve Et. Al.- This project delivers analysis on the hybrid power generation i.e., mixture of two or more energy sources. To charge the batteries hybrid power generation can be used.[6]

Piyush Gulve Et. Al.- The principal aim of this paper is rural electrification with wind and solar energy. To design a VAWT over HAWT. The wind turbine considered to generate power adequate for electrification in remote areas.[8]

2. Materials and Methodology

Aluminium 6061 T6 is selected for the following design which allows high tensile strength about 310 MPa and yield strength about 276 MPa. Term T6 refers to grade of rigidity and is attained by hardening. Good strength to wait ratio is attained by this grade.

- Design, calculations of a Darrieus H-type 3 bladed VAWT.
- To fabricate a VAWT for the given requirement.
- To choose a suitable airfoil for the blade of the rotor.

2.1. Calculations

Following values have been taken/considered for calculations for designing a VAWT H-type oriented.

1] Cp = 0.43
2] D = 2.5m
3] H = 3m
4] A= D*H 2.5*3=7.5m^2
5] V = 9m/s
6] ρ = 1.22
7] TSR = 5
8] Airfoil = NACA 0018

- For power 1000W,
  P = Cp* η* ½* ρ* A* V^3
  1000 = 0.43* η* ½* 1.22* 5* 9^3
  H = 69.72%

- Wind Power-
  Pw = ½* ρ* A* V^3
  Pw = ½* 1.22* 5* 9^3
  Pw = 3335.175 W

- Rotor Power-
  $Pr = ½* ρ* A* V^3* Cp$
  $Pr = ½* 1.22* 7.5* 9^3* 0.43$
  $Pr = 1434.12$ W

- Rotor Efficiency-
  $\eta = Pr/Pw$

  $\eta = 1434.125/3335.175$

  $\eta = 42.99\%$

- Considering Tip speed ratio= 5, for 3 blade turbine.
  TSR= 5

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

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

  $\omega = 5* 9/1.25$

  $\omega = 36$ rad/sec

  Now, for RPM

  $\omega = (2\pi n)/60$

  $36 = (2\pi n)/60$
  N= 343.77 rpm.

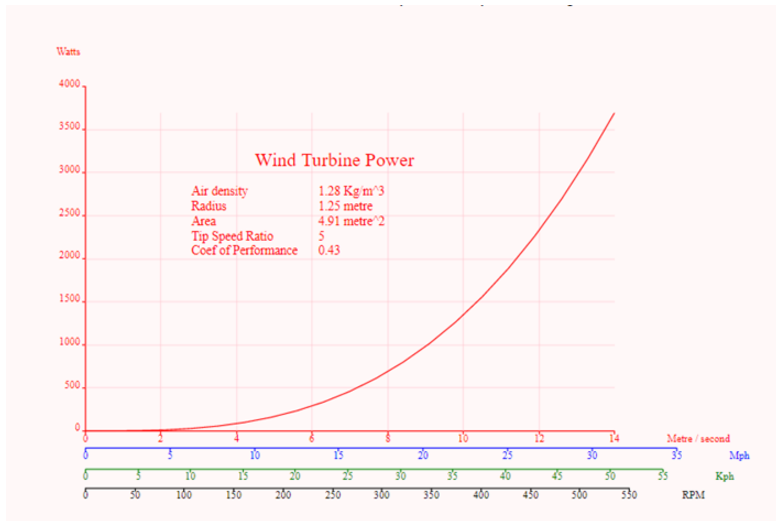


Fig. 5. Wind Turbine Power Graph

3. Modelling in Solidworks

Each component of wind turbine H-type oriented is designed on Solidworks. Dimensions of model were calculated and designed. Airfoil NACA 0018 was used for design of the blade. The material used for the model is aluminium 6061-T6. Figure 6 & 7 consists of full assembly.

