EC5051- POWER ELECTRONICS AND DESIGN

DESIGN TASK

BOOST CONVERTER

By:

Group EG19

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ABSTRACT

This report discusses designing and implementing a boost converter in power electronic circuits. It raises the voltage from a low level to a high level and amplifies the power with the minimum possible efficiency.

The design focuses on reaching high efficiency, reliability, and low cost in applications for renewable energy systems, electrified transportation, and portable electronics. The design would consider choosing appropriate components, the inductor, switch, diode, and capacitor, with a control strategy implemented to set the output voltage.

Key design parameters, such as duty cycle, switching frequency, and component ratings are calculated and optimized in the design process the duty cycle, switching frequency, and component ratings.

Simulation and experimental results are provided to validate the theoretical analysis and show the performance of the designed boost converter. These derived results show that the desired structure meets the specifications expected and is a competitive choice for its application within DC-DC.

CONTENTS :

INTRODUCTION:

The Boost Converter is a type of DC-DC converter that steps up an input voltage to have a higher output. A component like this is essential for many applications within the realms of electronics, where the input voltage supplied to the system is less than that which the desired operation requires. This is greatly used in renewable energy systems, electric vehicles, portable electronic devices, and other fields where high-efficiency voltage regulation is a must.

Basic Operation:

The basic operation of a boost converter involves two key phases:

1. Switch On (Switch is closed/ Charging Phase):
    - If the switch, generally a MOSFET, is on, the inductor gets connected to the input voltage source.
    - During this cycle, the inductor acts as an element of energy storage by developing a magnetic field. The current through the inductor increases linearly.

2. Switch Off (Switch is opened/ Discharging Phase):
    - At the moment when the switch is turned off, the inductor becomes disconnected from the input source, and the magnetic field collapses.
    - The energy is released from the inductor, and the inductor's voltage adds to the input voltage to make a higher output voltage.
    - This combined voltage then charges the output capacitor and flows through the diode to the load, preventing backflow.

The switch is on and off in a continuous cycle; the duty cycle, the proportion of time that the switch is on, is what provides the basis for the output voltage. In having control over the duty cycle, the boost converter can keep a stiff output voltage at its output by compensating for changes in the input voltage or in load conditions.

Key Components:

- Inductor: Stores and releases energy to boost the voltage.
- Switch (e.g., MOSFET): This is used to control the connection of the inductor to the input voltage.
- Diode: Provides a one-way flow of current from the inductor to the output, preventing backflow.
- Capacitor: Smoothens the output voltage by reducing the ripple voltage.
- Controller: Regulates the switching of the MOSFET to maintain the desired output voltage.

THEORETICAL ANALYSIS :

Assumptions:

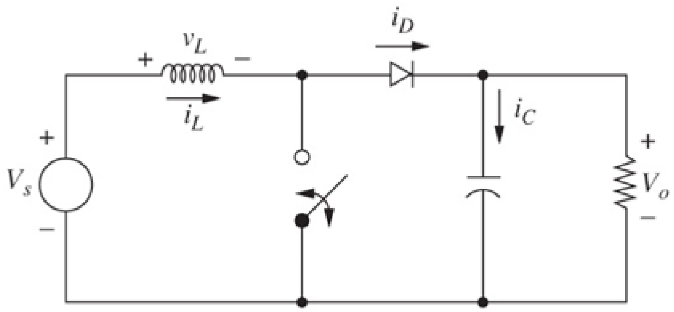
The circuit is operating in a steady state.

- The average voltage across the inductor is zero.
- The initial and final current in the inductor is equal in each cycle. The change in the current is equal in on and off period.
- The average current through the capacitor is zero

The inductor current is continuous and always positive.

The components are ideal. So there is no power loss or voltage loss in the components

The capacitor is large, and the output voltage is always constant. The output voltage is always constant.



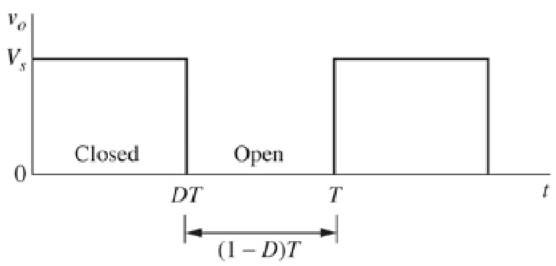
Assume the **periodic time** is **T** and the **duty cycle** is **D**.

