Application of Savonius Wind Turbine for Power Generation and its CFD Analysis.

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***Abstract*—**This paper indicates the importance of using non – conventional sources of energies. Use of Vertical Axis wind turbine on public places, where vehicles or trains pass fastly, roads or railway stations. As on roads, if such turbines are installed, they produce surplus energy with the vehicles passing from both sides. This energy generated can be used to further power appliances like emergency signs or speed meters, lights etc.

Keywords—Vertical axis wind turbine, Savonius wind turbine, power generation, non - conventional energy sources.

I. Literature Review

Research and optimization of Vertical Axis Wind Turbines (VAWTs) receive high attention because the Savonius turbine handles both low-wind and city conditions well. The field of Vertical Axis Wind Turbine development depends on investigators who implement experimental alongside computational approaches to advance aerodynamic features and structural strength as well as operational scope. A power performance analysis of Savonius wind turbines was executed through rotor wake flow analysis resulting in blade design optimization according to Kim and Im (2022). The researchers studied rotor overlap ratio together with blade curvature to examine their impact on downstream flow patterns and power coefficient performance which was published in Energies. The scientists discovered that how spacing wind turbines using rotors and setting blade positions results in increased energy production under turbulent environmental conditions typical of urban areas.

According to Mustaffa et al. (2015) a complete review explained the distinction between drag-type and lift-type VAWTs. The research showed Savonius outperformed Darrieus by being better at self-starting and possessing easier handling properties suitable for rural power generation and low wind speed areas. This classification system established basic guidelines for picking suitable VAWT designs based on wind patterns and installation restrictions.

Researchers at Driss et al. (2024) conducted an Ocean Engineering publication about novel helical Savonius rotor blade designs through experimental and numerical methods. Research conducted by Driss et al. (2024) showed that switching to optimized aerodynamically designed blade shapes from conventional semi-cylindrical blades led to better rotor performance because it decreased flow separation along with raising pressure differences throughout the entire rotor surface. Data from simulations along with test measurements strongly confirmed blade profile modification as an essential optimization technique according to their findings.

Hussain et al. (2012) conducted a detailed study which examined various VAWT configurations together with design approaches while emphasizing scalability aspects and efficiency level and material utilization. They emphasized that numerical simulations must integrate with experimental prototypes for developing multidimensional turbine configurations which would work across multiple terrain types and application sectors. The review sets the standard for exploring optimization techniques and rotor setup methods found in worldwide facilities.

The authors of Tan et al. (2023) suggested uniting CFD simulations with experimental testing to boost Savonius rotor performance. Their design implemented modern blade formation with flow concentrator housing components that produced significant enhancements in torque and power coefficient results. Research findings verify the possibility of using concentrators as architectural elements to boost the power output of wind turbines deployed in limited urban areas.

The aerodynamic behavior of a three-bladed Savonius turbine received investigation from Morshed and Rahman (2012) through both wind tunnel testing methods combined with numerical simulations. Results from the mentioned study validated the experimental findings by showing that turbine performance decreased while drag increased when blade count exceeded two. The research evidence shows that two-blade designs provide the most efficient combination of functionality with manufacturing feasibility.

Scheaua et al. performed a study which reviewed Savonius rotor metrics by examining torque rippling together with startup behaviors and tip speed ratios. Savonius turbines perform worse in efficiency than lift-based turbines but prove best suited for low-speed wind operations and off-the-grid installations because of their reliability and minimal upkeep demands.

Research into the Savonius turbine shows its ability to work well in low-speed wind settings as well as its basic design characteristics combined with suitability for urban environments. Multiple works within this field have acknowledged that finding optimal operation rates remains the main issue. The need for more efficient output performance from basic geometries leads us to develop a computational system that optimizes structures with and without concentrator applications.

