A TRANSFORMERLESS QUADRATIC BUCK-BOOST CONVERTER WITH HIGH VOLTAGE GAIN RATIO

A Project Report submitted to

Jawaharlal Nehru Technological University

in partial fulfilment of the requirements for the award of Degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRICAL AND ELECTRONICS ENGINEERING

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CERTIFICATE

This is to certify that the Project entitled is being **A Transformerless Quadratic Buck-Boost Converter with High Voltage Gain Ratio** is being submitted by **K Suchith Patel(21WJ1A0229), G Sai Sharan (22WJ5A0224), I Jagadeeswar Naik (22WJ5A0227)** in partial fulfilment for the award of Degree of **Bachelor of Technology** in **ELECTRICAL AND ELECTRONICS ENGINEERING** to the Jawaharlal Nehru Technological University is a record of Bonafide work carried out by him/her/them under my guidance and supervision.

The results embodied in this Project report have not been submitted to any other University or Institute for the award of any Degree or Diploma.

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PROJECT COMPLETION CERTIFICATE

This is to certify that the following students of final year B. Tech, Department of **ELECTRICAL AND ELECTRONICS ENGINEERING** – Guru Nanak Institutions Technical Campus (GNITC) have completed their training and project at GNITC successfully.

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The training was conducted on **MAT LAB** for the Completion of the project titled **A TRANSFORMERLESS QUADRATIC BUCK-BOOST CONVERTER WITH HIGH VOLTAGE GAIN RATIO USING MATLAB** in **2024-2025.** The project has been completed in all aspects.

Signature

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DECLARATION OF STUDENT

We, K.Suchith Patel (21WJ1A0229), G.Sai Sharan (22WJ5A0224), I.Jagadeeswar (22WJ5A0227**)**, hereby declare that the major project titled **"A TRANSFORMERLESS QUADRATIC BUCK-BOOST CONVERTER WITH HIGH VOLTAGE GAIN RATIO"** has been carried out by us as part of the requirements for the award of the Degree of **BACHELOR OF TECHNOLOGY** in the Department of **ELECTRICAL AND ELECTRONICS ENGINEERING** at **GURU NANAK INSTITUTIONS TECHNICAL CAMPUS**.

We confirm the following:

1. The project was undertaken by us under the supervision of our guide, R.Suresh Babu from the selection of the topic to the completion of the final report.
2. We have ensured that the results presented in the report are accurate and based on our original work.
3. To the best of our knowledge, the content of this report is free from plagiarism and adheres to ethical standards.
4. Each member of the team has contributed significantly and appropriately to the project work.
5. The project report has been prepared with diligence, ensuring clarity, accuracy, and adherence to academic standards.
6. We further declare that this report has not been submitted, in part or full, to any other institution or university for the award of any degree or diploma.

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DECLARATION OF GUIDE

I R.Suresh Babu, hereby declare that I have guided the major project titled "**A TRANSFORMERLESS QUADRATIC BUCK-BOOST CONVERTER WITH HIGH VOLTAGE GAIN RATIO**" undertaken by K Suchith Patel (21WJ1A0229), G Sai Sharan (22WJ5A0224), I Jagadeeswar (22WJ5A0227**)**. This project was carried out towards the fulfillment of the requirements for the award of the Degree of **BACHELOR OF TECHNOLOGY** in **ELECTRICAL AND ELECTRONICS ENGINEERING** at **GURU NANAK INSTITUTIONS TECHNICAL CAMPUS**.

As the guide, I confirm the following:

1. I have overseen the entire project process, from the selection of the project title to the submission of the final report.
2. I have reviewed and certified the accuracy and relevance of the results presented in the report.
3. The contributions of each student have been appropriately recognized and assessed.
4. The project report has been prepared under my supervision, ensuring adherence to high standards of quality, clarity, and structure.

I further certify that this project report has not been previously submitted in part or full for the award of any degree or diploma by any institution or university.

Name of Guide: Signature of the Guide

R.Suresh Babu

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Place:

Name of HOD: Signature of the HOD

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ACKNOWLEDGEMENT

We would like to express our sincere gratitude to our internal guide, R.Suresh Babu, Assistant Professor, Electrical and Electronics Engineering, for his valuable guidance, encouragement, and continuous support throughout the duration of this project.

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We are grateful to our friends and well-wishers for their encouragement, collaboration, and useful feedback throughout the project journey.

Lastly, we sincerely thank our parents for their constant support, patience, and motivation, which helped us complete this project successfully.

In All Sincerity

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ABSTRACT

A new transformer less quadratic buck–boost converter with a common ground and a high voltage gain ratio of $\frac{D}{(1-D^2)}$ is proposed in this study. The output and input currents of the proposed structure are continuous due to the presence of inductive filters in the output and input ports. The continuity of the output current simultaneously reduces the voltage ripple and also the capacitor stress at the output port. With the proposed quadratic structure, a lower total switching device power and a higher voltage gain ratio are attained at the same duty cycle. Due to the advantages of the proposed structure, it can be widely used with renewable energy. The presented model is investigated in terms of steady-state analysis, continuous conduction mode, small-signal modelling, and efficiency with parasitic resistance effects. To validate the performance of the proposed converter, experiments are conducted in the laboratory to claim the theoretical waveforms obtained from the piecewise linear electrical circuit simulation (PLECS) simulation.

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PLECS	Piecewise Linear Electrical Circuit Simulation
SEPIC	Single-Ended Primary-Inductor converter
OCP	Overcurrent Protection
OVP	Overvoltage Protection
DSP	Digital Signal Processors
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistors
SPD	Switched-Duty-Pulse
PWM	Pulse Width Modulation

CHAPTER-1

INTRODUCTION

1.1 Introduction to DC–DC Conversion

Renewable energy sources, such as solar and fuel cells, have recently been widely used to offer cost-effective electrical energy for a variety of industrial and residential applications. Each of these sources produces electricity with varied voltage and current qualities, which may severely limit its usefulness. For example, their integration with the grid necessitates an increase in voltage to control energy flow to the grid, whereas using them as the energy source for some home appliances necessitates a decrease in voltage to avoid overvoltage damage. In some applications, the input voltage can be variable, but the output is constant such as PV-supplied LED Street light; otherwise, the input source is constant with a wide range output voltage as an inverter multifunction source. Mathematical modelling of some topologies to gain a comprehensive insight into the dynamic behavior of the converter. This study also provides insights into the derivation of some configurations of new high-gain DC–DC converters in the field of DC microgrids. In negative-output (N/O) boost converters with normal voltage gain have been designed. In a related work, an N/O quadratic buck–boost converter with a wide voltage gain ratio is presented.

The N/O polarity plays an important role in the industry, such as data transfer interface, wind, and solar power generation. Nonetheless, in many applications such as solar energy conversion, the converter's discontinuous output/input current may limit its usage. Therefore, many buck–boost DC–DC converters are described in the literature in which the majority of which are based on traditional DC/DC converters such as buck, boost, buck–boost, CUK, SEPIC, ZETA, and Z-source converters. Some topologies use switched capacitor multipliers to maximize voltage gain without increasing the duty cycle. However, because these topologies use parallel capacitors switching, they produce high current stress and charging/discharging losses, as described. Traditional buck–boost converters are not suitable for photovoltaic applications due to the discontinuous current from the input source.

1.2 Voltage Conversion

In SEPIC with many elements to augment the voltage gain and diminish the voltage stress on the main switch for alternative energy applications is proposed. In this arrangement, SEPIC is connected to two voltage multipliers and an inductor. Because of its constant input current, it is an excellent choice for sustainable and renewable energy applications. Research reported a couple of new 2D voltage gain converter structures from the step-down/step-up converter family. However, in these configurations, the input current is irregular, and the usage of multiple switches adds to the circuit's complexity. In addition, by combining the KY model with a typical rectified step-down converter, a new step-down/step-up DC converter is created in realize the continuous output and input current port with similar polarity. In this converter, however, two switches are used. In another new buck–boost converter structure with a low-voltage gain ratio is presented to reduce the voltage stress in all the elements in the converter. This converter suffers an increased power ripple on the input side due to its discontinuous input current. Research in introduced a simple design with an input filter and a high-voltage gain ratio to overcome the shortcomings. In a similar study, a new buck–boost converter with inductive filters at the input and output port was introduced. The switch used in this converter has low voltage stress. But the number of semiconductor elements used in this converter is higher than other structures. Some applications do not require an isolated converter. In such cases, a non-isolated DC–DC converter is recommended to achieve a high-voltage gain ratio. To achieve high-voltage gain when integrating switched capacitor networks, the proposed converter uses a voltage multiplier cell. To overcome the issue of discontinuity, a quadratic buck–boost converter with a low number elements and continuous input/output current was proposed. This converter has a low-voltage gain ratio. Similarly, in a non-quadratic single switch with a continuous input/output current port is proposed without a common ground between the input and output. Considered quadratic buck–boost converters with a wide voltage gain ratio and continuous input current. In this regard, the converter proposed in a switched-capacitor/inductor within the conventional buck– boost converter, which offers quadratic voltage gain with discontinuous input and output current. However, the extreme duty cycle cannot be used because of the limitation of power semiconductor devices.

Moreover, although they all have simple structures, their voltage stress and current stress on components are high, and the voltage gain in the step-down mode is limited. Besides, some studies propose quadratic buck– boost converters with two power switches, requiring two gate drivers. This can result in increased size and complexity of the control system.

1.3 Overview of Conventional DC–DC Converter

This kind of converter requires two floating switches. Also, there exist ZETA DC–DC converters, which have recently been proposed. The voltage gain of the ZETA converter proposed is just twice that of the conventional ZETA converter. In a novel transformerless inverter is prototyped with dual modes for single-phase applications. With its simple structure, this single-phase inverter is capable of providing a variety of voltage gain ratios to overcome the shortcomings of modern dual-mode inverters (see the Appendix in the Supporting Information). A quadratic DC/DC converter with continuous current in the input and output terminal and positive-output polarity has been introduced and analyzed but this converter has a low-voltage gain ratio. The quadratic converters were introduced, which have a similar voltage gain ratio with continuous input current.

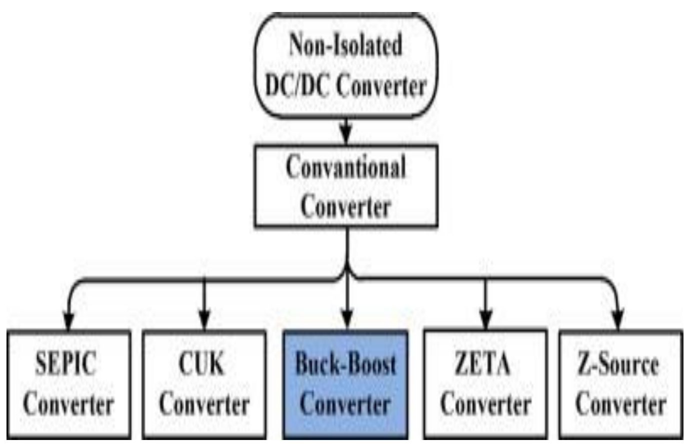


FIGURE 1.3.1 Types of Non-Isolated DC–DC Converters

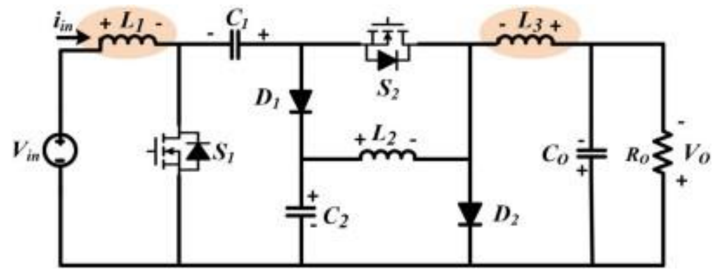


FIGURE 1.3.2 Structure of the Proposed Converter

However, due to the structures of these converters, the output current is discontinuous. In a non-isolated buck–boost converter is presented, using only one switch. Unfortunately, it suffers from discontinuous input/output current, which is considered a drawback, as continuous current input is more desirable for renewable energy. A summary of various types of DC–DC converted described earlier is illustrated in Figure 1. To overcome deficits in the above-mentioned DC–DC converter, this paper introduced a quadratic buck–boost DC– DC converter, which includes a wide range of conversions, a continuous input/output current port, making it suitable for renewable energy applications with a simple filter design. The content of this paper is as follows. First, the proposed converter is introduced, and then, steady-state evaluation and theoretical analyses are performed in Section 2. The small-signal modelling is investigated in Section 3. The advantages of the proposed converter are compared with other quadratic converters in Section 4. The results of the PLECS simulation are provided in Section 5. Experimental results of the laboratory-made prototype of the proposed converter are presented in Section 6. Finally, conclusions are made in Section 7.

CHAPTER-2
COMPONENTS

2.1 Power Semiconductor Switches

In a transformerless quadratic buck-boost converter, the power semiconductor switches are crucial for controlling the energy flow and achieving the desired voltage conversion. The choice of switch depends on factors such as voltage and current ratings, switching frequency, and efficiency requirements of the application.

Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs): MOSFETs are voltage-controlled devices with high input impedance and fast switching speeds. They are well-suited for applications with moderate voltage and current requirements and higher switching frequencies. Their low on-state resistance (RDS(on)) minimizes conduction losses. Both N-channel and P-channel MOSFETs can be used depending on the specific circuit configuration. The parasitic body diode inherent in MOSFETs can also be utilized for freewheeling purposes in the converter.

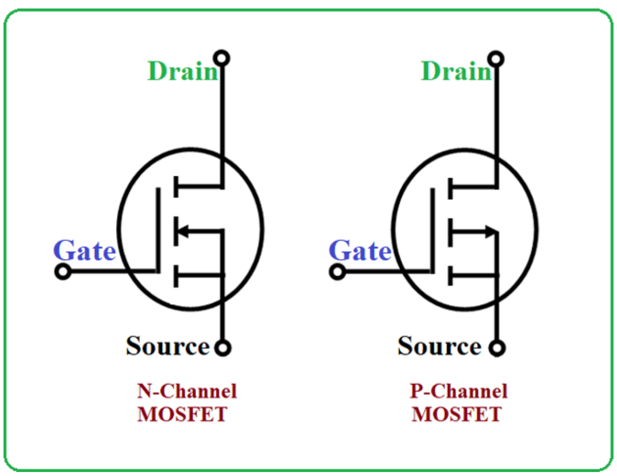


FIGURE 2.1 MOSFET

Key Characteristics of Power MOSFETs:

Voltage-Controlled: The current flow between the drain and source terminals is controlled by the voltage applied to the gate terminal. This high input impedance characteristic simplifies the driving circuitry.

Three Terminals: They have three terminals:

- Gate (G): The control terminal. Applying a voltage to the gate creates an electric field that modulates the channel conductivity.
- Drain (D): The terminal through which current enters (or exits, depending on the type and direction).
- Source (S): The terminal from which current exits (or enters).

Operating Principle: A voltage applied to the gate creates an electric field that forms a conductive channel between the source and drain in the semiconductor material. The strength of this field, and thus the channel's conductivity, is proportional to the gate voltage.

Low On-State Resistance (RDS (on)): When the MOSFET is turned on, it ideally acts as a low-resistance switch. A lower RDS (on) minimizes conduction losses, leading to higher efficiency.

High Blocking Voltage (VDS): MOSFETs are designed to withstand a specific maximum voltage across the drain and source when they are turned off. Selecting a MOSFET with an appropriate voltage rating for the application is crucial for reliability.

