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Closed Loop Control of DC to DC Converter with Hybrid Input Sources

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Abstract: This paper proposes a closed loop based dc-to-dc power conversion circuit for distributed generation systems. With the two-port converter, the load can be powered from two different dc sources, which can be a combination of two from a solar-cell panel, a fuel-cell set, a battery bank, etc. and for continuous supply and reliable output we extended the circuit into closed loop system. The power conversion circuit consists of two active power switches by commonly using an inductor and an output filter capacitor. By adjusting the duty-ratio of the active power switch and gate triggering pulses of the inverter with the closed loop method, the voltage regulation at the output as well as the power coordination between two input sources can be made. The circuit operation is described in detail with the theoretical analysis and computer simulation. An experimental circuit has been built and tested to verify the analyzed and simulated results.
Keywords- two-port dc-to-dc power converter; distributed generation system; power coordination

I. INTRODUCTION

In our daily life, power electronic converters have been widely used, not only for industry applications but also in many electronic products, such as portable devices and consumer electronics. Actually, most electronic devices are not using energy directly from the power system or a battery set. To provide the required voltage or current level to a load, in general, a power electronic converter is interposed between the power source and the load to perform the conversion of the voltage or current level and in addition to regulate the power requirement. A conventional power electronic converter is supplied from a single input source, but may provide multiple outputs. In the case that two or more voltage or current levels are required by the loads, a transformer with multiple output windings is employed [1], [2]. On the other hand, however, for some applications, the loads may not be powered from a single source but from two or more input sources specified by different voltage, current, and power ratings [3-13]. For example, a solar power based street lamp is mainly supplied from solar cells, but needs a subordinate battery power. Such a prerequisite can be found more and more frequently in applications with renewable power generation, especially in a hybrid system with different kinds of power sources. Conventionally, multiple power converters are needed to convert power from manifold power sources. Such a simple solution is obviously of high cost and inefficient. To cope with this prerequisite, this paper proposes a three-port dc-to-dc converter, which is capable of converting power from two inputs sources to the load. The hybrid power sources deliver energy to the load alternatively by switching active power switches on and off, respectively.

II. CIRCUIT CONFIGURATION

A. Open loop

The power conversion circuit of the proposed hybrid input dc-to-dc converter is shown in Fig. 1, which is essentially an integration of a boost converter and a buck-boost converter. The integrated power converter consists of two active power switches, S1 and S2, for boost conversion and buck-boost conversion, respectively, by commonly using a diode, D, an inductor, L, and a filter capacitor, C. The two dc sources, Vin1 and Vin2, are treated as the primary and secondary sources, depending on the capacity and the dependability of the power sources. The primary source has a capability of providing more energy to the load and is more durable than the secondary source is. Two active power switches are turned on and off periodically at a same frequency but are activated alternately in a period. The powers delivered by two sources are coordinated by controlling their duty-ratios.

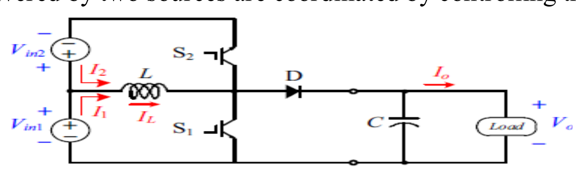

Fig 1: Proposed converter Circuit

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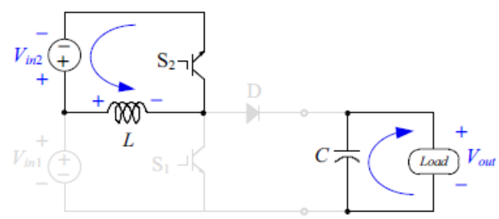
The power conversion circuit can be operated at the continuous conduction mode (CCM) or the discontinuous Conduction mode (DCM), depending on the continuity of the inductor current. In which, the duty-ratios of two active power switches are d_1 and d_2, respectively. At the CCM, the power conversion circuit is operated through Stages I, II, and III sequentially in a switching period, T2. Stage IV occurs only at the DCM when the inductor current falls down to zero. The steady state operation is described in the followings.

Stage 1:

As the active power switch S2 is turned on, the diode D will be reversely biased and turned off. The inductor is charged by the secondary voltage source, V2, and the inductor current, i_L, increases linearly. In this stage, the filter capacitor delivers the stored energy to the load.