II. Introduction

Nowadays, more sustainable energy technologies are required to replace conventional electricity generation resources such as fossil fuel, due to the worldwide demands especially in developed and developing countries. Fossil fuel-based energy sources are causing detrimental environmental issues such as global warming and climate change. The greenhouse gas emission into the atmosphere from power generation has increased exponentially in the past few decades. Renewable energy supplies 18% of the world's final energy consumption, counting traditional biomass, large hydropower, and ''new'' renewables.

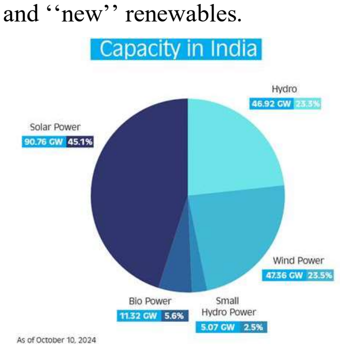


Fig. 1. (*Power sources distribution for India*)

Therefore, Renewable Energy (RE) technologies such as solar, wind, hydro, biomass, geothermal and hydrogen energies have been introduced to generate electricity to overcome current environmental crisis. Due to their environmentally friendly characteristics and ability to generate power with zero or almost nil emission of air pollutants, RE is getting more and more attention, due to the increasing awareness of clean environment among the society. RE not only helps in sustainability but also has economic importance. It benefits the economy by reducing the cost of electricity generation, as it generates energy using natural, renewable resources.

III. Wind Energy

A. *Horizontal Axis Wind Turbine*

Wind energy is the second major preference of renewable energy for electricity generation after hydro power due to its relatively simple/easy infrastructure, cost-effectiveness, and maturity of technology. Wind energy is converted into electricity by wind turbines-based power plants. There are two types: onshore wind farms, and offshore wind farms. Wind power plants can be classified based on axis type and the generator type that used in the wind turbines. Horizontal axis type, which is the most popular type of wind turbine. As shown in fig. 2 it consists of a support made from a steel or concrete pole, a yaw system that guides the wind turbine toward wind direction, which is connected between the nacelle (hub section of wind turbine) and the tower, a rotor with blades, a convertor, and gearboxes.

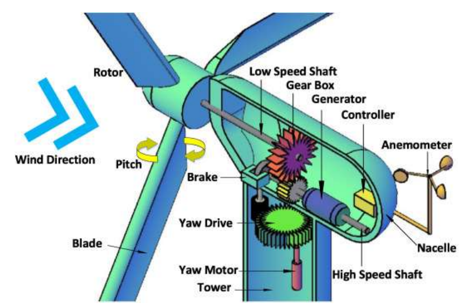


Fig. 2. (*Internal lstructure of HAWT.*)

Vertical axis wind turbine (VAWT) is characterized by its rotation axis that is perpendicular to the ground, and usually operates in urban application. VAWT is able to provide energy solutions for urban area and remote locations that are away from main distribution lines or the places where large scale of wind farm is not able to be implemented due to environmental concerns and only allow scattered generation units to operate. Researchers are exploring various new VAWT designs in order to enhance and improve their performance. The primary reason for this difference in efficiency is that the sliding surface of VAWTs provides an effective driving force for only slightly more than half of its total area. During the rotational cycle, the varying angle of attack for VAWTs results in flow detachment, dynamic stalling, and unequal force distribution on both sides of the rotor. Vertical-axis wind turbines (VAWTs) include both a drag-type configuration, such as the Savonius rotor, and a lift-type configuration, such as the Darrieus rotor. The simplest type of vertical-axis wind turbine is the Savonius rotor, the operation of which depends on the difference in drag force when the wind strikes either the convex or concave part of its semi-cylindrical blades. Savonius rotors are good at self-starting and work independently of wind direction. However, its efficiency is relatively lower than that of the lift-type VAWTs. Due to its simple design and low construction cost.

