Design, Fabrication & Testing of VAWT w/ Wind Deflectors

Submitted in partial fulfillment of the requirements
of the degree of
Bachelors of Engineering
by

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CERTIFICATE

This is to certify that the project entitled **"Design, Fabrication & Testing of VAWT w/ Wind Deflectors"** is a bonafide work of **"Kondkari Shoaib Anwar"** submitted to the University of Mumbai in partial fulfillment of the requirement for the award of the degree of **"Bachelor of Engineering"** in **"Mechanical Engineering"**.

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Project Report Approval for B.E.

This Project report entitled ***“Design, Fabrication & Testing of VAWT w/ Wind Deflectors”*** by Kondkari Shoaib Anwar is approved for the degree of Bachelor of Mechanical Engineering.

Examiners

1.---

2.---

Guide

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Date:

Place:

Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Date:

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1 INTRODUCTION

1.1 Introduction to the project

Design, fabrication and testing of a Vertical Axis Wind Turbine (VAWT) with wind deflectors and solar panel will be the ongoing final year undergraduate project of us. Here main purpose will be enhancing the performance of the VAWT by designing guide vanes and fabricating with a low cost and get more shaft torque and rpm. And also it is supposed to be a portable wind turbine.

1.2 Importance of the project

Energy is a hot topic in the news today: increased consumption, increased cost, depleted natural resources, our dependence on foreign sources, and the impact on the environment and the danger of global warming, something has to change,

Wind energy has great potential to lessen our dependence on traditional resources like oil, gas and coal and to do it without as much damage to the environment. Alternative energy sources, also called renewable resources, deliver power with minimal impact on the environment. These sources are typically more green/clean than traditional methods such as oil or coal. In addition, alternative resources are inexhaustible.

These benefits, as well as data that suggest the drop-off of conventional oil drilling will overtake the output of new drilling by 2014 make renewable energy a viable source to pursue.

1.2.1 Wind Energy

According to the U.S. Department of Energy, wind has been the fastest growing source of electricity generation in the world through the 1990s.

With largely untapped wind energy resources throughout the country and declining wind energy costs. Sri Lanka is now moving forward into the 21st century with an aggressive initiative to accelerate the progress of wind technology and further reduce its costs, to create new jobs, and to improve environmental quality. Advantages of wind energy:

- Wind is free.
- No fossil fuels are used to generate electricity.
- Newer technologies make energy production much more efficient.
- Wind turbines take up less space than the average power station (a few square feet for the base). The turbines can be placed in remote locations, such as offshore, mountains, highways and deserts.

- When combined with other alternative energy sources, wind can provide a reliable supply of electricity.

So, we are planning to fabricate low cost Vertical Axis Wind Turbine with Wind deflectors and Solar Panel.

Mainly this project includes following sub processes

- Designing of Vertical Axis Wind Turbine
- Designing Wind deflectors
- Flow and efficiency analyzing
- Fabricating of this wind turbine and wind deflectors
- Testing the shaft torque and rpm.
- Analyzing bending moment, stresses of the completed structure

By doing this project we expected to achieve certain primary objectives as well as secondary objectives which are related to power generation in Sri Lanka. So the aim of the project is to optimize the efficiency of the wind turbine and create a wind turbine which can perform in any area.

This project will cover a vast area of the mechanical engineering field. After completing the project we will gain the knowledge about following areas

- Design of the machine elements
- Strength of materials
- Simulation software knowledge(ANSYS, Solid Works, CFD…etc)
- Fluid dynamics
- Energy Technology
- Ergonomics

Finally we hope this will be a good opportunity to apply the knowledge we gain from the degree program with a real application. Because it covers various fields in the mechanical engineering and it will be a huge challenge to meet the customer requirements as well.

2 LITERATURE REVIEW

Wind turbines operate on a simple principle. The energy in the wind turns two or three propeller-like blades around a rotor. The rotor is connected to the main shaft, which spins a generator to create electricity. A wind turbine used for charging batteries may be referred to as a wind charger.

The result of over a millennium of windmill development and modern engineering, today's wind turbines are manufactured in a wide range of vertical and horizontal axis types. The smallest turbines are used for applications such as battery charging for auxiliary power for boats or caravans or to power traffic warning signs. Slightly larger turbines can be used for making small contributions to a domestic power supply while selling unused power back to the utility supplier via the electrical grid. 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.

So how do wind turbines make electricity? Simply stated, a wind turbine works the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity.

Wind turbines are classified in to two groups. They are Vertical Axis Wind Turbine (VAWT) and Horizontal Axis Wind Turbine (HAWT). [3]

2.1 Horizontal-axis wind turbines (HAWT)

Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator.

Since a tower produces turbulence behind it, the turbine is usually positioned upwind of its supporting tower. Turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted forward into the wind a small amount.

The rotor, torque and speed characteristics can be controlled and optimized in modern HAWTs by changing pitch angle of rotor blades. It can be done by using mechanical or electronic blade pitch control system. This technique improves the performances of wind turbine while protecting turbine against extreme wind conditions and over speed.

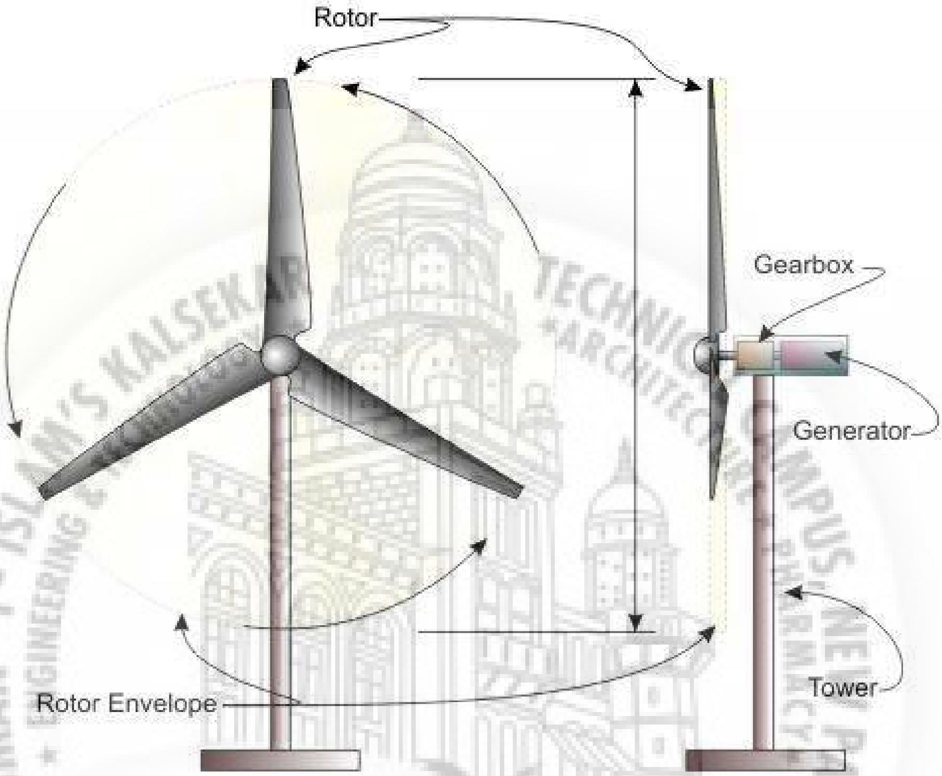


Fig. 2.1 shows the configuration of HAWT.

2.2 Vertical-axis wind turbines (VAWT)

Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically. One advantage of this arrangement is that the turbine does not need to be pointed into the wind to be effective, which is an advantage on a site where the wind direction is highly variable, for example when the turbine is integrated into a building. Also, the generator and gearbox can be placed near the ground, using a direct drive from the rotor assembly to the ground-based gearbox, improving accessibility for maintenance.

VAWTs offer a number of advantages over traditional horizontal-axis wind turbines (HAWTs). They can be packed closer together in wind farms, allowing more in a given space. They are quiet, Omni-directional, and they produce lower forces on the support structure. They do not require as much wind to generate power, thus allowing them to be closer to the ground where windspeed is lower. By being closer to the ground they are easily maintained and can be installed on chimneys and similar tall structures. [4]

Fig. 2.2 shows the configuration of VAWT.

The most popular types of VAWT are: Darrieus Wind Turbine and Savonius Wind Turbine.

2.2.1 Darrieus Wind Turbine

Darrieus Wind Turbine are commonly known as an “Eggbeater” turbine. It was invented by Georges Darrieus in 1931. A Darrieus is a high speed, low torque machine suitable for generating alternating current (AC) electricity. Darrieus generally require manual push therefore some external power source to start turning as the starting torque is very low. Darrieus has two vertically oriented blades revolving around a vertical shaft.

2.2.2 Savonius Wind Turbine

Savonius vertical-axis wind turbine is a slow rotating, high torque machine with two or more scoops and are used in high-reliability low-efficiency power turbines.Most wind turbines use lift generated by airfoil-shaped blades to drive a rotor, the Savonius uses drag and therefore cannot rotate faster than the approaching wind speed.

So, our task is to be increase the efficiency of the Savonius Vertical axis wind tubine with wind deflectors.

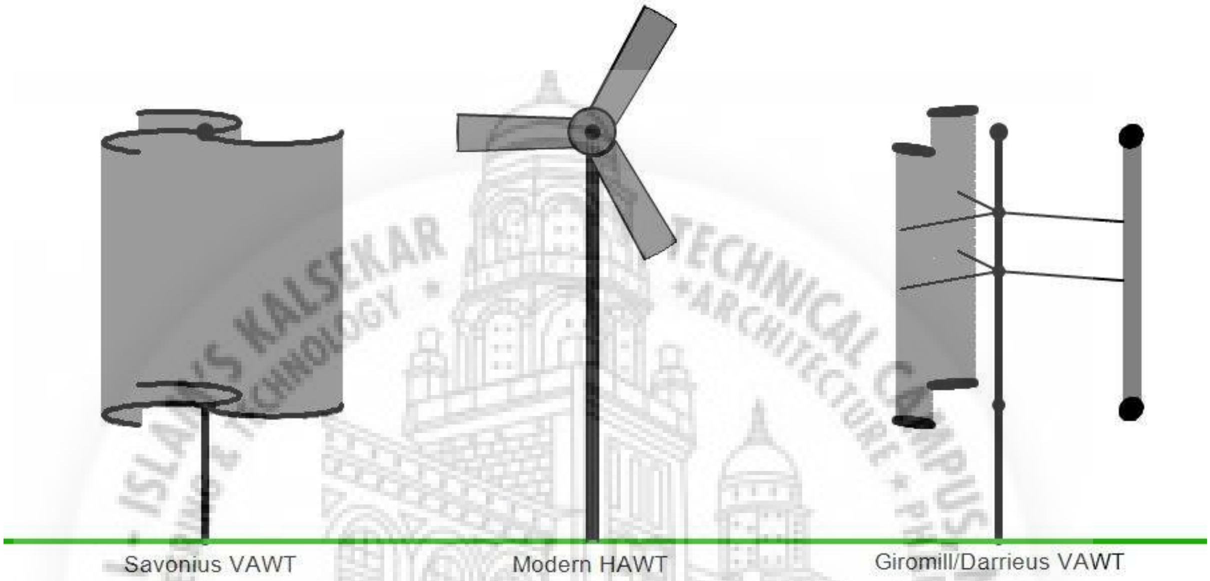


Figure 2.2.2 Horizontal Axis Wind Turbine Vs Vertical Axis Wind Turbine

2.3 Previous researches done

Lot of researches has done for increasing efficiency of the Vertical Axis Wind Turbine. They have developed basic wind turbines, and discover significant parameters that directly involve to changing performances of turbines. Some of them are blade solidity, lift force, drag force and angle of attack. And also they introduce system integration with a wind deflector.

