

Review Article

POWER COEFFICIENT IMPROVEMENT IN BOTTOM QUADRANT OF VERTICAL AXIS WIND TURBINE WITH DOWNSTREAM DEFLECTORS

¹Naveen Yadav Jathi, ²Althaf shaik, ³Anil Kumar K, ⁴D. Seshi Reddy, ⁵Jarupula Somlal,

^{1,2,3} UG Student, ⁴Associate Professor, ⁵Professor,
^{1,2,3,4,5} Department of EEE, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, A.P, India

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Abstract:

One of the significant wellsprings of sustainable power source is wind. To meet the present electrical demand we should capture the maximum wind energy. Availability of small windmills with less efficient in energy capture. In this paper, we will model and simulate power coefficient improvement in bottom deflector optimization with vertical axis wind turbine in ANSYS Fluent a two-dimensional vertical hub wind turbine (VAWT) and computational fluid dynamics (CDF) is used to solve the K-epsilon (RNG). First of all, open rotor design was optimized with the required parameters, to the impact speeding up that had on the turbine execution at the open rotor design 24.7208% achieved maximum efficiency. And the array of curved upstream deflector was used, in order to efficiency improvement at odds with the original rotor design. Arrange of deflector will represent the liquid type stream redirection from the returning turbine sharp edge, results negative torque actuated on the framework diminishes, redirector width edge of 45 and 36 degrees were found improve the exhibition of the turbine by almost 1%.

Keywords: vertical axis wind turbine, ANSYS, CDF, bottom quadrant, deflectors.

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INTRODUCTION

Production of electrical energy has many sources, most of the electrical energy production process uses fossil fuels, deduction of fossil fuels may cause damage to the environment and leads global warming, to prevent the damage to the environment, all the global showing interest towards the alternative energy resources like solar, wind, etc... Wind energy is one of the oldest alternative energy resources, and become the most used alternative energy resource; present advance technologies are producing a more efficient turbine design. Horizontal axis wind turbines attracted the researches with their maximum capability in power output and size. In the wind turbines concept, another major concept is the vertical axis wind turbine, it was started using in the 1980s and 1990s. We can operate vertical axis wind turbine without yaw controls because it is Omni direction there is no matter direction of wind it will rotate only in one direction, vertical axis wind turbine shows the many advantages's in design over the level hub wind turbine(HAWT), this expands the enthusiasm about vertical hub wind turbine(VAWT). It has guideline rotational center point masterminded in the vertical course. One of the innovative structures is that it doesn't have exhibited as suitable all things considered as flat hub wind turbines (VAWT). It has some great highlights including very activity include, vertical pivot wind turbines can be utilized in private and business areas since that are a lot calmer than the even hub wind turbines, in vertical hub wind turbine it has two types darrieus and savonius, it depends on the components of the aerodynamics force, Darrieus design is lift type and savonius is drag type. In darrieus wind turbine it will turn shaft utilizing lift power, and the savonius wind turbine four cups make the shaft rotation, vertical axis wind turbine can also produce electrical power at a variety of speed and at low speed. Vertical axis wind turbines vary widely in speed that's AC generator that connected to shaft can't produce constant output and we give that output to the inverter that converts standard AC either single-phase or three-phase. And we have another option that uses output as DC by connecting the normal generator. When we see in urban areas wind speed and directions are change frequently, wind speed low at urban because buildings and other objects create the wind shadow. In VAWT because of omnidirectional that raise an issue of negative torque instigated on the returning turbine edges (sharp edges that are acting against the breeze stream heading toward the finish of the revolution) raise an issue of negative torque instigated on the returning turbine edges (sharp edges that are acting against the

breeze stream heading toward the finish of the revolution) deflectors (guide vanes or stator) are installed to reduce this problem. Deflectors pass the airflow away from the returning turbine sharp edge. Those will lowdown the negative torque. Some of the researchers were experimentally investigated on the power output effect of the two lift type counter-rotating straight blade vertical axis wind turbine with the upstream deflector of flat type. As a result, they revealed counter-rotating straight blade VAWT has positive on output power, and they recognize the importance of position and geometry of the deflector on the turbine. They did the same experiment on different types of deflectors. They observed the positive effect on three-blade darrieus VAWT with manage vane push (a kind of redirector).they observed the power coefficient 1.8times more than the normal open rotor at the wind speed of 8m/s.

