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Three Phase Interleaved Boost Converter with Open Loop and Closed Loop Simulation

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ABSTRACT

A three-phase interleaved boost converter is a power electronics circuit used for DC-DC power conversion. It uses multiple power switches and inductors to increase the converter's power handling capabilities. The interleaved operation of the converter reduces the input and output ripple current. The interleaved boost converter is superior to a boost converter in that it is more effective, smaller, more reliable, and has lower total harmonic distortions (THD). This paper presents the design and simulation of a three-phase interleaved boost converter. The converter architecture can achieve great efficiency and power factor correction and is ideal for high power applications. For the converter, open-loop and closed-loop control strategies are examined. The open-loop control offers a straightforward and affordable approach and uses a fixed duty cycle. To manage the output voltage and give better dynamic responsiveness, the closed-loop control uses a proportional-integral (PI) controller. MATLAB/Simulink software is used to simulate both control strategies. The converter is determined to be appropriate for use in industrial power systems, electric cars, and renewable energy systems.

Keywords: Interleaved boost converter, Ripple currents, Proportional integral controller and Current controller, Voltage controller.

1. Introduction

In order to transform the high-voltage electricity from the battery into the lower-voltage power needed to run the vehicle's subsystems, power converters are crucial parts in electric vehicles. The following are the primary power converter types found in electric vehicles:

DC-DC Converters: These converters are used to reduce the battery's high voltage output to the lower voltage levels needed by the vehicle's subsystems, including the motor drive, lighting, and instrumentation. Being lightweight and effective, DC-DC converters are perfect for usage in electric cars.

AC-DC Converters: These converters are used to transform the AC power from the charging station into the DC power needed by the battery of the car. Depending on the architecture of the vehicle, the AC-DC converters may be aboard or off-board. DC-AC Inverters: The DC electricity from the battery is converted to the AC power needed by the motor drive using DC-AC inverters. The motor's speed and torque are managed by DC-AC inverters, which can also be utilized to provide regenerative braking.

Bidirectional Converters: A two-way power transfer between the battery and the motor drive is made possible by bidirectional converters. When the car slows down, they can be employed to produce regenerative braking and to charge the battery.

Furthermore, nonconventional and renewable energy sources, like photovoltaic (PV) panels and fuel cells (FC), generally require a high step-up converter due to their low DC output voltages because to their limited duty cycle, traditional boost converters cannot produce voltage improvements of this magnitude. It is theoretically possible to develop and use boost converters with extremely high duty-cycles to get bigger voltage gains. Nevertheless, due to numerous factors, including the voltage stress on the power switches and significant current ripples of inductance, such high voltage gains are difficult to obtain. Electric vehicles can effectively convert the high-voltage battery power to the lower-voltage power required to run the various subsystems by using interleaved boost converters, a form of power converter. Several boost converters are connected in parallel and interleaved with one another in an interleaved boost converter system. This configuration contributes to load distribution and reduces output voltage ripple, leading in a more reliable and effective power conversion.

Interleaved boost converters can increase the power density and efficiency of electric vehicles, extending their range and lowering their energy usage. They are especially helpful in situations where the load demands change quickly, like when driving or braking. The size and weight of the power electronics system can also be decreased with the use of interleaved boost converters, which is helpful in the design of electric vehicles.

Already, the switch to electric vehicles (EVs) from conventional cars is still being made, but it is increasing the speed. Concerns regarding global warming, environmental damage, and energy security, together with improvements in battery technology and government initiatives to encourage EV use, are some of the factors influencing this transformation. Despite these encouraging developments, the switch from conventional to electric vehicles is still in its infancy. A number of issues still need to be resolved, including the limited range of EVs, the requirement for more charging stations, and the higher initial costs of EVs compared to conventional vehicles. However, and, we may expect to see a continuous movement towards electrification in the transportation industry as technology advances and more people become aware of the advantages of EVs.

