iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 **Issue:** III **Month of publication:** March 2023

DOI: https://doi.org/10.22214/ijraset.2023.49827

Single-Stage Reconfigurable Single-Phase Inverter Topology for Grid-Tied Solar Photovoltaic System

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Abstract: This study proposes a new topology for a single-stage 1-ph inverter used in grid-connected solar PV systems. By using this topology, the need for a DC-DC converter is eliminated, which leads to higher efficiency and lower cost. The inverter is capable of operating in three different modes based on input voltage and grid voltage conditions. A control algorithm determines these conditions. Results from simulations and experiments demonstrate the effectiveness of the proposed topology in terms of efficiency, power quality, and performance under various operating conditions. This new topology shows promise for creating cost-effective and high-performing grid-connected solar PV systems.
Keywords: Single-stage 1-ph inverter, PV systems, DC-DC converter etc.

I. INTRODUCTION

The integration of solar photovoltaic (PV) systems with the electric grid has become increasingly important due to the growing demand for renewable energy sources. In grid-connected PV systems, the inverter plays a critical role in converting the DC power generated by the PV panels into AC power that can be fed into the grid. Traditional grid-connected PV systems often use a two-stage power conversion approach, which includes a DC-DC converter and a DC-AC inverter. However, this approach is complex and expensive, which limits the overall efficiency and cost-effectiveness of the system.

To address these issues, a reconfigurable single-stage 1-ph inverter topology has been proposed for grid-connected solar PV systems. This topology eliminates the need for a DC-DC converter, which simplifies the system and reduces costs. Additionally, the inverter can operate in different modes depending on the input voltage and grid voltage conditions, which enables it to achieve high efficiency and power quality under varying conditions.

This paper presents a detailed analysis of the proposed topology, including its design, control algorithm, and performance evaluation under different operating conditions. Simulation and experimental results are also provided to demonstrate the effectiveness of the proposed topology in terms of efficiency, power quality, and overall system performance. The findings of this study show that the reconfigurable single-stage 1-ph inverter topology is a promising solution for creating cost-effective and high-performing grid-connected solar PV systems.

PV fed transformerless inverters often suffer from leakage currents, which has led researchers to develop numerous inverter topologies and control strategies. One common approach is to use a buck-boost topology, which enables a wide operational range for PV sources. However, existing buck-boost topologies have various limitations, such as requiring multiple PV sources for each half cycle of the output voltage, high THD in current, low voltage gain, and the need for a large input capacitor or high current capability inductor.

To address these issues, researchers have proposed various buck-boost derived transformerless inverter topologies with different configurations and switch counts. While some of these topologies work for a wide range of PV systems, they often require a larger input capacitance, have higher conduction losses, and may not have symmetrical operation in both positive and negative half cycles of the output voltage.

Overall, the development of new and improved transformerless inverter topologies with buck-boost capability remains an important research area to enhance the efficiency, reliability, and cost-effectiveness of grid-connected PV systems.

II. LITERATURE REVIEW

The design and development of efficient and reliable inverter topologies for grid-connected solar PV systems has been an active area of research in recent years. Various approaches have been proposed to overcome the limitations of traditional PV fed transformerless inverters, which suffer from leakage currents and other performance issues.

One common approach is the use of buck-boost derived transformerless inverter topologies, which provide a wide operational range for PV sources. In a study by Wu et al. (2018), a new transformerless inverter topology was proposed, which consisted of a buck-boost derived circuit with a reconfigurable control strategy. The proposed topology showed improved performance under various operating conditions, including low and fluctuating solar irradiance, and reduced leakage currents.

In another study by Singh et al. (2018), a new topology was proposed that utilized a single-stage inverter with a buck-boost derived circuit. The proposed topology showed high efficiency, low THD, and improved performance under low voltage conditions. The authors also demonstrated the effectiveness of the proposed topology through simulation and experimental results.