Full Assembly-
Tower Height = 8.5m
Blade Height = 2.5m

Number of Blades = 3

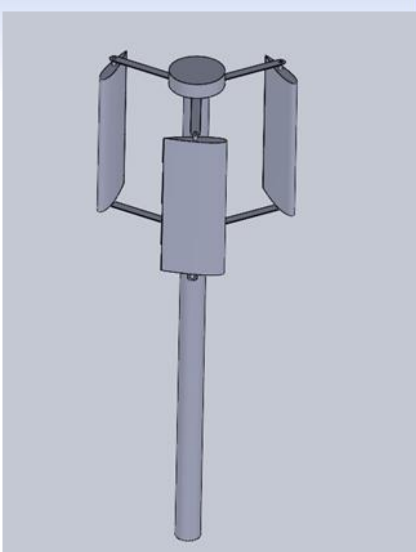


Fig. 6. Viewing Front of Assembly

Fig.7. Viewing Top of Assembly

4. Analysis

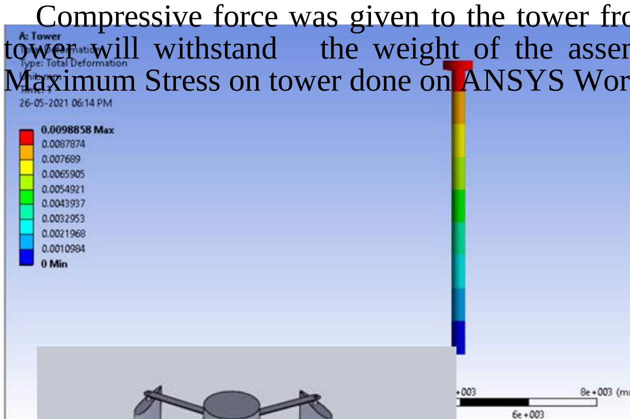
Structural Analysis of each component and full assembly is done on ANSYS Workbench to verify strength of the prototype in variable conditions. Rotor blade aerodynamic study is done on Q-blade Software to determine efficient Airfoil. Q-blade also gives us the graphical results, which are used to validate the design calculations and parameters. Also, to validate the Analytical results, verification through Omni calculator is done.

4.1. Structural Analysis

➢ Analysis of Tower

Equivalent Stress	2.08 MPa
Max Deformation	0.09mm
Material	Al 6061-T6

Compressive force was given to the tower from upper face of about 10000N, to check if the tower will withstand the weight of the assembly. We can see Maximum Deformation and Maximum Stress on tower done on ANSYS Workbench in figure 8 & 9 respectively.