Gate Threshold Voltage (Vth): This is the minimum gate-source voltage required to create a conductive channel and allow current to flow between the drain and source.

Gate Drive Voltage (VGS): The voltage applied between the gate and source to fully turn the MOSFET on. Proper gate drive is essential for achieving optimal switching performance and minimizing switching losses.

Gate Charge (Qg): The total electrical charge needed to switch the MOSFET on or off. It affects the switching speed and the power required to drive the gate.

Fast Switching Speed: Compared to other power devices like IGBTs, MOSFETs generally have faster switching speeds, making them suitable for high-frequency applications.

Body Diode: Power MOSFETs inherently have a parasitic diode between the drain and source terminals, often called the body diode. This diode can conduct current in the reverse direction when the MOSFET is off and can be utilized in certain converter topologies for freewheeling.

Temperature Dependence: The performance characteristics of MOSFETs, such as RDS(on) and threshold voltage, are affected by temperature. This needs to be considered in the thermal design of the converter.

Types of MOSFETs:

MOSFETs can be broadly classified based on their channel type and mode of operation:

Channel Type:

- N-channel MOSFET (NMOS): These are more common. Current flows when a positive voltage is applied to the gate relative to the source, attracting electrons to form the channel.
- P-channel MOSFET (PMOS): Current flows when a negative voltage is applied to the gate relative to the source, attracting holes to form the channel. NMOS devices generally have better performance (lower RDS(on) and faster switching) than PMOS devices for the same die size.

Mode of Operation:

Enhancement Mode: These MOSFETs are normally off (no channel exists at zero gate voltage).A gate voltage above the threshold voltage is required to create a channel and allow current flow. This is the most common type used in power switching applications.Depletion Mode: These MOSFETs have a channel present even at zero gate voltage and are normally on. Applying a gate voltage can deplete the channel of charge carriers, reducing the current flow and eventually turning the device off. Depletion mode MOSFETs are less common in power switching.

Advantages of MOSFETs in Power Converters:

- High Switching Speed: Allows for higher operating frequencies, leading to smaller and lighter passive components (inductors and capacitors).
- Low Gate Drive Power: Being voltage-controlled devices with high input impedance, they require minimal current to drive the gate, reducing driver power losses.
- Lower Conduction Losses (in many cases): Advancements in MOSFET technology have led to devices with very low RDS(on), minimizing I2R losses.
- No Second Breakdown: Unlike BJTs, MOSFETs do not suffer from second breakdown, making them more robust under certain operating conditions.
- Ease of Paralleling: MOSFETs have a positive temperature coefficient for RDS (on) at higher currents, which helps to balance current sharing when multiple devices are connected in parallel.

2.2 Inductors

In a transformerless quadratic buck-boost converter, two inductors typically play distinct but crucial roles in achieving the desired voltage conversion and the characteristic quadratic voltage gain.

Key Characteristics of Inductors:

Inductance (L): Measured in Henrys (H), inductance is the property of an electrical circuit element that opposes a change in current flowing through it. A higher inductance means a greater opposition to current change and a larger amount of energy stored for a given current.

Current-Voltage Relationship: The voltage across an inductor (vL) is proportional to the rate of change of current (di/dt) through it, given by the equation: vL=Ldtdi This relationship is central to how inductors smooth current waveforms and transfer energy in switching converters.

Energy Storage: The energy (E) stored in an inductor is given by: E=21Li2 where i is the current flowing through the inductor. This stored energy is released back into the circuit when the current decreases.

DC Resistance (DCR): Real inductors have some resistance in their windings, which causes power loss in the form of heat (I2R losses). A lower DCR is desirable for higher efficiency.

Saturation Current: Inductors with magnetic cores (like ferrite or iron powder) have a saturation current rating. If the current through the inductor exceeds this value, the core saturates, the inductance drops significantly, and the inductor no longer behaves as intended. This can lead to increased current ripple and potential component damage.

Core Material and Geometry: The type of core material and the physical geometry of the inductor (number of turns, core shape, air gap) significantly affect its inductance, saturation current, and losses.

Role of Inductors in a Quadratic Buck-Boost Converter:

The two inductors in a quadratic buck-boost converter typically perform different but interconnected functions:

Input Inductor (L1): This inductor is usually placed at the input of the converter.

Current Smoothing: It helps to smooth the input current drawn from the source, reducing current ripple and electromagnetic interference (EMI).

Energy Storage and Transfer: It stores energy during one switching phase and releases it during another, contributing to the overall energy transfer process.

Preventing Discontinuous Conduction Mode (DCM) at Light Loads: A sufficiently large input inductor can help maintain continuous conduction mode (CCM) even at lighter loads, which generally leads to lower current stress on components.

Intermediate/Second Inductor (L2): This inductor is often placed in the intermediate stage of the power transfer path, interacting with the switching elements and the first inductor.

Contributing to the Quadratic Gain: The interaction between this inductor and the switching network, along with the input inductor, is key to achieving the squared relationship between the duty cycle and the voltage gain.

Further Energy Storage and Transfer: It plays a role in shaping the current waveforms and transferring energy to the output stage.

Output Current Shaping (indirectly): By influencing the intermediate voltage and current, this inductor indirectly affects the current delivered to the output capacitor and the load.

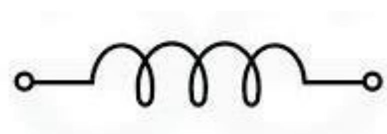


FIGURE 2.2 Figure of Inductor

Design Considerations for Inductors:

When selecting inductors for a quadratic buck-boost converter, several factors need careful consideration:

- Inductance Value: The inductance values of L1 and L2 are critical for determining the current ripple, the operating mode (CCM or DCM), and the dynamic response of the converter. These values are typically chosen based on the input voltage range, output voltage and current requirements, and the switching frequency.
- Saturation Current: The inductors must be designed to handle the maximum expected current without saturating, as saturation can lead to performance degradation and potential failure.

- DC Resistance (DCR): Lower DCR is essential to minimize conduction losses and improve efficiency.
- AC Losses: At higher switching frequencies, AC losses in the inductor windings (skin effect, proximity effect) and core losses (hysteresis and eddy current losses) become significant and need to be minimized through careful design and material selection.
- Physical Size and Cost: These are always important practical considerations any design.

2.3 Capacitors

In a quadratic buck-boost converter, at least two capacitors play vital roles, and sometimes more are used for specific filtering purposes.

Intermediate Capacitor (C1): This capacitor is often placed in the intermediate stage of the converter.

- Charge Pumping: It participates in the charge transfer process, helping to boost the voltage in conjunction with the switching action and the inductors.
- Voltage Stabilization: It helps to stabilize the voltage at the intermediate node, reducing voltage ripple.
- Energy Storage: It temporarily stores energy and releases it to other parts of the circuit as needed.

Output Capacitor (Co or Cout): This capacitor is placed at the output of the converter, connected in parallel with the load.

- Output Voltage Smoothing: Its primary function is to filter out the high-frequency switching ripple present in the current delivered to the load, resulting in a smooth DC output voltage.
- Energy Storage for Load Transients: It provides a резервуар of energy to supply the load during sudden increases in current demand (load transients), helping to keep the output voltage stable.
- Stability: The output capacitor also plays a role in the overall stability of the feedback control loop of the converter.

FIGURE 2.3 Figure of Capacitor

Key Characteristics of Capacitors:

- Capacitance (C): Measured in Farads (F), capacitance is the ability of a component to store an electrical charge. A higher capacitance means it can store more charge at a given voltage.
- Current-Voltage Relationship: The current through a capacitor (iC) is proportional to the rate of change of voltage (dv/dt) across it, given by the equation: iC=Cdtdv This relationship is crucial for understanding how capacitors smooth voltage waveforms by opposing rapid changes in voltage.
- Energy Storage: The energy (E) stored in a capacitor is given by: E=21Cv2 where v is the voltage across the capacitor.
- Equivalent Series Resistance (ESR): Real capacitors have some internal resistance, known as ESR, which causes power loss (I2R losses) and affects the output voltage ripple. A lower ESR is generally desirable, especially for the output capacitor.
- Equivalent Series Inductance (ESL): Real capacitors also have some internal inductance, known as ESL, which can affect their high-frequency behavior and contribute to voltage spikes during switching. Lower ESL is important for high-frequency applications.
- Voltage Rating: Capacitors have a maximum voltage they can withstand without failure. It's crucial to select capacitors with a voltage rating significantly higher than the maximum voltage they will experience in the circuit.

- Ripple Current Rating: Capacitors, especially the output capacitor, experience AC ripple current due to the switching action. They must be able to handle this current without excessive heating or failure.
- Temperature Coefficient: The capacitance value can change with temperature, and this needs to be considered in the design, especially for applications with wide temperature variations.
- Capacitor Type: Different types of capacitors (e.g., electrolytic, ceramic, film) have different characteristics in terms of capacitance range, voltage rating, ESR, ESL, cost, and temperature performance. The choice of capacitor type depends on the specific requirements of the application and the location in the circuit. For example, ceramic capacitors often have low ESR and ESL and are good for high-frequency filtering, while electrolytic capacitors offer high capacitance values but typically have higher ESR and lower frequency performance.

Role of Capacitors in Achieving High Voltage Gain:

In the transformerless quadratic buck-boost converter, the intermediate capacitor (C1) plays a particularly important role in enabling the high voltage gain. Through the switching cycles, this capacitor is charged and discharged in a way that contributes to boosting the voltage level before it reaches the output stage. The specific configuration and control strategy ensure that the voltage across this intermediate capacitor, in conjunction with the inductors, leads to the squared relationship between the duty cycle and the voltage gain.

Design Considerations for Capacitors:

- Capacitance Value: The values of C1 and Cout are chosen to achieve the desired voltage ripple, transient response, and stability.
- Voltage Rating: Ensuring that the capacitors can withstand the maximum voltages they will be subjected to is critical for reliability.
- ESR and ESL: Minimizing ESR is important for reducing output voltage ripple and improving efficiency. Lower ESL helps in reducing voltage spikes and improving high-frequency performance.
- Ripple Current Handling: The output capacitor must be able to handle the RMS ripple current without exceeding its temperature limits.

- Physical Size and Cost: These are practical constraints that need to be balanced with the performance requirements.
- **Input Inductor (L1):** This inductor often needs to handle a relatively high DC current with a smaller AC ripple component. Low DCR and a high saturation current capability might be prioritized. Depending on the frequency, either ferrite or powdered iron cores could be suitable.
- **Intermediate/Second Inductor (L2):** This inductor might experience larger current swings and could have different requirements for inductance and saturation current compared to the input inductor, depending on the specific topology and control strategy employed to achieve the quadratic gain.

2.4 Diodes

In a transformerless quadratic buck-boost converter with a high voltage gain ratio, two diodes are typically employed. The specific types of diodes chosen are crucial for the converter's efficiency and overall performance. Here's a breakdown of the considerations:

Types of Diodes Commonly Used:

Given the switching nature of the converter and the need for efficient current conduction and blocking, the following types of diodes are often considered:

1. Fast Recovery Diodes: These diodes are essential for minimizing switching losses. They have a short reverse recovery time (trr), which is the time it takes for the diode to stop conducting current after the voltage across it reverses. A shorter trr reduces the overlap between voltage and current during switching transitions, leading to lower power dissipation and higher efficiency. These are often preferred for the main rectifier diode and any freewheeling diodes in the circuit.
2. Schottky Diodes: These diodes have a metal-semiconductor junction, resulting in a very low forward voltage drop (VF) compared to traditional PN junction diodes. This lower VF reduces conduction losses, especially at higher current levels. They also exhibit very fast switching speeds and negligible reverse recovery charge, making them excellent for high-frequency applications. However, they typically have lower reverse voltage blocking capabilities compared to fast recovery diodes.

3. Silicon PN Junction Diodes (General Purpose or Ultrafast): While general-purpose diodes have relatively slow reverse recovery times, advancements have led to "ultrafast" PN junction diodes with improved switching characteristics. These might be used in less critical paths or in lower frequency designs where their voltage blocking capabilities are advantageous.

Role of Diodes in the Quadratic Buck-Boost Converter:

The two diodes in a typical transformerless quadratic buck-boost converter usually serve the following roles:

1. Output Rectifier Diode: This diode is typically placed at the output stage to allow current flow from the energy storage components (inductors and capacitors) to the output capacitor and the load during specific switching intervals. It blocks the reverse flow of current from the output capacitor back into the switching network. A fast recovery diode or a Schottky diode (if the voltage ratings allow) is crucial here to minimize switching losses and improve efficiency.
2. Intermediate Freewheeling/Rectifier Diode (D1): This diode is often part of the intermediate stage that helps achieve the quadratic voltage gain. It provides a path for the inductor current to flow when the main switches are turned off, preventing voltage spikes and ensuring continuous current flow in the inductive elements. Again, a fast recovery diode is generally preferred for this position.

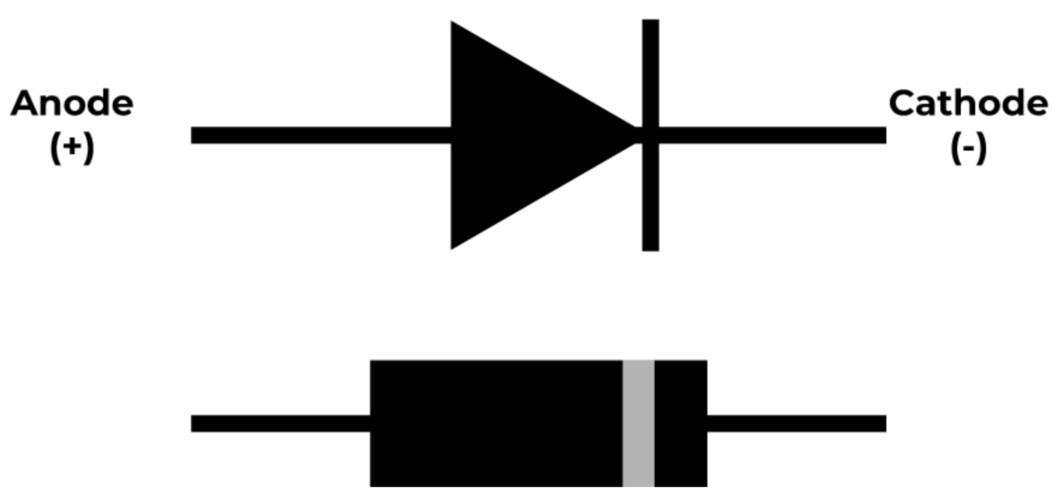


FIGURE 2.4 Diode

Key Characteristics to Consider When Selecting Diodes:

- Reverse Voltage Rating (VRRM or VR): The diode must be able to withstand the maximum reverse voltage that will be applied across it with a sufficient safety margin.
- Average Forward Current Rating (IF(AV)): The diode must be able to handle the average forward current flowing through it without exceeding its thermal limits.
- Peak Forward Surge Current (IFSM): The diode should be able to withstand short-duration peak currents that might occur during startup or transient conditions.
- Forward Voltage Drop (VF): A lower VF reduces conduction losses and improves efficiency.
- Reverse Recovery Time (trr): A shorter trr minimizes switching losses, especially in high-frequency operation.
- Junction Capacitance (Cj): Lower junction capacitance can also contribute to faster switching and reduced losses.
- Thermal Characteristics: The diode's thermal resistance and maximum junction temperature are important for ensuring reliable operation under the expected power dissipation.

