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Design of Solar Photovoltaic DC Water Pumping System Using MPPT

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Abstract— ***Solar Photovoltaic (PV) systems are having growing importance in present era of our power system due to its non-polluting, less maintenance, and free fuel characteristics. Photovoltaic systems are comprised of photovoltaic cells, devices that convert light energy directly into electricity. Since the source of light is usually the sun, they are often called solar cells. Photovoltaic modules are widely used in DC applications. One of these applications may be in water pumping system.***

The boost converter has been used boosting the weak output voltage generated by the cells. Boosting of voltage is being done in reality by the maximum power point technique (MPPT). In this technique the automated tracking to give the highest output power is done by an algorithm. This generated

power is fed to a boosting load across which the boosted output voltage is being received. This output voltage is then fed to operate a PMDC motor, driving a pumping system.

Keywords— ***Boost converter, Maximum power point tracking (MPPT), MATLAB (Simulink),Solar PV module.***

I. INTRODUCTION

Electrical energy is obtained from different sources; it may be renewable or non-renewable. Non-renewable or conventional sources are widely used to produce electrical energy in huge amount, but these sources are exhaustible and also pollute the environment. Renewable energy sources are those which are naturally replenished and these are mainly wind, sunlight, tides, waves and geothermal heat.

Energy is the basic requirement for human lives. So that its supply should be secure and sustainable and at the same time it should be eco-friendly, economic and socially acceptable. The regular hike of fuel prices together with increasing carbon footprints threatens our energy supply. Among all the renewable energy resources such as solar, wind, ocean, geothermal etc. solar is abundant. In recent years, various research work have been done on the application of PV as a alternate energy source. PV energy is one of the promising energy resources as a clean, inexhaustible and can be easily harvested. Several applications employing Solar PV technology have been developed for satellite power systems, solar power generation, solar battery charging station and solar vehicles.

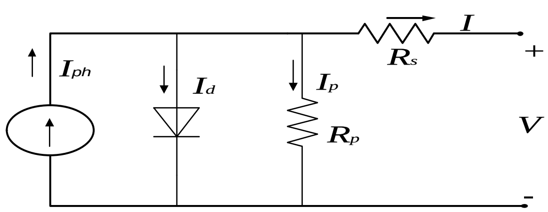

Fig no.1. Practical single diode model with R_s and R_p

The solar cells are represented as the single diode model fig no.1. The equivalent single diode model consists of a controlled current source, a diode, a series resistance and a shunt resistance. The controlled current source depends upon the solar irradiance.

At higher solar irradiance it gives greater value of current. Solar cells are connected in combination of series and parallel according to the voltage, current and power rating is required. The model of solar module is configured by using SIMULINK blocks. Boost converter is used for regulating the voltage of the solar PV system. The gate signal of dc-dc converter is given from the MPPT algorithm. Perturbation and observation technique is used for tracking the maximum power point of the PV module. The algorithm takes voltage and current signal from the solar PV module and after optimizing voltage value a referenced duty cycle is generated which is given to dc-dc boost converter.

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II. BLOCK DIAGRAM OF MODEL

The objective of this project is to design a DC-DC boost converter with MPPT to run a permanent magnet dc motor in water pump system using (PV cell) photovoltaic as a source. The simulation is able to model a PV array in order to plot the I-V curve and P-V curve to indicate the electrical characteristic of the PV cell. Then the project also includes Matlab Simulink to verify the output voltage level of the design in DC-DC converter (Boost Chopper), then, the combination of the PV array, DC-DC boost converter with MPPT and permanent magnet dc motor are simulated as well. The simulation is able to draw the curve torque, speed and current of the permanent magnet dc motor and draw the curve Current &Voltage of boost converter are better than without MPPT control mechanism. The block diagram of pumping system using PMDC motor fed by PV cell with MPPT boost converter shown in fig.1.1. The PV array consists of an array of solar cell modules to provide the desired DC voltage and current. The solar irradiance received on the surface of the PV cells is converted instantaneously into electric power by PV effect .The pumping subsystem is composed of a motor-pump set and a power conditioning equipment. The motor is a machine which transforms the electrical energy into mechanical energy. The motor used in the PV pumping systems is one of two main types, either induction motor or DC motor. In this system, a permanent magnet DC motor is considered.