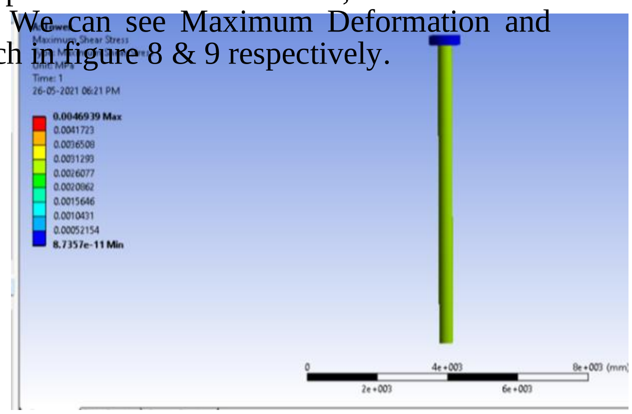


Fig. 8. Maximum Deformation on Tower

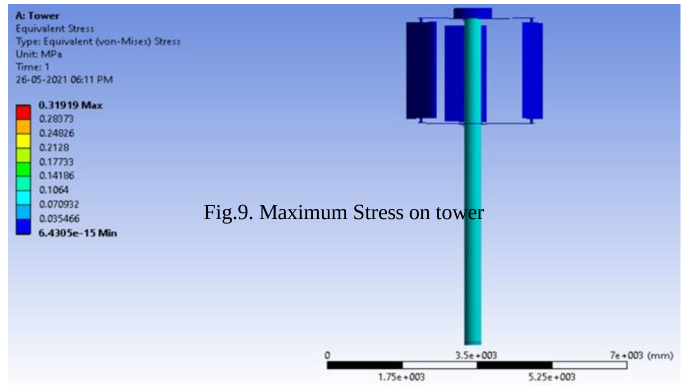


Fig.9. Maximum Stress on tower

- Analysis of Assembly

Equivalent Stress	3.19 MPa
Max Deformation	0.010 mm
Material	Al 6061-T6

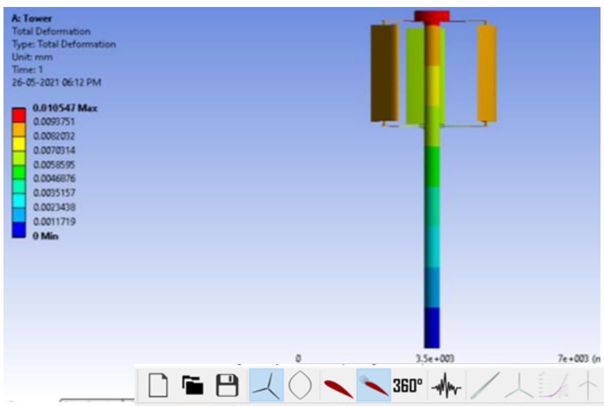


Fig.10. Total Deformation on Full Assembly

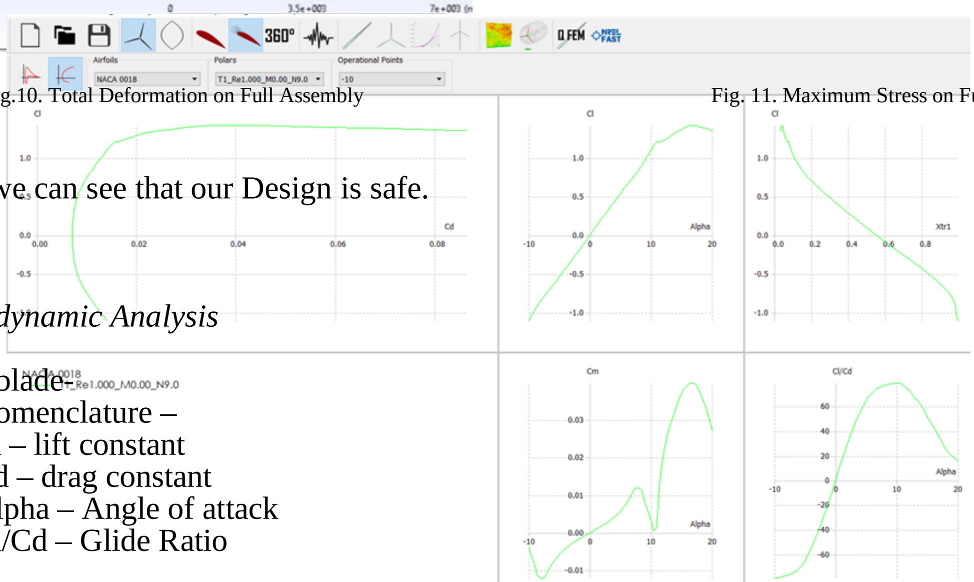


Fig. 11. Maximum Stress on Full Assembly

Hence, we can see that our Design is safe.

4.2. Aerodynamic Analysis

- Qblade-
- Nomenclature –

1. Cl – lift constant
2. Cd – drag constant
3. Alpha – Angle of attack
4. Cl/Cd – Glide Ratio

Airfoil Analysis was performed on Q-blade to find the Glide Ratio i.e., Cl/Cd ratio. After analysis and determining the most efficient airfoil NACA 0018 was selected for the wind turbine. In figure 12 we can see glide ratio and airfoil analysis on Q-blade.

