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# Grid-Interactive Solar Inverters and their Impact on Power System Safety and Quality

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***Abstract: Evolution in the photovoltaic (PV) industry over the last few decades have seriously decreased the cost of solar arrays and power inverters. Current government incentive programs such as rebates and tax credits have made electricity generation from PV arrays cost-effective and feasible. Implementation of measures like Net Metering, Feed In Tariffs (FITs), and Renewable Portfolio Standards (RPSs) could further transform the solar industry. The benefical interactive inverters are at the heart of this revolution. Although solar panels are the most expensive part of a PV system, these grid interactive inverters are the most sophisticated equipments which dictate the behavior of the PV system. The efficiency, reliability and safety features of these inverters are important for the success of a PV system. These solar inverters should remove the extreme available power from the PV arrays and efficiently transport the power to the utility grid without compromising the safety and integrity of the grid. In order to assurance these grid interactive qualities, all grid interactive inverters must meet IEEE 1547 necessity. This paper covers the design aspect of a solar inverter to meet IEEE 1547 demands. The essential control characteristic such as handling abnormal grid conditions (under voltage/ over/ frequency conditions), anti-islanding control, ground fault detection/interruption, and current harmonics control will be covered in some details. This paper will discuss about Gridinteractive Solar Inverters and their Impact on Power System Safety and Quality.***
***Keywords: Grid connected PV system, Boost converter, Maximum power point tracking (MPPT), PID controller, P&O Algorithm, MATLAB/SIMULINK.***

## I. INTRODUCTION

The inverter in a grid interactive structure can transform solar generated DC power into AC power that is then fed directly to the grid. As a building receives this AC energy, it is circulated to instruments and lighting or other devices where required. Any energy that overshoots the regular building usage goes back to the grid. At some instants, the utility issues a credit to the next bill. Grid interactive systems are established on their grid tied and off grid counterparts. nevertheless in grid interactive system, the inverter has numerous additional purposes to accomplish. Under normal conditions, the inverter preserves the battery in a state of full charge in preparation for use during power outages, when the grid goes down the grid interactive inverter seamlessly steps in to inverter DC power from both the solar and battery sources into feasible AC power to run specific loads.

The system will charge those batteries throughout the day from the the panels or as needed from a generator or both. The grid interactive inverter can automatically control the generator to run only when needed to recharge the batteries, appreciably minimize the generator's run time, noise output and fuel use. This paper presents interfacing of three phase grid connected PV system. DCDC boost converter with maximum power point tracking (MPPT) is used to extract the maximum power obtained from the sun and transfer it to the grid. In any PV based system, the inverter is a critical component responsible for the control of electricity flow between the dc source, and loads or grid.

## II. GRIDCONNECTEDPVSYSTEM

grid connected photovoltaic system is widely used, although solar energy is accessible in large quantities and free of cost, the cost of the photovoltaic cells is very high. Hence the initial cost on solar energy will be very high. The fundamental element of a PV system is the solar cell which transforms the solar irradiance into direct current. Grid interconnection of PV system needs an coherent converter to converter the low DC voltage into AC. The technical necessities from both the utility grid side and the PV system side need to be satisfied to protect the safety of the PV installer and the reliability of the utility grid to utilize the generated power successfully. An interface system must be developed to make the interconnection between the PV system and the grid. To ensure that the system will work as desired and to investigate its impact in different conditions; the system must be modeled and simulated. the main objective is developing a power electronics interface for a three-phase grid connected PV, capable of extracting supreme power from the PV arrays all insolation levels and Implementation of the inverter to convert the dc output voltage to a voltage suited with the utility grid and house appliances.

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### *A. Components included in a System of Photovolatic Conversion*

The principle schematic diagram of a grid connected PV system with voltage source inverter is shown below in Fig [1].

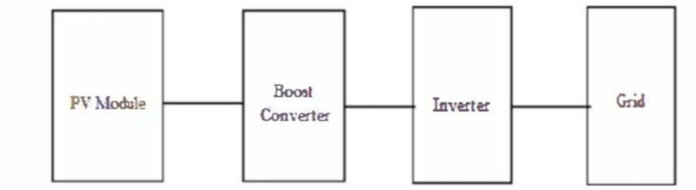


Fig. 1 Grid connected PV system block Diagram

The main components that can be involved in a system of photovoltaic conversion are Photovoltaic modules,converters, utility grid, loads DC and AC, and Inverters . It is an arrangement used in PV standby power supply units, it is called grid connected system without a battery backup. Although systems with battery backup oppose the issue of reliability of the grid supply but it is more tricky and more expensive.

