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Single Diode PV Panel Modeling and Study of Characteristics of Equivalent Circuit

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***Abstract:** In this paper single diode PV model is chosen for simulation of solar cell because it is fast and less complex. Here simulation based on different parameter and there effects on PV characteristics and efficiency, these parameters are irradiation, temperature, parasitic resistance, series cells, parallel cells and ideality factor. By varying anyone parameter keeping other parameter to constant, the pre-required data is obtained from solar panel model simulation is done by matlab software.*
***Keywords:** Single Diode Model, Solar Cell, Matlab, Simulation, PV Characteristics*

I. INTRODUCTION

Sun delivers huge amount of energy per year that is almost equals to 21 billion tons of energy generated by burning coal. These spectral of radiation consist of UV, 7 spectral of visible light, irradiation this ranges 250nm to 2500nm and radiation is a form of energy which is very dense as in 550nm it contains 1.75W/m^2/nm. There are two ways to harness this energy into usable , first by using blackbody effect which also applied to white car standing in sunlight , in which sunlight is concentrated and form steam to run turbine to generate electricity , second by photovoltaic (PV) effect which convert sunlight directly into electrical energy .[1] Photovoltaic energy is harness by solar cell , solar cell is an semiconductor which absorbs sunlight and generate photocurrents .[2]
Solar power is getting popular because it's free of cost, less service cost, abundant but it has some limitations high cost of manufacturing, less efficiency [2] efficiency can be improved by research in this field, in order to improve efficiency deep detailed simulation work is required to get optimum output power [2]. A faster way to get solar cell simulation is with single diode model it gives faster simulation time due to less no. Of equations and consist 5 parameter .Most of the researchers do simulation with single diode pv model , its equivalent circuit in figure 1 shows 5 parameters that are photo generated current (Iph) , diode saturation current (Io) , parasitic resistance series (Rs) & parallel(Rp) and ideality factor [3]

A. Modeling of Single Diode PV Cell

There are several mathematical methods available in those analytical method is simple and fast for calculation of characterization of IV and PV curve [4]. The equivalent circuit consist of series and parallel resistance which represent resistive loss in pv cell , an current source in parallel to circuit(Iph) this current is generated by photons or light and an diode in parallel which represent photo diode which can be made up of different kind of semiconductor material in mono or polycrystalline form.[5]

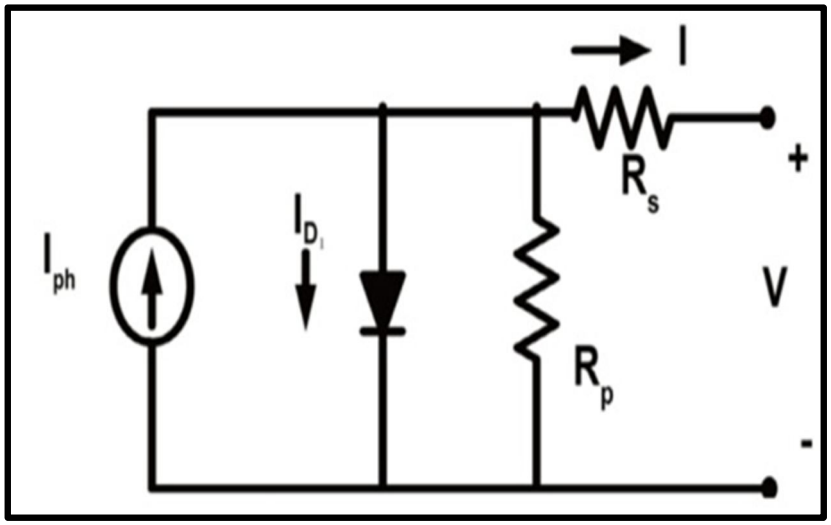

Fig 1 Equivalent Circuit Diagram of Single Diode PV cell

1) Mathematical Expression

$$I = Iph - I_0\left[\exp\left(\frac{V + IR_s}{aV_T}\right) - 1\right] - \frac{V + IR_s}{R_p} \quad (1)$$

$$Vt = \frac{NskT}{q} \quad (2)$$

$$Iph = \left(\frac{G}{Gn}\right)[Ipvn + ki\,(T - Tn) \quad (3)$$

$$I_O = Ion\left(\frac{Tn}{T}\right)\text{^}3\ \exp\left[\frac{qEg}{ak}\left(\frac{1}{Tn} - \frac{I}{T}\right)\right] \quad (4)$$

$$I_{On} = \frac{I_{scn}}{\exp(V_{0cn}/aV_{Tn}) - 1} \quad (5)$$

2) Nomenclature

a) I is total current at output.
b) Ns is no. of cells connected in series
c) Iph is photo generated current
d) Np is no. Of cells connected in parallel
e) Io is reverse saturation current of diode
f) a is ideality factor of diode D.
g) Rs & Rp is series and parallel resistance respectively
h) Id is diode current in single diode model
i) G is Irradiance
j) Vt is thermal voltage