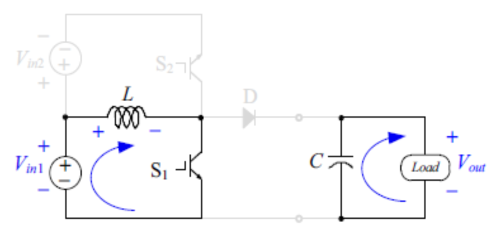
$$\Delta i_{L+(0-1)} = \frac{V_2 d_2 T_S}{L}$$



Stage 1 circuit

Stage 2:

As S2 is turned off, the active power switch, S_1 is turned on, and the diode D is now still turned off. The primary dc power source is providing electromotive force for charging the inductor in this stage. At the same time, i_L increases linearly after preceding stage.



Stage 2 circuit

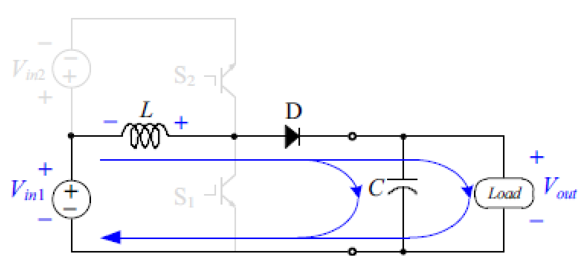
The filter capacitor is still providing energy to the load in this stage.

$$\Delta i_{L+(1-2)} = \frac{V_1 d_1 T_S}{L}$$

Stage 3:

When the power switch S1 is turned off, the diode D is forced to be turned on to conduct the inductor current. In this stage, the load draws energy from the primary source and the inductor.

$$\Delta i_{L-} = \frac{(V_O - V_1)(1 - d_1 - d_2)T_S}{L}$$



Stage 3 circuit

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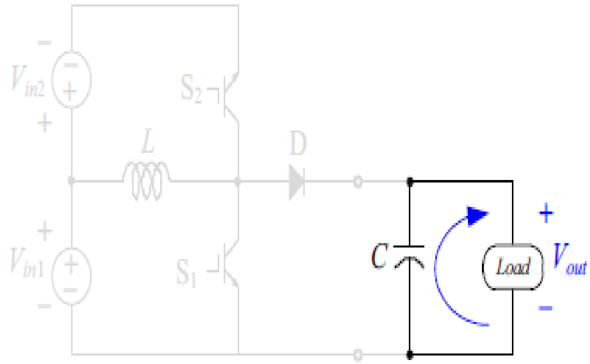
Stage 4:
This stage only happened when the inductor current declines to zero, both S and D are turned off. The filter capacitor supplies a current to the load, and voltage on the capacitor declines.
Fig. 2 depicts the theoretical waveforms on the key components of the power converter for CCM and DCM.



Stage 4 circuit

The output voltage of the power converter is the sum of V_1 and the buck-boost conversion output voltage from V_1 and V_2. This equation indicates the output voltage is always higher than the input voltage. In practice, the sum of d_1 and d_2 in one cycle is limited to be less than 0.9.

