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Design and Simulation of a High Gain Boost Converter with Reduced Input Current Ripple

Debadyuti Banerjee[1], Anirban Giri[2]
[1]Electrical Engineering Dept. Abacus Institute of Engineering and Management, Mogra , India
[2]Electrical Engineering Dept. Kalyani Government Engineering College, Kalyani, India

Abstract: This paper proposes a high gain novel DC- DC converter. According to this topology gain of the converter can be improved more than a boost converter without using any transformer. In this topology it is possible to increases the gain of the converter without increasing the current ripple in the input current. This proposed topology is capable to reduce the voltage stress of the switches. Implementation of non-isolated topology eliminates the need of the transformer and reduces the magnetic size. The maximum duty restriction problem can be reduced by the higher gain of this proposed converter. The ripple reduction in the input current increases the life of energy storage system.
Keywords: Continuous input current, Voltage lifting topology, Ripple reduction, Gain Improvement.

I. INTRODUCTION

For the past few years energy demand is increasing rapidly which has a major impact on the storage of energy. Though the energy demand is increasing day by day the storage of fossil fuel is decreasing with time. In this current scenario the focus on renewable energy is more concentrated. Another benefit of renewable energy is that it maintains the cleanliness of the environment. For electrical energy generation Photovoltaic system are gaining popularity [4]. In small power generating units the generated voltage is comparatively much lower than the voltage required to consume by the load. [2] To operate the load from this source a converter is needed which will boost the voltage. In low and medium power range a battery storage system is sometimes used as a energy storage system with the PV. Most of the cases 48V batteries are used [1]. To supply load 110V AC a bus voltage magnitude of 155V is needed. For the pulse width modulation control bus voltage is needed be increased upto 200V DC. With lower bus voltage, transformer is used in output side of the transformer to increase the output voltage level and provide isolation. Transformers connected in the output side of the inverter generally operates in low frequency which increases the magnetics size and thus increases the total size of the power converter. Low voltage DC supply can be boosted up by using a boost converter which can reduce the magnetics size because they operate at higher frequency. A conventional boost converter is not sufficient for higher voltage boosting application. The major problem associated with the conventional boost converter is the restriction of the maximum duty ratio. Though theoretically 99% duty is possible but in practical cases the duty is restricted after a certain level. Generally, a boost converter is used to generate maximum output voltage equal to four times of the input voltage [2]. If duty of the converter is increased to a higher value, then off time reduces which will be the cause of the reverse recovery problem and thus the Electromagnetics interreference (EMI) issue. If the off time is increased, it will increase the magnetics size and current ripple of the converter.[3] Another issue is that by increase in duty the voltage stress of the switch increases. Voltage level of a converter can be improved by using transformer which will increase the magnetics size of the converter. One of the most suitable way is to use some extra passive components to improve the gain of a non-isolated converter. To improve the gain of a boost converter several voltage lifting topologies are introduced in the past few years. In several voltage boost topologies, it is recommended to reduce the voltage stress of the switching devices. Generally, the voltage stress of the devices is equal to the output voltage. By increasing the voltage level of the switches on state resistance increases which reduces the efficiency. Some of the voltage lifting topology in input side increases the current ripple which increases the size of the bus capacitor. If two boost converters are connected in series then the voltage stress of one switch can be reduced whereas that of another switch becomes equal to the output voltage of the converter.

This paper proposes a novel DC-DC converter topology by using two switches. In this proposed topology the voltage stress for both the devices can be reduced. No series parallel combination of passive elements is used in the first stage of the converter which maintains the continuous input current as well as reduces the input current ripple of the converter which is highly recommended for a battery storage system. Though this converter is used for voltage boost application this converter is different form a boost converter. This proposed converter is capable to supply maximum output at lower duty as well as maximum duty. Both of the switch operates in complementary operation which reduces the complexity of the converter. Gain of the converter is more than two boost converters connected in series.

