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Comparative Analysis of Maximum Power Point Tracking Techniques in a Solar PV System

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***Abstract:** Due to severe crisis of acute energy, global warming, green house effect and the narrow availability of non renewable sources, the demand of renewable energy is out breaking for generating the electricity. Of all the renewable energies available solar energy is easy to access and untapped source. With the help of PV cells the available solar energy can be transformed to the fruitful electrical energy. However, being dynamic source of energy and its penetration, the solar PV system has low efficiency and high capital cost. To overcome this issue, maximum power point tracking technique can be adopted in the solar PV array. In this paper the MPPT techniques with its merits, demerits and algorithms is presented. Also the comparative analysis between all the techniques is carried out.*

***Keywords:** Solar PV modelling, PV cells, MPPT methods, renewable source of energy, solar power*

I. INTRODUCTION

In last few years, the world's energy demand and the number of distributed generation systems are both growing. Therefore, in addition with the use of conventional energy systems, the renewable energy systems must also be used. Among all the renewable energy systems, solar energy is clean and inexhaustible, and these facts make it wide spread. Also, the solar energy is environmentally friendly as it has zero emissions while generating the electricity or heat. The constraint on scalability is the availability of space, since in all the current applications, solar power is space intensive. Moreover, in the absence of effective storage, solar power is characterized by a high degree of variability. This would be particularly true for the monsoon season.

The solar PV cell coverts the available solar light into electricity. The solar PV cells are either connected in series or parallel according to the requirement to form the PV module. The MPPT technique is basically used so that it gives the best possible efficiency of the solar module as it is driven by a specific technique in which the panels turn itself in the direction of the maximum power point of PV module. The photovoltaic cell has an optimum operating point to extract the maximum power of the PV module. This point is known the maximum power point. As such, many of the methods for MPPT has been implemented and developed till date. They vary depending upon the sensors used, complexity, implementation of hardware, cost, speed of convergence, effectiveness range, quick tracking under varying atmospheric conditions and many more. The focus on the research work in this area is strong and it has considerably grown in past few years.

The aim of this paper is to learn and compare the adopted MPPT techniques in order to find and understand that which technique has the optimum performance.

II. PV SYSTEM

A PV system typically consists of a PV array, a DC / DC intermediate stage and a DC / AC converter, which can receive AC voltage in grid-connected or stand-alone applications. The DC-DC converter not only plays an important role in amplifying the PV module, but also in achieving MPP. MPPT systems are used to reach Maximum Power Point on the PV curve automatically from solar modules. This means that the PV system will work at maximum efficiency.

Where PV curve is the characteristic of the PV Panel which is defined according to temperature and irradiance conditions. These characteristic curves present the parameters that describe the operation of the PV cell such as the open-circuit voltage Voc, short circuit current Isc, and the cell voltage, current, and power at the maximum power point, Vmpp , Impp, and Pmax, respectively. The maximum power Pmax is the product of the maximum power voltage Vmax and the maximum power current Imax in the I-V curve. That is,

$$P_{max} = V_{max} \cdot I_{max}$$

Figure 1 presents the I-V and the P-V characteristic curve of a PV cell,

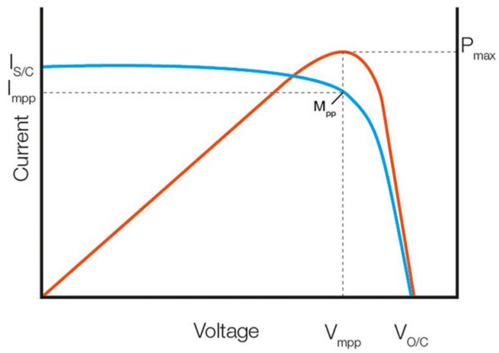

Fig. 1 I-V and P-V characteristic curve

The fill factor FF and efficiency η are also significant while selecting MPPT. FF measures the quality of the PV array. It is the ratio of the actual MPP (Pmax) to the product of Voc and Isc i.e.

$$FF = \frac{Pmax}{Isc.Voc}$$

The efficiency η, of a solar cell is defined as the ratio of the output electric power over the input solar radiation power under standard illumination conditions at the maximum power point.

