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Numerical Analysis of Savonius Wind Turbine Using Fluid Dynamics

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Abstract: The purpose of this paper is to numerically analyze the Savonius wind turbine to design a wind turbine to capture wind energy from vehicles on the highway and from Seashore. Wind energy is considered the fastest growing clean energy source. However, it is limited by variable natural wind. Highways and Seashore can provide a considerable amount of wind to drive a turbine. This energy is unused. Extensive research on wind patterns is required to determine the average velocity of the wind created by vehicles. The wind turbines will be placed on the medians therefore air flow from both sides will be considered in the design. Using all of the collected data, existing streetlights on the medians can be fitted with these wind turbines. Since the wind source will fluctuate, a storage system for the power generated will be designed to distribute and maintain a constant source of power. Ideally, the turbine can be used globally as an unlimited power source for streetlights and other public amenities.

Keywords: Savonius wind turbine, Vertical Axis wind Turbine, Computational Fluid Dynamics

I. INTRODUCTION

A wind turbine is a device that converts kinetic energy from the wind into electrical power. 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.

The Savonius wind turbine was invented by the Finnish Engineer Sigurd Johannes Savonius in 1992. However, Europeans had been experimenting with curved blades on vertical wind turbines for many decades before this. The earliest mention is by the Italian Bishop of Czanad, who was also an engineer. He wrote in his 1616 book Machinae novae about several vertical axis wind turbines with curved or V-shaped blades. None of his or any other earlier examples reached the state of development made by Savonius. In his Finnish biography there is mention of his intention to develop a turbine-type similar to the Flettner-type. Aerodynamically, it is a drag-type device, consisting of two or three scoops. Looking down on the rotor from above, a two-scoop machine would look like an "S" shape in cross section. Because of the curvature, the scoops experience less drag when moving against the wind than when moving with the wind. The differential drag causes the Savonius turbine to spin. The Savonius turbine blade is shown in Figure 1. Because they are drag-type devices, Savonius turbines extract much less of the wind's power than other similarly-sized lift-type turbines. Much of the swept area of a Savonius rotor may be near the ground, if it has a small mount without an extended post, making the overall energy extraction less effective due to the lower wind speeds found at lower heights.

The effect of blade aspect ratio, blade overlap and gap besides the effect of adding end extensions, end plates and shielding were tested by Alexander and Holownia [1]. The test was carried out in a wind tunnel on a number of Savonius rotor geometries with wind speeds ranging from 6 to 9 m/s. They concluded that, there is an improvement in rotor performance with increasing the aspect ratio. The tests for three and four bladed geometries gave appreciably lower values of efficiency than two blades rotor. They used four values of the extensions and found that the efficiency increases with the increase of the extension. They concluded also that the efficiency for the rotor with end plate and shielding is greater than that with end plate and without shielding. Furthermore, the efficiency obtained for a rotor with end plate and without shielding is greater than that of rotor without end plate. They found also that, increasing the rotor overlap ratio increases the rotor efficiency.

Fig. 1. Savonius turbine blade

Modi et al [2] reported that the optimum values of the aspect and overlap ratios are 0.77 and 0.25 respectively. Mojola [3] examined the performance of Savonius wind rotor under seven values of the rotor overlap ratio namely 1/8, 1/5, 1/4, 1/3, 1/2, 3/4 and 7/8. He concluded that the effect of overlap ratio on rotor performance depends on its tip speed ratio (k ¼ x R=V) where x is the angular speed, R is the rotor radius =D/2 and V is the wind speed. The aerodynamic performance and the flow fields of Savonius rotors at various overlap ratios have been investigated by Nobuyuki [4]. The static torque performance of the rotor, specially of the returning blade, is improved by the presence of the overlap and the best value of the overlap is 0.15.