II. PROPOSED CONVERTER

This topology proposes a high gain DC-DC converter for voltage boosting application by reducing the input current ripple. This proposed topology follows the operation of a boost converter. To reduce the current ripple of the converter no passive component is used in parallel with the inductor L1 during its charging time. In this converter S1 is the main switch and S2 is the auxiliary switch. On time of the Switch S1 is DT. When the Switch S1 is off the auxiliary switch will conduct. Dead time is not required for this proposed converter. During the on time of S1 if S2 turns on then it will freewheel only the current of inductor L2. It will however, not be able to affect the load current or the capacitor C1 current because of the presence of diode D1 in reverse biased condition. This proposed converter follows some rules of the boost converter. During the on time of the switch S1 the inductor L1 is charged from the supply voltage Vs. In voltage lifting application some extra passive components are generally connected in parallel with the inductor of the boost converter during its charging time and connected in series during the discharging time which increases the input current ripple of the converter. In this proposed topology voltage lifting is not applied in the first stage of the converter which reduces the current ripple of the converter. One of the most advantageous points in this converter is that all of the switch voltage stress of this proposed converter is less than the output voltage. This converter will supply minimum input voltage at 50% of the duty cycle. This converter is capable to supply maximum voltage at the minimum duty as well as at the maximum duty. The second stage of the converter is controlled by the auxiliary switch S2. When the switch S1 turned off S2 turn on and the series combination of charged inductor and the supply voltage charge the parallel combination of the capacitor C1 and the inductor L2. When the auxiliary switch S2 is turned on the diode D1 is in reverse biased condition which makes the series combination of C1 and L1 which are already charged. So this series combination of capacitor and inductor increases the voltage level and transfer the energy to the load. The diode D2 is used to avoid the discharge of load during the charging of capacitor C1. As during transferring the power to the load, L2 and C2 are connected in series the load voltage cannot appear across the Switch S2 which reduces the voltage stress of the switch S2. With the reduction of the maximum voltage stress on state resistance of the switch decreases which improves the efficiency of the system. As the volage lifting is introduced in the second stage of the converter, it will not increase the input current ripple. The major difference of this converter from a boost converter is that during on time of the switch S1, energy is transferred to the load whereas in a boost converter energy is transferred to the load during the off period.

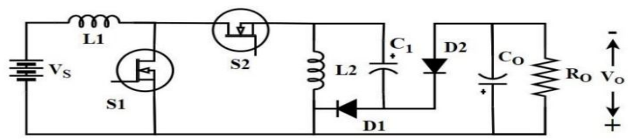

Fig .1 Schematic diagram of the proposed converter

When the switch S1 is turned on the inductor is connected across the supply voltage Vs and store energy from the source. Hence the current of inductor L1 increases in this mode to the peak current. During this time the switch S2 is in off condition. There is no voltage present to charge the C1 and L2. C1 and L2 both are in discharging mode. Now D1 is in reverse biased and D2 is in forward biased. The series combination of the inductor L2 and capacitor C1 charges the load and the inductor current starts decreasing. The conduction path of this mode will be D2-C1-L2-load. In this mode the load current is not directly drawn from the load, so sudden change in load current or transient in the load current will not affect the input current of the converter.