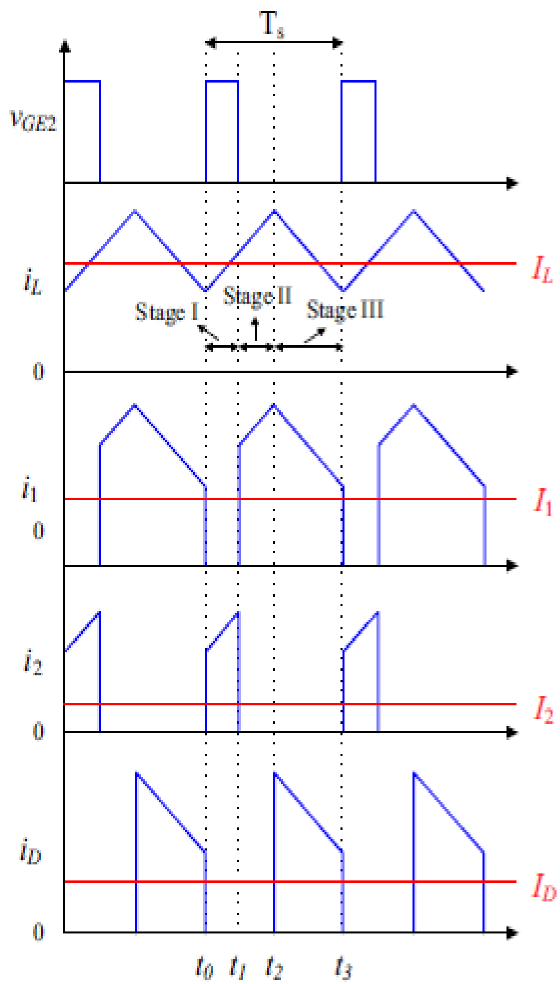


Fig 3(a) CCM

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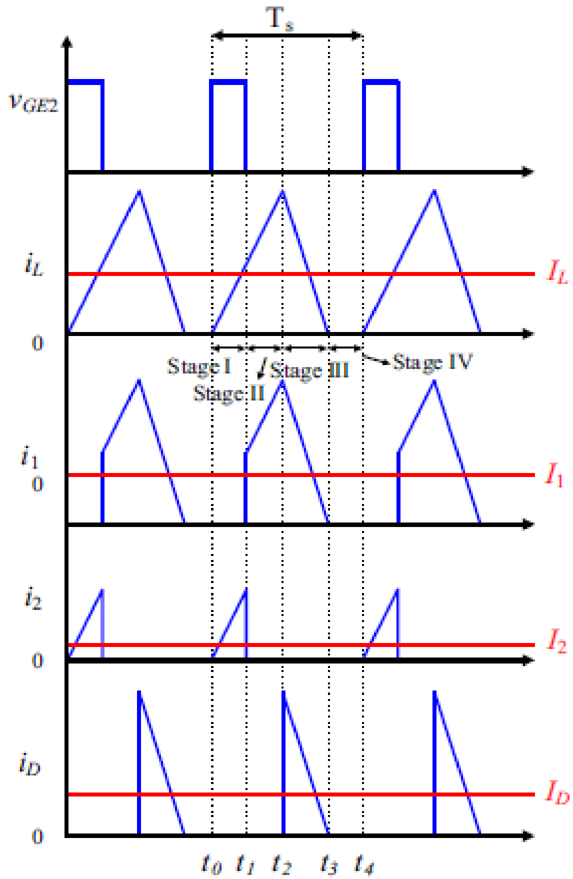

Fig 3(b) DCM

B. Closed Loop

The control strategy for dc-dc converter under both CCM and DCM modes are developed under closed loop control base. In both DCM and CCM modes the pulses for switches are obtained by comparing output voltage with reference value of dc output voltage as per the CCM and DCM values. And also conventional PI controller is used to control the output voltage as shown in figure4.

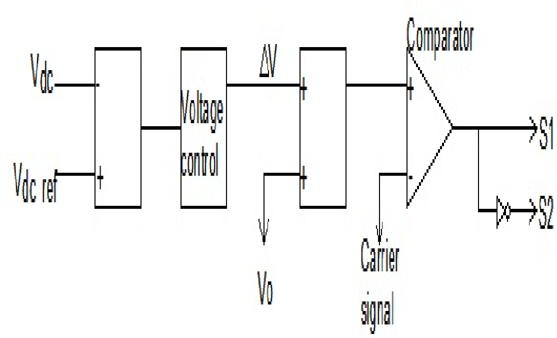

Fig 4: Closed loop control strategy for DCM and CCM modes

III. EXPERMENTAL RESULTS

A laboratory circuit of the proposed converter is built for performing experiments to verify the theoretical analyses. The converter is supplied from two dc power supplies to emulate primary and secondary input sources. Both two dc voltage sources can be varied in a wide range from 10 V to 30 V. An electronic load is used to regulate the power, voltage or current at the output. Fig. 6 shows

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the measured current waveforms on the key components when the converter is operated at CCM and DCM, respectively. Primary input voltage 10V, Secondary input voltage 5 – 30 V, Constant Load current0.3A, Inductance 237uH, Filter capacitor330uF, IGBT S1 and S2 IXGR35N120B, Diode PSR10C40

Case 1: OPEN LOOP

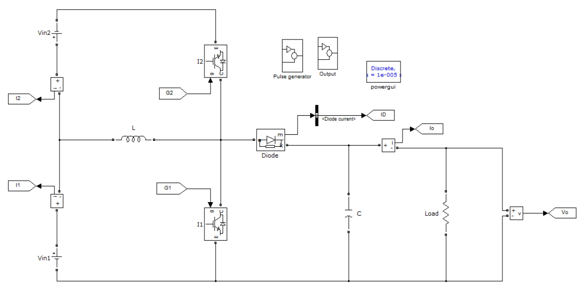

Fig 5: Simulation Circuit for Open Loop Circuit

Fig. 6 shows the measured current waveforms on the key components when the converter is operated at CCM and DCM, respectively.

