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Simulation of Micro Wind Turbine Blade in Q-Blade

Mr. Shubham Raut[1], Mr. Shubham Shrivas[2], Mr. Rohan Sanas[3], Mr. Navjyot Sinnarkar[4], Prof. M. K.Chaudhary[5]
[1,2,3,4,5] *"Trinity academy of engineering", Department of Mechanical Engineering*
Savitribai Phule Pune University, Pune, India.

Abstract: This paper consists of design and optimization of micro (less than 1 KW) wind turbine blades at rated wind speed 8.4 m/s. SG6043 airfoil is selected as it gives maximum lift coefficient of 1.63. Simulation of blade length of 1.2m is done by using Q-blade software and optimized values of chord length and twist angle at each respective section are calculated by mat lab programming. Multiple parameter BEM simulation is done in Q-blade and graphs of C_p and power is plotted against tip speed ratio. While considering the rotor radius flange, hub and shaft radius is considered in it. Maximum value of power coefficient (C_p) at rated wind speed of 8.4 m/s is observed to be 0.45 in Q-blade simulation.
Keywords: Micro wind turbine, Q-blade, power coefficient, simulation.

I. INTRODUCTION

Flow of the air is caused due to pressure gradient in the atmosphere, i.e. wind flows from high pressure zone to low pressure zone. Wind is clean, green and renewable source of energy. Understanding the need for renewable sources, few scientists came forward such as Albert Betz, Palmer Putnam, and Percy Thomas [1] and the conversion of wind to useful form of energy came into account. Kinetic energy of wind is converted into mechanical energy for generation of electricity.

A. Micro Wind Turbine

Small wind turbines are categorized as micro (1kw), midrange (5kw) and mini wind turbines (20kw+) [2].Concentrating the need for small house and low wind speed for micro wind turbine was selected.

B. Effect of Reynolds Number

Reynolds number is the ratio of inertia force to viscous force.

$$Re = \frac{\rho V D}{\mu}$$

As density and dynamic viscosity for air is constant under normal condition, Reynolds number will vary according to changes in velocity and rotor diameter. Laminar flow is expected for Airfoils at low Reynolds number. Flow separation may occur due to formation of bubbles [3].

C. Micro Wind Turbine Rotor Blades and Effect of Root, Flange and Hub on Blade Design

While designing the blades for micro wind turbine, rotor radius is taken from centre including radius of shaft, hub and flange.

Rotor radius = R_s + (R_H-R_s) + (R_F-R_H) + length of blade from chord '1'.

R_s= Radius of shaft

R_H= Radius of Hub

R_F= Radius of flange

II. METHODOLOGY FOR BLADE GEOMETRY

A. Constant Chord Blade Geometry

Constant chord length is taken from root to tip of the blade for variable angle of twist for each section.

B. Variable Chord Blade Geometry

Chord length varies from root to tip of the blade in decreasing order for each section. Also, angle of twist for each section varies.

C. Comparison Between Constant Chord Blade Geometry and Variable Chord Blade Geometry

By considering the following chord length results are plotted in Q-blade. For various tip speed ratios ranging from 1-10 value of

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power coefficient is analysed in Q-blade.

Fig.1 below shows power coefficient [C_p] vs Tip speed ratio[λ] for constant chord and variable chord geometry.

