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# Modeling and Analysis of Controllers for PV sourced Grid Connected inverter with Unbalanced Nonlinear loads

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***Abstract*— nowadays, the majority of Photovoltaic power sources connected with the grid has been increased. One of the major problems is the poor PV utilization under changing operating condition. So in order to improve the PV utilization along with grid connected inverter, this system has been implemented with controller analysis and model. This system is mainly used for non linear load compensation. As well as, it also controls the active power generation and provides the reactive power compensation under unbalanced condition. And this module is also used to maintain the maximum injected power to the grid and also compensates the unbalanced nonlinear currents. In the existing method, Peak current of the inverter is reduced during the unbalanced grid-voltage sags with the help of current harmonics injection which increases the total harmonic distortion. In order to reduce the Total Harmonic Distortion, inverter current is maintain within its rated value in this proposed method. Also this module constitutes about voltage sag, swells problems and the controller has been designed using grid connected Inverter control techniques. As well as the maximum power point of PV is tracked using Incremental Conductance technique to reduce the error and improves the system efficiency. The theoretically designed models are confirmed using MATLAB/Simulink software.***

***Index Terms*—Solar Power Generation, Grid connected inverter, Modeling and Controller Analysis, Unbalanced Nonlinear load, Current control, Compensation, Digital signal controller.**

## I. INTRODUCTION

The Photovoltaic System is the solar power generation system which has been widely used for the past decades in all over the world. It has been used in several domestic and industrial applications since it does not have any impact on the environment like pollution effects such as in other renewable energy sources[1]-[3].

As global warming crisis is increased due to the high rate of pollution produced by the recycling of industrial wastage and biogas, so in order to reduce such type of problems PV system can be effectively used for the power generation both in ON-grid and OFF-grid applications. However the installation cost of Photovoltaic System is high, it has been increasingly utilized for the grid connected systems. And also in order to improve the efficiency and the system stability in grid connected PV systems, a Power Electronic conversion is needed in between the PV source and the grid. It is also used to track the maximum power from the PV panels during the variation of solar irradiation and the temperature. Different types of MPPT techniques are developed such as Constant Voltage and Current, Perturb and Observe, Incremental Conductance [4]-[7]. Incremental Conductance method is used to track the maximum PV power. In this paper, a new mathematical model for grid connected PV inverter under unbalanced condition is presented. The proposed new model is based on the dq representation and it is derived on the basis of synchronous frames of reference. The controller is designed by using grid synchronization technique with voltage oriented control.

## II. SYSTEM DESCRIPTION

Using PV cell-solar radiation is converted into DC current. Boost converter is implemented to boost and to maintain the constant dc-link voltage during irradiation. A controller is designed for PV sourced inverter depending upon variable dc voltage and variable dc current where power control is done. Switching time of the boost converter is derived from voltage control. Phase voltage and current is also controlled by using DSC TMS320F82335. Voltage and current signals are fed to the input of the power controller. The output of the power control is providing the voltage reference for the voltage controller and ac current reference to the current controller. The current controller generates the modulating signals and those signals are given to the PWM block.

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The generated PWM pulses are given to the gate drive circuit to trigger the inverter circuit. Filter circuit is provided to reduce the oscillation in the voltage and current (smoothing purpose). Double synchronous reference frame technique with PLL is used to synchronize PV with grid. Boost converter acts as MPPT charge controller. Normally, the non-linear load will generate a current harmonics wherever it is used. The controller designed is especially used for the reduction of harmonics present in the ac side.