2. Literature review

The three-phase interleaved boost converter's structural and functional features are detailed. The input current and output voltage ripples can be greatly reduced without increasing switching losses by interleaving the switching circuit patterns, resulting in a sufficient converter efficiency. Each switching component's power and current ratings can be decreased. The three-phase interleaved boost converter fault tolerant control approach with a proportional integral (PI) controller and a phase- shift mechanism is described for both normal and abnormal operation situations. The simulation results are presented the usefulness of the three-phase interleaved boost converter's fault-tolerant control capabilities in both normal and open-circuited switch failure operations. The control approach was reconfigured for both healthy and defective operations, which increased converter dependability. It uses the PI controller with a single current loop and a distinct voltage loop. The converter is phase-shifted appropriately to achieve ripple cancellation. Investigations have been done into the converter's characteristics under both normal and open-circuit fault operations. The waves in the input current and output voltage were greatly reduced, resulting in converter performances that were comparable to those of a healthy operation. Moreover, even with a single PI current loop control, equal inductor current sharing can be accomplished. Further research will focus on accurate switch-fault identification techniques and quick open-circuit fault detection techniques. The suggested fault-tolerant three-phase interleaved boost converter will be put into practice in an experimental setting to make sure it works as intended. [1].

To achieve high voltage conversion ratio and high efficiency, a step-up converter is suggested. This converter has a structure that is interleaved. The traditional interleaved boost converter reduces output voltage and input current ripples. Using capacitance and inductor switches improves efficiency. A soft-switching cascade boost converter's design considerations and simulation results are described in this work. Compared to conventional boost converters, this converter has a longer turn-off time, a higher voltage gain, and fewer switching losses. The diodes employed in the proposed converter turn on and off during soft switching without experiencing any voltage stress, in addition to the primary switch of the converter turning on under ZVT conditions and off under ZVS conditions. The proposed soft switching cascade boost converter's operating principles and design issues are also illustrated in the study. [2].

Increased demand for electric vehicles is a result of rising desire for environmentally friendly transportation (EVs). The DC/DC converter, which transforms the high voltage output of the battery to the necessary voltage for the vehicle's electrical systems, is one of the most important parts of an EV. A three-phase interleaved DC/DC boost converter using just Silicon Carbide (SiC) semiconductors may be created to raise the converter's efficiency and power density. Selecting the converter topology, picking the components, planning the control strategy, putting effective thermal management into practise, and designing the PCB are all steps in the design process of a three-phase interleaved DC/DC boost converter using all SiC semiconductors. The converter architecture consists of three interleaved SiC MOSFET-based DC/DC boost converters that each have a diode, an inductor, a capacitor, and a silicon-based MOSFET. The SiC MOSFETs, inductors, and capacitors need to have particular characteristics to enable efficient operation, depending on the converter's parameters, which will determine the component choice by altering the MOSFETs' duty cycle in response to the discrepancy between the desired and actual output voltages, a digital proportional-integral (PI) controller may be used to manage the converter's output voltage. An effective thermal management system that makes use of a heat sink, liquid cooling, or a mix of the two should be developed to disperse the heat produced by the SiC MOSFETs. In the design of the DC/DC converter, SiC semiconductors and the three-phase interleaved architecture result in high efficiency, lower power losses, and a longer battery lifespan, increasing the vehicle's range. Also, the converter's tiny size and the high power density of SiC semiconductors make it lighter and smaller, which helps make EVs lighter and more effective. [3].

A DC-DC converter architecture known as the Interleaved Boost Converter (IBC) is employed in a number of applications, including electric cars, aerospace systems, and renewable energy systems. Compared to traditional boost converters, the IBC provides a number of benefits, including less input and output current ripple, more power handling, and more dependability. IBC does have certain disadvantages, too, such increased complexity and higher costs. The IBC's decreased input and output current ripple is one of its main advantages. The input and output currents are divided among the parallel inductors and capacitors used in the IBC. As a consequence, there is less electromagnetic interference, increased power factor, and reduced current ripple (EMI). Moreover, the IBC is appropriate for high-power applications since it has a wider power range than a traditional boost converter. The IBC's increased dependability is another benefit. The parallel arrangement of several inductors and capacitors adds redundancy, improving the dependability of the system. Moreover, the IBC is more efficient than a typical boost converter, which results in less heat loss and a longer system lifespan. A number of factors, including efficiency, power handling capability, input voltage range, and output voltage range, may be used to assess the IBC's performance. The number of interleaved phases and the component ratings employed determine the input voltage range of the IBC. The greater the input voltage range, the more interleaved phases there are. The duty cycle of the switching waveform and the component ratings employed determine the output voltage range of the IBC. The switching frequency, the number of interleaved phases, and the component rating all affect how efficient the IBC is. The current rating of the employed components determines the IBC's ability to handle power. The IBC does, however, have several restrictions that must be taken into account. The IBC's main drawbacks over the traditional boost converter are its greater complexity and higher price. The system becomes more complex and expensive due to the parallel use of several inductors and capacitors. Moreover, it might be difficult to obtain the precise current sharing that is required by the IBC among the interleaved stages. However, a comprehensive evaluation of the IBC's performance is required based on a number of factors, including the input and output voltage range, efficiency, and power handling capability. However, the IBC's drawbacks—such as greater complexity, higher price, and increased EMI—must be taken into account while choosing the best converter architecture for a particular application. [4].

