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Modeling and structure analysis of Vertical Axis Wind Turbine

Alloli Rajasri, Anusha Ragi, Santosh Nalla

***Abstract:** Turbine design is usually fascinating to research the optimum layout of the wind turbine system are studiedby several researchers however it still continue d up to now. The purpose of this study is to implement and demonstrate a fully automated (self-start) system to optimize a vertical axis wind turbine (VAWT) aerofoil cross-section. The goal is to maximize torsion while imposing constraints on typical wind turbine design such as tip speed ratio, strength and blade profile. There is an aerofoil cross-section and solidity for which the torque can be maximized, allowing the implementation of an iterative design process, by evaluating the maximum velocity of the wind turbine. In this analysis, a small VAWT has been investigated. With many tasks to identify the crucial elements of the wind turbine, the design modifications were initiated, subsequently the modifications were evaluated and strengthened in line with the origin of weakness. Thus, we came to a conclusion that composite material (Glass fiber) made blade profile generated to be effective in durability, High strength and stiffness, Light weight, Corrosion resistance, Design and formulation flexibility.*

***Keywords:** Vertical Axis Wind Turbine (VAWT), Aerofoil, Tip Speed Ratio, Solidity*.

I. INTRODUCTION

Wind turbine converts wind energy into mechanical energy that is used for electricity production. By spinning propeller-like blades around a rotor, wind turbine transforms the power in air to electricity. The rotor turns an electrical generator's drive shaft." The Darrieus wind turbine could be a type of wind turbine with a vertical axis used to generate electricity from the wind energy. The turbine is sometimes made up of a variety of aerofoil but not always mounted vertically on a rotating shaft or frame. The word Darrieus defines a class of lift-powered Vertical Axis Wind Turbines (VAWT).This lift is created due to the turbine blades ' aerofoil shape. Such blades move through the air with a wind angle of attack that creates a differential pressure.

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The resulting pressure differentials result in a force called a lift that propels the blade forward. The net torque induced by lifting forces should be greater
than the net torque caused by drag forces in order to drive the turbine. This research aims at studying and improving a VAWT used under extreme climatic conditions that is implemented to generate energy with the condition that the turbine operates properly to generate electricity. Simultaneously, its architecture should be light weight and high power generation capacity. A kind of VAWT was therefore attempted to be planned. Using Creo modeling software Build the NACA4415 aerofoil using simulation point data and design the 3-bladed vertical axis wind turbine The structural analysis is carried out using the 3.91 m/s wind speed ANSYS-FLUENT software.

Castillo designed A small wind turbine with a vertical axis which was intended to be made with locally available materials. Wood is the chosen material for manufacturing the rotor blades. The selected aerofoil was NACA 0021, which has better self-starting behavior compared to the NACA 0015; however, the NACA 0021 aerofoil is much thicker—and heavier, making the static load and centrifugal forces during operation much larger [1]. Bavin investigated a vertical axis wind turbine on a domestic scale taking into account blade geometry with semi-circular shaped blades during operation under a range of wind speeds. At first, a 16-bladed rotor was designed and its torques and angular velocities were tested using a wind tunnel over a range of wind speeds. In addition, a new cowling system design has been created to increase turbine performance by directing air flow from the rear blades into the atmosphere. Another 8-bladed rotor was also developed to analyze the effect of blade number on the peak turbine power generation [2].Tillman presented an improvement to Self-starting vertical axis wind turbine blades. In this study the authors have investigated, improvements in aerofoil and blade layout to help start the vertical axis wind turbine (VAWT) type H-rotor and how these improvements will affect the performance of the VAWT H-rotor. The authors concluded that the asymmetric aerofoil's can enable a VAWT to auto-start with a larger cord and a thicker cross section to work better with lower wind speeds and Reynolds number. [3]. Verónica Cabanillas Sánchez studied aerofoil selection. It has been determined four different configurations within the NACA aerofoil family. With most of them negative results have been obtained except for using the NACA 4415 for the entire blade. The use of this last configuration has yielded a 10.2% beneficial energy production over a year.

The application of NACA 4415 has really good aero dynamical performance over low Reynolds numbers, fitting the needs and requirements of the environment of Cajamarca[4].

II. METHODOLOGY

The approach explains the step-by-step phase of this analysis. Modeling of VAWT and Simulation of a VAWT for analyzing the Structural properties like strength, strain and deformations.
Process based on the following methodology.

Design VAWT components in CREO 2.0 are PART MODELING and ASSEMBLING. This VAWT has three main components.