2.5 Control Circuity

The brain of the operation! The control circuitry is absolutely vital in a transformerless quadratic buck-boost converter. It's responsible for generating the precise switching signals that govern the power semiconductor switches, ensuring the output voltage is regulated at the desired level despite variations in input voltage and load.

key aspects of the control circuitry:

Core Functions:

1. Generating Switching Signals: The primary function is to produce the Pulse Width Modulation (PWM) signals that drive the power MOSFETs (or other switches). These signals dictate when each switch turns on and off, thereby controlling the flow of energy through the inductors and capacitors.
2. Output Voltage Regulation: The control circuit continuously monitors the output voltage and compares it to a reference voltage. Any deviation from the desired output voltage triggers [1] an adjustment in the duty cycle of the PWM signals to bring the output back to the setpoint. This forms a closed-loop feedback system.

3. Stability and Compensation: The feedback loop needs to be stable to prevent oscillations in the output voltage. Compensation networks are often included in the control circuitry to shape the loop's frequency response and ensure stability over a range of operating conditions.
4. Protection Features: Robust control circuitry often incorporates protection mechanisms to safeguard the converter and the load from faults such as:
   - Overcurrent Protection (OCP): Limits the current flowing through the switches and inductors to prevent damage.
   - Overvoltage Protection (OVP): Shuts down the converter if the output voltage exceeds a safe limit.
   - Undervoltage Lockout (UVLO): Ensures the control circuitry and switches operate only when the input voltage is within a safe range.
   - Overtemperature Protection (OTP): Monitors the temperature of critical components and shuts down the system if it exceeds safe limits.

Common Components and Techniques:

The control circuitry for a quadratic buck-boost converter typically involves one or more of the following:

1. PWM Controller ICs: These integrated circuits are specifically designed for generating PWM signals and implementing control loops for switching power converters. They often include:
   - Voltage Reference: A precise internal voltage source for comparison with the output voltage.
   - Error Amplifier: Amplifies the difference between the output voltage and the reference voltage.
   - PWM Comparator: Compares the error amplifier output with a ramp or sawtooth waveform to generate the PWM signal.
   - Oscillator: Sets the switching frequency of the converter.
   - Dead-Time Control: Ensures that both switches are not on simultaneously, preventing short circuits.
   - Protection Circuits: Built-in OCP, UVLO, and sometimes OVP.

2. Microcontrollers (MCUs) and Digital Signal Processors (DSPs): For more sophisticated control strategies and features, microcontrollers or DSPs can be used to implement the PWM generation and control algorithms. This offers greater flexibility in implementing non-linear control techniques, adaptive control, and communication interfaces.
3. Analog Control Circuits: Discrete analogy components like operational amplifiers, comparators, and RC networks can also be used to build the control circuitry, although this approach is less common for complex converters compared to using dedicated ICs or digital controllers.
4. Current Sensing: To implement current-mode control or overcurrent protection, the control circuitry needs to sense the current flowing through the switches or inductors. This can be achieved using:
    - Sense Resistors: Small-value resistors placed in the current path, with the voltage drop across them proportional to the current.
    - Current Transformers: Provide isolated current sensing.
    - Hall Effect Sensors: Offer non-contact current sensing.
5. Voltage Sensing: The output voltage needs to be accurately sensed for regulation. This is typically done using a resistive voltage divider to scale the output voltage down to a level suitable for the control IC or microcontroller's analog-to-digital converter (ADC).
6. Gate Driver Circuits: The output signals from the PWM controller or microcontroller need to be amplified and level-shifted to properly drive the gates of the power MOSFETs. Gate driver ICs provide the necessary voltage and current to switch the MOSFETs efficiently and quickly. They also often include features like shoot-through protection.

Control Strategies for High Voltage Gain:

The control strategy employed plays a significant role in achieving and maintaining a stable high voltage gain. Common control techniques include:

- Voltage Mode Control: The duty cycle is directly controlled based on the output voltage error. Compensation networks are crucial for stability.
- Current Mode Control (Peak Current Mode or Average Current Mode): The duty cycle is controlled based on both the output voltage error and the inductor current. This often offers better transient response and inherent current limiting.

- Hysteretic Control: The duty cycle is varied based on the output voltage staying within a defined window. This can offer fast transient response but may result in variable switching frequency.
- Digital Control: Using microcontrollers or DSPs allows for the implementation of advanced control algorithms like PID control, sliding mode control, and model predictive control, which can be tailored for optimal performance and high voltage gain operation.

CHAPTER-3
CONVERTERS

3.1 DC-DC Converter Basics

A DC-to-DC converter is a device that accepts a DC input voltage and produces a DC output voltage. Typically, the output produced is at a different voltage level than the input. In addition, DC-to-DC converters are used to provide noise isolation, power bus regulation, etc.

3.2 Buck Converter

In this circuit the transistor turning ON will put voltage V_{in} on one end of the inductor. This voltage will tend to cause the inductor current to rise. When the transistor is OFF, the current will continue flowing through the inductor but now flowing through the diode.

We initially assume that the current through the inductor does not reach zero, thus the voltage at V_x will now be only the voltage across the conducting diode during the full OFF time. The average voltage at V_x will depend on the average ON time of the transistor provided the inductor current is continuous.

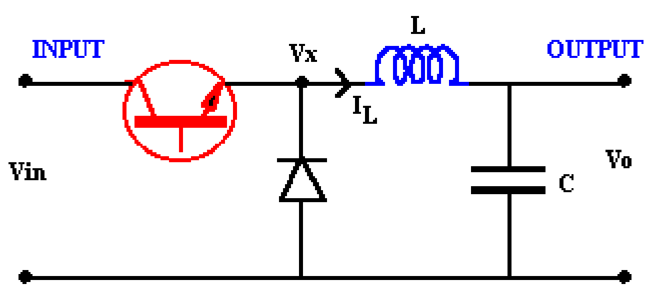


Fig 3.2.1 Buck Converter

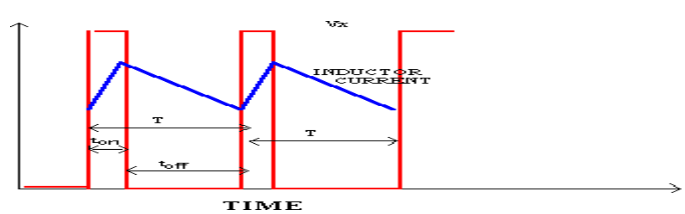


Fig 3.2.2 Voltage and Current Changes

Working Principle:

The buck converter operates in two main states, controlled by the switching of the transistor:

1. Switch ON: When the switch is closed, the input voltage (Vin) is directly connected across the inductor (L). This causes the inductor current to rise, and the inductor stores energy in its magnetic field. The diode (D) is reverse-biased and does not conduct. The capacitor (C) supplies energy to the load (RL) and helps to smooth the output voltage.

2. Switch OFF: When the switch is opened, the inductor current cannot change instantaneously. The voltage across the inductor reverses its polarity, and the inductor now acts as a source, releasing the stored energy. The diode becomes forward-biased, providing a path for the inductor current to flow through the capacitor and the load. This keeps the current flowing and prevents a sudden drop in output voltage. The capacitor is charged by the inductor and continues to supply energy to the load.

The output voltage (Vout) is controlled by the duty cycle (D) of the switch, which is the ratio of the time the switch is ON (Ton) to the total switching period (T):

D=TTon

The average output voltage of an ideal buck converter is given by:

Vout=D×Vin

Since the duty cycle D is always between 0 and 1, the output voltage is always less than the input voltage, hence the name "step-down" converter.

Key Components:

- Switch (Transistor): Typically a MOSFET, it rapidly turns ON and OFF to control the energy flow.

- Inductor (L): Stores energy during the switch's ON time and releases it during the OFF time, helping to smooth the current flow.

- Diode (D): Acts as a freewheeling diode, providing a path for the inductor current when the switch is OFF. In synchronous buck converters, this diode is replaced by another MOSFET for higher efficiency.
- Capacitor (C): Filters the pulsating output voltage from the switching action, providing a smoother DC output voltage to the load.

Modes of Operation:

Buck converters can operate in two main conduction modes:

- Continuous Conduction Mode (CCM): The inductor current never falls to zero during the switching cycle.
- Discontinuous Conduction Mode (DCM): The inductor current falls to zero for a portion of the switching cycle.

CCM is generally preferred for higher power applications due to lower ripple and higher efficiency.

Efficiency:

Buck converters are known for their high efficiency, often reaching 90% or higher, especially synchronous buck converters that replace the diode with a MOSFET. Losses occur due to the resistance of the components (especially the inductor and MOSFETs), switching losses in the MOSFET, and core losses in the inductor.

Applications:

Buck converters are widely used in various applications requiring a lower DC voltage from a higher DC source, including:

- Regulated Power Supplies: Providing stable voltage for electronic circuits.
- Point-of-Load (POL) Converters: Supplying low voltages to microprocessors and other digital ICs in computers and laptops.
- Battery Chargers: Efficiently stepping down voltage to charge batteries.

- LED Lighting: Providing the correct voltage and current for LEDs.
- Automotive Applications: Powering various electronic systems from the car battery.
- Portable Devices: Voltage regulation in smartphones, tablets, and other battery-powered devices.
- Solar Power Systems: Stepping down the voltage from solar panels to charge batteries or power devices.

3.3 Boost Converter

The schematic shows the basic boost converter. This circuit is used when a higher output voltage than input is required.

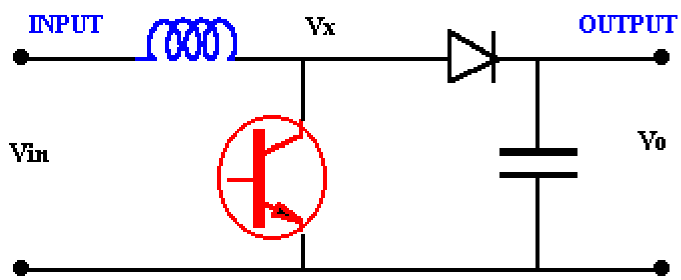


Fig 3.3.1 Boost Converter Circuit

While the transistor is ON $V_x = V_{in}$, and the OFF state the inductor current flows through the diode giving $V_x = V_o$. For this analysis it is assumed that the inductor current always remains flowing (continuous conduction). The voltage across the inductor is shown in Fig. 7 and the average must be zero for the average current to remain in steady state

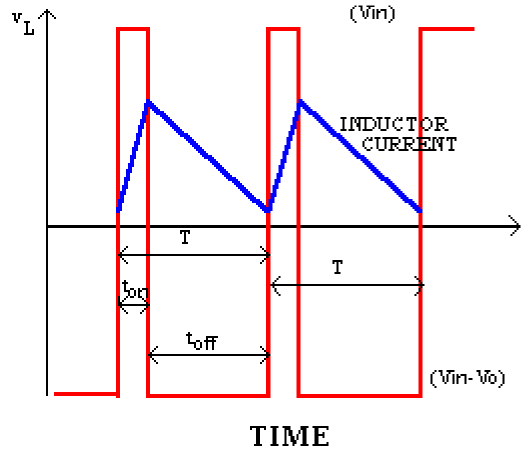


Fig 3.3.2 Voltage and Current Waveforms

Since the duty ratio "D" is between 0 and 1 the output voltage must always be higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage.

The boost converter also operates in two main states, controlled by the switching of the transistor:

1. **Switch ON:** When the switch is closed, the input voltage (Vin) is connected across the inductor (L). This causes the inductor current to rise, and the inductor stores energy in its magnetic field. The diode (D) is reverse-biased, isolating the output stage from the input. The capacitor (C) supplies energy to the load (RL).

2. **Switch OFF:** When the switch is opened, the inductor current must continue to flow. The inductor's voltage polarity reverses, and it acts as a voltage source in series with the input voltage. This combined voltage (Vin+VL) is applied across the diode, capacitor, and load. The inductor releases its stored energy, charging the capacitor and supplying current to the load.

The average output voltage (Vout) of an ideal boost converter is related to the input voltage (Vin) and the duty cycle (D) of the switch by the following equation:

Vout=1−DVin

Here, the duty cycle D is the ratio of the time the switch is ON (Ton) to the total switching period (T):

D=TTon

As the duty cycle D ranges from 0 to 1, the output voltage Vout will always be greater than or equal to the input voltage Vin, hence the name "step-up" or "boost" converter. In practical applications, the duty cycle is kept below 0.7 or 0.8 to maintain stability.

Key Components:

- **Switch (Transistor):** Typically a MOSFET, rapidly switches ON and OFF to control energy storage and release in the inductor.
- **Inductor (L):** Stores energy when the switch is ON and releases it to the output when the switch is OFF, facilitating the voltage increase.
- **Diode (D):** Acts as a rectifier, allowing current flow from the inductor to the output capacitor and load only when the switch is OFF.
- **Capacitor (C):** Filters the pulsating output voltage, providing a smoother DC output to the load and storing energy to supply the load during the switch's ON time.

Modes of Operation:

Similar to the buck converter, the boost converter can operate in:

- **Continuous Conduction Mode (CCM):** The inductor current never falls to zero during the switching cycle.
- **Discontinuous Conduction Mode (DCM):** The inductor current falls to zero for a portion of the switching cycle, typically under light loads.

CCM is generally preferred for higher power applications due to lower ripple and higher efficiency.

Efficiency:

Boost converters can achieve high efficiencies, often in the range of 85% to 95%, depending on the quality of the components and the operating conditions. Losses occur in the switching elements (conduction and switching losses), the inductor (resistance and core losses), and the diode (forward voltage drop and reverse recovery losses). Replacing the diode with a synchronous rectifier (another MOSFET) can further improve efficiency, especially in low-voltage applications.

Applications:

Boost converters are essential in numerous applications where a higher DC voltage is needed from a lower DC source:

- **Portable Electronics:** Boosting battery voltage to power different components in devices like smartphones, tablets, and laptops.
- **LED Lighting:** Stepping up voltage to drive LEDs efficiently.
- **Automotive Applications:** Increasing battery voltage for certain systems.
- **Power Factor Correction (PFC):** Used at the input stage of AC-DC power supplies to improve the power factor.
- **Photovoltaic (PV) Systems:** Boosting the voltage from solar panels to match the DC link voltage of inverters.
- **Battery-Powered Systems:** Increasing the voltage from a battery pack for applications requiring higher voltage.
- **Hybrid and Electric Vehicles:** Boosting battery voltage to power the electric motor.
- **Joule Thief Circuits:** Simple, unregulated boost converters used to extract the last bit of energy from nearly depleted batteries to power low-power device

3.4 Buck-Boost Converter

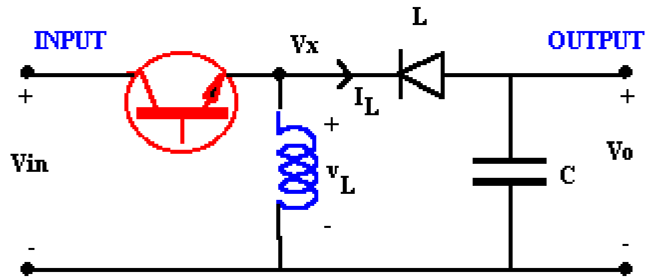


Fig 3.4.1 Schematic for Buck-Boost Converter

With continuous conduction for the Buck-Boost converter $V_x = V_{in}$ when the transistor is ON and $V_x = V_o$ when the transistor is OFF. For zero net current change over a period the average voltage across the inductor is zero.