Menet [5] aimed to construct a prototype of Savonius turbine to charge a battery. He used blades from plastic tube (PVC) and steel shaft. He utilized a rotor with aspect ratio of 4 and overlap of 0.25. He found that starting velocity was 3 m/s, velocity for maximum production is 13 m/s and the mean efficiency between 5 and 10 m/s was found to be 29%. The range of speed rotation was 200– 800 rpm. Kamoji et al [6] examined helical Savonius rotors in an open jet wind tunnel. From their results, the helical rotors with shaft have lower power coefficient than the helical rotors without shaft.

Saha et al [7] carried out a comparison between Savonius rotor with different geometries. They reported that, the optimum number of blades is two for the Savonius rotor whether it is single-, two- or three-stages. Twisted geometry of the blade profile has a good performance as compared to the semicircular blade geometry. Two-stages Savonius rotor has better power coefficient as compared to the single- and three-stage rotors. Altan et al [8] studied the curtain arrangement using two plates, one in the upper end of rotor and the second at the rotor lower end. This arrangement is used to prevent the air leakage from the concave side. They concluded that the arrangement increases the rotor performance. They used three curtaining arrangements by changing the two plate lengths and its angle on the horizontal axis. The results showed that the curtaining which has longest plates is better and the optimum angle is 15 on the horizontal axis for the upper plate and 45 for the lower one.

The notations which are used for the calculations are:

E	- Kinetic Energy (J)
ρ	- Density (kg/m^3)
m	- Mass (kg)
A	- Swept Area (m^2)
v	-Wind Speed (m/s)
C_p	- Power Coefficient
P	-Power (W)
r	-Radius (m)
dt/dm	-Mass flow rate (kg/s)
x	-distance (m)
dE/dt	-Energy Flow Rate (J/s)
t	-time (s)

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II. MATHEMATICAL MODEL

Figure 2 shows the design of the blade. In reality the blade is made up of fibre reinforced plastic (FRP) i.e. (POLY CARBONATE) This turbine works in a similar fashion as that of all turbine, as the air strikes the blade, the turbine tend to rotate along the direction of wind. One major differentiating factor from other wind turbine is that, it is a vertical axis wind turbine; they do not need much wind to generate the power. Vertical axis wind turbines are quiet, rugged, Omni-directional and they do not create much stress on the support structure.

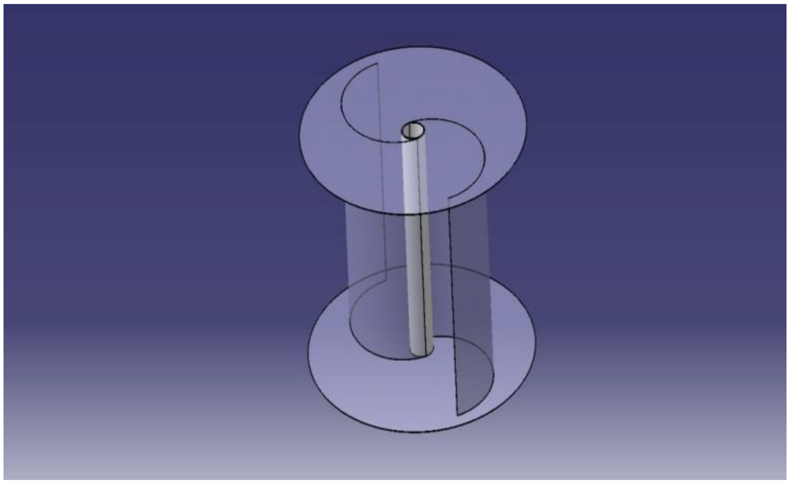

Fig 2. design of the blade

Under constant acceleration, the kinetic energy of an object having mass *m* and velocity *v* is equal to the work done *W* in displacing that object from rest to a distance *s* under a force *F*.i.e.,

$$E = W = F s$$

According to Newton's Law, we have:

$$F = m a$$

Hence,

$$E = m a s \ldots (1)$$

Using the third equation of motion:

$$V^2 = U^2 + 2as$$

We get:

$$a = v^2 - u^2/2s$$

Since the initial velocity of the object is zero, i.e.

