TO DEVELOP AND ANALYZE RAPID PROTOTYPE MODEL OF VERTICAL AXIS WIND TURBINE BY COMBINING HELICAL SAVONIUS AND DARRIEUS ROTOR TO ENHANCE ITS PERFORMANCE

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Abstract - *We all know the harm that CO2 emissions of thermal power plant has done to life on earth; so we have to search for a more sustainable alternative like wind energy for energy production. Study of India's wind potential was carried out by the prof. Jami Hoossain of TERI Delhi and proposed that India has more than 200GW capacity. The best way to achieve this goal of 200GW is to use VAWT, which can be operated at very low wind speed and not like HAWT. Here we are designing the small actual prototype of VAWT for OFF grid connections. We have tried to achieve the benefit of combining the Savonius and Darrieus VAWT, such that assembly will start at low speed and will produce the high power at high speed and more power than that of standalone Savonius or Darrieus turbines. In this paper we have used S1210 aero foil to design wings and its effect is analyzed with ANSYS FLUENT. We have checked the usefulness of helical shape for both VAWT rotors. In this paper we have performed analysis on rotors assembly with ANSYS FLUENT. Here we have used FDM rapid prototyping technology and studied its usefulness for future applications. In this paper we are listing some materials for wing design.*

Key Words: VAWT, HAWT, FDM, ABS, ANSYS.

1. INTRODUCTION

Wind turbines, wind systems or wind machines are accepted terms for devices that extract power from the wind and produce mechanical or electrical power. The VAWT considered in this paper consists of two helical blades for each rotor, in which rotor axis lies perpendicular to the wind flow. Due to low operating speed the VAWT is quiet and can be used in an urban area without being trouble to neighborhood. Also, the aesthetic look of the VAWT makes it attractive. The common measure of the efficiency of a rotor is the power coefficient C_p. It is the fraction of the total kinetic energy passing through a certain swept area that is captured by the rotor, which is given as,

$$Cp=P/0.5*A*v^3*\rho_{air}$$

1.1 Literature Survey

The choice of an airfoil is of paramount importance as the power produced by a VAWT at different wind speeds is largely determined by its blade airfoil shape [1]. NACA 00-series aero foil which are symmetrical and they were used before but were having self-starting problem [2]. More recent research has considered cambered aerofoils for VAWTs. A cambered aero foil, while increasing the drag a bit which impacts little negatively, has the potential to allow for self-starting of the VAWT in an entirely passive way. In particular, a VAWT experiences flow with a wide range of angle of attack during each rotation [3]. The lift force generated by the blade has a tangential component in the direction of rotation. If the contribution of the drag force is smaller than that of the lift force, the blade contributes positive torque which drives a load connected with the central rotating shaft [4]. The problem of self-starting can be alleviated by (i) using high-lift low-drag special purpose airfoil (ii) by incorporating a Savonius rotor [5]. S.S. Suprajha , K.Vijayan in there research paper has shown that the efficiency has been improved by using helical shape for their VAWT and optimum angle of attack which they found for there design was 4.5^0 at C_p of 33% there design was for Darrieus wind turbine using Aluminium Alloy 1060-H18 as there fabrication material using three bladed design having 12^0 pitch angle of helix[16][17]. Arturo Reza, Guilibaldo Tolentino and Miguel Toledo has shown in there savonius VAWT design that making the helical circular hollow shapes of wings increases the efficiency. Construction of a helical vertical axis wind turbine for electricity supply [18].The primary concern for a lighter turbine is one of structural or dynamic loads. Heavier, more massive blades are generally stronger and dampen vibrations is better. Thus a trade-off must be made between a turbine that will ensure a safe, long operation and one that is lighter and more responsive [6]. Typically scale models of larger components are printed. 3D Printing rapid prototyping has been utilized in the sustainability technology sector to produce aerodynamic research models. Hydro turbine prototypes and recently micro-scale wind turbines too [7] [14]. As pointed out by Howell et al, solidity is one of the main parameters dictating the rotational velocity at which the turbine reaches its maximum performance coefficient [8]. Li S. and Li Y. performed a series of numerical analysis about the effect of solidity on a straight-bladed VAWT, changing both blade chord and number of blades. In this paper they state that the VAWT with larger solidity achieves maximum power at lower tip speed ratio. However, too large solidity will decrease the power coefficient. Furthermore, even for the same solidity, the different combination of blade number and chord affects the power [9] [13]. Blade pitch angle has significant effect on pressure distribution acting on single blade surface, when the azimuth angle is in the upstream region, the pressure difference acting on the blade surface reaches maximum at the blade pitch angle of 6º [10][12]. The vertical axis wind turbine basically has non-stationary aerodynamic behavior, mainly due to the continuous variation of the blade angle of attack during the rotation of the machine: this peculiarity involves the continuous variation both of the relative velocity with respect to the blade profile and - although to a lesser extent - of the corresponding Reynolds number [11]. Deglaire et al., who did a numerical study to evaluate the forces on a rotating blade of the straight type VAWT, mentioned that a blade profile is one of the key factors to affect the performance of a wind turbine. A study illustrate that the performance of a turbine is enhanced with increasing the Reynolds number, and decreasing the number of blade [15].