The starting torque and power coefficients characteristics of Horizontal axis wind turbines (HAWT) are higher than the vertical axis wind turbines (VAWT). Because of this reason commercial wind power market fills with HAWT. Anyhow, small vertical axis wind turbines are more appropriate to urban environments because the reduced risk associated with their slower rate of rotation and the lower noise pollution compare to their horizontal axis Wind turbine.

In research, a deflector system which can guide the wind towards the vertical axis wind turbine blades has been introduced to increase the power coefficient, and tested with CFD.

They designed vertical axis wind turbine along with a wind deflector system and simulations were done with computational fluid dynamics (CFD) software which may be more reliable than the analytical or semi – empirical models adopted with simplifying assumptions. Then the starting performances and the power performances were analyzed. [1]

They took following results for the coefficient of performance (Cp) and tip speed ratio (λ) regarding performances in simulations

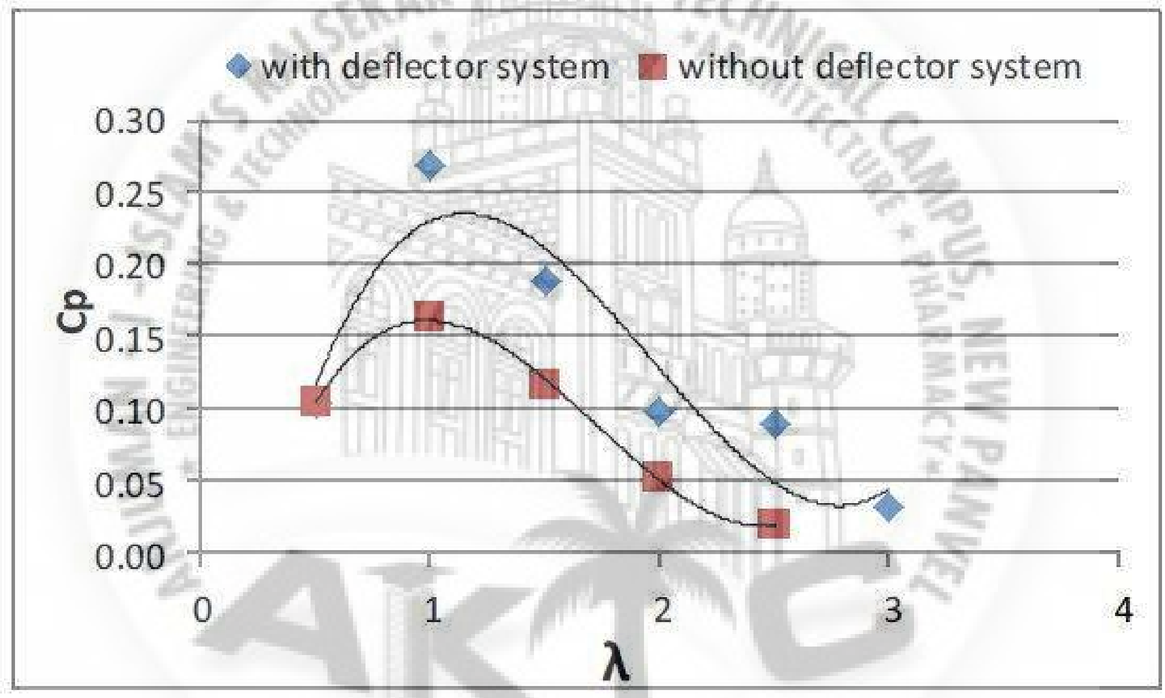


Figure 2-4 Power coefficient variation of the turbine

Furthermore, So many researchers have done with considering blade profile. The modern VAWTs occupied blades that developed by NACA which has ability to self-start. However, researchers are involved to modify common VAWT and increase its efficiency.

3 PROCEDURE OF THE PROJECT

3.1 Literature Review

Information of the Wind turbines and deflectors were collected and we selected vertical axis wind turbine for our project. Because of that, they can be packed closer together in wind farms, allowing more in a given space, they are quiet in operation, they produce lower forces on the support structure and especially they do not require as much wind to generate power. There are two types of Vertical Axis Wind Turbine. They are,

- Darrieus Wind Turbine
- Savonius Wind Turbine

There are lots of thing to explore about the wind turbines. We will do as much as possible.

3.2 Proposal

After the Literature review, we prepared project proposal to guide the others about the project. Project proposal was contained introduction as well as the procedure and the budget.

3.3 Flow and efficiency analyzing

There so many types of software to analyze the profile of wind turbines and to virtually simulate the behavior of flow patterns and other important parameters. Wind PRO, Wind Farm, Gambit and Fluent, Wind Farmer, Open Wind and Wind Sim are some of them. In this project CFD analyzing did with the commercial software ANSYS and Fluent.

3.4 Design of the Wind turbine

In this project, the wind deflectors are very important for achieving the goals of our project as well as for increasing the performance of the wind turbine. Designed system can be divided to the several design parts because we expect to design the system step by step.

- Design of the guide vanes

  We used Fluent software to analyze flow patterns and get most efficient angular positions. We are planning to rip the barrel for 3 parts to make 4 guide vanes.
- Design of the wind deflectors

Wind deflectors play major role of this system. Because of that Vertical Axis Wind Turbine has low efficiency than Horizontal Axis Wind Turbine. So, our task is to be improving the performance of the VAWT. We used CFD to analyze flow patterns.

- Design of the Tripod

  We used Solid works software to design of this tripod. Tripod is one of the main part of this turbine. It should bear complete structure. So, it is need to be withstanding for variable torque and stresses of the system.

3.5 Call quotations

We called quotations from different places to get necessary equipments for the project. That places were Rajasthani Aluminium, Janta metals, DC Motors, JM engineering co. Final quotation list is shown in the below figure.

Name	Description	Quantity	Costing
Pulley-A	V-belt, ID-25mm, OD-5”.	1	450
Bearing	ID-25mm, OD-50mm.	2	1250
Bolts	3/8”, half threaded.	6	200
MS Main shaft	OD-25mm, 5’.	1	6000
Tripod Stand Angle	4’	3	450
MS Strips	40’	15	1500
Vice Head	ID-25mm, OD-28mm	2	100
Aluminium blades	50*90cm,0.4mm thick	3	1000
Circular Plates	ID-25mm, OD-120mm.	2	400
MS Shafting Pipe	ID-25mm, OD-60mm, 1’	1	7000
Coupling	OD-30mm ,2”	2	500
Deflector	55*95cm	2	500
			Total=19350

Figure 3-1 Final quotation list

3.6 Fabrication

After designing we were thinking about the fabrication of the wind turbine which will take more time from the time plan. In fabrication steps material was selected & doing welding, fixing, fasting, bending of sheet metals etc…The fabrications were done withiN the resources of the Mechanical department workshop. In addition if there is any process can't be achieved in the workshop they would be outsourced.

3.7 Performance testing

Its performance can be checked by using wind tunnel and also in the site after the fabrications. In this section we are planning to measure shaft torque, rpm…etc. By using that we calculate shaft power.

3.8 Improvement

After doing the performing testing, we are planning to do some improvements if it is possible. We will continue these improvements so that meet necessary condition. Because increasing the performance of the vertical axis wind turbine is the main goal of the project.

3.9 Performance analysis

At finally the performance will be analyzed to show the achievement of the project.

We have shown that performance after the improvement of Vertical Axis Wind Turbine has been increased than existing one. Performance analysis has to be done using fluent software and calculating output power.

Solid works model of the completed design structure are shown in the below figure.

4 CFD (Computational Fluid Dynamics)

In order to develop this project the calculations were done with CFD, which is one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyze. This software gives the power to simulate flows, heat and mass transfer, moving bodies, etc., through computer modeling.

In order to obtain an approximate solution numerically, a discretization method have to be used to approximate the differential equations by a system of algebraic equations, which can later be solved with the help of a computer. The approximations are applied to small domains in time and/or space. The accuracy of numerical solutions depends on the quality of the discretization used as much as the accuracy of experimental data depends on the quality of the tools used.

It is important to bear in mind that numerical results are always approximate because there are reasons for differences between computed results and reality like:

- The differential equations might contain approximations or idealizations.
- The approximations made in the discretization process.
- Iterative methods are used in solving the discretizated equations. So, unless they are run for a very long time, the exact solution of the discretizated equations is not produced.

Discretization errors can be reduced by using more accurate interpolation or approximations or by applying the approximations to smaller regions, but this usually increases the time and cost of obtaining the solution.

Compromise is needed in solving the discretized equations. Direct solvers, which obtain accurate solutions, are not very much used because they are too expensive. Otherwise iterative methods are more common but the errors produced by stopping the iteration process too soon need to be taken into account.

4.1 Fluent package for CFD simulation

Fluent is a package of simulation computational fluid dynamics (CFD) and the most used in the world, with a background of more than 25 years of development carried out by Fluent Inc. who are certified under the international standards of ISO 9001.

4.2 ANSYS software

ANSYS offers a comprehensive software suite that spans the entire range of physics, providing access to virtually any field of engineering simulation that a design process requires. Organizations around the world trust ANSYS to deliver the best value for their engineering simulation software investment.

Simulation-Driven Product Development takes engineering simulation to another level — the unequalled depth and breadth of our software coupled with its unmatched engineered scalability, comprehensive multiphysics foundation and adaptive architecture set our technology apart from other CAE tools. These ANSYS Advantages add value to the engineering design process by delivering efficiency, driving innovation and reducing physical constraints, enabling simulated tests that might not be possible otherwise

We used ANSYS software for mesh generation of the 2D drawn model by using solid works.

4.3 Working procedure in ANSYS for mesh generation.

Fluent problems can be solved by using two different ways such as 2D model and 3D model. In a case of 2D model it's intrinsically assumed as there are no velocity gradients in the direction normal to the grid. In 2D models ANSYS consume less memory and take less time to solve problems.

ANSYS software was used to create 2D mesh for solving fluid problem on ANSYS fluent interface. At the beginning, it is required to draw object that want to solve fluid problem in solid works as 2D drawing. The solid works drawing can be export to ANSYS as a STEP file.

We can summarize the ANSYS mesh generation procedure like below.

- Sketch 2D drawing by using solid works.

  In here, we first draw the rotating region. Then that part saves as a STEP AP203 file. After that we draw the boundary layer. That part also saves as a STEP AP203 file.