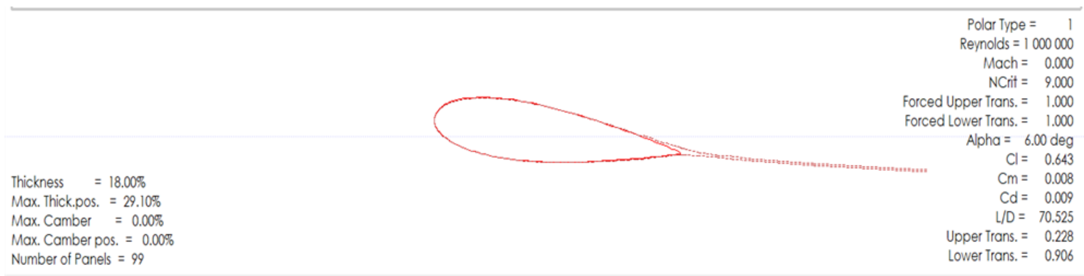


Fig. 12. Airfoil Analysis on Q-blade

➢ Airfoil
NACA 0018
We can see how wind and pressure acts along the blade in figure 13.

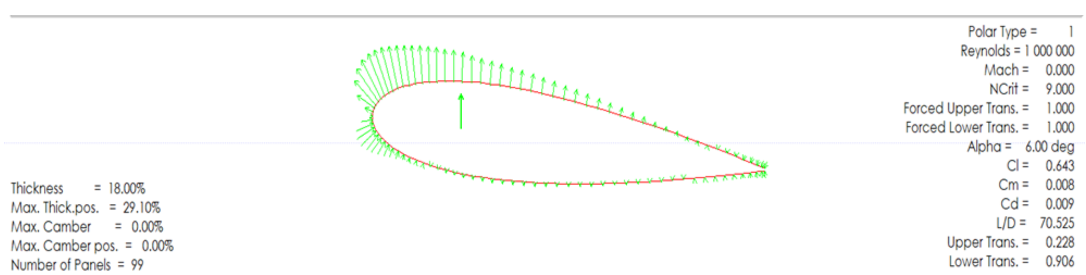
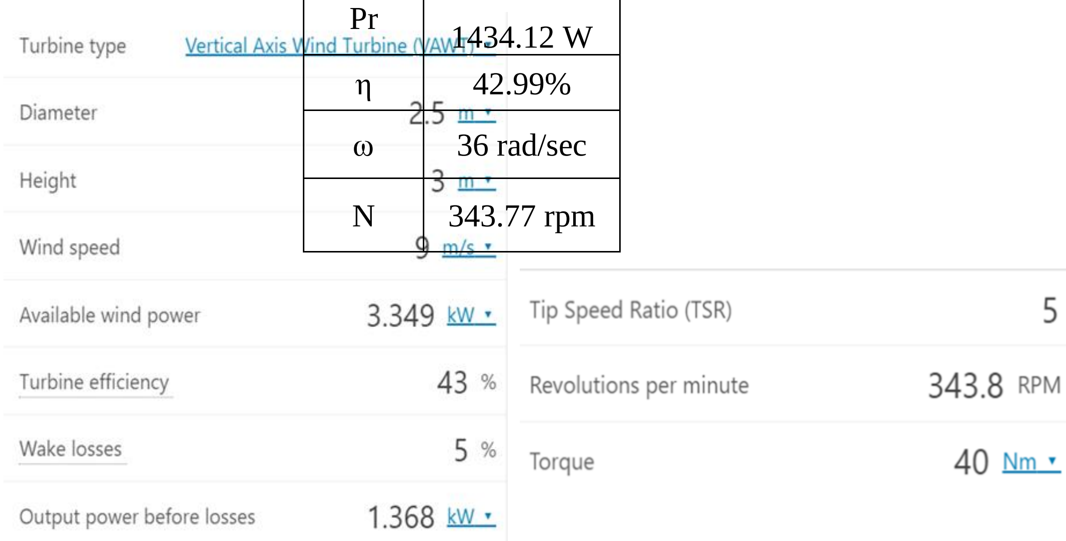


Fig. 13. Airfoil NACA 0018

5. Results and Discussion

5.1. Analytical Results

Pw	3335.175 W
Pr	1434.12 W
η	42.99%
ω	36 rad/sec
N	343.77 rpm



5.2. Verification through Omni Calculator

Fig. 14. Omni Calculator

- Verification of analytical results is done with online Omni calculator.
- Hence, it proves that calculations done can be used in real world conditions.
- The turbine can produce up to 1KW of power in varying or unsteady wind conditions.
- The calculations were done on wind velocity of 9m/s.
- Hence, we can see in figure 14 the calculations done on Omni calculator.