1.2 Filament deposition method [FDM]

Sometimes also called filament free form fabrication, is a 3D printing process that uses a continuous filament of a thermoplastic material. Filament is fed from a large coil through a moving, heated printer extruder head, and is deposited on the growing work. The print head is moved under computer control to define the printed shape. The accuracy of machine which was used for printing was 1mm. We exported the geometric model to standard triangular language format where it converts the surface to triangles which then be printed as surface more the triangles more the accuracy.

material	Filament ($/K)	Weather resistance	Notes
ABS	30	High	Heated print bed required
PLA	29	Low	biodegradable
Epoxy	85	High	Poly jet type printer required
Lay wood	40	medium	Heated print bed required
Polycarbonate	50	High	Heated print bed required
Nylon	40	high	-

Table 1 Material available for FDM

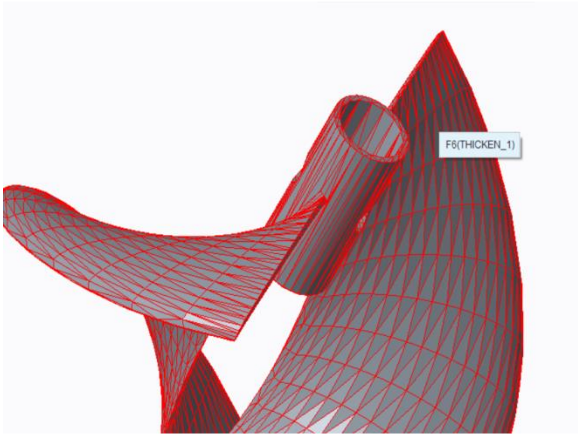

Fig. 1 Standard Triangular Language (STL) file

2. DESIGN OF VAWT

2.1 Material selection for VAWT

Material for VAWT is selected depending upon the requirement of application as sometime the VAWT has to operate in cold regions or in hot regions there it has to face the wear and tear, again life expectancy decides what material has to be chosen .Cost of production also decides the material which has to used, as the VAWT works in dynamic state so it requires the high working strength ultimately the higher tensile strength. The density plays very vital roles in selecting the material for construction of VAWT, if weight of VAWT is high then it will require the high starting torque losing self-starting ability. The materials which were best chosen for construction of blades were Alumunium7020, wood, polycarbonate, ABS (Acrylonitrile butadiene styrene).Here density to cost ratio is less for ABS and UTS of ABS is good hence chosen for design.

Material	UTS (MPa)	E (GPa)	Density Kg/m³
Aluminium 7020	350	70.0	2770
Polycarbonate	70	2.00	1230
ABS	49	1.50	1200
wood	7	10	700

Table 2 Material and their Properties

2.2 Selection and plot of air foil S1210

It is shown experimentally that the lift coefficient of S1210 is much higher as compared to the NACA2412 and hence we choose the S1210 as our design air foil. As we are working under very low velocity which produces very low Reynolds number. Kirke suggests that low Reynolds numbers contribute to difficulty in the self-starting of a VAWT. Hence larger Reynolds numbers are desired. Research shows that the Reynolds number increases the power coefficient of a given VAWT.

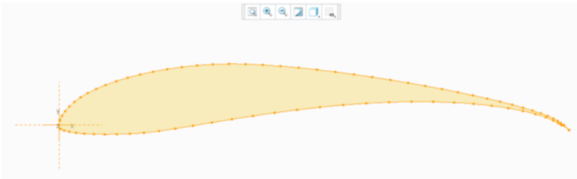

Fig. 2 Plot of S1210 Aero Foil

2.3 To design the helical shape of Darrieus VAWT-

We are designing here darrieus type rotor for prototype fabrication, as we are designing here for the prototype and to make it self start. We have assumed that the shape of VAWT to be helical or DNA type which has shown the better output characteristics than straight bladed VAWT. We had design the geometric model with the help of CREO PARAMETRIC 3.0.