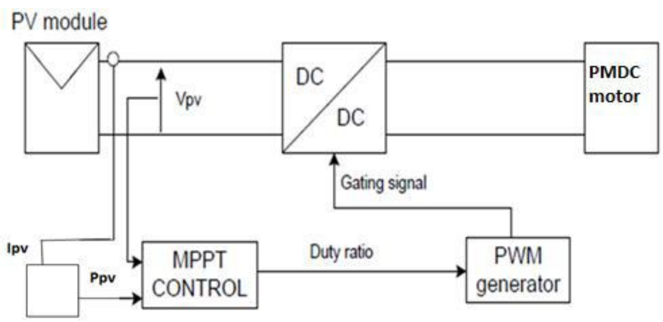

Fig.2. Block diagram of proposed PMDC Pumping system

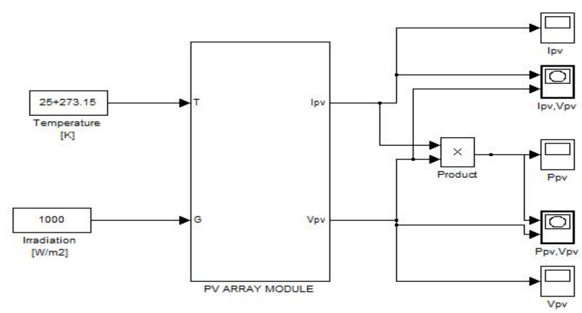

Fig.3 PV System Modeling

III. MODELING OF PV MODULE

Equivalent circuit representation of solar cell is of four types. This model does not consider the internal losses by current.

A. Ideal single diode model

Ideal single diode single model Fig 3.1, a diode is connected in anti-parallel with the light generated current source. In this model loss due to current is not taken care. In this model recombination loss is represented by diode which is connected to parallel to the current source, but in the reverse direction, because the recombination current flows in the opposite direction to the light-generated current.

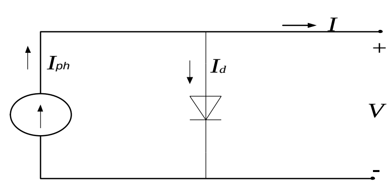

Figure 3.1 Ideal single diode model of solar cell

The output current I is obtained by Kirchhoff's current law:

$$I = I_{ph} - I_d \qquad 1$$

Where I_{ph} = light generated current or photon current

I_d = diode current

Diode current is proportional to the saturation current and is given by the equation:

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$$I_d = I_0\left[\exp\left(\frac{V}{A.N_s.V_T}\right) - 1\right] \qquad 2$$

$$V_T = k.\frac{T_c}{q} \qquad 3$$

Where V = voltage imposed on the diode

I_0 = reverse saturation current or leakage current of the diode in ampere

T_c = actual cell temperature (K)

k = Boltzmann constant = 1.381×10^{-23} J/K

q = electron charge = 1.602×10^{-19} Coulombs

V_T = thermal voltage (exclusively depend on temperature)

N_s = number of PV cells connected in series

A = ideality factor

A is constant which depends on PV cell technology shown in Table 1. For Si-polycrystalline technology its value is 1.3.

Table-1

Technology	Ideality factor
Si-mono	1.2
Si-poly	1.3
a-Si-H	1.8
a-Si-H tandem	3.3
a-Si-H triple	5
CdTe	1.5
CTs	1.5
As-Ga	1.3

Table 1 Ideality factor based on PV cell technology [29]

All the terms by which, V is divided in equation (2) is named as ‘a’ which is called as “the modified ideality factor” [30] and is considered as a parameter to determine.

$$a = \frac{N_s.A.k.T_c}{q} = N_s.A.V_T \qquad 4$$

B. Single diode model with R_s

Practically, it is impossible to ignore the series resistance R_s and the parallel resistance R_p because it affects the efficiency of the PV cell and PV module. The Ohmic loss is due to the series resistance $R_s$and parallel resistance. Series resistance is the resistance offered by the solar cell in the path of current flow and parallel resistance is resistance due to the leakage path of the current in solar cell and therefore, connected in parallel to the solar cell. When R_s is taken into consideration (figure 3.2), equation (2) should be taken as:

$$I_d = I_0\left[\exp\left(\frac{V + I.R_s}{A.N_s.V_T}\right) - 1\right] \qquad 5$$

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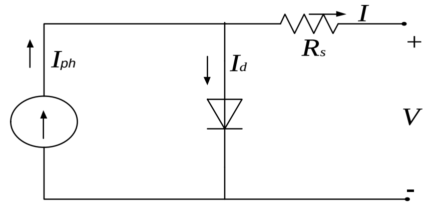

Fig 3.2 Practical single diode model with R_s

Figure 3.2 is the simplified model and easy to implement in simulators but not accurate. So that single diode model with R_s and R_p is more accurate.