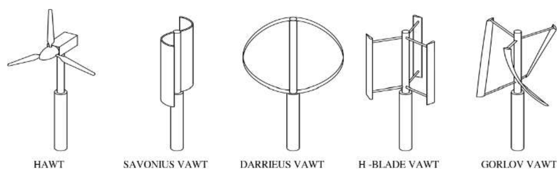


Fig. 3. (*Types of VAWT*)

B. Comparison of HAWT and VAWT

TABLE I. COMAPRISON BETWEEN HAWT AND VAWT

	HAWT	VAWT	RESULT
Torque	High	Higher	Both have value of torque suitable for electricity generation.
Expansion	Lower	Higher	VAWT have ability of expand more than the HAWT, because it is had low cost and easier to install than the HAWT.
Durability	Lower	Higher	The maintenance of the VAWT is easier and suitable for more working conditions.
Noise	Higher	Lower	VAWT is a quieter than the HAWT and it is suitable for working conditions within cities and over a wider range.
Driving force	Lift force	Both lift and drag according to the type	HAWT exploits the lifting force mainly in order to generate the momentum force to rotate the rotor. As for the VAWT, the drag force is the most exploited
Total mass	Higher	Lower	HAWT have a total mass higher than the VAWT, also the reasons are result of higher capacity.
Maintenance	Difficult and Higher cost	Easier and less cost	Maintenance is complicated in the HAWT due to highs above the ground.
Altitude	Higher	Lower	VAWT in general it has lower elevations than the earth's surface, compared with HAWT which is characterized by great heights.

C. Savonius wind turbine:

As discussed above, Savonius turbines have advantages, such as, easy to manufacture, operational ability in low-speed region and good self-starting capability. That's why Savonius turbine is widely utilized for wind energy purposes. The Savonius turbine, capable of generating power even in low wind-speed areas due to its lower rotor operating speed, has been considered as a reference geometry for developing user-friendly urban wind turbines.

IV. Boundary Conditions and Setup

A. Geometry:

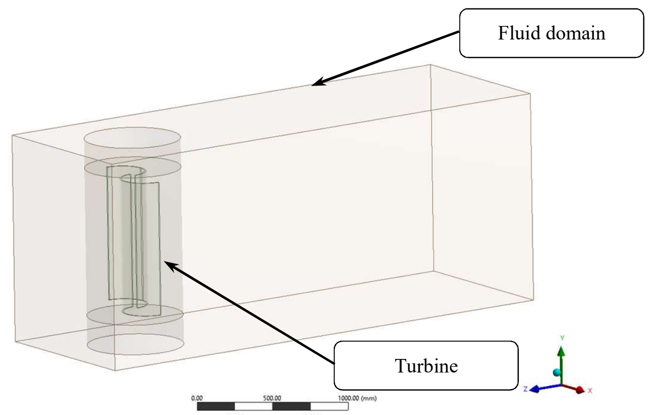


Fig. 4. (*Geometry taken for analysis.*)

Above shown is Savonius VAWT having 2 vanes. The solid model was designed using both SolidWorks and Ansys Design Modeler.

TABLE II. SETUP CONDITIONS

Sr. no.	Property	Description
1.	Overall diameter	600 mm
2.	Vane diameter	330 mm
3.	Height	700 mm
4.	Initial thickness	10 mm
5.	Fluid domain	3500 * 1000 * 1000 mm
6.	Dynamic mesh interface	Between the inner cylinder and outer box.

B. Mesh:

For meshing, tetrahedron and hexahedral elements are used of standard minimum size of 50 mm in region of turbine vanes. In region of fluid domain, the element size is being reduced to 150 mm for reducing the computation time.

In the region of vane faces, dense meshing is done by the function of inflation. The inflation is of total thickness type with number of layers: 10, growth rate: 1.2 and total thickness of 2 mm. The element size on vane face is of 20 mm.