III. MPPT TECHNIQUES

The MPPT process is used in photovoltaic systems to continuously maximize the output power of the PV array. According to the maximum power theorem, the power supply output of a circuit is maximum when the source impedance of the circuit matches the load impedance. As known output power generally depends on solar radiation and cell temperature, which varies continuously during the day. In this state, the MPP of the PV array changes continuously, so the operating point of the PV system must be changed to maximize the energy generated. Therefore, MPPT techniques are used to maintain the operating point of PV arrays at its MPP.

MPPT methods can be roughly divided into two categories. There are traditional methods such as perturbation and observation methods (P&O) and incremental conductivity methods (IncCond) as well as advanced methods such as MPPT methods based on fuzzy logic (FL).

A. Perturb and Observe (P&O) / Hill climbing method

The perturb and observation algorithms are simple and do not require any prior knowledge of the properties of the PV generator or the measurements of the solar intensity and the cell temperature and it can easily be implemented in analog and digital circuits.

As the power drawn from the PV array increases, the operating point shifts to MPP as a result, the input voltage of the PV array will perturb in the desired or in the same direction. Conversely, the operating point shifts away from MPP and the input Voltage perturb in the opposite direction when the power drawn from the PV array decreases. Due to this working process, P&O method is also known as the Hill climbing method. Figure 2 shows the P&O algorithm diagram.

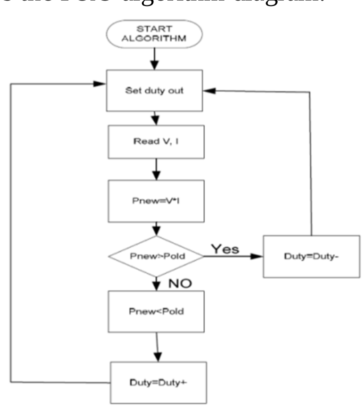

Fig. 2 P&O Algorithm

For an operating point A where the system voltage is V, assuming if atmospheric conditions remain constant, then a perturbation ΔV voltage will shift the operating point to B. After which the perturbation will be reversed due to a decrease in power. However, when the solar radiation increases, the power curve will change from P1 to P2. Hence the operating point will shift from A to C. This represents an increase in power and the perturbation remains the same. As a result, the operating point deviates from the MPP and continues to diverge as the irradiance increases steadily.

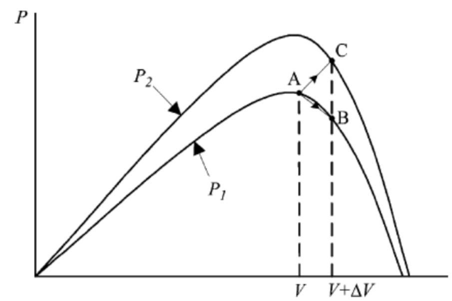

Fig. 3 Divergence of P&O from MPP

It is the most widely used MPPT algorithm because its performance and simplicity. However, they suffer from the lack of speed and adaptability required to track fast transients under different environmental conditions. Hence, to overcome this issue certain modifications in the design algorithm were made.

B. Modified dP P&O method

A common problem with P&O algorithms is that the terminal voltage of the array is perturbed every MPPT cycle. When the MPP is reached, the output power oscillates near its maximum value, which leads to a loss of power in the PV system. Hence, to overcome this issue modified P&O method is introduced, by which MPP tracker will compare PV output power with the parameters of the two previous perturbations instead of single cycle. By this method it will check whether P&O is reached or not & consequently bypass the perturbation stage.

At the mid-point of the MPPT control period an additional PV array power is measured in modified P&O mechanism & average of several samples of the array power is used to adjust the perturbation magnitude of the PV operating point.