A DC-DC converter topology called the Interleaved Boost Converter (IBC) employs a number of interleaved phases to boost the converter's power handling capability, lessen input and output current ripple, and boost reliability. In this situation, an IBC's design and simulation are crucial to assess its performance and guarantee the dependability and effectiveness of the converter based on the intended input and output voltage range, power handling capability, and efficiency, the design of an IBC entails choosing the proper component values, such as inductors, capacitors, and switching devices. To obtain the required output voltage and reduce current ripple, the switching waveform's switching frequency and duty cycle are also chosen throughout the design. An IBC is simulated by modelling its internal workings and modelling how it would behave under various operating scenarios, such as input voltage and load fluctuations. To obtain the target output voltage, reduce current ripple, and optimise efficiency, for instance, the simulation results may be utilised to choose the suitable component values and switching frequency. The converter's design can take into account potential concerns, such as EMI and thermal issues, by taking into account the simulation findings. To confirm the correctness and dependability of the simulation model, the simulation results can also be compared with experimental data. Building a physical converter prototype and evaluating its performance under various operating situations will yield the experimental data. The converter's design may be improved to assure its dependability and efficiency by comparing the simulation and testing findings. To sum up, an IBC's design and simulation are crucial for assessing the converter's performance and guaranteeing its dependability and efficiency. To obtain the target output voltage, reduce current ripple, and increase efficiency, the design must choose the proper component values and switching frequency. The components of the converter are modelled, and the behaviour of the converter is simulated under various operating situations. The experimental findings may be used to evaluate the simulation model's correctness and dependability, while the simulation results can be utilised to enhance the converter's design and performance. [5].

A DC-DC converter architecture known as the Three Phase Interleaved Boost Converter (TP-IBC) has three interleaved phases to boost the converter's power handling capability, lessen input and output current ripple, and enhance reliability. High-power applications including motor drives, renewable energy sources, and power supply frequently employ the TP-IBC. Three interleaved boost converters are linked in parallel to form the TP-IBC. Each converter operates out of phase with the others, so that the switching of each converter is staggered by 120 degrees. The input current ripple is spread out over time thanks to the staggered switching, which lowers the peak current and boosts the converter's effectiveness**.** A control circuit that manages the converter's output voltage is also part of the TP-IBC. The control circuit changes the duty cycle of the switching waveform to maintain the required output voltage by comparing the converter's output value to a reference voltage. The converter's input and output currents are also checked by the control circuit to make sure they stay within safe working ranges. The great power handling capacity of the TP-IBC is one of its key benefits. The converter can withstand larger power levels than a single-phase converter because to the interleaved phases. Also, compared to a single-phase converter, the TP-IBC has reduced input and output current ripple, which lessens strain on the converter's parts and increases dependability. The TP-great IBC's efficiency is another benefit. The converter's input current ripple is decreased by the interleaved phases and staggered switching, which also increases the efficiency of the converter by lowering switching-related power losses. Also, to maintain the proper output voltage, the control circuit modifies the switching waveform's duty cycle. This lowers power losses resulting from voltage regulation. There are some drawbacks to the TP-IBC as well. The usage of several phases makes the converter more complex and necessitates the addition of new parts like inductors and capacitors. This can raise the price and size of the converter. The switching of the interleaved phases must also be coordinated by the control circuit, which might make it more complex. The Three Phase Interleaved Boost Converter, in summary, is a DC-DC converter architecture that makes use of three interleaved phases to boost the converter's power handling capability, lessen input and output current ripple, and increase reliability. Because to its excellent efficiency and power handling capabilities, the TP-IBC is frequently utilised in high-power applications. Yet it also has certain drawbacks, such higher costs and complexity. [6].