1. Base assembly
2. Magnet assembly.
3. Rotor and Stator assembly.
4. Blade assembly.

PERFORMANCE PARAMETERS

1. Blade Swept Area: $S=\Pi r^2$

2. Tip Speed Ratio: $TSR=\dfrac{R\omega}{Va}$

3. Solidity: $\sigma = \dfrac{Nc}{R}$

4. Power: P = Q ω

5. Power Coefficient: $C_p=\dfrac{P_{ROTAR}}{P_{WIND}}=\dfrac{Q\omega}{0.5\rho SV^3}$

IV. MODELLING OF VAWT

VAWT DESIGN

In this paper VAWT designed adjustable blades with the help of nuts and bolts. The tools we used to design VAWT components in CREO 2.0 are PART MODELING and ASSEMBLING.

Table 1: Blade Parameter Specifications

Parameters	Values	Units
Velocity(V)	3.91	m/s
Radius of turbine(R)	747.223x10-3	m
Blade Height(H)	1	m
Rotating Speed(N)	50	RPM
Chord length(L)	0.3	m
Swept Area(Swept)	1.75	m2
Air Density(ρ)	1.2	kg/m3

BASE ASSEMBLY:

It holds the whole weight of the turbine. The material used for all the base parts is mild steel. Base assembly contains subcomponents like:
Foundation Plate
Base plate

Base pole

Bush

Hub

Ribs

Shaft

Bearings (Roller and Thrust bearings)

Design of Base plate:

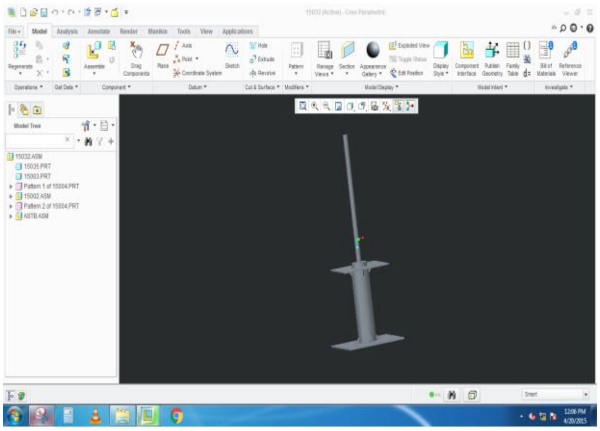

Fig.1: Base assembly 3D Model

Plate details:

Material: structural steel

Dimensions: 400×400×5mm

STATOR:

Stator is a part which consists of enameled copper coils. The stator is a straightforward 12-wheel single-layer arrangement, one of the easiest to do, and it is wired in star in three phases.
Diameter of coil: 25mm (Copper coil)

- Angle b/w magnets: 30º
- Angle b/w coils: 30º

Drawing with dimensions and 3D design of a stator shown in below figures.

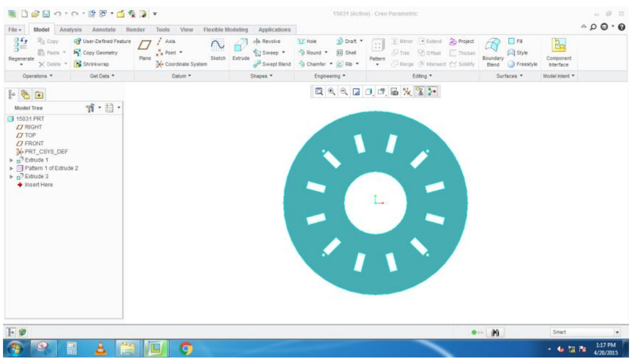

Fig.2: stator

ROTAR DISK WITH MAGNET ASSEMBLY:

Rotor: On each disk there are 12 magnets, they have to be put in an opposing configuration every 30o. So one magnet facing north will go down and the next one facing south.

- Number of magnets used: 12 (Neodymium)
- Size of magnet: 50 X 20 X 12.5(mm)
- Neodymium permanent magnet (magnetized through)

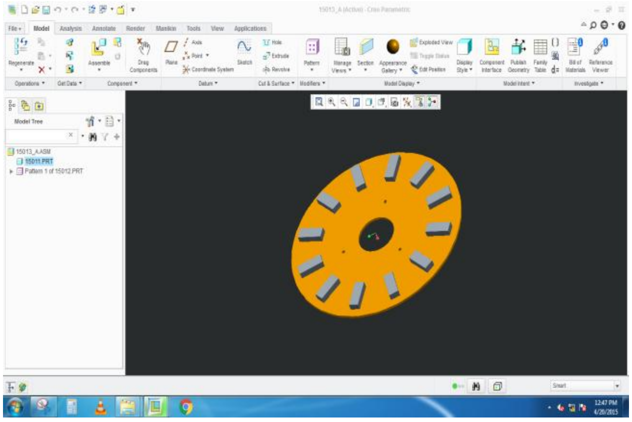

Fig.3: Rotor disk with magnets

Design of blades:

