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Design and Analysis of Vertical Axis wind Turbine

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Abstract: *Wind is amongst the most popular and fastest growing source of energy. Due to its abundance presence, the energy harnessed from it could contribute an indispensable share in meeting hiked energy requirements. Vertical axis wind turbines(VAWT) amongst many others unconventional energy generating devices could be used for energy generation purpose. Efficiency remains a crucial factor for justifying performance of a VAWT. VAWTs working due to generation of lift on turbine blades can be optimised to harness maximum energy. Small VAWTs operate at Reynolds number around 1,00,000 under some specific aerodynamic characteristics of aerofoil. These factors affect the turbine performance and its ability to self start. Therefore the first step is selection of aerofoils to obtain positive power coefficient between tip speed ratios ranging from 1 to 3 for small scale models working at wind speed of 6m/s.Computational Fluid Dynamics(CFD) tool is used to optimise the parameters for obtaining maximum power coefficient and torque. The structural analysis is done in ANSYS workbench software to obtain effects of stresses on turbine blades. Overall study is done to optimise power coefficient of small scale VAWTs at low wind speeds.*

Keywords: *Darrieus turbine, Savonius turbine, Vertical axis wind turbine,*

I. Introduction

Wind Turbines is a device which converts the wind's Kinetic energy into Mechanical work which is further converted into Electrical Energy with the help of generator.Wind turbines are manufactured in a wide range of vertical and horizontal axis. The smallest turbines are used for applications such as battery charging for auxiliary power for boats or caravans or to power traffic warning signs**.** Arrays of large turbines, known as wind farms, are becoming an increasingly important source of renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuels. Wind has the lowest relative greenhouse gas emissions, negligible water consumption compared to other renewable energy methods and fossil fuels.Vertical Axis Wind Turbine have the rotor shaft and blades in vertical direction. Advantage of this system is that the turbine is omnidirectional, which is helpful in places where the wind direction changes frequently. Also, the generator and gearbox are placed at ground level making it more accessible for maintenance. However, the Vertical Axis Wind Turbine produces less energy as compared to Horizontal Axis Wind turbine, which is a major drawback.

II. Parameter Finalization

The first step in our project was finalizing the basic parameters of the blades. The basic parameters of the blade include the Rotor diameter and height. Using these parameters a theoretical power coefficient is obtained and a basic design is created. Our design incorporates two rotors, Savonius and Darrieus. Therefore calculation for both the rotors were done separately before arriving a theoretical power coefficient keeping in mind the losses in both rotors and the wind speed. The basic parameters needed for designing a VAWT are as follows:

2.1 Swept Area

The swept area is the part of air that encloses the turbine in its movement. The two types of turbines (HAWTs and VAWTs) swept areas are different. The swept area of an HAWT is circular shaped while for a straight-blade vertical axis wind turbine the swept area is a rectangular shape and is calculated using:

$S = 2*R*L$ ……………………………………………………(1)

Where, S is the swept area (m^2)
R is the rotor radius (m)
L is the blade length (m).
The rotor converts the wind energy in rotational movement of blades , so as bigger the area, bigger power output in the same wind conditions.

2.2 Power and Power Coefficient

The power available from wind for a vertical axis wind turbine is determined by formulae:

$P_w = 0.5 * \rho * S*(V_0)^3$……………………………………..……….(2)

Where, V_0 is the velocity of the wind (m/s)
ρ is the air density (kg/m^3), reference density used its standard sea level value (1.225 kg/m^3 at 15^{0}C).
The power which is harnessed by the wind turbine is calculated is the power coefficient:

C_p = Power obtained from turbine / Available power in wind…….(3)

C_p value represents the power obtained from total available power from wind, which can be understood as efficiency. There is a theoretical limit in the efficiency of a wind turbine determined by Lanchester- Betz limit. The maximum power coefficient has been found to be ranging from 0.15 to 0.45.