Design, Validation, and Economic Behaviour of a Three-Phase Interleaved Step-Up DC-DC Converter for Electric Vehicle Use, the creation and evaluation of a three-phase interleaved step-up DC-DC converter for use in electric cars are covered. The writers discuss the necessity of a DC-DC converter in an electric car, which transforms the low voltage of the battery to the greater voltage necessary to power the motor. In comparison to previous topologies, the authors' three-phase interleaved step-up converter provides benefits in terms of efficiency, size, and cost. The article discusses the converter's design procedure, which includes picking the best components and figuring out the best switching frequency. The authors also go through the converter's control technique, which uses pulse width modulation. The control method for the converter, which uses pulse width modulation and feedback control to maintain the required output voltage, is also covered by the authors. The authors performed simulations and experimental experiments to confirm the converter's functionality. The converter's suitability for use in electric car applications was demonstrated by the findings, which indicated that it attained a high efficiency and a low output voltage ripple. The authors calculated the cost of the components and compared it to the costs of various DC-DC converter topologies in order to examine the converter's economic behaviour. The findings demonstrated that the suggested converter was more affordable than other topologies, making it a more sensible choice for applications involving electric vehicles. The essay concludes with a thorough analysis of the design, verification, and financial performance of a three-phase interleaved step-up DC-DC converter for use in electric vehicle applications. The suggested converter is a viable option for supplying electricity to electric cars since it has advantages in terms of efficiency, cost, and compactness. [7].

A popular converter architecture in a variety of renewable energy systems, electric cars, and aerospace applications is the three-phase interleaved boost converter (TPIBC). The TPIBC is vulnerable to a number of defects, such as Open-Circuit Faults (OCFs), which can result in significant system failures. Thus, to increase system reliability and performance, it is crucial to create efficient fault diagnostic techniques for TPIBC. This research proposes a brand-new, reliable fault diagnostic approach for TPIBC in this situation. The suggested approach employs a decision tree algorithm to categorise the faults and a sliding mode observer (SMO) to estimate the fault states. By measuring the output voltage and current of the converter, the SMO calculates the fault parameters. The calculated fault parameters are used by the decision tree method to categorise the defects. Simulation simulations using the

MATLAB/Simulink software were carried out to assess the performance of the suggested technique. The suggested approach has a number of benefits, including high accuracy, resilience, and quick calculation times. Future studies might concentrate on implementing the suggested strategy in real-world TPIBC systems to assess how well it performs when used in real-time operations. [8].

Electric cars, renewable energy systems, and other high power applications frequently employ the Three-Phase Interleaved Boost Converter (TPIBC). Switching issues, however, might alter the TPIBC's behaviour and cause the converter to malfunction. The behaviour of a TPIBC under open-circuited switch fault circumstances is examined in this work. Three interleaved boost converters are linked in tandem to form the TPIBC. Each converter has a switch, an inductor, a diode, and a capacitor. Pulse width modulation (PWM), which generates an AC voltage across the load, is used to activate the switches. High power applications may be handled by the TPIBC, which also offers a high degree of dependability. Yet problems in the switches might happen for a number of reasons, such age or manufacturing flaws. The TPIBC may act erratically and the converter's performance may suffer from an open-circuited switch problem. By modelling the fault in MATLAB/Simulink, the behaviour of the TPIBC under open-circuited switch fault circumstances was investigated. To examine the effects of these factors on the converter's performance, simulations were run with various duty cycles and switching frequencies. The outcomes of the simulation demonstrated that the location of the faulty switch inside the converter had an impact on how the TPIBC behaved in open-circuited switch failure situations. The converter's output voltage would drop noticeably if a problem developed in one of the outer switches. In conclusion, the investigation of the behaviour of a TPIBC under open-circuited switch fault conditions shows that the fault can significantly affect the converter's performance and reliability. The converter's output voltage and ripple can be affected by the position of the defective switch, the duty cycle, and the switching frequency. The dependability of the converter may also be impacted by an increase in inductor current and a drop in capacitor voltage. Fault-tolerant control solutions, such as employing redundant switches or fault isolation techniques, can be used to lessen the consequences of open-circuited switch faults. [9].