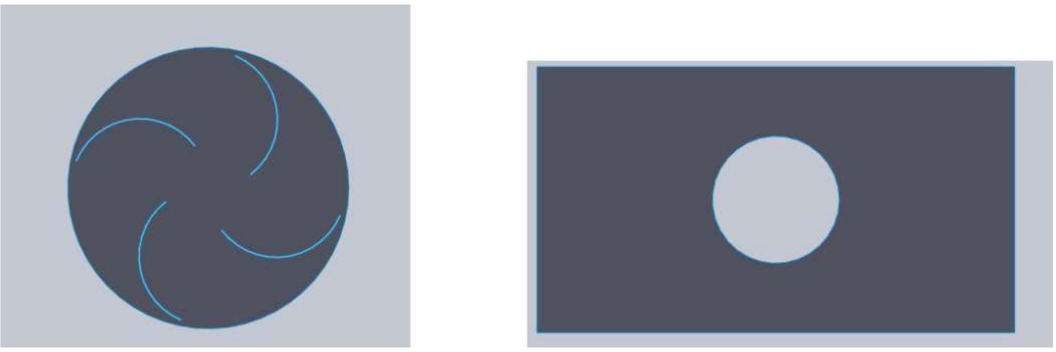


Figure 4-1 Solid works 2D drawing of rotating region and boundary layer respectively

- That STEP files import to ANSYS.
- Define working area

It was basic requirement of ANSYS to define working area and interfaces that used to solve problem. Four interfaces have defined as required to rotate wind turbine. Defined working areas are shown in the below figure.

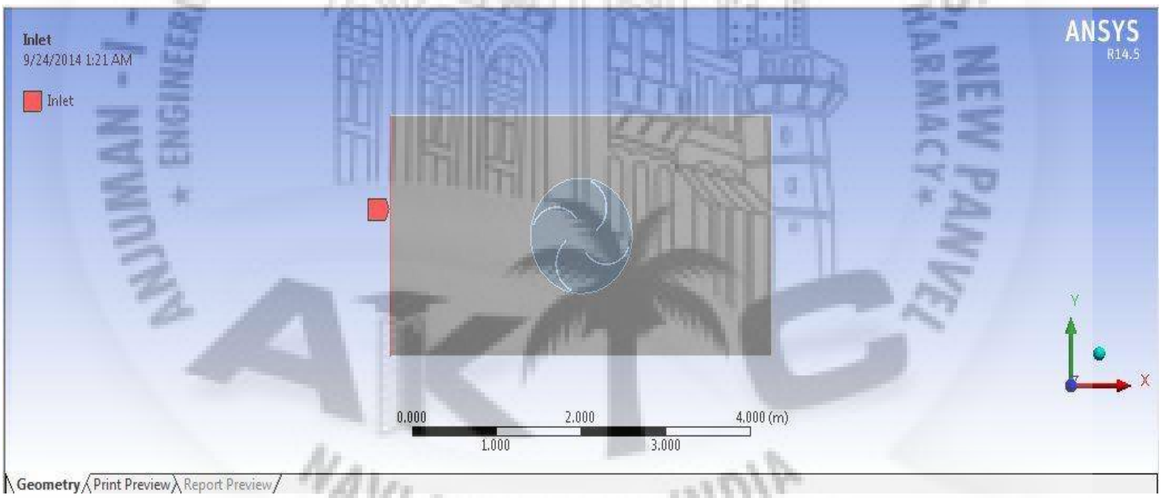


Figure 4-2 Defined working area

- Create Mesh sizing

In mesh sizing, we used high smoothing, fine span angle center. We used 0.005 m minimum face size and 0.05m maximum face size. Capture of that part of the software is shown in the below figure.

- Finally, mesh file exports as a Fluent input file.

In here we used different names for each turbine blades amount. Then we can compare each other. Final mesh file is shown in the below figure.

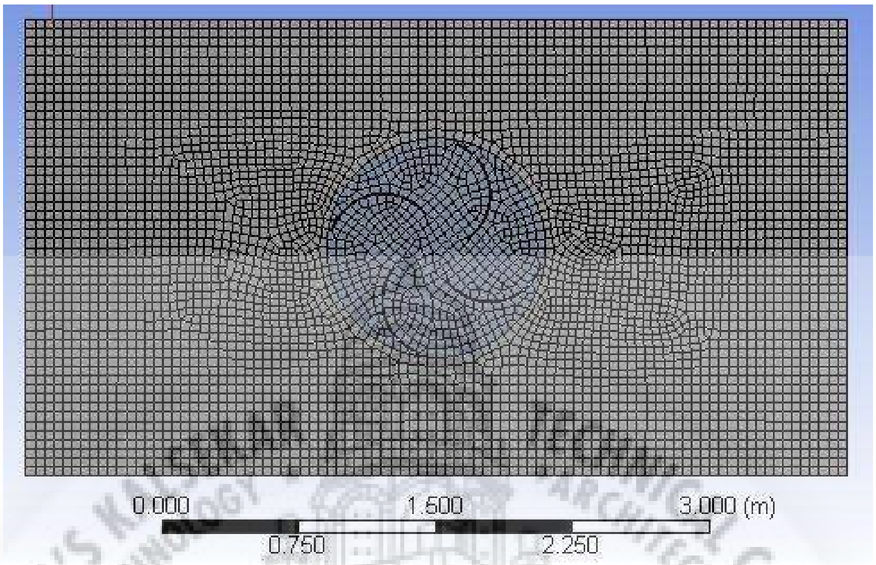


Figure 4-3 Final Mesh file

4.4 Working procedure in Fluent

After the mesh has been exported to Fluent, there are few last parameters to be set before running the simulation. First of all it is necessary to Grid all the interfaces defined in ANSYS and then the grid has to be checked and scaled in order to make sure the mesh was well built.

- Defining solver

  Here we used pressure based type, Absolute velocity formulation, planer 2D space and studied transient time base.

- Defining models

  Here, we used K-epsilon viscous model for analyzing turbulent flow.

- Defining materials

  We used air as a working material

- Defining cell zone condition.

In this section we had to define boundary layer type and rotating region type. We used fluid for boundary layer and rotating region. Specially, when defining boundary layer we should give mesh motion rpm value. We gave 150 rpm.

- Defining boundary condition

In this section, we should define inlet and outlet boundary condition.

- Creating mesh interface

Noted that: It is important in the process of analysis of the 2D models to take into account that in the reference values. It can be seen in the below figure, the table of the reference values which is used in the analysis of the 2D models. Before running the analysis the model has to be initialized from the boundary condition inlet. The preferred results in Fluent are drag coefficient, lift coefficient and moment coefficient.

- Defining time step and number of time steps
- Finally, compare the results to get higher necessary conditions.

4.5 Selecting the best turbine blades quantity

We used fluent simulated data for selecting the best wind turbine blades quantity in this section. We checked 2 to 6 turbine blades with respect to air velocity 1ms^{-1} – 10ms$^{-1.}$ We found that, 3 turbine blades are more efficient than others. Here we used constant 60 rpm value for the various wind speeds.

By using simulated data, we can draw the graphs. By using that graphs, we can simply identify which turbine blades are more suitable than others.

4.6 Finding the optimum turbine blades angel

We used fluent simulated data for selecting the optimum turbine blades angle. We checked 13cm to 21 cm distance from center to edge of the turbine blades with respect to air velocity 1ms^{-1} – 10ms$^{-1.}$ We found that 16cm is the optimum solution. Average air velocity is 3 ms^{-1} – 5 ms^{-1} in Sri Lanka. According to the graph, we could see high moment acting on the turbine blades when 16 cm distance from the center to edge of the turbine blades when 3 ms^{-1} – 5 ms^{-1} . So, we used that value.

Table No 01: simulated force data when 3 wings of the wind turbine with150 rpm rotation (with blade edge distance from center)

Velocity	13cm	14cm	15 cm	16 cm	17cm	18cm	19cm	20cm	21cm
1	19.298042	15.615556	19.056822	15.786231	9.8583	5.7504737	8.6974085	2.6798253	-2.745097
2	13.284116	11.193868	14.422746	12.627229	9.4065	7.8729775	10.601583	7.1729685	-13.78194
3	14.042429	16.017717	17.452255	23.483927	30.103419	34.02548	41.107696	42.451064	12.73720
4	5.0222805	1.626173	-0.611891	4.2204722	-8.5426502	-8.820274	-2.76267	-6.87426	38.4672
5	7.7016369	-6.358112	-17.56662	-18.86783	-18.601767	-20.03762	-23.20925	-11.29168	-13.8316
6	-0.097183	9.2055971	9.5088507	-23.49221	45.092758	26.838462	3.8704163	21.44697	74.85126
7	46.296378	36.560314	27.137192	54.066954	40.170322	39.132048	55.772907	39.31975	118.1737
8	103.42511	88.166881	86.468772	105.63139	105.9903	115.72242	105.46915	115.10684	114.7912
9	89.817587	94.516349	89.576825	93.113137	98.59206	95.799844	113.05522	91.804228	108.6927
10	129.25903	131.70681	123.61401	143.10385	169.56067	165.82116	165.49356	164.63208	182.3135

Table No 02: simulated force coefficient data when 3 wings of the wind turbine with 150 rpm rotation (with blade edge distance from center)