When the main switch is on voltage across the passive elements are-

$$V_{L_1} = V_S$$

$$V_{L_2} = -\frac{V_S}{D}$$

$$V_{C_1} = \frac{V_S}{1-D}$$

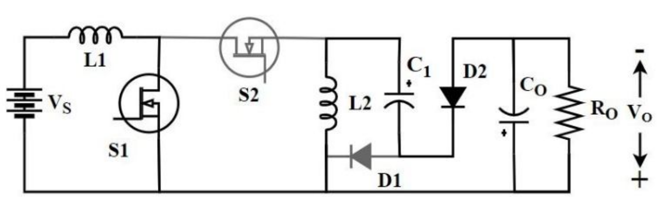

Fig .2 Conduction path during the on time of S1

Now the inductor L2 is charged and the current reached at the peak current. The switch S1 is turned off and the auxiliary switch S2 is turned on. Inductor L1 is in discharging mode. Series combination of source voltage and the inductor voltage will charge the parallel combination of L2 and C1. The diode D1 is in forward biased condition. The conduction path of the current will be Source voltage Vs-L1-S2 and the current will be divided into two paths- one will be L2 and another will be C2-D1. As diode D1 is in forward biased there is a negligible voltage drop across it. Load voltage is more than the diode D1 voltage which make the diode D2 reverse biased condition. In this mode no current will flow towards the load through D2. The inductor L1 current will decrease gradually and the L2 current increases.

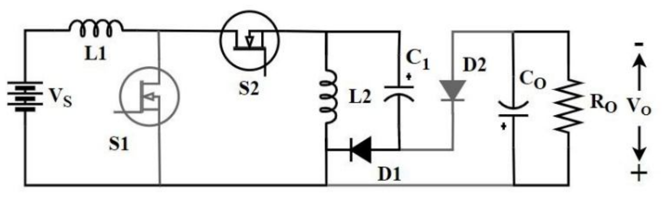

Fig .3 Conduction path when the S1 is off

When the switch S1 is in off condition the voltage across the passive elements are-

$$V_{L_1} = -\frac{V_S}{1-D}$$

$$V_{L_2} = V_{C_1} = \frac{V_S}{1-D}$$

In both of the on and off period the main switch source current flows which ensure about the continuous conduction of the source current.

III.DESIGN AND ANALYSIS

This proposed converter is highly capable to improve the gain of the converter by avoiding the maximum duty of the converter. At the time DT the inductor L1 charges and L2 discharges. At the time (1-D)T the inductor L1 discharge and L2 charge. During the discharge of the inductor L2 power is transferred to the load.

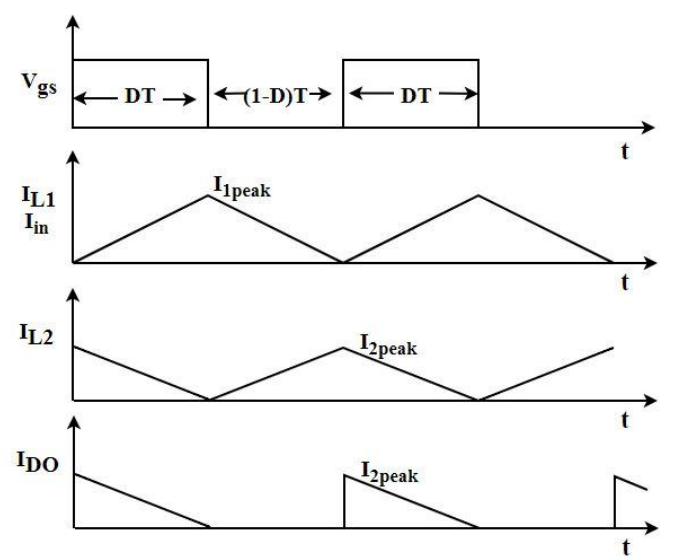

Fig .4 Inductors and diode current

All the passive elements should be selected at the values more than the critical value to ensure about the continuous conduction mode of operation. By decreasing the duty of this converter inductor L2 and diode peak current should be increased if the load current is constant where the L1 peak current should reduce. By decreasing the duty opposite behavior should be observed.

Output voltage of the proposed converter will be-

$$V_O = \frac{V_S}{D(1\text{-}D)}$$

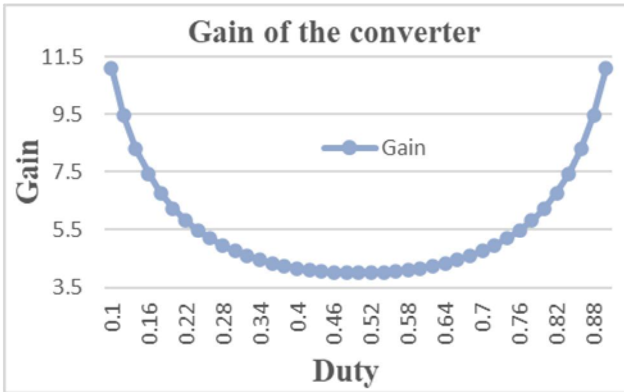

Fig .5 Gain of the proposed converter in different duty.