With the help of computational fluid dynamics (CDF) studied the effect of using deflectors for the different type of rotors, like darrieus, savonius. And also this represented the importance of geometrical parameters and position of deflector whiles the design of the turbine. All the simulations are obtained here from two-dimensional computational fluid dynamics. The major purpose of this paper is to show, how the upstream deflector effecting, to get the maximum power coefficient with proper geomantic parameters and position

CONCEPT OF AERODYNAMICS

Aerodynamics will deal with the motion of air, which is interacted with solid objects such as 'airplane' and 'wind turbines', it will give an idea about the motion of air around the object and sanction the calculation of moments and force acting on the object. Coming to the use of aerodynamics in wind turbines, vertical and flat hub wind turbines have a number of aspects in common, with some other aspects that can distinguish them.VAWT blades will rotate on a rotational surface having the axis perpendicular to wind direction, during the rotation aero-dynamical angle of attaching of the blade varies constantly. Downwind side of the second blade first blade will move in the range of 180 to 360 degrees of rotational angle and energy will be extracted by the upwind blade, so then wind speed in that area will reduce. Because of this in the downwind sector of rotation power generation is less. Aerodynamic forces and flow velocities show torque will produce in this way that caused by lift force. Drag force-torque or braking torque is much lower than lift force torque. In a single rotor blade for one revolution generates positive torque and also short negative

torque. For total torque negative torque, will shows a reduction in positive torque on the downwind side. In the three-blade rotor, the variation of torque with the transformation will be adjusted, all through the revolution, all the exchanging torque will turn into a positive torque. In the vertical pivot, rotor torque can build up the torque if the rotor is in circumferential speed. Generally, the vertical hub wind turbine is definitely not a self-beginning. In the flow conditions, the mathematical treatment is more complex in vertical axis rotor then with propeller type. It means that mathematical and physical model of calculation for power generation and the loading is also complex. With different approaches and involving an assortment of weightings of a parameter, many have been distributed in the writing. Most distributors determine estimations of 0.40 to 0.42 for the greatest C_p for the darrieus wind turbine. To get the power generation information and aerodynamics analysis of the rotor it needs to consider the steps of wind turbine work, that converting the kinetic energy of wind flow into electrical energy. Figure 1, can see the steps of converting wind energy to electrical energy. The wind turbines will rotate by wind flow and that rotating rotor will connect to the main shaft or gearbox, this will connect to the electrical generator which will provide the power to the grid.

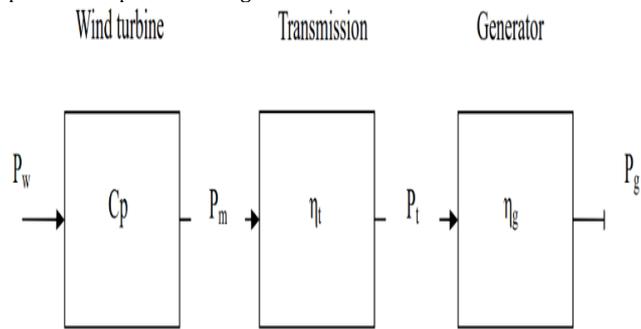


Figure 1: Process of converting wind energy into electrical energy

LIFT AND DRAG FORCE

While the airflow is acting on the blade, it produces two types of forces, named as lift force and drag force, this force will rotate the blades.

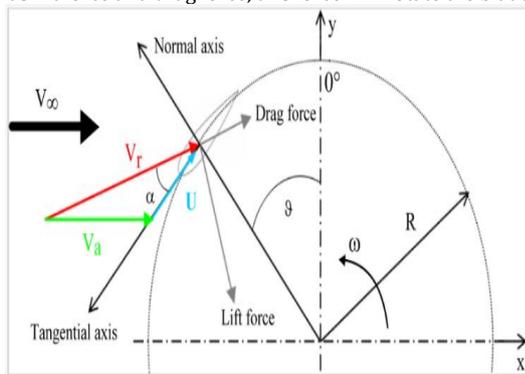


Figure 2: Forces driving on VAWT

With the help of above figure 2, can explain the forces that are driving the vertical axis wind turbine. Two significant speed segments are there. One is airfoil speed that is significant to the pole, which is corresponding to the harmony constantly, and size equivalent to the rotational speed increased to the sweep. Speed of twist additionally there nearly as a steady speed one way. Speed of the air comparative with the airfoil is the resultant of these two speeds. The edge between the harmony of the airfoil and the resultant speed is an approach (alpha). When the angle of attack is not equal to zero then pressure difference occurs which creates the lift force. The angle of attack is when the azimuth position is zero or 180 degrees. Only a drag force exists at this time. The blade moves out of this position lift force starts and angle of attaching improves.