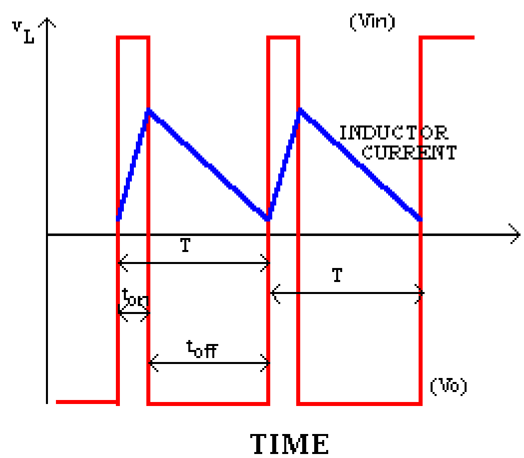


Fig 3.4.2 Waveforms for Buck-Boost Converter

Key Characteristics:

- Output Voltage: Can be greater than, less than, or equal to the input voltage magnitude.
- Output Polarity (Traditional): Typically inverted relative to the input voltage (positive in, negative out, or vice versa).
- Single Inductor: Usually employs a single inductor for energy storage.

- Switch, Diode, Capacitor: Similar to buck and boost converters, it uses a switch (MOSFET), a diode, and a capacitor.

Working Principle (Simplified):

This type of DC-to-DC converter can produce an output voltage (V_o) that is either higher (boost) or lower (buck) in magnitude than the input voltage (V_{in}). The output voltage polarity is typically opposite to the input voltage polarity.

Let's break down the circuit and its operation over a switching cycle, assuming continuous conduction mode (CCM). The operation is divided into two states based on the switching state of the transistor (Q).

Components:

- V_{in}: The input DC voltage source.
- Q (Transistor): The switching element, typically a MOSFET or BJT. It is controlled by a switching signal (not shown).
- L (Inductor): The energy storage element.
- D (Diode): Allows current to flow in only one direction.
- C (Capacitor): Filters the output voltage and provides energy to the load during the transistor's OFF-state.
- Load (Not explicitly shown but implied across V_o): The device receiving the output power.

- Operation:

1. ON-State (Transistor Q is ON):

- When the transistor Q is turned ON, it acts like a short circuit between its collector (or drain) and emitter (or source).
- The input voltage V_{in} is directly connected across the inductor L.
- The current through the inductor (i_L) starts to increase linearly with time, storing energy in the inductor's magnetic field. The rate of increase is given by:

- $\frac{di_L}{dt} = \frac{V_{in}}{L}$
- During this time, the diode D is reverse-biased because the voltage at its anode (connected to the inductor) is approximately ground (due to the conducting transistor), while its cathode is at a negative voltage $-V_o$ (assuming the standard polarity for V_o in a buck-boost converter).
- The capacitor C provides the current to the load, so the capacitor discharges, and the magnitude of the output voltage $|V_o|$ tends to decrease slightly.

2. OFF-State (Transistor Q is OFF):

* When the transistor Q is turned OFF, the current through the inductor i_L cannot change instantaneously. The inductor now acts as a voltage source, reversing its polarity to maintain the current flow.

* The inductor's voltage adds to the input voltage, making the anode of the diode D more negative than its cathode (which is at $-V_o$). The diode D becomes forward-biased and starts conducting.

* The current i_L now flows through the diode D, charging the capacitor C and supplying current to the load.

* The energy stored in the inductor during the ON-state is now transferred to the output capacitor and the load.

* The current through the inductor (i_L) starts to decrease linearly with time. The voltage across the inductor is approximately V_o, so the rate of decrease is given by:

$\frac{di_L}{dt} = \frac{V_o}{L}$ (Note the magnitude here, considering the voltage polarity across the inductor)

* The capacitor C is charged by the current flowing through the diode, so the magnitude of the output voltage $|V_o|$ tends to increase.

Output Voltage Relationship:

In a steady state, the average voltage across the inductor over one switching cycle must be zero. By equating the volt-seconds during the ON and OFF states, we can derive the relationship between the input voltage (V_{in}), output voltage (V_o), and the duty cycle (D) of the switching signal (where D is the ratio of the ON-time to the total switching period T).

During the ON-state, the voltage across the inductor is V_{in} for a duration of DT.

During the OFF-state, the voltage across the inductor is $-V_o$ for a duration of (1-D) T.

For zero average voltage across the inductor:

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

From this equation, we can see that:

* If $D < 0.5$, then $|V_o| < |V_{in}|$ (Buck operation).

* If $D > 0.5$, then $|V_o| > |V_{in}|$ (Boost operation).

* If $D = 0.5$, then $|V_o| = |V_{in}|$.

Key Characteristics of the Buck-Boost Converter:

* Inverting Output: The output voltage V_o has a polarity opposite to the input voltage V_{in}.

* Buck or Boost Capability: The magnitude of the output voltage can be either lower or higher than the input voltage depending on the duty cycle.

* Single Inductor: Uses only one inductor for energy storage.

* Switching Operation: Relies on the switching of the transistor to transfer energy.

3.5 CUK Converter

The buck, boost and buck-boost converters all transferred energy between input and output using the inductor, analysis is based of voltage balance across the inductor. The CUK converter uses capacitive energy transfer and analysis is based on current balance of the capacitor. The circuit in Fig. below (CUK converter) is derived from DUALITY principle on the buck-boost converter.

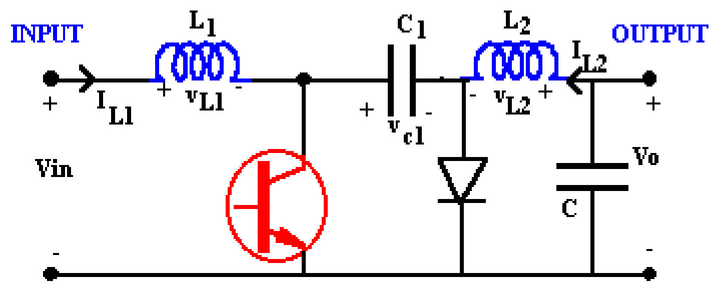


Fig 3.5.1 CUK Converter

The Ćuk converter is a type of DC-to-DC converter that, like the buck-boost converter, can produce an output voltage (V_o) that is either higher or lower than the input voltage (V_{in}). However, unlike the buck-boost converter, the Ćuk converter has a non-inverting output polarity. It also utilizes capacitive energy transfer as its primary mechanism, in addition to inductive energy storage.

Key Components:

V{in}: The input DC voltage source.

L1: Input inductor. It smooths the input current.

C1: Coupling capacitor. This is the primary energy transfer element.

Q (Transistor): The switching element (typically a MOSFET or BJT).

L2: Output inductor. It smooths the output current.

D (Diode): Allows current to flow in only one direction.

C: Output capacitor. Filters the output voltage and stores energy.

Load (Not explicitly shown but implied across (Vo): The device receiving the output power.

If we assume that the current through the inductors is essentially ripple free, we can examine the charge balance for the capacitor C1. For the transistor ON the circuit becomes.

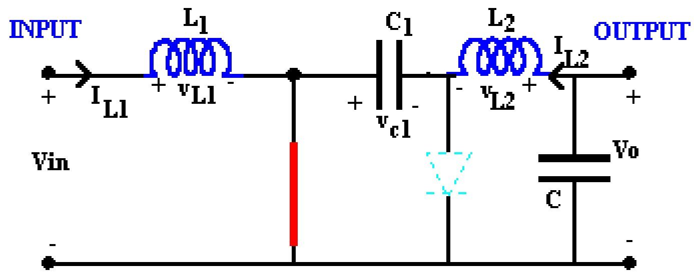


Fig 3.5.2 CUK "ON-STATE"

ON-State (Transistor Q is ON):

When the transistor Q is turned ON, it creates a short circuit between its collector (or drain) and emitter (or source).The coupling capacitor C1 is connected between the input side (approximately V{in}) and the output inductor L2 and diode D. Since the transistor is ON, the voltage across C1 (v{C1}) forces current to flow through C1, L2, and the diode D to charge the output capacitor C and supply the load. The current through L2 (i{L2}) increases linearly, storing energy in its magnetic field. \frac{di{L2}} {dt} = \frac{v{C1} - Vo} {L2}. The diode D is forward-biased during this interval, allowing current flow to the output. The current in C1 is I_{L1}. When the transistor is OFF, the diode conducts and the current in C1 becomes I_{L2}.

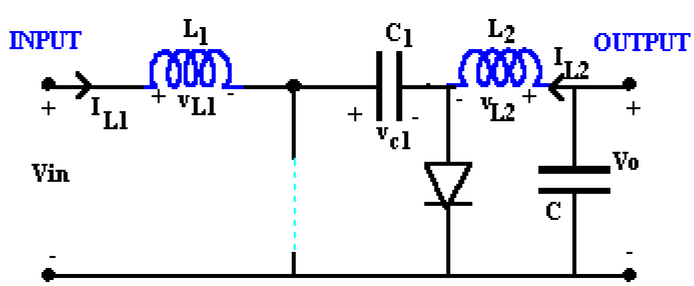


Fig 3.5.3 CUK "OFF-STATE"

OFF-State (Transistor Q is OFF):

When the transistor Q is turned OFF, the current through L1 must continue to flow. This current now flows through L1, the capacitor C1, and the diode D. This charges the capacitor C1. The voltage across C1 (v_{C1}) increases. $\frac{dv_{C1}}{dt} = \frac{i_{L1}}{C1}$.

The current through the output inductor L2 also continues to flow. This current now flows through L2, the output capacitor C, and the load. The diode D remains forward-biased. The current through L2 (i_{L2}) decreases linearly, releasing the stored energy. $\frac{di_{L2}}{dt} = \frac{-Vo}{L2}$.

During this time, the output capacitor C supplies energy to the load and is also being charged by the current through L2.

Energy Transfer Mechanism:

The Ćuk converter's primary energy transfer mechanism involves the capacitor C1. During the ON-state of the transistor, C1 is effectively connected in series with the output stage (inductor L2 and output). During the OFF-state, C1 is charged by the input source and the input inductor L1. This cyclical charging and discharging of C1 facilitates the transfer of energy from the input to the output.

Output Voltage Relationship:

In a steady state, by applying the principle of average inductor voltage being zero over one switching cycle and the average capacitor current being zero over one switching cycle, the ideal voltage gain of the Ćuk converter in continuous conduction mode (CCM) is given by:

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

where:

Vo is the average output voltage.

V{in} is the input voltage.

D is the duty cycle of the switch (the ratio of the ON-time to the total switching period).

Similar to the buck-boost converter, the output voltage can be either lower or higher than the input voltage depending on the duty cycle D. However, the output polarity is the same as the input polarity in the Ćuk converter.

Key Characteristics of the Ćuk Converter:

- Non-Inverting Output: The output voltage has the same polarity as the input voltage.
- Buck or Boost Capability: The magnitude of the output voltage can be either lower or higher than the input voltage.
- Capacitive Energy Transfer: Primarily uses a capacitor for energy transfer between the input and output stages.
- Continuous Input and Output Currents: Due to the presence of inductors on both the input and output sides, the current waveforms tend to be more continuous (lower ripple) compared to basic buck or boost converters.
- Higher Component Count: Typically requires more components than basic buck or boost converters.
- Since the steady state assumes no net capacitor voltage rise, the net current is zero.

3.6 Block Diagram Of Boost Converter

A boost converter (step-up converter) is a power converter with an output DC voltage greater than its input DC voltage. It is a class of switching-mode power supply (SMPS) containing at least two semiconductors' switches (a diodes and a transistor) and at least one energy storage element. Filters made of capacitors (sometimes in combination with induction) are normally added to the output of the converter to reduce output voltage ripple.

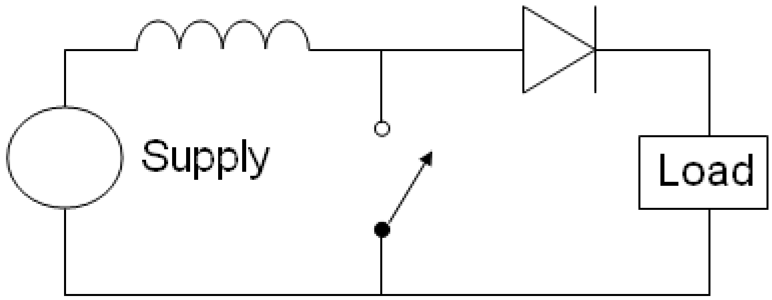


Fig 3.6.1 BOOST CONVERTER

Power can also come from DC sources such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is DC-DC Convertors with an output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it "steps up" the source voltage. Since power ($P = VI$ or $P = UI$ in Europe) must be conserved, the output current is lower than the source current.

A boost converter may also be referred to as a 'Joule thief'. This term is usually used only with very low power battery applications, and is aimed at the ability of a boost converter to 'steal' the remaining energy in a battery. This energy would otherwise be wasted since a normal load wouldn't be able to handle the battery's low voltage.

- This energy would otherwise remain untapped because in most low-frequency applications, currents will not flow through a load without a significant difference of potential between the two poles of the source (voltage).

- The voltage source provides the input DC voltage to the switch control, and to the magnetic field storage element. The switch control directs the action of the switching element, while the output rectifier and filter deliver an acceptable DC voltage to the output.

The basic building blocks of a boost converter circuit are shown in Fig.

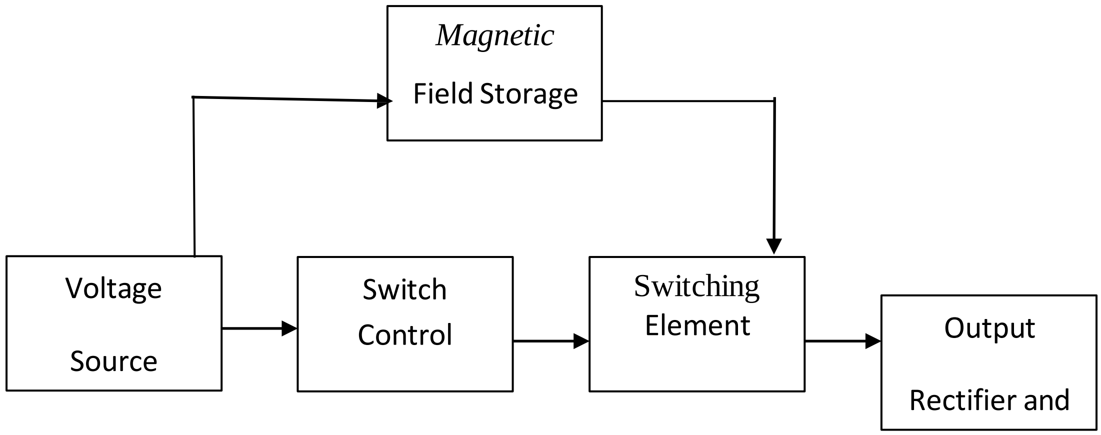


Fig.3.6.2 Block diagram Boost Converter

The voltage source provides the input DC voltage to the switch control, and to the magnetic field storage element. The switch control directs the action of the switching element, while the output rectifier and filter deliver an acceptable DC voltage to the output.

A block diagram of a Boost Converter circuit. A boost converter is a type of DC-to-DC power converter that steps up the input voltage to a higher output voltage. Let's break down the function of each block:

* Voltage Source: This is the input DC voltage that needs to be increased.

* Switch Control: This block generates the control signals that drive the switching element. Typically, this involves Pulse Width Modulation (PWM), where the duty cycle of a switching signal is varied to control the amount of energy transferred and thus the output voltage.

* Switching Element: This is typically a semiconductor switch like a MOSFET or a BJT. It rapidly turns ON and OFF based on the control signals from the "Switch Control" block. This switching action is crucial for storing and releasing energy in the magnetic field storage element.