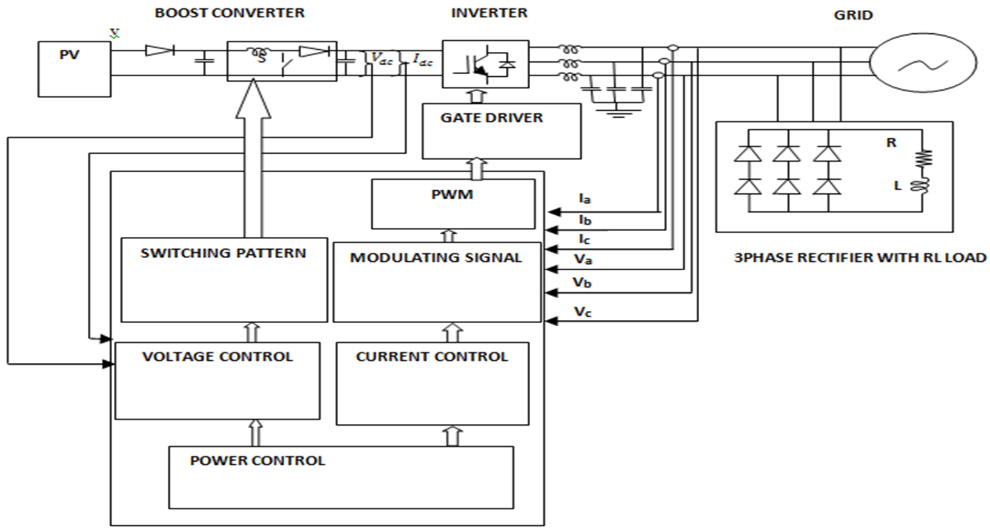


Fig 1: Block Diagram of PV sourced Grid connected inverter with unbalanced Nonlinear Load

## III. MODELING

### A. PV Modeling

In the proposed method, two diode PV array model is used. The two diodes model uses an equivalent circuit and takes into account the mechanism of electric transfer of charges inside the cell. In this model, the two diodes represent the PN junction polarization phenomena.

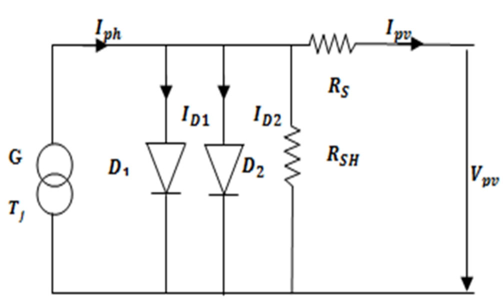


Fig 2: Equivalent Circuit of PV Array Model

The PV power equation has been derived for the above model and given in the Appendix [13]. These diodes represent the recombination of the minority carriers, which are located both at the surface of the material and within the capacity of the material. The photocurrent $I_{ph}$ produced by the current source, which is directly proportional to solar irradiance G. where K Boltzmann's constant, A diode ideality factor of the junction, $T_j$ junction temperature of the panels, $R_s$ and $R_{sh}$ are series and shunt resistors, ns the number of cells in series, G Global irradiance on a plane ($W/m^2$), $G_{ref}$ is the Reference irradiance (1000 $W/m^2$), $I_{sh}R_{sh}$ Current of the resistance, $T_{ref}$ to the reference panel temperature of 25°C, q is the electron charge ($1.6029 \times 10^{-19}$C), $E_g$ which represents the gap energy and $I_{ph}$ is the photocurrent.

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*B. Modeling Of Grid Connected Inverter*

*1) Under Balanced Condition:* This model has been done for the grid connected inverter under balanced condition. It is entirely based on the dq frame conversion with rotating reference frame.

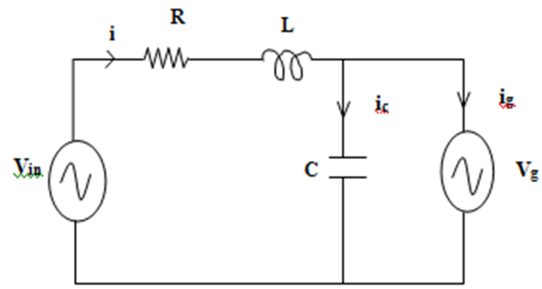


Fig 3: Equivalent circuit for Grid Connected Inverter

The state space model has been calculated for the balanced condition of grid connected inverter and it is given in the Appendix. Where $i_{id}$ and $i_{iq}$ are inverter current in dq frame, $V_{id}$ and $V_{iq}$ are inverter voltage in dq frame, $V_{cd}$ and $V_{cq}$ are the voltage across the capacitor, $i_{gd}$ and $i_{gq}$ are the grid current in dq axis, $R_g$ and $L_g$ refers to grid impedance, $V_{gd}$ and $V_{gq}$ are the grid voltage in dq axis.