5.3. Flow Simulation

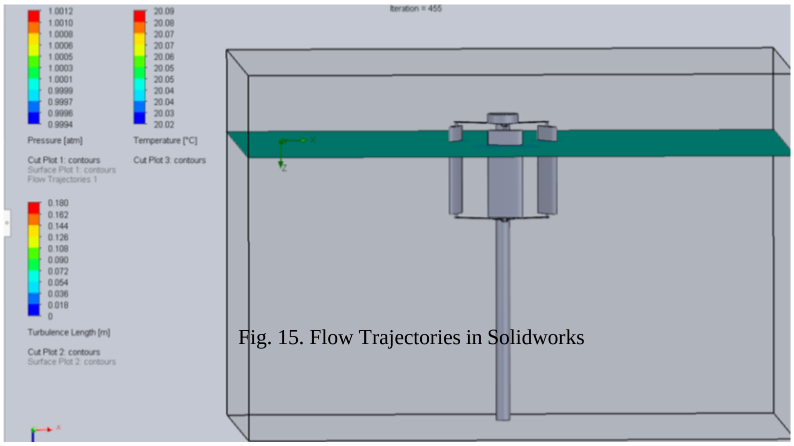


Fig. 15. Flow Trajectories in Solidworks

5.4. Cut Plot

1. Max Pressure- 1.0012 [atm]
2. Max Temperature- 20.09 [C]
3. Max Turbulence- 0.180 [m]

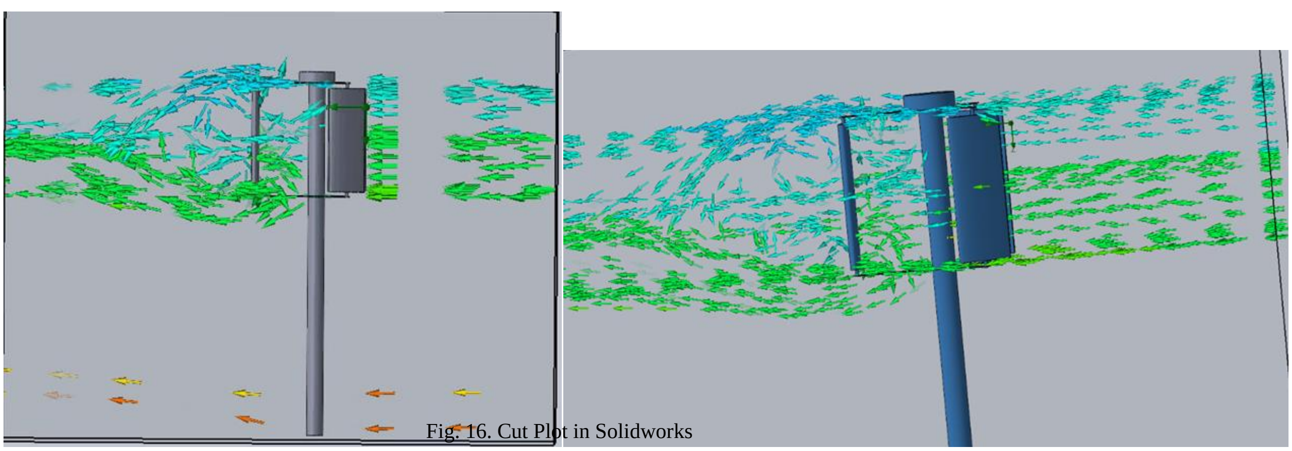


Fig. 16. Cut Plot in Solidworks

5.5. Results from Q-blade

➢ Graph- Cp vs TSR

As we can see in figure 17 at TSR 5 we get Cp up to 0.43 which validates our calculations and design parameters

