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Design and Analysis of Vertical Axis Wind Turbine for Household Application

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ABSTRACT

In recent years, there have been an exponential growth in the use of small scale green energy technology. This further emphasizes the need of innovation in this field especially for small scale application. Wind energy is the most effective way of harnessing renewable energy. Two types of wind turbine are used viz. vertical axis wind turbine VAWT and horizontal axis wind turbine HAWT. Among these two vertical axis wind turbine finds its suitability in small scale application. In this work a detailed study of vertical axis wind turbine with savonius rotor is investigated in order to obtain the optimal characteristic. The designed savonius wind rotor assembly was developed on CAD software. Computerized fluid dynamics CFD of the interaction between flow of air and blades were developed through FEM. A result of CFD shows the velocity and pressure distribution of the profile blades, also to find coefficient of drag shows flow of air over the blades profile which makes the rotor efficient. Structural and dynamic analysis is performed to calculate the value of deformation of blades. Multistage generator is designed with permanent magnet on either side of plate to increase electrical power output with the same size of rotor.

Keywords : Renewable Energy, VAWT, Savonius Rotor, Multistage Generator, Permanent Magnet

I. INTRODUCTION

The high energy demand in the world causes new interest in different energy areas. Instead of fossil fuel or non renewable energy sources, human realized the necessity of renewable energies to cleanse the world. In recent era, research and development activities in the field of renewable energy especially wind and solar, have been considerably increased due to worldwide energy crisis and high global emission. Wind is inexhaustible energy source available all around the world. In fact onshore energy is extremely large and of course not entirely usable as the wind might be too slow or too fast for practical application. Some of the location are also very remote and very far from consumption hub , making the energy transportation not economically viable. Although HAWT generates more power compared to VAWT but it needs yaw control mechanism. Deployment of VAWT on rooftop building is more suitable for generation of electricity. VAWT with small capacity makes them ideal for light load application also suitable for low wind speed condition.

There are two types of forces that cause the wind turbine to rotate i.e drag force and lift force.

Drag force has same direction as the fluid flow and lift force is perpendicular to the direction of wind flow.

Savonius turbine makes use of drag force to push the blades to generate torque. The working of wind turbine are based on Betz law which states that there is a maximum power that can be extracted from flow of air.Betz proved that no turbine can extract all the speed out of the flowing wind and the wind will always have a flow after passing through the turbine. Factors affecting wind turbine are

A. Power curve- It is a plot that describes the performance of a wind turbine at different wind speed. It shows the electrical energy power output vs wind speed, and gives an idea about minimum and maximum wind speed for a wind turbine
B. TSR- It is the ratio of speed of tip of blade to the speed of wind. I t determines whether a turbine desined on the basis of impulse drag or lift.
C. Turbulence- This presents a major challenge for wind turbine as it makes the generation profile inconsistent and decrease the lifetime of turbine blades because of the mechanical stresses. The random and sudden change in wind speed and direction poses many problems on turbine component.

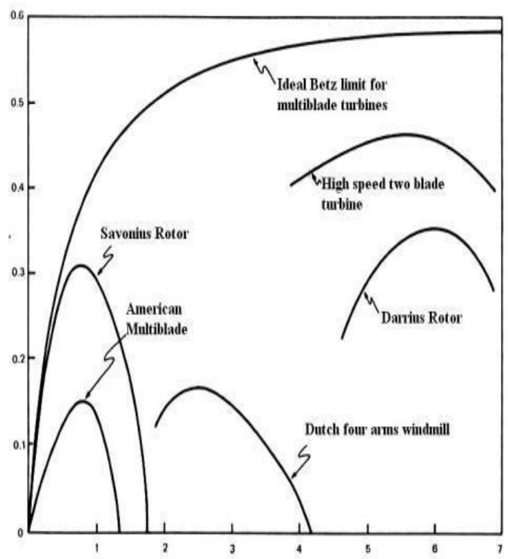

Fig.1- Ratio of TSR vs Power coefficient

II. DESIGN

A. Design of turbine rotor

Calculate power to be generated by monthly electricity
Consumption i.e 340 unit=340 kwh/month.