### *B. PV Module*

The solar panel is the power source of all photovoltaic installation. It is the outcome of a set of photovoltaic cells in series and parallel. PV cell directly transforms the solar irradiance into electricity in the form of dc when sunlight interconnects with semiconductor materials in the PV cells.Figure The equivalent circuit of a PV is shown in Fig [2], from which non linear I-V characteristic can be deduced. Hence, the cells are connected in series and in parallel combinations in order to form an array with intended voltage and power levels, solar cells are merged to form 'modules' to obtain the voltage and current (and accordingly power) desired as shown in Fig [2].

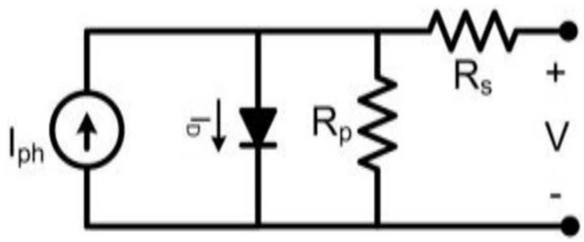


Fig. 2 Equivalent circuit of photovoltaic cell.

### *C. DC-DC Boost Converter*

The positioning of the boost converter will improve the whole photovoltaic installation, allowing different controls from the system. Depending on the applied regulation, the panels will contribute to the maximum energy given to the system or the optimal energy for their operation. The boost converter is a medium of power transmission to perform energy absorption and injection from solar panel to grid-tied inverter. The process of energy absorption and injection is performed by a combination of four components which are an inductor, electronic switch, and diode and output capacitor . The connection of a boost converter is shown in figure (3).

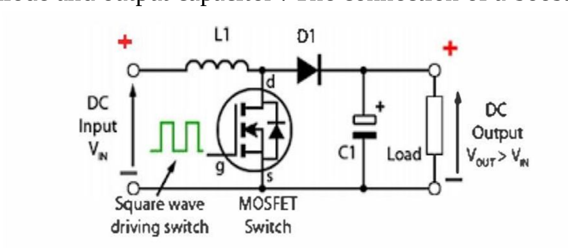


Fig. 3 Basic Boost Converter Circuit

When switch is closed for time $t_1$, the inductor current rises and energy is stored in inductor L. If the switch is open for time $t_2$, the energy stored in the inductor is translated through diode D and inductor current falls, the switching duty cycle a is defined as the ratio of the on duration to the switching time period so the output voltage is greater than the input voltage and is expressed as in eq. (1)

$$V_{out}/V_{in} = 1/(1 - a) \qquad (1)$$

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### *D. Inverter*

It is the main part of the system which is consists of semiconductor switches with a controller that provides the right switching pulses to control the inverter. It converts the DC power produced by the PV array into AC power consistent with the voltage and power quality required by the utility grid. The inverter topology selected for this design is the voltage source inverter (VSI). Figure (4) shows a schematic diagram of a 3 phase VSI. It is composed of six switches $S_I$ through S6 with each phase output connected to the middle of each "inverter leg". Two switches in each phase are used to construct one leg. The AC output voltage from the inverter is obtained by controlling the semiconductor switches ON and OFF to generate the desired output .

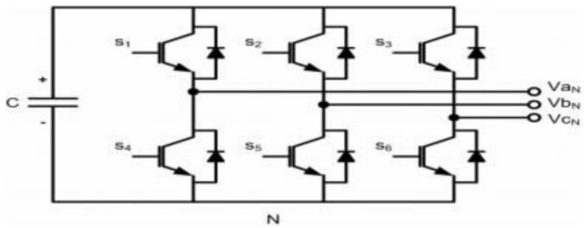


Fig. 4 Topology of Three Phase Inverter

The AC output waveforms shape and quality are directly related to how the conduction intervals of the switches are controlled. The method chosen for this application was sinusoidal pulse width modulation (SPWM), it allows the control of the phase, magnitude, and frequency of the generated AC waveform. It requires three reference sinusoidal waveforms (for three phase operation) of the same frequency as the desired output waveform and one high frequency triangle waveform known as the carrier signal. The process is done by comparing the magnitudes of the sinusoidal and triangle waveforms. When the amplitude of the modulating signal is greater than that of the carrier signal, the upper switch in the corresponding phase leg in figure (4) is activated. This leads to the output voltage having the same magnitude of the DC link voltage and the vice versa. The magnitude of the output phase voltage (RMS) can be determined using equation (2). Where $m_a$ is the modulation index and calculated as in equation (3). $V_{rms}= m_a V\text{-}Dc/2\sqrt{2}$ (2) $m_a= V_m/ V_{carrier}$ (3)