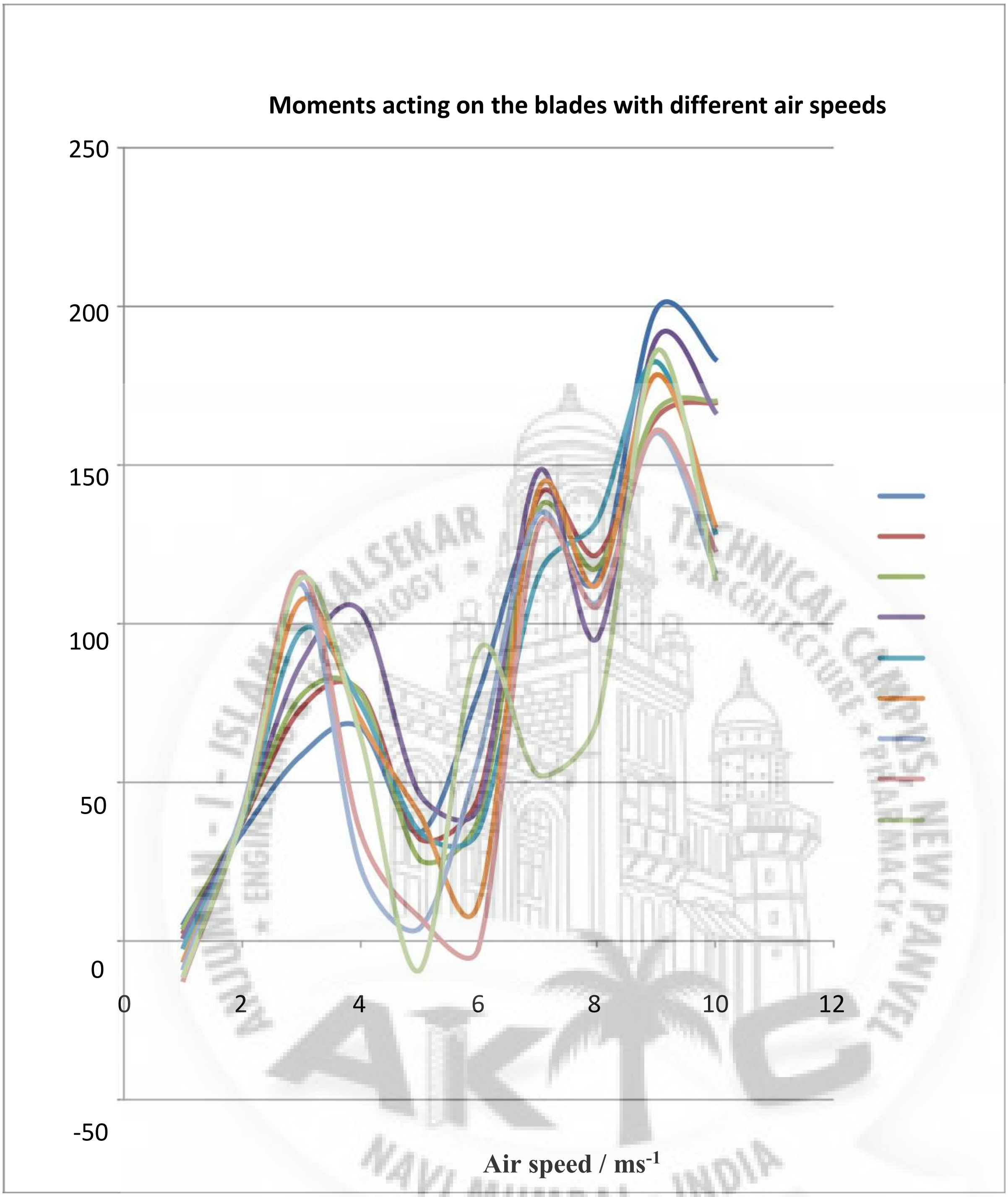
Velocity	13cm	14cm	15 cm	16 cm	17cm	18cm	19cm	20cm	21cm
1	31.507007	25.494786	31.11317	25.773439	16.0952	9.3885284	14.199851	4.3752249	-4.4817918
2	21.688353	18.275703	23.54734	20.615885	15.3576	12.853841	17.308707	11.710969	-22.501125
3	22.926415	26.151375	28.49347	38.341106	49.14844	55.551807	67.114605	69.30786	20.795434
4	8.1996416	2.6549764	-0.99901	6.8905669	-13.947184	-14.400447	-4.5104825	-11.223286	62.803692
5	12.574101	-10.380591	-28.6802	-30.804616	-30.370231	-32.714491	-37.892659	-18.435394	-22.582222
6	-0.1586666	15.029546	15.52465	-38.354625	73.620829	43.817896	6.319047	35.015459	122.20614
7	75.585924	59.690309	44.30562	88.272579	65.5842	63.889057	91.057807	64.195512	192.93669
8	168.85732	143.94593	141.1735	172.45941	173.04538	188.93456	172.19453	187.92953	187.41423
9	146.64096	154.31241	146.2478	152.02145	160.96663	156.40791	184.57996	149.88445	177.45749
10	211.03515	215.03153	201.8188	233.63894	276.83375	270.72842	270.19358	268.78707	297.65469

Table No 03: simulated moment data when 3 wings of the wind turbine with 150 rpm rotation (with blade edge distance from center)

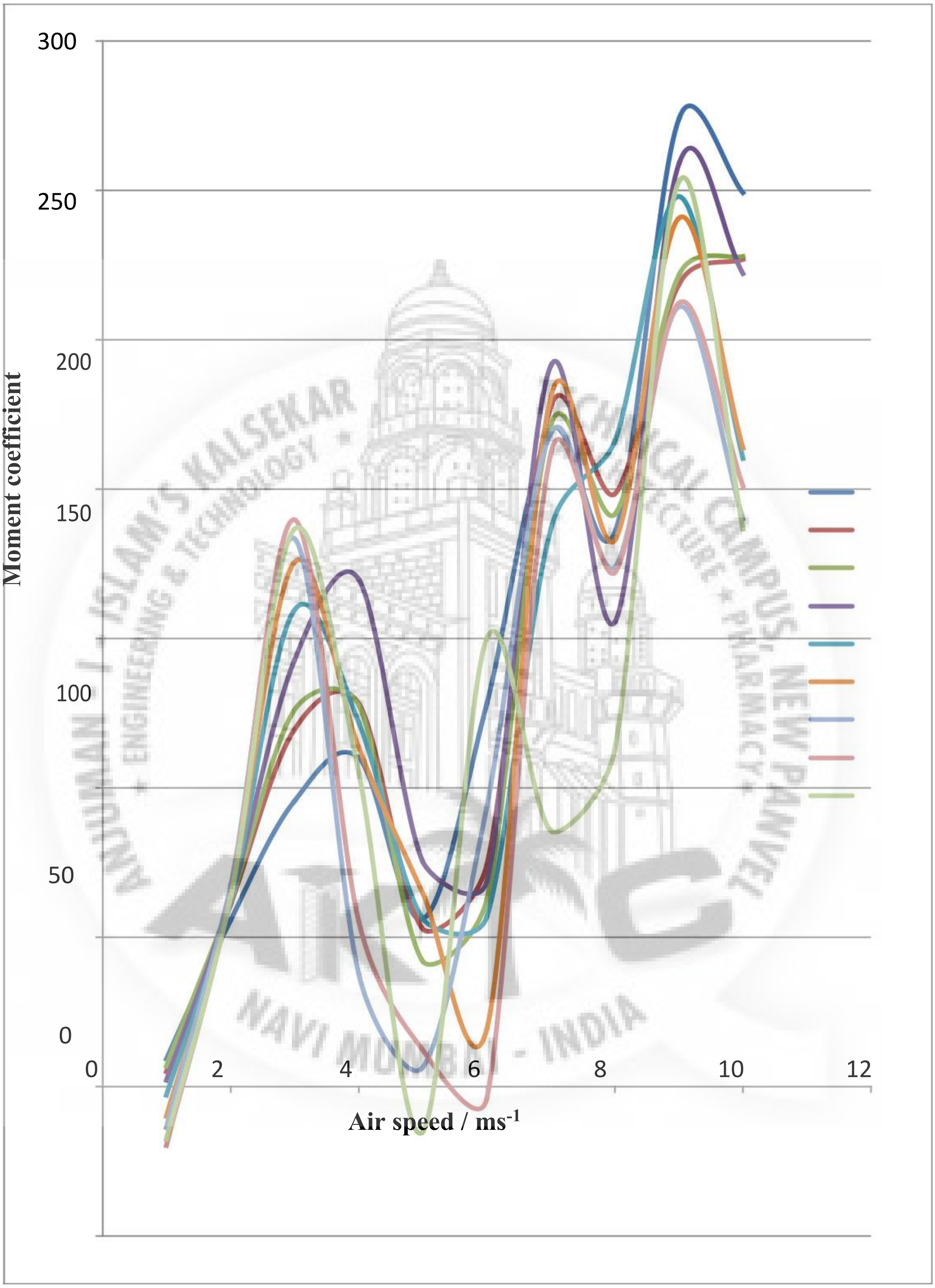
Velocity	13cm	14cm	15 cm	16 cm	17cm	18cm	19cm	20cm	21cm
1	5.5613583	2.9512427	4.186892	1.2413327	-1.74768	-6.1337525	-8.3824666	-12.157237	-10.843758
2	34.06360	37.399511	38.02234	38.431655	38.10267	39.287343	41.303703	39.484504	39.023165
3	58.525503	73.189461	77.12459	87.428808	97.730192	107.48706	112.32845	116.1732	114.32403
4	67.299992	78.497956	78.08676	103.93607	74.66546	69.45430	23.031142	33.792621	64.301957
5	34.238308	32.401538	25.73518	46.300307	34.496791	39.832579	3.8778239	7.4680373	-9.3788821
6	78.424539	45.367896	38.31165	42.077784	34.703499	11.725835	57.276529	-2.4649997	91.854245
7	134.46226	139.6278	135.8200	147.90189	114.54822	141.76245	134.08982	130.01953	52.323021
8	113.65132	121.59806	117.385	95.182017	132.32112	112.05083	106.57113	105.37564	69.104351
9	198.67859	164.55539	166.5547	189.42354	182.50385	178.15325	159.92875	160.79218	185.72069
10	183.21564	169.50307	170.1668	166.73553	128.75342	130.93651	116.35463	123.16709	114.1982

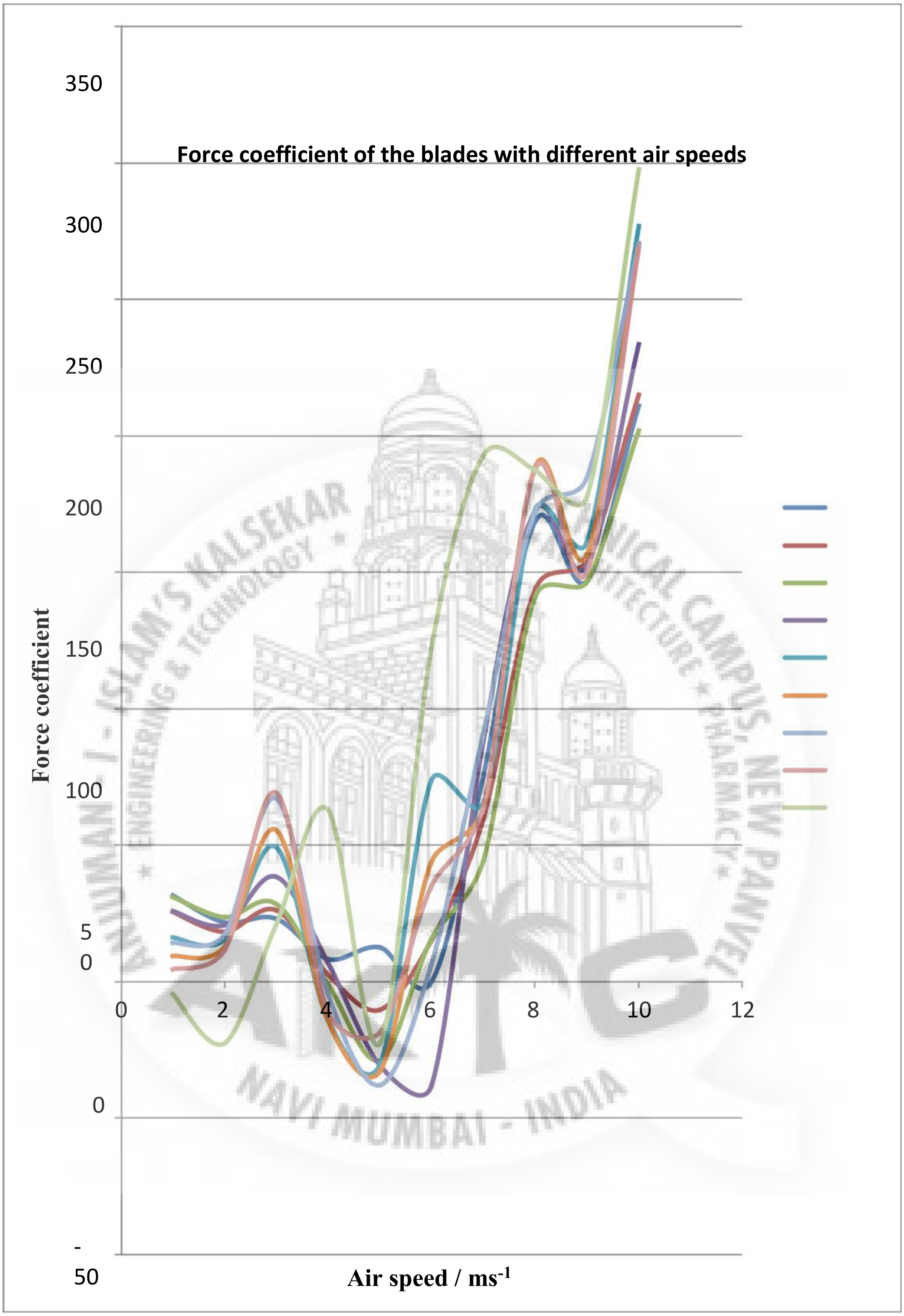
Table No 04: simulated moment coefficient data when 3 wings of the wind turbine with 150 rpm rotation (with blade edge distance from center)