1) *Single diode model with R_s and R_p*: Practical single diode model of solar cell with R_s and R_p is shown in figure 3.3.

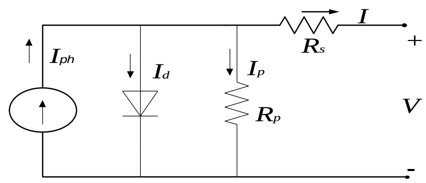

Figure 3.3 Practical single diode model with R_s and R_p

By applying Kirchhoff's current law in figure (3.3), the current will be finding out by the equation:

$$I = I_{ph} - I_d - I_p \qquad 6$$

Where I_p = leakage current in parallel resistor

The output current of a module containing N_s cells in series will be given as:

$$I = I_{ph} - I_o \left[\exp\left(\frac{V + I.R_s}{A.N_s.V_T}\right) - 1\right] - \frac{V + I.R_s}{R_p} \qquad 7$$

To determine the parameters of this transcendental equation is not easy. But this model is the best match with experimental values.

2) *Double diode model with R_s and R_p*: The exact representation of solar cell is shown in figure 3.4, which is double diode model with series resistance and parallel resistance. In this model one diode represents recombination in the bulk and emitter region, including surfaces of the solar cell. Another diode represents the recombination in the space charge region of the solar cell.

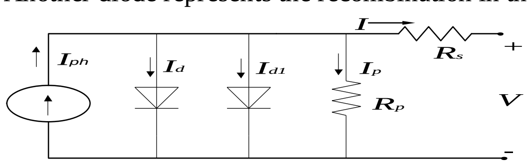

Figure 3.4 Double diode model with R_s and R_p

But generally the recombination in the space charge region is neglected and hence single diode model with series and parallel resistor is considered. The double diode model with R_s and R_p is shown in figure 3.4.From the figure 3.4, applying Kirchhoff's current law,

$$I = I_{ph} - I_d - I_{d1} - I_p \qquad 8$$

$$I = I_{ph} - I_o \left[\exp\left(\frac{V + I.R_s}{a}\right) - 1\right] - \frac{V + I.R_s}{R_p} - I_{d1} \qquad 9$$

$$I_{d1} = I_{o1} \left[\exp\left(\frac{V + I.R_s}{2a_1}\right) - 1\right] \qquad 10$$

Where I_{o1} = reverse saturation or leakage current of another diode

a_1 = modified ideality factor of second diode

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IV. IMPLEMENTATION OF PV MODULE

According to the mathematical expressions discussed Simulink model is developed. The datasheet of solar PV module is taken from the solar BP3210N, which is given in table 2. Table 2 Electrical Characteristics of BP3210N Module

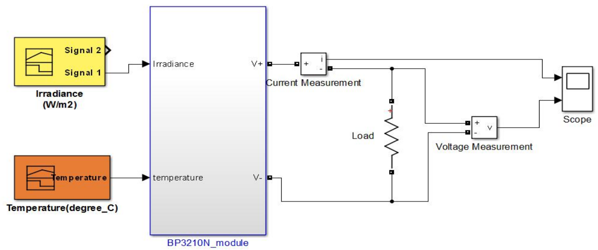

Fig 5.1 Solar PV Module BP3210N with load resistance

Maximum Power (P_{max})	210W
Voltage at maximum power (V_{mp})	28.9 V
Current at maximum power (I_{mp})	7.30 A
Short-circuit current (I_{sc})	8.20 A
Open Circuit Voltage (V_{oc})	36.1 V
Temperature coefficient of I_{sc}	(0.065+-0.015)% /K
Temperature coefficient of V_{oc}	-(0.36+-0.05)% /K
Temperature coefficient of power	-(0.5+-0.05)% /K
Maximum fuse rating	15 A
Maximum system voltage	1000 V
NOCT	47 ± 2^0
Solar cells	60 cells in series
Solar Cell technology	Polycrystalline

V. PHOTOVOLTAIC PMDC PUMPING SYSTEM WITH MPPT BOOST CONVERTER

The implementation of solar PV module with DC-DC boost converter. Voltage and current is sensed from the PV module and boost converter and analyzed in the scope. The output voltage is controlled by using PWM technique by changing the duty cycle.