Numerically lift and drag forces are defined as

$$F_D = \frac{1}{2} \rho A v^2 C_D \tag{1}$$

$$F_l = \frac{1}{2} \rho A v^2 C_l \tag{2}$$

From above equations can found lift and drag force coefficient

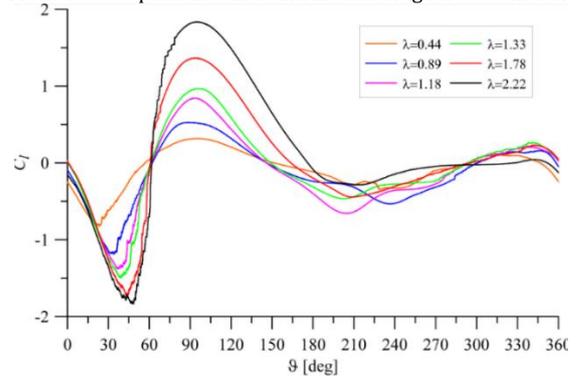


Figure 3: Azimuth angle vs lift force coefficient

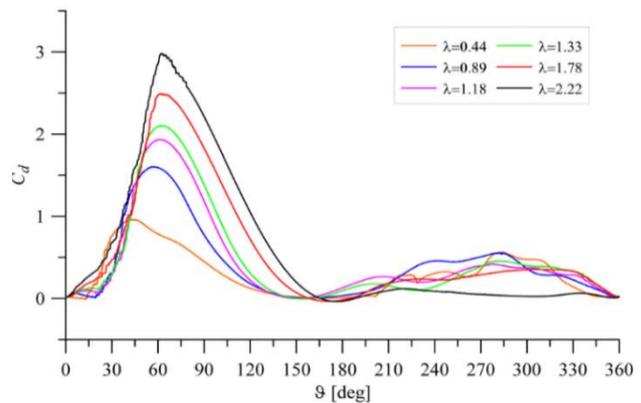


Figure 4: Azimuth angle vs drag force coefficient

In figure 3, at different tip speed ratios, it represents the lift behavior of the lift force with respect to the azimuth angle, at 30 degrees it shows maximum lift force, after that gradually reduce come to the minimum at 90 degrees. And increases from 90 degrees place at the next peek in 150 degrees. At zero degrees component of lift, force is parallel to the flow of wind and no tangent force is extended on the blade, when the blade start rotates from 0 to 90 degrees lift force increases and shows the tangent force on the blade, moment in the blades are constrained because of fixed blades, that shall make turbine rotate. From 90 to 180 degrees blade progress it covered by flaps due to which the blades are not exposed to wind.

In figure 4, at 60 drags force is maximum and that gradually reduced to a minimum of 150. Wind force acting on the concave and convex shape of the flap improves the drag force on the turbine. The drag coefficient on the convex surface is less than the drag coefficient on the concave surface which surmounts and rotates the turbine.

TYPES OF VERTICAL AXIS WIND TURBINE

In darrieus wind turbine it will turn shaft utilizing lift power, and the savonius wind turbine four cups make the pole pivot vertical hub wind turbine can likewise deliver electrical force at an assortment of speed and at low speed. vertical pivot wind turbine differs generally in speed that is air conditioning generator that associated with shaft can't create steady yield and we give that yield to the inverter that changes over standard AC either single-stage or three-stage. Also, we have another choice that is to use yield as dc by associating the typical generator. At the point when we see in urban zones wind speed and headings are change every now and again, wind speed low at urban in light of the fact that structures and different articles make the breeze shadow.

Darrieus wind turbine

Darrieus vertical axis wind turbine if we observe physical appearance is like a large egg beater

In this type of vertical axis wind turbine generator is located at the bottom of the blades .at the top of the pole guy wires that hold the pole in the place when the force wind make the blade rotation.

Giromill Turbine And Cyclo Wind Turbine Giromill Darrieus Wind Turbines:

Giromill darrieus wind turbine is also one of the vertical axis wind turbines. In this design, we convert wind energy in rotational energy by using the lift force that generates by the vertical airfoils. It is cheaper and easier to construct compared to the darrieus turbine. In these two or three aerofoils that are attached at the central for horizontal support. And this is not efficient it requires high-speed wind to start and it is hard to maintain a constant rotation, it will give good result at turbulent wind-conditions,



Figure 5: Giromill wind turbine

cyclo darrieus wind turbines:

One of the advanced variations of giromill is that cycloturbine, one of the main advantage of the giromill is self-started, the maximum efficiency occurs by orient the pitch of blades.at low winds drag force was generated by arranging the blades pitched flat against the wind. because of this wind flows across the aerofoils and accelerate the turbine by generating the lift force, because of the lift and drag force make efficient vertical axis wind turbine design, we can see the cyclo-turbine design in figure 6

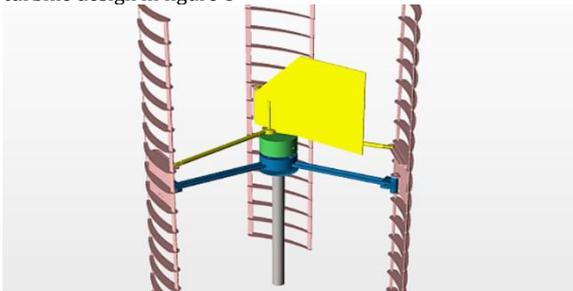


Figure 6: Cyclo wind turbine

savonius wind turbine:

In the year 1920 S.J.Savonius was introduced the savonius vertical axis wind turbine

It is a drag type vertical axis wind turbine and working is similar as cup anemometer if we can see an anemometer rotor is mounted by three cups which spin freely, all the time front of one cup is facing in to wind and other cups are facing back on the wind when we take three cups. back facing cups will experience less drag compared to the front-facing cups. Because of that open cup extended force is more than the total force. With this greater force on an open cup, the rotor will move around.