At the duty of 50% this converter offers minimum gain of 4, which also ensure about the boosting operation. To increase the gain of this converter the duty can be increased or decreased. By increasing the duty of the converter peak current stress of the diode D2 and peak current of the switch S2 should be increased. Inductor L1 behaves like a boost converter inductor.

Peak current of the inductor L1 is

$$I_{1Peak} = 2I_{in} = \frac{2I_o}{D(1\text{-}D)}$$

As the inductor is connected with the source in series and operating in continuous conduction the source peak current will be same as the L1 peak current. The average input current of the of the converter will be

$$I_{in} = \frac{I_o}{D(1\text{-}D)}$$

The inductor charges during the time (1-D)T and discharge at the interval DT. Peak current of the inductor L2

$$I_{2Peak} = \frac{2I_o}{D} = 2I_{in}(1\text{-}D)$$

The output voltage of the converter is improved due to the series combination of the L2 and C1 during discharge. Output voltage of the proposed converter.

$$V_O = \frac{V_S}{D(1\text{-}D)}$$

Critical value of the inductance L1 will be

$$L_1 = \frac{V_S \times D^2 \times (1\text{-}D)}{2 \times I_O \times f}$$

Critical Value of the inductance L2 will be

$$L_2 = \frac{V_S \times D}{2 \times I_O \times f}$$

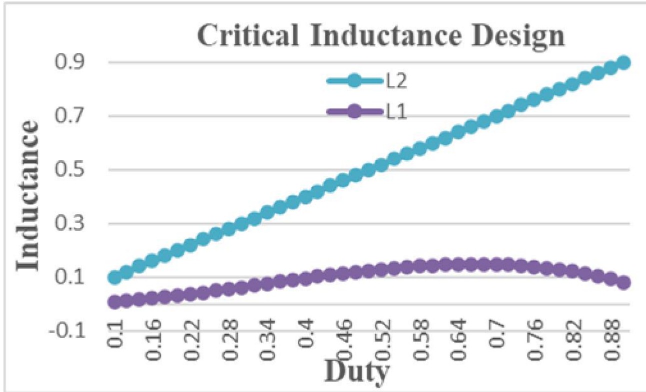

Fig .6 Critical value of the inductance in different duty.

The switch S1 is operating as a conventional boost converter switch. As in this proposed topology a voltage lifting topology has been introduced in the second stage of the converter. The maximum voltage stress of the main switch is less than the output voltage.