In this paper selected blades which have asymmetrical cross section, in order to increase the lift coefficient, which in turn increases the self-starting capacity. The blades are designed on the basis of Aerofoil. After testing many structures it is found NACA4415 to be the most useful structure, which gives more lift than drag and gives better efficiency at low wind speeds of VAWT. The NACA 4415 aerofoil has a 4 percent maximum camber centered 40 percent (0.4 chords) from the leading edge with a 15 percent max chord thickness.

The blades are designed with the material of E-glass fiber which has high strength and high stiffness properties. The blade dimensions are considered as follows:

- Chord length 300mm
- Thickness 36mm
- Length 1000mm.

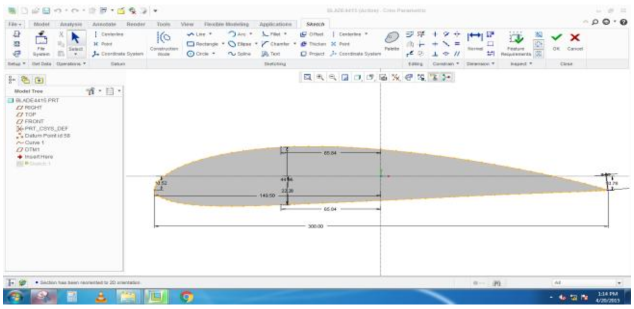

Fig.4: Aerofoil of NACA4415

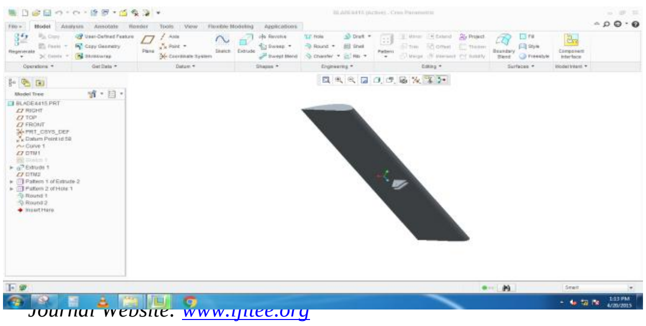

Fig.5: Blade 3D Model

Design of Shaft:

Select structural steel as shaft material because it has adequate strength. We go for hallow structural steel shaft rather than a solid shaft because, though its strength decreases by 34% its weight drastically decreases which reduces the inertia.

Shaft details:

Material: Structural steel, Type: Hollow type, length: 1500 mm, Diameter outside: 50 mm Diameter inside: 40 mm

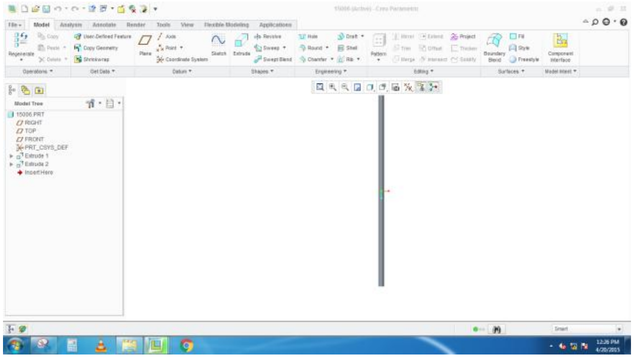

Fig Design of Shaft

VAWT FINAL ASSEMBLY:

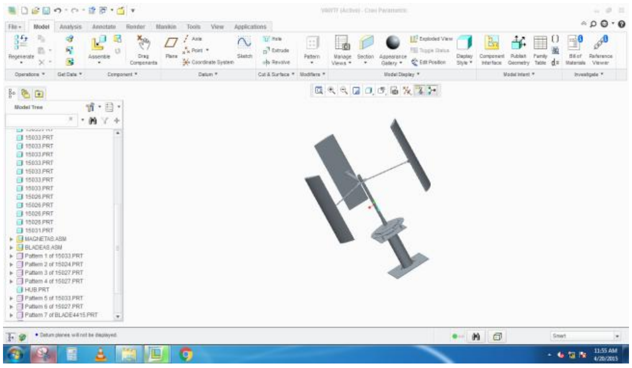

Fig.7: Final design of VAWT

IV.RESULT AND DISCUSSION

EFFICIENCY CALCULATIONS OF VAWT

1. Power calculation by wind velocity and swept Area:

Air density (ρ) = 1.225 kg/m3

Extreme Radius of turbine (r) = 747.223x10-3m

RPM (N) = 50 RPM

Swept Area of turbine.

$$S = \Pi \times r^2$$

= 1.753 m2

Velocity $V = r \times N \times 0.10472$

= 3.91 m/s

P = 0.5 x Density of air x Swept Area x Cubic Wind speed

= 58.94 watts

Calculations of Aerodynamic forces on the VAWT model:

Considering the blade as an aerofoil and computing the forces with the help of aerodynamic characteristics as per thin plate theory.