Average yearly consumption of electricity is
340*12=4080kwh/year =4080/24*365=465.75w/h

Electricity required per hour in an house is 465.75
The electricity to be produced through wind turbine is at least 10% of rated power= 10%*Pr=0.1*465.75=46.575w/h

Considering power losses P=46.75+5=51.75W,
As 5W is mechanical losses when power transferred.

Therefore turbine will be designed to generate 51.75W power. Due to multistage generator, power generation will double. Hence, the turbine will produce 100W approximately without increasing the size of rotor.

P=Power required or mechanical power
Cp=Power coefficient=0.3, from ratio of Cp vs TSR
P=Density of air=1.225kg/m3
V=velocity of air=6 to 14 m/s
P=Pr=51.75W

Power required is given by the equation,

P=0.5*Cp*p*A*V2
V=9m/s
51.75=0.3*0.5*1.225*729*A

A=0.376 m^2

Now varying the diameter of blade from 0.4 to 1m to get different values of area, but for compact design and also for household application diameter of rotor =0.4 m, Material of the blade should be light weight like aluminium With 4 rotor to accept air through all direction.

A=D*h

Where h is height of rotor

A=D*h

0.376=0.4*h

h=0.83 m

TSR=0.7 TO 0.8

TSR=V_{tip}/V_{wind}

Vtip=TSR*Vwind

=0.7*9=6.3 m/s

Angular velocity of rotor=w=Vtip/Rrotor=15.75 rad/sec

Torque=power/w=3.89 Nm

B. Design of generator

Generator is the main component for power output of turbine. The permanent magnet rotor consist of two component one is rotor which is rotating with the vertical shaft and second one is stator which is fixed. The cylindrical shape neodymium magnet are placed on both component of permanent magnet rotor with specific angle with the help of star wiring configuration. Neodymium magnet are the powerful earth magnet. The repulsive force of the magnet are very strong. Two stages of permanent magnet rotor on either side of plates are formed to increase the power output with same size of rotor. This rotor are helpful to rotate with low wind speed.

Magnet specification

Type – Ceramic magnet (brushless permanent)

Shape – Disk magnet (Circular cross section)

Total number of magnets= 48(24 on stator + 24 on rotor)

Size - Diameter= 50 mm

Width = 8 mm

Coil specification

Coil shape – Trapezoidal

Total number of coils = 24(12 on each stator)

Number of turns for each coil = 50

Copper wire – Thin

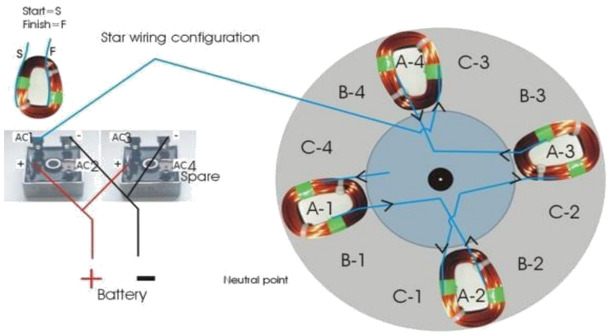

Fig.2.-Circuit diagram of 4 coils single phase

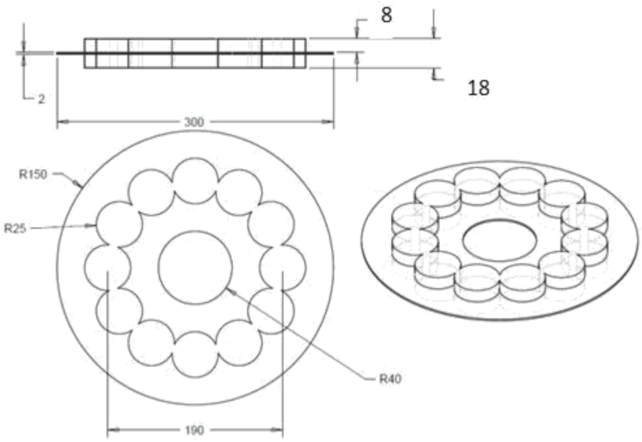

Fig.3. Disk of generator with magnet on periphery

C. Design of shaft and bearings-

Design of shaft and design of bearing should be designed on the basis of torque, calculating internal and external diameter of shaft and increasing diameter 4 to 5 times, as it carries weight of blade, and assembly thereby providing rigidity to shaft. Therefore shaft is designed for this purpose by considering weight criterion and its strength. Two number of ball bearing found more suitable for this application because of light radial load and it is also an anti-friction bearing. By calculating diameter of shaft through torsion equation i.e d=50mm, bearing is selected for this size of diameter, Bearing No. 6010, Bore No. 10 series 60