$$u = 0, \text{ we get:}$$

$$a = v^2/2s$$

Substituting it in equation (1), we get that the kinetic energy of a mass in motions is:

$$E = 1/2mv^2 \ldots (2)$$

The power in the wind is given by the rate of change of energy:

$$p = dE/dt = 1/2mv^2 dm/dt \ldots (3)$$

As mass flow rate is given by:

$$dm/dt = \rho A dx/dt$$

The rate of change of distance is given by:

$$dt/dx = v$$

We get:

$$dm/dt = \rho A v$$

Hence, from equation (3), the power can be defined as:

$$P = ½ \ \rho A v^3 \ldots (4)$$

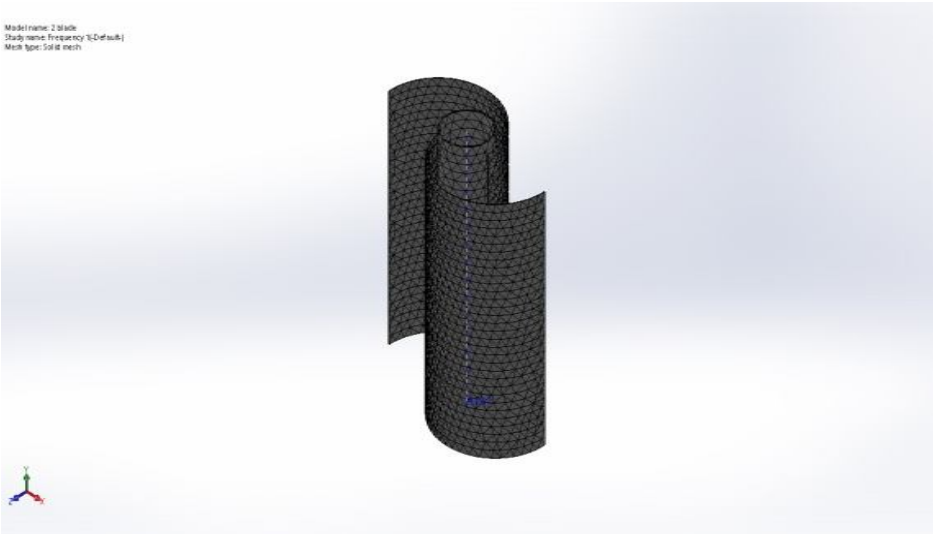

Fig 3. Meshing of Two blade

III.NUMERICAL METHOD

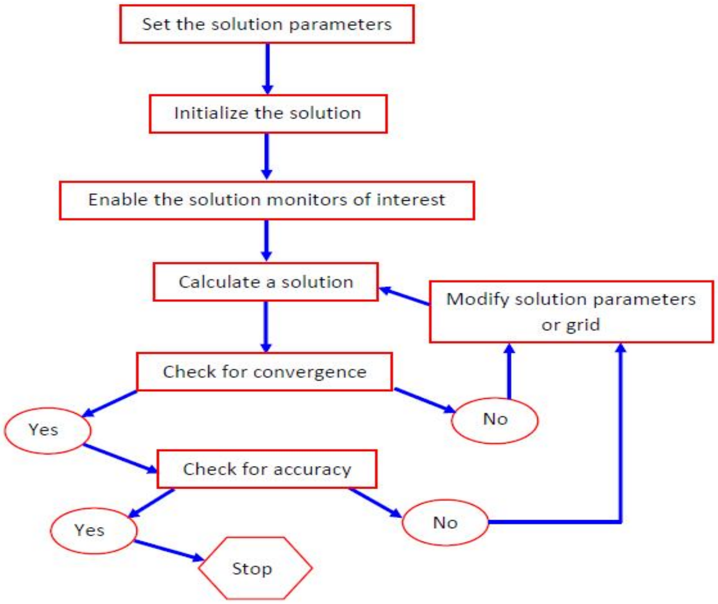

Fig 4. Methodology

Initially, the model created using modelling software was imported into the meshing software in the required format. The model which represents a single volume is being segregated into two volumes, fluid and solid. Then the two volumes where meshed separately with tet/hybrid elements and the necessary cell zones were specified in Figure 3. A brief description of the methodology is shown in Figure 4. In the next step, model in the required format was imported into the analysis software where the results are simulated. As a first step a grid check is performed to verify the perfectness of the mesh. Now the various boundary conditions involved in the model is set. The pressure based solver was selected and Green-Gauss cell based method was used to solve the problem. The first order upwind scheme was used to model the convective terms of the