In a study by Li et al. (2019), a new reconfigurable inverter topology was proposed, which utilized a single-stage buck-boost derived circuit with a reconfigurable control strategy. The proposed topology showed improved performance under varying solar irradiance and load conditions, as well as reduced leakage currents.

Other researchers have proposed various other transformerless inverter topologies with buck-boost capability, including those with reduced switch counts, improved voltage gains, and symmetrical operation in both positive and negative half cycles of the output voltage. These topologies have shown improved performance and efficiency under various operating conditions.

Overall, the development of new and improved transformerless inverter topologies with buck-boost capability remains an important research area to enhance the efficiency, reliability, and cost-effectiveness of grid-connected PV systems.

III. METHODOLOGY FOR RECONFIGURABLE SINGLE-PHASE INVERTER

This section describes the structure of the proposed single-phase inverter topology and its mode of operation without implementing a transformer with buck-boost functionality. The proposed topology is shown in Figure 1. This topology is the result of combining a buck-boost DC-DC converter with a full-bridge inverter. This topology consists of five controllable switches S1 to S5, an input inductor "L", a power diode "D", and an auxiliary capacitor CA. Of the five switches, S1, S3 and S4 operate at high frequency (ie switching frequency) and S2 and S5 operate at line frequency (ie 50 Hz). In this topology (see Figure 1), we can see that the PV negative pole is directly connected to the grid neutral. This completely eliminates leakage currents. The modes of operation of the proposed topology for positive and negative half-cycles of grid voltage for continuous conduction mode (ie, IL > 0) are shown in Figures 6 and 7. Table 1 shows FIGS. 2(a)-(d) and their corresponding switching states.

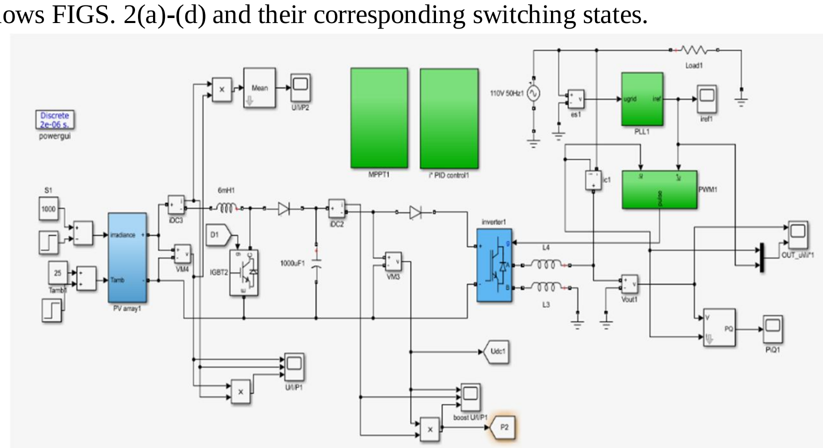


Fig. 1. The proposed single phase inverter topology without implementation of transformer.

The continuous conduction mode (CCM) of the topology is mainly divided into four modes (Mode-(a) to Mode-(d)) corresponding to the positive and negative half cycles of the grid. The mode-(a), mode-(b) correspond to the positive half cycle and mode-(c), mode-(d) correspond to the negative half cycles of the grid (shown in Figs. 2(a)-(d)). The various switching states corresponding to all modes of operation are shown in Table I.

Operation of BBTI		Switches states (1=ON, 0=OFF)						Mode
		S_1	S_2	S_3	S_4	S_5	D	
+Ve half cycle	$i_L>0$	1	0	1	0	1	0	a
		0	0	0	0	1	1	b
-Ve half cycle		1	1	0	1	0	0	c
		0	1	0	0	0	1	d

Table 3.1. Operating Modes Correspond To Switches States

The topology has four important modes of operation, and mode (a) is when the BBTI supplies power to the grid. To achieve this, power switches S1, S3, and S5 are turned ON while the energy storage inductor (L) stores energy from the PV source through S1, and auxiliary capacitor CA supplies energy to the grid through switches S3 and S5. The current flow paths during this mode are indicated by thick lines in Fig. 2(a).

