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Computational Fluid Dynamics Analysis of Wind Lens

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Abstract: The wind-lens turbine consist of shrouded diffuser which increases the wind speed at rotor, developing electric power even in low speed wind. Energy crisis is one of the major problems facing the countries globally. One of the methods to overcome energy trouble is to use the energy available efficiently and also to reduce the energy that is being wasted. The fact that non-renewable sources of energy become cause of pollution and the increased ecological hazards and their rate of depletion has required to use of nonconventional and renewable sources. Therefore to adopt the methods of energy recovery is required. Energy recovery is a technique used to reduce the vitality input to an overall system by exchanging the energy from one system of an overall system to another. Wind lens turbine is the next generation small wind which can be installed anywhere. It has significant reduction in wind turbine noise, concentration of wind energy, compact and highly efficient, adaptable to the surroundings, highly safe systems and significant reduction in birds strike.
Keywords: Wind Lens, Wind Turbine, Analysis, CFD

I. INTRODUCTION

Wind power has ended up one of the foremost temperate renewable vitality advances in recent years. Today, wind turbines that generate electricity provide a safe and sustainable power supply and employ tried and tested technology. Wind power can presently compete effectively with conventional power generation in good, windy locations. Numerous nations have significant wind assets, which are yet unexploited.

Fig. 1: Wind Turbine

A technology that offers outstanding benefits isn't utilized to its full potential, such as:

1) Wind energy does not produce nursery gases.
2) Wind control plants can make a notable commitment to the territorial electricity supply and diversification of energy supply.
3) Compared to traditional energy projects, an awfully brief lead time is needed for arranging and development.
4) Concerning the increase in energy demand, wind energy projects are flexible - individual turbines can effectively be included in an existing stop.
5) Lastly, wind projects can utilize nearby assets of labor, capital and materials.

With the innovative advancement of later a long time, wind power has become more cost-effective causing more coherent and more dependable wind turbines. In common, the specific energy costs per year kWh diminish with the measure of the turbine in spite of existing supply problems.

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To capture wind power in a more efficient way, wind turbine has modified into wind lens. The modification has an annular structure called "brim" or "wind lens" that has blades in the surrounding area to divert air away from the debilitate stream behind the blades. The turbulence from the modern setup creates a low pressure area at turbine, which causes reactor winds to go through the turbine, which in turn increments blade turn and power production. In Japan, the Department of Wind Engineering at Kyushu University is conducting research on wind lenses.

Fig. 2: Wind Lens

II. LITERATURE REVIEW

1) Yuji Ohya et al presented Covered Wind Turbine Producing High Yield Power with Wind Lens Techniques, in 2010. They have found a method to enhance the efficiency of wind turbine by installing a shrouded diffuser close to outlet outskirts and the wind turbine interior it. A large boundary layer wind tunnel was used. Be allied to advantages of wind lens turbines is the yaw control with brim based. It had a measuring section of 15 m long x 3.6 m broad x 2 m tall and also a most extreme wind speed of 30 meter/sec. Several kind of wind lens were tested and compared which have different Lt/D. When the height of the brim was greater than 10% , that is, in the event of h is greater than 0.1D, the Cw of a wind lens turbine causes nearly bi-fold increment compared to an uncovered wind turbine and therefore Lt/D=0.371 showed an increase of 2.6 times. Hence, they expected two-three times increment in yield performance, albeit they used a really dense brimmed diffuser because of the structure of wind lens. Along a comparatively lengthy diffuser (Lt = 1.47D), an interesting increment in power output of about four-five times such of a standard turbine was accomplished. Even adopting the cleared zone A * rather than A (due to the rotor breadth), where A * is the circular zone thanks to the external breadth of the brim at the outlet of a diffuser, for those dense wind lens turbines, the output coefficient supported A* becomes 0.48-0.52. It is yet higher than Cw (=0.37) of ordinary wind turbines. It implies the dense wind lens turbine clearly indicates greater effectiveness compared to ordinary wind turbines, indeed though the rotor breadth of an ordinary wind turbine is the same as the breadth of brim.
2) MagdiRagheb and Adam M. Ragheb presented Wind Turbines Theory, The Betz Equation and Optimal Rotor Tip Speed Ratio, in 2011. The basic theory of wind turbine design and operation has been supported as a primary approach using mass conservation and energy conservation during the wind stream. The author compared the Betz equation to the Carnot cycle productivity in thermodynamics because an engine cannot draw out all the energy from a given source and must reprobate some back into the environment. In turbine coefficient of power has been characterized and associated with the Betz restrain. For various designs of wind machines, the coefficient of power Cp may be a work of the tip speed proportion. A graph of power coefficient versus interference was plotted and therefore the hypothetical greatest proficiency of a turbine was given by the Betz limit and is approximately 59 percent. For all intents and purposes, wind turbines work underneath the Betz limit. It has been noted that when a rotary wing go across the air stream it takes off turbulent wake in its way. On the off chance that subsequent blade inside the turning rotor arrives at the wake while the air remains unstable, it will not be ready to extricate power from the wind effectively, and can be liable to higher vibration stresses. If the rotor turned slowly, the air striking each rotary wing will not be unstable. Completely obstructing a wind stream doesn't permit any energy withdrawal. Just by permitting the wind stream to be due to a high velocity region to a slow velocity region can extricated energy by a turbine.