governing equations, while the second-order central difference schemes were employed for the viscous and source terms. Finally, the problem set is being initialized and an efficient, iterative scheme with solution algorithm was used to solve the problem. The solution monitors of interest where enabled before the iteration starts to view the progress. The solution converged at approximately four hundred and sixty eight iteration. Prior to computation, a thorough verification of the grid-independence of the numerical solution was performed in order to ensure the accuracy and validity of the numerical results. The above analysis procedure is repeated for the remaining input parameters.

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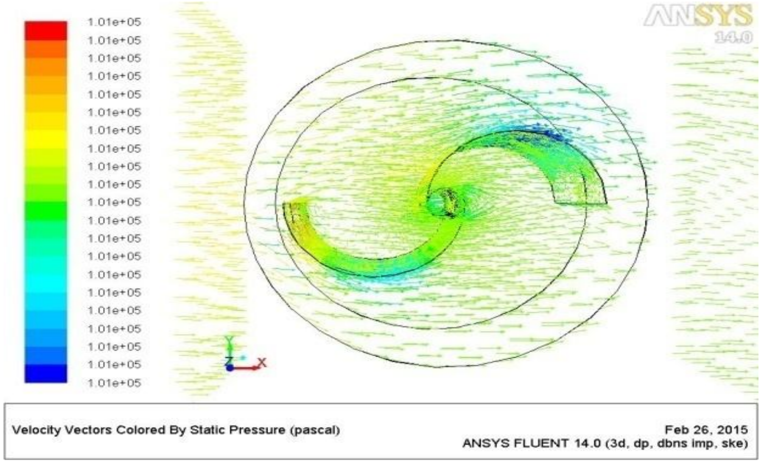

Fig.5. Velocity Vector by Static Pressure

IV. RESULTS AND DISCUSSIONS

Using Solidworks, it was possible to model the fluid flow through our designed Savonius rotor. Once again the importance of offsetting the hemispheres by 1 radius was demonstrated. As the fluid flows through the inlet, it bounces off the wall and escapes through the outlet. This fluid analysis was completed after the prototype was built confirming the theory Based on the above values the analysis of the wind turbine is done. By that analysis we got 2423 Nodes and elements of 4302. And the solution is converged at 193. The computational results of such velocity vector by static pressure and their velocity magnitude as shown in Figure 5 and 6.