- The Periodic Induction Current
  $i_L(t+T) = i_L(t)$

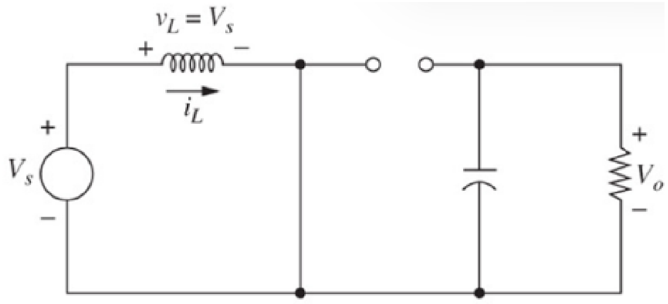
- The Average Inductor Voltage is zero
  $V_L = \frac{I}{T}\int_t^{T+t} V_L(\lambda)\, d\lambda = 0$

- The Average Capacitor Current is zero
  $I_C = \frac{I}{T}\int_t^{T+t} i_c(\lambda)\, d\lambda = 0$

- The Power Supplied by the source is equal to the Power Delivered to the load
  $P_s = P_o$



When the switch is ON:



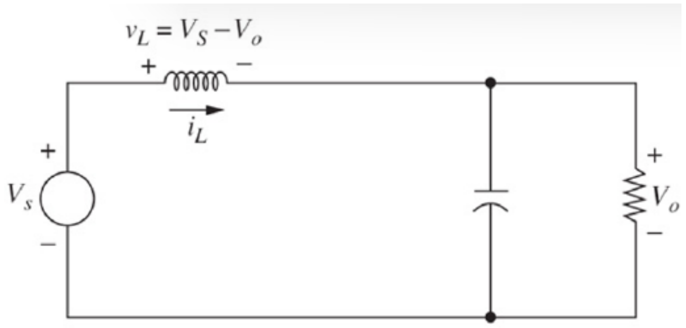
The voltage across the inductor $V_L = V_S = L\frac{di_L}{dt}$

$$\frac{di_L}{dt} = \frac{V_S}{L}$$

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_S}{L}$$

$$\Delta i_{L\ closed} = \frac{V_S}{L}\ DT$$

When the switch is OFF:



The voltage across the inductor $V_L = V_S - V_o = L\frac{di_L}{dt}$

$$\frac{di_L}{dt} = \frac{V_S - V_o}{L}$$

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

$$\Delta i_{L\ opened} = \frac{V_S - V_o}{L}\ (1-D)T$$

Finding the Output Voltage:

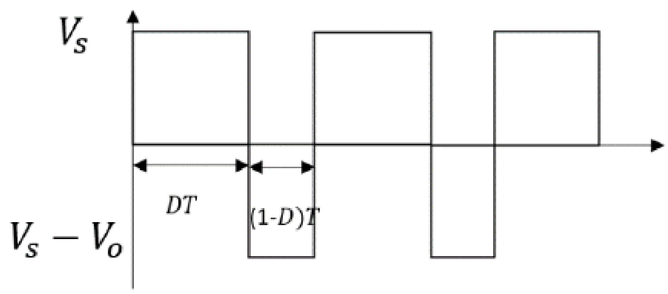
1. By using the change in the Inductor Current;
   By adding the change in the current in ON and OFF periods:
   $\Delta i_{L\ closed} = \frac{V_S}{L}\ DT$
   $\Delta i_{L\ opened} = \frac{V_S - V_o}{L}\ (1-D)T$

$$\Delta i_{L\ closed} + \Delta i_{L\ opened} = 0$$

$$\frac{V_S}{L}\ DT\ +\ \frac{V_S - V_o}{L}\ (1-D)T = 0$$

$$V_o = \frac{V_S}{1-D}$$

2. By using the average Inductor Voltage;



$$V_{avg} = \frac{I}{T}\int_0^T V_i\,(t)\,dt = 0$$

$$V_{avg} = V_s \times DT + (V_s - V_o) \times (1-D)T$$
$$V_s\,D + V_s - V_o - V_s\,D + V_o\,D = 0$$
$$V_s - V_o + V_o\,D = 0$$
$$V_o\,(1 - D) = V_s$$
$$V_o = \frac{V_S}{1-D}$$

Where D is given by;

$$D = \frac{T_{ON}}{T_{ON} + T_{OFF}} = \frac{T_{ON}}{T}$$

Always $0 \leq D \leq 1$; so $V_o \geq V_s$
If the switch is always open $D = 0$ then $V_o = V_s$

Finding the minimum inductor value to keep a continuous current:

$I_{L,avg} \neq I_{R,avg}$ but $P_{in} = P_{out}$

$$V_s I_s = V_o I_s = \frac{V_o^2}{R}$$

$$V_s I_L = \frac{V_o^2}{R}$$

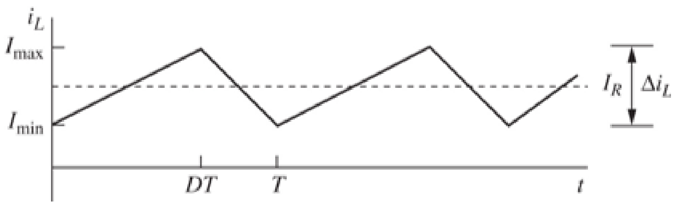
but $I_{S,avg} = I_{L,avg}$;

$$V_s I_L = \frac{\left(\frac{V_S}{1-D}\right)^2}{R} = \frac{V_S^2}{(1-D)^2 R}$$

$$I_{L,avg} = \frac{V_S^2}{(1-D)^2 R V_S}$$

$$I_{L,avg} = \frac{V_S}{(1-D)^2 R}$$

$$I_L = I_S = \frac{V_S}{(1-D)^2 R}$$



$$I_{max} = \frac{V_S}{(1-D)^2 R} + \frac{V_S}{2L} DT$$

$$I_{min} = \frac{V_S}{(1-D)^2 R} - \frac{V_S}{2L} DT$$

∴ The minimum current in the inductor;

$$I_{L,\,min} = \frac{V_S}{(1-D)^2 R} - \frac{V_S}{2L} DT$$

To be a continuous current in $I_{L,min}$ always needs to be greater than zero.

$$I_{L,\,min} = \frac{V_S}{(1-D)^2 R} - \frac{V_S}{2L} DT = 0$$

$$\frac{V_S}{(1-D)^2 R} = \frac{V_S}{2L} DT$$

$$L_{min} = \frac{D(1-D)^2 R T}{2}$$

$$T = \frac{1}{f};$$

$$L_{min} = \frac{D(1-D)^2 R}{2f}$$

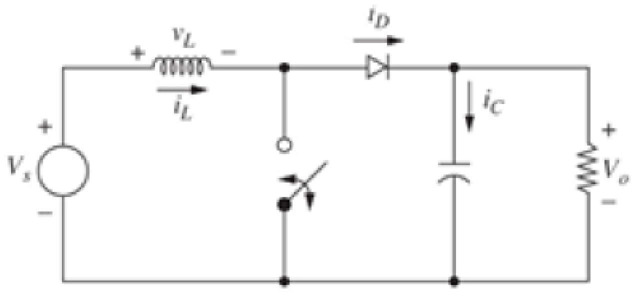
$$\Delta i_L = \frac{V_S}{L} DT$$

$$\Delta i_L = \frac{V_S}{L} D \frac{1}{f}$$

$$\Delta i_L = \frac{V_S}{Lf} D$$

$$L = \frac{DV_S}{\Delta i_L f}$$

Evaluating the Output Ripple Voltage:



$$Q = CV_o$$

$$\Delta Q = C \Delta V_o$$

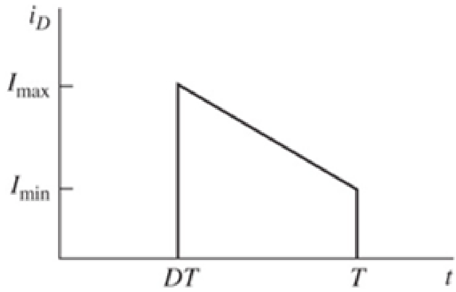
$$\Delta V_o = \frac{\Delta Q}{C}$$

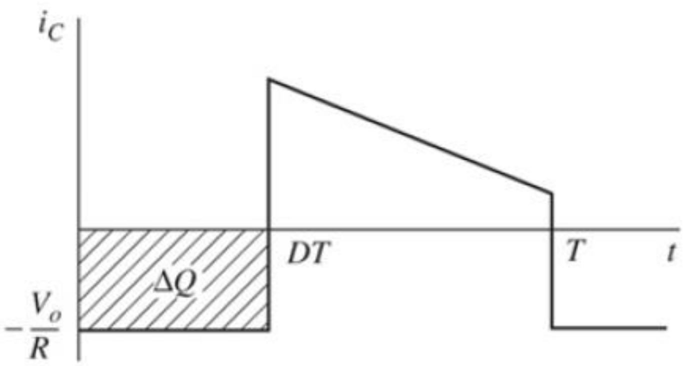
The switch is closed:

$$I_D = 0$$

The switch is open:

$$I_D = I_L$$





$$\Delta Q = DT \frac{Vo}{R}$$

$$\Delta Q = \frac{Vo\ DT}{R}$$

$$C \Delta V_o = \frac{Vo\ DT}{R}$$

$$\Delta V_o = \frac{Vo\ DT}{RC}$$

$$\Delta V_o = \frac{Vo\ D}{RCf}$$

$$\frac{\Delta Vo}{Vo} = \frac{D}{RCf}$$

Derived equations:

$$\Delta i_{L\ closed} = \frac{V_S}{L}\ DT$$

$$\Delta i_{L\ opened} = \frac{V_S - V_O}{L}\ (1-D)T$$

$$V_o = \frac{V_S}{1-D}$$

$$I_{L,avg} = \frac{V_S}{(1-D)^2\ R}$$

$$I_{max} = \frac{V_S}{(1-D)^2\ R} + \frac{V_S}{2L}\ DT$$

$$I_{min} = \frac{V_S}{(1-D)^2\ R} - \frac{V_S}{2L}\ DT$$

$$L_{min} = \frac{D\,(1-D)^2\ R}{2f}$$

$$L = \frac{DV_S}{\Delta i_L\ f}$$

$$\frac{\Delta Vo}{Vo} = \frac{D}{RCf}$$

CALCULATIONS OF SPECIFICATIONS:

The given data:

Input Voltage Range: 34V to 45V

Output Voltage Range: 48V $\pm \frac{1}{2}$ V

Output Load Range: 0W to 150W

Calculating the value of Resistor (R):

$$P = \frac{V_O^2}{R}$$

$$R = \frac{V_O^2}{P}$$

$$R = \frac{48^2}{150}$$

$$R = 15.36\Omega$$

The switching frequency was taken as 100kHz.

$$I_{max} = \frac{p_{max}}{V_o}$$

$$I_{max} = \frac{150}{48}$$

$$I_{max} = 3.125A$$

Inductor current does not exceed 40% of the average Inductor current.

$$\Delta I_L = 3.125 \times \frac{40}{100}$$

$$\Delta I_L = 1.25A$$

For 34V input voltage;

$$D = 1 - \frac{V_s}{V_o}$$

$$D = 1 - \frac{34}{48}$$

$$D = 0.292$$

$$I_{L,avg} = \frac{V_s}{(1 - D)^2 R}$$

$$I_{L,avg} = \frac{34}{(1 - 0.292)^2 \times 15.36}$$

$$I_{L,avg} = 4.416A$$

For 45V input voltage;

$$D = 1 - \frac{V_s}{V_o}$$

$$D = 1 - \frac{45}{48}$$

$$D = 0.0625$$

$$I_{L,avg} = \frac{V_s}{(1 - D)^2 R}$$

$$I_{L,avg} = \frac{45}{(1 - 0.0625)^2 \times 15.36}$$

$$I_{L,avg} = 3.333A$$

$\therefore$ $0.0625 \leq D \leq 0.292$

Worst-case duty ratio = 0.292

$$D = 0.292$$

Calculating the value of the Inductor (L):

$$L = \frac{DV_s}{\Delta i_L f}$$

$$L = \frac{0.292 \times 45}{1.25 \times 100 \times 1000}$$

$$L = 105.12\mu H$$

Calculating the value of the Capacitor (C):

$\frac{\Delta V_o}{V_o} = 0.5\% = 0.005$

$$C = \frac{D}{R\frac{\Delta V_o}{V_o}f}$$

$$C = \frac{0.292}{15.36 \times 0.005 \times 100 \times 1000}$$

$$C = 38.021\mu F$$

$$I_{min} = \frac{V_S}{(1-D)^2 R} - \frac{V_S}{2L} DT$$

$$I_{min} = \frac{45}{(1-0.292)^2 \times 15.36} - \frac{45}{2 \times 105.12 \times 10^{-6}} 0.292 \times \frac{1}{100 \times 1000}$$

$$I_{min} = 5.845 - 0.625$$

$$I_{min} = 5.22A$$

$$I_{max} = \frac{V_S}{(1-D)^2 R} + \frac{V_S}{2L} DT$$

$$I_{max} = \frac{45}{(1-0.292)^2 \times 15.36} + \frac{45}{2 \times 105.12 \times 10^{-6}} 0.292 \times \frac{1}{100 \times 1000}$$

$$I_{max} = 5.845 + 0.625$$

$$I_{max} = 6.47A$$

Summary of results:

Resistor value:

$R = 15.36\Omega$

Inductor value:

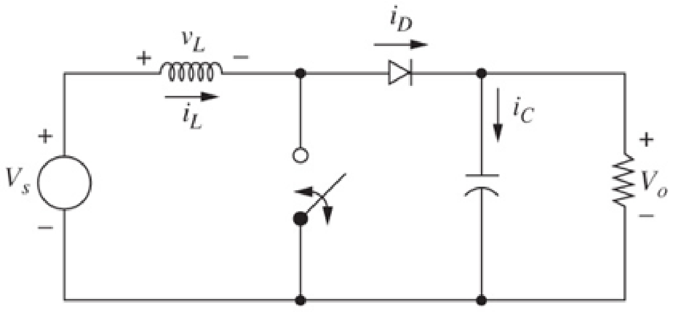
$L = 105.12\mu H$

Capacitor value:

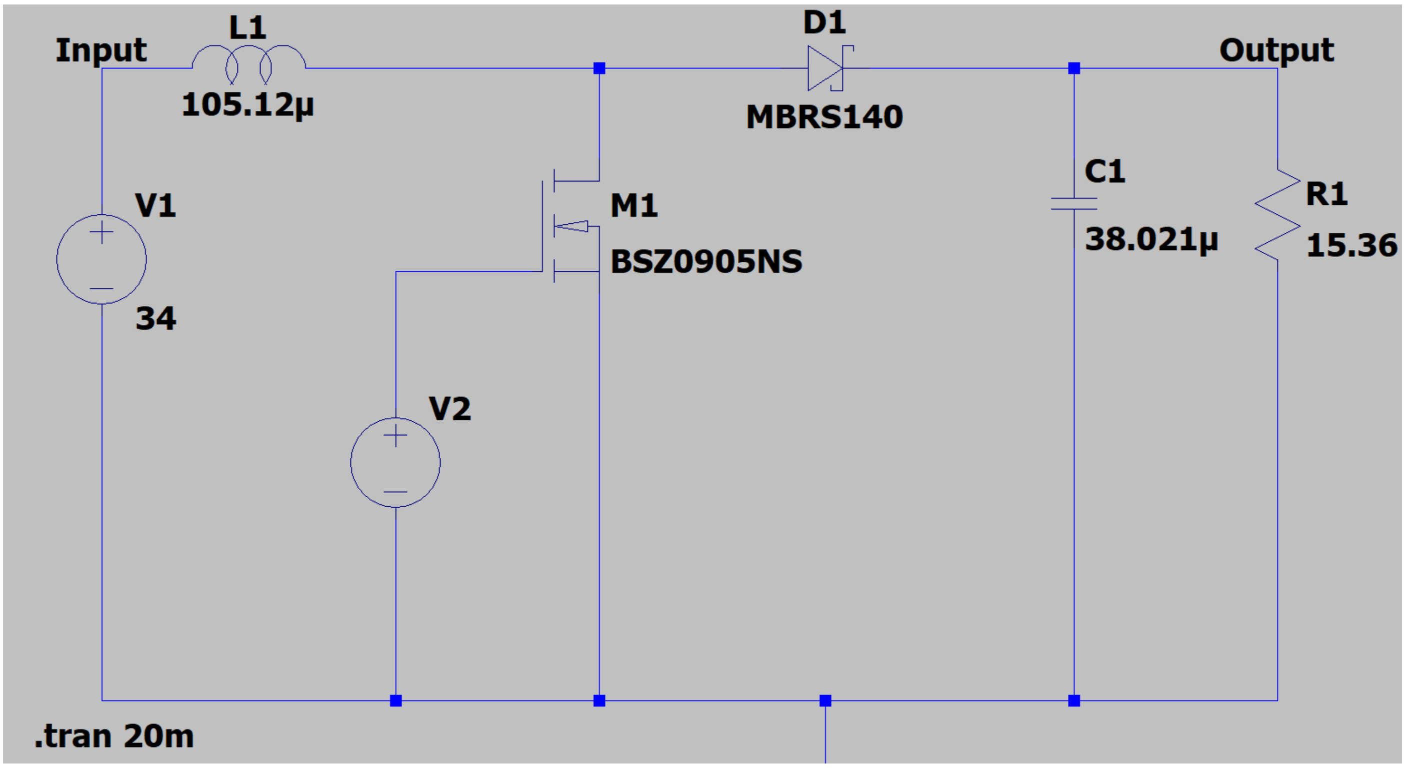
$C = 38.021\mu F$

CIRCUIT DIAGRAM:

The Design of the Circuit Diagram:



The Implemented Diagram:



WORKING PRINCIPLE OF BOOSTER CONVERTER:

A boost converter, also known as a step-up converter, is one particular type of DC-DC converter designed to raise the input voltage to a greater output voltage without polarity reversal. Energy is stored in the inductor and then willfully released to realize the conversion of voltage. A simple boost converter involves an inductor, a switch (normally a MOSFET), a diode, and a capacitor.

In the boost converter operation, the switch alternates between two states: on and off. When the switch is turned on, current flows through the inductor, thus forming a magnetic field, which stores energy in the inductor. Since the inductor resists the change in current during this phase, the current ramps up slowly, and correspondingly, the voltage across the inductor increases. Since the switch is turned on, the input voltage appears directly across the inductor, and the diode is reverse-biased; thus, no current flows to the output.