3) Raju Govindharajan et al, presented Numerical investigation and style optimization of brimmed diffuser wind lens around a turbine in 2013. For a given turbine, power output is often increased by wind lens. In the analysis, a comparative numerical estimate of mass flow rates across the turbine with distinctive types of wind lenses which respectively helps to improve the torque gain. It was proven that there's remarkable increase in wake formation and vortex strength when brimming effect is added to the diffuser. The rotor diameter of the turbine was 3.5m and therefore the clearance between rotor and diffuser section was set to 0.1m. Inlet velocity was taken as 14 m/s and further analysis was done to match wind turbines with and without brim. The inlet and outlet diameter of the diffusing passage was kept constant while the outer surface of the diffuser was modified to urge different flow pattern and vortex formation. An unstructured tetra mesh was formed within the flow domain for computations. Velocity contours showed a significantly low behind the diffuser blade. It was establish that brimmed turbines induced wake formation which resulted in induced pressure at the exit of turbine. This gave significant increase in mass flow for the given turbine. The above considerations were also experimentally proven.
4) Kazuhiko Toshimitsuet. al, presented Experimental examination of performance of the wind turbine along with the flanged diffuser shroud in Sinusoidally oscillating and Fluctuating velocity flows, in 2012. The turbine performance was analyzed for both steady and unsteady airflow. The rotors are planned for two tip speed proportions of 3.7 and 5.0. Blade cross-section outline was interchanged from NACA63218 at the root to NACA63212 at the tip with an extension whose wind speed was taken as 7 m/s. The ratio between the diffuser length to diameter was 0.225. Performance of turbine (with wind lens) was examined for steady and unsteady winds by CFD and PIV. A graph of coefficient of power versus tip speed proportions was plotted for bare turbine and wind lens. It was understandable from the graph that the dense kind wind lens turbine indicated greater performance than single-rotor turbines in both stable and unstable winds.
5) WT Chong et al, in 2012, presented a performance realization of a powered vertical pivot wind turbine for high urban applications. The new power augmentation guide vane (PAGV) that encompasses the Sistani wind turbine is planned to progress the performance of the wind rotor by expanding the speed of the incoming wind and directing to the ideal stream point sometime recently it is attached to the rotor edges. From wind burrow test estimations where the wind turbine is beneath free-running state meaning that as it were rotor dormancy and bearing grinding were implemented; the wind rotor rotation speed was expanded by 75.16 percent. In the interim, computational fluid dynamics reenactment appears that the torque has been expanded by 2.88 times with the presentation of PAGV. The power generated by the rotor with PAGV was incremented 5.8 times at a wind velocity of 3 meter/sec, by method of semi-empirical. Also, visualization of the stream vector proves that a bigger region of the upstream stream was persuaded via rotor using PAGV. From CFD flow visualization, excessive mass stream rate is transmitted and directed to the rotor edges and this gives the increased positive torque and power yield, along with PAGV present.

III. PROBLEM STATEMENT

20th century is the century of exploitation of nonrenewable resources. Various technologies for renewable energy have been implemented since the awareness created about the depletion of conventional resources.

Wind power is one of the free resources of energy that is being utilized on a huge scale recently such as wind mills but with a greater disadvantage of location far from cities, noise, improved efficiency, cost, controlled yawing mechanism and bird striking. Here the need for improved efficiency and new technologies to reduce defects and help capture and concentrate wind power locally so the energy generated by wind turbines can be increased dramatically increases. Lens wind turbines can develop electrical power indeed in moderate speed winds because the diffuser cover increments wind speed of the rotor. Energy crisis is one of the major issues confronting the nations globally.

One of the methods to overcome energy trouble is to use the energy available efficiently and also to reduce the energy that is being wasted.

The fact that nonrenewable sources of energy become cause of pollution and the increased ecological hazards and their rate of depletion has required to adopt the methods of energy recovery and to use of non-conventional and renewable sources. Energy recuperation incorporates any strategy for diminishing input energy to general system by exchanging vitality from one system of the overall system to another.

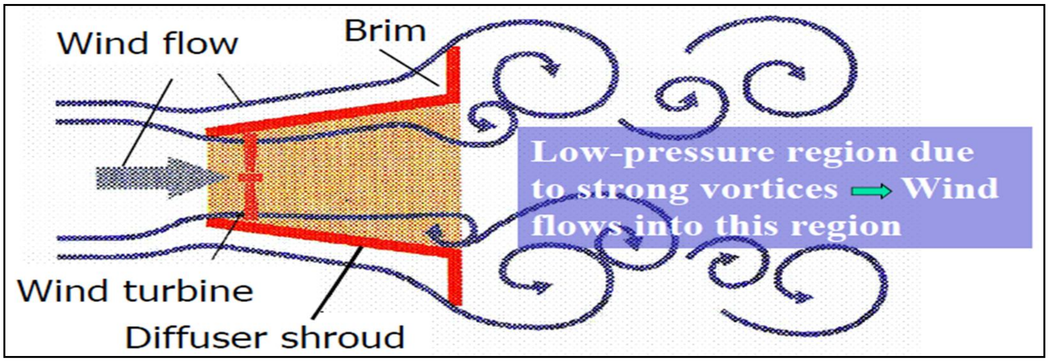


Fig. 3: Mechanism of acceleration of wind using windless

IV. OBJECTIVES

The major objective of the project are as under:

1) To implement a technique/concept of wind lens to improve efficiency of normal wind turbine.
2) To study the effect of different type of wind lenses using computational fluid dynamic analysis.
3) To increment velocity of the incoming wind to a turbine using wind lens.