3) Fill Factor and Efficiency: The fill factor is the ratio of the actual maximum obtainable power to the product of the open circuit voltage and short circuit current. This is a key parameter in evaluating performance. Fill Factor is a measure of the "squareness" of the IV curve. [13] Efficiency shows the performance of the solar cell which is determined by ratio of output power and the maximum input power get from sun.

$$FF = \frac{V_m I_m}{V_{oc} I_{sc}} \quad (6)$$

$$\eta = \frac{V_{oc} I_{sc} FF}{P_{in}} \quad (7)$$

$$\Delta T = T - T_n \quad (8)$$

B. Simulation of Single Diode Model

Simulation is done under matlab software over single diode model and extracting PV curve and efficiency based on output power .[2][4][[8][9] And observation on 7 parameters one by one while keeping other parameter constant to see exact changes in PV characteristics and efficiency. From equation (1,2,3,4,5) which shows that single diode model is fast to calculate parameters , this simulation can is done by computer simulators or math software like matlab , this help to determine Mpp for each iteration of all varying parameter. The data of Adani Eternal series is taken are specified in below table

Table I. Specification of PV Model

Properties	Values
pmax of real module	300w
open circuit voltage (voc)	39.53v
short circuit current (isc)	10.01a
temperature coefficient of voc (kv)	-0.31%/°c
temperature coefficient of isc (ki)	0.068%/°c
reference temperature (tn)	25°c/298k

C. Irradiation

Irradiation absorbed by solar cell under blackbody effect, as the irradiation rises the amount of charge rises hence current rises. As seen from the figure below describes as the irradiation increases the power also increases simultaneously where as no changes is seen in voltage [10]. At 200W/m^2 output power is 48W and at 1000W/m^2 output power is 261W which makes the statement true.

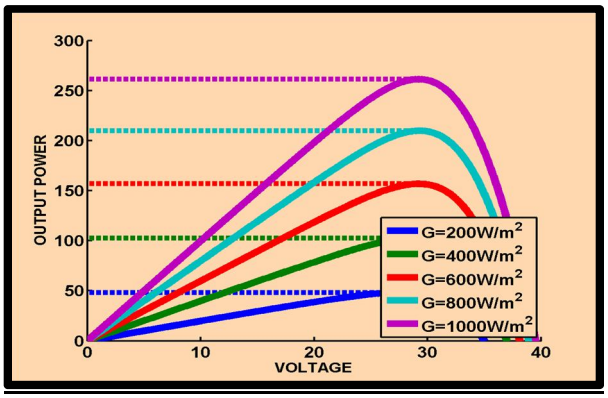

Fig 2 P-V Characteristics at Different Irradiation

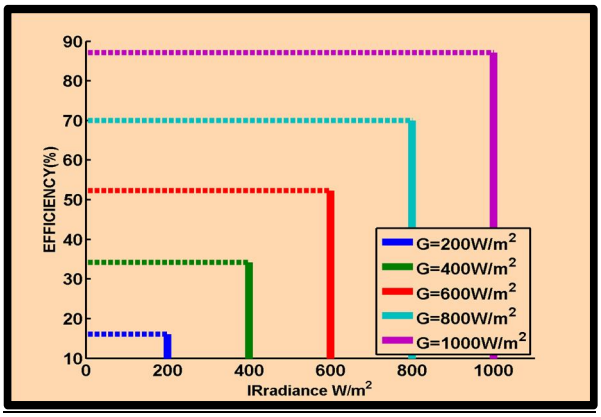

Fig 3 Efficiency at Different Irradiation

D. Temperature

As the temperature rises the effect on semiconductor clearly can be seen from the output voltage that decreases with increase in temperature where as no effect on current is seen in IV curve due to same irradiation. at 15°C output power is 280W as the temperature rises to 55°C it decreases to 205W[4][10][11] and efficiency also decreased as described in fig 3.