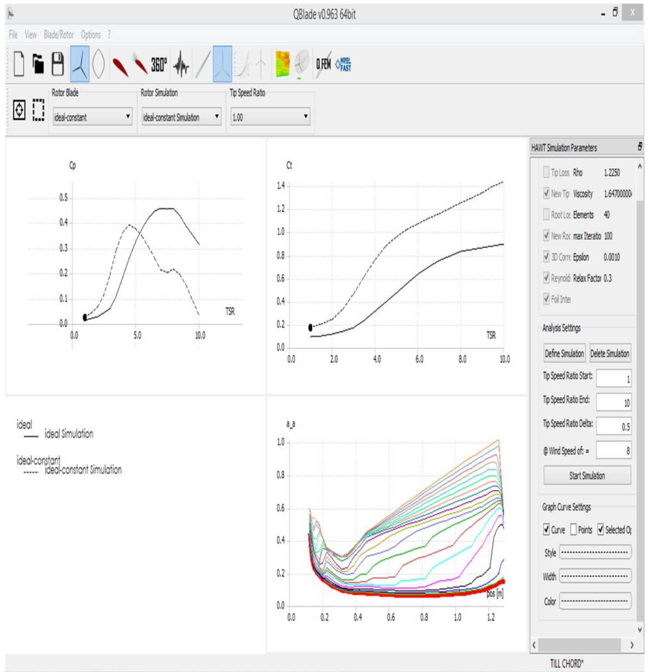

Fig.1 Q-blade analysis.

Dotted curve shows the maximum value of power coefficient i.e. 0.38 at tip speed ratio 4, whereas the plain curve represents maximum value of power coefficient 0.45 for tip speed ratio between 6-8.

As observed from the graphs the value of Cp variable chord length is much greater than constant chord length. Hence, variable chord length blade geometry is selected.

Power (P) = 0.15*D^2*v^3

0.15= $\eta_g \eta_a \eta_{ef} \frac{1}{2} * \rho * \frac{\pi}{4} * C_p$

Chord(c) =$\frac{16\pi}{9N\lambda\sqrt{((\frac{4}{9})+(\lambda r+21)(9\lambda r))^2}}$

Twist angle (φ) = $\tan^{-1}(\frac{2}{3\lambda r})$

η_g= Generator efficiency

η_a= Airfoil efficiency

η_{ef}= effective area of hub

ρ = Density of air

C_p= Power coefficient = 0.59 theoretical.

III. ROTOR SPECIFICATION

Diameter= 2.4m
Hub diameter=0.24m
Effective rotor radius=1.189m
Shaft diameter=0.022m
Airfoil= SG6043
Annual average speed=6m/s
Rated wind speed=8.4m/s
Tip speed ratio=7

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IV. SIMULATION OF BLADE IN Q-BLADE

A. Various Airfoils Compared in Q-Blade Simulation

Airfoils such as NACA 4415, NACA 4420, SG6041, SG6042 and SG6043 are compared.

Fig. 2 shows five different airfoils whose coordinates are imported and plotted in Q-blade. Black coloured dotted curve shows SG6043 blade profile having maximum thickness of 10.02% at 32.01% chord length.

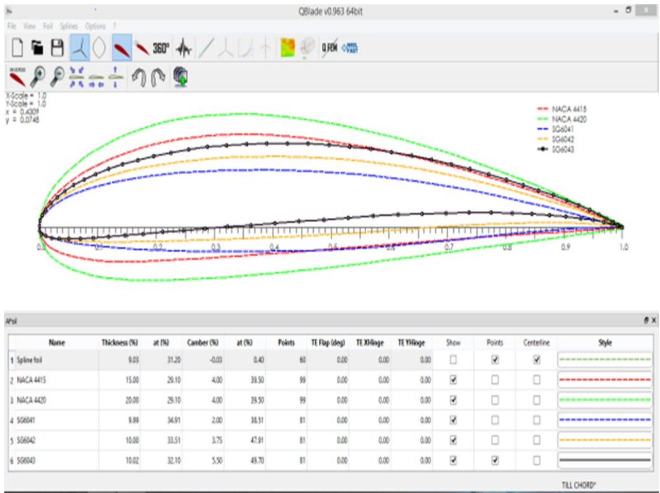

Fig. 2 Comparison of different airfoils.

B. Lift and Drag for Various Airfoils

Lift on body is force on body in a directional normal to flow direction. Drag on body is force on body in direction parallel to flow direction. [4]

Lift to drag coefficient= $\frac{coefficient\ of\ lift}{coefficient\ of\ drag} = \frac{C_l}{C_d}$

Where,

$$C_l = \frac{l}{\frac{1}{2}\rho V^2 A}$$

$$C_d = \frac{d}{\frac{1}{2}\rho V^2 A}$$

A graph of lift coefficient is plotted against angle of attack for 5 different airfoils as shown in Fig.3 below.