* Magnetic Field Storage: This element is usually an inductor. When the switch is ON, the inductor stores energy in its magnetic field. When the switch is OFF, the stored energy is released, causing the voltage across the inductor to reverse polarity and add to the input voltage, resulting in a higher output voltage.

* Output Rectifier and Filter: The rectifier (usually a diode) ensures that current flows in only one direction to the output. The filter (typically a capacitor) smooths out the pulsating DC voltage from the rectifier to provide a more stable DC output voltage.

In summary, the boost converter works as follows:

* The voltage source provides the initial DC voltage.

* The switch control dictates when the switching element is ON and OFF.

* When the switch is ON, the magnetic field storage (inductor) stores energy.

* When the switch is OFF, the energy stored in the inductor is released and adds to the input voltage.

* The rectifier and filter ensure a DC output voltage that is higher than the input voltage.

Operating principle:

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. When being charged it acts as a load and absorbs energy (somewhat like a resistor), when being discharged, it acts as an energy source (somewhat like a battery). The voltage it produces during the discharge phase is related to the rate of change of current, and not to the original charging voltage, thus allowing different input and output voltages.

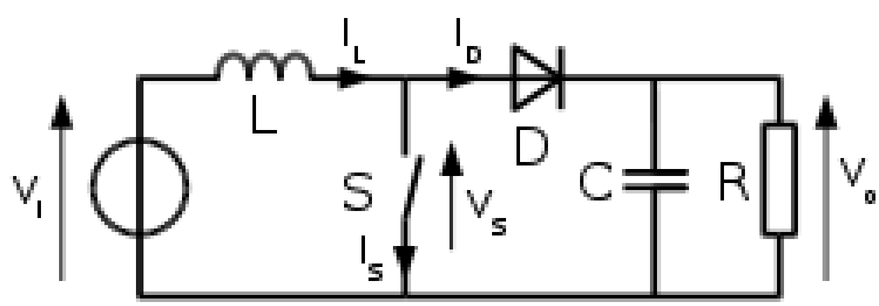


Fig 3.6.3 Boost Converter Schematic

- In the On-state, the switch S (see figure) is closed, resulting in an increase in the inductor current;
- In the Off-state, the switch is open and the only path offered to inductor current is through the flyback diode D, the capacitor C and the load R. This result in transferring the energy accumulated during the On-state into the capacitor.

The operation can be divided into two main states: the ON-state (when the switch S is closed) and the OFF-state (when the switch S is open).

1. ON-State (Switch S is closed):

* When the switch S is closed, it creates a short circuit across it, so the voltage across the switch, v_S, becomes ideally zero.

* The input voltage source, Vi, is directly connected across the inductor L.

* According to Faraday's law of induction, a voltage across an inductor causes the current through it to change. In this case, the voltage across the inductor is Vi, which is positive.

* Therefore, the current through the inductor L, starts to increase linearly with time. The rate of increase is given by:

$$\frac{diL}{dt} = \frac{Vi}{L}$$

* During this time, the diode D is reverse-biased because the voltage at its anode (connected to the inductor) is lower than the voltage at its cathode (which is held at approximately the output voltage Vo by the capacitor C).

* Since the diode is reverse-biased, it blocks current flow to the output side.

* The capacitor C provides the current to the load resistor R, and thus the capacitor discharges, causing a slight decrease in the output voltage Vo.

* The current through the switch, i_S, is equal to the inductor current, iL (iS = iL). The diode current, iD, is zero.

2. OFF-State (Switch S is open):

* When the switch S is opened, the current through the inductor iL cannot change instantaneously due to the inductor's property to resist changes in current.

* The inductor now acts as a voltage source with a polarity that opposes the change in current. The inductor's voltage adds to the input voltage Vi.

* The voltage at the anode of the diode D becomes Vi + VL, where VL is the voltage across the inductor. If Vi + VL is greater than the output voltage Vo, the diode D becomes forward-biased and starts conducting.

* The current iL now flows through the diode D to the output capacitor C and the load resistor R (iL = iD + io, where io is the output current through R).

* The inductor releases the energy stored in its magnetic field during the ON-state.

* The capacitor C is charged by the current flowing through the diode, and it also supplies current to the load resistor R. Ideally, if the inductor's energy release is sufficient, the capacitor voltage Vo will be maintained or increased.

* The current through the inductor iL decreases linearly with time during this state. The rate of decrease depends on the voltage across the inductor, which is approximately Vo - Vi (assuming the diode is ideal with zero voltage drop).

\frac{diL}{dt} = \frac{Vi - Vo}{L}

* The switch current i_S becomes zero, and the diode current iD is equal to the inductor current iL.

Continuous Operation:

For the boost converter to operate in a steady state, the energy stored in the inductor during the ON-state must be transferred to the output during the OFF-state. By controlling the duty cycle (D) of the switch (the ratio of the ON-time to the total switching period), the output voltage Vo can be made higher than the input voltage Vi.

The ideal voltage gain of a boost converter in continuous conduction mode (CCM) is given by:

$$Vo = \frac{Vi}{1 - D}$$

where:

* Vo is the average output voltage.
* Vi is the input voltage.
* D is the duty cycle of the switch ($0 < D < 1$).

As you can see from this equation, as the duty cycle D increases, the output voltage Vo also increases, always being greater than Vi.

The input current is the same as the inductor current as can be seen in figure. So it is not discontinuous as in the buck converter and the requirements on the input filter are relaxed compared to a buck converter.

CHAPTER-4

PROPOSED TOPOLOGY

4.1 Proposed Converter and Steady-State Evaluation

Cost-effectiveness, constant input current, high efficiency, low noise, and low input ripple current are among the most essential qualities of DC–DC buck–boost converters used in solar PV applications. Figure 2 presents the proposed quadratic buck–boost converter, in which three capacitors (C1, C2, Co), three inductors (L1, L2, L3), two switches (S1, S2), two diodes (D1, D2), and resistive load (Ro) are integrated to attain a high-voltage gain

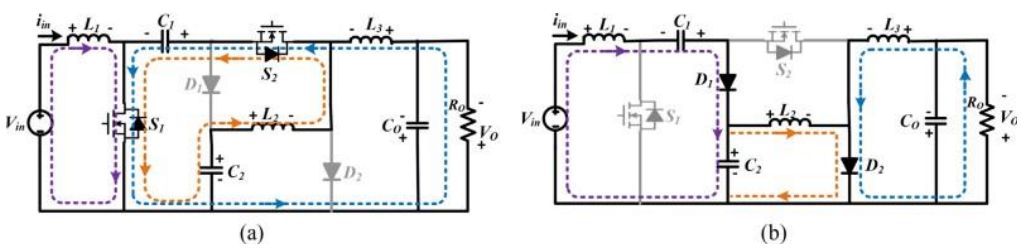


FIGURE 4.1 Operating Modes of the Proposed Converter: (a) State1; (b) State2

buck–boost converter. To simplify the steady-state analysis of the proposed converter, first, components are considered to be ideal, and second, all capacitors are considered large enough to maintain capacitor voltages nearly constant. This means that their voltage and current are assumed to be constant during a full period. The presence of inductors L1 and L3 in the input and output ports of the proposed converter can make a continuity of the input/output current. Two main operating states can be defined for the converter in the continuous conduction mode (CCM) as shown in Figure 3. State1 $[0 \leq t \leq DTs]$: This mode works when power switches S1 and S2 are ON with reverse-biased mode in two diodes D1 and D2 as shown in Figure 3a. The inductors L1, L2, L3 are energized via the capacitor C1 and input source Vin. In this state, while charging, the capacitors C1 and C2 are discharged. It is followed by a rise in currents of the inductor (iL1, iL2, iL3). The output load Ro is fed by the output capacitor Co. For this mode, the following equations can be obtained through kirchhoff 's current law (KCL) and kirchhoff 's voltage law (KVL):

$$V_{L1} = V_{in},\ V_{L2} = V_{C2} - V_{C1},\ V_{L3} = -V_o - V_{C1}$$
$$i_{C1} = i_{L2} + i_{L3},\ i_{C2} = -i_{L2},\ i_{Co} = i_{L3} - \frac{V_o}{R_o}$$

State2 [DTs ≤ t ≤ Ts]: This mode works with power switches turned off, and the two diodes D1 and D2 are in conduction mode as shown in Figure 3b. The inductors L1, L2, and L3 are demagnetized. In this state, the capacitor C2 is charged and the capacitor C1 is discharged. Besides, the output load Ro is fed by inductor L3. It also charges Co. Energy is discharged from capacitor C1 by the current path of D1 and D2 diodes, leading to a rise in the inductors' currents. In this mode, the following current and voltage equations are obtained through the KCL and KVL:

$$V_{L1} = V_{in} + V_{C1} - V_{C2},\ V_{L2} = V_{C2},\ V_{L3} = -V_o$$
$$i_{C1} = -i_{L1},\ i_{C2} = i_{L1} - i_{L2},\ i_{Co} = i_{L3} - \frac{V_o}{R_o}$$

The inductors and capacitor charge and discharge waveforms are presented in Figure 4.

4.2 Calculation of A Capacitor Voltage and Voltage Gain Ratio

According to Figure 3, the voltage values and gain ratios of the proposed converter can be obtained. The average voltage values of all capacitors are calculated based on the voltage–second balance principle of inductors L1, L2, and L3 during the charge–discharge periods. Thus, assuming D to be the duty cycle, the average voltages of capacitor C1 and C2 is shown as follows:

$$V_{C1} = -\frac{1}{(1-D)^2}V_{in},\ V_{C2} = -\frac{D}{(1-D)^2}V_{in}$$

Accordingly, the transfer function of the DC voltage (MCCM) of the proposed converter can be expressed as

$$M_{CCM} = \left(\frac{V_o}{V_{in}}\right) = \frac{D}{(1-D)^2}$$

4.3 Calculation of Current Gain and Inductor Currents

The assumption a lossless system, the converter input power is equal to output power as follows:

$$P_o = P_{in} \Rightarrow V_o I_o = V_{in} I_{in}$$

Hence the current gain of the converter can be obtained as

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

Next, the ampere–second balance principle of capacitors C1, C2, and Co is used to calculate the mean current value of all inductor currents. Therefore, IL1, IL2, and IL3 currents will be equal t

$$I_{L1} = \frac{D}{(1-D)^2} I_o,\ I_{L2} = \frac{D}{(1-D)} I_o,\ I_{L3} = I_o$$

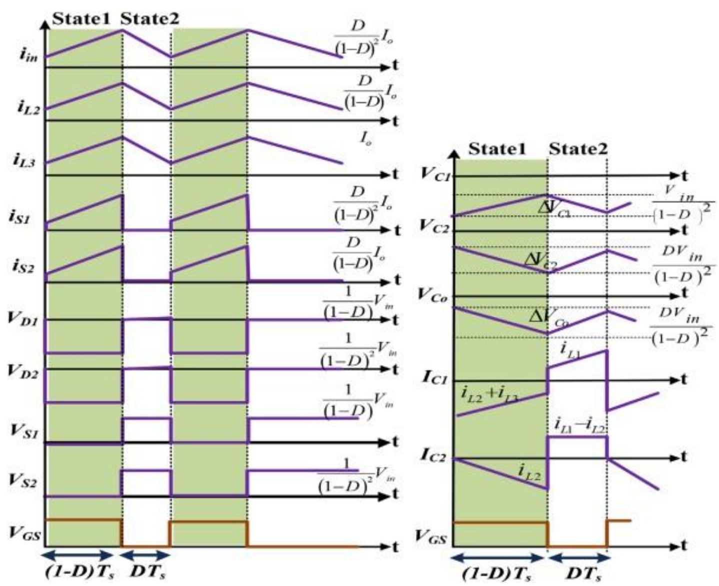


FIGURE 4.3 Switching Sequence and Sample Time-Domain Waveforms

4.4 Electrical Stress on Semiconductor Components

For power switches, S1 and S2, the voltage and average current stresses are calculated in both on- and off-state of operation as follows:

$$V_{S1} = \frac{1}{(1-D)}V_{in},\ V_{S2} = \frac{1}{(1-D)^2}V_{in}$$

$$I_{S1-avg} = \frac{D}{(1-D)^2}\left|I_o\right|,\ I_{S2-avg} = \frac{D}{1-D}\left|I_o\right|$$

Furthermore, the voltage and average current stresses of each diode are calculated as follows:

$$V_{D1} = \frac{1}{(1-D)}V_{in},\ V_{D2} = \frac{1}{(1-D)^2}V_{in}$$

$$I_{D1-avg} = \frac{D}{(1-D)}\left|I_o\right|,\ I_{D2-avg} = \left|I_o\right|$$

4.5 Efficiency Calculation

In this part, the number of losses of each circuit component is considered according to the circuit shown in Figure 5. First, the RMS values of the current passing through the power switches in the circuit and the diodes are obtained using

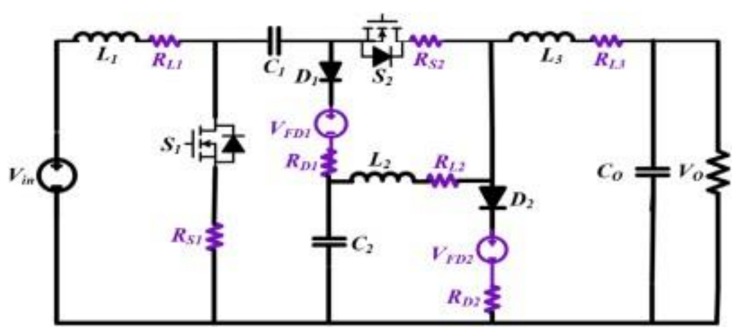


FIGURE 4.5 Simplified Buck–Boost Converter Circuit with Parasitic Parameters

Equations (9) and (11) as follows:

$$I_{S1-rms} \approx \frac{\sqrt{D}}{(1-D)^2}\,|I_o|\,,\; I_{S2-rms} \approx \frac{\sqrt{D}}{(1-D)}\,|I_o|$$
$$I_{D1-rms} \approx \frac{D}{\sqrt{(1-D)^3}}\,|I_o|\,,\; I_{D2-rms} \approx \frac{1}{\sqrt{(1-D)}}\,|I_o|$$

Also, the RMS values of inductor and capacitor currents of the circuit are calculated as follows:

$$I_{L1-rms} \approx \frac{D}{(1-D)^2}\,|I_o|\,,\; I_{L2-rms} \approx \frac{D}{(1-D)}\,|I_o|\,,\; I_{L3-rms} \approx |I_o|$$

$$I_{C1-rms} \approx \frac{\sqrt{D}}{(1-D)^{3/2}} I_o,\; I_{C2-rms} \approx \sqrt{\frac{D^3}{(1-D)^3}}\, I_o,\; I_{Co-rms} \approx 0$$

By defining the total of power switches (PS1, 2) as the sum of the switching losses (PS-L) and conducting power dissipations (PR-DS), the toff and RDS values represent the turn-off delay time of the power switch and conduction resistance. Thus,

$$P_{S1,2-Total} = P_{R-DS} + P_{S-L} + P_{S-off}$$

where

$$\begin{cases} P_{R-DS1} = R_{DS1} I^2{}_{S1-rms} = R_{DS1} \dfrac{D^3}{(1-D)^4} I_o^2 \\ P_{R-DS2} = R_{DS2} I^2{}_{S2-rms} = R_{DS2} \dfrac{D}{(1-D)^2} I_o^2 \\ P_{S-L1} = f_S C_{S1} {V_{S1}}^2 = f_S C_{S1} \dfrac{1}{(1-D)^2} {V_{in}}^2 \\ P_{S-L2} = f_S C_{S2} {V_{S2}}^2 = f_S C_{S2} \dfrac{1}{(1-D)^4} {V_{in}}^2 \\ P_{S1,2-off} = \dfrac{1}{2} I_{S1,2} V_{S1,2} t_{off} f_S \end{cases}$$