## III. METHODOLOGY

The system is consists mainly as following; Photovoltaic array converts the sun irradiance and generates dc voltage and current, the DC-DC boost converter controlled by maximum power point tracking (MPPT) using (P&O) algorithm to track the maximum power point of the array then the three phase Inverter converts the dc voltage to AC for grid interfacing or supply to the local load. The band pass filter withdraws harmonic components from the inverter output.

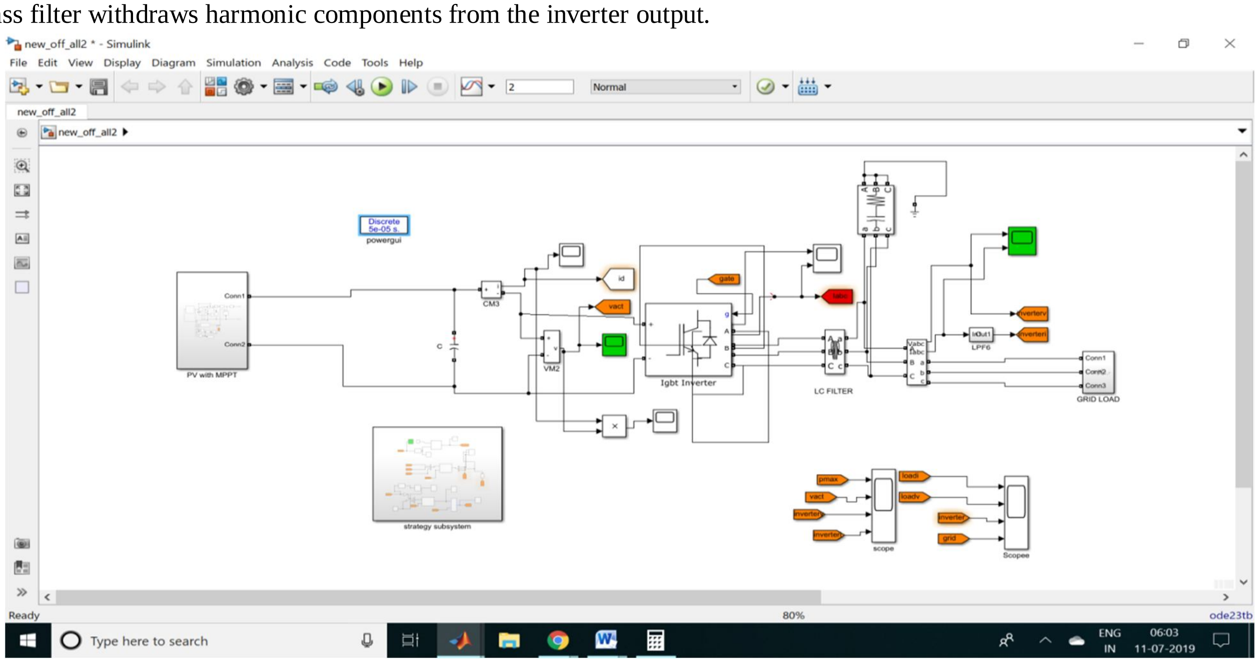


Figure 5 MATLAB model of grid interactive pv system

*A. Perturb & Observe MPPT Algorithm*

This MPPT algorithm continuously maximizes the power generated by PV systems by controlling the voltage. The Perturb and observe (P&O) algorithm is extensively used MPPT techniques for solar PV applications due to its coherence in design and implementation with good production. This algorithm track maximal Power Point by measuring the PV attributes are perturbs the operating point of PV module to get the position change in direction. When there is a rate of change of power with respect to voltage is zero, the maximal power point is reached. When the PV panel voltage is perturbed by a small gain, the resulting in change power of is positive then the system is going in the direction of MPP and to keep on perturbing in the same direction i.e δ′ is increased. If P is negative, then the system going away from the direction of MPP and the sign of perturbation supplied has to be changed i.e δ′ is reduced. The identical step is to continue till maximal power point is reached. The equivalent voltage at which MPP is reached is known as reference point (Vref). Fig. (6) Shows Flowchart of Perturb and Observe (P&O) algorithm.