2.3 Tip Speed Ratio
The power coefficient strongly depends on tip speed ratio, which is defined as TSR = Tangential speed at the blade tip / Actual wind speed,

$TSR = R * \omega / V_0$ ……………………………………………..(4)

Where,ω is the angular speed (rad/s)
R is rotor radius (m)
V_0 is the ambient air velocity.
3.1.5 Solidity
The solidity σ is defined as the ratio between the total blade area and the area of the wind blocked by turbine blades. This dimensionless parameter affects the self starting capacity and is calculated as,

$$\sigma = \frac{N_b * c}{R}$$ ……………………………………………(5)

Where, N is the number of blades
c is the blade chord,
L is the length of the blade.
For solidity σ ≥ 0.4 self starting turbine is achievable.[2]

Table 1: Parameters and their initial values

Symbol	Parameter	Starting value
TSR	Tip speed ratio	2
R	Rotor radius	1 m
c	Blade chord	0.3 m
L	Blade length	2 m
N	Number of blades	3
α_0	Initial angle of attack	0^0

III. Aerofoil Selection

For Darrieus Wind Turbine, Aerofoil is selected with the aid of Software. Primarily, Qblade software was used to analyse different NACA Aerofoil profiles. Profiles analysed included NACA 0015 and NACA 0021. Coefficient of Lift v/s Angle of Attack graphs helped identify the angle at which we get highest lift thus a higher power coefficient is achieved.

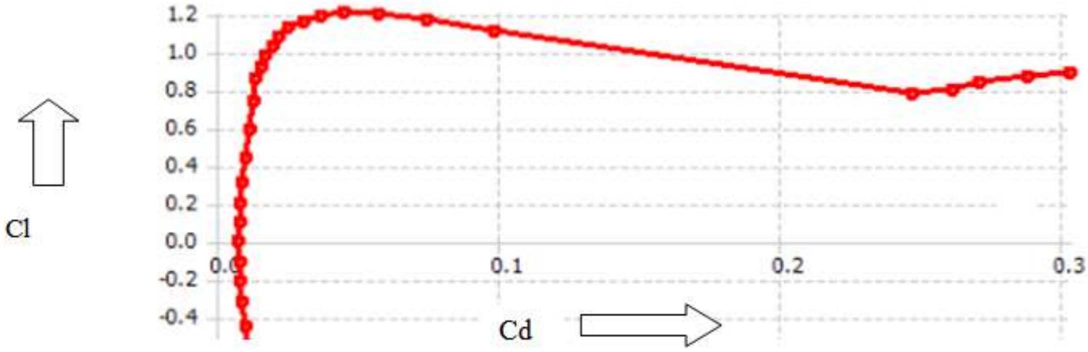

Fig.1-coefficient of lift v/s coefficient of drag

The coefficient of lift with the variation of Azimuthal angle(Θ)increases up-to certain limit followed by and abrupt increase in coefficient of Drag. The coefficient of Lift for NACA0015 is found to be maximum at 15°-17 ° degrees. [1]