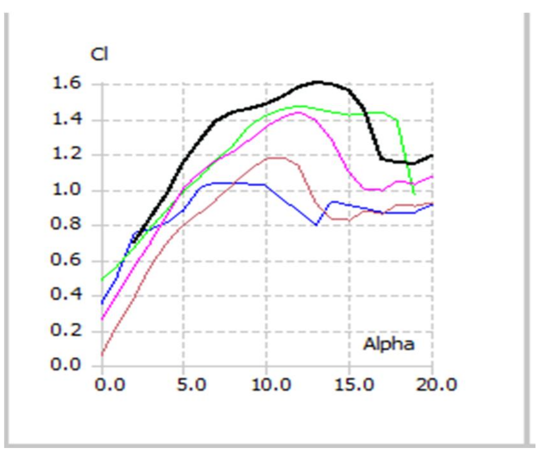

Fig.3 Lift coefficient[C_L] Vs Angle of attack [α].

This graph shows that SG6043 blade profile gives maximum value of lift coefficient 1.63 for angle of attack from8°-14°.The optimized chord and twist angle values are calculated with the help of equation [3][4][5] in mat lab programming. The obtained values of chord and twist angle are tabulated below.

Figure 4 show's lift to drag ratio versus angle of attack for different airfoils.

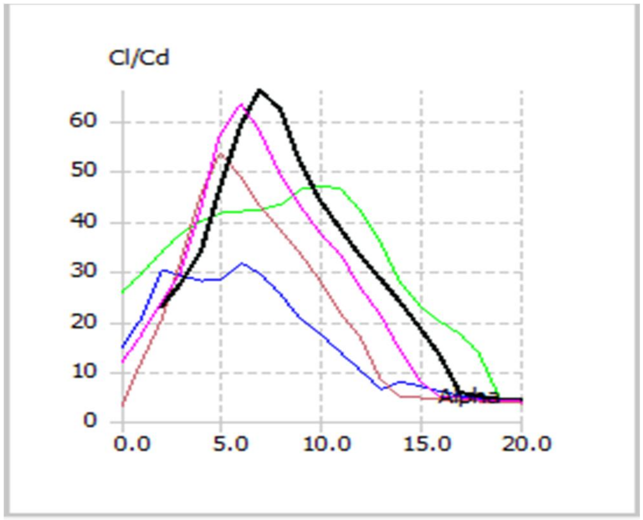

Fig.4 Ratio of Lift coefficient and Drag Coefficient $[C_l/C_d]$ vs Angle of attack[α].

Black coloured curve shows that SG6043 profile gives maximum value of lift to drag ratio for angle of attack 6°-8°.

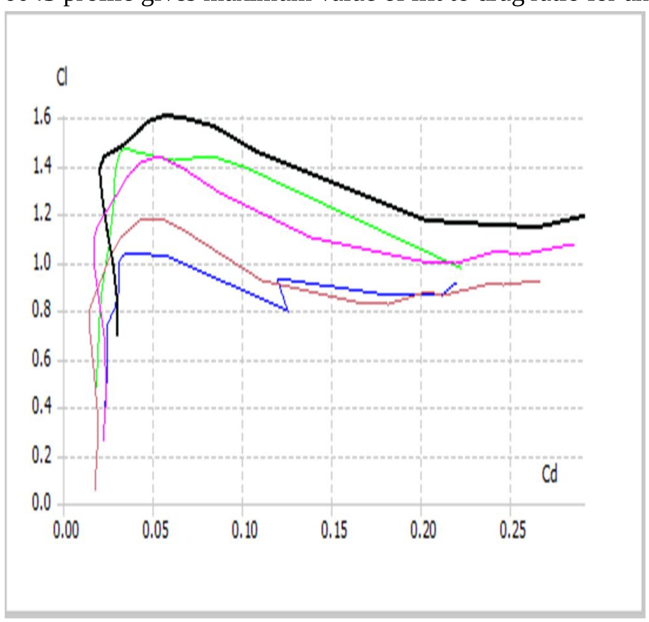

Fig.5 Above graph in figure 5 shows comparison of 5 different airfoils for lift coefficient and drag coefficient values.