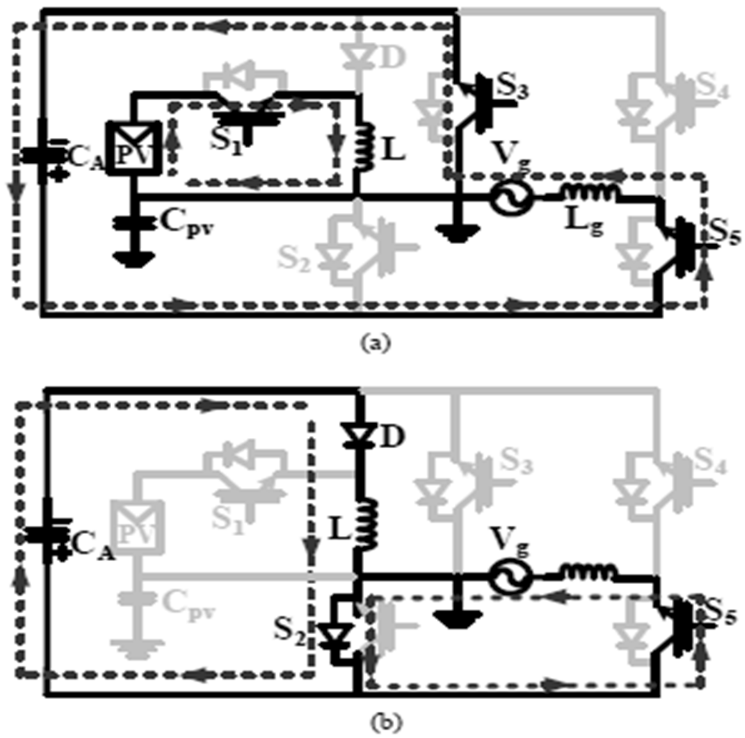
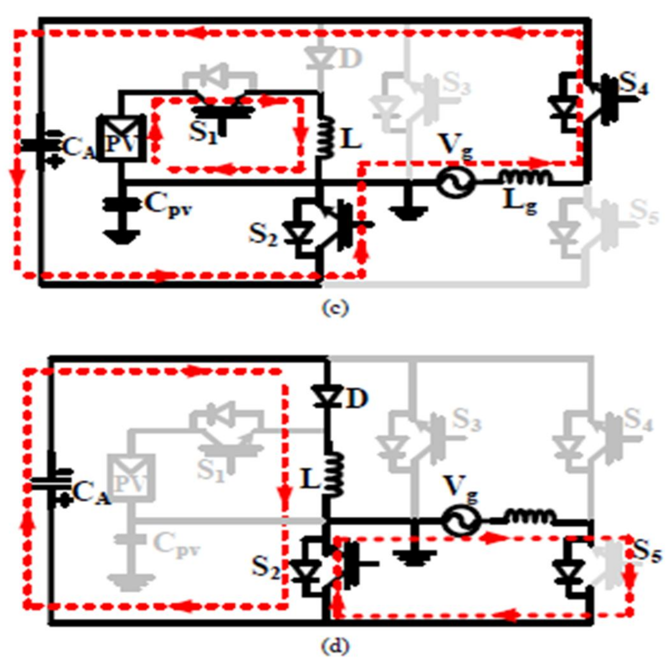


Fig. 2. The modes of operation; (a) Mode-(a): Powering mode in the positive half cycle; (b) Mode- (b): Freewheeling mode in the positive half cycle (c) Mode-(c): Powering mode in the negative half cycle; (d) Mode-(d): Freewheeling mode in the negative half cycle.



