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Design and Simulation of Interleaved Boost Converter

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Abstract: In this project Interleaved Boost Converter (IBC) with modified inductor techniques is proposed. It reduces the current stress of the main circuit components, in addition to this itcan also reduces the ripple of the input current and output voltage.
In this approach, it can be faster switching, reduce the size and cost with suitable impedance matching is achieved with reduction in auxiliary circuit reactance that has contributed much increase in the overall performance. Coupled inductor in the boosting stage helps higher current sharing between theswitches.
The overall ripple and Total harmonics distortions are reduced in this technique without sacrificing the performance and efficiency of the converter. The driving circuit can automatically detect operational conditions depending on the situation of the duty cycle whether the driving signals of the main switches are more than 50% or not and get the drivingsignal of the auxiliary switch.
Auxiliary circuit acts as support circuit to both main switches(two conditions) and reduce the total losses and improve efficiency& power factor for large loads. The operational principle, theoretical analysis, and design method of the proposed converter are presented. The entire proposed system will be tested using MATLAB/SIMULINK and the simulation results are also present.

OBJECTIVE

The interleaved boost converter design involves the selection of the inductors, the input and output capacitors, the power switches and the output diodes. Both the inductors and diodes should be identical in both channels of an interleaved design. In order to select these components, it is necessary to know the duty cycle range and peak currents. Since the output power is channeled through two power paths, a good starting point is to design the power path components using half the output power. Basically, the design starts with a single boost converter operating at half the power. However, a trade-off exists that will depend on the goals of the design. The designer may use smaller components since currents are smaller in each phase. Or, larger components may be selected to minimize losses.
Specifically, this design uses the criteria of room temperature operation over the entire input voltage range without the requirement of airflow. Obviously, there are many trade-offs possible, such as requiring external airflow that would allow the use of smaller components and more power per watt.

In this minor project we have achieved the two main objectives which are as follows:-
1) Simulation of interleaved boost converter.
2) Comparative analysis between boost converter and interleaved boost converter.

I. INTRODUCTION

A. Interleaved Boost Converter

The Interleaved Boost Converter (IBC) consists of two boost converters connected in parallel with a 180° phase delay, and operating at the same frequency. The IBC has better characteristics when compared to a boost converter with improved efficiency, reduced size, greater reliability and lower Total Harmonic Distortions (THD). The gating pulses of the two switches in the converter are shifted by a phase difference of 360/n where n is the number of parallel boost converters.
The converter considered is operating in Continuous Conduction Mode (CCM) which results in lower input peak current (amplitude) and less conduction losses. It operates at larger duty cycle say 0.5 due to high output voltage and low input voltage. The input current for the IBC is the sum of each inductor currents and as the two devices are phase shifted by 180°, the input current ripples are small.

The proposed interleaved boost converter is as shown in Figure 1.1

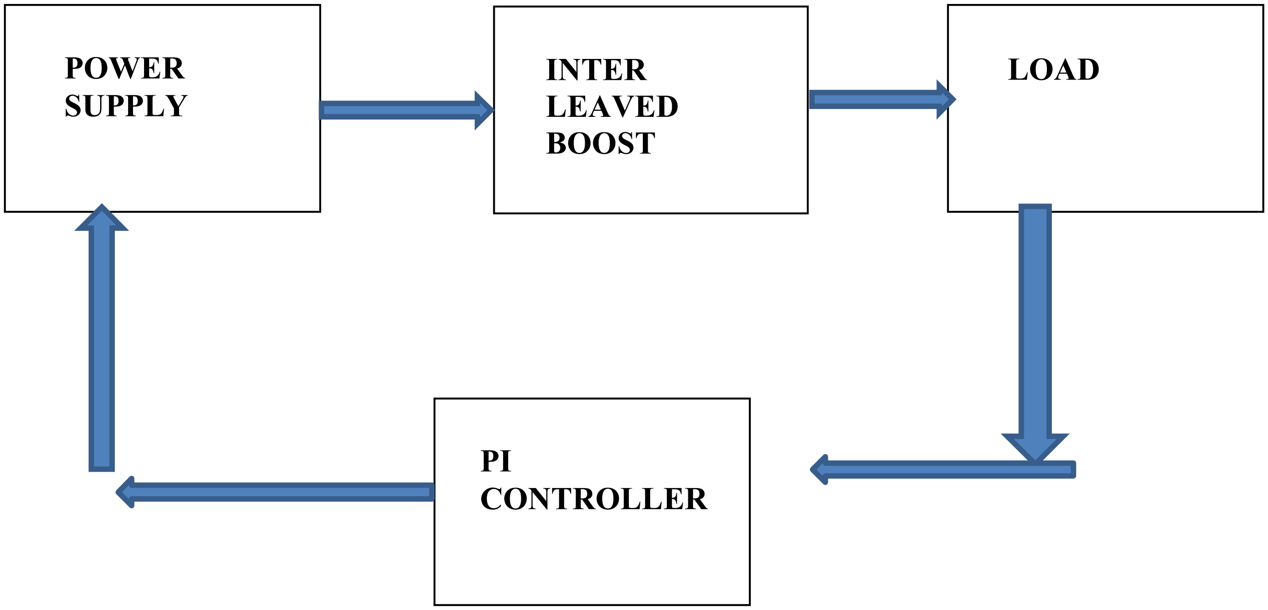

FIG 1. 1 Proposed model of interleaved boost converter

The input is an unregulated DC voltage, which is obtained by rectifying line voltage. DC-DC converters are switched mode DC to DC converter and are used to convert unregulated DC input to controlled DC output. The IBC consists of two boost convertersin parallel with a phase delay of 180° operating in CCM mode. The converter uses two MOSFET switches, two inductors, two diodes, one capacitor and a resistive load.