The power difference dP0.5 is measured between the mid-point power $P(K-0.5)$ and the staring power $P(K-1)$ .This MPPT control method includes both power variation caused due to MPPT control & change in irradiation respectively and the power dP1 contains power variation caused only due to change in irradiation.

$$dP0.5 = P(k - 0.5) - p(k - 1)$$

$$dP1 = P(k) - p(k - 0.5)$$

Hence, a power difference dP caused due to MPPT control is :

$$dP = dP0.5 - dP1$$

Figure 4 shows the modified P&O algorithm diagram.

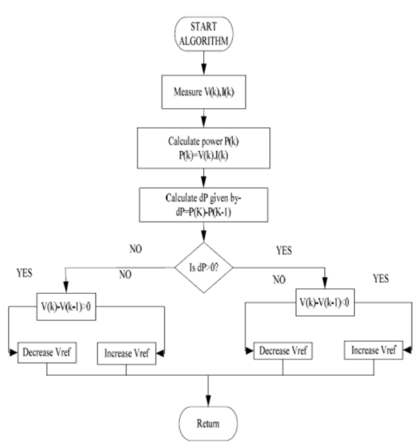

Fig. 4 Modified P&O Algorithm

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C. Constant Voltage

The Constant Voltage algorithm is the simplest MPPT method. The operating point of the PV module is kept near the MPP by regulating and matching the array voltage to a constant reference voltage Vref. The Vref value is set equal to the maximum power point voltage Vmpp to the PV panel's best-fixed voltage. This method assumes that the solar radiation and temperature variations of the array are not significant and that a constant reference voltage would give a better approximation of the actual MPP. Therefore, this method never exacts at the MPP and so different data has to be collected for different locations.

Constant Voltage method is more effective than the PV or IC method when the insulation of the PV module is low or low varying atmospheric conditions. Figure 5 shows the CV algorithm diagram.

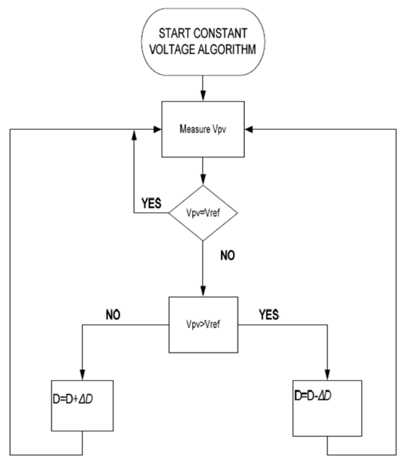

Fig. 5 Control Voltage (CV) Algorithm

D. Incremental Conductance (IC) method

The IC process offers excellent performance under rapidly changing atmospheric conditions hence overcoming the limitations of the P&O algorithm by using the incremental conductance of the photovoltaic.

When the optimum operating point on the PV curve is to the right of the MPP, we have (dIpv/dVpv) + (Ipv/Vpv)<0, and when the optimum operating point on the PV curve is to the left of the MPP, we get (dIpv/dVpv) + (Ipv/Vpv) >0. Where Ipv/Vpv is the instantaneous conductance and dIpv/dVpv is incremental conductance.

Thus, the MPP can be tracked by comparing the instantaneous conductance to the incremental conductance. Therefore the sign of the quantity of the equation indicates the correct direction of perturbation leading to the MPP. As soon as the MPP has been reached, the operation of PV module is maintained and the perturbation is stopped unless a change in Dipv is noted. If the operating point is far from the MPP, the step size of the algorithm increases, which allows the algorithm to quickly reach the operating point in the direction of the MPP and vice versa.