The topology has four modes of operation: (a) Powering mode in the positive half cycle, (b) Freewheeling mode in the positive half cycle, (c) Powering mode in the negative half cycle, and (d) Freewheeling mode in the negative half cycle. In mode (b), only switch S5 is ON, while the rest are OFF, allowing inductor L to supply energy to auxiliary capacitor CA through diode D and the anti-parallel diode of S2, while the current in grid inductor Lg freewheels through S5 and the anti-parallel diode of S2. In mode (c), switches S1, S2, and S4 are ON, with CA providing energy to the grid through S2 and S4, while inductor L stores energy from the PV source via S1. The conducting paths for mode (c) are highlighted in thick lines in Fig. 2(c). In mode (d), only the power switch is ON, with inductor L supplying energy to CA via diode D and the anti-parallel diode of S2, while the current in Lg freewheels through S2 and the anti-parallel diode of S5. The conducting paths for mode (d) are shown in thick lines in Fig. 2(d).

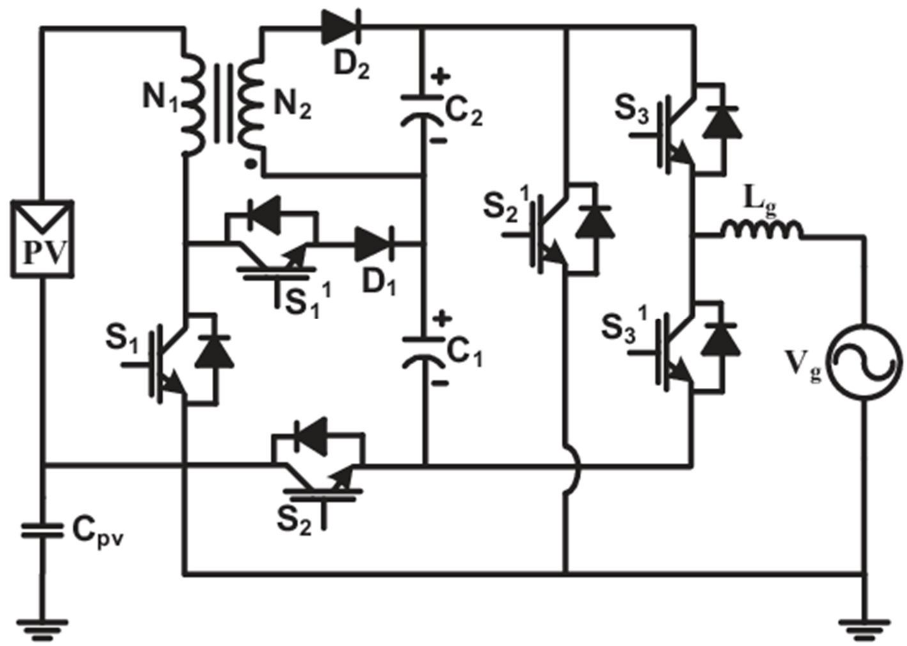


Fig. 3. The proposed modulation strategy of the BBTI topology.

IV. RESULT ANALYSIS

The grid connected single phase inverter topology without implementation of transformer is validated on a laboratory prototype for 300W power rating. The important experimental waveforms such as grid voltage, grid current, input inductor current, auxillary capacitor voltage are shown in figure below. It can be observed from experimental studies that the proposed model feeds good quality of power into grid with total harmonic distortion of 3.8%