Some important point related to interleaved boost converter are as follows:-

1) The interleaved boost converter means parallel connection of converters, by parallel connection the current divided. So, the I^2R losses minimized and current stress decreased.
2) The current ripple at the output side will be reduced, and this shall reflect the input current also.
3) The rating of the converter increase and the overall efficiency also increases due to theabove reasons.
4) Interleaving technique is a various switching interconnection that improves synchronizingof the effective pulse frequency.
5) The energy can be rescued and enhances power conversion without affecting conversionefficiency by an interleaving technique
6) The interleaved boost converter comprises two parallel switches; S1, S2 inductors L1, L2; diodes D1, D2 ;Capacitor C and load resistor R with a trustworthy source of input (Vin). Phase-shifted switching function controls the switches. The boost converter interleavedcan operate in four modes. Only continual current mode (CCM) is analyzed in this paper in order to simplify the calculation .The two inductance values are considered similar (L1=L2=L) and similar dutycycles (D1=D2=D) with time delay by T/2.
7) A basic boost converter converts a DC voltage to a higher DC voltage. Interleaving adds additional benefits such as reduced ripple currents in both the input and output circuits. Higher efficiency is realized by splitting the output current into two paths, substantially reducing I 2R losses and inductor AC losses.

A. Boost Converter

A boost converter is one of the simplest types of switch mode converter. As the namesuggests, it takes an input voltage and boosts or increases it.

All it consists of is an inductor, asemiconductor switch (these days it's a MOSFET, since you can get really nice ones these days), a diode and a capacitor. Also needed is a source of a periodic square wave.

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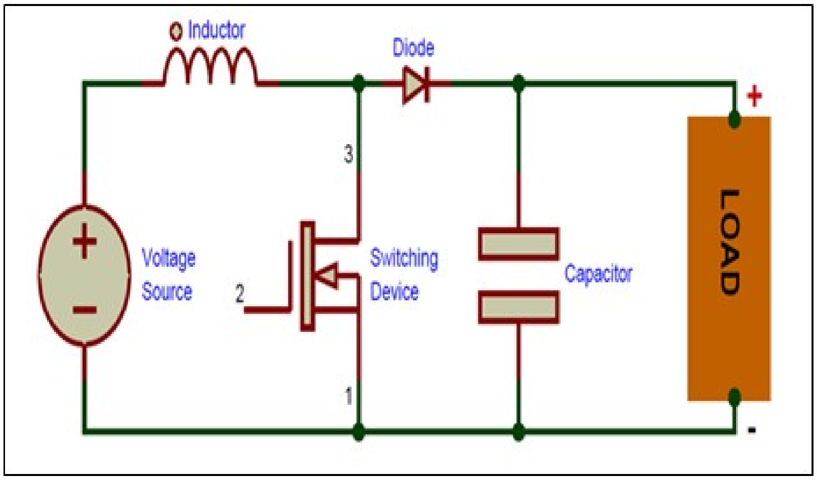

FIG 1. 2 Boost Converter circuit diagram

As we can see, there are only a few parts required to make a boost converter. It is less cumbersome than an AC transformer or inductor.

They're so simple because they were originally developed in the 1960s to power the electronics systems on aircraft. It was a requirement that these converters be as compact and as efficient as possible.

The biggest advantage boost converters offer is their high efficiency – some of them can evengo up to 99%. In other words, 99% of the input energy is converted to useful output energy, only 1% is wasted.

DC-DC converters are also known as Choppers. Here we will have a look at the Step Up Chopper or Boost converter which increases the input DC voltage to a specified DC output voltage.

The input voltage source is connected to an inductor. The solid-state device which operates as a switch is connected across the source The second switch used is a diode. The diode is connected to a capacitor ,and the load and the two are connected in parallel as shown in the figure above.

The inductor connected to input source leads to a constant input current, and thus the Boost converter is seen as the constant current input source.

And the load can be seen as a constant voltage source. The controlled switch is turned on and off by using Pulse Width Modulation(PWM).

PWM can be time-based or frequency based Frequency-based modulation has disadvantages like a wide range of frequencies to achieve the desired control of the switch which in turn will give the desired output voltage. Time-based Modulation is mostly used for DC-DC converters.

It is simple to construct and use. The frequency remains constant in this type of PWM modulation. The Boost converter has two modes of operation. The first mode is when the switch is on and conducting.

B. Applications

1) Automotive applications
2) Power amplifier applications
3) Adaptive control applications
4) Battery power systems
5) Consumer Electronics
6) Communication Applications Battery Charging circuits
7) In heaters and welders
8) DC motor drives
9) Power factor correction circuits
10) Distributed power architecture systems

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II. METHODOLOGY

A. Proposed Topology

1) Proposed IBC

The circuit diagram and the ideal waveforms of the currents in the inductors L1 and L2for interleaved boost converter operating a Tccm are shown in Figures2.1and2.2.