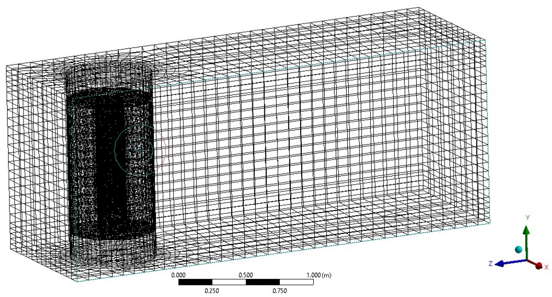


Fig. 5. (*Mesh of fluid domain and turbine.*)

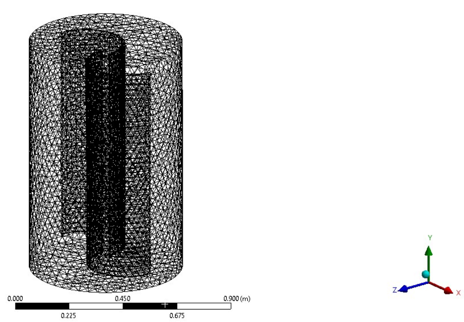


Fig. 6. (*Mesh of turbine.*)

TABLE III. MESH QUALITY PARAMETERS

Sr. No.	Parameter	Maximum value	Minimum value	Average value
01	Skewness	0.811	0.000015	0.23936
02	Aspect ratio	27.28	1.0349	3.7969
03	Orthogonal quality	0.99464	0.00354	0.7244

TABLE IV. MESH METRICS

Sr. No.	Parameter	Value
01	Type of mesh	Linear
02	Mesh element	Tetrahedron
03	Minimum element size	20 mm
04	Number of nodes	42151
05	Number of elements	1018039

C. Methodology:

To determine the pressure effects on the surface of the turbine vane at different wind speed and of different blade types. Also determined the turbine rotational speed, moment, force on turbine and calculated power on the basis of that. Following are the conditions applied to the model.

TABLE V. INTIAL PARAMETERS

Sr. No.	Property	Values / details
1.	Turbine type	Semicircular VAWT
2.	No. of vanes	02
3.	Fluid type	Air
4.	Density of fluid	1.225 kg/m^3
5.	Viscosity	1.7894 x 10^{-5}
6.	Fluid domain size	3500 * 1000 * 1000 mm
7.	Fluid free stream velocity	8 m/s and 19.5 m/s (worst case)
8.	Reynold's no.	1.274 * 10^6
9.	Analysis model	K – epsilon model

First, we took data from the fluent software after analysis. It provided plots of omega to timestep variation, max velocity to timestep variation, force in x direction to timestep variation, and rotational speed to timestep variation.

From that in excel sheet we calculated the power by the following formula:

$$P_{rotor} = T * \omega$$

Where, P = power
T = moment applied to turbine
ω = angular velocity

Also, we calculated theoretical power by the following formula:

$$P_{Available} = 0.5 * \rho A V^3$$

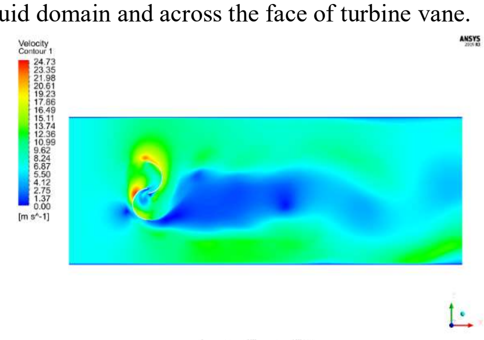
Where, ρ = density of air
A = frontal area
V = velocity of air.

From above available data, we calculated the power coefficient by following formula:

$$C_P = \frac{P_{rotor}}{P_{Available}}$$

D. Results:

Below image depicts the velocity variation in the fluid domain and across the face of turbine vane.



In above image, the turbine is rotating in clockwise directions. Behind the trailing edge, a low velocity zone is created and ahead of leading edge a high velocity zone is created.