Velocity	13cm	14cm	15 cm	16 cm	17cm	18cm	19cm	20cm	21cm
1	9.0797686	4.8183554	6.8357423	2.0266656	-2.85335	-10.01429	-13.68566	-19.84855	-17.704094
2	55.614052	61.060426	62.077293	62.74556	62.2084	64.142601	67.434617	64.464497	63.71129
3	95.551841	119.493	125.9177	142.74091	159.5595	175.48908	183.39339	189.67053	186.65147
4	109.87754	128.15993	127.48859	169.69154	121.90279	113.39479	37.601865	55.171625	104.98279
5	55.899278	52.900469	42.01662	75.592338	56.321291	65.032782	6.3311411	12.192714	-15.312461
6	128.04006	74.070034	62.549633	68.698422	56.658773	19.14422	93.5127	-4.0244894	149.96611
7	219.53021	227.96375	221.74701	241.47247	187.0175	231.44889	218.92215	212.27679	85.42534
8	185.55317	198.52745	191.64955	155.39921	216.03448	182.94012	173.99368	172.04187	112.82343
9	324.3732	268.66187	271.92607	309.26292	297.96548	290.86244	261.10816	262.51784	303.21745
10	299.12757	276.73971	277.8234	272.22128	210.20966	213.7739	189.96675	201.08912	186.44604


Moments acting on the blades with different air speeds
250
200
150
100
50
0
-50
0
2
4
6
8
10
12
Air speed / ms-1

Moment coefficient of the blades with different air speeds




Force coefficient of the blades with different air speeds
Force coefficient
Air speed / ms^{-1}
350
300
250
200
150
100
5
0
0
-
50
0
2
4
6
8
10
12

5 DESIGN AND OPTIMIZATION PROCEDURE OF THE WIND DEFLECTORS

Here in this project, optimization and development of deflectors were done in a sequence according to the methodology. Actually here the expectation is further increase of the power coefficient values of the turbine by introducing deflector. Here the expectation is to enhance the effect of torque on the turbine shaft by effective projection of the wind towards the rotational blades

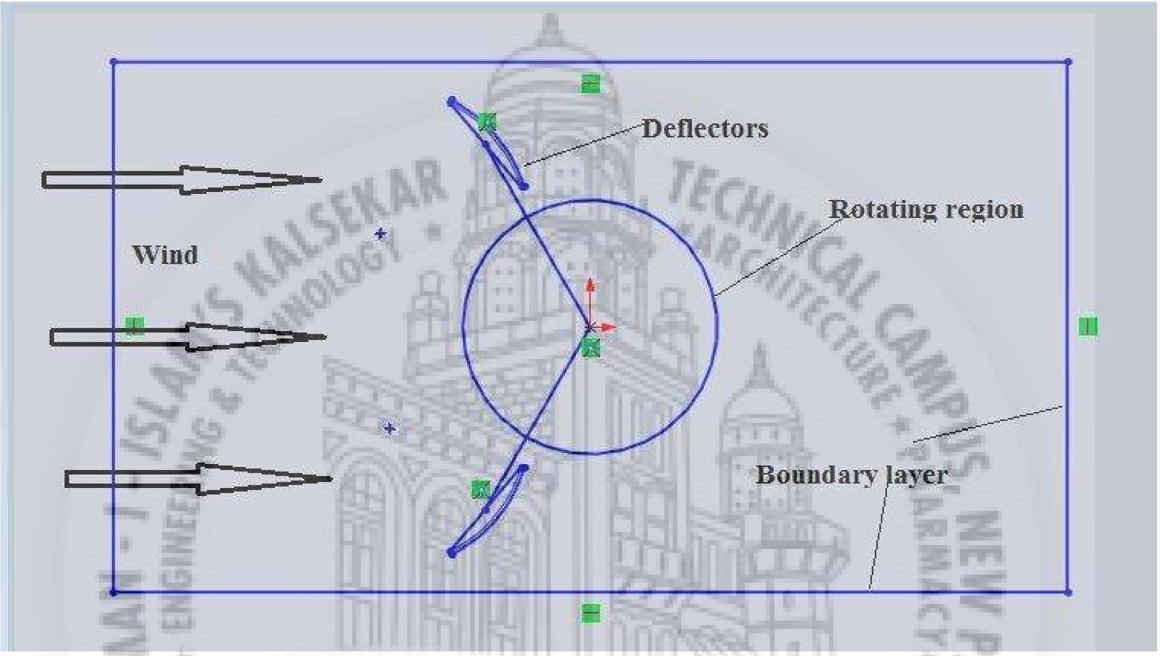


Figure 5-1 Top view of the designed wind turbine with wind deflectors

Three types of different deflector shapes were considered for the analyzing. The deflector shape which gives the best Cp value was intended to be chosen as best. Fig 5.2 represent the considered deflector shapes a, b and c. The dimensions of the three different deflectors are as shown in the Fig 5.3.

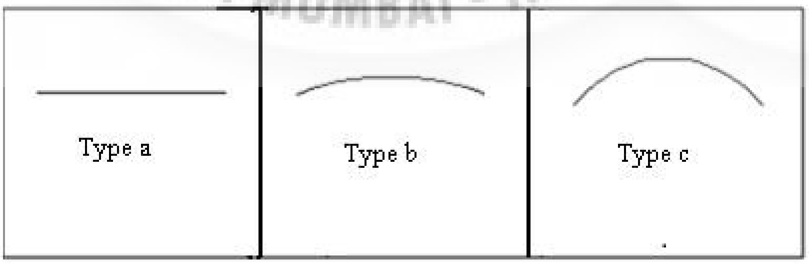


Figure 5-2 Type a,b and c

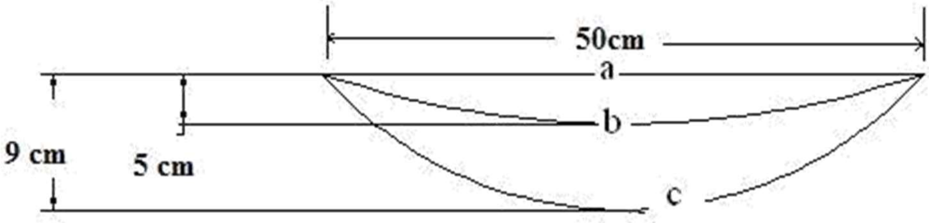


Figure 5-3 Specifications of the three types of deflectors

5.1 Selection and optimization process of deflectors

We used fluent simulated data for selecting the optimum deflector type. We checked 3 types of deflectors with different angular position with respect to air velocity $1ms^{-1}$ – $10ms^{-1}$. We found that Type b is the best solution. Analyzed force coefficient and moment coefficient acting on the blade with respect to air speeds are shown in the below tables.

Figure 5.4 shows how we defined the angular positions for the deflectors.(For the type b deflector)

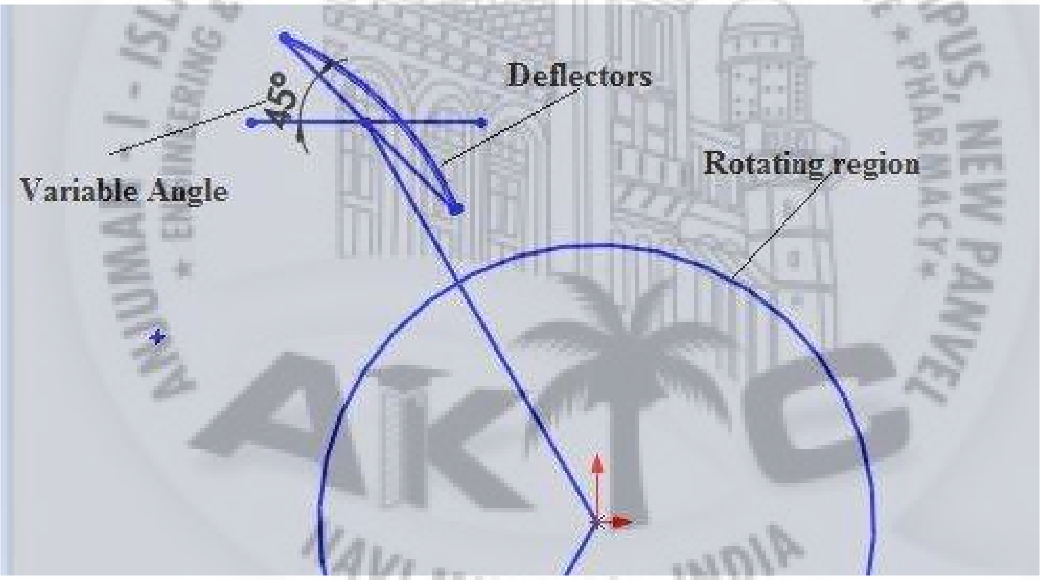


Figure 5-4 Changing angular position for the type b deflectors

Table No.05: Analyzed Force coefficient Data with **Type A** deflectors

Velocity /ms^{-1}	10deg	25deg	40deg	55deg	70deg	80deg
1	38.3191	52.0835	69.5101	83.007125	88.907205	85.6564
2	45.9365	71.5185	119.190	151.04865	140.80274	135.625
3	70.6378	111.827	78.8867	93.2129	62.1570	48.8233
4	29.0555	44.4180	97.0517	168.06324	167.3318	159.88905
5	10.2135	144.720	180.959	236.7539	275.72168	266.5087
6	85.0380	155.1423	288.685	381.5585	436.7896	438.6758
7	143.025	217.7857	395.015	538.8947	635.3978	645.79517
8	178.345	305.0339	512.571	727.8974	852.8443	862.4462
9	229.551	392.5532	677.442	948.64319	1102.275	1110.9361
10	307.744	519.2004	848.688	1194.6733	1385.1635	1390.3488

Table No.06: Analyzed Force coefficient Data with **Type B** deflectors

Velocity /ms^{-1}	5deg	15deg	25deg	40deg	50deg	60deg	70deg
1	38.6951	48.566	60.696	78.576	92.524	97.562	97.334
2	48.069	65.498	91.742	149.59	166.259	152.42	142.756
3	76.2108	90.728	114.680	82.488	112.883	89.463	92.631
4	25.746	43.8176	74.474	152.313	175.08	191.260	188.303
5	13.347	53.682	133.879	218.357	266.364	305.416	317.991
6	43.333	119.324	206.307	331.858	407.421	458.758	486.658
7	101.639	176.632	268.216	445.788	564.917	679.650	727.904
8	164.211	217.471	347.822	594.933	787.679	936.970	996.683
9	208.373	288.934	455.589	784.2830	1027.374	1218.552	1295.667
10	257.508	382.516	593.358	987.503	1295.832	1536.854	1627.647