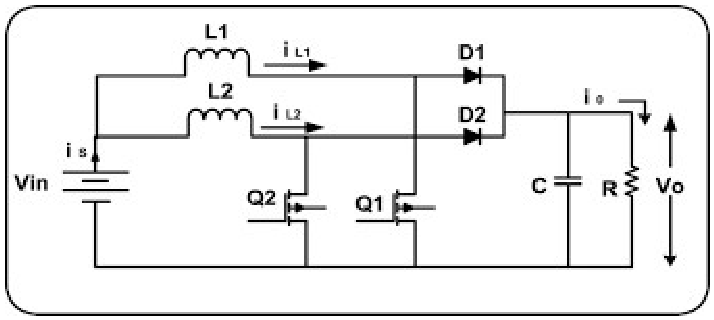

Figure 2.1 : Circuit diagram of IBC

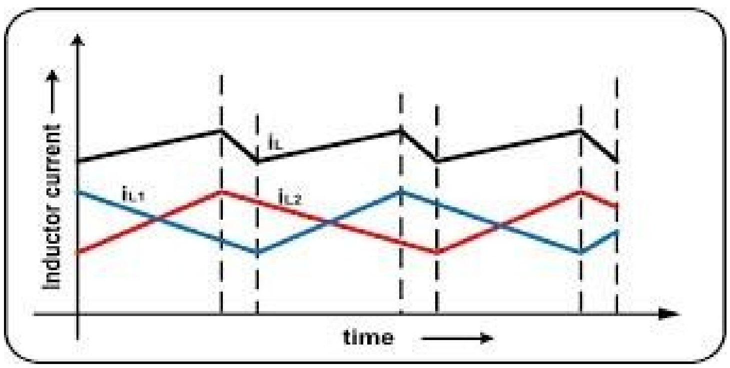

FIG 2. 2 Ideal waveform of IBC

B. Modes Of Operation

The mode of operation can be analyzed based on one channel. Since both power channels share current and because both inductors are identical, each power channel behaves identically. Based on the amount of energy that is delivered to the load during each switching period, the boost converter can be classified into continuous or discontinuous conduction mode. If all the energy stored in the inductor is delivered to the load during each switching cycle, the mode of operation is classified as discontinuous conduction mode (DCM). In this mode the inductor current ramps down to zero during the switch off-time. If only part of the energy is delivered to the load, then the converter is said to be operating in continuous conduction mode (CCM).

The mode of operation is a fundamental factor in determining the electrical characteristics of the converter. The characteristics vary significantly from one mode to the other.

1) *Mode-1:* During mode1 the switches Q1 and Q2 are switched on and the diodes D1 and D2are under off condition. Figure:2.3 shows the equivalent circuit for this mode.

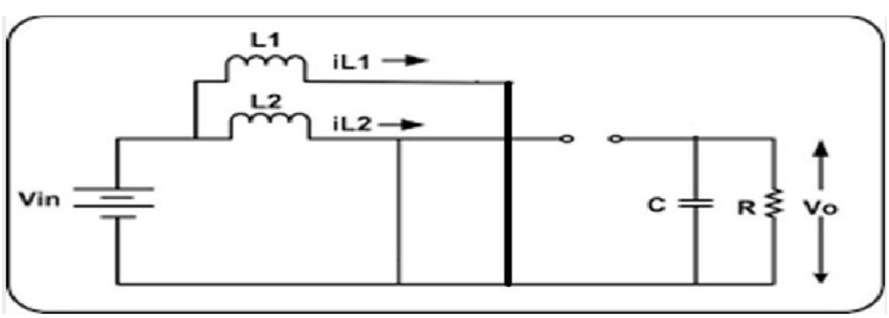

FIG 2. 3 Mode 1 operation of IBC

2) *Mode 2:-* During mode 2, the switch Q1 is in on condition and switch Q2 is in off condition and D1 is in off condition and D2 is in on condition respectively. The figure 2.4represents the operation under mode 2.

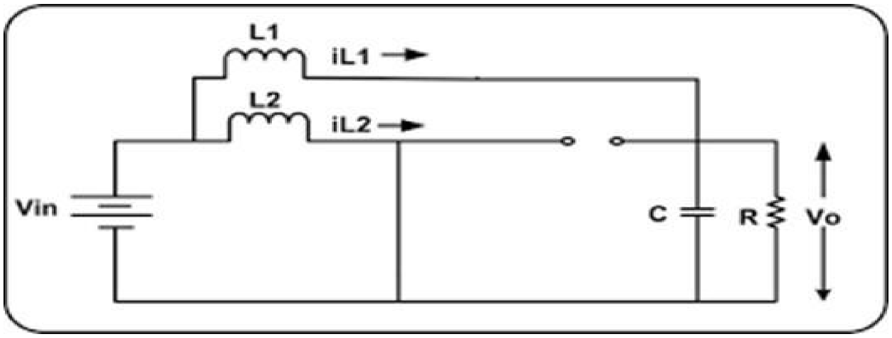

FIG 2. 4 Mode 2 operation of IBC

3) *Mode:-3* In mode 3, the switch Q1 is in off condition and the switch Q2 is in on conditionand the corresponding diodes such as D1 and D2 are in on and off conditions respectively.The figure: 2.5 represents the operation of IBC under mode3.

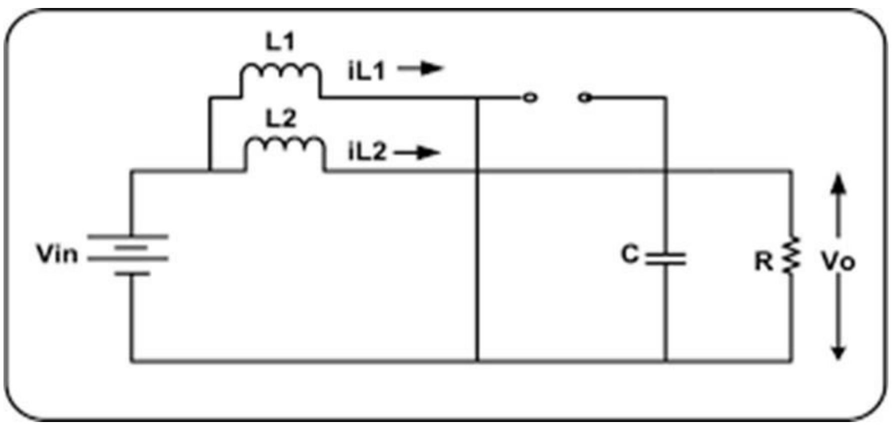

FIG 2.5 Mode 3 operation of IBC

4) *Mode:-4* The figure 2.6 represents the operation of IBC under mode 4.