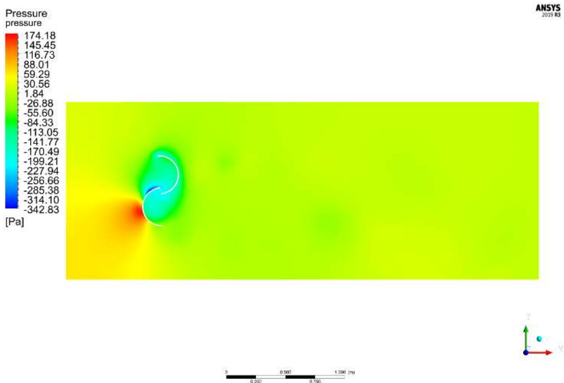


Fig. 7. (*Pressure distribution in 2 vane turbine.*)

For 2 vanes semicircular VAWT the power generated variation to time was as follows:

Fig. 8. (Power output and average power for 2 vane turbine.)

From above results, we can see that the average power produced is 587.897 W.

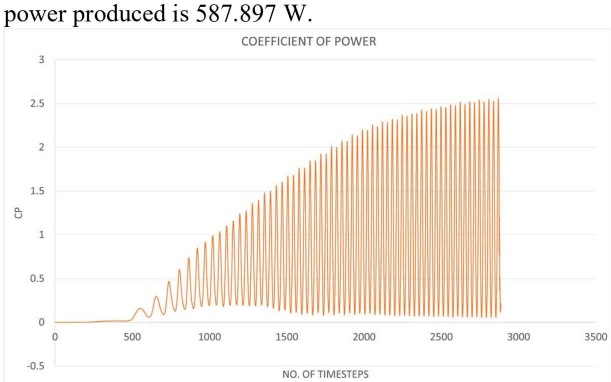


Fig. 9. (*coefficient of power variation for 2 vane configuration.*)

In same way from above graph, we can see that the average power coefficient produced is 0.30104. that means that the turbine is converting 0.30104.

E. Comparison of various blade types:

For comparing we have semicircular turbine vanes and increased the no. of vanes as variation. As shown below images, we analyzed for 2 vane, 3 vane and four vane configurations.

Also, we analyzed helix and straight VAWT. And helix turbine with concentrator

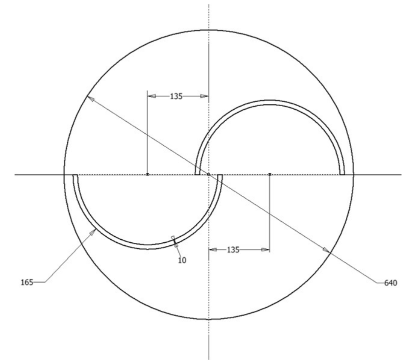


Fig. 10. (*Dimensions of 2 vane configuration.*)

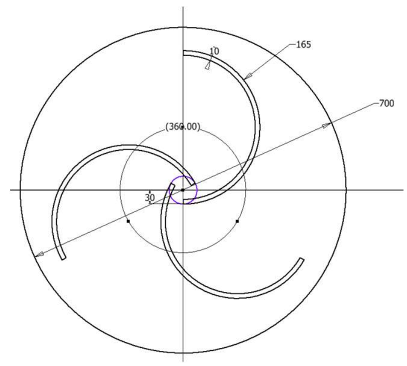


Fig. 11. (*Dimensions of 3 vane configuration.*)

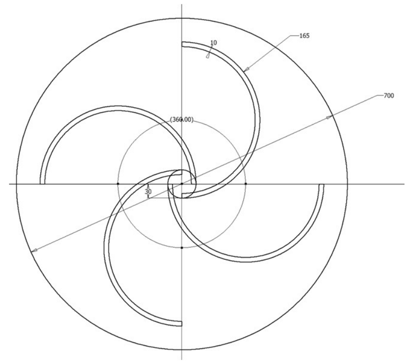


Fig. 12. (*Dimensions of 4 vane configuration.*)