When seeing the three-cup s-type wind turbine if the rotor moves one-third of the revolution present open cup will be back facing cup, and the very next side cup will be the open cup, this will be continued all the time and make revolution,

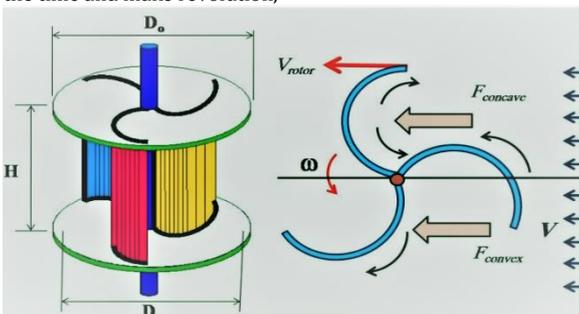


Figure 7: Savonius wind turbine

in savonius wind turbine, the direction of wind blow is not a matter since anyone cup will extract the wind which is facing towards the wind, and make the rotor rotate to make a complete revolution, And one of the bad thing in savonius wind turbine is only having 15% efficiency, it means that only the 15% of the wind was converted into rotational mechanical energy from 100% of wind and this is much less, we can get this in darrieus wind turbine using lift force rather than drag. The savonius wind turbine cups can't rotate faster than the speed of the wind, so they have a tip speed ratio (TSR) which is less than or equal to one. Because of this savonius wind turbine will generate high torque and rotate slowly. An S-type wind turbine is not ideal for electricity generation and generator that going connect to the rotor need gearbox, it will increase the RPM of the generator using gears, savonius wind turbine is not a self-started it needs stronger wind to spin.

In olden days, this type of wind turbines is used in such applications like pumping water, grinding grains and oil barrel to welded a pole which is passed through the bearings, because it can produce high torque and bearings servicing are required every couple of months.

WINDPOWER CALCULATION

Power in the wind can be described by :

$$P_{kin} = \frac{1}{2} m v^2 \tag{3}$$

P_{kin} =Kinetic power[w];

V =speed[m/s];

M =mass of flow= $A \cdot v \cdot \rho$ [kg/s];

ρ =density of air [kg/m³];

wind speed can estimate through frequency distribution and the Weibull distribution, in the below graph it will show Weibull distribution, it is more accurate compared to the frequency distribution

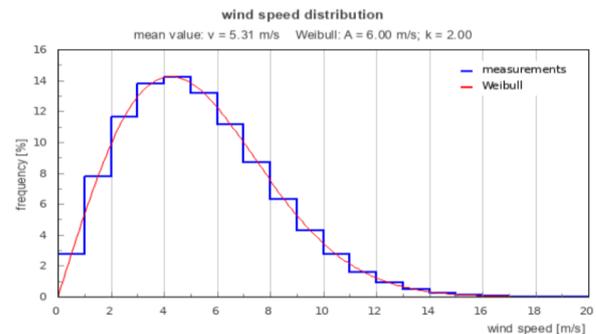


Figure 8: Frequency data vs Wind Speed

OPERATION OF THE CYCLO WIND TURBINE

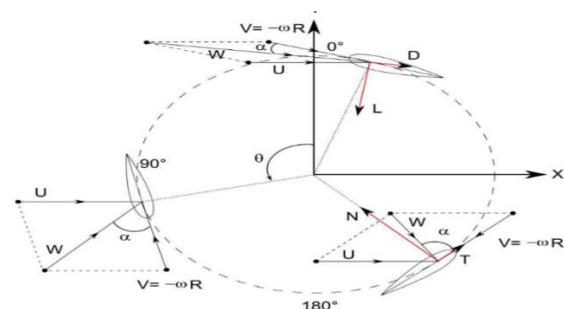


Figure 9: Forces acting in one revolution

In one revolution each blade gets maximum torque(lift) only twice, During the operation, all the natural frequencies of vibrations that consist in VAWT are avoided.

While the turbine spins the angle of attack changes this is one of the disadvantages. Because of this, each blade gets maximum torque at the front and back. It may produce a sinusoidal power cycle and the complex of the design represents.

Another disadvantage is that high centrifugal stress may lead, rotating mechanism mass majorly depends on the periphery than the hub, it needs stronger periphery.it is at S-type turbine, and less for D-type with egg beater shape, H-type windmills have less problem about this, most circular mass depends on central axis.