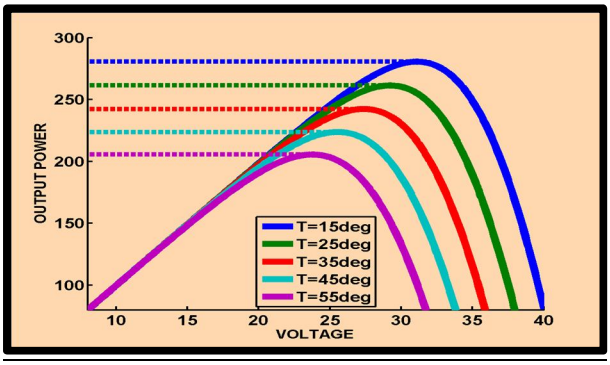

Fig 4 P-V Characteristics at Different Temperature

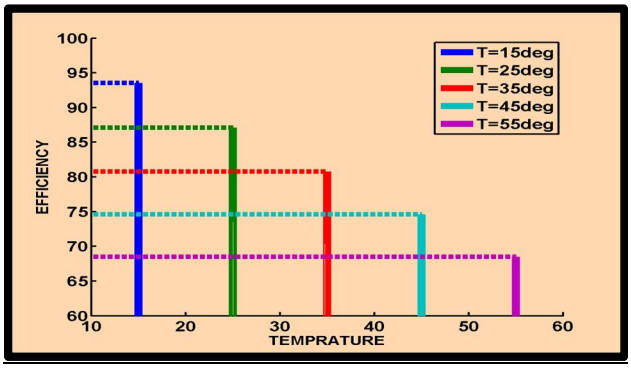

Fig 5 Efficiency at Different Temperature

E. Series Resistance

This is an parasitic resistance between junction and output terminal ,this resistance happen due to impurities cause of manufacturing defect and high series resistance can be seen in low grade solar panels, as this resistance become high the voltage become lower where no effect on horizontal part of IV curve.[10][12]

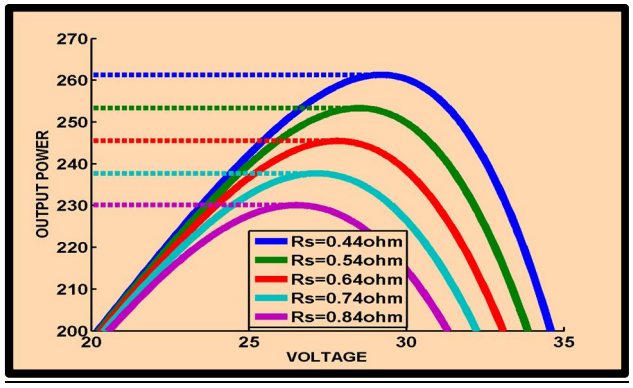

Fig 6 P-V Characteristics at Different Rs

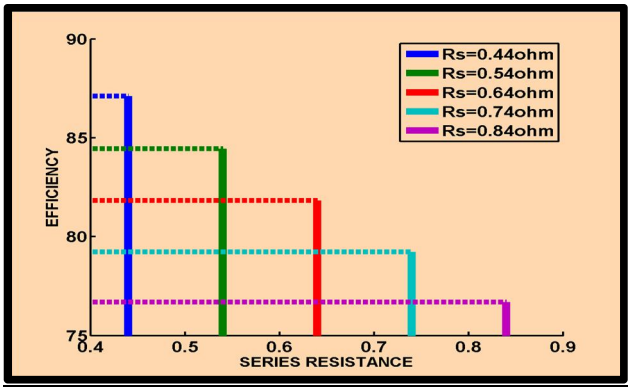

Fig 7 Efficiency at Different Rs

F. Shunt resistance

As the shunt resistance rises the output voltage will be get near to Pmax and fill factor will get reduced , at low resistance as 355Ω the output power is 261.3W and where 755Ω output power is 262.5W as getting higher resistance power becoming constant as described from fig 5[4][7][10][12]