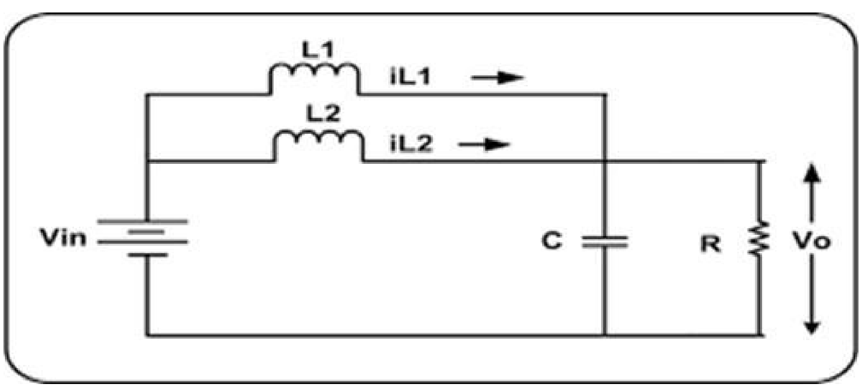

FIG 2.6 Mode 4 operation of IBC

C. Continuous Versus Discontinuous Mode

Both modes of operation have advantages and disadvantages. The main disadvantages in using CCM is the inherent stability problems caused by the right-half-plane zero in the transfer function . However, the switch and output diode peak currents are larger when the converter is operating in the DCM mode. Larger peak currents necessitate using largercurrent and power dissipation rated switches and diodes. Also, the larger peak currents cause greater EMI/RFI problems. Most modern designs use CCM because higher power densities are possible. For these reasons, this design is based on continuous conduction mode.

D. Selection of Boost Power Stage Components

The interleaved boost converter design involves the selection of the inductors, the input and output capacitors, the power switches and the output diodes. Both the inductors and diodes should be identical in both channels of an interleaved design. In order to select these components, it is necessary to know the duty cycle range and peak currents. Since the output power is channeled through two power paths, a good starting point is to design the power path components using half the output power. Basically, the design starts with a single boost converter operating at half the power. However, a trade-off exists that will depend on the goals of the design. The designer may use smaller components since currents are smaller in each phase. Or, larger components may be selected to minimize losses. Specifically, this design uses the criteria of room temperature operation over the entire input voltage range without the requirement of airflow. Obviously, there are many trade-offs possible, such as requiring external airflow that would allow the use of smaller components and more power per watt. Knowing the maximum and minimum input voltages, the output voltage, and the voltage drops across the output diode and switch, the maximum and minimum duty cycles are calculated. Next, the average inductor current can be estimated from the load current and dutycycle. Assuming the peak-to-peak inductor current ripple to be a certain percentage of the average inductor current, the peak inductor current can be estimated. The inductor value is then calculated using the ripple current, switching frequency, input voltage, and duty cycle information. Finally, the boundary between CCM and DCM is determined which will determine the minimum load current. Once the inductor value has been chosen and the peak currents have been calculated, the other components may be selected. Selection of the input and output capacitors differ from a single phase design because of the reduced ripple and increased effective frequency.

E. Design Equations

1) Boost Ratio

The boosting ratio of the IBC is a function of the duty ratio. It is same as in conventionalboost converter .It is defined as;

$V(o) / V(in)=1 / (1-D)$

Where, V_o is the output voltage, V_{in} is the input Voltage and D is the duty ratio.

2) Selection of Inductor

In the power electronic systems the magnetic components play a major role for energy storage and filtering. As discussed in the operation of IBC the inductor is used to transform the energy from the input voltage to the inductor current and to convert it back from the inductor current to the output voltage. As per the principle the two inductors are identical in order to balance the current in the two boost converters.

3) Duty Cycle Formula

The first step to calculate the switch current is to determine the duty cycle, D, for the minimum input voltage. The minimum input voltage is used because this leads to the maximum switch current.

$D=1-(V_{in}*efficiency) / V_{out}$

The efficiency is added to the duty cycle calculation, because the converter has to deliver alsothe energy dissipated. This calculation gives a more realistic duty cycle than just the equation without the efficiency factor.

4) Output Current

The output current is measured by using the below formula $I_{out} = P_{out} / V_{out}$Where;

P_{out} = Output Power & V_{out} = Output Voltage

F. Boost Converter Design

1) STEP – 1

To begin with, we need a thorough understanding of what our load requires. It is highly recommended (from experience) that if you attempt to build a boost converter at the beginning it is very important to know the output voltage and current independently, the product of which is our output power.

2) STEP – 2

Once we have the output power, we can divide that by the input voltage (which should alsobe decided) to get the average input current needed.

We increase the input current by 40% to account for ripple. This new value is the peak inputcurrent.

Also the minimum input current is 0.8 times the average input current, so multiply theaverage input current by 0.8.

Now that we have peak and minimum current, we can calculate the total change in current bysubtracting the peak and minimum current.

3) STEP – 3

Now we calculate the duty cycle of the converter, i.e. the ratio of the on and off times of theoscillator.

Duty cycle is given by this textbook formula:

D.C. = (Vout – Vin)/(Vout)

This should give us a reasonable decimal value, above 0 but below 0.999.

4) STEP – 4

Now it is time to decide upon the frequency of the oscillator. This has been included as a separate step because the signal source can be anything from a 555 timer (where the frequency and duty cycle are completely under your control) or a fixed frequency PWM controller.

Once the frequency is determined, we can find out the total time period by taking an inverse.Now the time period is multiplied by the duty cycle value to get the on time.

5) STEP – 5

Since we have determined the on time, input voltage and change in current, we can plug thosevalues into the inductor formula which has been rearranged a little:

L = (V*dt)/dI

Where V is the input voltage, dt is the on time and dI is the change in current.

G. Mode of operation in Boost Converter

1) Mode I: Switch is ON, Diode is OFF.