The paper begins with an introduction to the Interleaved Boost Converter and its advantages over traditional DC-DC converters. The IBC utilizes two or more interleaved converters in parallel to distribute the load current among them, resulting in reduced output ripple current and improved efficiency. The paper also provides a brief overview of the various topologies of DC-DC converters and their limitations. The paper discusses the topology and operation of the Interleaved Boost Converter. The IBC consists of two or more boost converters connected in parallel, with each converter sharing the load current. The interleaved operation of the converters reduces the input and output ripple current and increases the switching frequency, resulting in reduced size and cost of the passive components. The paper also discusses the switching waveforms and the control strategy of the IBC. The design considerations for the Interleaved Boost Converter are discussed in detail in the paper. The design process involves selecting the appropriate inductor, capacitor, and switch for each converter, based on the desired output voltage and current. The paper also discusses the impact of the interleaving factor, duty cycle, and switching frequency on the converter's performance. The paper discusses the implementation of the Interleaved Boost Converter, including the circuit diagram and the component selection. The paper also discusses the challenges faced during the implementation, such as component placement and thermal management. The paper provides a detailed analysis of the converter's efficiency, output voltage ripple, and load regulation. The paper presents the experimental results of the Interleaved Boost Converter, including the efficiency, output voltage ripple, and load regulation. The paper also discusses the impact of the interleaving factor, duty cycle, and switching frequency on the converter's performance. The experimental results demonstrate the superior performance of the IBC over traditional DC-DC converters. The paper discusses the various applications of the Interleaved Boost Converter, such as in renewable energy systems, electric vehicles, and industrial power supplies. The paper also discusses the advantages of the IBC in these applications, such as improved efficiency and reduced size and cost of the passive components. The paper concludes by summarizing the key points discussed in the paper and highlighting the advantages of the Interleaved Boost Converter. The paper also identifies areas for future research, such as the optimization of the interleaving factor and the use of advanced control techniques. In conclusion, the paper on the design and implementation of the Interleaved Boost Converter provides a comprehensive overview of the topology, operation, design considerations, implementation, experimental results, and applications of the IBC. The paper highlights the advantages of the IBC over traditional DC-DC converters and provides valuable insights into the design and implementation of the IBC for high-power applications.

[10].

3. Modes of Operation

A three-phase interleaved boost converter can operate in various modes depending on the input voltage, output voltage, and the load current. The operation modes of the 3-phase interleaved boost converter are as follows:

Continuous Conduction Mode (CCM): In this mode, the inductor current never reaches zero, and it flows continuously throughout the switching cycle. This mode is used when the input voltage is high and the load current is also high.

Discontinuous Conduction Mode (DCM): In this mode, the inductor current drops to zero before the end of the switching cycle, and the current flows in a discontinuous manner. This mode is used when the input voltage is low and the load current is also low.

Boundary Conduction Mode (BCM): In this mode, the inductor current crosses zero at the end of the switching cycle, and the current flows in a boundary manner. This mode is used when the input voltage and the load current are in between the CCM and DCM regions.

Critical conduction mode (CRM): In this mode, the converter operates at the boundary between CCM and DCM, and the inductor current falls to zero at the end of the switching cycle. This mode is suitable for high load currents.

The mode of operation of the three-phase interleaved boost converter is crucial in determining the efficiency and performance of the converter. Proper design and control techniques should be implemented to ensure that the converter operates in the desired mode, depending on the load conditions.

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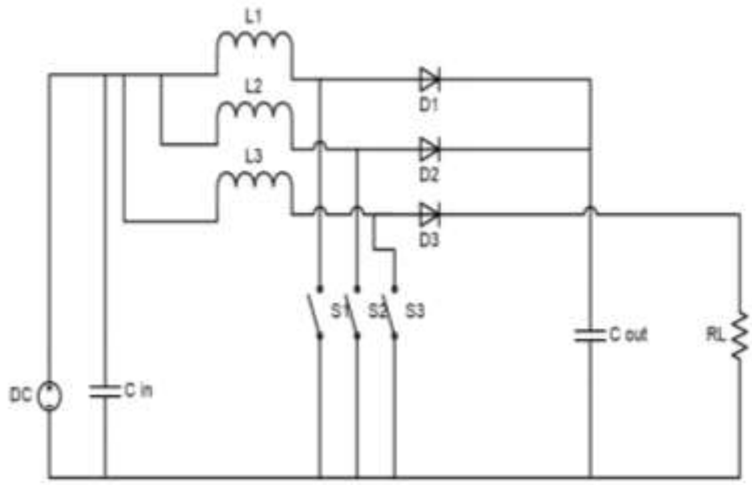
4. Procedure:

The three-phase interleaved boost converter takes in a three-phase AC input voltage and rectifies it into a DC voltage using a three-phase diode bridge rectifier. A filter capacitor is then used to smooth out the DC voltage to produce a DC bus voltage. With respect to one another, the three boost converters operate out of phase. This indicates that the other two converters are in their freewheeling stages while one converter is in its boosting phase. The input and output ripple currents are minimized, and the converter efficiency is increased, by interleaving the three converters. The boost converter raises the DC bus voltage to a higher voltage level during the boosting phase. To do this, a power MOSFET is turned on and off at a high frequency, usually between 20 and 100 kHz. The converter's control circuit produces a pulse width modulation (PWM) signal that is used to operate the MOSFET.



The boost converter raises the DC bus voltage to a higher voltage level during the boosting phase. To do this, a power MOSFET is turned on and off at a high frequency, usually between 20 and 100 kHz. The converter's control circuit produces a pulse width modulation (PWM) signal that is used to operate the MOSFET. The output voltages of all the boost converters combined make up the three-phase interleaved boost converter's output voltage. By altering the PWM signal's duty cycle, the output voltage can be changed

States of Operation:

State A: During this state, all the switches in the converter are open, and the input voltage is disconnected from the circuit. The inductors and capacitors in the circuit are charged and store energy. In State A, the three inductors are disconnected from the input voltage source, and their magnetic fields collapse, causing a voltage spike across them. This voltage spike charges the output capacitor, which starts to store energy. At the same time, the inductors are charged with current and store energy in their magnetic fields. State A allows the converter to prepare for the next cycle by charging the inductors and capacitors with energy.

State B: During this state, the switches in the first phase of the converter S1 is closed, and the input voltage is applied across the first inductor. The other two inductors remain open. The first inductor is charged with current, and the output capacitor discharges its stored energy to the load. The first inductor also transfers its stored energy to the output capacitor, which increases the output voltage.

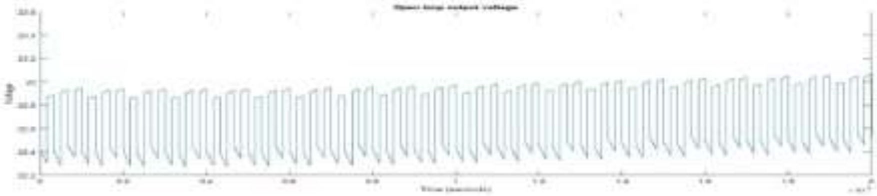
State C: During this state, the switches in the second phase of the converter S2 is closed, and the input voltage is applied across the second inductor. The first inductor is opened, and its stored energy is transferred to the output capacitor and load. The second inductor is charged with current, and the output capacitor continues to discharge its stored energy to the load. The second inductor also transfers its stored energy to the output capacitor, which further increases the output voltage.

State D: During this state, the switches in the third phase of the converter S3 is closed, and the input voltage is applied across the third inductor. The first and second inductors are opened, and their stored energy is transferred to the output capacitor and load. The third inductor is charged with current, and the output capacitor continues to discharge its stored energy to the load. The third inductor also transfers its stored energy to the output capacitor, which further increases the output voltage.

State E: In this state, all the switches in the converter are open, and the inductors and capacitors in the circuit discharge their stored energy. This state allows the inductors and capacitors to reset before the next cycle begins. State E also helps to reduce the output voltage ripple by discharging any remaining stored energy in the inductors and capacitors.

5. Simulation Results:

Open loop output voltage



Closed loop output voltage

6. Conclusion:

The three-phase interleaved DC-DC boost converter is a popular topology in power electronics applications due to its high-power density, reduced current ripple, and improved efficiency. The converter can be controlled using open or closed-loop control techniques to regulate the output voltage and maintain good system performance. Under open-loop control, the converter operates without feedback and relies on a predefined duty cycle to control the output voltage. This approach is simple and cost-effective but may not provide adequate voltage regulation, especially under load and input voltage variations. In closed-loop control, a feedback loop is added to the converter to regulate the output voltage. This technique provides better voltage regulation and stability, especially under varying load and input voltage conditions. Overall, the choice of control technique depends on the application requirements, such as cost, complexity, performance, and operating conditions. Both open and closed-loop control techniques have their advantages and limitations. This paper consists of simulations and results of three phase interleaved dc boost converter under open and closed loop control.

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