Moreover, the overall losses of the diodes may be computed as the sum of the forward bias losses (PFD (and the reverse bias losses (PFR) by considering RFD being the forward conduction resistance of the diode and VFD as its forward bias voltage as follows:

$$P_{D-Total} = P_{FD} + P_{FR} = \sum_{i=1}^{i=2} (R_{FD} I_{Di-rms}^2) + \sum_{i=1}^{i=2} (V_{FDi} I_{Di})$$

The inductor losses are categorized into two sections: the copper loss and the core loss. It is possible to acquire the core loss of the inductors as follows:

$$P_{L-Core} = P_{L-Core1} + P_{L-Core2} + P_{L-Core3}$$

$$P_{L-Core} = a_1 B_1^b f_1^c l_{m1} A_{C1} + a_2 B_2^b f_2^c l_{m2} A_{C2} + a_3 B_3^b f_3^c l_{m3} A_{C3}$$

where α, b, and c parameters can be acquired from the datasheets. B, f, Ac, and lm represent half the AC flux, the frequency, the area of the core, and the core's magnetic path length. Given RL and RC, the following relation can be used for calculating equivalent series resistance values of capacitors, inductors. The copper loss and total losses of inductor and capacitor are defined by

$$P_{L-Copper} = \sum_{i=1}^{i=3} (P_{Li}) = \sum_{i=1}^{i=3} (R_{Li} I_{Li-rms}^2)$$

$$P_{L-Total} = P_{L-Core} + P_{L-Copper}$$

$$P_{C-Total} = \sum_{i=1}^{i=3} (P_{Ci}) = \sum_{i=1}^{i=3} (R_{Ci} I_{Ci-rms}^2)$$

4.6 Simplified Circuit with Parasitic Parameters

Figure 5 represents the simplified circuit with parasitic parameters, including the MOSFETs (S1, S2), the diodes (D1, D2), and the inductors (L1, L2, L3), respectively. VFD1 and VFD2 are diodes' threshold voltage. Then, the inductor voltage equations with parasitic parameters (RS1, RS2, RD1, RD2, RL1, RL2, RL3) can be obtained as follows:

State1:

$$
\begin{aligned}
V_{L1} &= V_{in} - R_{L1}I_{L1} - R_{S1}I_{S1} \\
&= V_{in} - R_{L1}\frac{D^2}{(1-D)^4}\frac{V_{in}}{R_o} - R_{S1}\frac{D^2}{(1-D)^4}\frac{V_{in}}{R_o} \\
V_{L2} &= -R_{L2}I_{L2} - R_{S2}I_{S2} - R_{S1}I_{S1} - V_{C1} + V_{C2} \\
&= -R_{L2}\frac{D^2}{(1-D)^3}\frac{V_{in}}{R_o} - R_{S2}\frac{D^2}{(1-D)^3}\frac{V_{in}}{R_o} \\
&\quad - R_{S1}\frac{D^2}{(1-D)^4}\frac{V_{in}}{R_o} - V_{C1} + V_{C2} \\
V_{L3} &= -R_{L3}I_{L3} - R_{S2}I_{S2} - R_{S1}I_{S1} - V_{C1} - V_o \\
&= -R_{L3}\frac{D}{(1-D)^2}\frac{V_{in}}{R_o} - R_{S2}\frac{D^2}{(1-D)^3}\frac{V_{in}}{R_o} \\
&\quad - R_{S1}\frac{D^2}{(1-D)^4}\frac{V_{in}}{R_o} - V_{C1} + V_{Co}
\end{aligned}
$$

State2:

$$
\begin{aligned}
V_{L1} &= V_{in} - R_{L1}I_{L1} - R_{D1}I_{D1} - V_{FD1} + V_{C1} - V_{C2} \\
&= V_{in} - R_{L1}\frac{D^2}{(1-D)^4}\frac{V_{in}}{R_o} - R_{D1}\frac{D^2}{(1-D)^3}\frac{V_{in}}{R_o} - V_{FD1} \\
&\quad + V_{C1} - V_{C2} \\
V_{L2} &= -R_{L2}I_{L2} - R_{D2}I_{D2} - V_{FD2} + V_{C2} \\
&= -R_{L2}\frac{D^2}{(1-D)^4}\frac{V_{in}}{R_o} - R_{D2}\frac{D}{(1-D)^2}\frac{V_{in}}{R_o} - V_{FD2} + V_{C2} \\
V_{L3} &= -R_{L3}I_{L3} - R_{D2}I_{D2} - V_{FD2} - V_o \\
&= -R_{L3}\frac{D}{(1-D)^2}\frac{V_{in}}{R_o} - R_{D2}\frac{D}{(1-D)^2}\frac{V_{in}}{R_o} - V_{FD2} + V_o
\end{aligned}
$$

The voltage across the charge pump capacitor C1 and C2 with parasitic parameters are obtained using the voltage–second balance principle on the inductors L1, L2, and L3, as follows: proposed converter in the step-up mode, whereas the input port current is lower than the output port current in the step-down mode. Thus, the step-down mode has a lower overall efficiency

$$
V_{C1} = \frac{\begin{gathered} D^2R_{L1}V_{in} + D^2(1-D)^2R_{L2}V_{in} + D^4R_{S1}V_{in} + D^3(1-D)^3R_{S2}V_{in} \\ + D^2(1-D)^2R_{D1}V_{in} + D(1-D)^4R_{D2}V_{in} + (1-D)^5R_oV_{FD1} + (1-D)^6R_oV_{FD2} - (1-D)^4R_oV_{in} \end{gathered}}{(1-D)^6R_o}
$$

$$
V_{C2} = \frac{\begin{gathered} D^3R_{L1}V_{in} + D^2(1-D)^2R_{L2}V_{in} - D^3(1-2D)R_{S1}V_{in} + D^3(1-D)^2R_{S2}V_{in} \\ + D^3(1-D)^2R_{D1}V_{in} + D(1-D)^4R_{D2}V_{in} + D(1-D)^5R_oV_{FD1} + (1-D)^6R_oV_{FD2} - D(1-D)^4R_oV_{in} \end{gathered}}{(1-D)^6R_o}
$$

DUTY CYCLE CALCULATION

For attaining the desired output voltage at the given input voltage, it is possible to obtain duty cycle D from Equation (4) as

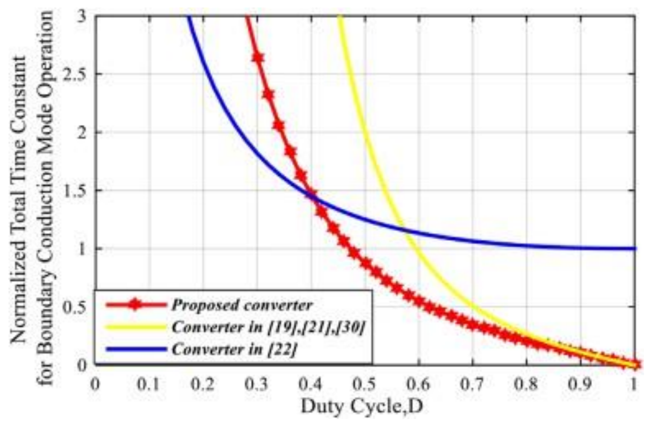


FIGURE 4.6 Normalized Total Time Constant For Boundary Conduction Mode Operation

4.7 Small-Signal Modelling

A small-signal model is used to dynamically analyze the proposed converter [34]. According to Figures 3a and 3b, the equations of the dual modes can be achieved as follows:

$$\text{State1}: \begin{cases} L_1 \dfrac{di_{L1}}{dt} = v_{in}, L_2 \dfrac{di_{L2}}{dt} = -v_{C_1} + v_{C_2}, L_3 \dfrac{di_{L3}}{dt} = -v_{C_1} - v_o \\ C_1 \dfrac{dv_{C1}}{dt} = i_{L_2} + i_{L_3}, C_2 \dfrac{dv_{C2}}{dt} = -i_{L_2}, C_o \dfrac{dv_o}{dt} = -\dfrac{v_o}{R_o} + i_{L_3} \end{cases}$$

$$\text{State2}: \begin{cases} L_1 \dfrac{di_{L1}}{dt} = v_{in} + v_{C_1} - v_{C_2}, L_2 \dfrac{di_{L2}}{dt} = v_{C_2}, L_3 \dfrac{di_{L3}}{dt} = -v_o \\ C_1 \dfrac{dv_{C1}}{dt} = -i_{L_1}, C_2 \dfrac{dv_{C2}}{dt} = i_{L_1} - i_{L_2}, C_o \dfrac{dv_o}{dt} = i_{L_3} - \dfrac{v_o}{R_o} \end{cases}$$

Using the average method and Equations (41), the average model of the intended converter is derived as follows:

$$L_1\frac{d\langle i_{L1}\rangle}{dt} = d(\langle v_{in}\rangle) + (1-d)(\langle v_{in}\rangle + \langle v_{C1}\rangle - \langle v_{C2}\rangle)$$

$$L_2\frac{d\langle i_{L2}\rangle}{dt} = d(\langle -v_{C1} + v_{C2}\rangle) + (1-d)\langle v_{C2}\rangle$$

$$L_3\frac{d\langle i_{L3}\rangle}{dt} = d(\langle -v_{C1} - v_o\rangle) + (1-d)\langle -v_o\rangle$$

$$C_1\frac{d\langle v_{C1}\rangle}{dt} = d(\langle i_{L2}\rangle + \langle i_{L3}\rangle) + (1-d)\langle -i_{L1}\rangle$$

$$C_2\frac{d\langle v_{C2}\rangle}{dt} = d(\langle -i_{L2}\rangle) + (1-d)\langle i_{L1} - i_{L2}\rangle$$

$$C_o\frac{d\langle v_o\rangle}{dt} = d\left(\left\langle -\frac{v_o}{R_o}\right\rangle + \langle i_{L3}\rangle\right) + (1-d)\left(\langle i_{L3}\rangle - \left\langle \frac{v_o}{R_o}\right\rangle\right)$$

where ⟨iL1⟩, ⟨iL2⟩, ⟨iL3⟩, ⟨vC1⟩, ⟨vC2⟩, ⟨vo⟩, and ⟨vin⟩ are the average values of iL1, iL2, iL3, vc1, vc2, vo, and vin, respectively. Also, d is the duty cycle. For obtaining the small-signal model, small AC values of the mentioned elements are defined as ∧ iL1, ∧ iL2, ∧ iL3, ∧ vC1, ∧ vC2, ∧ vo, ∧ vin, and ∧ d . In addition, the relationships among mean, DC, and AC values can be achieved as follows:

$$\begin{cases} \langle v_{in}\rangle = V_{in} + \hat{v}_{in} \\ \langle v_{C1}\rangle = V_{C1} + \hat{v}_{C1} \\ \langle v_{C2}\rangle = V_{C2} + \hat{v}_{C2} \\ \langle v_o\rangle = V_o + \hat{v}_o \\ \langle i_{L1}\rangle = I_{L1} + \hat{i}_{L1} \\ \langle i_{L2}\rangle = I_{L2} + \hat{i}_{L2} \\ \langle i_{L3}\rangle = I_{L3} + \hat{i}_{L3} \\ \langle d\rangle = D + \hat{d} \end{cases} \quad \begin{cases} |\hat{v}_{in}| \ll |V_{in}| \\ |\hat{v}_{C1}| \ll |V_{C1}| \\ |\hat{v}_{C2}| \ll |V_{C2}| \\ |\hat{v}_o| \ll |V_o| \\ |\hat{i}_{L1}| \ll |I_{L1}| \\ |\hat{i}_{L2}| \ll |I_{L2}| \\ |\hat{i}_{L3}| \ll |I_{L3}| \\ |\hat{d}| \ll |D| \end{cases}$$

By substituting (44) into (43) and (42) to extract DC and AC values and omitting the higher order small-signal terms, we will have the following. Also, the state-space form of equations can be achieved as follows:

$$Kx^{\bullet} = Ax + Bu, y = Cx + Eu$$

with

$$x = \begin{bmatrix} \hat{i}_{L1} & \hat{i}_{L2} & \hat{i}_{L3} & \hat{v}_{C1} & \hat{v}_{C2} & \hat{v}_{o} \end{bmatrix}^T, u = \begin{bmatrix} \hat{d} & \hat{v}_{in} \end{bmatrix}^T$$

$$K = \begin{bmatrix} L_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & L_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & L_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & C_1 & 0 & 0 \\ 0 & 0 & 0 & 0 & C_2 & 0 \\ 0 & 0 & 0 & 0 & 0 & C_o \end{bmatrix}$$

$$A = \begin{bmatrix} 0 & 0 & 0 & 1-D & -(1-D) & 0 \\ 0 & 0 & 0 & -D & 1 & 0 \\ 0 & 0 & 0 & -D & 0 & -1 \\ -(1-D) & D & D & 0 & 0 & 0 \\ 1-D & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & -\frac{1}{R_o} \end{bmatrix},$$

$$B = \begin{bmatrix} V_{C2} - V_{C1} & 1 \\ -V_{C1} & 0 \\ -V_{C1} & 0 \\ I_{L1} + I_{L2} + I_{L3} & 0 \\ -I_{L1} & 0 \\ 0 & 0 \end{bmatrix}$$

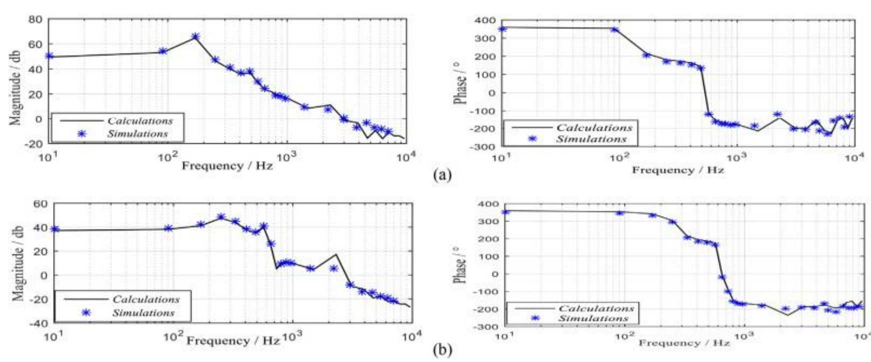


FIGURE 4.7.1 PLECS simulation and control-to-output transfer functions frequency response of small-signal modelling: (a) step-up mode, (b) step-down mode

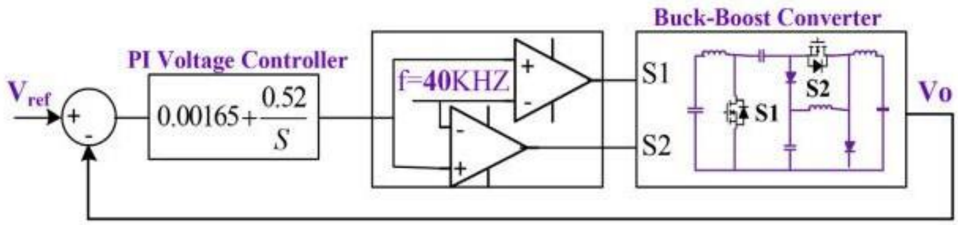


FIGURE 4.7.2 Structure of control system for the proposed converter

CHAPTER-5

ADVANTAGES OF THE PROPOSED CONVERTER

The properties of the proposed converter and other DC–DC buck–boost converters. According to this table, the number of semiconductor elements, voltage gain ratio, SDPavg/Po, switches voltage stress, diodes voltage stress, capacitors voltage stress, output polarity, common ground, continuous input/output current, and experimental results for other buck– boost converters and proposed quadratic converter are investigated. Moreover, the supremacy of the proposed converter can be categorized as shown in the following section.