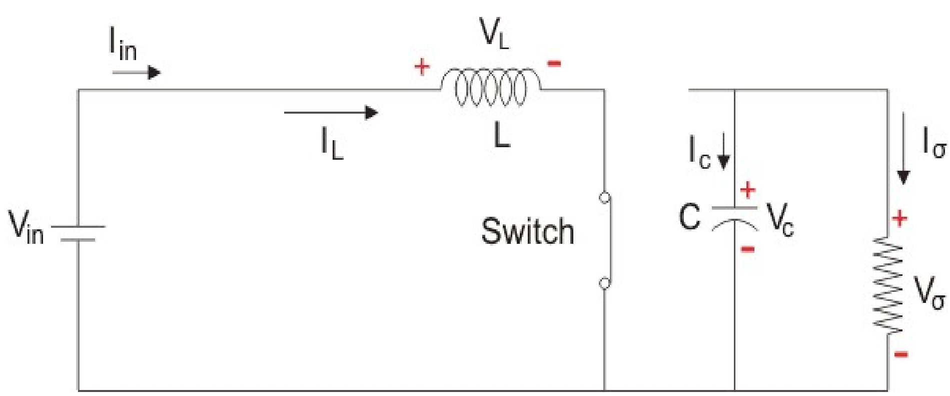

FIG 2.7 Mode 1 operation of Boost converter

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The Switch is ON and therefore represents a short circuit ideally offering zero resistance to the flow of current so when the switch is ON all the current will flow through the switch and back to the DC input source. Let us say the switch is on for a time T_{ON} andis off for a time T_{OFF}. We define the time period, T , as and the switching frequency,

Fswitching =1/TLet us now define an other term, the duty cycle,

D = Ton / T

Let us analyze the Boost converter in steady state operation for this mode using KVL,

Vin = VL

VL = L(diL / dt) = VindiL / dt = Vin / L

Since the switch is closed for a time TON=DT we can say that Δt=DT.

2) Mode II: Switch is OFF, Diode is ON.

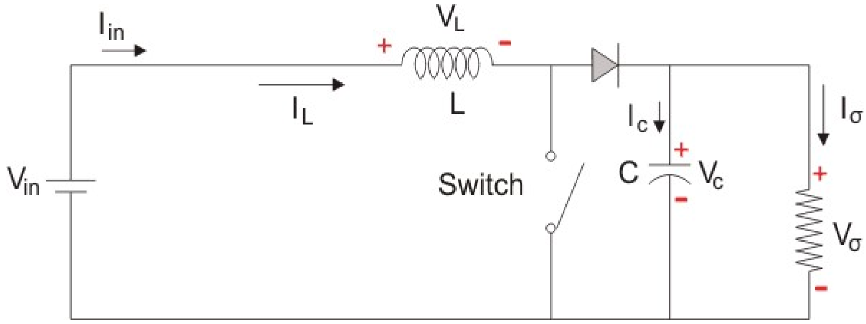

FIG 2.8 Mode 2 operation of Boost converter

In this mode, the polarity of the inductor is reversed. The energy stored in the inductor is released and is ultimately dissipated in the load resistance, and this helpsto maintain the flow of current in the same direction through the load and also step- up the output voltage as the inductor is now also acting as a source in conjunction with the input source. But for analysis, we keep the original conventions to analyze the circuit using KVL.

Let us now analyse the Boost converter in steady state operation for Mode II using KVL.

Since the switch is open for a time

$$\therefore V_{in} = V_L + V_o$$

$$\therefore V_L = L\frac{di_L}{dt} = V_{in} - V_o$$

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} = \frac{V_{in} - V_o}{L}$$

We can say that;

$$T_{OFF} = T - T_{ON} = T - DT = (1-D)T$$

It is already established that the net change of the inductor current over any one completecycle is zero

$$\Delta t = (1-D)T$$

$$(\Delta i_L)_{open} = \left(\frac{V_{in} - V_o}{L}\right)(1-D)T$$

$$\therefore (\Delta i_L)_{closed} + (\Delta i_L)_{open} = 0$$

$$\left(\frac{V_{in} - V_o}{L}\right)(1-D)T + \left(\frac{-V_o}{L}\right)DT = 0$$

$$\frac{V_o}{V_{in}} = \frac{1}{1-D}$$

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III. EXPERIMENTATIONS AND ANALYSIS

A. Simulation of Interleaved Boost Converter

The two phase interleaved boost converter is shown here. The phase difference between thesetwo power stages will be 180 degree. Its simulation is shown in the next slide.

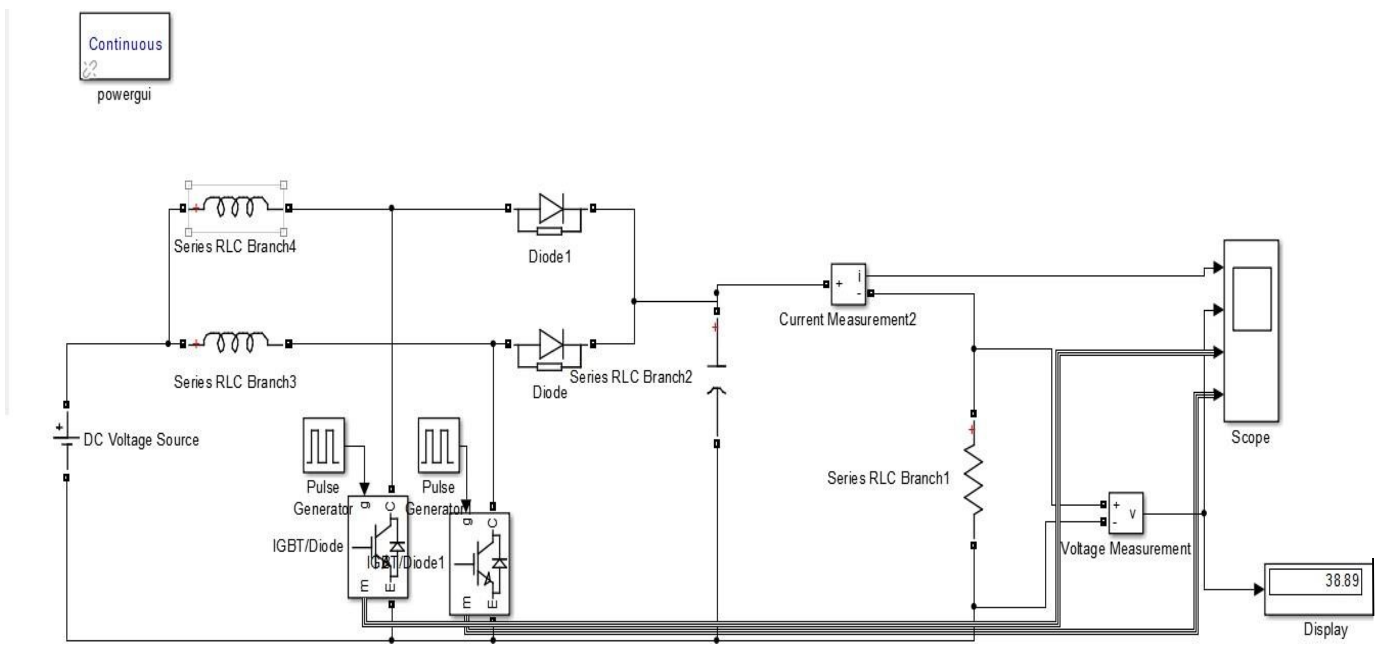

FIG 3.1 Simulation of IBC obtained on matlab

To find the phase difference between the power stages we have the formula 360/n .
Where 'n' is the number of power stages. Since we are dealing with two stages therefore thephase difference between them will be 180 degree.