Surface area of the aerofoil: S = 747223x10-6m2
Angle of Attack: α = 12º
Density of air: ρ = 1.225 kg/m3
Air Velocity: V = 3.91m/s
Extreme radius of turbine: r = 747.223x10-3m
Length of aerofoil: l = 1m

Lift force acting on the aerofoil is calculated by using equation:

$$L=\frac{1}{2}\times C_L\times \rho\times V^2\times S$$

Where,
CL = Coefficient of lift

Table 2: Turbine Property Specification

Component name	Blades	Support plate	Shaft, Bolts &Nuts
Material	E-glass fiber	Aluminum	Plain carbon steel
Yield Strength	2.05e+009 N/m^2	2.75742e+007 N/m^2	2.2059e+007 N/m^2
Tensile Strength	3.4e+009 N/m^2	6.89356e+007 N/m^2	3.9826e+007 N/m^2
Elastic Modulus	5e+009 N/m^2	6.9e+010 N/m^2	2.01e+01 N/m^2
poisons Ratio	8.5e+010 N/m^2	0.33	0.28
Mass density	0.23	2700 kg/m^3	7801 kg/m^3
Shear Modulus	2770 kg/m^3	2.7e+011 N/m^2	7.91e+012 N/m^2
Thermal expansion of coefficient	3.61e+10 N/m^2	2.41e-05 /Kelvin	1.31e-05 /Kelvin
Tensile Yield Strength	2050MPa	280MPa	250MPa
Tensile Ultimate Strength	3450MPa	310MPa	460MPa
Compressive Yield Strength		280MPa	250MPa

$$C_L= 2\times \Pi\times \alpha$$

C_L = 75.36

The surface area is also calculated using the radius of extreme turbine and length of aerofoil:

$$S = r\times L$$

=747223x10-6 m2

L = 527.291 N

Drag force acting on the aerofoil is calculated by using equation:

$$D = \frac{1}{2}\times C_f\times \rho\times V^2\times S$$

Where,
Cf = Coefficient of Skin Friction

$$C_f=\frac{1.328}{\sqrt{R_e}}$$

Re = Reynolds Number

$$R_e=\frac{\rho\times V\times l}{\mu}$$

Where,
l = length of blade
μ = Dynamic Viscosity

Re = 2.4154 x 10-5

C_f= 270.21

D= 1890.65N

Resultant force is calculated by using sum of lift force and drag force which effect on the VAWT.

$$R =\sqrt{L^2+D^2}$$

R = 1909.86 N

Pressure affected on the VAWT is calculated below using force and Area of turbine:

$$P =\frac{F}{A}$$

Where,
F = Force acted on the turbine
A = Area of turbine
P= 0.0031004 MPa

VAWT ANALYSIS

Wind turbine analyzes are simulated in ansys 16.0. This provides the total stress that can endure the full theory pressure and the deflection diagram. Examination of blade content yields positive results.

STRUCTURAL ANALYSIS:

Table 3: Mesh information

Sizing	Parameters
Use Advanced Size Function	On: Curvature
Relevance Centre	Fine
Initial Size Seed	Active Assembly
Smoothing	High
Transition	Fast
Span Angle Centre	Fine
Curvature Normal Angle	18.0 °
Minimum Size	0.359280 mm
Maximum Face Size	35.9280 mm
Maximum Size	71.8560 mm
Growth Rate	1.85
Minimum Edge Length	0.50 mm

Stress Analysis:

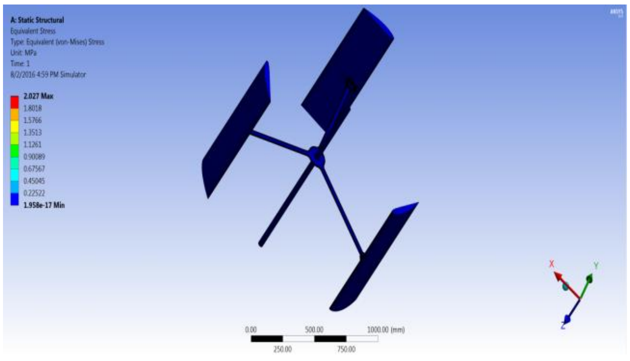

Fig.8: Stress Analysis

Elastic Strain:

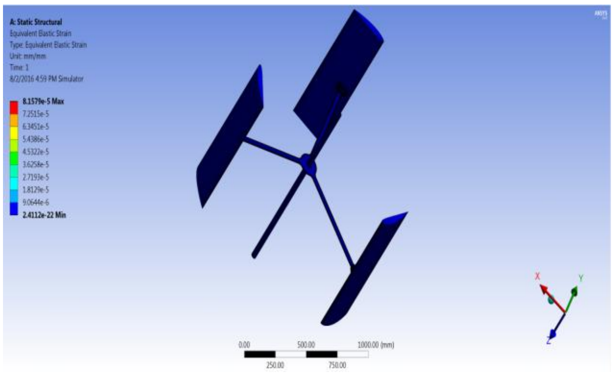

Fig.9: Elastic Strain

Total Deformation:

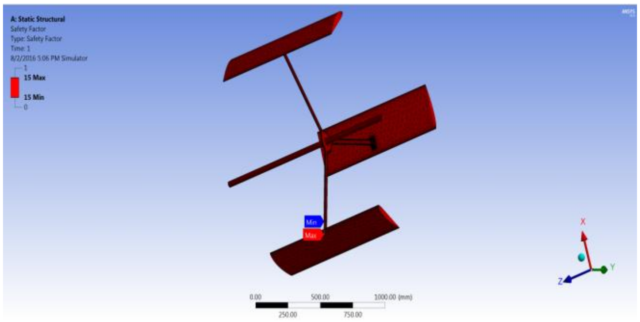

Fig.10: Total Deformation

Safety Factor:

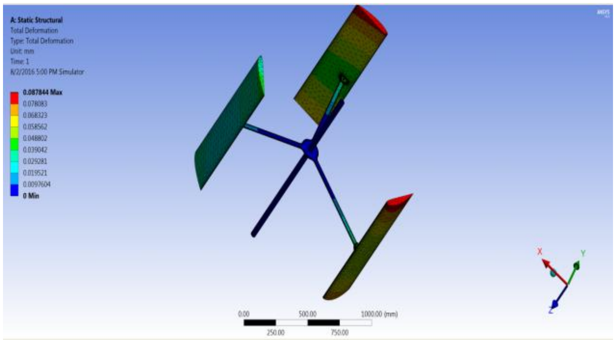

Fig.11: Determination of Safety Factor

V.CONCLUSION

In this paper a model was developed to evaluate the energy efficiency and aerodynamic forces acting on small straight bladed Darrius style vertical axis wind turbine depending on the geometric section of the blade, based on an analytical code coupled with a solid modeling program linked to FEA (Finite element analysis) of structural for calculation of rotor performance.Here the design of VAWT with NACA 4415 aerofoil which is able to generate the max power of 59.8 watt at velocity of air 3.91m/s is an optimal design at rated 50 RPM. The above design has been studied with aerodynamic static structural analysis using ansys 16.0 which results to safe design without any potential failure in model.

REFERENCES

1. Castillo, Javier. 2011. Small-scale Vertical Axis Wind Turbine Design. Bachelor Thesis, Tampere University of Applied Sciences.
2. Royal Academy of Engineering (2010) Wind Turbine Power Calculations. RWE Npower Renewables, Mechanical and Electrical Engineering Power Industry.
3. S.Brusca, R.Lanzafame, M.Messina ‘‘Design of a Vertical-Axis Wind Turbine: How The Aspect Ratio Affects The Turbine’sPerformance”, International Journal Energy Environment Engineering (2014)5:333-340.
4. Samaraweera, Pathirathna K.A.B, Development of Darrieus-type vertical axis wind turbine for stand-alone applications, University of moratuwa,Srilanka(2013).
5. Joseph P. Tillman, Improvements to vertical axis wind turbine blades to aid in self-starting, School of Technology , Eastern IIlinois University 1 st January 2011.
6. Design and Optimization of a Small Wind Turbine by John McCosker,Rensselaer Polytechnic Institute Hartford, Connecticut December 2012.
7. SMALL-SCALE VERTICAL AXIS WIND TURBINE DESIGN by Javier Castillo, Tampere University of Applied Sciences 2012.
8. Analysis of Straight Bladed Vertical Axis Wind Turbine by H. A. El Gamal,, Alexandria University,Egypt,International Journal of Engineering Research & Technology (IJERT)ISSN: 2278-0181,Vol. 4 Issue 07, July-2015.

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