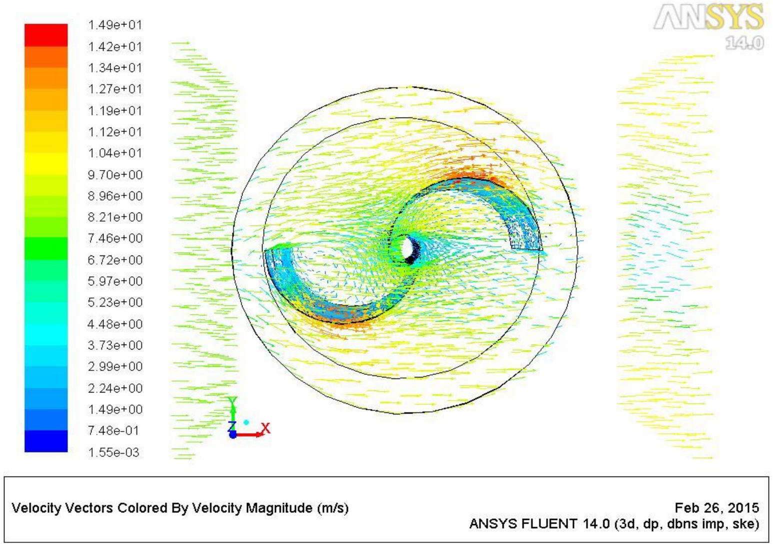

Fig.6. Velocity Vector by Velocity Magnitude

A. Input Values

1) Boundary : Rectangular Boundary
2) Area : 1 m^2
3) Density : 1.225Kg/m³
4) Temperature : 300k
5) Pressure : 101325pa
6) Velocity : 8m/s
7) Viscosity : 1.7894e^{-5} kg/ m s
8) Specific heat : 1006.43J/Kg k

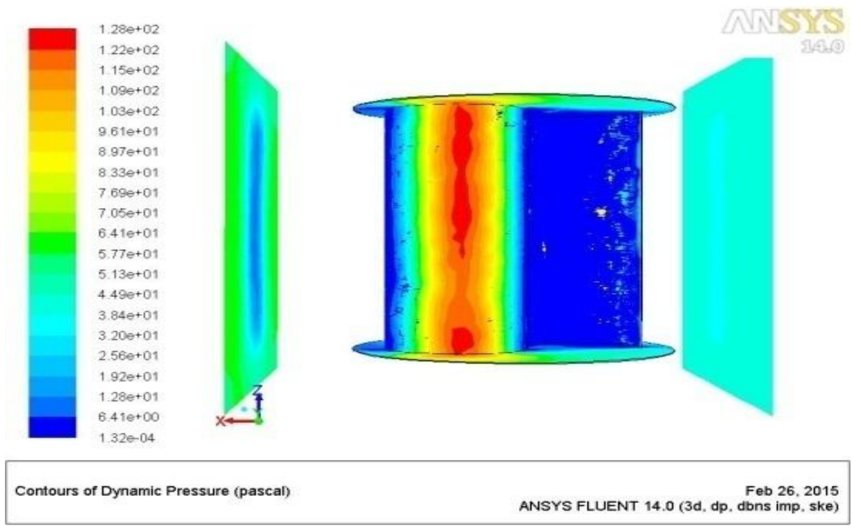

Fig.7. Contour of Dynamic Pressure

The pressure created by the velocities on the blades of the wind turbine. The maximum pressure created is 1.28e^{+02} pa and minimum pressure is 1.32e^{-04} pa. The computational results of Contour of dynamic pressure as shown in Figure 7.

V. CONCLUSIONS

On doing the analysis we are taking rectangular layer as the boundary for our analysis and also the analysis is density based one. Due to this density based analysis result of the analysis will be more accurate. Since we are going to place our wind turbine in highway or seashore we took basic atmospheric pressure and temperature as the environmental condition. Based on the statistics we give 8m/s as the velocity of the wind at the inlet condition. The analysis solution control is based on the formulation of implicit. We set the Rectangular Boundary of 1200mm x 500mm.In that we have triangular Mesh. The analysis is based on the Density and the velocity formulation is absolute. The equation of the analysis is K-Epsilon Turbulence. This type of numerical analysis could be useful for the development of similar type of savonius wind turbine.

VI. SCOPE FOR IMPROVEMENT

A. Reducing the weight of the Turbine by using Composite Material such as FRP etc.
B. Testing the Output by using the Horizontal Axis Wind Turbine.
C. Attaching the Compound Gear to Increase the Output.
D. Improving the Blade Design by using helical Blade.
E. Improving the Gear Design by using helical Gear.
F. By making it as hybrid, we get the continuous Power Supply even less rate of wind Energy.
G. When the electrical energy is not required, this setup can be utilized for generating Hydraulic Energy.
H. To make the set up Portable.
I. To make a battery setup for continuous power supply to the LED Light.