GIROMILL SWEAT AREA CALCULATION

Giromill is a type of VAWT, named as H-type rotor, the sweat area is. $A=h*d$; (5)

d =rotor diameter[m];
 h =blade length[m];

Wind power formula can also written as

$$P_{kin} = \frac{1}{2} \rho v^3 \quad (6)$$

The density of the wind not constant all the time it varies along with the see level above height and temperature. Usually, European countries Sweden takes the density at sea level as 1bar and temperature as 9 degrees Celsius. And the density of the air is 1.25kg/m3

Based on the Rotational speed and undisturbed wind speed wind turbine will give the mechanical power.

POWER COEFFICIENT

When the flow of air is crossed the wind turbine, energy of flow mass will convert into the rotational energy by rotating the wind turbine. And this conversion has some limitations, Betz law will show the limit mathematically, while the conversion is going on.

To explain the limit, power coefficient (C_p) was given

$$C_p = \frac{P}{\frac{1}{2} A \rho v^3}; \quad \text{Or} \quad (7)$$

$$C_p = C_m * TSR;$$

C_m =function of time;

$$P = \frac{\pi}{2} r^2 v^3 \rho \eta; \quad (8)$$

η =efficiency factor;

The power coefficient C_p will represent how much energy a particular wind turbine can absorb from the wind.

The HAWT Betz' limit is 16/27 which is equivalent to practically 60% for proficiency factor. It speaking to that, if the breeze turbine working in the best condition. Wind speed before the rotor is 2/3 times the breeze after the rotor. That speaks to in the underneath figure 10

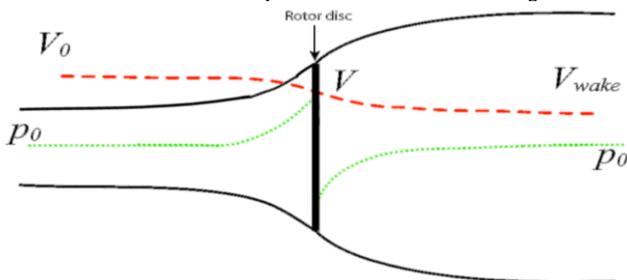


Figure 10: Airflow, pressure, speed before and after the turbine.

The power coefficient C_p value is depending on the type of wind turbine. And the tip speed ratio (λ) is given as

Tip speed ratio = (rotational speed of the turbine*rotor radius)/(undisturbed wind speed)

$$\lambda = \frac{\omega * R}{v} \quad (9)$$

Tip speed ratio and power coefficient C_p relation for the different types of wind turbines are shown in figure 11

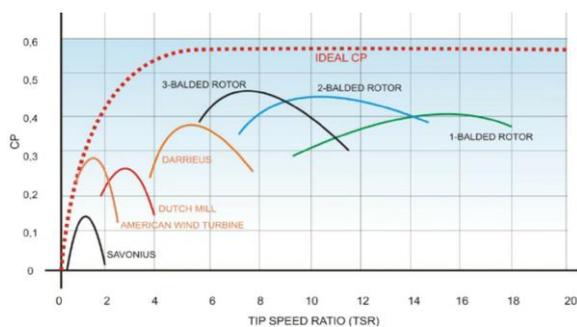


Figure 11: Different wind turbines have different optimal speed ratios and optimal power coefficient C_p .

For savonius rotor usually take optimal tip speed ratio around 1,

POWER CURVE

In the design process of the wind turbine, the major step is the prediction of the power curve. In these calculations, constrains of the rotor, generator, wind speed are involved,

In mathematical power of wind turbine is described by

$$P = \frac{1}{2} * C_p * \rho * \eta * A * v^3; \quad (10)$$

C_p =power coefficient

A =wind turbine sweat area

η =generator efficiency

ρ =density of air[kg/m3]

V =undisturbed wind speed

All the parameters mentioned here were described and calculated previously, all that is dependent on the tips peed ratio, type of rotor, power coefficient, etc.

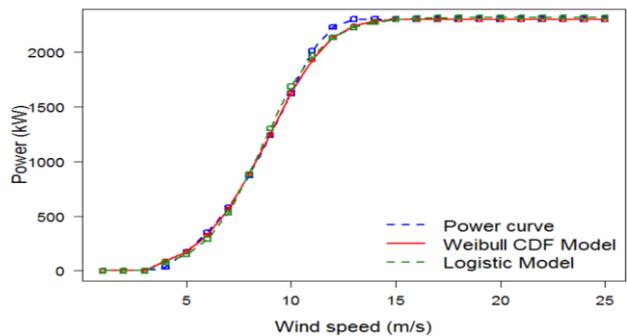


Figure 13: Typical wind turbine power output with steady wind speed

Figure 13 represents the power curve, the initial speed wind turbine is known as cut-in speed, at this point, it starts generating power, the wind speed raises from cut-in speed and output power also increases gradually. And saturate at rated output speed. In figure13 that shows above as rated output speed, after that parallely increased and reaches cutoff speed.at the cutoff speed, it causes may damage to the wind turbine, at this time we need to control the turbine.