Table No.07: Analyzed Force coefficient Data with **Type C** deflectors

Velocity /ms^{-1}	0deg	10deg	25deg	40deg	55deg	70deg
1	37.9633	43.8065	60.1450	76.778	90.837	93.8869
2	43.1642	56.0683	84.6117	137.425	157.109	144.998
3	72.4069	82.6501	115.2759	82.6733	104.130	67.8651
4	24.4374	42.9041	67.2385	123.4614	175.825	182.834
5	11.5081	43.2759	163.623	207.499	264.662	295.312
6	19.1952	135.144	201.9924	329.197	403.688	452.2752
7	106.527	173.168	255.115	435.8218	568.784	670.567
8	164.993	177.711	329.712	574.2147	795.647	912.685
9	198.148	229.943	432.7013	754.4919	1038.153	1187.266
10	241.151	303.449	568.7535	947.9765	1311.832	1495.284

Table No.08: Analyzed moment coefficient Data with **Type A** deflectors

Velocity /ms^{-1}	10deg	25deg	40deg	55deg	70deg	80deg
1	1.74310	18.27198	32.3878	42.928057	45.959874	47.2874
2	71.1238	93.57644	110.595	118.11409	114.97498	127.2635
3	145.340	146.2591	123.107	112.78613	148.0464	152.0097
4	144.009	122.0241	133.206	190.88149	232.9769	243.6572
5	84.7599	150.1167	206.932	238.25042	278.43382	296.7281
6	75.8677	210.5117	237.863	320.1569	358.62769	367.2008
7	167.277	264.1314	358.664	377.11631	410.535	420.852
8	230.839	319.8782	358.795	413.028	477.6277	490.986
9	297.996	314.0207	378.031	468.48448	548.12473	560.567
10	255.862	281.5100	443.687	528.33732	616.7809	632.61584

Table No.9: Analyzed moment coefficient Data with **Type B** deflectors

Velocity /ms^{-1}	5deg	15deg	25deg	40deg	50deg	60deg	70deg
1	-1.858	7.836	20.858	32.017	38.7774	41.590	44.071
2	65.184	78.628	94.992	101.013	106.124	104.354	115.703
3	139.958	142.597	133.935	104.056	108.531	137.606	149.793
4	125.99	113.437	91.062	131.096	200.253	225.745	249.247
5	80.897	83.0894	179.590	195.173	227.807	261.068	291.710
6	59.165	136.970	178.589	264.607	309.033	339.584	364.218
7	220.947	219.591	283.201	355.750	355.526	388.767	426.556
8	220.092	261.247	295.453	352.737	403.281	467.680	516.011
9	246.821	253.608	266.638	386.800	469.228	545.354	596.387
10	248.629	264.358	270.621	451.635	535.611	622.470	681.052

Table No.10: Analyzed moment coefficient Data with **Type C** deflectors

Velocity /ms^{-1}	0deg	10deg	25deg	40deg	55deg	70deg
1	-2.78823	3.7198	19.1392	34.5157	39.366	44.604
2	60.6047	70.1093	91.8428	103.9308	105.843	116.188
3	138.273	136.082	138.665	110.8125	113.343	154.883
4	139.841	124.697	89.6032	130.866	201.007	238.662
5	85.9007	93.8887	154.087	196.2335	229.119	281.851
6	56.8863	160.692	161.605	262.952	318.245	355.406
7	222.137	120.797	276.7370	366.5246	370.197	406.650
8	198.242	263.399	329.712	352.015	415.559	488.599
9	247.144	232.835	274.4861	380.716	481.338	562.196
10	239.785	259.341	266.129	446.565	548.055	639.460

By considering above values, we found that each deflector type has high moment and force coefficient in 70 degree. So, we took each 70 degree values and compared each other. Then we were able to understand Type b is the best type. Comparison graph is shown in the below figure.

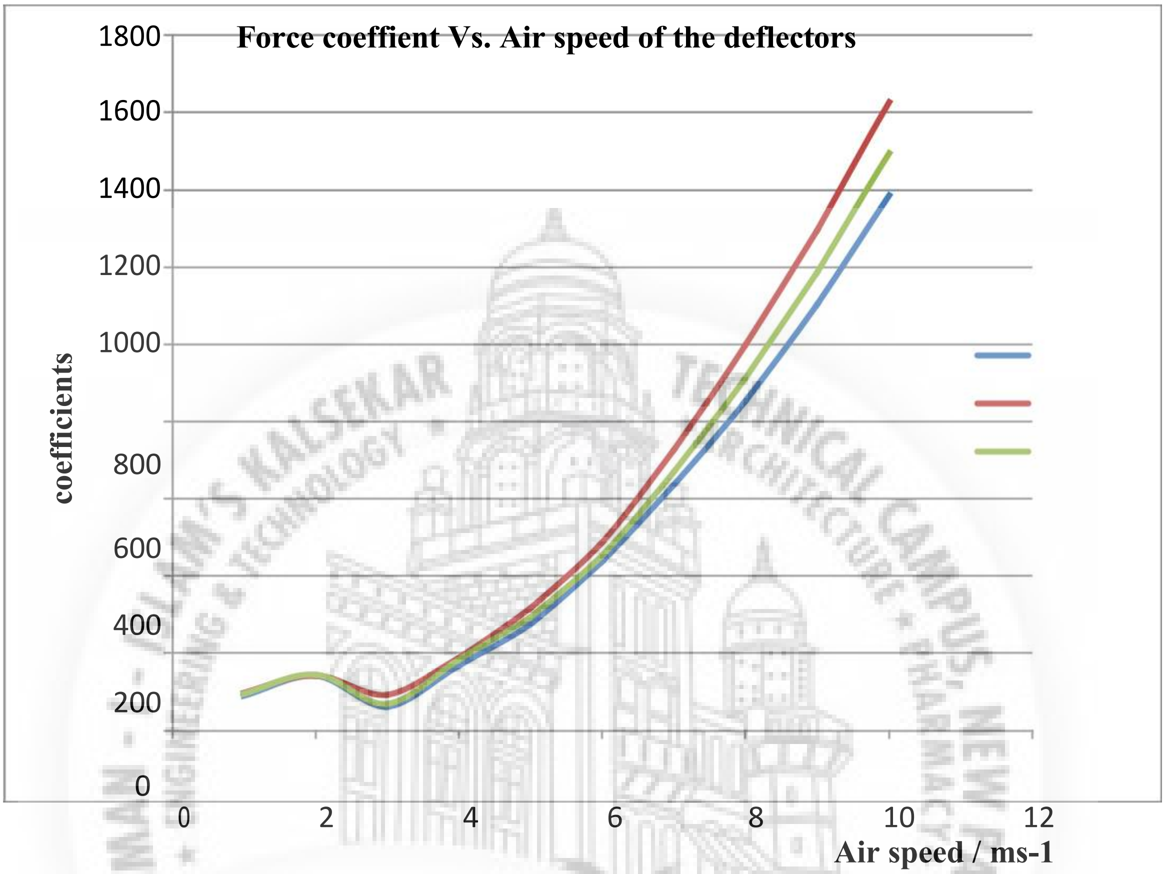


Figure 5-5 Force coefficient Vs. Air speed of the deflectors

Pressure distribution of the Turbine blades with type b deflector is shown in the below figure.

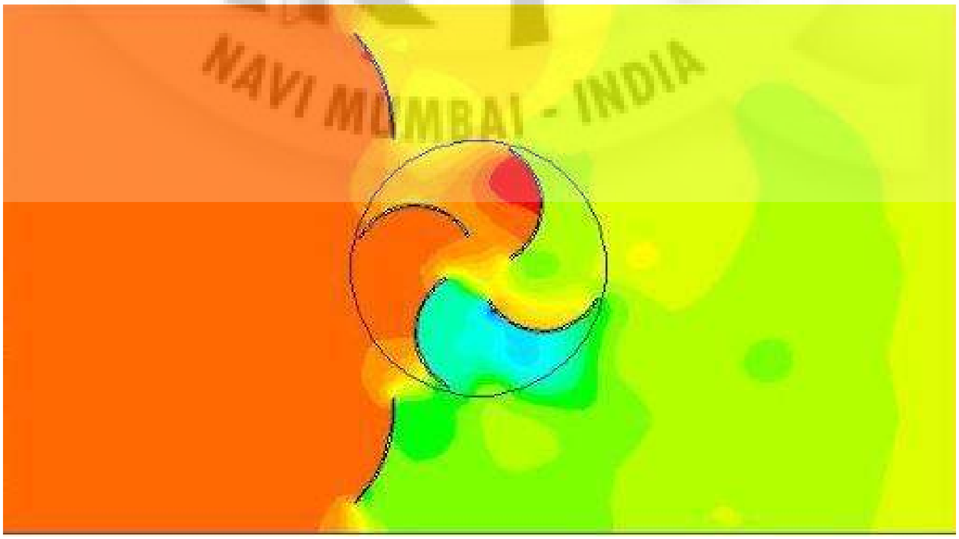


Figure 5-6 Pressure distribution of the Turbine blades with type b deflector

6 FABRICATION OF WIND TURBINE

We planned to fabricate wind turbine as part by part. Fabrication procedures are mentioned in below.

- Fabrication of blades
- Fabrication of rotating part
- Fabrication of support
- Assemble rotating part & support
- Fabrication deflectors
- Assemble deflectors to wind turbine

6.1 Fabrication of blades

After designing we are thinking about the fabrication of the wind turbine which will take more time from the time plan. In fabrication steps material will be selected, doing welding, fixings, fasting, bending of sheet metals etc…The fabrications will be done within the resources of the Mechanical workshop. In addition if there is any process can't be achieved in the workshop they would be outsourced.

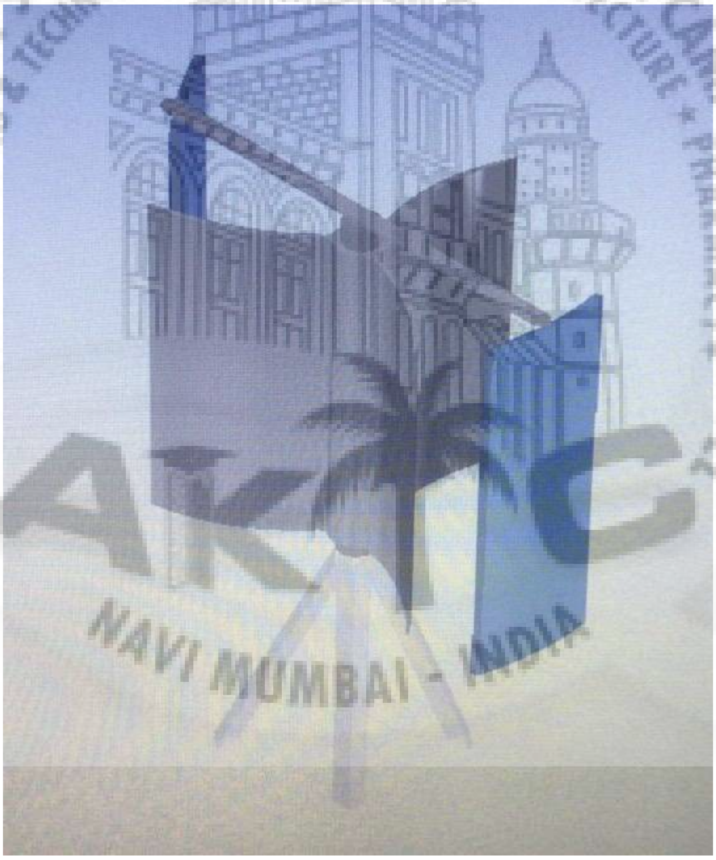


Figure 6-1 Used Aluminium Sheets

So, we used cutting machine for cut the barrel & after used rolling machine to make it's original curve shape. We rip the barrel for 3 parts. That one part was our one blade. So, we rip 2 barrel for make 4 blades. Top of the barrel used to keep blade support.