In this model the duty cycle is constant hence MPP is not achieved all the instant of time. For varying irradiance and temperature signal builder block is used. Various signal of output of PV module and DC-DC converter is analysed in scope.

VI. RESULT ANALYSIS

A. Photovoltaic Array Simulation

The simulation of a photovoltaic Array was done using MATLAB / SIMULINK.

The Power (W), Voltage (V), Current (A) vs. Time (s) and I-V, P-V curves from the simulation are as shown fig

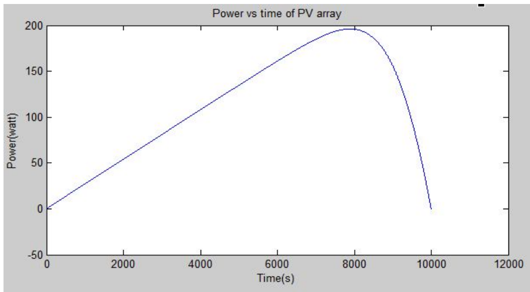

Fig.6.1 (a): Power (w) vs. time(s) of PV array

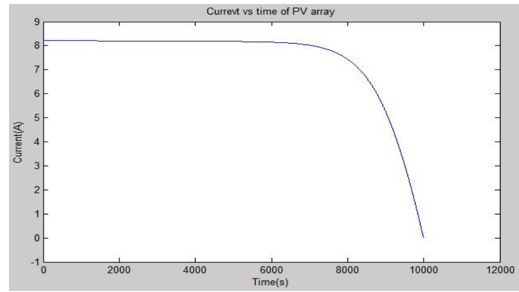

Fig.6.1 (b): Current (A) vs. time (s) of PV array

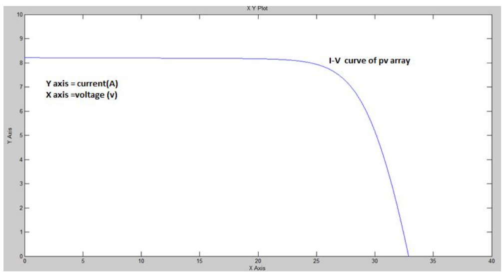

Fig.6.1(c):I-V output characteristics of PV array

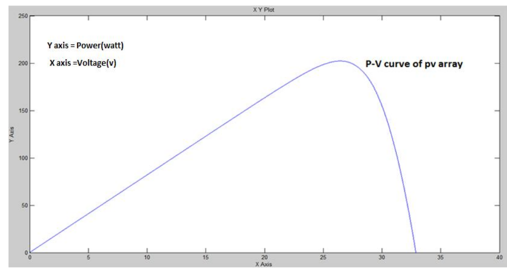

Fig.6.1 (d): P-V output characteristics of PV array

B. Simulation Results of the Boost Converter Model

The simulations were carried out in Matlab/Simulink and the various Voltages (V), Currents (A) and Power (watt) vs. time (s) plots in MPPT shown in fig