*2) Under Unbalanced Condition:* Unlike the balanced case, the steady-state active and reactive powers include a constant component and time varying sine components with a frequency of twice the grid frequency. In this situation, it is common to choose the constraints of the three components of the active power, which have a direct effect in the progression of the dc bus voltage, and the mean value of the reactive power. Usually, the reference value for the sine components of the active power is set to be zero to avoid the ripple of the dc bus voltage during unbalanced voltages on the grid side.

The equations to solve for the power on the grid connection point of the converter are formed and converted into positive-negative sequence components in dq reference frames. They are given in the Appendix. The inverter controller design is done by Voltage Oriented Control since it is based on the use of a dq frame rotating at grid frequency. It depends on the d axis which is aligned on the grid voltage vector. In this proposed scheme, PI based controller is used which decides the reference d and q components of the reference current while the dc voltage control has the impact on the reference current.

C. *Load modeling*

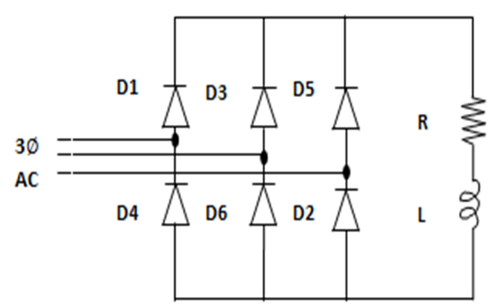


Fig 4: Equivalent circuit of Three Phase Diode Bridge Rectifier with R-L load

Let us consider a three-phase diode bridge rectifier as shown in Figure. The rectifier consists of a three-phase diode bridge, comprising diodes D1 toD6. In the analysis, it is assumed that the impedances of the supply lines are low enough to be neglected, and that the load current is not constant in time. Now, the three phase current in abc frame is obtained by integrating the $i_a(\theta)$, $i_b(\theta)$ and $i_c(\theta)$ and it is further converted into dq reference frame. The diode current equations are derived and it s given in the Appendix.

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Where $I_m\theta(t)$ is the peak current value with respect to time?

## IV. SIMULATION RESULT

The entire system shows the PV source supplying power to the AC side (grid) and the input variation of PV is generated with variable irradiance. The transformation of three phase variables to two phases is also done using park transformation according to the theoretical concept. The real & reactive power measurement is made for performance analysis. The modulation index is provided to inverter, according to the pulse requirement. And this system includes PV array model. The separate voltage, current and both PQ measurements are done for variable irradiance effects.