V. METHODOLOGY

1) *Choosing the no. of Blades:* Having exact no. of blades to run is more important to the efficiency we get from the turbine. Various theories help us understand the exact number of blades we might need to fit a particular design.
2) *Aerofoil Selection:* After selection of the blades according the cost and efficiency, the aerofoil section of the blade is of greater importance. The most important factor is availability and cost. Thus generally optimum aerofoil is selected to meet both the needs. There are a number of aerofoil profiles available but only few are suitable to the described wind conditions and meet the efficiency and cost needs.
3) *Output Power Adjustment:* Depending on the output requirements and applications considered, the output power is determined. Generally assumed relatively higher than the requirements due to losses.
4) *Selection Of The Material Of Each Part:* The material of each part should be selected based on its strength and capacity. Materials are one of the most important factors affecting the cost; hence it must be taken care of.
5) *Wind Velocity:* The wind velocity for a given area is determined by the IMD section.
6) *Rotor Diameter:* we know the relationship of power torque and angular velocity. Using this relationship with Betz's law and mechanical and electrical efficiency, the diameter of the rotor is calculated. This diameter leads directly to the height of the tower.
7) *Tip Speed Ratio (TSR):* Specified graphs are available to calculate the tip speed ratio based on number of blades. According to specified range the optimum value can be selected. Based on tip speed ratio number of rotations can be directly calculated also the local tip sped ratios can be calculated.
8) *Angle of Attack:* Completing stressing on the blade geometry the angle can be calculated, hence the angle of attack can be calculated. Angle of attack for a blade should be in between 6-8º. Angle of attack is an important dimension as the lift and drag forces directly depends on it. Angle of attack directly influences the forces and twist which is also calculated after angle of attack.
9) *Lift and Drag Forces:* These are the two main driving forces on the blade. The coefficients of lift and drag along the angle of attack and area help us to calculate the forces. Lift forces should be maximum and drag forces should be minimum. After calculating the forces with the help of coefficients of lift and drag the chord lengths can be calculated.
10) *Dimensions of wind Lens:* Based on the empirical relationships and the vorticity concept the dimensions of wind lens can be calculated. The radial arms that hold the lens should be designed and the materials for the lens and radial arms along with nacelle should be selected.
11) *Modelling the Dimensions:* The above calculated data is modelled into a cad model with the help of software such as CATIA or SOLIDWORKS.
12) *Analyzing:* The results of the model is been studied and conclusion will be drawn.

VI. THEORETICAL DESIGN OF WIND LENS

Wind lens is a shrouded brim that completely works on the principle of vorticity and pressure. We know that as pressure increases velocity of the fluid decreases. The density of air in the particular region is usually constant at marine level with 15 ° C. The air contains density of about 1.225 kg/m3 agreeing to ISA. Knowing that velocity and pressure are inversely proportional and velocity cube is directly proportional output power we can make use of this concept in order to increase the output.

In continuum mechanics, the vorticity could be a pseudo vector field that depicts the nearby rotational movement of a continuum close to a certain point (the ability of something to turn) as a spectator at that time would see it there and travel with the stream.

Theoretically, the vorticity might be decided by checking the portion of a continuum in a little neighborhood of the point in address, observing their relative relocations as they move along the stream. The vorticity vector would be double the mean angular speed vector of these fragments with respect to their center of mass, situated agreeing to the right hand rule. This amount should not be confused with the angular speed of the fragments with respect to another place. More promptly, the vorticity may be a pseudo vector field$\vec{\omega}$, which is called as curl (twist) of the stream velocity $\vec{u}$vector. The characterization is often indicated by the vector analysis equation:

$$\omega = \nabla \times \vec{u}$$

While∇ represents the operator Del. The vorticity of a 2D stream is generally at right angle to the plane of the stream and thus often thought of as a scalar quantity.

The vorticity is associated to the circulation of the stream (linear integral of the speed) along a closed way by Stokes' hypothesis. In other words, for any minuscule surface component C of ordinary heading $\vec{n}$ and region dA, the circulation dΓ across the circumference of C is the dot product $\vec{\omega}$ (dA$\vec{n}$) while $\vec{\omega}$is the vorticity by the centre about C.

Wind lens is a simply shrouded brim, where at the exit vortices become parallel to each other thus leading to a low pressure zone at the centre creating increase in the velocity that leads to increase in power output. If the pressure difference is twice then the velocity increased is also twice thus substantially increasing the power output. Due to this advantage the size of the turbine is reduced and hence reducing the cost of turbine. Due to the brim, the chances of bird attack are reduced. Wind lens calculations are as follows, The Geometry of the Lens is as shown in Figure:

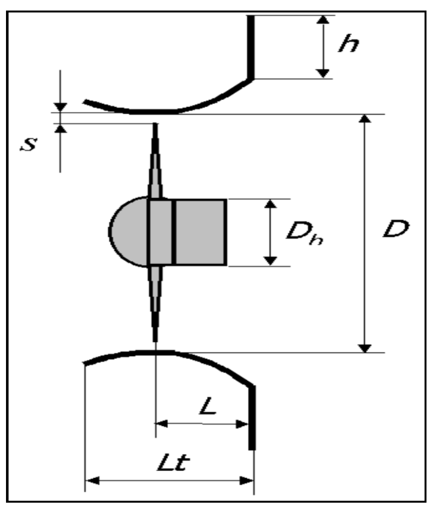


Fig.4: Geometry of wind lens

D_h = Hub Diameter (m)
D = Brim Diameter (m)
L = Length Of brim (m)
Lt = Total length $(m)H$ = Flange height (m)
$H_t = s$ = Clearance between the brim and the turbine $(\%)$

According to the empirical relations that have been achieved by Kyushu University the following relations have been used to determine the lens dimensions.

Hub diameter/Brim diameter = 0.2
We know that Hub diameter = 0.264m
Thus,
Brim diameter = Hub diameter/0.2
$D = 0.264/0.2$
$D = 1.32m$
Diameter of the brim is ***1.32m.***
Now,
Length of brim/Diameter of brim = *0.225*
Length of brim = *0.225 × Diameter of brim*
$L = 0.225 \times 1.32$
$L = 0.22m$
Length of brim is ***0.22m***.

A. *Tip Clearance*

H_t = *1.5% of Diameter of brim*

$$H_t = \left(\frac{1.5}{100}\right) \times 1.32$$

$H_t = 0.0198m$
$Ht = 2mm$
Thus tip clearance is *2mm.*

B. *Flange Height h*

Flange height/diameter of brim = *0.1*
$H/D = 0.1$
$h = 0.1 \times D$
$h = 0.1 \times 1.32$
$h = 0.132m$
Thus, flange height is 0.132m.
Hence the final dimensions of the lens are as follows.