B. Parameters Considered

The value of the parameters considered in the simulation of interleaved boost converter isshown in Table T-1.

SL. NO.	PARAMETERS	VALUES
1	Input voltage	20 volt
2	Inductance	38 micro henry
3	Capacitance	330 micro farad
4	Resistance	3 ohm
5	Pulse amplitude	5 volt
6	Pulse frequency	1/10000
7	Pulse width	50%

T-1 Components used in case of interleaved boost converter

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C. Simulation

Using MATLAB/SIMULINK the simulation of interleaved boost converter is performed. The waveforms of the input voltage, output voltage, inductor currents, and voltage ripple are shown.

An interleaved boost dc-dc converter system has been modeled using MATLAB SIMULINK. A comprehensive simulation was conducted to verify the performance of interleaved boost dc-dc converter system.

The model parameters are listed in Table T-1. The simulation waveform of interleaved boostdc-dc converter are also obtained in MATLAB.

D. Graph of Interleaved Boost Converter Obtained After Simulation In MATLAB

First graph represents the sum of current coming out from the two power stages.Second graph represents the voltage ;

Here we can see that the ripple in voltage is present and it vary from 38.9 to 39.4.It means ripple present in voltage is, 0.5 which is very less. This paper mainly focuses on the comparison of two interleaved DC converter topologies of Conventional boost converter (CBC) using MATLAB / SIMULINK software under same design specifications and duty cycle.

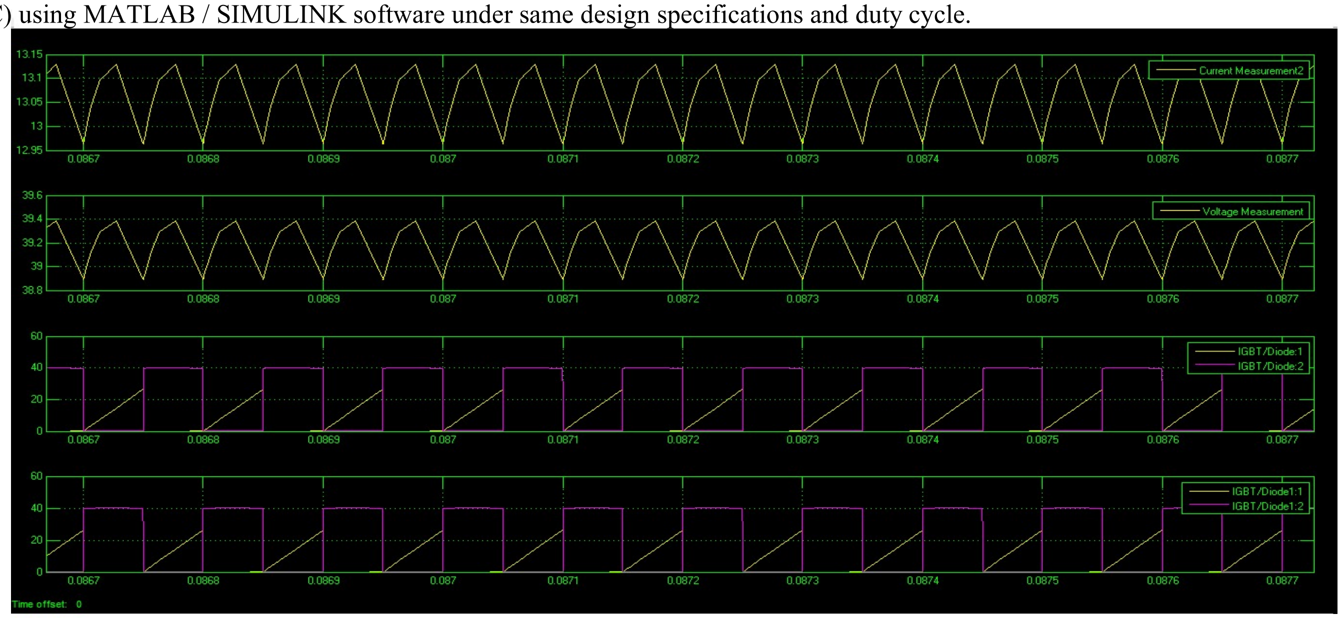

FIG 3.2 Graph of IBC obtained on simulation

E. Simulation of Boost Converter

Boost converter is a DC-to-DC converter that steps up voltage from its input to its output. This unique capability is achieved by storing energy in an inductor and releasing it to the load at a higher voltage.