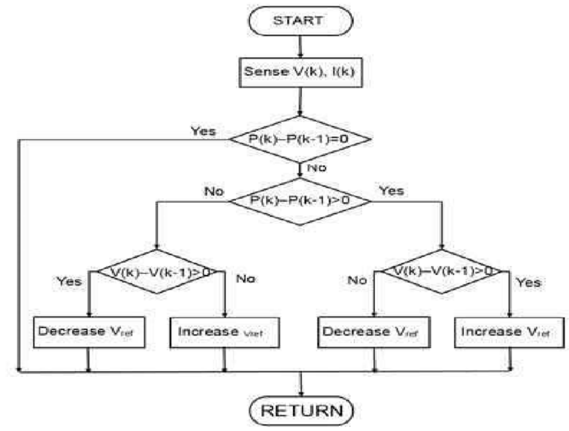


Fig.6 Shows Flowchart of P and O algorithm

Perturb and observe (P&O) algorithm was implemented in MATLAB and the mazimum power point tracking (MPPT) controller inputs were:

1) Voltage and Current from the PV array.
2) Maximal, minimal, Increment value and the initial value for duty cycle.

*B.Band Pass Filter*

The band pass filter withdraws harmonic components from the inverter output. Filters are connected between the inverter and the grid. The filter used is a band pass filter centered at 50 Hz with very low band width. To meet IEEE 519 level about harmonic introduces in system.

## IV. RESULTS AND DISCUSSIONS

Simulated three-phaseInverter side current and voltage is shown in figure 7 and figure 8 respectively. Figure 9 and 10 shows the three-phase simulated Load side current and voltage showing that the system is dynamically stable under varying load conditions. The tuned $V_{dc}$ simulated waveforms specified in figure 11. It has been found that by using MPPT, PID controller and three-level inverter, the efficiency of our system is swelled and the dynamic stability of our system connected to the grid is also preserved.