For Cartesian coordinate system, enter parametric equation in terms of t for x, y and z

Equation of helix which we are chosen is

x = -150* cos (t * 360*0.5)

z = 150* sin (t * 360*0.5)

y = 400*t; t= parametric parameter

The dimensions of the rotor which we are designing for are of

D=300mm; Height=400mm

Size of Airfoil=50mm; Pitch of helix=800 mm

2.4 Design and modeling of Darrieus Turbine-

The dimensions of the rotor which we are designing for are of

D=300mm; Height=400mm

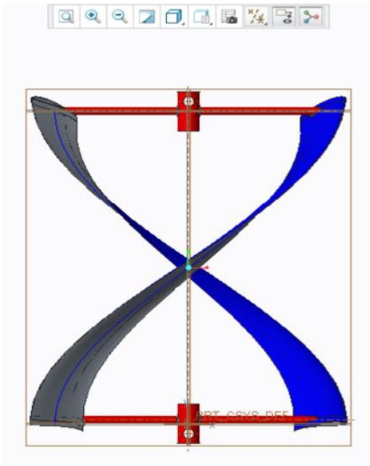

Fig. 3 Geometric Model of Darrieus Rotor

Material=ABS; Power=5 W; Speed=60RPM

Size of Airfoil=50 mm; Pitch of helix=800 mm

Cut in, rated and cut out wind speed [m/s] =25 m/s

Density of air=1.2 kg/m^3; Viscosity of air=1.67e-05 N.s/m^2

No. of air foil= 2; Air foil type = S1210 , C_l=1.1 , C_d=0.09

Mass of whole Darrieus= 0.157 Kg

Normal Angle of attack=6^0

Approx. swept area =0.12m^2

Max Kinetic energy that can be captured=0.5*125*1.2*0.12*0.5925=5.3325W

Re= c * U_N/ ν; c =50mm; unaided air velocity=U_N =5 m/s; dynamic viscosity=ν =1.67e-5 N.s/m

R_e=15000

For c =50mm; U_N =25 m/s; ν =1.67e-5 N.s/m

Reynolds No. =R_e=74850.29

To calculate forces on the air foil and supporting tubes

For speed of air 5 m/s

F_l=0.5* ρ *C_l*A* V^2=1.98N

F_d=0.5*ρ*C_d*A*V^2=0.162N

For speed of air 25 m/s

F_l =49.5 N; F_d=4.05 N

So maximum force for designing the turbine supporters will be the resultant of this max value of force =49.5 N

At ω =166.67 Rad/s at TSR = 1.0 for v=25m/s; mass=0.157Kg

Centrifugal force will be F_c

As the F_c will be carried by the 4 arms so stress will be divided into 4 arms

F_c= (mass/4)*r* ω^2=163.55N

Total tensile force will be =49.5 N+163.55N =213.04N

Diameter of support tubes chosen to be

D_0=10mm; D_i=5mm

Material is ABS having the tensile strength equal to S_{yt}=49 MPa

Factor of safety=FOS=2

Stress carrying capacity =24.5 MPa

Induced stress=213.04/3.142* $(0.01^2-0.005^2)$ =904204.679=0.904 MPa

Therefore the induced stress will be far lesser than the carrying capacity so the design is safe.

2.5Design and modeling of Savonius Turbine

Here we are using the elliptical cup type wing for better collection of wind. Then we have given the thickness to the blade as 1.5 mm as the material is somewhat capable of withstanding the stresses; and to decrease the mass of VAWT,

Material= ABS, U_N =5 m/s; Swept area=0.051 m^2 , mass =0.143 kg

Max power captured by the savonius VAWT will be

Power=P=0.5*A*v^3*0.5925*ρ_{air}=0.5*1.2*0.051*125*

0.5925=2.266 W

Height (H2)	Rotor Diameter D2	Blade Thickness	Eccentricity	Major Dia.	Minor Dia. (mm)	Aspect Ratio (H1/D2)
300	170	1.5	25	75	25	1.77