5.1 High-Voltage Gain Ratio

The intended converter provides a higher voltage gain for $D > 0.5$ in comparison with similar converters. It compares the ratios of voltage gain following the information presented in Table 1, providing data on the proposed converter and other competitor converters. The horizontal axis in this figure represents the duty cycle, which has been adjusted between 10% and 80%. The vertical axis shows the output voltage ranging from 0 to 20 V.

TABLE 5.1 A comparison of the proposed converter with the similar converter in step-up/down mode

Topology		Proposed	IN [30]	IN [29]	IN [28]	IN [22]	IN [21]	IN [19]	Conventional CUK
Switch, diode		2, 2	2, 2	2,4	1,2	1, 2	2, 2	1, 5	1, 1
Capacitor, inductor		3, 3	3, 3	2,2	4,3	4, 3	3, 3	3, 3	2, 2
Number of elements		**10**	**10**	**10**	**10**	**10**	**10**	**12**	**6**
Voltage gain		$\frac{D}{(1-D)^2}$	$\left(\frac{D}{1-D}\right)^2$	$\frac{D}{(1-D)^2}$	$\frac{2D}{1-D}$	$\frac{2D}{1-D}$	$\left(\frac{D}{1-D}\right)^2$	$\left(\frac{D}{1-D}\right)^2$	$\frac{D}{1-D}$
Norm. SDP_{avg}/P_o		$\frac{1+D}{D(1-D)}$	$\frac{1+D}{D(1-D)}$	$\frac{2D^3-D^2+1}{D(1-D)^2}$	$\frac{1}{D(1-D)}$	–	$\frac{2}{D(1-D)}$	$\frac{6D^2-8D+4}{D(1-D)^2}$	–
Switch voltage stress (V_S/V_{in})	S_1, S_2	$\frac{1}{1-D}$ $\frac{1}{(1-D)^2}$	$\frac{1}{1-D}$ $\frac{D}{(1-D)^2}$	$\frac{2D^2-2D+1}{(1-D)^2}$ $\frac{D}{(1-D)^2}$	$\frac{1}{1-D}$	$\frac{1}{1-D}$	$\frac{1}{(1-D)^2}$ $\frac{D}{(1-D)^2}$	$\frac{1}{(1-D)^2}$	$\frac{1}{1-D}$
Diode voltage stress (V_D/V_{in})	D_1, D_2, D_3, D_4, D_5	$\frac{1}{1-D}$ $\frac{1}{(1-D)^2}$	$\frac{1}{1-D}$ $\frac{D}{(1-D)^2}$	1 $\frac{1}{(1-D)^2}$ $\frac{D}{(1-D)^2}$ $\frac{1}{1-D}$	$\frac{1}{1-D}$ $\frac{1}{1-D}$	$\frac{1}{1-D}$ $\frac{1}{1-D}$	$\frac{1}{1-D}$ $\frac{D}{(1-D)^2}$	$\frac{1}{1-D}$ $\frac{D}{(1-D)^2}$ $\frac{1}{(1-D)^2}$ $\frac{1}{1-D}$ $\frac{D}{(1-D)^2}$	$\frac{1}{1-D}$
Voltage stress on capacitors (V_C/V_{in})	C_1, C_2, C_3	$\frac{1}{(1-D)^2}$ $\frac{D}{(1-D)^2}$	$\frac{1}{1-D}$ $\frac{D}{(1-D)^2}$	$\frac{D}{1-D}$	$\frac{2D}{1-D}$ $\frac{D}{1-D}$ $\frac{D}{1-D}$	1 $\frac{D}{1-D}$ $\frac{D}{1-D}$	$\frac{1}{1-D}$ $\frac{D}{(1-D)^2}$	$\frac{1}{1-D}$ $\frac{D}{(1-D)^2}$	$\frac{1}{1-D}$ $\frac{1}{1-D}$
Output polarity		Negative	Positive	Positive	Positive	Positive	Positive	Negative	Negative
Common ground		YES	YES	NO	YES	NO	YES	YES	YES
Continuous input/output current		YES/YES	YES/YES	YES/NO	NO/YES	YES/YES	YES/YES	YES/YES	YES/YES
If $V_o/V_{in}=1$		$D=0.38$	$D=0.5$	$D=0.38$	$D=0.33$	$D=0.33$	$D=0.5$	$D=0.5$	$D=0.5$

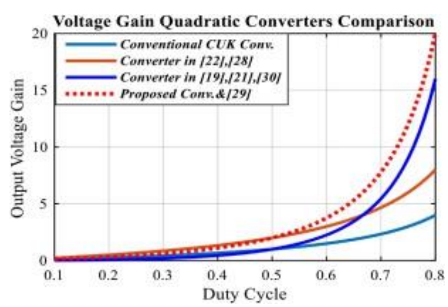


FIGURE 5.1; Comparison of voltage gain ratios and duty cycles of the proposed converter with other converters

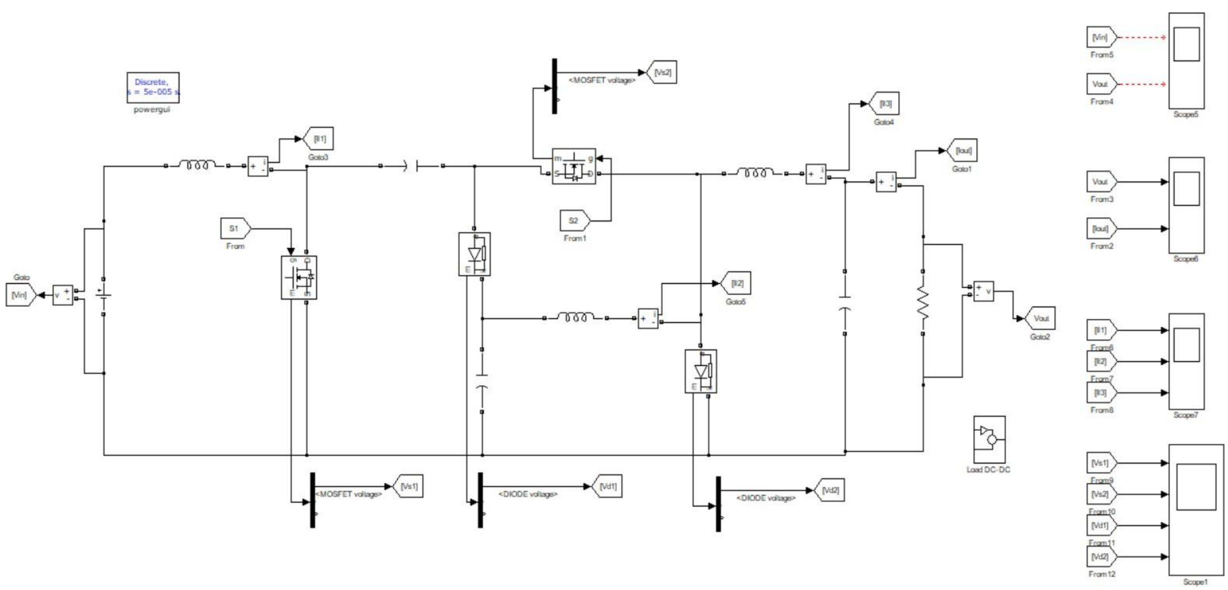
CHAPTER-6

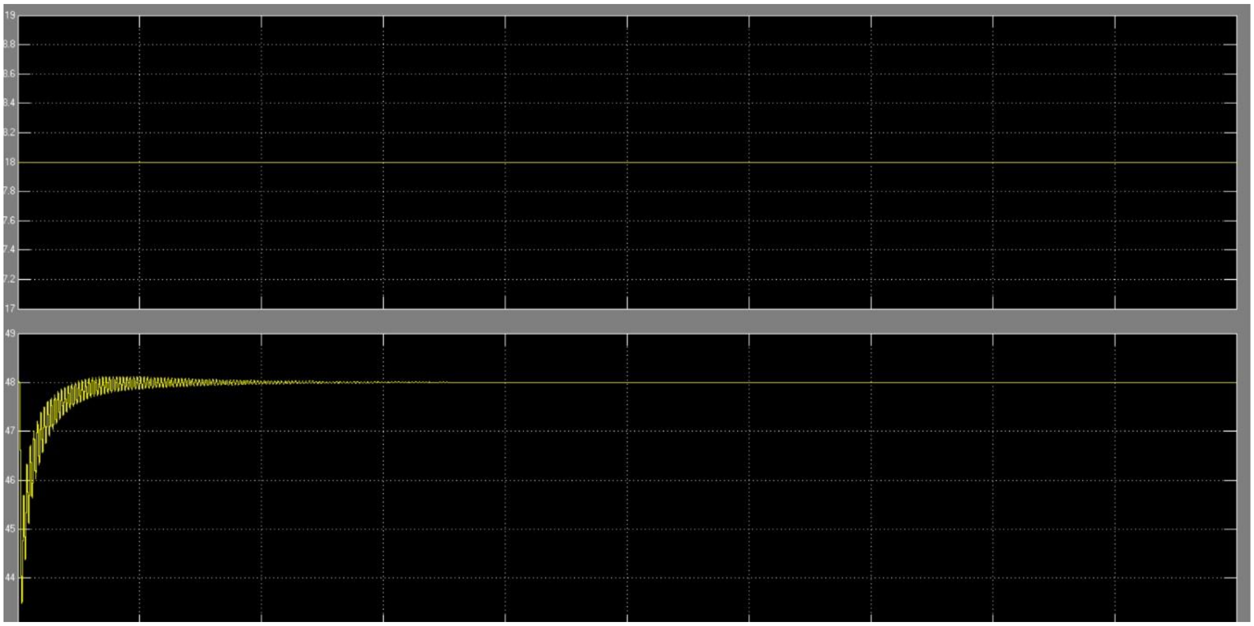
DESIGN AND SIMULATION RESULTS

6.1 Introduction

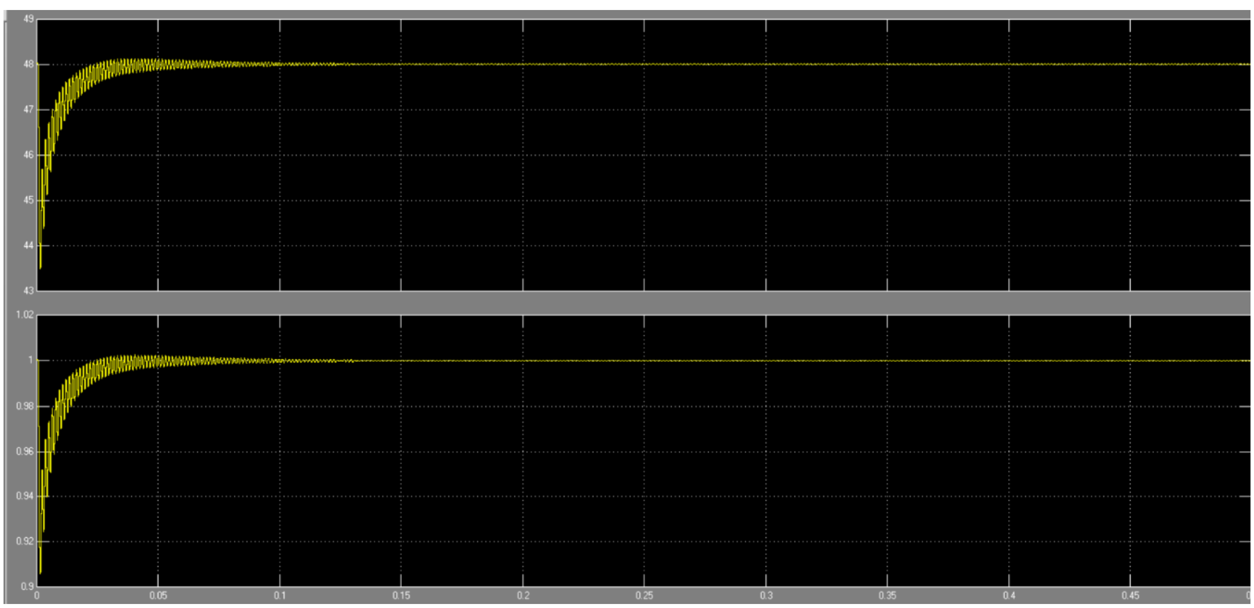
A DC-to-DC converter is a device that accepts a DC input voltage and produces a DC output voltage. Typically, the output produced is at a different voltage level than the input. In addition, DC-to-DC converters are used to provide noise isolation, power bus regulation, etc.