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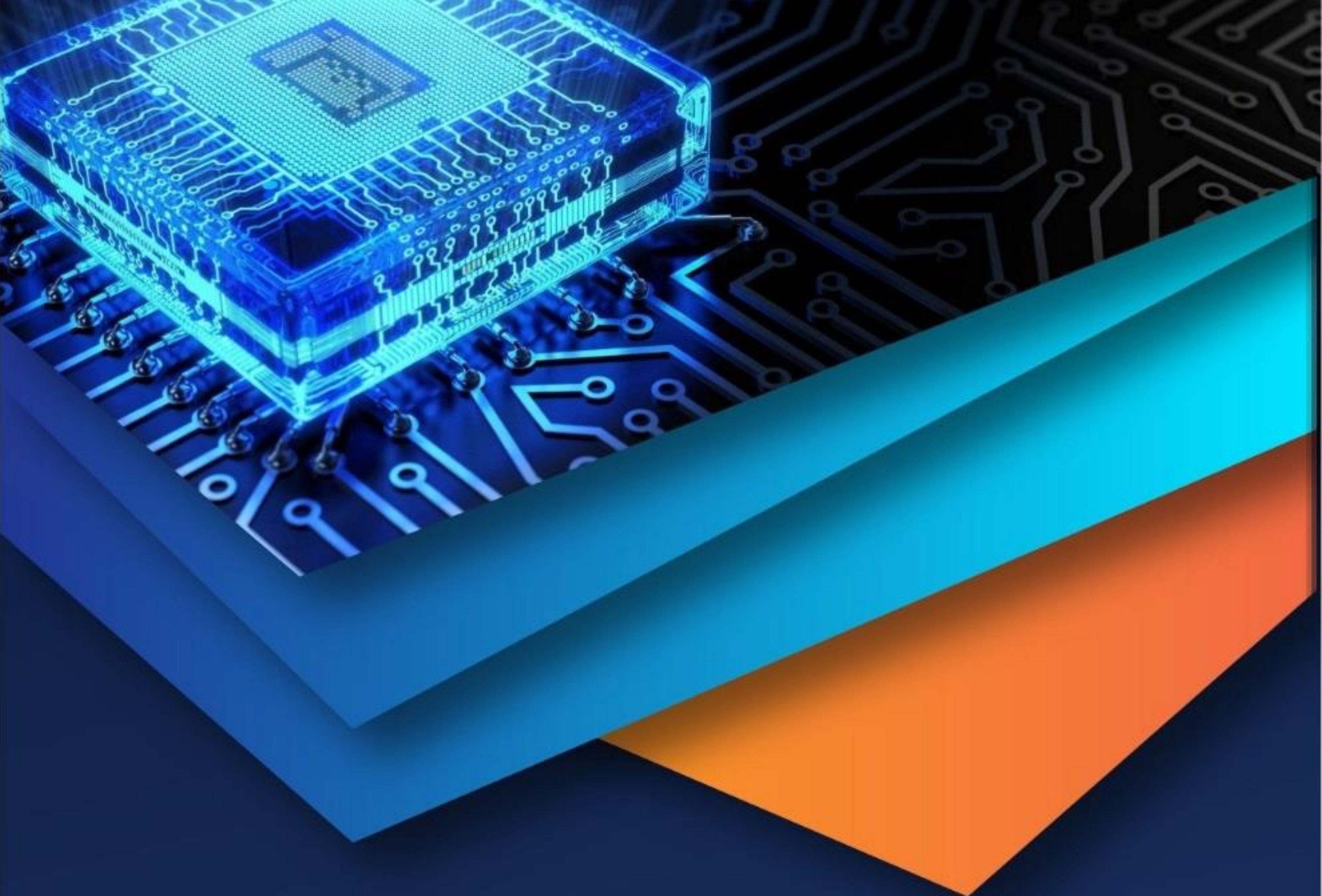

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