POCO
SHOT ON POCO F1

After the assembling of four blades it will be appeared like below.

Figure 6-2 Turbine blades

6.2 Fabrication of rotating part

After making the turbine blades, we assembled those blades to the main shaft according to the analyzed position. And also we had to mount bearings to the main shaft. We used 2 ball bearings & 2 thrust bearings.

Figure 6-3 Rotating part

6.3 Fabrication of the support

After fabrication of the rotating part ,we fabricated support of the wind turbine. It has 3 legs. We fabricated that support so that stress distribution is very low.

Figure 6-4 While the support & rotating assembling

6.5 Fabrication of deflectors

The exact deflector angular positions, deflector angles, deflector types and the gap between the deflectors and the turbine blades were obtained by the CFD simulations. So then the deflectors had to be designed according to the obtained parameters. So mainly the solid works was used and the main concerns of the design were high strength, less weight, low cost and easiness of assembly.

6.5.1 Design process of the deflectors

Each deflector was fabricated, which had 90cm height and 50cm width. Low weight and ability to assemble and disassemble easily and ability to withstand at average wind without deforming were selected as critical design parameters. It was very important to make proper design before the start of the fabrication process. It helps to avoid material wastage and product failures that can be occur at the testing.

The rough sketch of deflector was drawn by considering above mentioned design factors. There after it was modeled by using solid works design software.

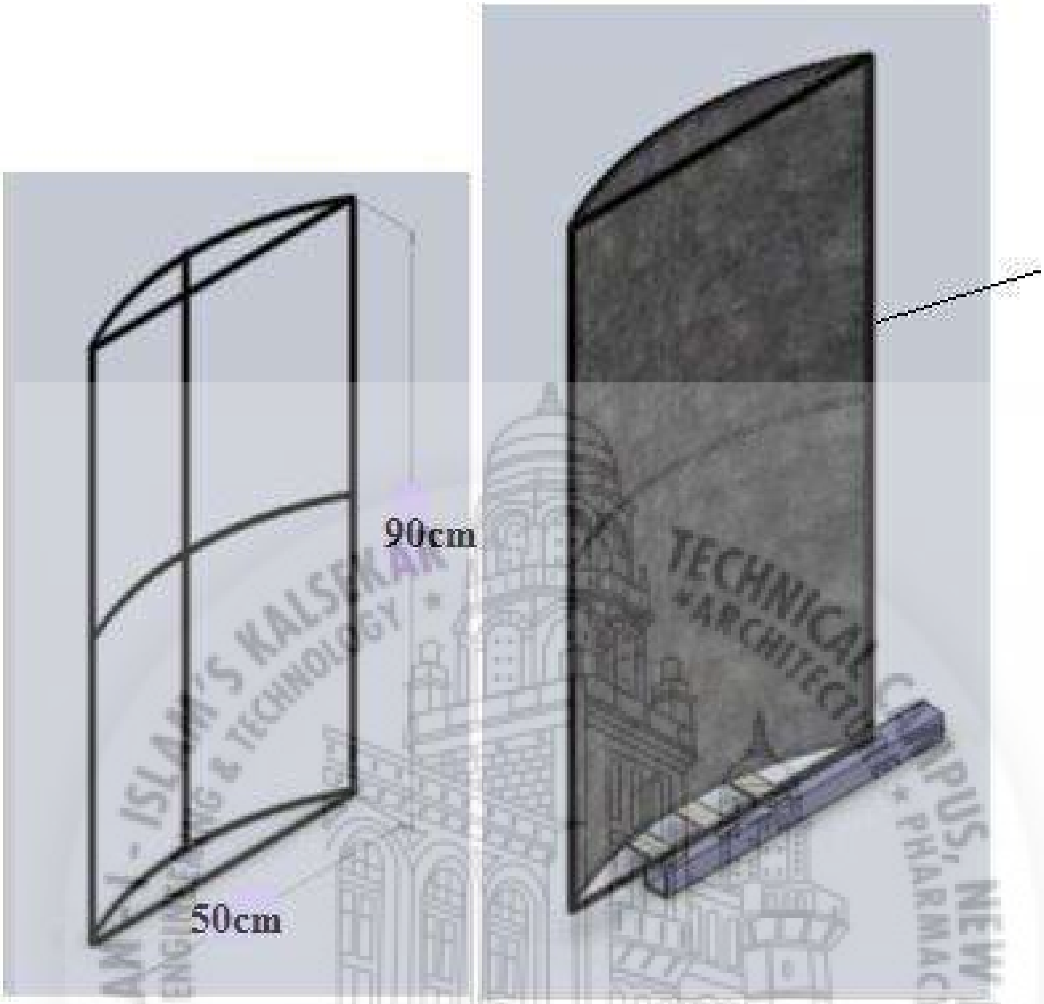


Figure 6-6 Solid works design of deflector

By using material, it can be calculate total mass of deflector and mass center of deflector. It was very important to know when considering balance of deflector. The center of mass should be maintained at lower level for the better stability of deflector.

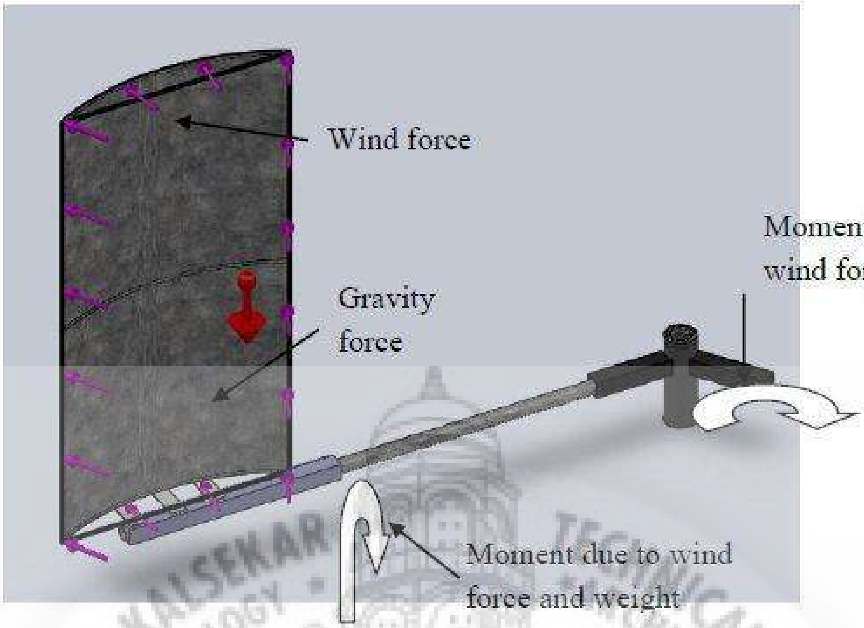


Figure 6-7 Forces acting on deflector system

It can be simulated at solid works interface by supplying actual parameters and calculate stress, strain and deflection of deflector at the supply wind force. By running that simulation process, it can be make sure the deflector does not fail at that condition and what are the critical areas that have maximum stress concentration.

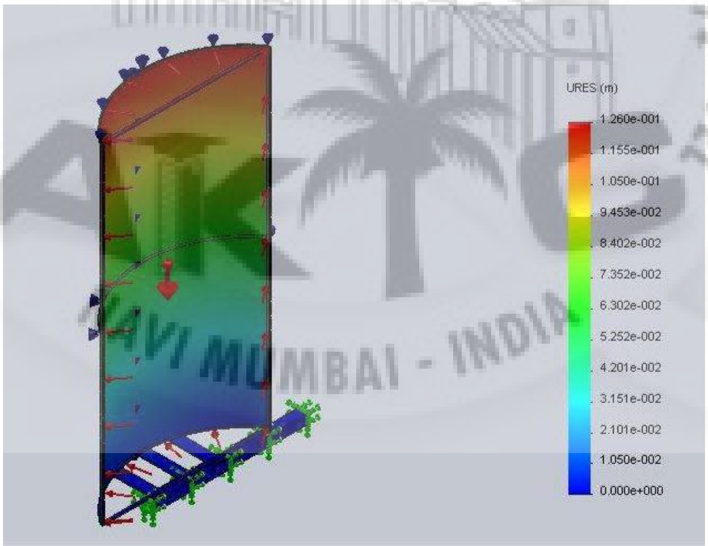


Figure 6-8 Solid work simulation of deflector for deformation

According to simulation data that was given by solid works, the deflector design was ok for the average wind forces. Deflector mounting parts also should be checked for deflector weight and induced torque by deflector due to wind force.

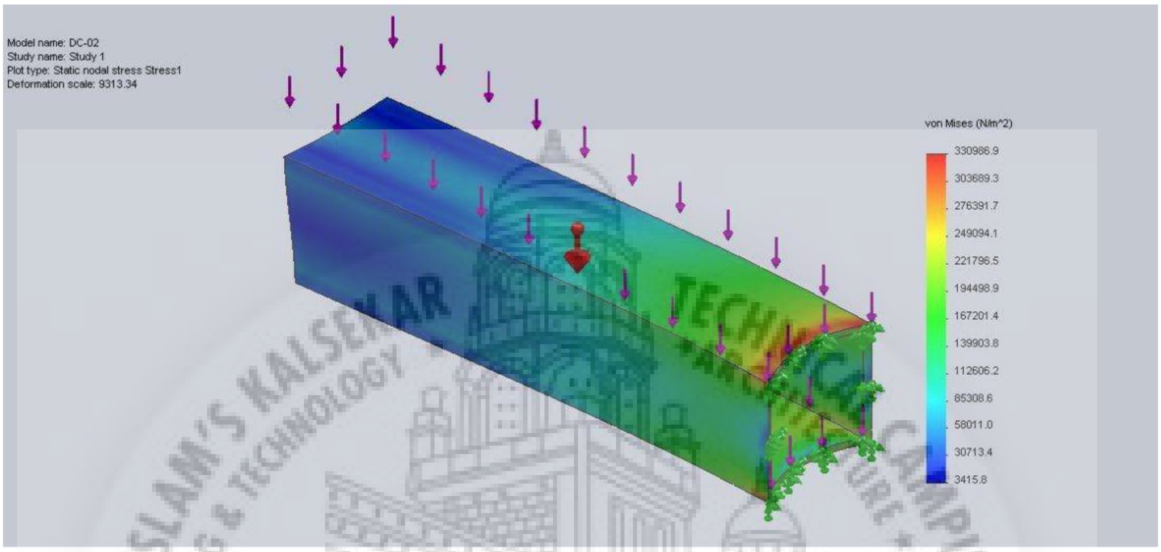


Figure 6-9 Deflector connecting box Stress simulation

Deflector was designed by using solid works and it has been done several simulations to check stress stain and fatigue failures when wing load applied. Deflector will be well mounted to the wind turbine through only its bottom side. So it is very important to run several simulations and get details about the deflector strength over wind power. It has to be fabricated with ability to face high unexpected wind load for the safety of both wind turbine and people who deal with it.