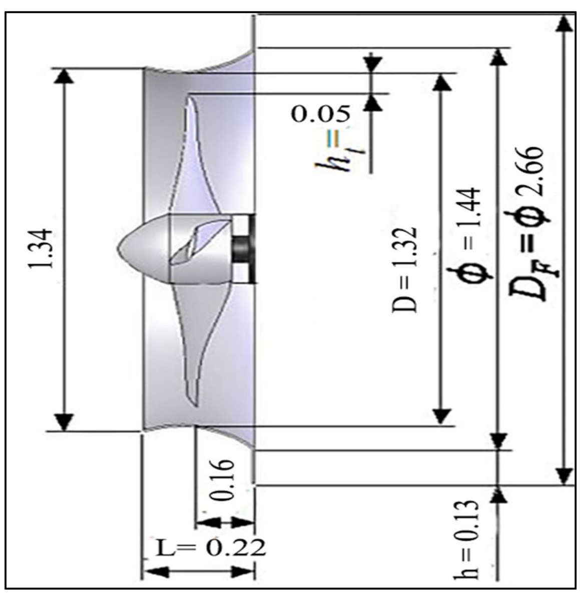


Fig. 5: Wind Lens with dimension

VII. COMPUTATIONAL FLUID DYNAMICS ANALYSIS OF WIND LENS

Along computational fluid dynamics, we show the numeral result of the differential equations administering the flow about fluids, using personal computers. This strategy presents a vast selection of engineering uses. Within the field of aerodynamic experimentation, this system has ended up more and more dominant and important to the study of turbo machines.
Several valuable advantages are obtained following an approach CFD of fluid dynamics issues:

1) CFD is definitely cheaper as well as faster. The significant lessening of your schedule with troubleshooting price can be obtained compared to normal methods. The responsive evaluation of various results is present within first stage of the plan procedure, to match the assignments required. Hence, empirical analysis will get performed only upon some prototype, resulting among the CFD analysis.
2) Full-size examination is difficult to carry out for huge frameworks, such as advanced wind turbines, or utmost thermo-flow situations as well as contract geometries. A CFD analysis may be an appropriate option in such cases.
3) Key— one of CFD's most important features is the detailed solutions that modern technologies (computer innovations) allow, indeed for time-dependent streams and compound frameworks.
4) Numeral prototypes of the physical issues have great exactness and unwavering quality, again because of the latest scientific enhancements to arrangement plans and turbulence prototypes.
5) Owing to the final two approaches, in most of cases the forecast of a fluid dynamic issue does not require a committed effective workstation and occasionally an individual computer may enough.
6) Numerical modeling of a fluid dynamics case initially involves an accurate perusing of physical occurrence. All significant highlights in that first step must be indicated together with geometry, materials, and boundary conditions, to be determined simply, but without presenting extraordinary blunders into the speculation. However, many simplifications are continuously acknowledged and inescapable to correctly demonstrate fluid dynamic issues.

After four cases, the models were studied with an inlet condition of 6 m/s wind speed, and results in pressure drop with average speed were observed in the different locations of wind lens.