Maximum voltage stress across the Switch S1

$$V_{S1} = \frac{V_S}{(1\text{-}D)}$$

Maximum voltage stress across the switch S2

$$V_{S2} = \frac{V_S}{D}$$

Maximum voltage stress across the diode D1

$$V_{D1} = \frac{V_S}{D(1\text{-}D)}$$

Maximum voltage stress across the diodes D1 and D2

$$V_{D1} = V_{D2} = \frac{V_S}{D(1\text{-}D)}$$

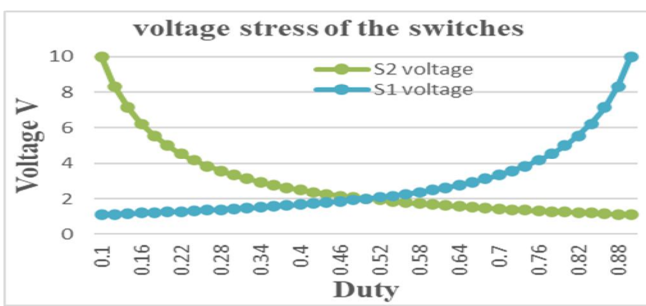

Fig .7 Voltage stress of the switches for different duty cycle

To improve the gain of the converter the duty cane be increased or decreased. It has been observed from the maximum voltage stress plot of the device that at lower duty (less than 0.5) S1 voltage stress is decreased where S2 voltage stress is increased. By increasing duty more than 0.5 S2 voltage stress decrease and S1 voltage stress increases. From the view point of magnetics design, it has been observed that at lower duty both of the magnetics size should be reduced. So, all of the above-mentioned parameters indicate about the lower duty operation of the converter to boost up the output voltage. In this converter the switch S1 operates in low voltage high current mode, whereas in high voltage high current mode in a boost converter. S2 voltage stress increases by decreasing the duty. The lower duty operation will offer the better performance of the converter. All the switches, diode should be selected by the worst-case analysis.

IV. SIMULATION AND RESULT ANALYSIS

This proposed high gain boost converter is designed on the basis of the above mentioned equations.

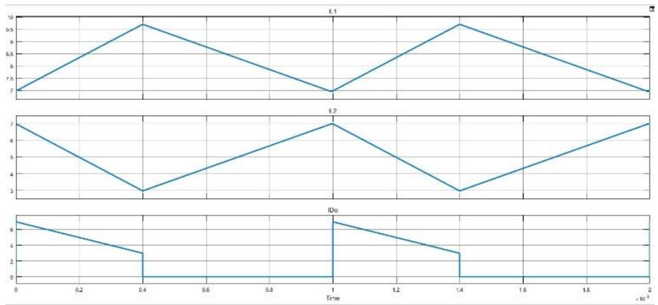

Fig .8 Inductors current and the output diode current.

All the passive components are selected at the values more than the critical value for continuous conduction. This proposed system is designed to supply average load current of 2A. Operating frequency of this converter is 100Khz. This converter is simulated in MATLAB Simulink. From the simulated waveform of the inductor current it has been observed that both of the inductors are operating at continuous conduction mode. During the discharge of the inductor L1 another inductor L2 charges. The current of the output diode Do is flowing during the off time of the main switch S1. The output diode current waveform ensures about the continuous conduction of the inductor L2.

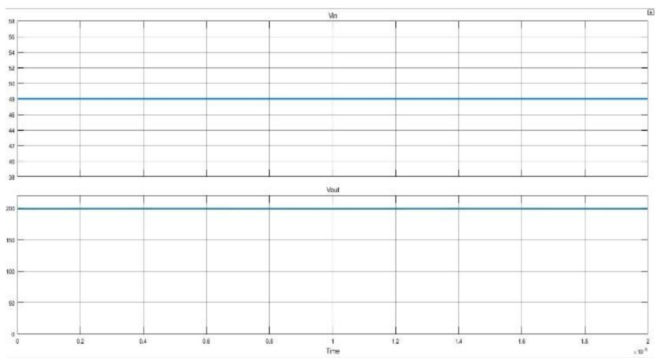

Fig .9 Input output voltage waveform

This converter is simulated for the input voltage of 48V at the duty 0.4. According to the equation the output voltage will be 200. From the simulation the output voltage is 199.1V. The voltage drop occurs due to the output diode voltage drop and the voltage drop of the switches. The output voltage of the converter is following the above-mentioned output voltage equations.

V. CONCLUSION

This proposed improved gain boost converter is designed by the help of equation and the passive elements are selected for the continuous conduction operation. The designed converter is simulated in MATLAB Simulink. All of the output waveform ensures about the continuous conduction of the passive elements. Output voltage of the converter obeys the equation by ignoring the small voltage drop of the semiconductor devices. This converter is suitable to deliver power from a 48V battery to a inverter DC bus to generate 110V AC. Inverter DC bus voltage require more than the equivalent DC voltage of the generated AC voltage due to the PWM control. This proposed converter can be applicable for low or medium power PV application where PV array voltage is not too much and the loads are operating at higher voltage.