NUMERICAL ANALYSIS

ANSYS fluent 19R is used to perform the two dimensional CDF simulation Blades are designed by using the solid works, and ANSYA FLUENT 19R design modeler was used to create the mesh and geometry of the open rotor. All the governing equations are based on momentum and continuity. K-epsilon (RNG) turbulence model is used to solve continuity and momentum equations. Numerical modeled turbine power output can be overestimated when 2D models are used. Numerically open rotor optimized before the augmented rotor (with deflector)

A.augmented rotor and open rotor design and setup

By the open rotor module turbine configuration was optimized in the order of azimuthal angle (theta), and the wind speed (U). In the sequel, deflector angle optimization was done by open rotor including deflector (augment rotor).

In this, turbine was designed by the three NACA 1175 airfoil blades, and the chord length of the blade is 1m, model domain dimensions are chosen based on the flow stability on the rotor domain, from the inlet domain rotor placed over the twelve diameters and from outlet it was twenty, occurring of recirculation flow prevention, domain made symmetrically in size With the width of eight rotor diameter,

All the perimeter models and sizes ate displayed in the table1, mathematical model geometry was displayed in figure 14, inlet fluid domain, outlet fluid domain and rotating rotor fluid domain, these three domains are used in numerical analysis. This was represented in fig 14. For meshing the model was split, to make simple. Mesh contains more than 150,000 elements, and each airfoil perimeter contains 500 elements approx. to measure the large pressure and velocity variations around the airfoils blades, the mesh was refined in the rotor domain. The rotor domain was moving reference, tip speed ratio (λ) of the turbine was varied by input parameters of angular velocity. To

measure the turbine efficiency output perimeter of torque(T) was used. In the same manner, the augmented rotor was modeled. With the deflector plate and shown in the results, the bottom quadrant deflector was simulated to evaluate the turbine performance for the operating conditions, an angle of attack was based on the blade azimuth angle.

And the variation is with respect to the fluid flow direction (U), show in results and discussion

Table1: components and values

Components	values
Airfoil type	NACA1175
Number of airfoils	3
Airfoil chord length	1m
Rotor radius	1.5m
Rotor height	1m
Inlet length	20
Outlet length	10
Domain width	24
Inlet velocity	Variable
Deflector angle	Variable
Deflector radius	Variable
Solver type	Pressure based
Viscous model	K-epsilon (RNG)
Inlet-turbulent intensity	2%
Inlet-turbulent-length scale	1m
Backflow-turbulent intensity	2.2%

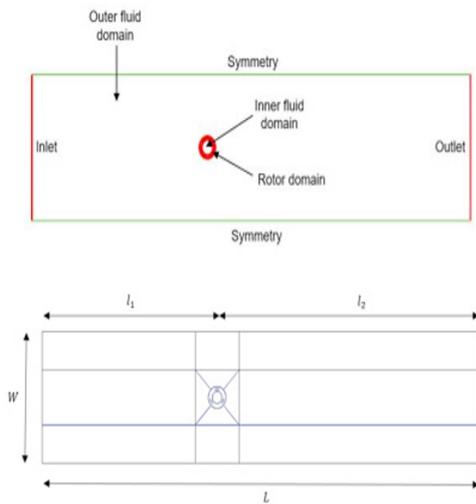


Figure 14: inlet and outlet flow with dimensionals

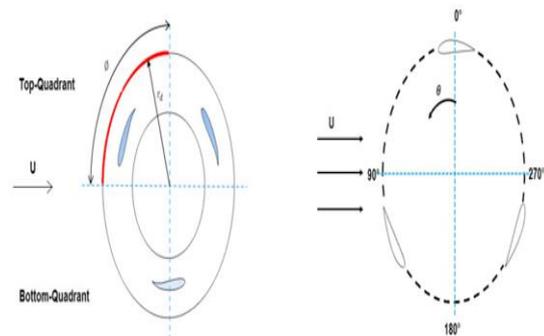


Figure 15:top and bottom quadrant

MODELLING RESULTS AND DISCUSSION:

A.Bottom deflector optimization:

Table2: Cp max, efficiency, with different deflector angle, TSR

Deflector angle (deg)	Cp, MAX	Efficiency (%)	λ (Cp, MAX)
0 (open rotor)	0.247208559	24.72085586	1.2
90	0.082519859	8.251985878	1.4
63	0.153976873	15.39768729	1.6
45	0.25594005	25.59400497	1.4
36	0.244966674	25.49666744	1.4