6.5.2 Fabrication process of the deflectors

Here the thinnest and lightest flat iron was used for the deflectors for the light weight. In addition its strength was well within the limits which can withstand a considerable amount of wind speed and pressure. The preferred shape of the deflector with the relevant curvature has been obtained by bending the flat iron. After the structure was fabricated it was drilled for the mounting of the metal sheet which would provide the smooth surface of the deflector. Here also it was carefully examined and tested to have the minimum number of holes for each deflector structure as it could weakened the strength of the structure. All the fabrication works were carried out inside the department workshop.

7 TURBINE TEST

After the fabrication process, next step was testing the turbine performances without deflectors and with deflectors. According to the testing results, we can get conclusion about its performance.

The turbine was tested for the evaluation of the performances without deflectors. In order to do that the height of the three legs of the turbine were increased to make easier the RPM measuring and also to enhance the stability of the turbine. In addition a simple mechanism was designed and fabricated to take the torque values. Anemometer was used to take the wind speed and Tachometer was used to take the RPM values of the turbine. In the case of testing the turbine a simple brake and a torque measuring mechanism has been introduced.

7.1.1 Torque measuring mechanism

The pulley was connected to the rotating shaft. So the belt was wrapped around the pulley and then it was connected to 2 spring balances in its both ends. Those two spring balances have been connected to the L angle which was running through the thread bar. With the bolts at the both ends of the L angle it can be steadily placed while the readings are being taken. The L angle can be moved along the tread bar with different loads. The thread bar also has been mounted to one of the legs of the turbine structure as it can to be removed easily with two nuts. With this mechanism the torque values can be measured easily

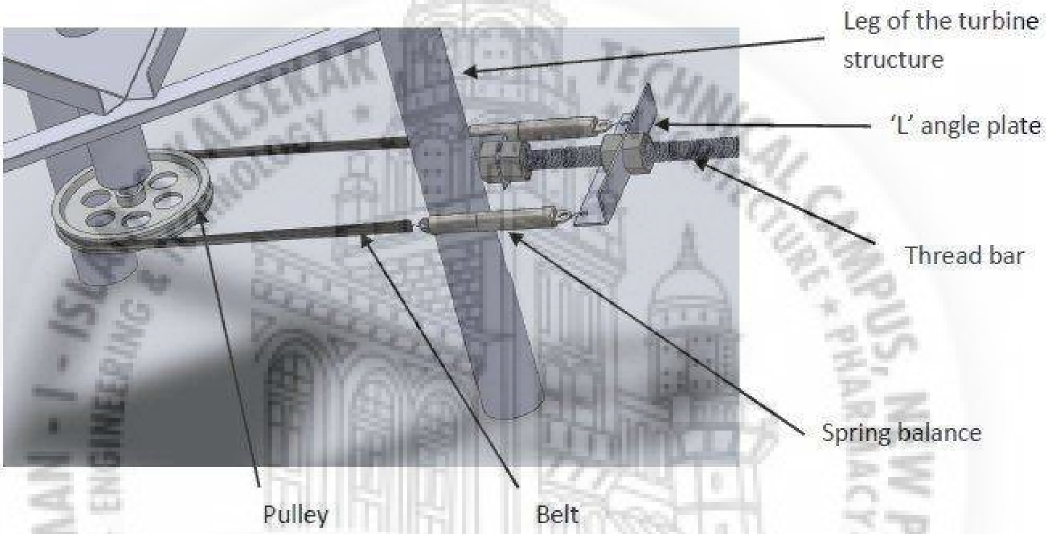


Figure 7-3 Torque measuring mechanism

7.1.2 Power in the wind

Another point to consider during the design and evaluation of any wind turbine is how to calculate the wind power in the blades. But the available wind power is different from the usable wind power. First the expression is shown in Equation 7.1 which is to calculate the available wind power:

$P= 0.5\rho\ A\ U^3$ ………………………………….. eq: 7.1

P = Wind power in watts

A = area perpendicular to the wind direction formed by the rotor in m^2

U = wind speed in m/s

The expression to calculate the usable wind power is shown in equation 7.2:

$P= 0.5\rho\ A\ U^3\ C_p$ ……………………………….. eq: 7.2

In this expression Cp is the power coefficient that depends on the type of machine and for each variable in turn to the relationship between the peripheral speed of the blades and wind speed.

7.1.3 Power coefficient

The power output of a wind turbine rotor changes with the rpm, so the rotor performance is normally presented in power coefficient vs. tip to wind speed ratio graph

The power coefficient is defined in equation 7.3:

$$Cp = \frac{P}{\frac{1}{2}\rho U^3 A}$$

………………………… eq: 7.3

Where, P = rotor power

The tip to wind speed ratio, or tip speed ratio, or TSR is defined in equation 7.4:

$$\lambda = \frac{wR}{U}$$

……………………………………. eq: 7.4

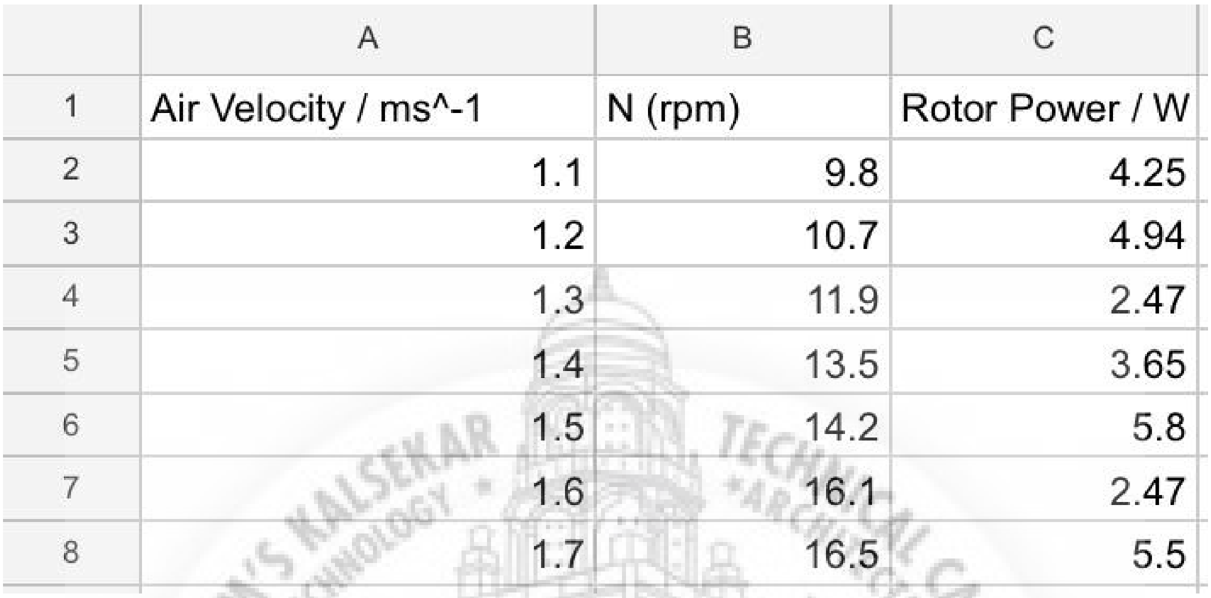
w = Rotor RPM

R= Max rotor radius

U= Wind speed

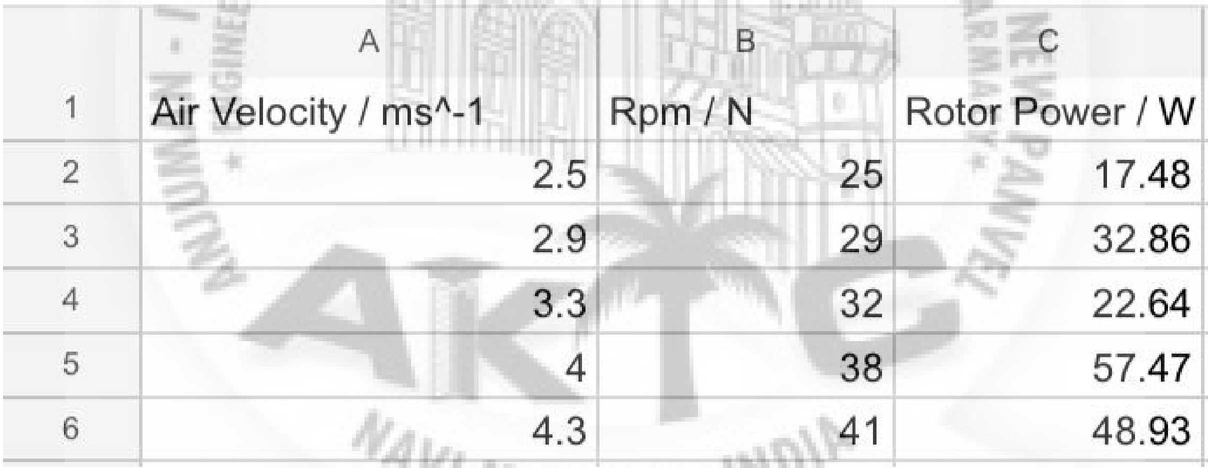
RESULTS:

Power Generated when cars are moving at 0 Km/Hr –



	A	B	C
1	Air Velocity / ms^-1	N (rpm)	Rotor Power / W
2	1.1	9.8	4.25
3	1.2	10.7	4.94
4	1.3	11.9	2.47
5	1.4	13.5	3.65
6	1.5	14.2	5.8
7	1.6	16.1	2.47
8	1.7	16.5	5.5

Power Generated when cars are moving at 40 Km/Hr –



	A	B	C
1	Air Velocity / ms^-1	Rpm / N	Rotor Power / W
2	2.5	25	17.48
3	2.9	29	32.86
4	3.3	32	22.64
5	4	38	57.47
6	4.3	41	48.93

7.5 Drawbacks and Solutions

One of the main drawbacks of this turbine was the air speed should be more than 2 ms^{-1} to rotate the wind turbine with deflectors. Because of that, in low velocities turbine rotation disturb by the deflectors due to inertia. So, one of the main modifications can be done to get rid of that problem is increasing the length of the deflector support. Then it won't disturb to the rotation of the wind turbine.

8 CONCLUSION

The use of wind deflectors increases the overall efficiency by a significant measurement. When the testing was done without wind deflectors, the output was neglible or very less whereas when testing was done with deflectors, the output was almost twice in comparison with theoretical reading.

Also we can add solar panel, to add some amount of energy when the turbine is kept in sunny places in day time.

The main motive is to increase efficiency & overall power at the end of the day.

Use of wind energy and VAWT will thus reduce the depend on such fuels which cause a lot of pollution.

In future, using VAWT will be very useful since it generates electricity using wind energy.

Use of VAWT in rural places will be a huge step in the development of lives living there and the country too.

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