NACA 4415
NACA 4420
SG6041
SG6042
SG6043

Above figure shows different airfoils according to colour.

From the results plotted in Q-blade among all the airfoils SG6043 blade profile gives maximum lift coefficient, lift to drag

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coefficient at various angle of attack (α). The maximum lift coefficient of SG6043 is 1.63 at $\alpha = 14^{\circ}$. Hence, SG6043 airfoil is selected.

C. Optimized Chord and Twist Angle for SG6043:

The table below depicts optimized twist angle and chord length values for 10 different sections of 1.17 m blade length.

Sr No:	Position(m)	Chord (m)	Twist angle (Deg.)
1	0.00	0.076	0.00
2	0.09	0.126	15.97
3	0.21	0.100	10.9
4	0.33	0.083	7.72
5	0.45	0.070	5.55
6	0.57	0.061	3.98
7	0.69	0.053	2.80
8	0.81	0.048	1.87
9	0.93	0.043	1.12
10	1.05	0.039	0.51
11	1.17	0.036	0.00

Table.1 Optimised chord and twist angle

D. Blade Model in Q-Blade

Further the optimized chord and twist angle values are entered in Q-blade hence we get three bladed model.

Figure below shows 3 bladed model which is plotted in Q-blade after entering the values of chord and twist for each section respectively.

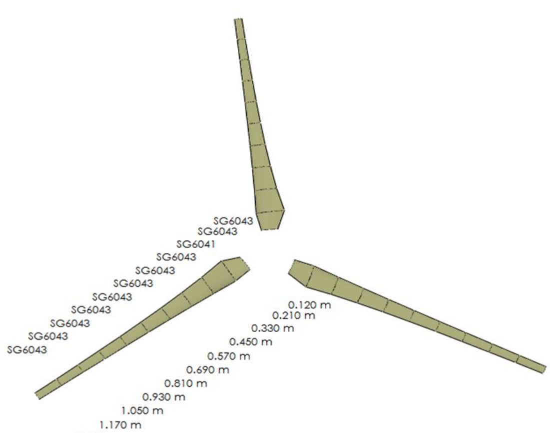

Fig.6 3-Bladed model in Q-Blade.

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E. Simulation of Three Bladed Model

The obtained 3D model is simulated in Q-blade by multi-parameter BEM theory and the simulation is further carried out and the results are obtained of power coefficient (C_P), Power (P) and torque (T) are plotted as follows:

1) Power coefficient [C_P] Vs Tip Speed Ratio [λ].
2) Power [P] Vs Tip Speed Ratio [λ].
3) Torque [T] Vs Tip Speed Ratio [λ].

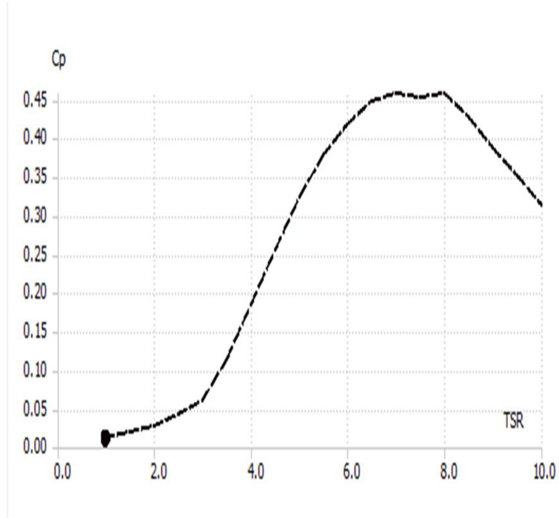

Fig. 7 Power coefficient [C_P]Vs Tip Speed Ratio [λ].

Above graph in figure 7 shows maximum value of power coefficient 0.45 for tip speed ratio 6 to 8.