A. CFD Results of Straight Wind Lens without Brim

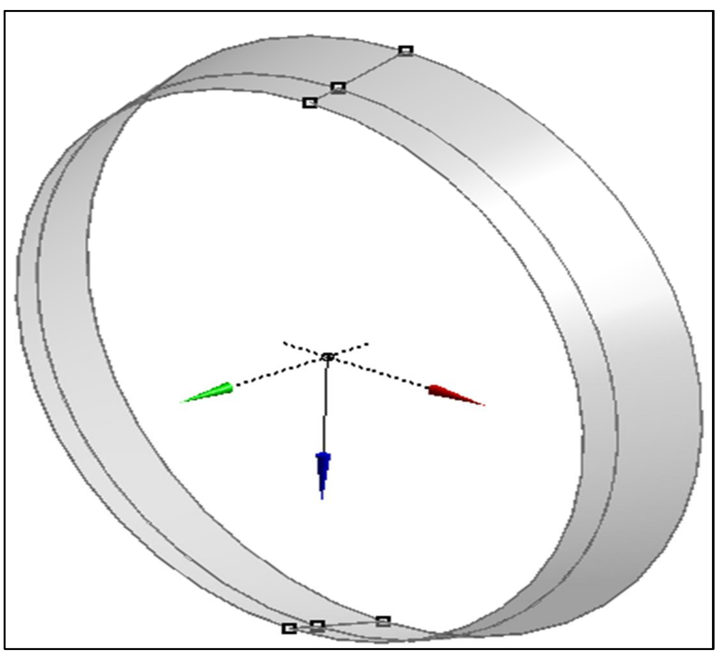


Fig. 6: Design Straight Wind lens without brim

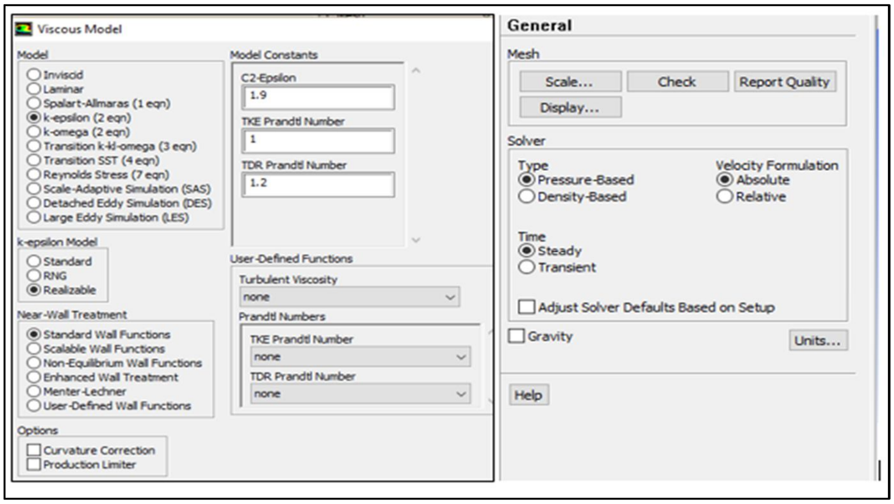


Fig. 7: Analysis Settings Used

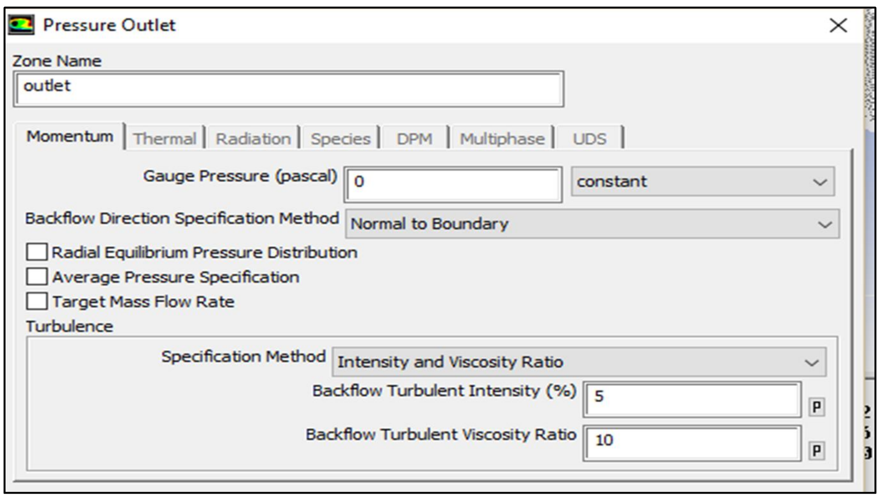


Fig.8: Outlet Boundary Condition

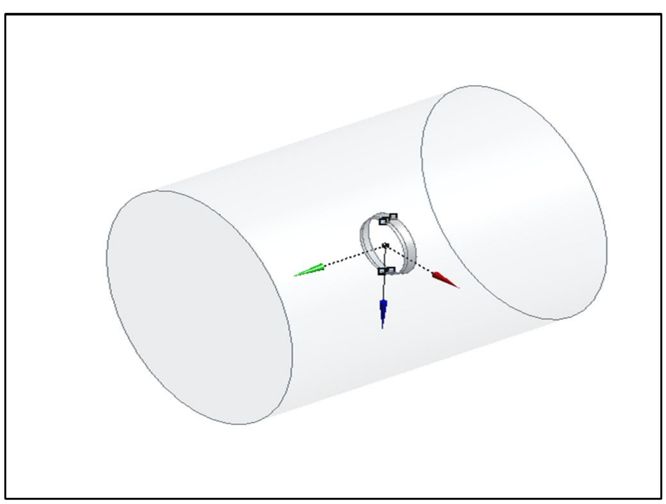
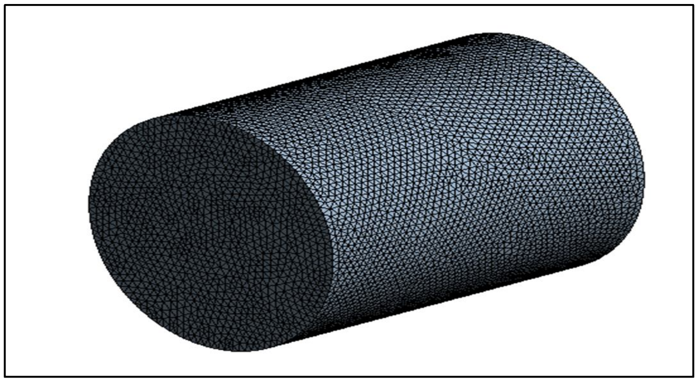