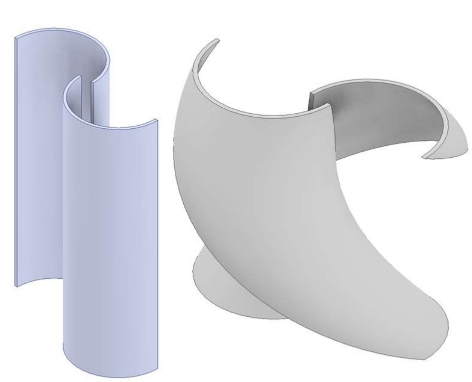
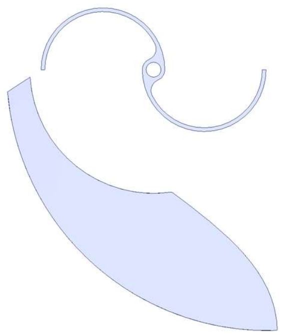


Fig. 13. (*3D model of straight and helix type 2 vane turbine.*)

F. *Concentrator Design:*

The concentrator is an accessory that is used to improve the turbine efficiency. The concentrator concentrates the flow of the coming air on to the turbine blade in such a way that the force on the blade increases, which results in more power generation.

Below, designed concentrator focusses on diverting the flow going on second part of the blade to one which is taking the drag effort.



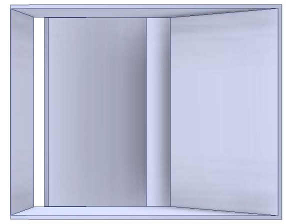


Fig. 14. (*3D model of 2 vane turbine with concentrator.*)

TABLE VI. COMPARISON OF DIFFERENT CONFIGURATION

Sr. no.	Type of rotor	Peak rotor power	Average power	Coefficient of power
01	2 vane config	402	146.8	0.30104
02	3 vane config	16.69	2.06	0.035
03	4 vane config	168.56	28.18	0.024
04	2 vanes with concentrator	740.3	602.3	0.3498
05	2 vane helix config	130.023	76.176	0.128