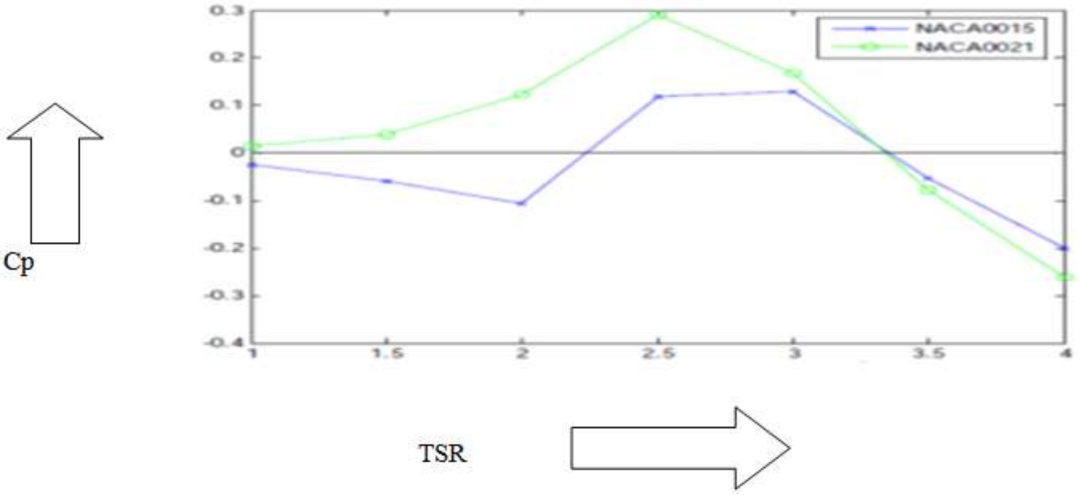

Fig.2- coefficient of power vs tsr

IV. Modelling

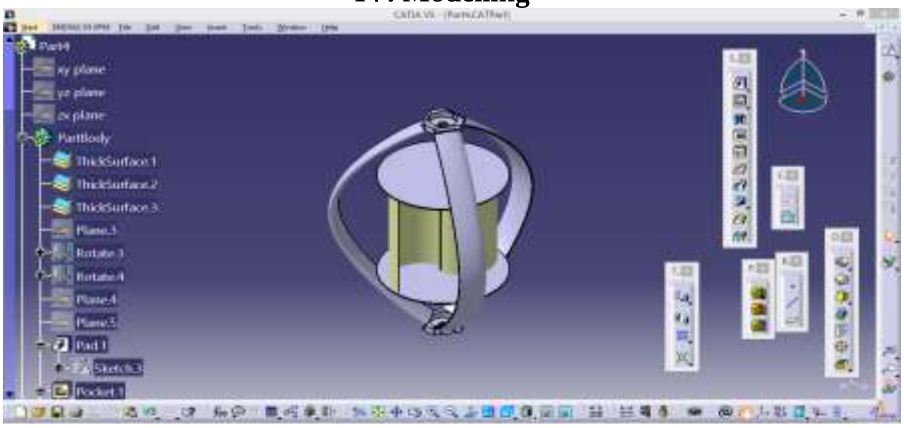

Fig.3-combined savonius-darrieus rotors

CATIA V5 software is used to create the design. For the Darrieus rotor, the selected Aerofoil is imported and used as a base to create the design. The designed model is Darrieus model which is characterised by egg beater shape(Profile). This shape provides increased strength of blades experiencing centrifugal force which if exceeds safe designed limit can devastate the shape of the blade leaving it for no further use. This model is an integrated model of Darrieus egg beater shape and Savonius drag type shape. Savonius drag type VAWT works on the force offered by drag when the incoming wind strikes the blade area. Due to pressure difference generated between the facing area and the hidden area a force acts on blade resulting in rotation . The shape of drag type model can further be optimised to obtain optimum force which would help in self starting of the above integrated model. The number of blades of lift type model can be selected and optimised to obtain optimum power coefficient.

V. Analysis

The study of wind flow around the turbine is an important step in the design. ANSYS FLUENT is used to study airflow. First, the selected aerofoil is loaded and studied. The Aerofoil is studied for different wind speeds form 1m/s to 15m/s. Properties like Temperature, Pressure contours are plotted and studied to make sure under all circumstances the wind flow does not detach from the aerofoil surface and no unforeseen circumstance like production of vortices is achieved which can negatively affect the performance of the turbine.