Fig.9: Geometry for CFD Flow Analysis



Statistics	
Nodes	567426
Elements	1946876
Mesh Metric	None

Fig.10: Meshing Statistics and Meshed Model Image

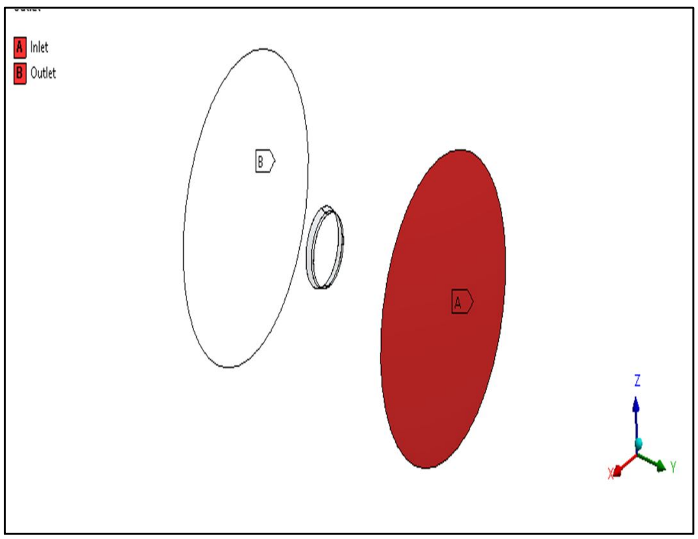


Fig.11: Inlet and Outlet Name Selections

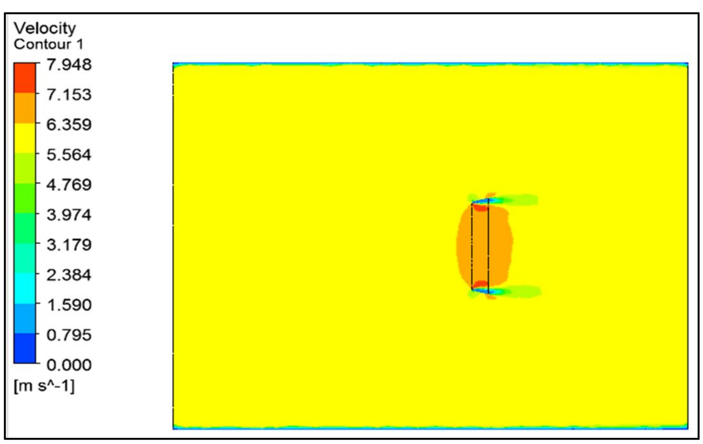


Fig.12: Velocity Plot at C/S

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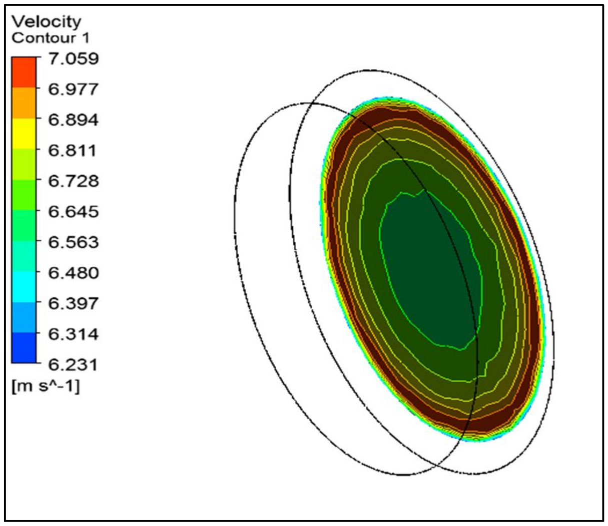

Fig.13: Average Velocity at cross section outlet 6.17 m/s – in 0.3 m radius region

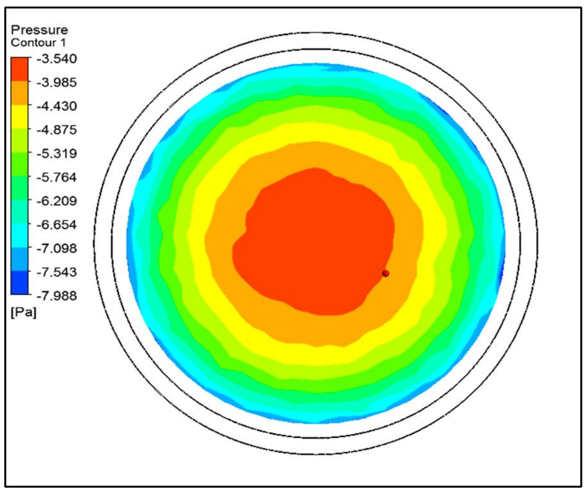

Fig.14: Pressure at Inlet -4.65 Pa

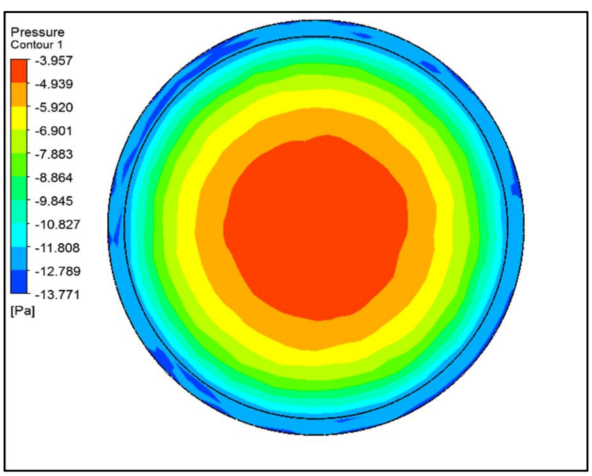

Fig.15: Pressure at Outlet -6.61 Pa

Total pressure drop across the wind lens observed as 1.96 Pa.

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B. CFD Results of Curved Wind Lens with Brim

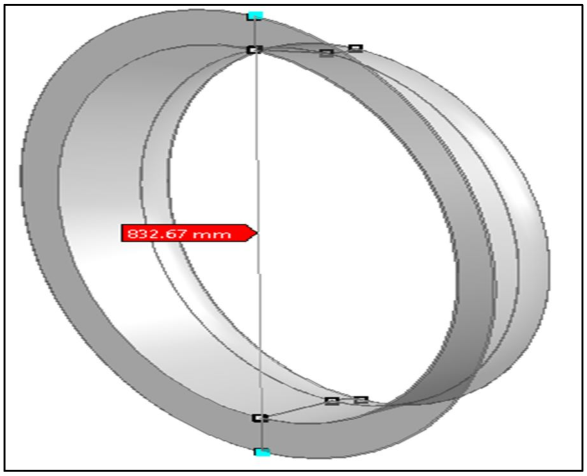


Fig.16: Dimension Curved Wind Lens with Brim

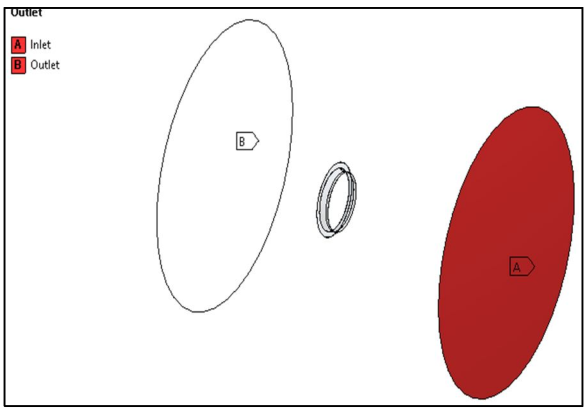
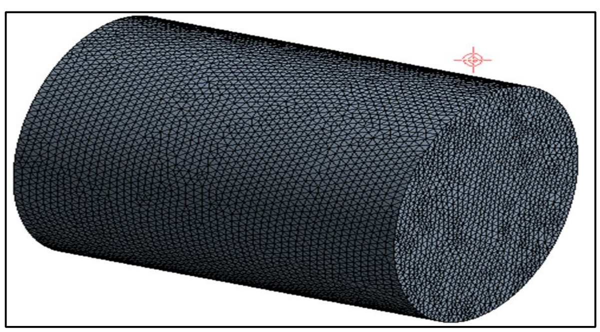