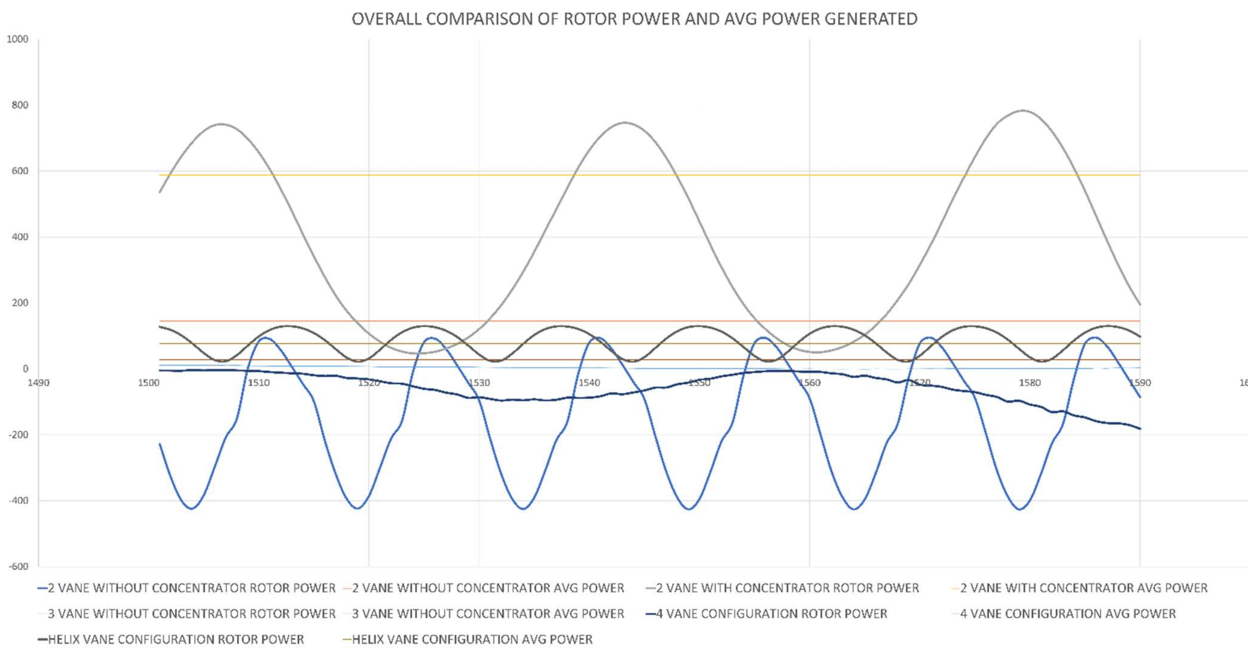


Fig. 15. (*Overall comparison of rotor power and avg. power generated.*)

From above graph we can conclude that the 2 vane configuration with concentrator gives the maximum efficiency or power. Then second is 2 vane configuration without concentrator and on third is helix turbine configuration.

Considering the manufacturing cost of all blades, the 2 vane configuration is easy and cheap to manufacture. The helix is more complex and costlier, though it produces more power than the 2 vane configuration, its return on investment is less.

V. OPTIMISATION OF HELIX TYPE TURBINE:

As discussed above the helix wind turbine gives good power but still its manufacturing cost is higher. So for reducing the cost following any methods can be adopted:

- Reduce material which will increase the efficiency.
- Material selection.
- Optimizing manufacturing method.
- Making in mass production.

For purpose of project we have changed the thickness and tried to optimised the helix type turbine.

A. Methodology:

We first did fluent analysis of the turbine, took that pressure data to static structural and analyzed the strength on the basis of deformation and Von – mises stresses. Initially the thickness was 10 mm; after analyzing we reduced it to 5 mm.

TABLE VII. INITIAL PARAMETERS FOR STATIC STRUCTURAL.

Sr. No.	Property	Values / details
1.	Turbine type	Helix type Semicircular VAWT
2.	No. of vanes	02
3.	Material	Aluminum and PLA
4.	Density of material	2270 kg/m^3
5.	Load data	Pressure data from fluent analysis.

B. Mesh and setup:

For meshing, tetrahedron and hexahedral elements are used of standard minimum size of 50 mm in region of turbine vanes. In region of fluid domain, the element size is being reduced to 150 mm for reducing the computation time.

In the region of vane faces, dense meshing is done by the function of inflation. The inflation is of total thickness type with number of layers: 10, growth rate: 1.2 and total thickness of 2 mm. The element size on vane face is of 20 mm.

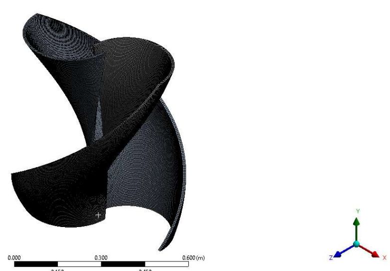


Fig. 16. (*Mesh for turbine vanes.*)

Below image shows that pressure imported from fluent.

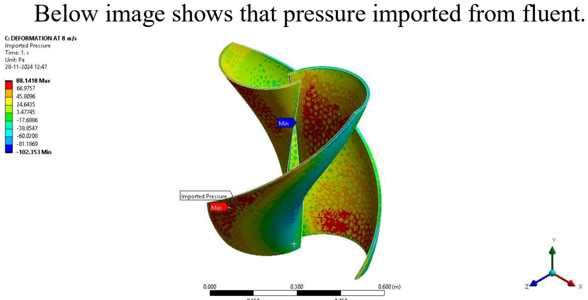


Fig. 17. (*Imported pressure data from Ansys Fluent at 10 mm.*)

C. Results:

After analyzing in static structural following results were obtained. The total deformation was 0.0013229 mm. and maximum Von – Mises stress was 0.41162 MPa.