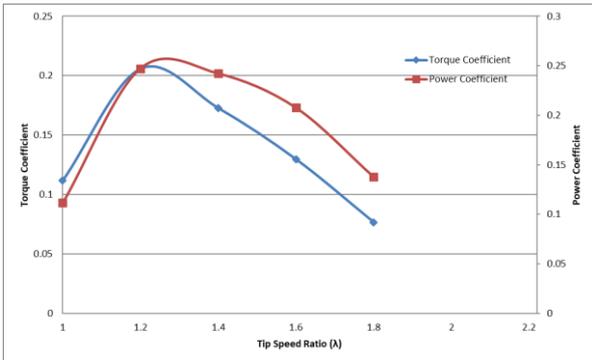


Figure 16: At 0 degrees torque and power coefficient vs TSR

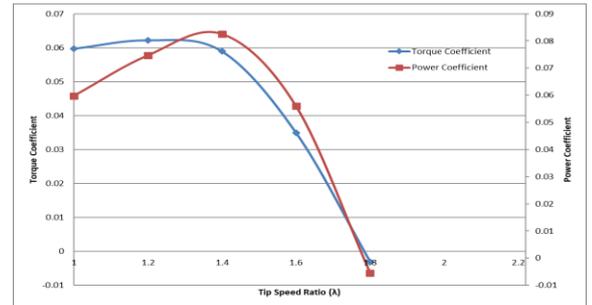


Figure 17: At 90 degrees torque and power coefficient vs TSR

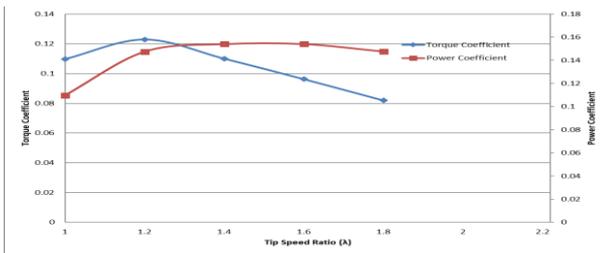


Figure 18: At 63 degrees torque and power coefficient vs TSR

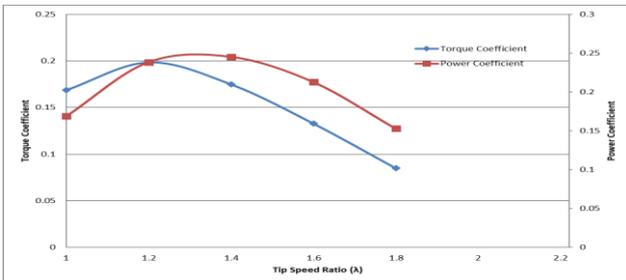


Figure 19: At 45 degrees torque and power coefficient vs TSR

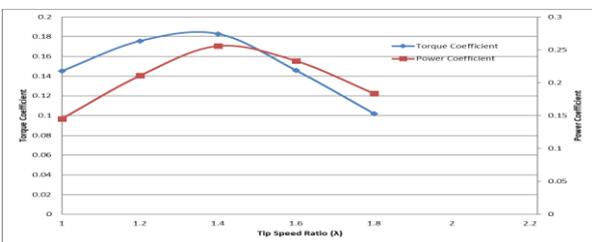


Figure 20: At 36 degrees torque and power coefficient vs TSR

Top deflector optimization was simulated with a width of 90°, 63°, 45°, and 36° and the result was displayed in the above table. Cp is reduced at the width of 90°, 63°, 36° by 8.25%, 15.39%, 24.4%. At the width of 90 and 60 Cp was decreased heavily, and at 36 decreases slightly. because of the sudden increase in the flow velocity behind the deflector.