Table 3 Dimensions of savonius rotor

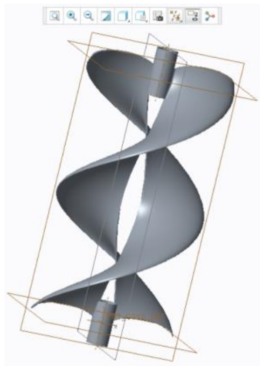

Fig. 4 Geometric Model of Savonius Rotor

To calculate forces on the wings

Coefficient of lift=C_l =0.75; Coefficient of drag=C_d = -0.9

Chord length=L=0.075 m

A) ω= 6.67 rad/sec
B) ω=33.34 Rad/sec

at ω=6.67rad/s, v=5 m/s, TSR =1.0

F_l=0.5* ρ *C_l*A* V^2=0.5737 N

F_d=0.5*ρ*C_d*A*V^2=-0.6885 N

F_c= (mass)*r* ω^2=0.541N

At ω=166.67 rad/s, v=25m/s , TSR = 1.0

Lift force=F_l=0.5* ρ *C_l*A* V^2=14.34N

Drag force=F_d=0.5*ρ*C_d*A*V^2=-17.21N

Centrifugal force=F_c= (mass)*r* ω^2=337.65 N

So the total force which is being acted will go approx. 352 N.

3. ANALYSIS OF DESIGN

3.1 Analysis of S1210 and NACA1200 series aero foil

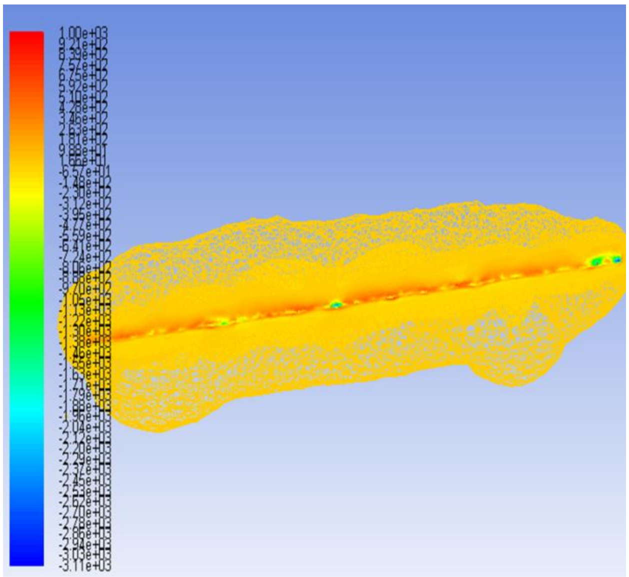

Fig. 5 Aero foil S1210 static Pressure Drop in ANSYS for 5m/s air velocity

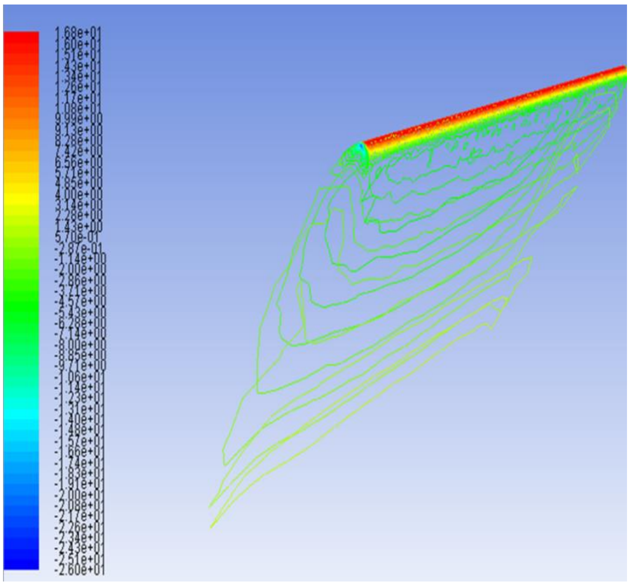

Fig. 6 Aero foil NACA2412, Static pressure drop at 5m/s

From above two figures we can interpret that the pressure drop across two faces of S1210 aero foil is 7 times more compared to NACA2412 aero foil. This drop of pressure is directly utilized for producing torque so S1210 aero foil is much useful in this regard.

3.2 Analysis of Darrieus turbine

From analysis it was observed that the pressure was dropping in the direction of wind flow and it was more for Savonius as compared to Darrieus wind rotor. Pressure which was dropped produces the lift force which finally produces the torque.