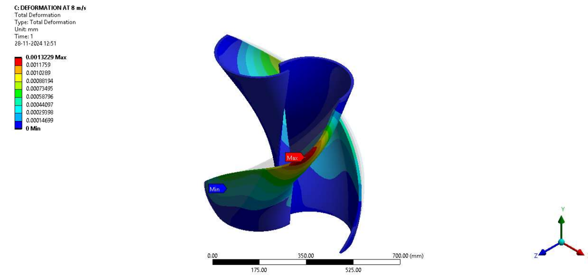


Fig. 18. (*Total deformation in case of above analysis.*)

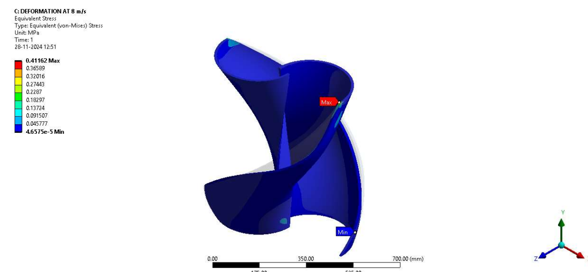


Fig. 19. (*von mises stress in case of above analysis.*)

As the induced stress is much lesser than the allowable stress, so thickness of the blade can be further reduced. After reducing the thickness to 5mm following results were obtained.

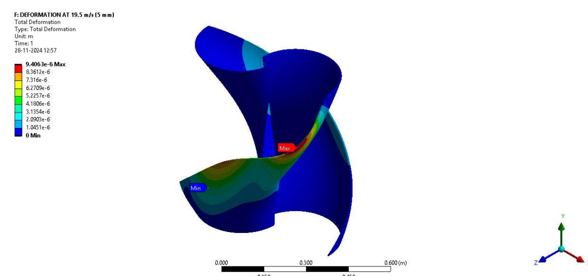


Fig. 20. (*Total deformation in case with thickness 5mm.*)

After analyzing in static structural following results were obtained. The total deformation was 0.00946 mm. and maximum Von – Mises stress was 1.7185 MPa.

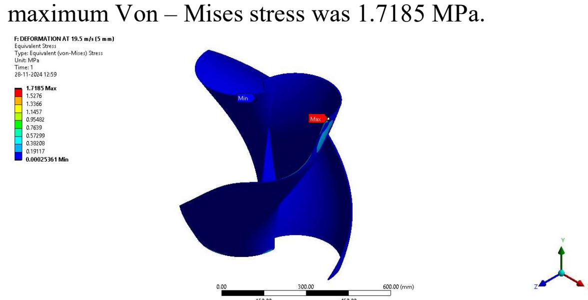


Fig. 21. (*Von - mises stresses in case with thickness 5mm.*)

The overall weight of the turbine was reduced by 10.369 kg. The overall optimisation was done on the base of strength basis.

VI. Future Scope

The energy demand is ever increasing, so the innovation in the field of the energy generation is desirable. In the field of VAWT there are many chances of innovation. Some future scopes are as follows:

- Material optimization.
- Change in blade type.
- Use of cheaper composite material.
- Using well designed concentrators.

VII. Conclusion

From project work, we calculated power output from different configuration. Out of which, semicircular 2 vane with concentrator configuration was most efficient and produces maximum power. But considering the manufacturing cost and feasibility, 2 vane configuration is optimum choice for assembling in public places like roads, railway stations etc.

The 2-vane configuration produced average power of 146.8 W.

Acknowledgment

After doing the project work, we have explored the importance of alternate power generation in today's world. For doing this project we used ANSYS and other designing software, which improved our software skills. For same, we would like to thank mechanical department and faculties for designing EDI course.

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