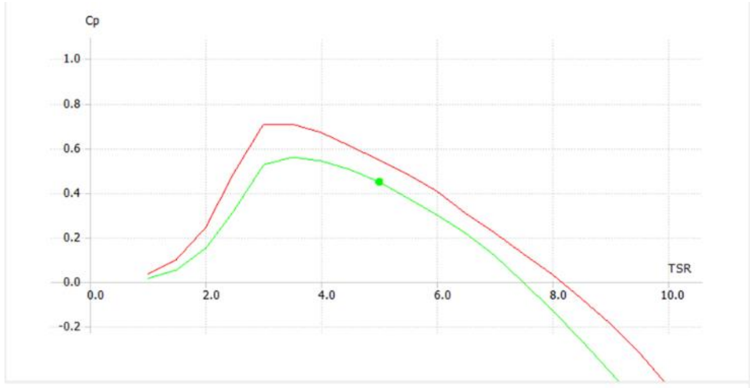


Fig. 17. Cp vs TSR Graph

6. Conclusion

Maximum Strength of each component was checked on ANSYS Workbench and analysis of all components with assembly was done. Aerodynamic analysis was done on Q-blade software. Coefficient of performance and Tip speed ratio was evaluated and verified through simulations on Q-blade software (MATLAB). Verification of calculations and design parameters was done through Omni calculator. Simulation of the windmill was done on Q-blade software to check the power output. The environmental flow analysis was done in Solidworks flow simulation to calculate max and min pressure as well as flow trajectory of velocity of wind. Analytical results and results from omni calculator coordinated approximately. Hence the wind turbine designed analytically is verified with software's like ANSYS Workbench, Solidworks, Q-blade and Omni calculator. As we successfully designed 1KW power generating wind turbine, to generate electricity in rural areas to cut off the electricity bills and also to use as an alternative in times of power cut-off or load-shedding.

References

1. Balduzzi F., Bianchini A., Carnevale E.A., Ferrari L., Magnani S. Feasibility analysis of a Darrieus vertical-axis wind turbine installation in the rooftop of a building. Applied Energy, 2012; 97: 921 – 929.

2. Hill N., Dominy R., Ingram G., Dominy J. Darrieus turbines: the physics of self-starting. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 2009; 223: 21 – 29.

3. Bhutta, M.M.A., Hayat, N., Farooq, A.U., Ali, Z., Jamil, S.R., Hussain, Z. Vertical axis wind turbine – a review of various configurations and design techniques. Renewable and Sustainable Energy Reviews 2012;16(4):1926 – 1939.

4. Brusca, S., Lanzafame, R., Messina, M. Design of a vertical-axis wind turbine: how the aspect ratio affects the turbines performance. International Journal of Energy and Environmental Engineering 2014;5(4):333–340.

5. Batista N.C., Melicio R., Mendes V.M.F., Figueiredo J., Reis A.H. Darrieus wind turbine performance prediction: computational modelling. Technological Innovation for the Internet of Things, SPRINGER, Heidelberg, Germany, April 2013; 382-391.

6. Bhushan D. Agarkar, Shivprakash B. Barve. A review on Hybrid solar/ wind/ hydro power generation system. International Journal of Current Engineering and Technology, INPRESSCO, March 2016; P-ISSN 2347-5161, (https://inpressco.com/category/ijcet)

7. R.R. Ambriz, D. Chicot, N. Benseddiq, G. Mesmacque, S.D. de la Torre, Local mechanical properties of the 6061-T6 aluminium weld using micro-traction and instrumented indentation, European Journal of Mechanics - A/Solids, Volume 30, Issue 3,2011, Pages 307-315, ISSN 0997-7538, (https://www.sciencedirect.com/science/article/pii/S0997753810001452)

8. Piyush Gulve, Dr. S.B. Barve. Design and Construction of Vertical Axis Wind Turbine. International Journal of Mechanical Engineering and Technology (IJMET), Volume 5, Issue 10, October (2014), pp.148-155, ISSN 0976-6359.