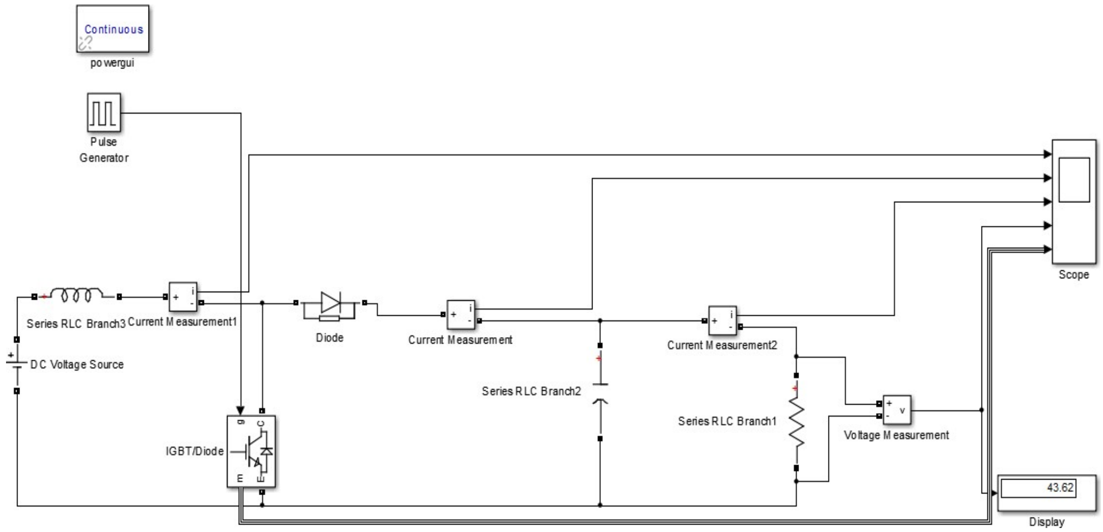

FIG 3.3 Simulation of boost converter obtained on matlab

Based on the proposed design, Matlab/simulink software is used to simulate the boost converter's performance. The simulation results of the boost converter with different values of input voltage and duty cycle are shown with respect to both mode of operation without feedback and with feedback.

From the simulation results, the proposed converter is capable of providing a constant DC output voltage. The transient response does exists for a few milliseconds before settles to a steady state.

F. Parameters Considered

The value of the parameters considered in the simulation is shown in Table T-2.

SL.NO.	PARAMETERS	VALUE
1	Input voltage	20 volt
2	Inductor	38 micro henry
3	Capacitor	330 micro farad
4	Resistance	3 ohm
5	Pulse amplitude	5 volt
6	Pulse frequency	1/10000
7	Pulse width	50%

T-2 Components used in case of boost converter

G. Graph of Boost Converter Obtained After Simulation on MATLAB

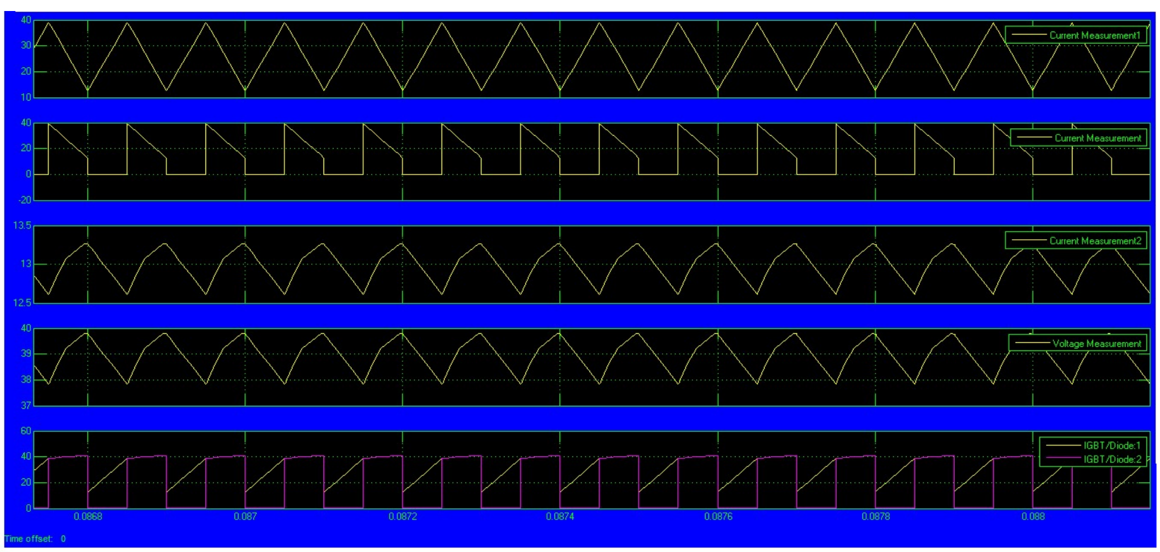

FIG 3.4 Graph of boost converter obtained on simulation

IV. RESULTS

In case interleaved boost converter; the ripple present in voltage is;

38.9 to 39.4

it means ripple present in voltage is

= 39.4-38.9

= 0.5 ripple

In case of boost converter ; the ripple present in voltage is ;

37.8 to 39.8

it means ripple present in voltage is

=39.8-37.8

=2 ripple

So from the simulation of these two converter we conclude that in case of interleaved boostconverter the ripple in voltage has been reduced in comparison to simple boost converter.

Therefore interleaved boost converter is better in operation in comparison to boost converter.

1) The advantages of interleaved boost converter compared to the classical boostconverter are:-

a) Low input current ripple,2]high efficiency,

b) Faster transient response,

c) Reduced electromagnetic emission and5]improved reliability.

2) The interleaved boost converter improves low – voltages stress across the switches, low input current ripple also improving the efficiency compared with a traditional boost converter.

3) To validate the performance in terms of input and output ripple and values, the two converters were tested using MATLAB/SIMULINK.

V. FUTURE SCOPE

The use of applications driven by batteries improves the demand for effective dc-dc converters during modern day-to-day life. These include a wide range of solar based applications, Fuel cell systems, uninterrupted power supplies (UPS) and hybrid electric vehicles. Boost converters are the suitable converters among the DC to DC converters to charge the batteries due to their capability of boosting up the voltage since low level to high level. But conventional boost converters suffer from high ripple content in the output voltage and input current with less reliability. The interleaved connection of the two conventional converter topologies is one of the best solutions to overcome some of these problems. The basic working principle of interleaved converters is that the input current is transferred between the inductors to provide increased efficiency and high reliability in power systems. This paper mainly focuses on the comparison of two interleaved DC converter topologies of Conventional boost converter (CBC) using MATLAB / SIMULINK software under same design specifications and duty cycle. It is found that while comparing the results of the conventional topologies, interleaved connections results less ripple content at output voltages and input currents. And with the comparison of simulation results of two interleaved converters, the ITBC is found as the best suited converter for the battery charging applications. Methods discussed herein can be extended to other converter types like boost, buck boost andsimilar other derivatives. The closed loop control conventional boost converter and the 2- phase interleaved boost converter is simulated using PID controller and implemented using Arduino microcontroller. As a future scope, a high step-up interleaved boost converter can be simulated with different types of feedback control like fuzzy logic[10]control, genetic algorithm ,artificial neural network and others for power quality improvement or to get high efficiency advanced tuning and to check the constant output voltage with least ripple and to support different appliances with different voltage ratings.