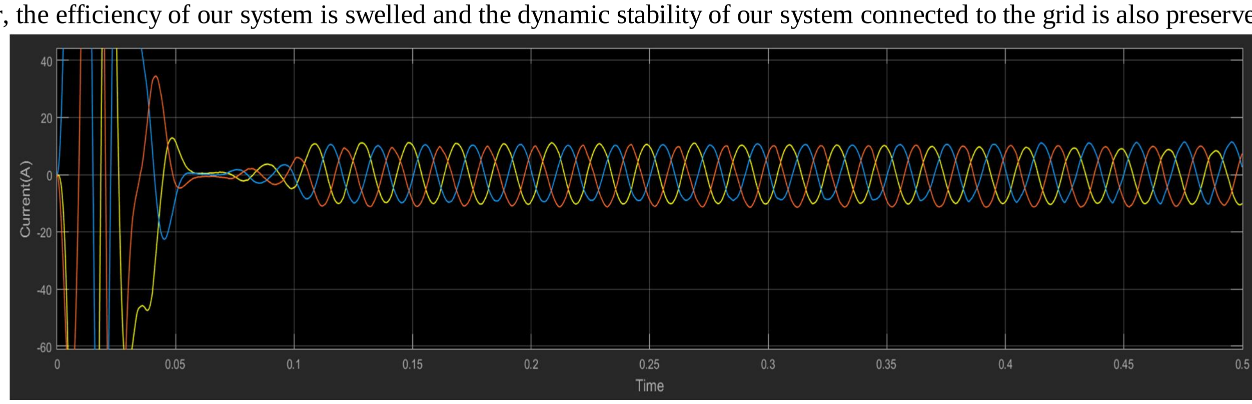


Fig.7 Three-phase inverter side current

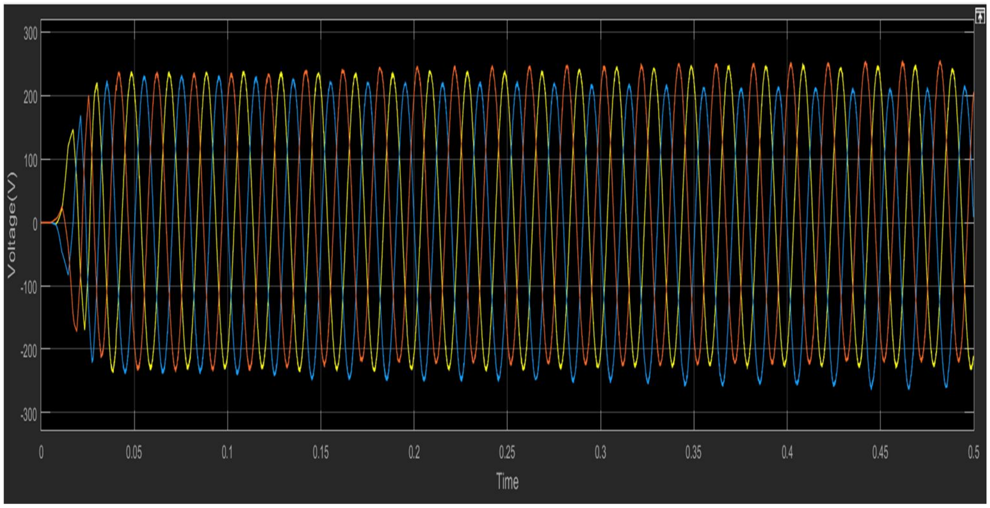


Fig.8 Three-phase inverter side voltage

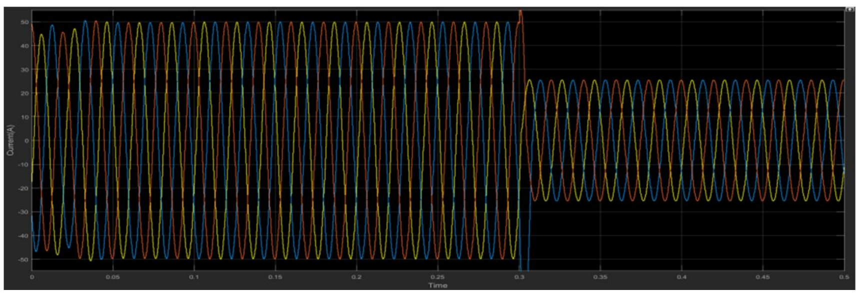

Fig .9 Three-phase simulated Load side current

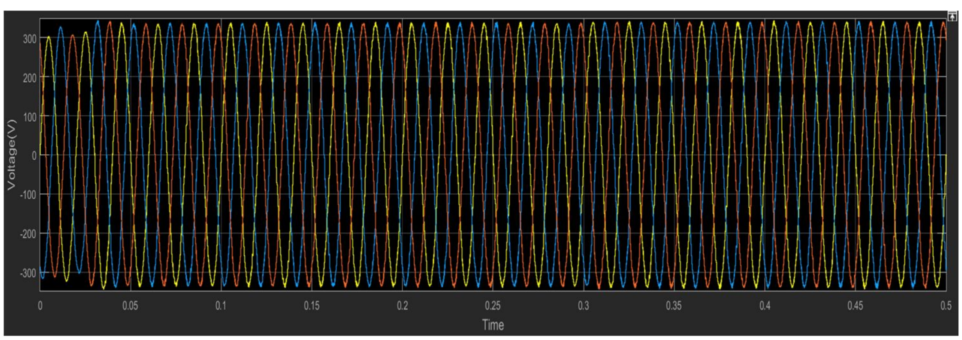


Fig.10 three-phase simulated Load side voltage

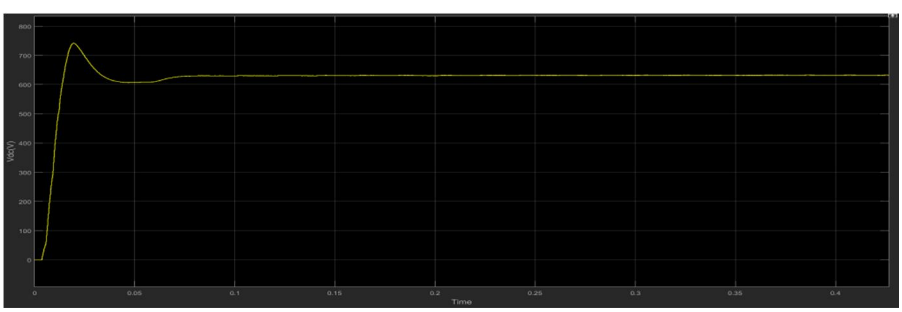

Fig. 11 tuned $V_{dc}$ simulated waveform

## V. CONCLUSION

This paper gives interfacing of grid-connected PV system, recognize its elements, and gives details how it works. The MPPT with perturb and observe (P&O) algorithm has take out the supreme amount of power from the PV array with high efficiency in a dynamic response time. Three phase inverter was implemented successfully and its output was fed to a band pass filter and gave a accessible sinusoidal alternative current, its power quality output meets the grid benchmark. The sinusoidal pulse width modulation technique used in the VSI was implemented correctly and diminish the filtering needs. All simulation outcomes, acquired under MATLAB Simulink environment, show the control production and dynamic behavior of grid connected photovoltaic system supplies good outcome and show that the control system is efficient.