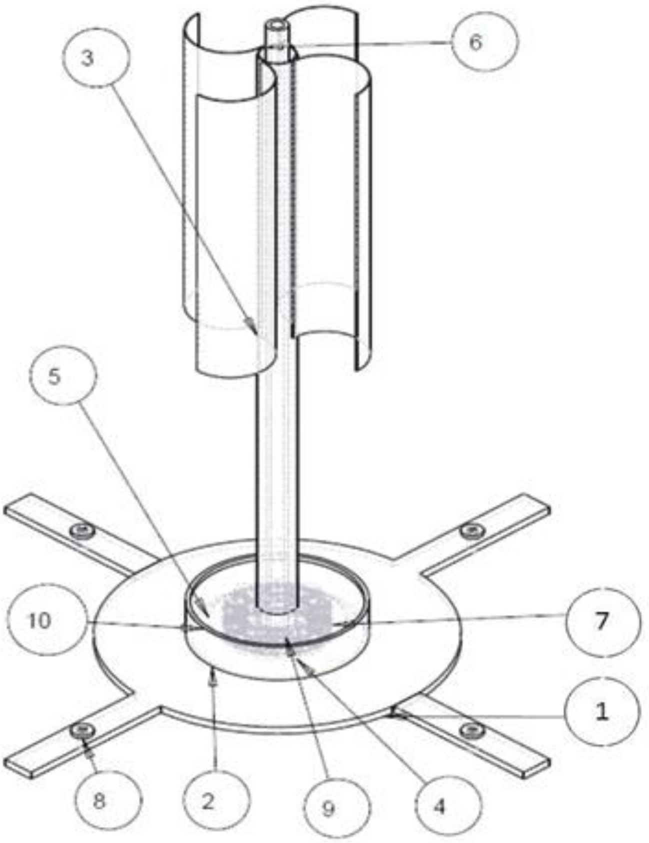

Fig.4.Wiremesh drawing of VAWT

TABLE : 1Nomenclature of VAWT parts

Index No.	Part	Quantity
1	Base	1
2	Cover	1
3	Blades	4
4	Magnets	48
5	Top disk	1
6	Shaft	1
7	Mid disk	1
8	Nuts	4
9	Pipe	1
10	Coils	24

III. ANALYSIS

CFD is used to analysis and solve the problems related to fluid flow by numerical approximation. Here it is first used to determine the coefficient of drag to determine forces acting on rotor called drag force. CFD is also used to study parameters like pressure and velocity of wind flow on blade.

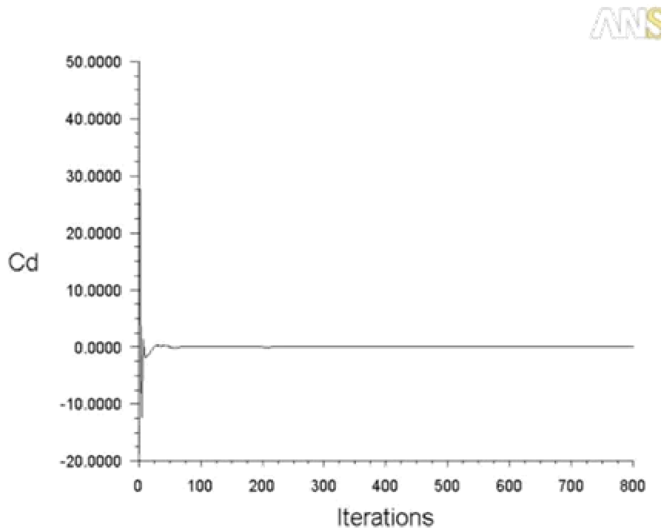

Fig.5: Graph of co-efficient of drag

Cd=3.75 (maximum value observed in above graph)

Drag force=F_D =0.5*p*A*V^2*C_d=68.92 N

Dynamic load=Fe=(XFr+YFa)Ks*Ko*Kp*Kr

Where Fr=68 N, X=1, Y=0, Ks=1, Ko=0.5,

Kp=1, Kr=1.4

Fe=47.75 N

A. Structural analysis- A static structural analysis determines the displacement stresses, strain and forces in structure or component caused by loads that do not induce significant inertia and damping effect. In this loads and the structures response are assume to vary slowly w.r.t time. Types of loading that can be applied in static analysis include externally applied forces, pressure , temperature etc.