B. All the counter velocity magnitudes different deflector widths are arranged in below:

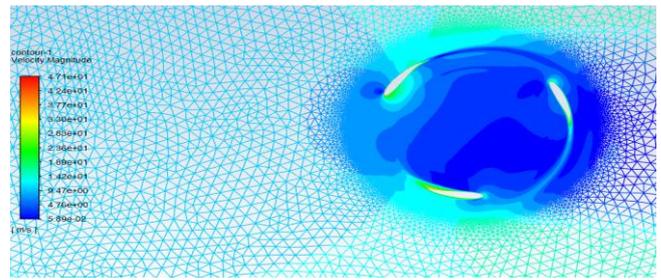


Figure 21: Counter velocity magnitude at 0°

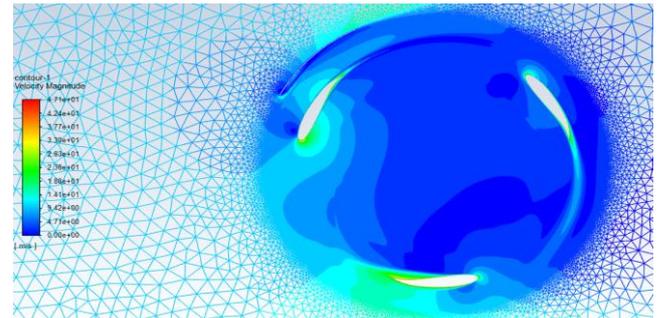


Figure 22: Counter velocity magnitude at 36°

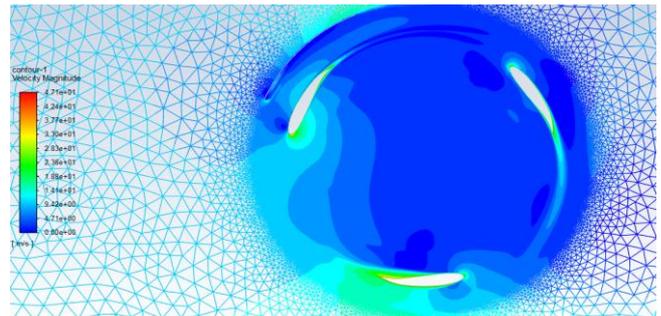


Figure 23: Counter velocity magnitude at 45°

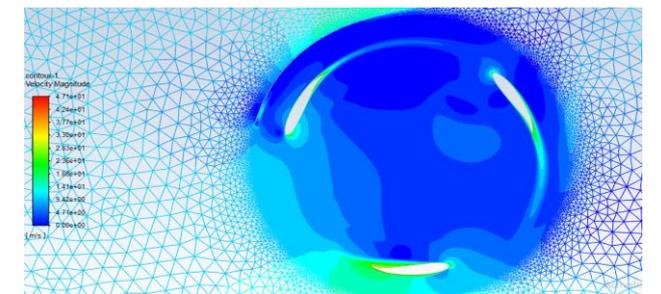


Figure 24: Counter velocity magnitude at 63°

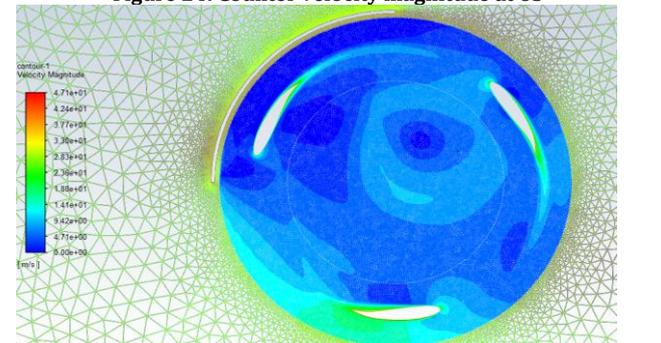


Figure 25: Counter velocity magnitude at 90°

C.The maximum coefficient of performance for varying deflector angles:

Four Bottom-Quadrant deflector varieties were tried, with diverter edges or widths of 90°, 63°, 45°, and 36°, all of which had a deflector range (rd) of 3 m. The coefficient of execution esteems for changing diverter edges are shown in Table2. The outcomes show that redirector points of 90° and 63° abatement the presentation of the turbine by 16.17% and 9.077%, individually. Though the littler, 45° and 36° diverter edges increment the most extreme effectiveness of the rotor by 1% and 0.9%, individually. The tip speed proportion, at which the most extreme coefficient of execution happens ($\lambda_{CP,MAX}$), is likewise observed to drop by 0.2 and 0.2for these diverter points individually. The effectiveness drops with bigger redirector widths of 90° and 63° are because of the manner by which they direct the stream. Despite the fact that they were intended to lessen the impact of negative torque, they are in certainty seen to change the stream to sharp edges 1 and 3, diminishing the powers of lift. This relationship is shown in the weight shape and speed streamline plots on page 2 &5. With bigger redirector widths (90° and 63°) the weight disseminations on the diverter do accomplish the ideal consequence of lessening the weight circulation and accordingly stream, around the returning cutting (edge 2). Be that as it may, the size of the redirectors prompts the redirection of the stream to cutting edge 1, lessening the actuated power of lift on the sharp edge. For the littler redirector widths (45° and 36°) the stream onto sharp edge 1 isn't changed altogether. This takes into account the age of torque as though the turbine was in its 'open-rotor' condition while decreasing the stream to the returning cutting edge (sharp edge 2). This takes into account the improvement of the framework's productivity while lessening the rotational speed of the framework required arriving at ideal efficiencies.

CONCLUSION

Using the ANSYS fluent, the three-blade vertical axis wind turbine was designed, solving for the K-epsilon and Navier stocl equations, and founded that curved upstream deflectors improving the performance of the turbine into 1% . with the turbine requiring decreased rotational velocity to provide optimal performance values. Thus, the use of the deflector was seen to have a positive effect on the turbine's performance. This was deduced to be from the redirection of flow from the returning blade of the turbine, thus reducing the negative torque induced in the system.

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