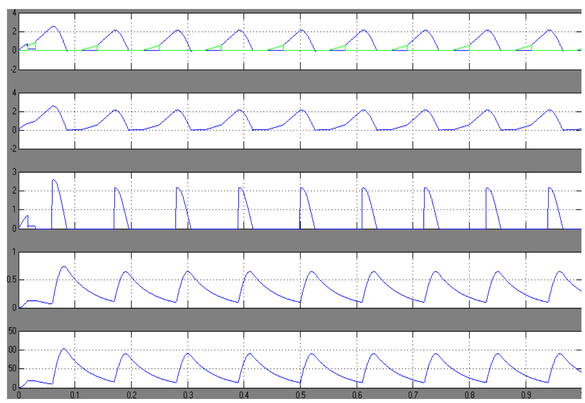

Fig 6(a) Simulation Results for DCM Mode

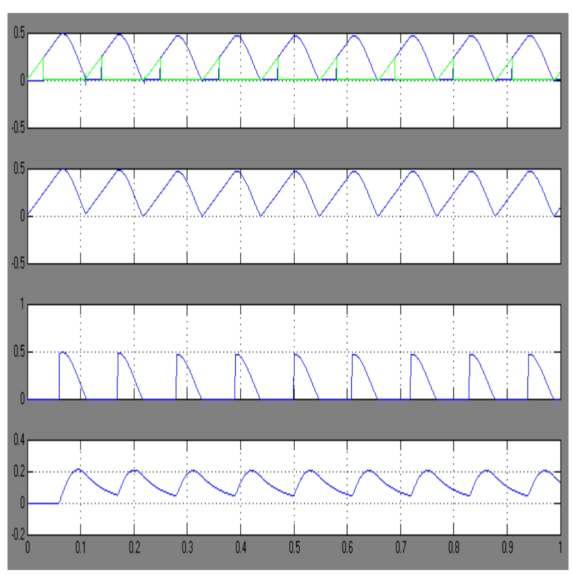

Fig 6(b) Simulation Results for DCM Mode

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The converter is operated in CCM mode, in this case V_0 and current wave forms are shown in figure 6(a) and figure 6(b) shows the current waveforms for DCM mode. In this the inductor current rises faster than that CCM.

Demerits

1) In this Output is inaccurate.
2) They are unreliable.
3) Any change in output cannot be corrected automatically
4) Unfortunately this type of open-loop system is inadequate as variations or disturbances in the system

Case 2: CLOSED LOOP

Fig 7 shows the simulation result for closed loop diagram for both CCM and DCM modes.