Fig.17: Selection Components



Statistics	
Nodes	141224
Elements	614331
Mesh Metric	None

Fig.18: Meshing Statistics

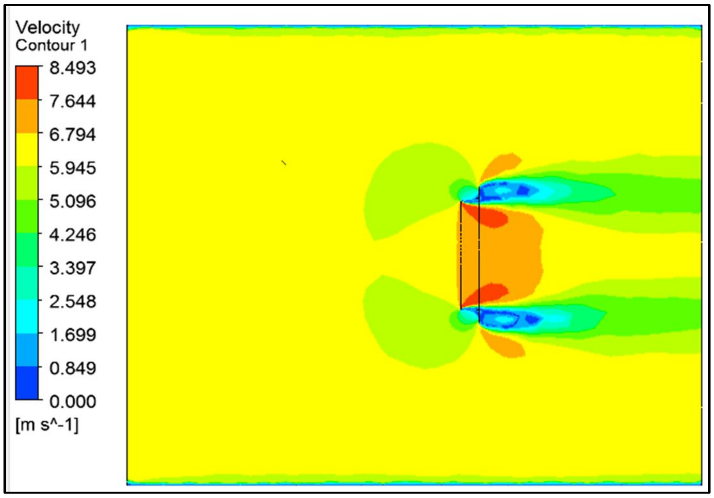


Fig.19: Velocity Plot at Cross section

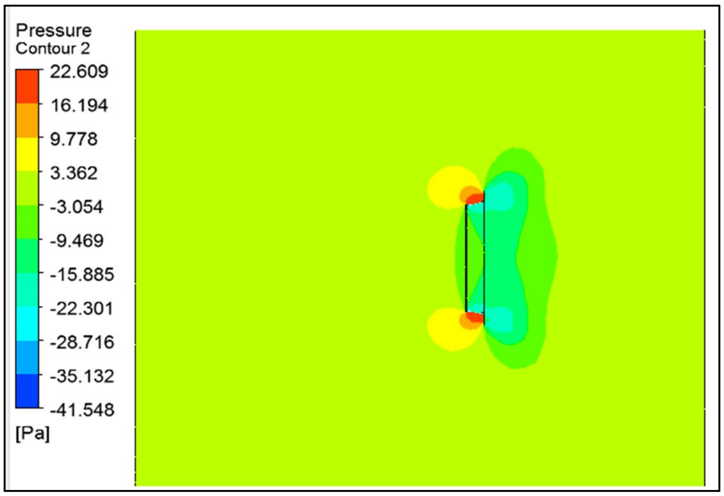


Fig.20: Pressure Plot at Cross section

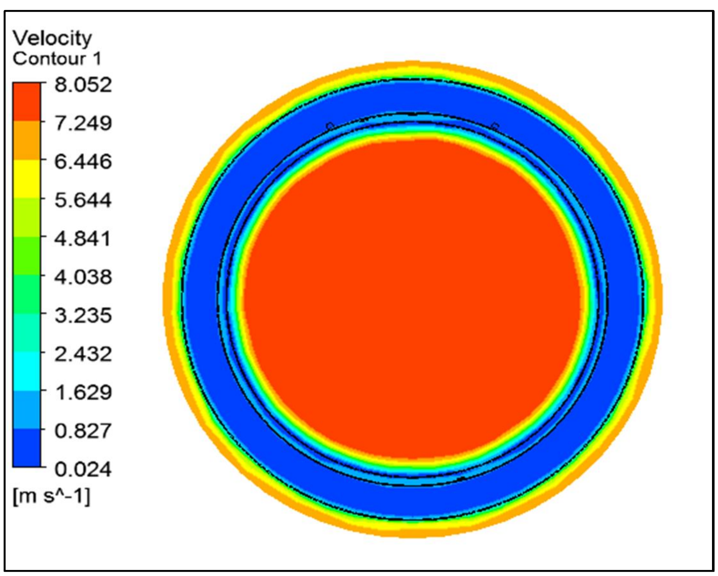


Fig.21: Average Velocity at cross section outlet 6.7 m/s – in 0.35 m radius region

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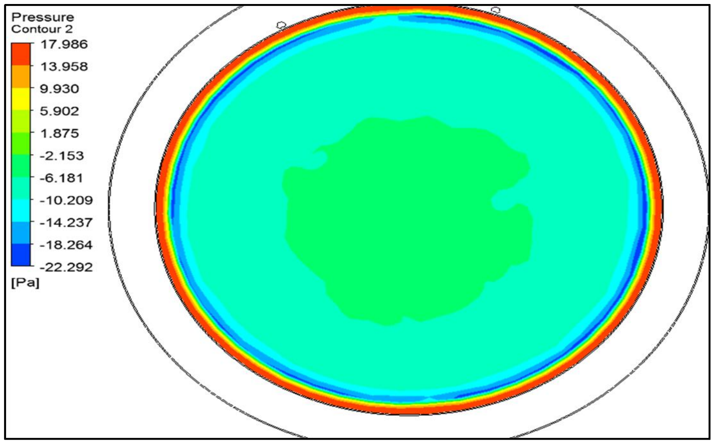

Fig.22: Pressure contour at Inlet with Avg pressure -5.84 Pa

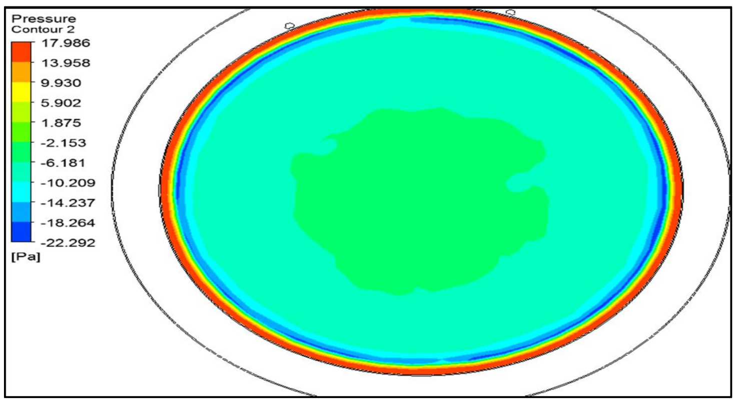

Fig.23: Pressure Contour at Outlet with Avg. Pressure of -12.64

Total pressure drop across the wind lens observed as 6.8 Pa.