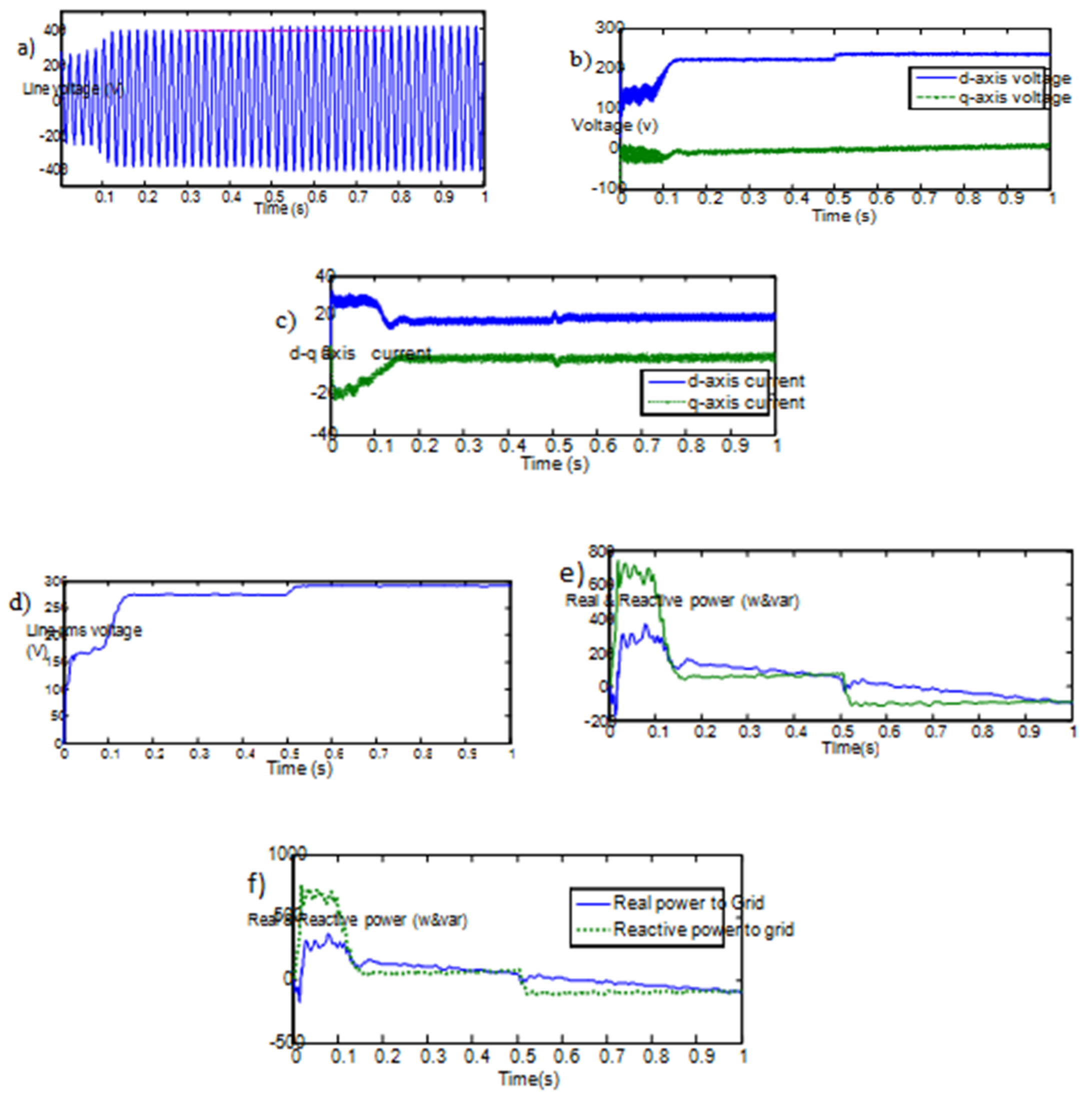


Fig 5: Waveform a) Line voltage at pcc without controller for Variable irradiation, b) Voltage at pcc in dq0 frame with Variable irradiation, c) PV inverter Current in dq0 frame with variable irradiation, d) Line voltage at pcc without controller for Variable irradiation, e) Real & Reactive power flow from PV to grid for viable irradiation and f) Real & Reactive power flow from PV to grid for viable irradiation.

## V. CONCLUSION

Compared other conventional methods, this proposed method using reference frame techniques eliminates the current harmonics generated

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by the unbalanced nonlinear loads. Also the d-q model of grid connected PV inverter (VSI) has been designed efficiently in this module. The injection of unbalanced current components has also been shown to suppress the harmonics on the dc bus voltage due to the oscillation of the power injected to the grid with unbalanced non-linear loads. The real power injection to the grid has to be controlled during reactive power generation. This will be carried out for the future work. And also the control method has been proposed to calculate the current reference.