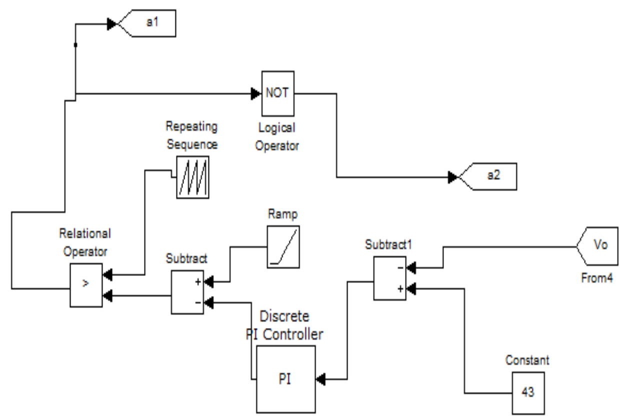

Fig 7: Simulation Diagram for Closed Loop System

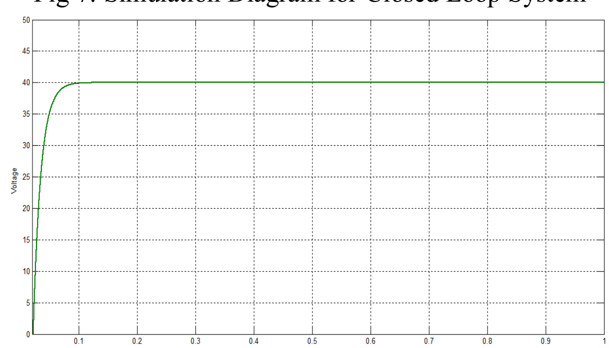

Fig 8(a) Experimental results for CCM

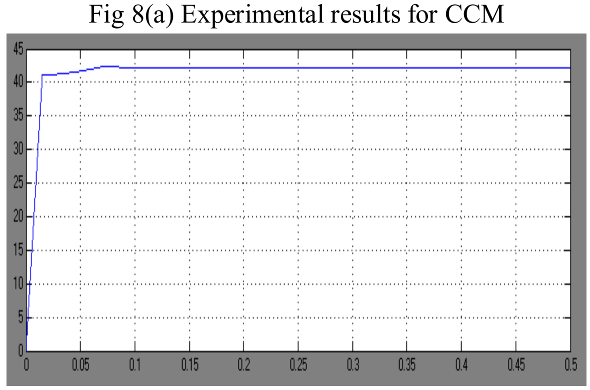

Fig 8(b) Experimental results for DCM

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IV. CONCLUSION

This paper proposed a closed loop controlled three-port dc-to-dc power conversion circuit which can be powered from three input sources. The power coordination between input sources and the voltage regulation can be made by adjusting the duty-ratios of two active power switches and gate pulses of the inverter switches with the help of closed loop. As compared with the conventional open-loop multiple-input power converter, the proposed conversion circuit has less component count and generates a better results. The power conversion circuit can be used in a distributed generation system with different dc power sources.

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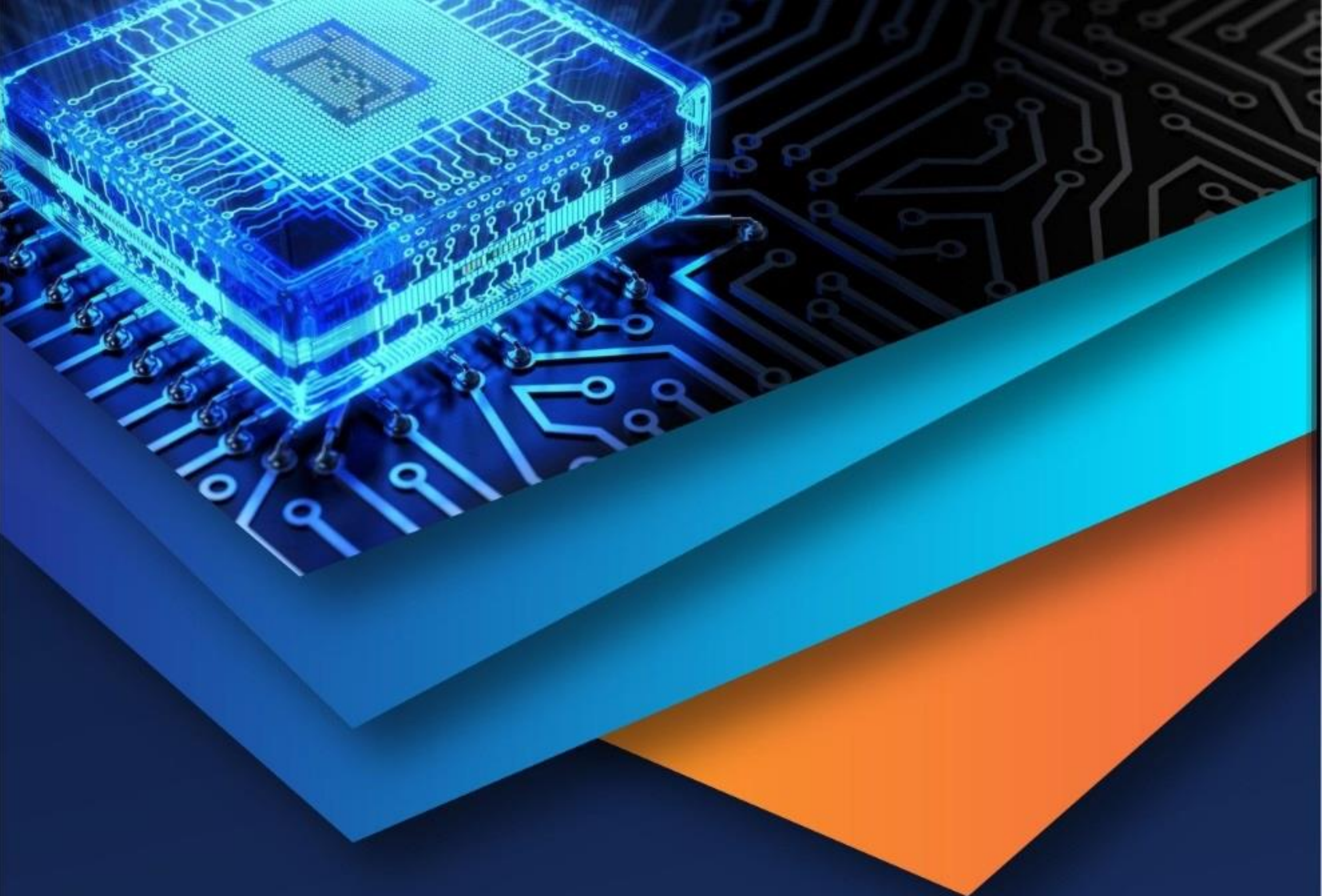

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