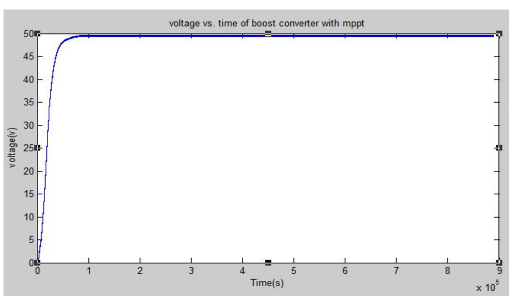

Fig.6.2. (a): Voltage (v) vs. time (s) of boost convertor with MPPT

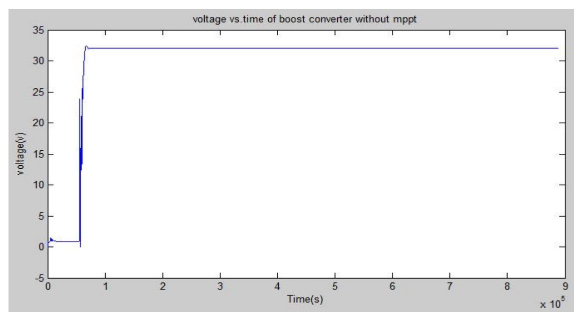

Fig.6.2 (b):Voltage(v) vs. time(s) of boost convertor with MPPT

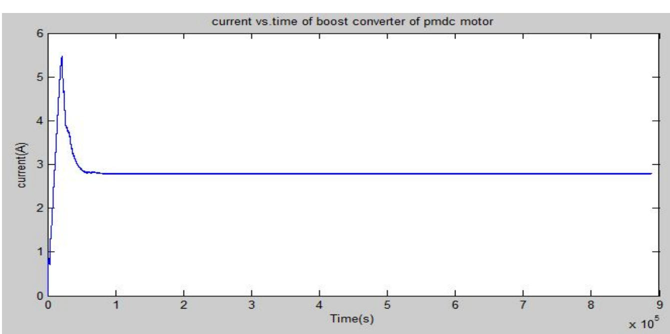

Fig.6.2(c):Current (A) vs. time (s) of boost convertor with MPPT

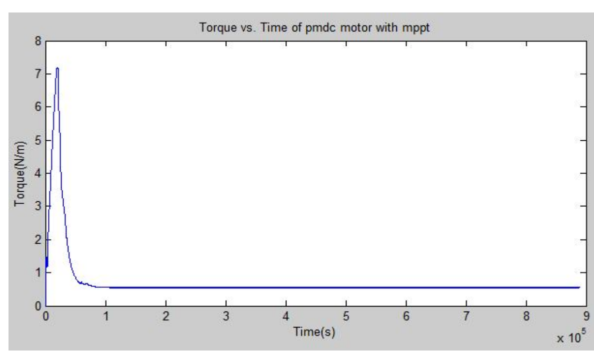

Fig.6.3 (a):. Torque (N-m) vs. time (s)of PMDC motor with MPPT

C. Simulation Results of the Permanent Magnet DC Motor at no load

The simulations were carried out in Matlab/Simulink and the various Torque (N-m) ,Armature Currents(A) and Speed(red/sec) vs. time(s)plots in fig 6.3 (a)

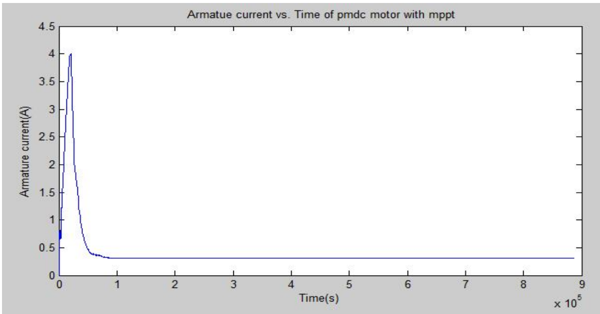

Fig.6.3(b):Armature Current (A) vs. time (s) of PMDC motor with MPPT

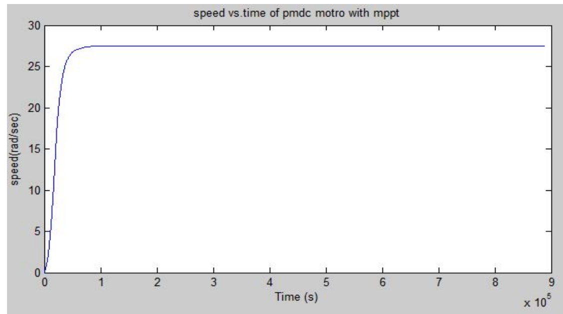

Fig.6.3 (c): Speed (red/sec) vs. time (s) of PMDC motor with MPPT

VII.CONCLUSION

First, the simulations of the PVA showed that the simulated models were accurate to determine the characteristics voltage current because the current voltage characteristics are the same as the characteristics given from the data sheet. In addition, when the irradiance or temperature varies, the PVA models output voltage current change. Then, the simulation showed that Perturb and observe algorithm can track the maximum power point of the PVA, it alwaysruns at maximum power no matter what the operation condition is. The results

showed that the Perturb and observe (hill climbing method)algorithm delivered an efficiency close to 100% in steady state. Finally the overall cascaded system consisting of PV array, DC – DC boost converter insisting MPPT and PMDC motor without any load is simulated to show the related results such as torque, speed armature current of PMDC motor at no load and current as well as voltage curves of boost converter . After that the results are compared for the system consisting MPPT and without the same. The result shows that PV water pumping system with MPPT is better than without MPPT system. It is understood that PMDC pumping system is economical for low power range when comparing with the other pumping systems. The discharge rate of water and efficiency of the PMDC pumping system is better than the AC pumping system.