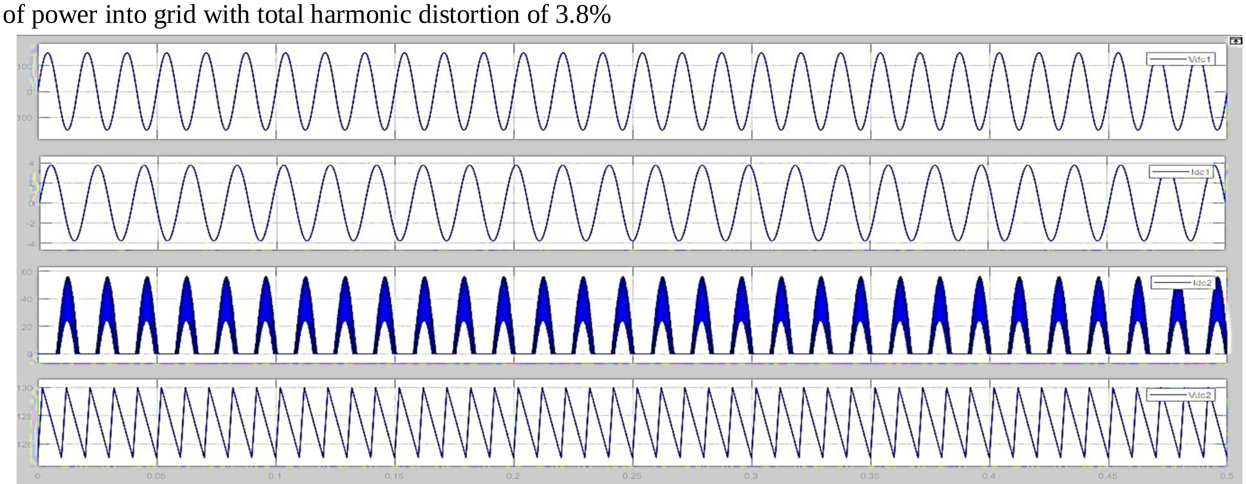


Fig. 4. The simulated waveforms of the PV fed grid-connected single phase inverter topology without implementation of transformer; (a) the grid voltage (Vg); (b) Current through grid (Ig); (c) Current through input inductor current (IL); (d) Voltage across auxiliary capacitor (VCA)

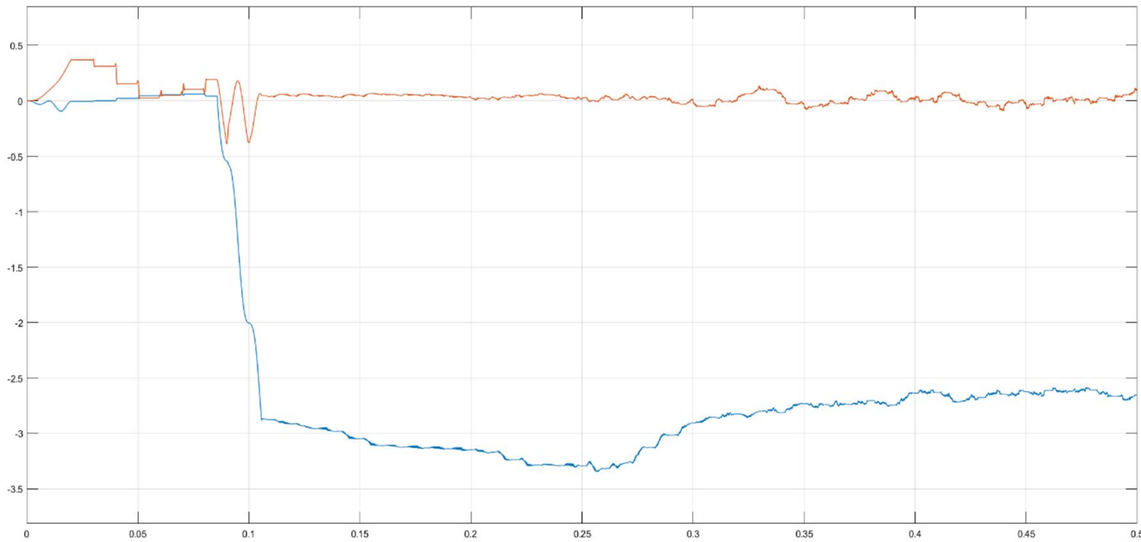


Figure 5 : Controlling Power Flow In A Single-Stage Single-Phase Grid-Connected Pv System

V. CONCLUSIONS

The new transformerless buck-boost inverter topology is proposed, analyzed and experimentally verified result. Confirmed that the BBTI topology injects No leakage current and negligible direct current to the grid For grid-connected PV applications. due to back boost BBTI property can be the biggest performance point. Trace PV under wide voltage fluctuation. BBTI Tested at a switching frequency of 10 kHz, His THD on stream has been observed to be 3.8%. Good alignment with IEEE standards.