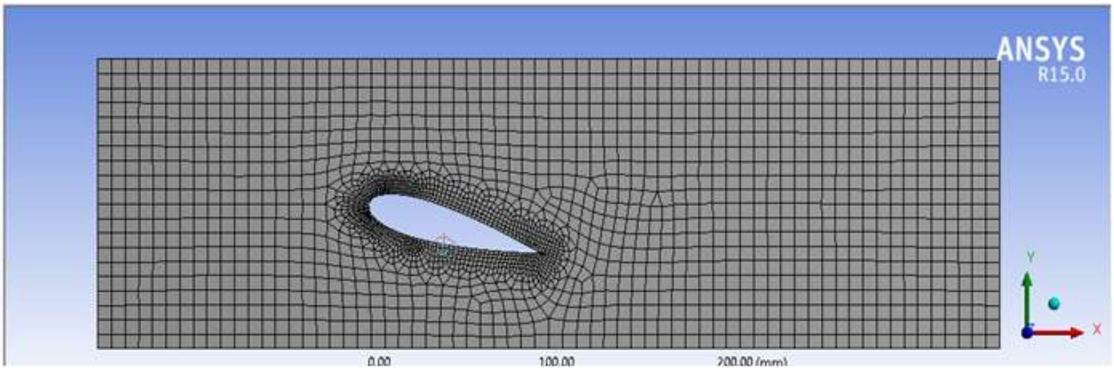

Fig.4- Mesh Generation for NACA 002

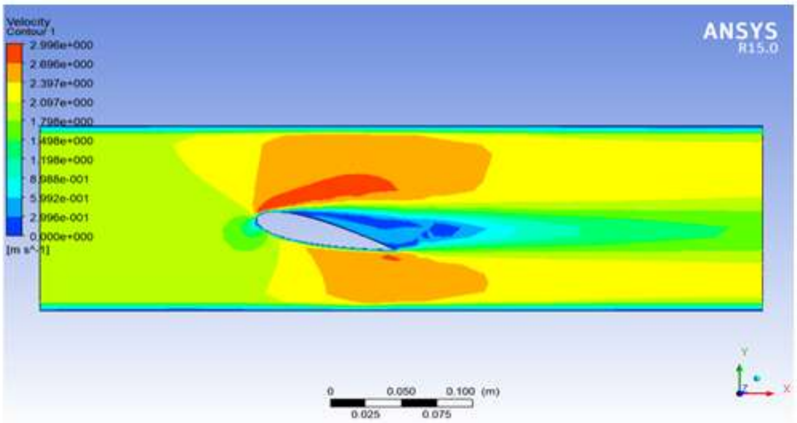

Fig.5- Velocity contour at 2 m/s

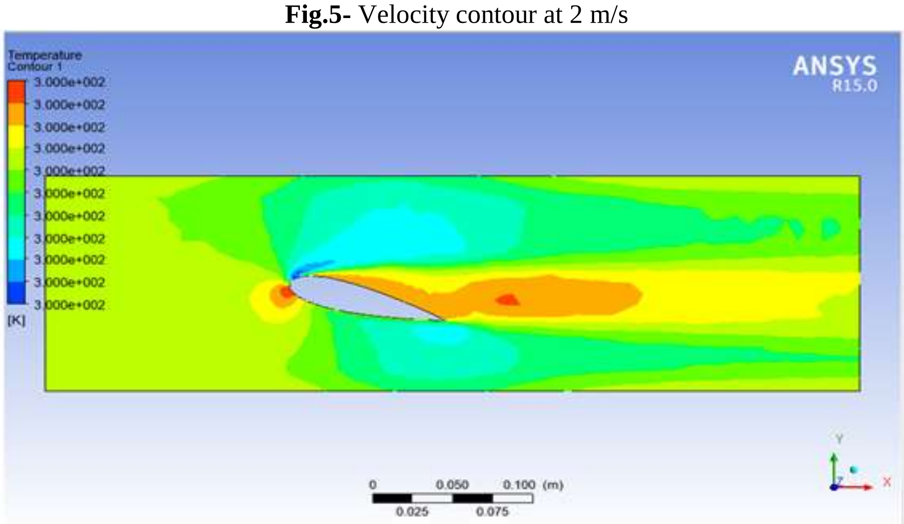

Fig.6- Temperature Contour at 2 m/s

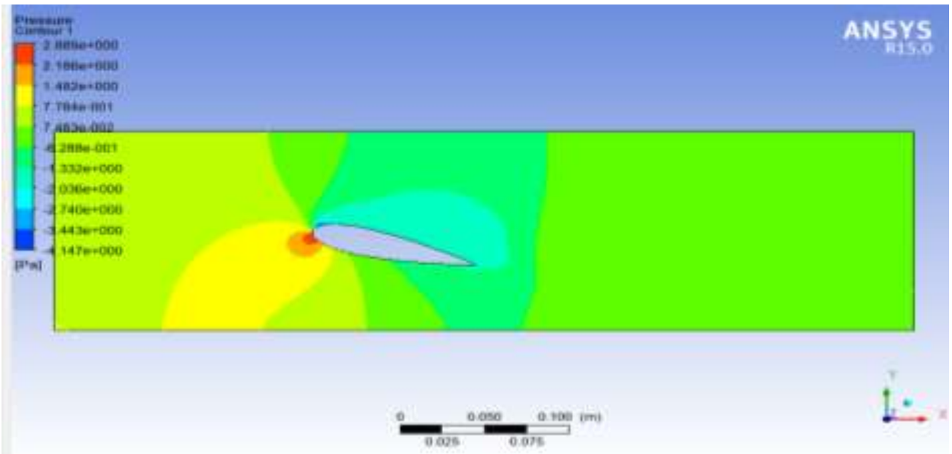

Fig.7- Pressure contour at 2 m/s

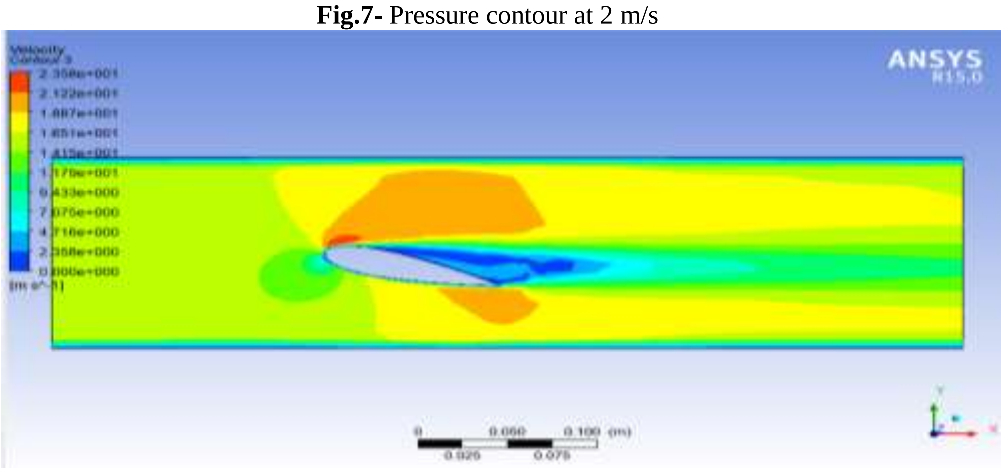

Fig.8- Velocity contour at 12 m/s

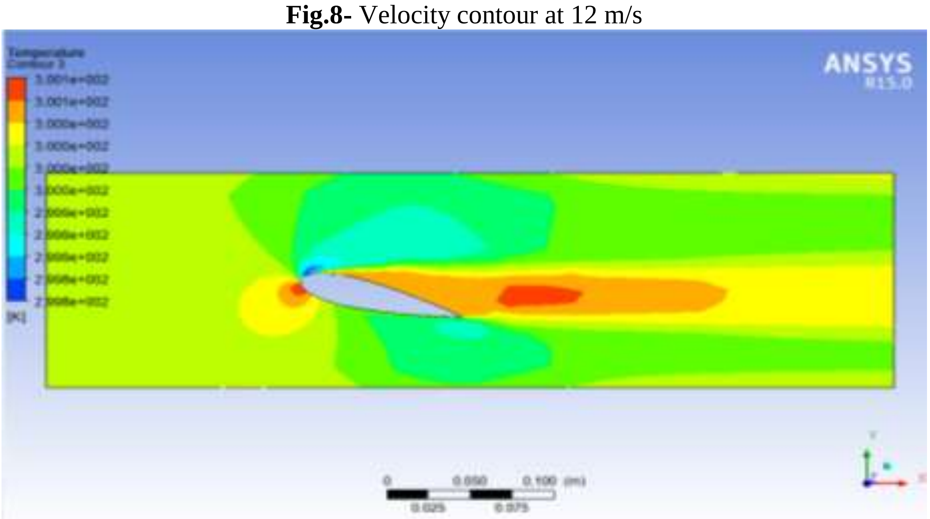

Fig.9- Temperature contour at 12 m/s

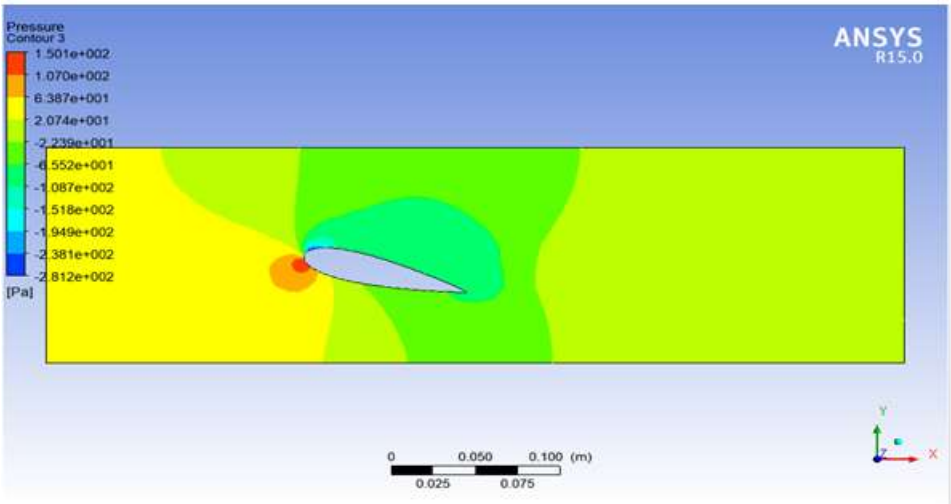

Fig.10- Pressure Contour at 12 m/s

VI. Conclusion

Performance of the combined turbine depends on numerous factors of both Savonius as well as Darrieus. Parameters such as overlap ratio, number of blades, tips speed ratio etc. decide the overall performance of the turbine. Simulation plays an integral part, 2D of the aerofoil selected as well as the turbine. 3D simulation helps study the turbine separately as well as combined.

Conflict of interest: The authors declare that there is no conflict of interests regarding the publication of this paper.

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