## VI. APPENDIX

The PV power is given by

$$P_{pv} = \{P_1G[1 + P_2(G - G_{ref}) + P_3(T - T_{ref})] - \frac{V_{pv} + R_s I_{pv}}{R_{sh}} - [P_4T_j^3 \\ [\exp(\frac{-E_g}{KT_j})][\exp\frac{q(V_{pv} + R_s I_{pv})}{AN_{(s-cell)}KT_j} - 1] - [P_5T_j^3[\exp(-\frac{E_g}{2KTj})] \\ [\exp(\frac{q(V_{pv} + R_s I_{pv})}{2AN_{(s-cell)}KT_j}) - 1]]\}V_{pv} \quad (1)$$

The state space model for balanced condition is given by,

$$\frac{d}{dt}\begin{bmatrix} i_{id} \\ i_{iq} \\ V_{cd} \\ V_{cq} \\ i_{gd} \\ i_{gq} \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & \omega & -\frac{1}{L} & 0 & 0 & 0 \\ -\frac{R}{L} & -\omega & 0 & -\frac{1}{L} & 0 & 0 \\ \frac{1}{C} & 0 & 0 & \omega & -\frac{1}{C} & 0 \\ 0 & \frac{1}{C} & -\omega & 0 & 0 & -\frac{1}{C} \\ 0 & 0 & \frac{1}{L_g} & 0 & \frac{R_g}{L_g} & \omega \\ 0 & 0 & 0 & \frac{1}{L_g} & -\omega & -\frac{R_g}{L_g} \end{bmatrix} \begin{bmatrix} i_{id} \\ i_{iq} \\ V_{cd} \\ V_{cq} \\ i_{gd} \\ i_{gq} \end{bmatrix} + \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & \frac{1}{L} \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} V_{id} \\ V_{iq} \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ -\frac{1}{L_g} & 0 \\ 0 & -\frac{1}{L_g} \end{bmatrix} \begin{bmatrix} V_{gd} \\ V_{gq} \end{bmatrix} \quad (2)$$

The positive and negative sequence currents are represented in dq frame.

$$i_{iq}^{+} = [\frac{v_{gq}^{+2}}{v_{gq}^{+2} - v_{gq}^{-2}}[i_{lq}^{+} - i_{wq}^{+}] - \frac{v_{gq}^{-2}}{v_{gq}^{+2} - v_{gq}^{-2}}[i_{lq}^{+} - i_{wq}^{+}]] \quad (3)$$

$$i_{id}^{+} = [\frac{v_{gq}^{+2}}{v_{gq}^{+2} + v_{gq}^{-2}}[i_{wd}^{+} + i_{ld}^{+}] + \frac{2v_{gq} + v_{gq}^{-}}{v_{gq}^{+2} + v_{gq}^{-2}} i_{wd}^{-} + \frac{v_{gq}^{-2}}{v_{gq}^{+2} + v_{gq}^{-2}}[i_{lq}^{+} - i_{wq}^{+}]] \quad (4)$$

$$i_{iq}^{-} = [-\frac{v_{gq}^{-2}}{v_{gq}^{+2} - v_{gq}^{-2}}[i_{lq}^{-} - i_{wq}^{-}] + \frac{v_{gq}^{+2}}{v_{gq}^{+2} - v_{gq}^{-2}}[i_{lq}^{-} - i_{wq}^{-}]] \quad (5)$$

$$i_{id}^{-} = [-\frac{v_{gq}^{+2}}{v_{gq}^{+2} + v_{gq}^{-2}}[i_{ld}^{-} - i_{wd}^{-}] + \frac{2v_{gq} + v_{gq}^{-}}{v_{gq}^{+2} + v_{gq}^{-2}} i_{wd}^{+} + \frac{v_{gq}^{-2}}{v_{gq}^{+2} + v_{gq}^{-2}}[i_{ld}^{-} + i_{wd}^{-}]] \quad (6)$$

The load current equations in dq frame is given by

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$$i_d = \sqrt{\frac{2}{3}}\left[\frac{3}{\pi} I_m \theta(t) \cos\theta - \frac{2}{\pi} I_m \theta(t) \cos\left(\theta - \frac{2\pi}{3}\right) - \frac{3}{\pi} I_m \theta(t) \cos\left(\theta + \frac{2\pi}{3}\right)\right] \quad (7)$$

$$i_q = \sqrt{\frac{2}{3}}\left[\frac{3}{\pi} I_m \theta(t) \sin\theta + \frac{2}{\pi} I_m \theta(t) \sin\left(\theta - \frac{2\pi}{3}\right) - \frac{3}{\pi} I_m \theta(t) \sin\left(\theta + \frac{2\pi}{3}\right)\right] \quad (8)$$