## VI. ACKNOWLEDGMENT

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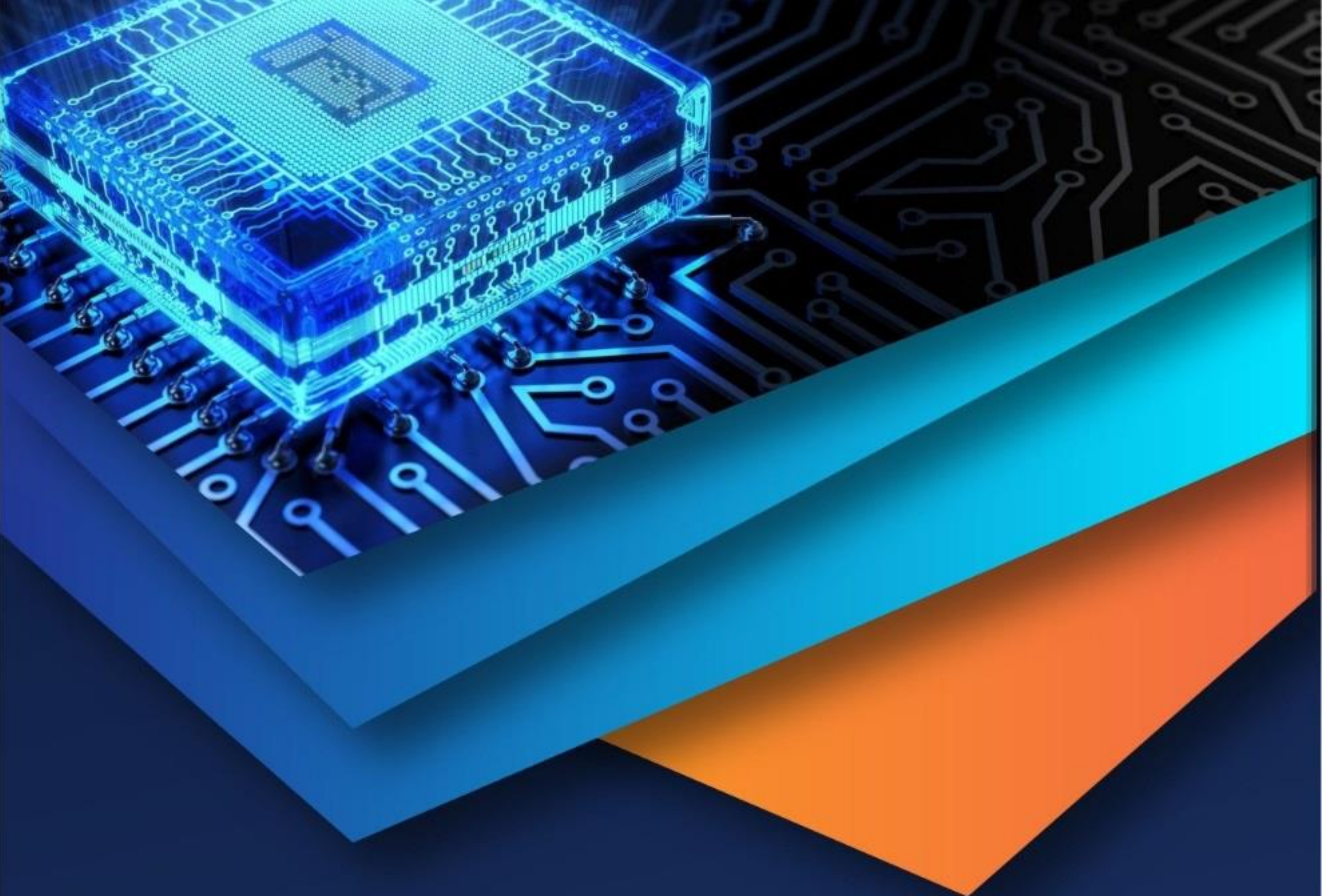

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