To get the result for behavior of the model under predefined condition, the force of 68.72N is applied on rotor and checked the model for various physical quantities.

Dynamic analysis is done to determines the effect of varying loads on structure i.e from 47.75 to 68.72 N.

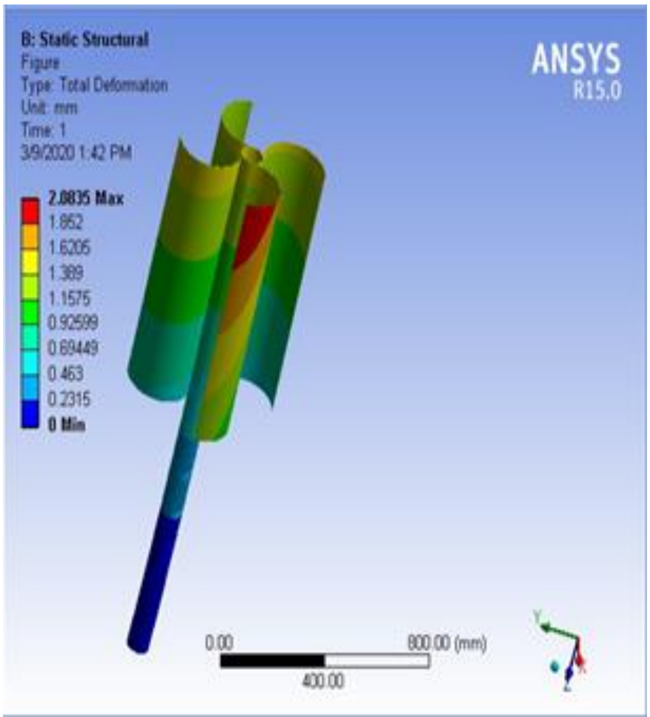

Fig. 7. Total deformation under static loading

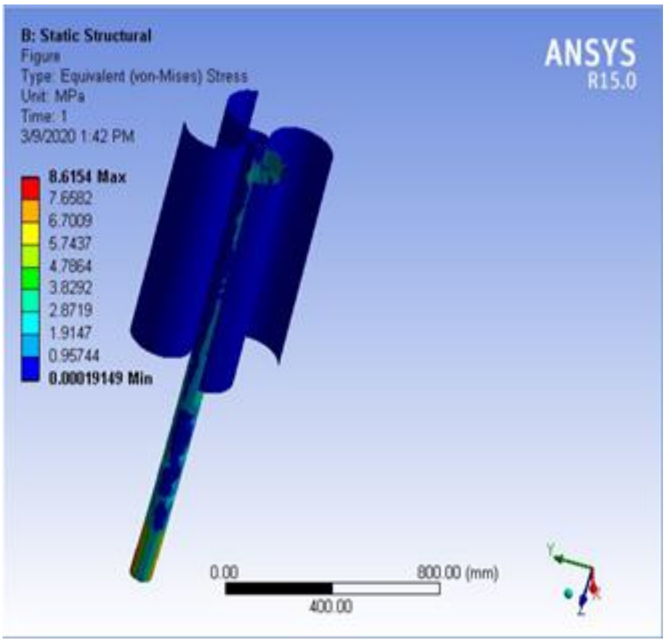

Fig.8. Equivalent stress under static loading

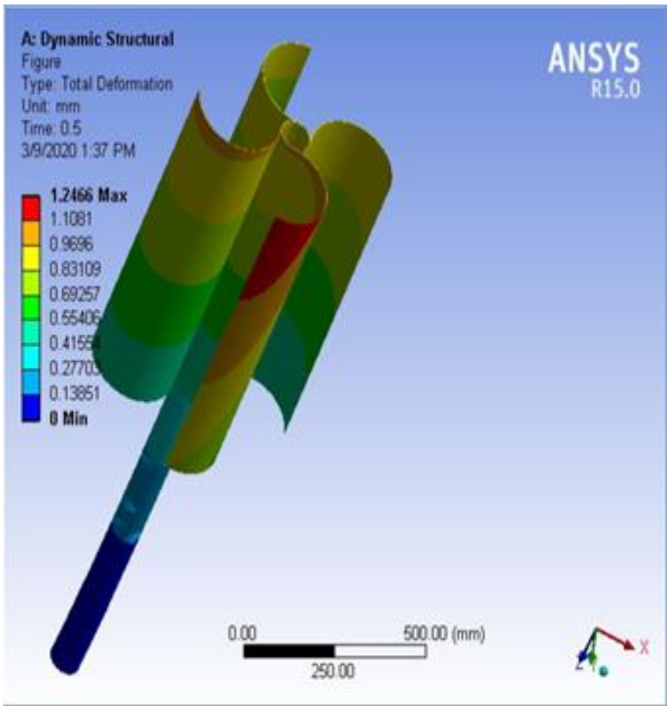

Fig.9. Total deformation under dynamic loading

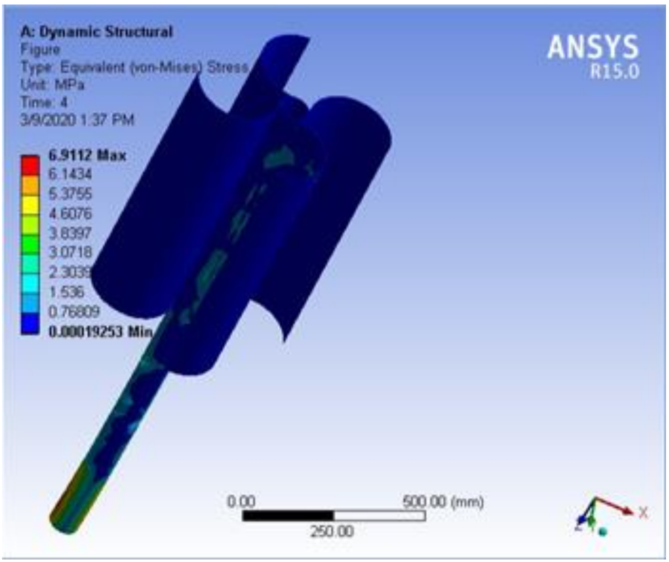

Fig.10. Equivalent stress under dynamic loading

IV. RESULT AND DISCUSSION

The result obtained were up to expectation. There is increase in efficiency due to permanent magnet rotor which reduces the torque required to rotate the rotor blade and also reduce the friction losses during rotation. This Savonious turbine system with permanent magnet rotor gives better results. For instance, they are able to rotate with wind speed at 2.0 m/s. Also, they can operate in winds up to 20 m/s. It helps to increase power generation by 20% and decrease maintenance costs by 50% as compared to other vertical axis wind turbines.This model is checked on the various parameter for the maximum stresses and maximum deformation all parameter are under control, therefore material aluminium is selected for blade as it is light weight.

The maximum and minimum deformation as well as equivalent stress bare given as below table.

Static analysis

Range	Total Deformation	Equivalent stress
Maximum	2.0835 mm	8.6154 Mpa
Minimum	0 mm	0.00019149 Mpa

Dynamic analysis

Range	Total Deformation	Equivalent Von Mises stress
Maximum	1.2466 mm	6.9112 Mpa
Minimum	0 mm	0.0001925 Mpa

V. CONCLUSION

The result obtain in this project which will benefit the future development of modern VAWT. This turbine will helps to increase the power production in the field of renewable energy. The effective fabrication of this VAWT which helps to minimize the friction losses during the rotation of rotor blades. The newly designed blades are simple, strong and light in construction. It has ability to capture wind from any direction and can withstand any weather condition. A main advantage of this savonious VAWT is that its cost is limited and it can easily affordable for commercial power generation. Considering the all-weather point of view the material used which are noncorrosive. Air gap between coil and magnet is very important parameter it affect the power output.

VI. FUTURE SCOPE

The efficiency can be increased by precise fabrication of prototype and also by proper design of the blades. By increasing the generator capacity and large savonious unit with increased number of generators units which will achieve large power generation with optimized cost. Two or more stage of generator will help to increase power output. Number of blade should decrease by one or two to provide maximum surface area along the wind. Slight increase in height of VAWT can gives some better result to get maximum benefits of increased in velocity of air.

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