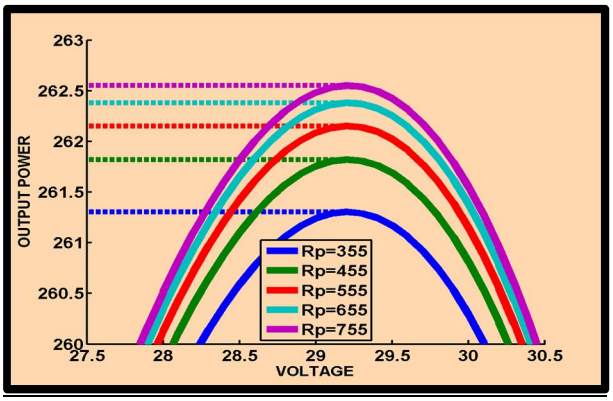

Fig 8 P-V Characteristics at Different Rp

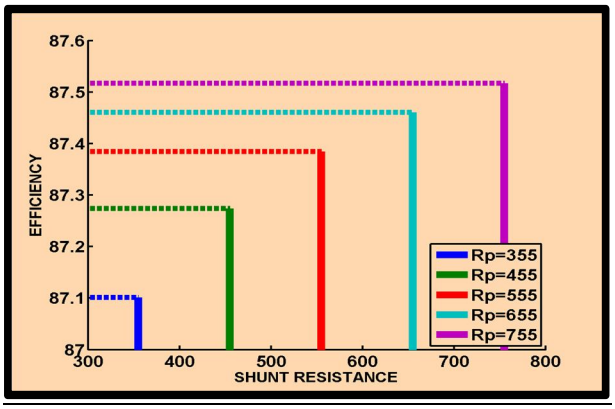

Fig 10 Efficiency at Different Rp

G. No of Series Cells

Series connection add voltage of each cell as similar to battery, as the series cells increases the output power and voltage increases [13] series string of cells is made to make a panel and later those panels can attach into m*n size of large array for hotels, factory or industry as this statement described from fig 6 series cells increases power as well as efficiency.