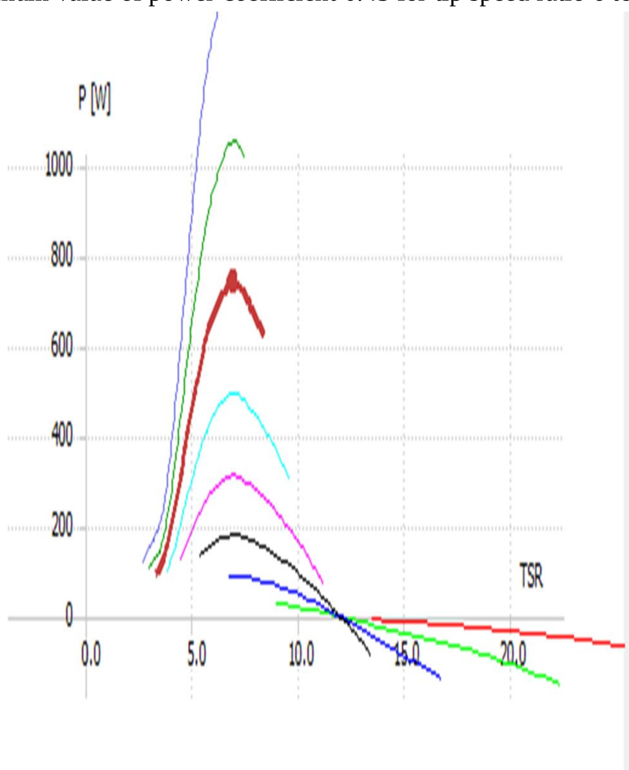

Fig.8 Power [P] Vs Tip Speed Ratio [TSR].

Above Fig.8. Shows graph of power versus tip speed ratio here SG6043 profile gives 700 watt power output for tip speed ratio 7.

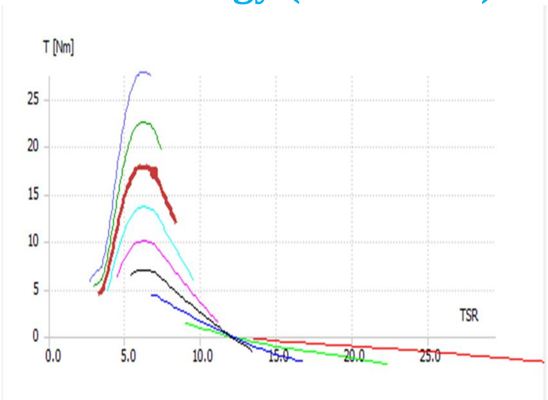

Fig. 9Torque [T] Vs Tip Speed Ratio [TSR].

Above Fig.9. Shows graph of torque plotted against tip speed ratio.

V. RESULTS AND DISCUSSION

From the airfoils taken into consideration such as NACA 4420, NACA 4420, SG6042, SG4043.The lift to drag coefficient of SG6043 is maximum with the value of 1.63 as compared to other airfoils at angle of attack 14̊. Hence SG6043 airfoil is selected. Optimised values of the chord length and twist angle are obtained by mat lab programming. Power coefficient and power output are calculated by Q-blade simulation at rated wind speed. The values obtained of power coefficient and power are C_p =0.45 and P = 700 W.

While designing the blades, the dimensions of the shaft, hub, flange and handle are taken into considerations.

After plotting the constant chord blade geometry and variable chord blade geometry on $C_p$vs. TSR (λ), we conclude that by taking constant chord. The value of C_p severely decreases to 0.38 as compared to the variable chord. Power coefficient of the variable chord is greater with the value 0.45.

A. Nomenclature

N - Number of blades.
λ -Tip speed ratio.
ρ -Air density (Kg/m^3).
V -Wind speed (m/s).
d - Drag force (N).
l - Lift force(N).
D - Rotor Diameter (m).
μ - Dynamic viscosity(Ns/m^2).
TSR - Tip speed ratio.
C_l - Lift coefficient.
C_d= Drag coefficient.