VI. CONCLUSION

1) This paper has discussed the basic design aspects of interleaved boost converters.The feature and performance of the interleaved boost converter under various duty cycle conditions have been investigated.

2) The interleaved boost dc-dc converter with coupled-inductors is analyzed in detail basedon the fundamental circuits.

3) To boost up the voltage level boost converter is adopted with interleaving technique. It hasadded some advantages like,can be used for high ratios, also for high power application.

4) Two boost converters are connected in parallel manner,they are studied and simulatedproperly and presented.

The conventional boost converter and 2-phase IBC is modelled using state space averaging technique considering all parasitic elements of the converter which gives the accurate modelling of the converter. And the modeling is analysed based on small signal analysis to find the transfer function output voltage to variations in duty ratio.The conventional boost converter and 2-phase IBC is designed, in which the size of passive components i.e., Input inductors and output side capacitor filter is halved. Also Simulation is performed in Matlab- Simulink for the designed values and an expected output is achieved in both open and closedloops.

Also from the results the following conclusions can be drawn:

a) Interleaving techniques divides the current between the phases at a same frequency equalto the switching frequency.
b) As the input current is the sum of the two inductor current of the two phases, thefrequency of the total input current is twice that of the switching frequency.
c) Also the frequency of the output voltage ripple is high.
d) The switching DC-DC power supply has inductor current ripple leading to output voltageripple.

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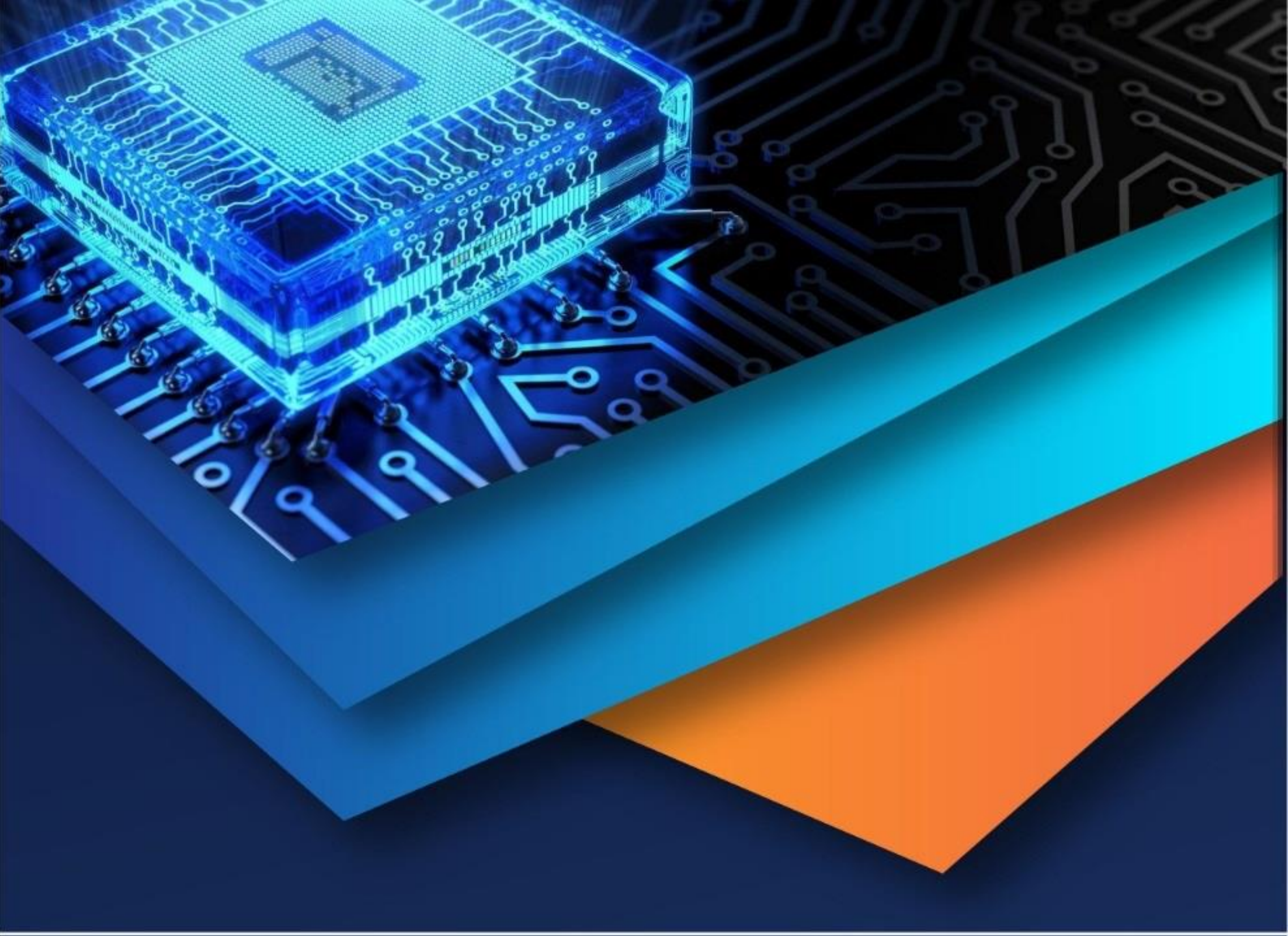

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