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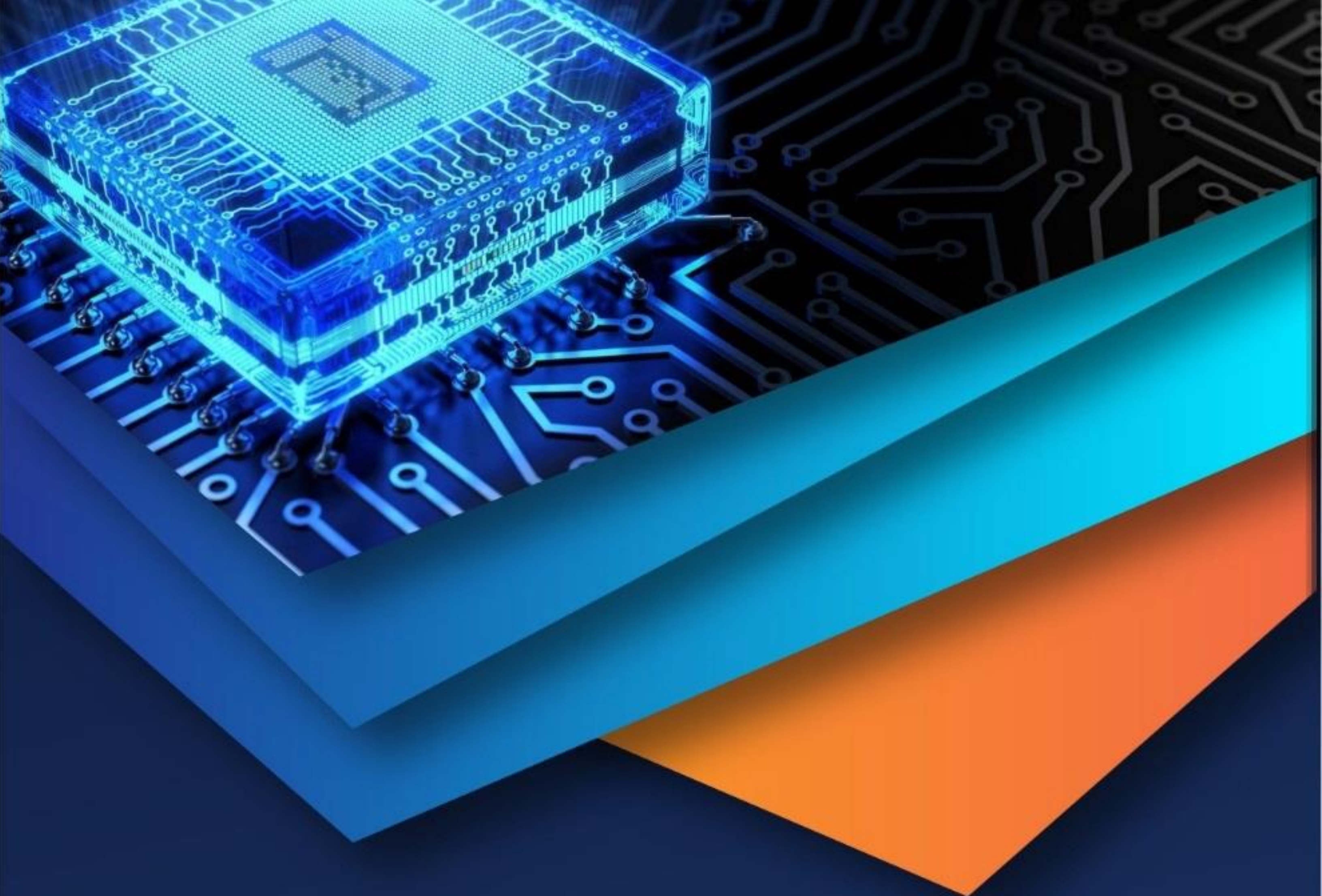

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