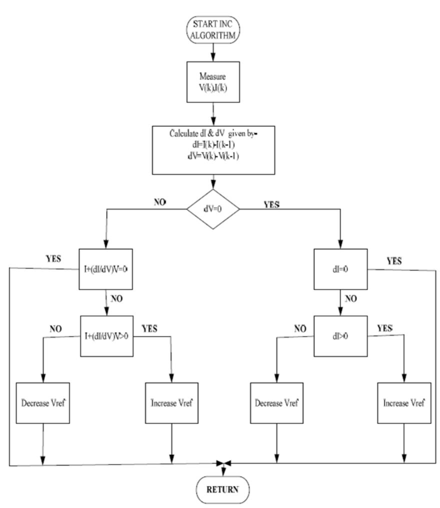

Fig. 6 Incremental Conductance (IC) Algorithm

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E. Temperature (T) method

The open-circuit voltage of the PV cell varies mainly with the cell temperature and the short-circuit current of PV cell is proportional to the irradiance level & is generally steady when the PV cell temperature changes.

In this technique both temperature and voltage are measured using sensors which are placed on the PV panel. The MPP voltage VMPP is then determined using the sensor output values. The equation for Vmpp can be given as:

$$Vmpp(T) = Vmpp(Tref) +$$
$$Umpp\ (T - Tref)$$

Where, T is the measured temperature, Tref is the reference temperature and UMPP is the temperature coefficient of VMPP .Therefore, the difference between the value obtained from the above equation VMPP and the measured PV voltage is used to determine the incremental duty cycle. Algorithm for this method is shown in Figure 7.

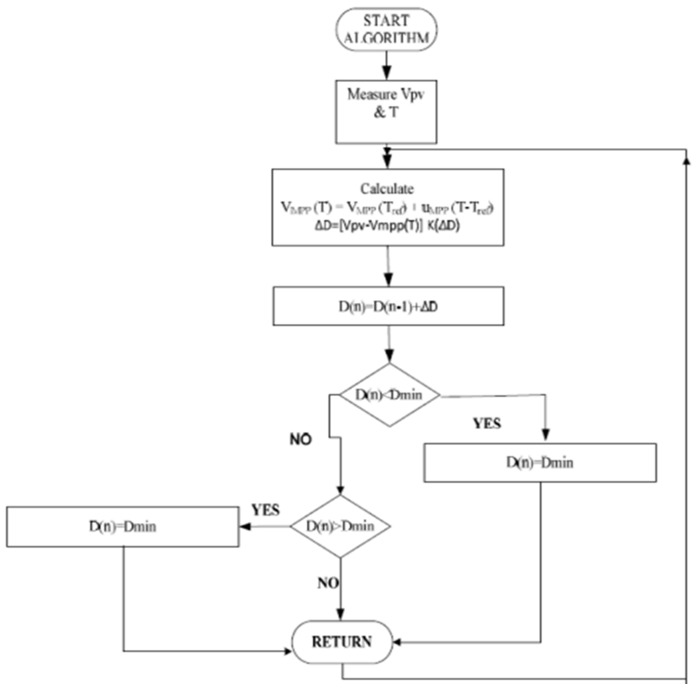

Fig. 7 Temperature (T) Algorithm

F. Open Circuit Voltage (OCV) Method

For this method it is assumed that for most of the times, the MPP voltage is close to the open circuit voltage. The MPP is adjusted within 2% tolerance band in accordance with the temperature and solar irradiation level. The condition at which the maximum power is available is that the optimum voltage is considered as approximately 76% of the open circuit voltage. The equation below shows the relationship between operating maximum voltage and the open circuit voltage.

$$Vmpp = kVov$$

Where, k= proportionality constant for commonly used crystalline silicon panel and its value lie between 0.71 and 0.78.As the value of k is dependent on the characteristics of the PV array being used, it is usually calculated beforehand by empirically determining $Vmpp$ and Vov for the specific PV array at different irradiance and temperature levels.

So, the according to the above formula the value of $Vmpp$ can be found out by sensing the value of Vov. The prerequisite requirement for this MPPT technique is a static switch. It is used for the measurement of the open circuit voltage Vov according to the demand.

Moreover, during the measurement of open circuit voltage, the current in the panels is zero and so the power delivered during this period is zero and due to it there is consequent loss in the power for that specific time interval.

Figure 8 shows the algorithm for open circuit voltage method.