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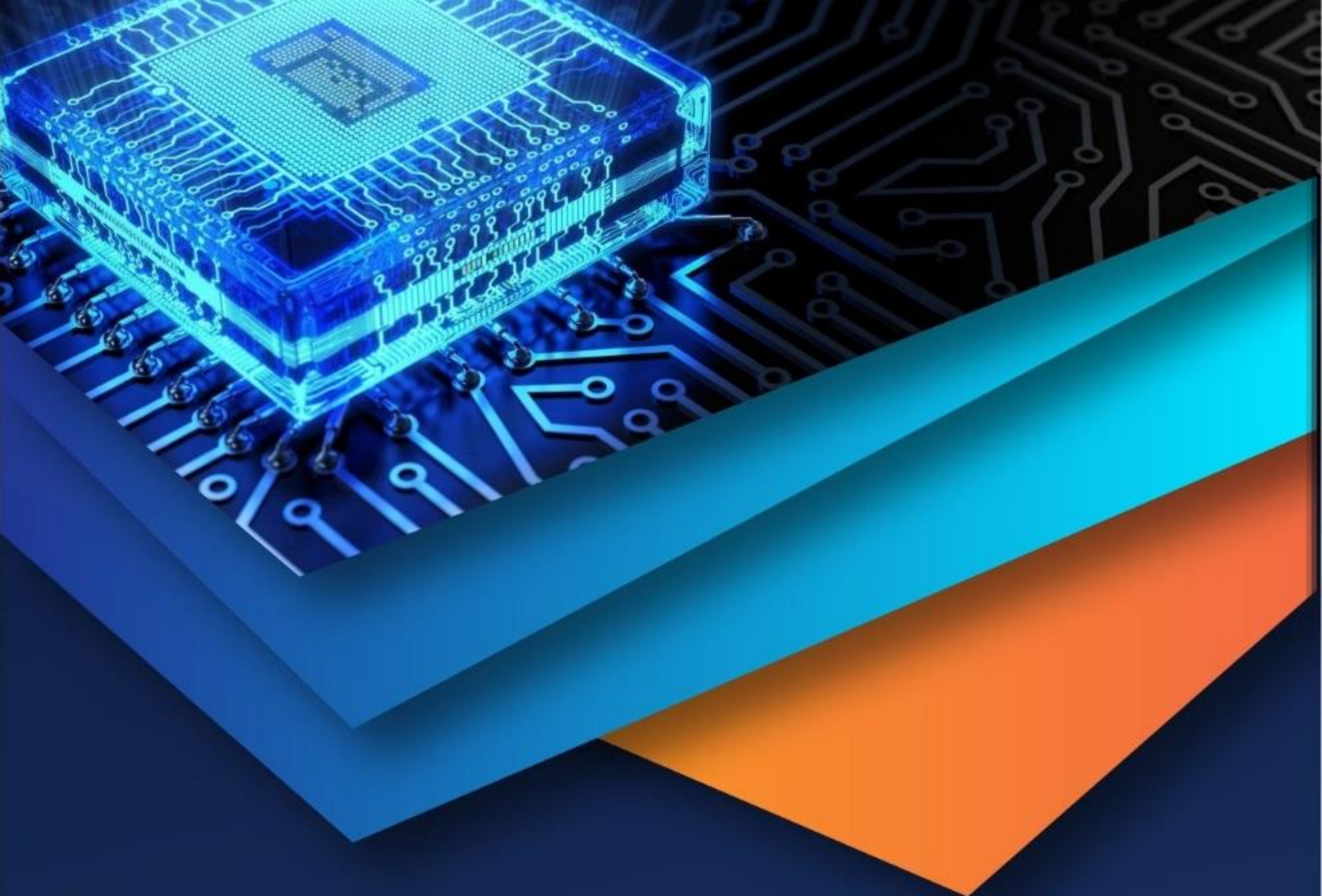

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