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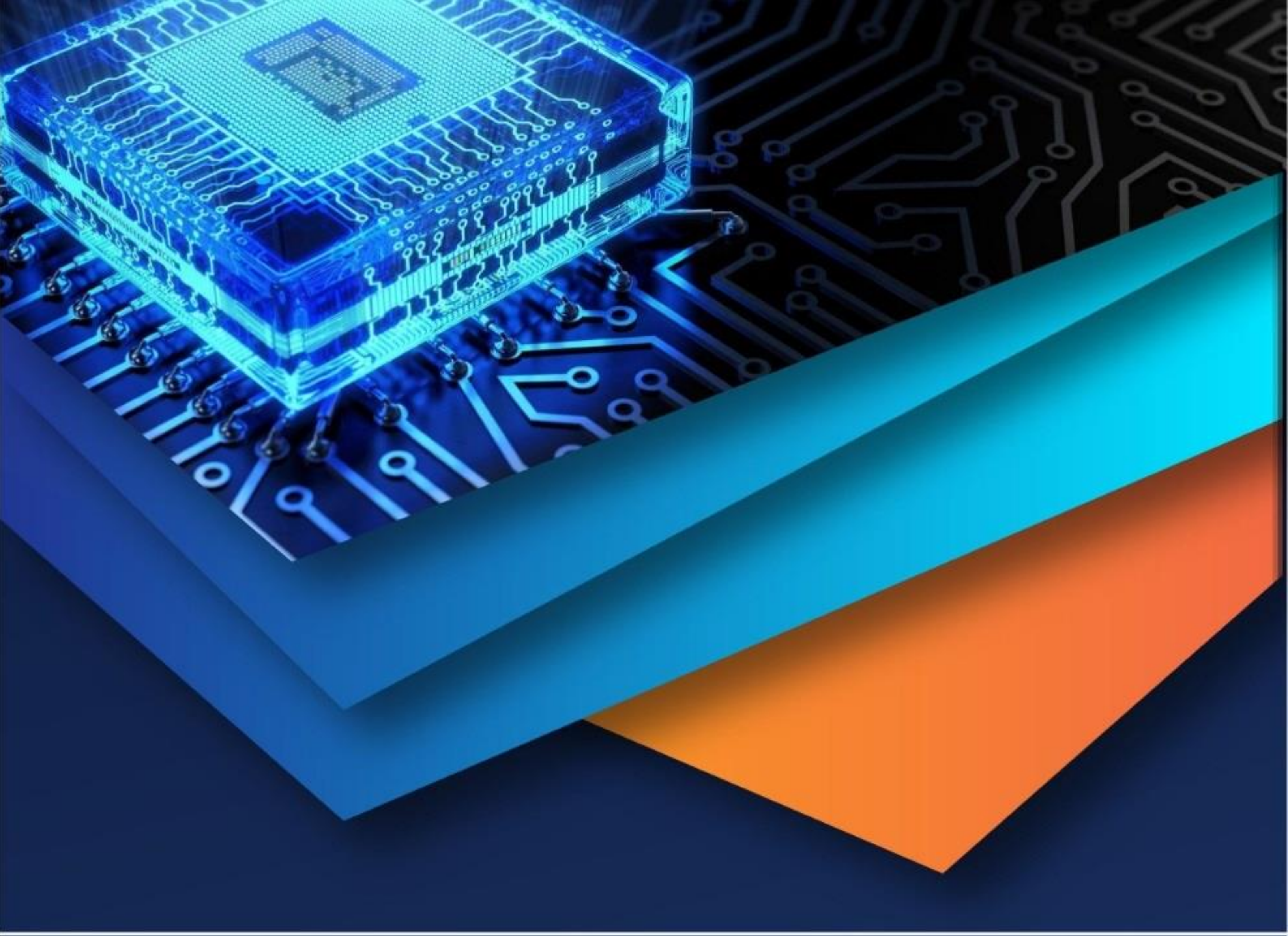

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