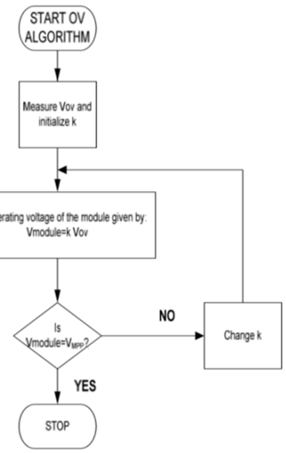

Fig. 8 Open Circuit Voltage (OCV) Algorithm

G. Short Circuit Current (SCC) Method

The assumption made for this method of MPPT is that there is an existence of linear relationship between maximum operating current $Impp$ and the short circuit current Isc. The relation between maximum operating current and short circuit current is given as:

$$Impp = kIsc$$

Where, k is the proportionality factor and its value lie between 0.78 and 0.92. By formula we can say that by sensing the value of short circuit current the value of maximum operating current can be found out as the value of K will be known to us as it is dependent on the characteristics of the PV array.

To sense the value of short circuit current a static switch in parallel with the PV array is prerequisite requirement so that the switch periodically shorts the PV array. During the short circuit across the PV array the value of voltage is zero and so no power is supplied. The diagram below shows the algorithm for this method.

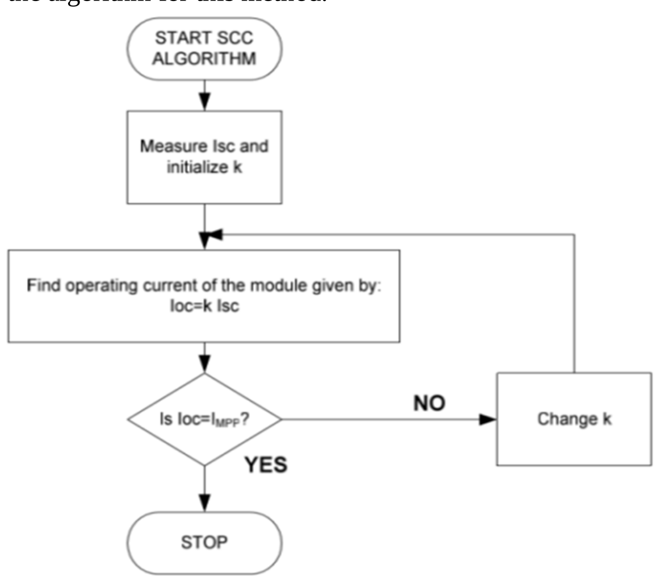

Fig. 9 Short Circuit Current (SCC) Algorithm

H. Feedback Voltage (Current) Method

This method of MPPT is used for fastening of the bus voltage at constant level. To make the PV array work at the point closer to the MPP, the PV voltage is continuously compared with the constant voltage and the duty cycle of the converter is adjusted. This method is comparatively cheap and simple as only a single feedback control loop is used. However, this method fails to operate during the frequent varying environment conditions.

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I. Fuzzy Logic Control Method

This method uses microcontroller for its operation. This method is divided into four stages: fuzzification, rule base table lookup, interference engine and defuzzification.

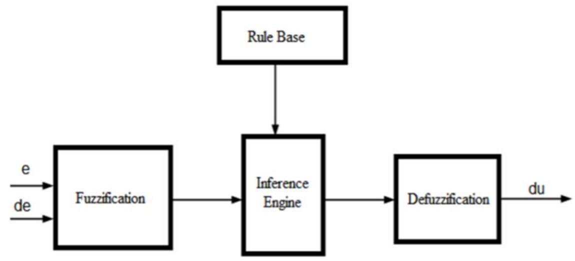

Fig. 10 Four basic elements in fuzzy logic

In the fuzzification process, based on the membership function the numerical input variables are converted into linguistic variables. Controller's accuracy is directly proportional on the number of membership functions used. Hence, more the number of membership functions, higher will be the accuracy. During the process of defuzzification, the output of the fuzzy logic controller is converted to a numerical variable from a linguistic variable using the membership function. By this an analog signal is obtained which is used for the operation and control of power converter. Two inputs are given to the fuzzy logic controller; they are error signal (E) and the change in the error signal (ΔE). These inputs are given as:

$$E(k) = \frac{\Delta I}{\Delta V} + \frac{I}{V}$$

and

$$\Delta E(k) = E(k) - E(k-1)$$

The FLC method of MPPT has various advantages such as it works efficiently with varying atmospheric conditions, it can work with not so precise inputs, accurate mathematical model is not required and it can handle non linearity. However, a trained person is needed who has knowledge of computing the error signal value for controlling this method and for successful operation.

J. Neural Network Method

This method is well adopted with the microcontrollers. This method of MPPT have mainly three layers: input, hidden and output as shown in the figure.

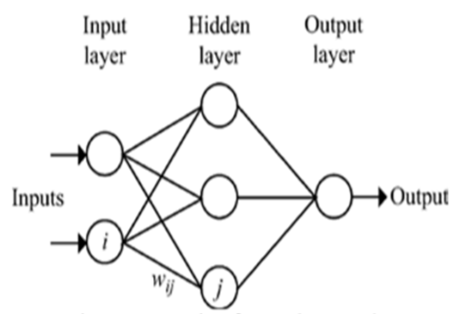

Fig. 11 Example of neural network

The number of nodes used in each layer may vary according to the user requirement. The variables of input can be PV array parameters like Voc and Iscor any atmospheric data such as irradiance and temperature or combination of these.

The closeness of the operating point with respect to MPP depends upon the algorithm that is being used by the hidden layer and also depends on how well the neural network is being initially trained. The link between nodes i and j is weighted and it is labelled as wij. The wij's have to be determined carefully through a training process so as to accurately identify the MPP. By doing so the patterns are recorded and an appropriate neural network of inputs and outputs is recorded. The output is usually represented by several reference signals or by the duty cycle signal which is used to drive power converter. However, this method has a demerit that the pattern of neural network is dependent on the PV characteristics so it has to be well trained and the characteristics of PV varies with atmospheric conditions and so the neural network has to be trained periodically.

IV. COMPARATIVE ANALYSIS

MPPT Techniques	PV array dependent?	Tracking speed	Tracking accuracy in varying condition	Implementation	Parameters to be sensed	Datasheet required regarding environmental condition
P&O	No	Slow	Low	Simple	Voltage, current	No
Modified P&O	No	Fast	High	Simple	Voltage, current and extra PV array voltage at mid-point of the MPP	No
Incremental conductance	No	Fast	High	Medium	Voltage, current	No
Open circuit voltage	Yes	Slow	Medium, based on the assumption that MPP voltage is nearer to fixed % of open circuit voltage	Medium	Voltage	No
Short circuit current	Yes	Slow	Medium, based on the assumption that there exists linear relationship between Impp and Isc	Medium	Current	No
Feedback voltage(current)	No	Fast	Non operative	Simple	Voltage, current	No
Fuzzy logic control	Yes	Fast	High	Complex	Varies	No
Neural network	Yes	Fast	High	Complex	Voltage, current	No
Temperature	Yes	Medium	Varies as per solar irradiation & temperature	Simple	Voltage, current	Yes
Constant voltage	No	Slow	Low	Simple	Voltage	Yes

TABLE I Comparative Analysis of all MPPT Technique

V. CONCLUSION

The MPPT algorithm is necessary for every PV system to maintain the operating point at its MPP. In this paper, different techniques for tracking the maximum power point (MPPT) are presented. Each MPPT has its own properties and behaves accordingly with specific strengths and weaknesses. MPPT methods must be able to minimize oscillations about MPP also while keeping its simplicity, reliability, and accuracy in mind.

In this comparative study, it is concluded that among all the different methods the most preferable method are fuzzy logic control and neural network method. As it offers maximum performance, maintains at MPP regardless of changing conditions though it has a complex model. Also, both these MPPT techniques have high speed of tracking and they possess a high tracking accuracy towards the varying conditions.