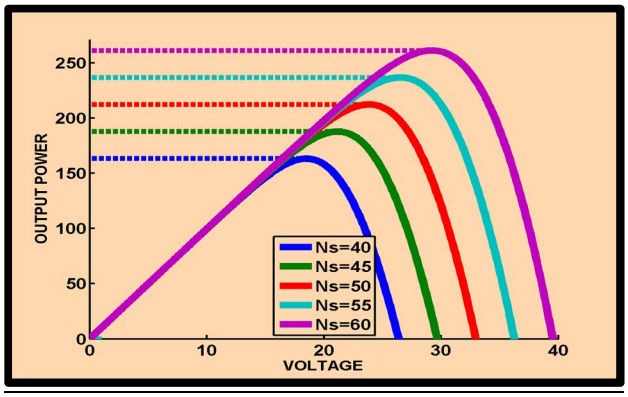

Fig 11 P-V Characteristics at Different Ns

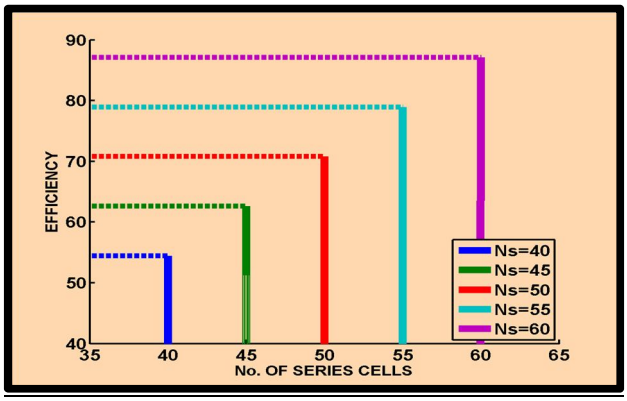

Fig 12 Efficiency at Different Ns

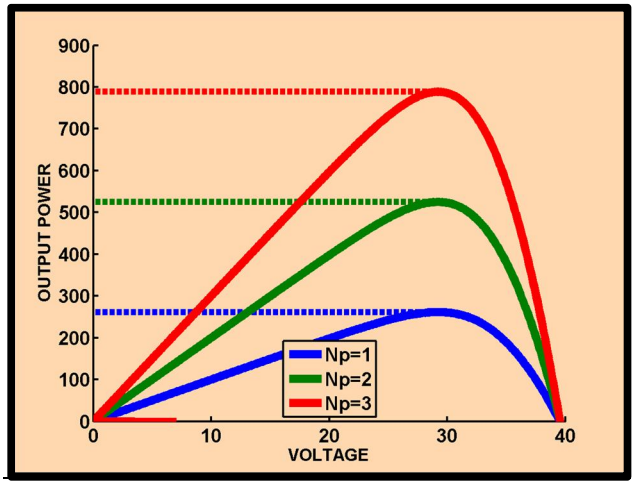

Fig 13 P-V Characteristics at Different Np

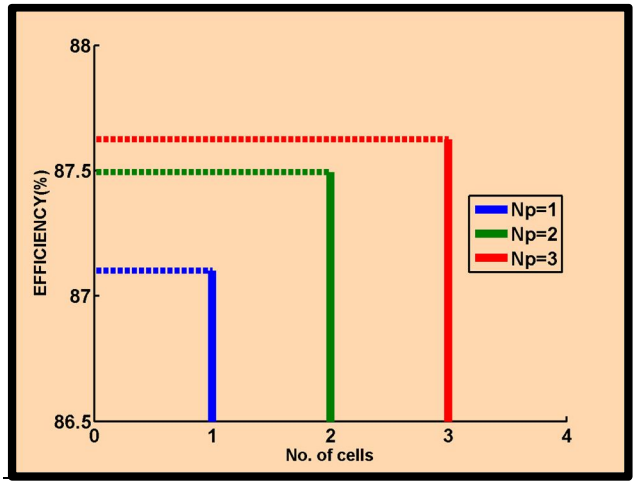

Fig 14 Efficiency at Different Ns

H. No. of Parallel Cells

Parallel connection is based on required load, as the no. Of parallel cell rises the amount of current rises and the voltage will be same, parallel connection can be done in many ways like cell to cell or string to string output power will be same. The power rises with no. Of parallel cell and efficiency also rises

I. Ideality Factor

Ideality factor depends on type of semiconductor and amount of impurities in it and recombination in charge region dominates, the main reason in ideality factor increment is that recombination of charge carrier becoming dominant and this causes increment in depletion layer or junction bandwidth, for ideal diode it is 1 as this factor rises the power and efficient decreases [2][5][7][12].

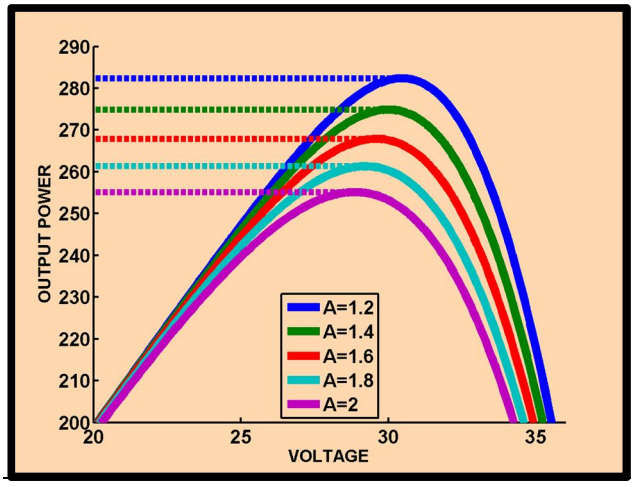

Fig 15 P-V Characteristics at Different Ideality Factor

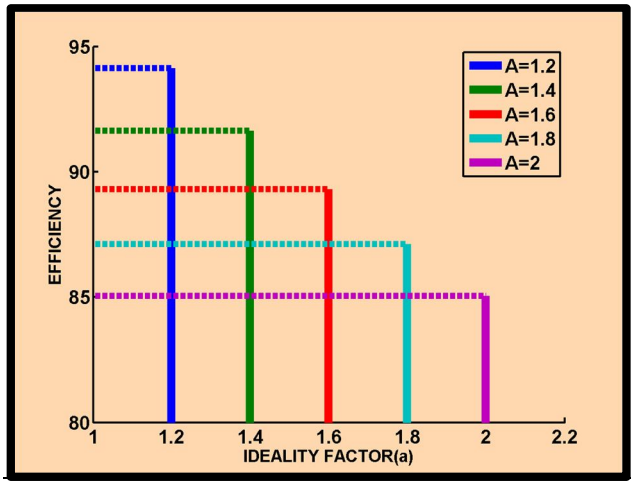

Fig 16 Efficiency at Different Ideality Factor

J. Programming Algorithm

1) Step1 –Mentioning all variable and constant values.
2) Step2 –Start for loop iteration for 1 to 5
3) Step3 –Calculate Vt, Io and Iph values.
4) Step4 –start for loop iteration for V from 0 to 40
5) Step5 –Calculate I and P for each iteration
6) Step6 – Determine FF and Eff. For each iteration of step 2
7) Step7 –Increment in parameter on which observation is to be done
8) Step8 – Return to step 1 for observation of next parameter

II. CONCLUSION

For development of PV system simulation is done based on real module data provided by manufacturer. In this paper Adani eternal series module is used which gives maximum 300W power, and this simulation is based upon single diode model which requires less equation as mentioned in introduction it has 5 parameters to include in this simulation. And this simulation is done under 7 varying parameters irradiation, temperature, parasitic resistance, series - parallel cells and ideality factor which shows there effect on output power and efficiency .In P-V characteristics Mpp is determine all varying parameters which is very useful for manufacturer to track out problems related to real module, thus the single diode model can help in fast simulation and can use in modeling of solar cell in the field of PV technology.