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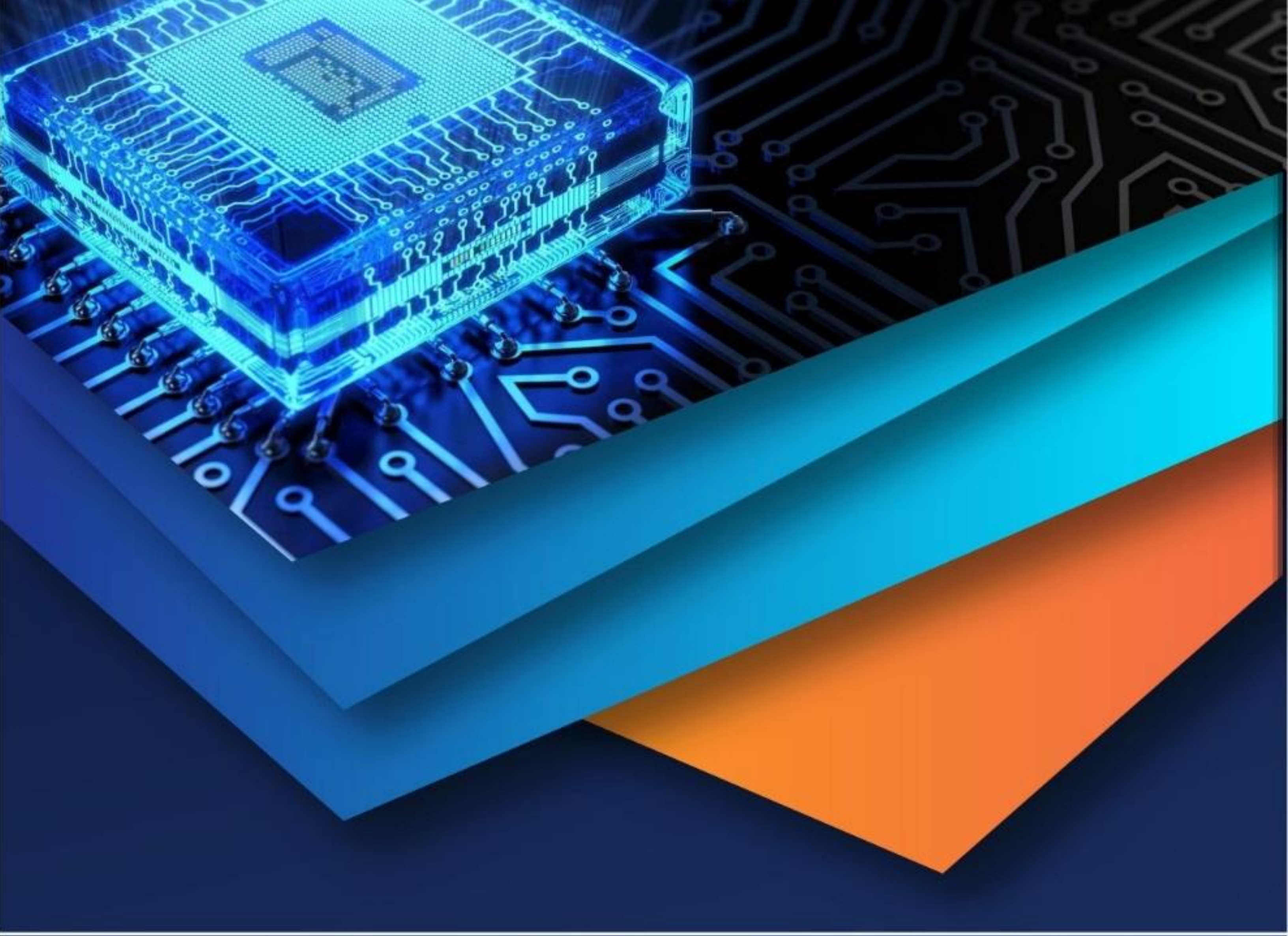

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