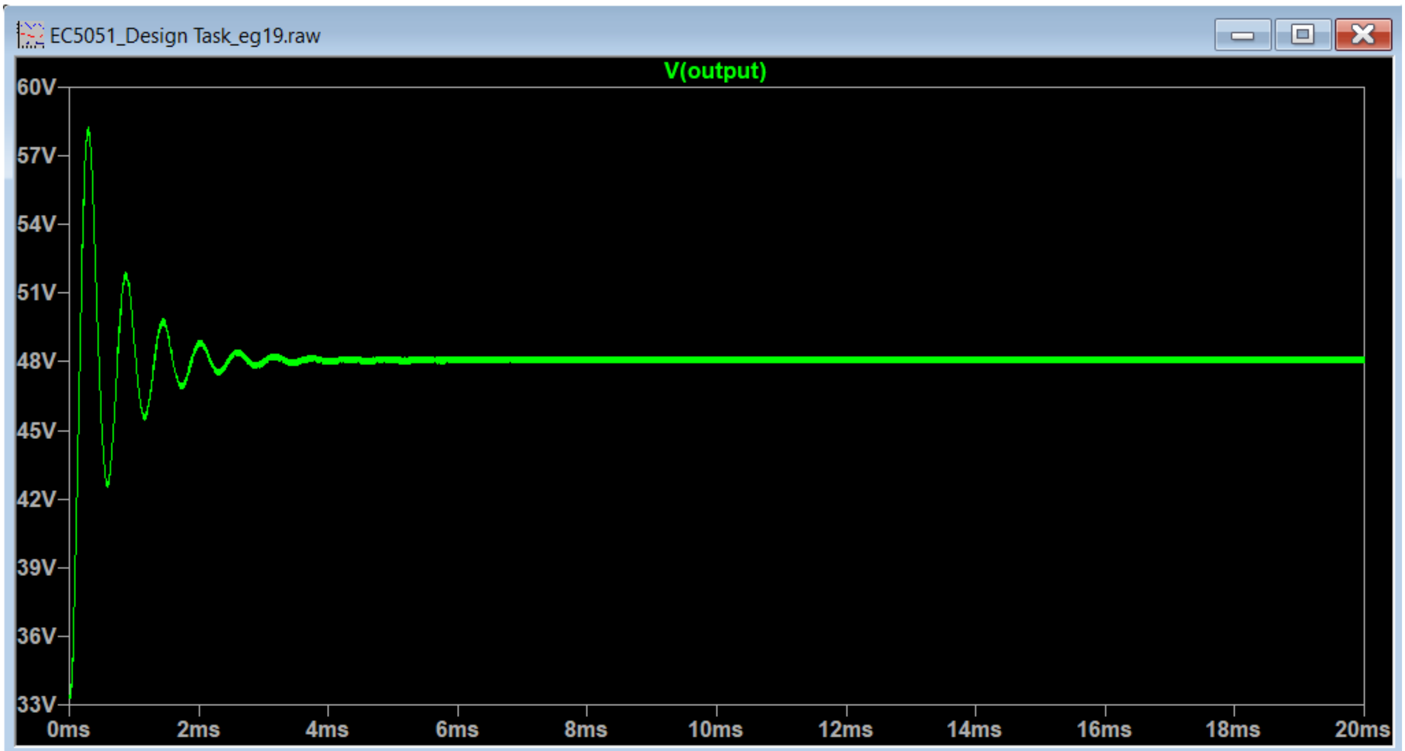
When the switch turns off, the magnetic field around the inductor collapses, and energy stored in the inductor starts to release. The inductor generates a voltage that opposes in direction of the one maintaining the current flow, which then adds to the input voltage. This makes the diode forward biased, allowing current to flow to the output capacitor and load. Therefore, the output voltage from this is always higher than the input voltage due to the additive effect of the voltage on the inductor and the voltage at the input.

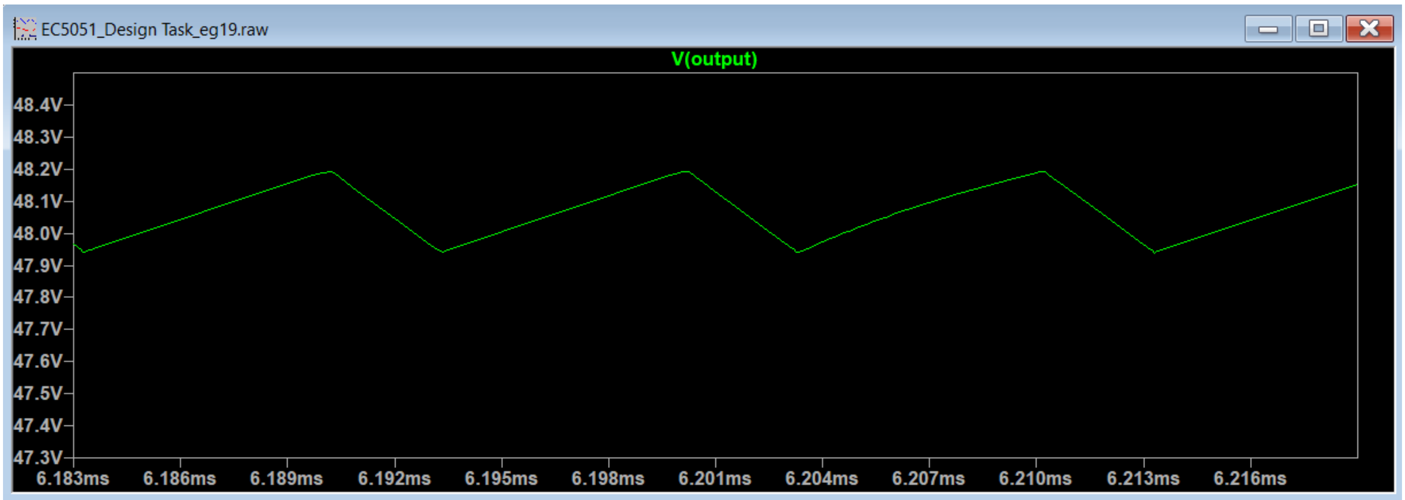
The output capacitor smoothes the voltage to provide a steady DC output at its terminals. The output voltage is controlled based on the ratio of the switch's on-time to the total period of the switching cycle. In this way, the boost converter can adjust the output voltage to a specific value by varying the duty cycle. It typically has quite high efficiency, ranging from 80% to 95%. That is why a boost converter is usually applied to increase the voltage level when the source voltage is at a lower value than required—for instance, in battery-operated devices.