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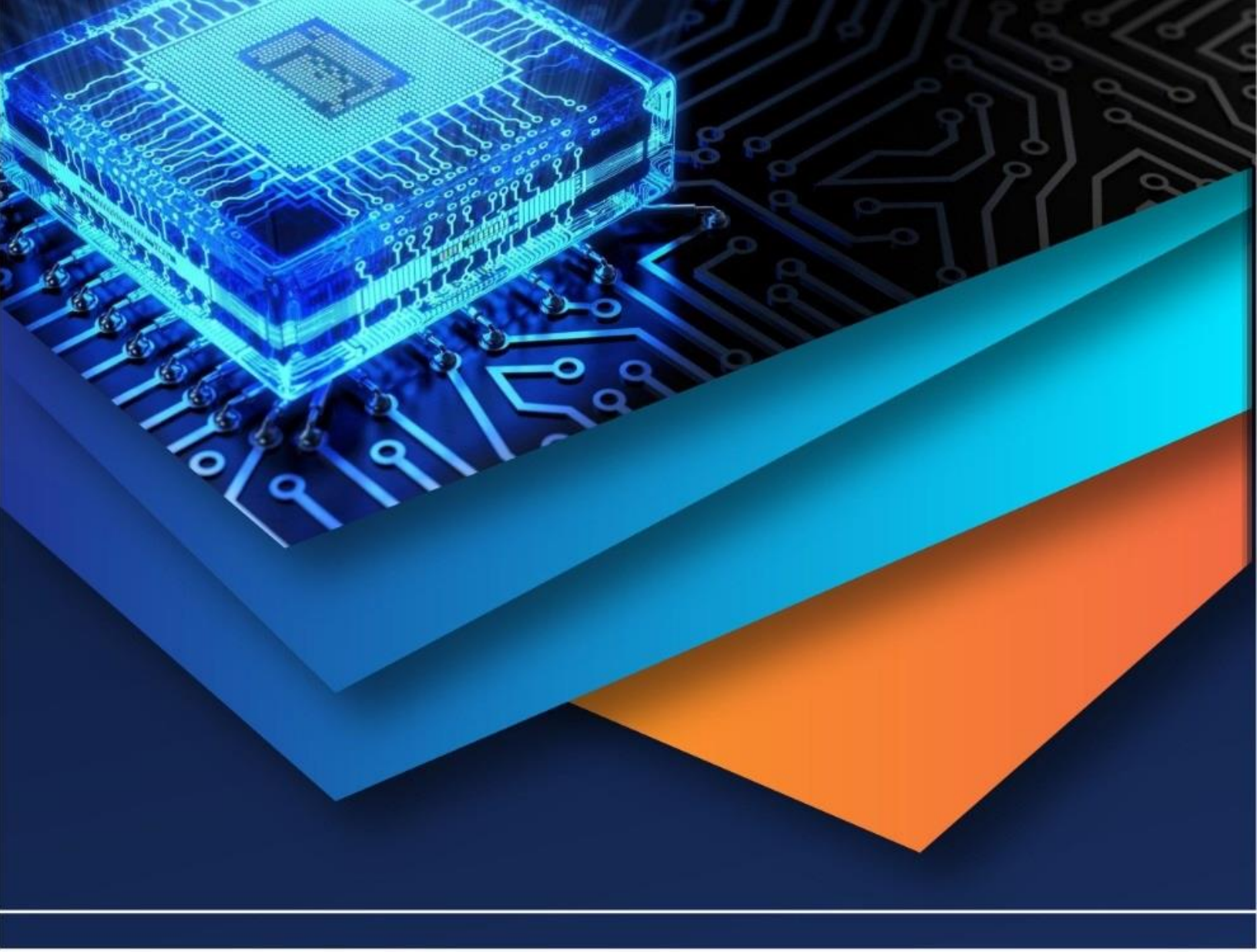

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