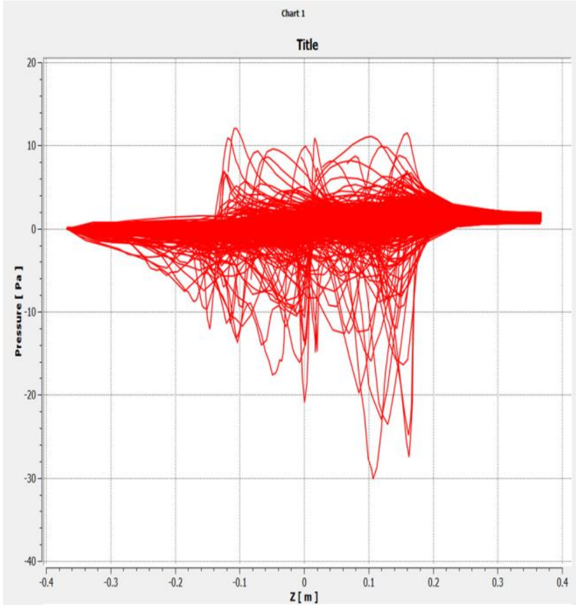

Fig. 7 Plot of Pressure vs. Z direction for Darrieus Turbine

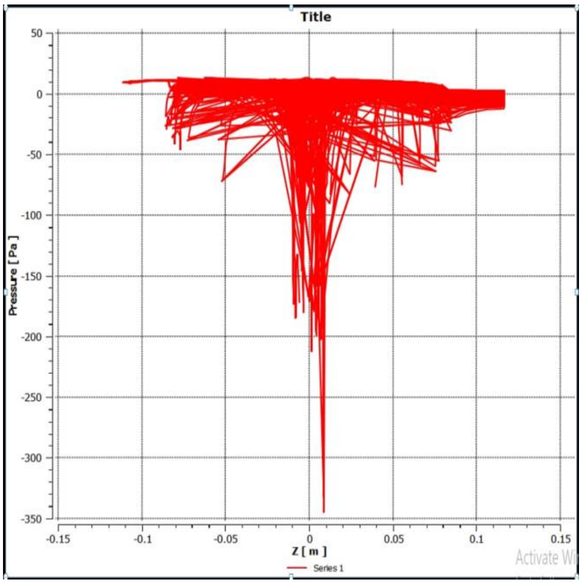

Fig. 8 Plot of Pressure vs. Z direction for Savonius Turbine

4. ASSEMBLY OF MECHANICAL ELEMENTS AND OUTPUT OF TURBINE

Here we have used Savonius, Darrieus, rotors, Shaft (PVC), SKF 6304 bearing, Plywood, screws and stud for assembly, with DC motor with plastic pulley. Assembly and output of turbine is shown in respective figure and table.

Fig. 9 Final assembly of all Mechanical Elements

Speed (RPM)	Voltage (mV)	Current (mA)	Air speed (m/s)	I/p power (W)	O/P Power (µW)
128	330	6.5	6	3.6936	2145
134	370	5	4.3	1.36	1850
134	398	4.8	4.2	1.266	1910.4
122	270	0.7	4.0	1.0944	189
88	190	0.4	2.4	0.237	76
54	100	0.2	2.0	0.1368	20

Table 4 Reading of Voltage and Current at specified Speed of air

5. CONCLUSION

When we installed separately Savonius and darrieus VAWT the effect was that savonius was moving at very high speed at around 300 RPM at 5 m/s of air velocity and that of darrieus was moving at 87RPM. When we combined both VAWTs the savonius helped the Darrieus and assembly was rotating at very small air velocity even at 2.4 m/s and the RPM of assembly was find out to be 88 RPM. By combing VAWTs and doing the static structural analysis we found that our design is safe at the 33.34Rad/s speed of rotation. When we used the helical shape, the lift coefficient has been increased which causes to increase the torque and speed of rotation. By using the traditional NACA 2412 Aero foil the pressure difference was found to be 42 Pa, while that of using the S1210 aero foil the maximum pressure was found to be 1000Pa while that of minimum pressure (vacuum) was found to be 3100 Pa. More the pressure difference the more is the lift and drag forces on the aero foil which ultimately gets converted into the torque which produces positive power. Hence using the S1210 Aero foil has positive effect on aero foil. FDM rapid prototype which was prepared here for study has shown that it can be used for further production of VAWTs and only requirement is little cost cutting. After one year of working in real environment it was found that the blades of Darrieus turbine were found to be distorted and further study of this problem is required. For higher efficiency of design this prototype has to be scaled up.

6. FUTURE SCOPE

Optimum dimensions for operation has to be find out by simulation study. Study and effect of deflectors can be carried out for combined assembly and there optimum dimensions can be obtained. Optimum angle of attack has to be find out for S1210 aero foil and there study is yet to be published. Study of concentrators on VAWT output can be studied. The combination of savonius and darrieus VAWT and its output parameters yet to be studied.

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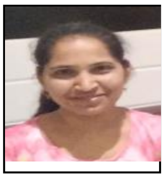

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