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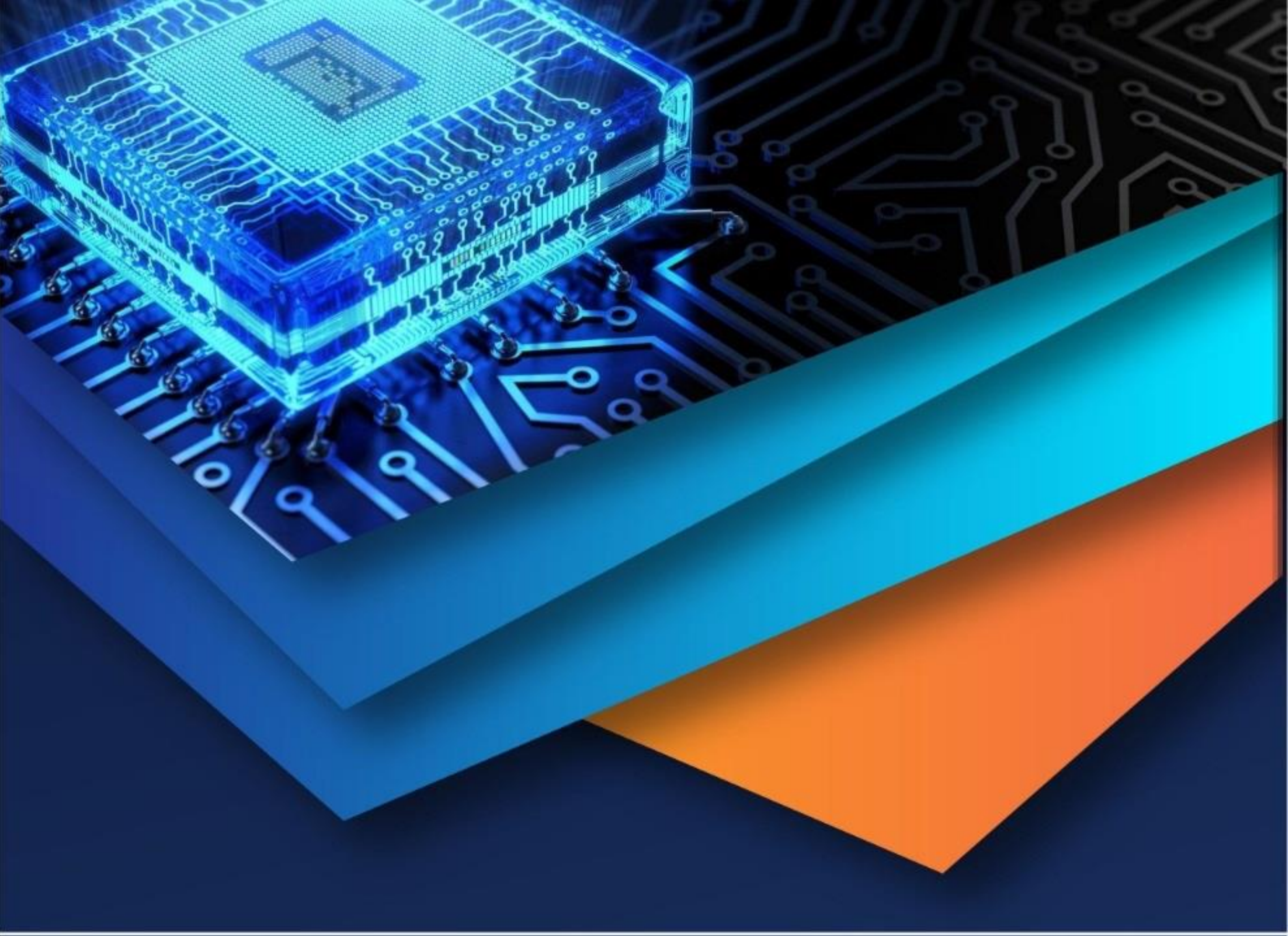

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