6.2 Design and Simulation Results of Boost Converter

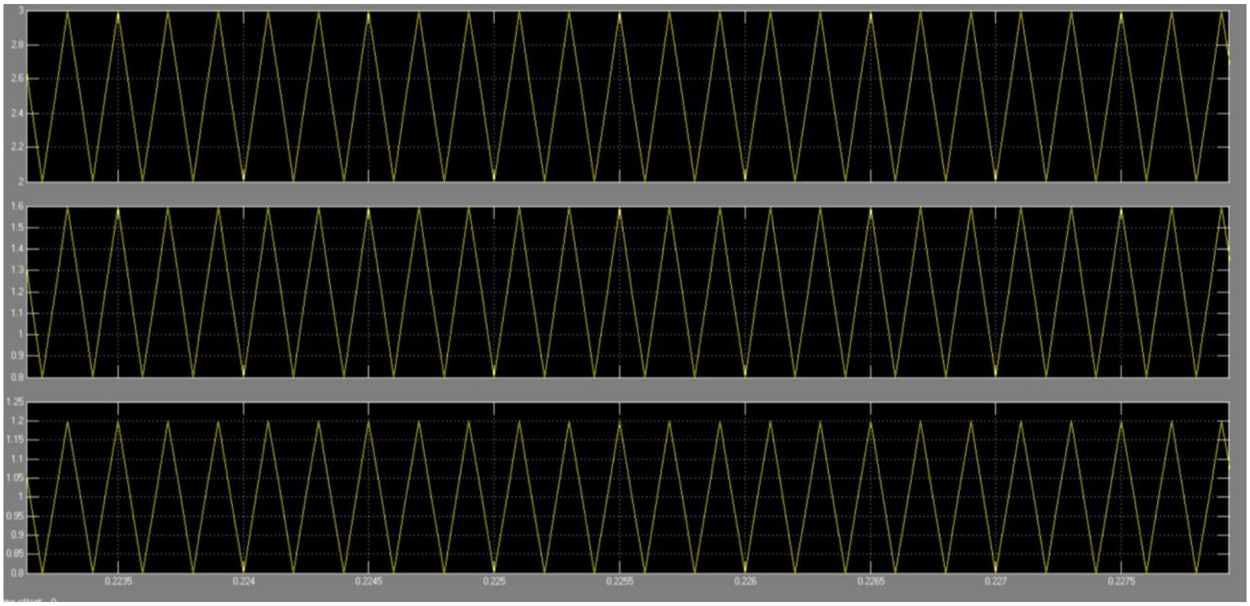




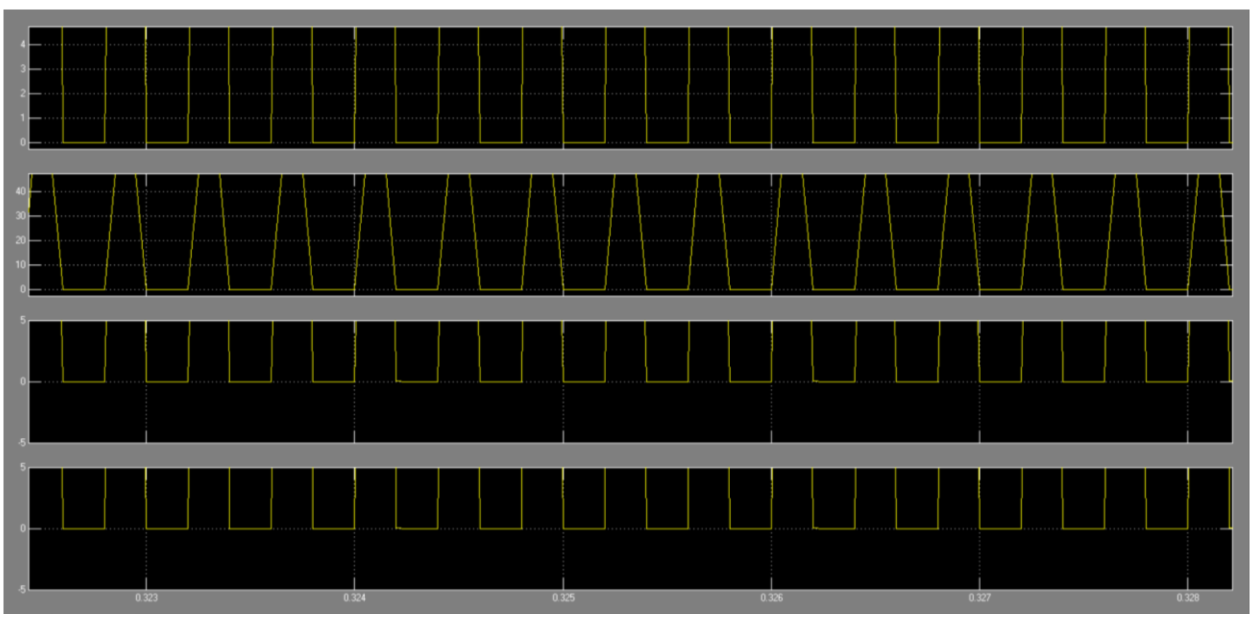
Voltage Graph(X-Axis=T Y-Axis=V)



Current Graph(X-Axis=T Y-Axis=I)

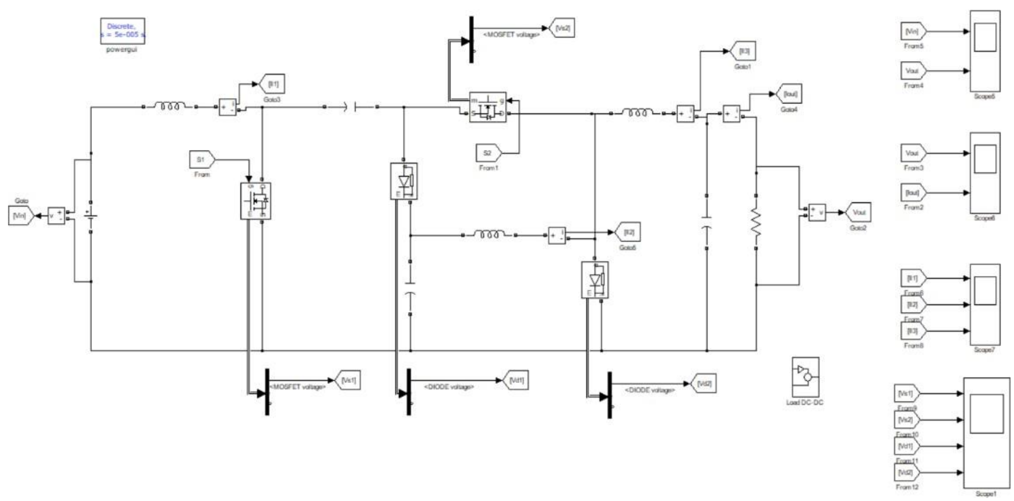


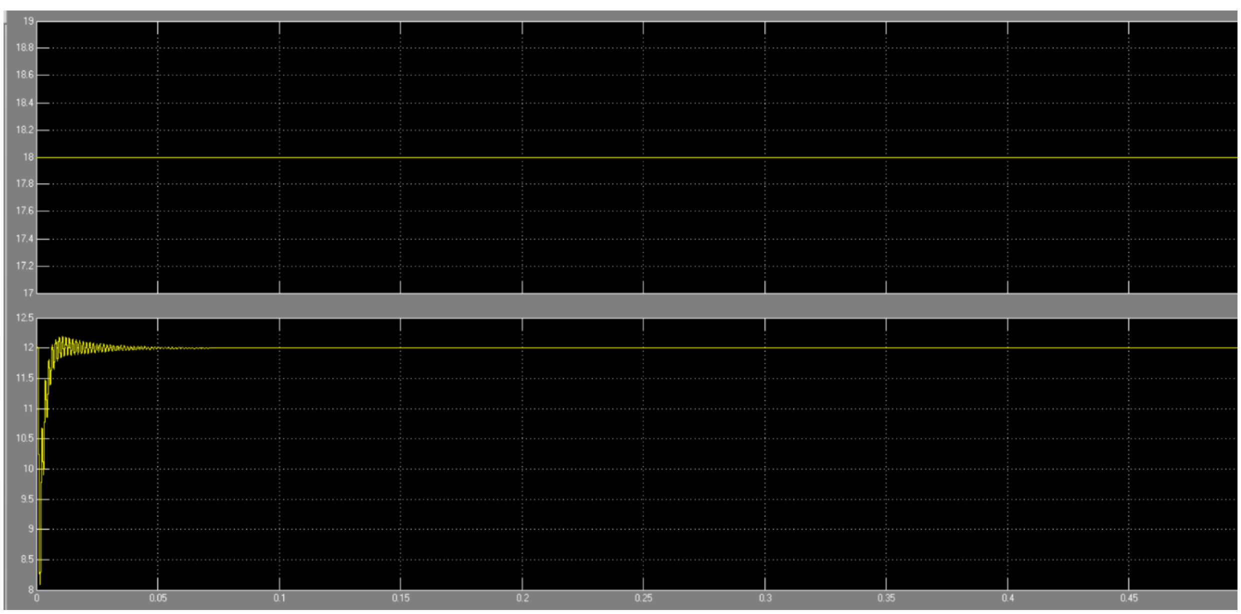
Inductor Graph(X-Axis=T Y-Axis=V_{in})



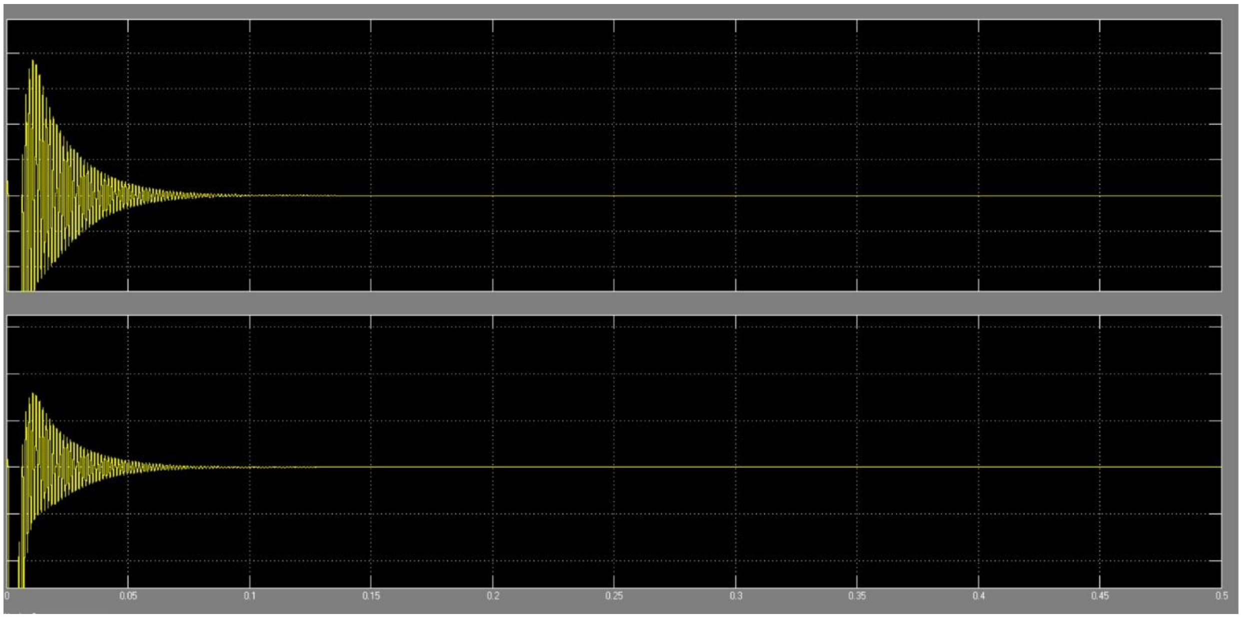
Switching Current (X-Axis=T Y-Axis=V)

6.3 Design and Simulation Results of Buck Converter

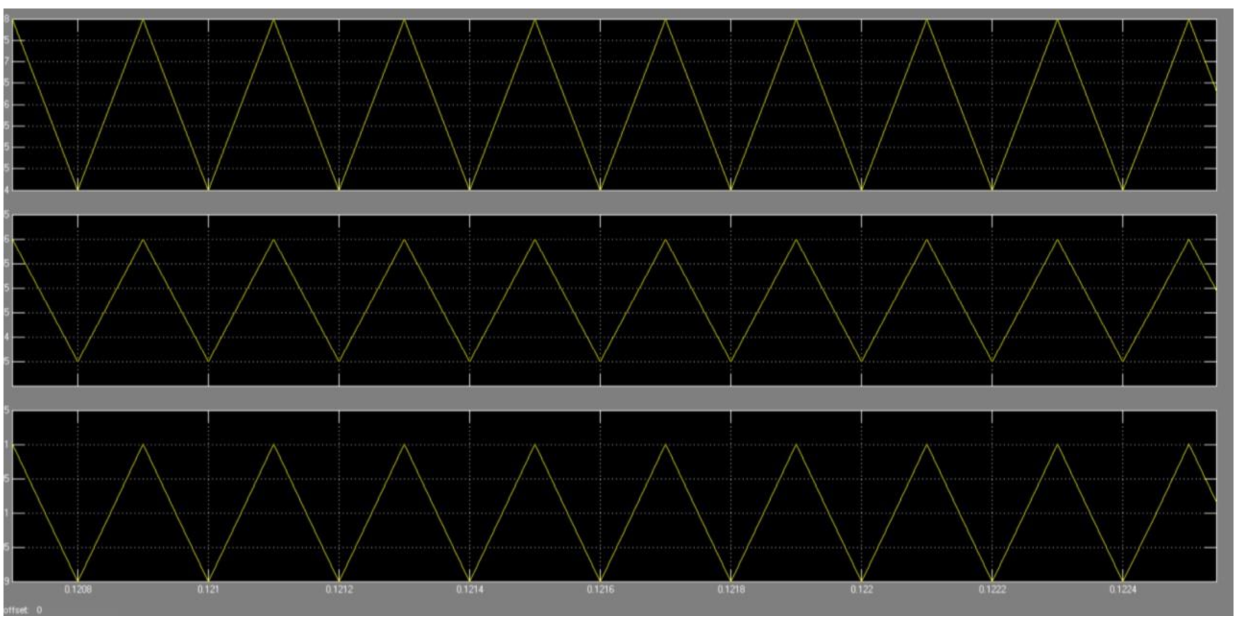




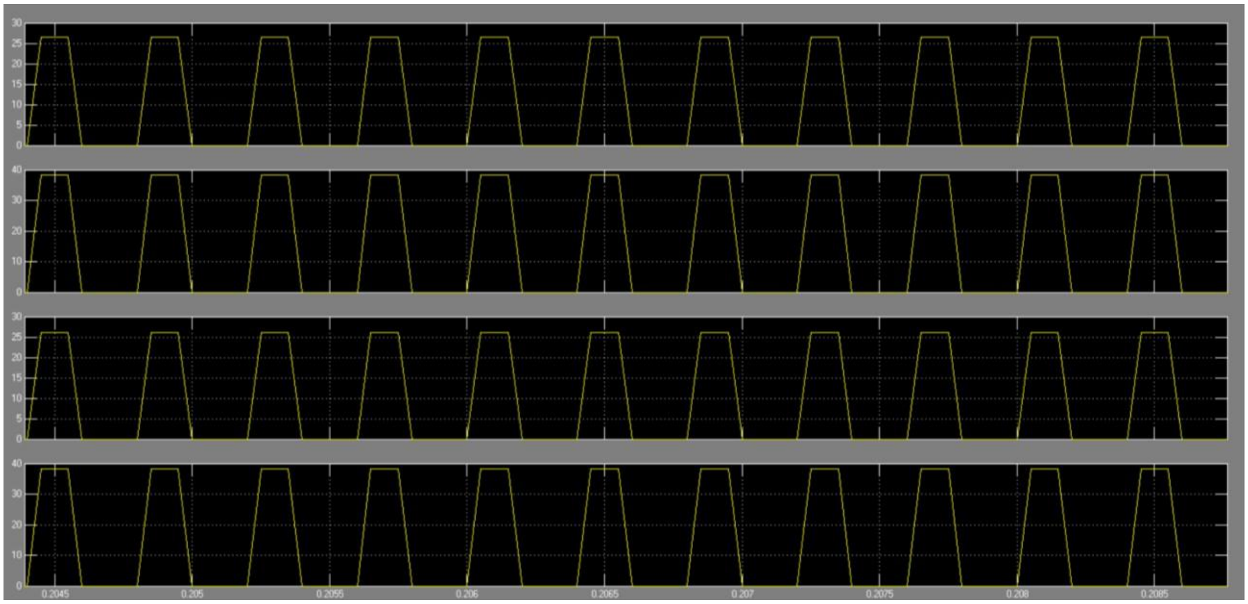
Voltage Graph(X-Axis=T Y-Axis=V)



Current Graph(X-Axis=T Y-Axis=I)



Inductor Graph(X-Axis=T Y-Axis=V_{in})



Switching Current (X-Axis=T Y-Axis=V)

CHAPTER-7

CONCLUSION

This paper demonstrated a new DC/DC converter based on a conventional CUK converter with the following features: (i) inherently continuous input/output currents that reduce the input/output ripple and also EMI problems; (ii) provide N/O polarity; (iii) a transformerless quadratic buck–boost converter, which work over a wide voltage range with a minimal variation of duty cycle. The performance comparisons of the proposed converter with related converters in terms of SDP, the total time constant of the inductive components, voltage gain ratio, and power losses are analysed. The proposed converter has a greater voltage gain ratio, small SDP, and high efficiency compared to other similar quadratic converters. Moreover, as a result of the input/output current's continuous characteristic in the proposed converter, it is an appropriate alternative for photovoltaic applications, multi-function power supply, audio amplifiers, signal generators, and data transmission interfaces in applications needing a negative voltage source. Validation the performance of the proposed converter, experiments are conducted in the laboratory to claim the theoretical waveforms obtained from the piecewise linear electrical circuit simulation (PLECS) simulation.

CHAPTER-8

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