VIII. RESULTS

Table No.1: CFD Results

Sr. No.	Diffuser	Pressure (N/m^2)			Velocity (m/s)		
		inlet	outlet	Pressure drop across diffuser (Pa)	Inlet	centre	outlet
2	Straight without brim	-6.61	-4.65	1.96	6	6.83	6.17
3	Straight with brim	-0.56	-15.22	14.66	6	7.91	6.32
4	Curved without brim	-6.9	-5.59	1.31	6	6.99	6.57
5	Curved with brim	-5.84	-12.64	6.8	6	7.3	6.7

IX. CONCLUSION

A. General study of the wind energy utilized for electricity generation through wind turbines is performed and literature referring to power generation using wind energy in the low wind velocity region is studied through extensive literature survey.
B. Wind lens has proved to be option which has been proven useful for increasing the wind energy concentration around the wind blade in the regions where quality of wind energy (wind velocity) is not available throughout the year.
C. Wind lens dimension height of the flange for the wind lens for low velocity region is designed.
D. Parametric study of the wind lens flange angle will be performed in the future work on this project using CFD to understand the impact of the same on the performance of the wind lens.
E. Also the impact of brim parameter changing will also be captured using CFD analysis.
F. We have CFD analysis for 4 different types of wind lens & find different results. We find the best result for straight wind lens with brim.
G. Velocity for straight wind lens with brim at centre is 7.91 m/s which is maximum in all results.
H. Pressure drops at diffuse for straight wind lens with brim is 14.66 Pa

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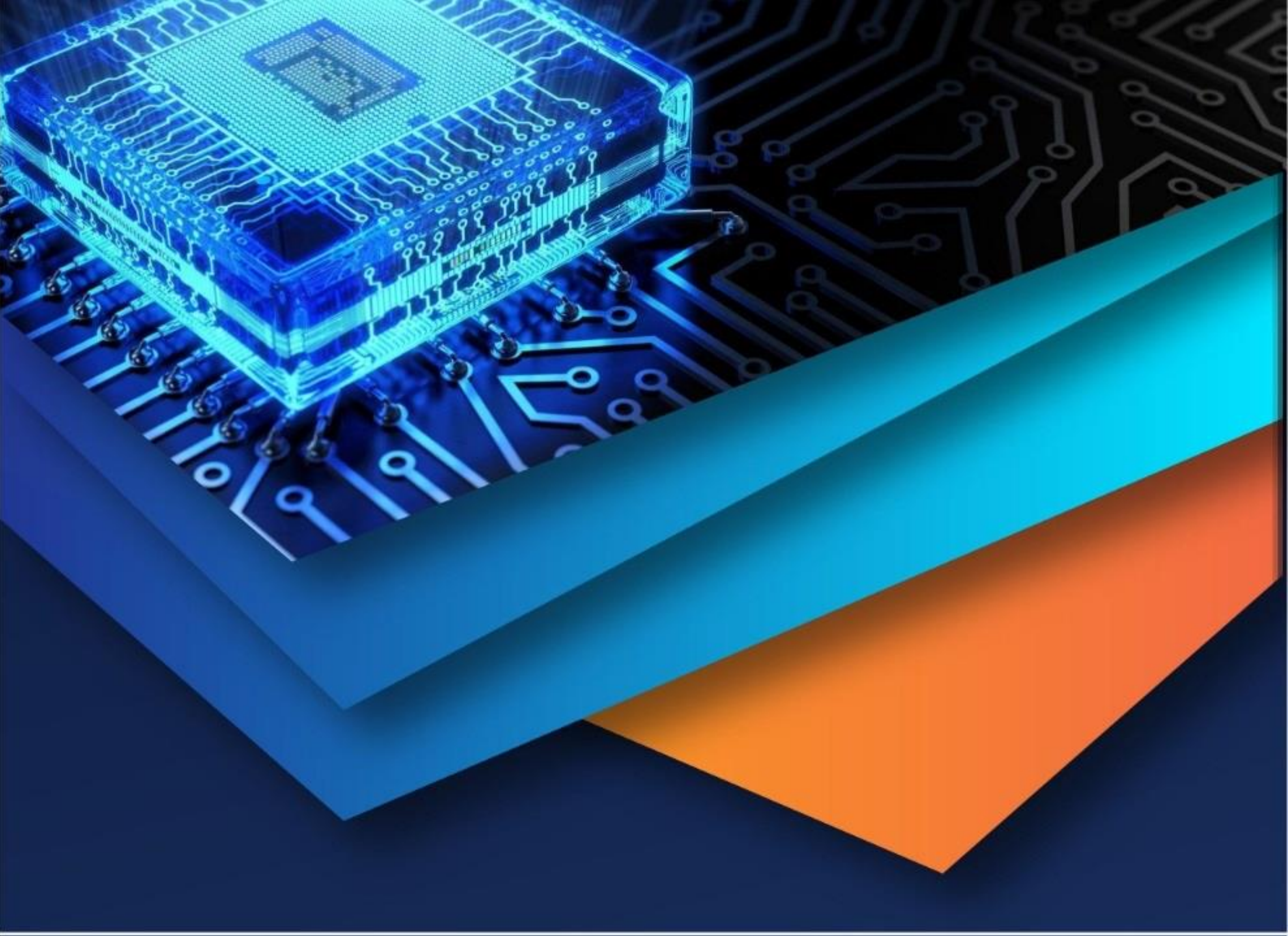

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