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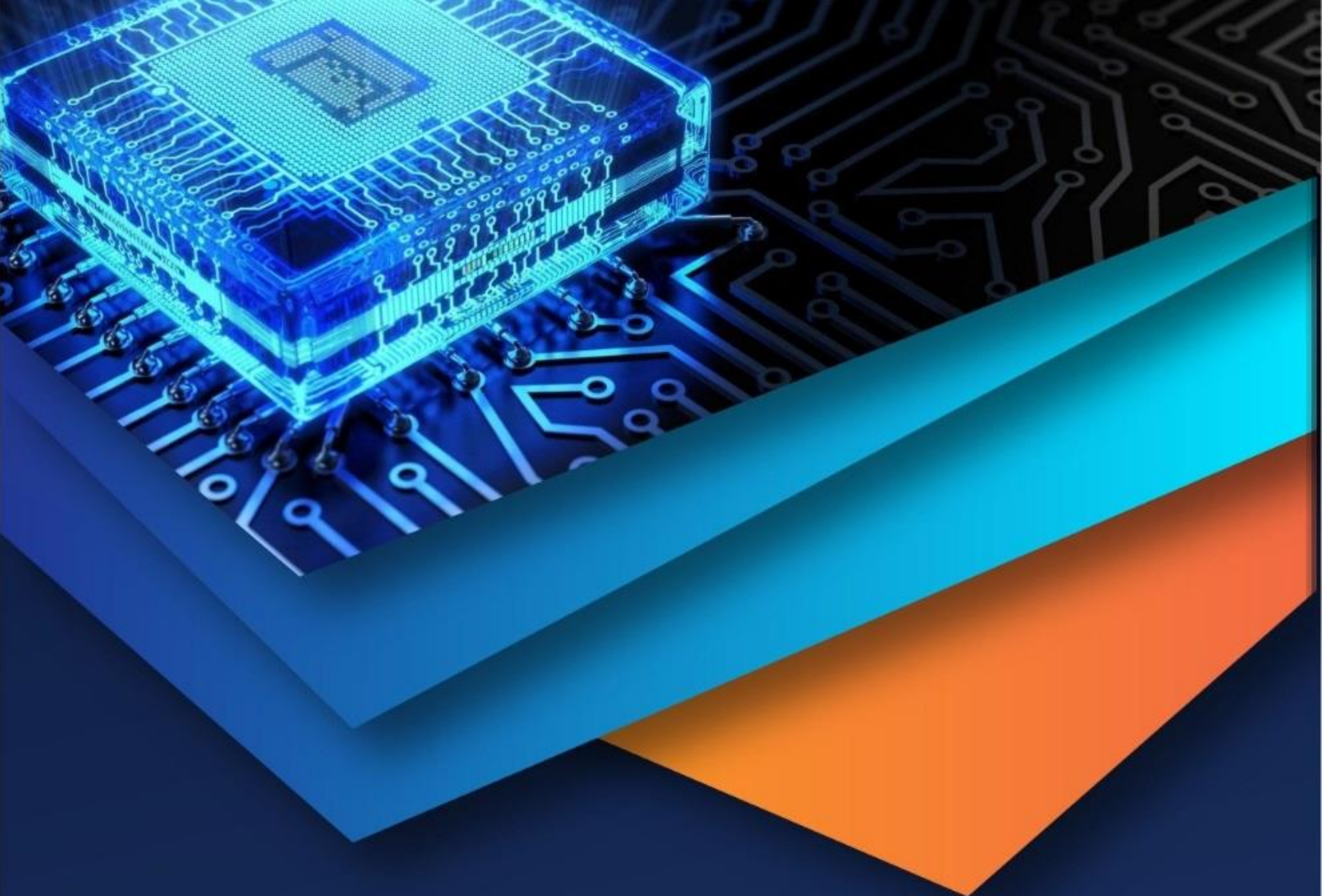


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