LTSPICE SIMULATION DESIGN:

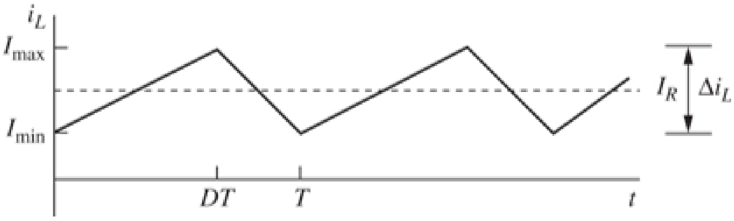
Input voltage:

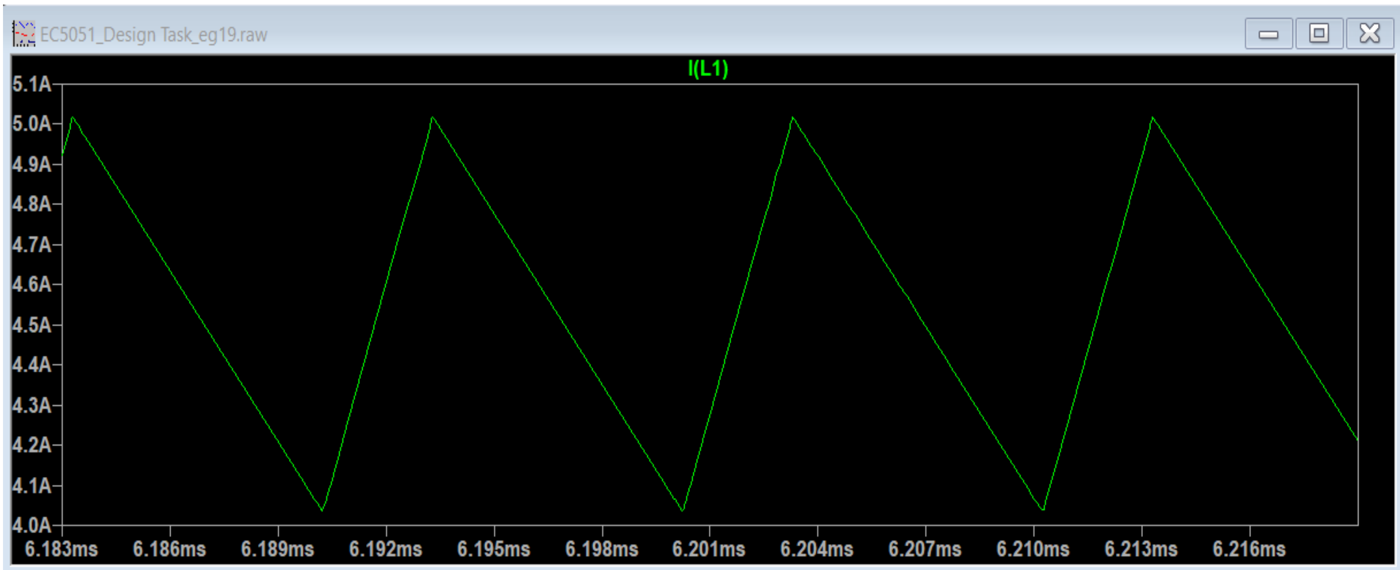
Output voltage:



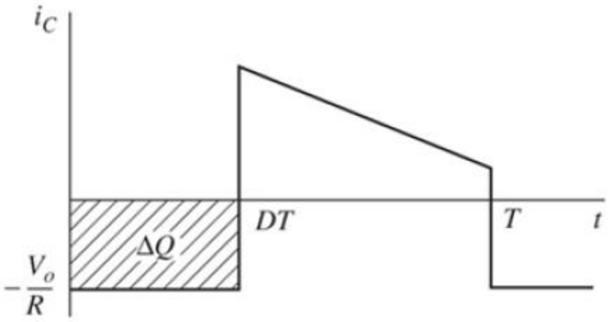


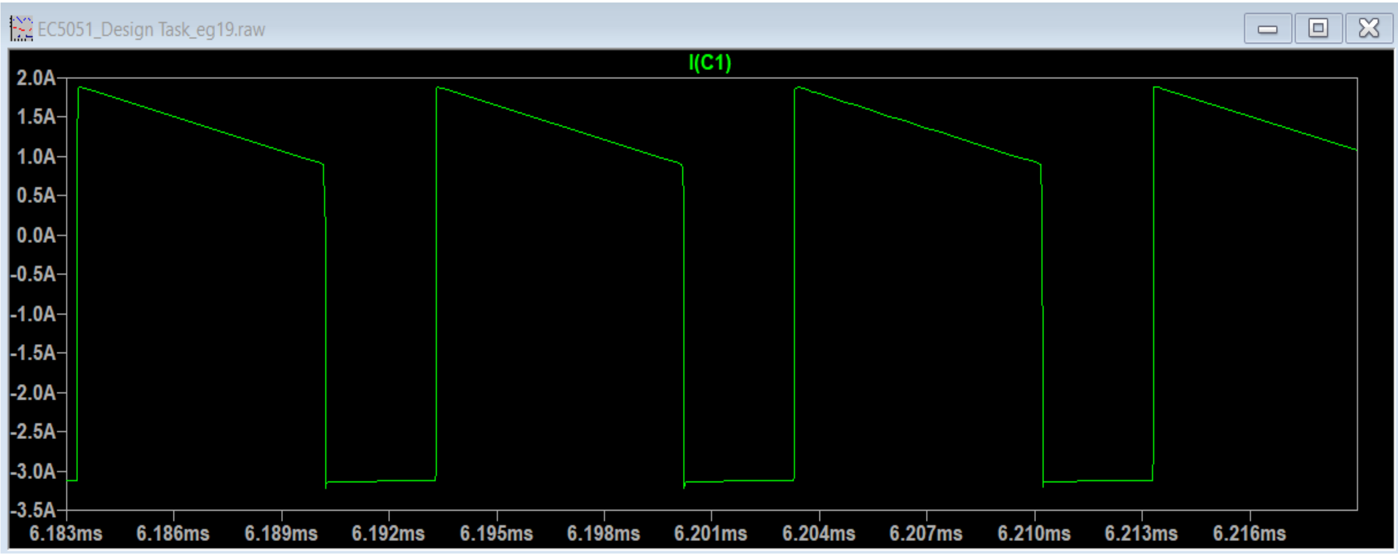
Current through the Inductor:





Current through the Capacitor:





APPLICATIONS:

Battery-Powered Gadgets:

Portable Electronics: Most devices, such as smartphones, tablets, and laptops, make use of boost converters to step up the voltage supplied by the battery to the required level for various components. For instance, lithium-ion batteries usually supply about 3.7V, and this may be boosted up to 5V or even more for some functionality.

Electric Vehicles: These converters are employed in electric vehicles to raise the voltage from the battery pack to higher values needed at the motor or any other electronic component.

Renewable Energy Systems:

Solar cells generate relatively low voltages, and these have to be boosted to be stored in batteries or forwarded to grid-tied inverters. Boost converters can be applied to raise the voltage from the solar panels to the desired levels.

Fuel Cells: Similar to a solar cell, fuel cells often result in a relatively low output voltage. Boost converters help in raising these voltages to usable levels with respect to the powering of devices or charging batteries.

Power Supply Systems:

Power Supply Units: In power supply units, boost converters are utilized to obtain higher voltages from a lower input voltage. For instance, they may be used in uninterruptible power supplies (UPS) in applications for boosting the voltage from the battery to the required levels during a power failure.

Voltage Regulation: In applications that require constant, higher voltage, boost converters can be used along with other components to provide constant output voltage despite fluctuations in the input voltage.

Lighting Systems:

LED Drivers: LEDs almost always need higher voltage than is provided by regular batteries or power sources. The boost converters help increase it to the voltage needed by the drivers to drive them effectively.

Automotive Lighting: In vehicles, the boost converters are used in powering high-intensity discharge or light-emitting diode lighting where the converters step up the level of voltage from the battery to what each requires.

Communication Equipment:

RF Transmitters: The boost converter can be used in RF transmitters to supply the high voltage required for the RF power amplifier from a lower-voltage battery or power source. Satellite Communication: In satellite communication systems, the boost converter is used to raise the voltage for sending signals over long distances.

Portable Medical Devices:

Portable Oxygen Concentrators: These devices are often powered using batteries, and boost converters are applied to raise the voltage up to what might be required by the concentrator. A portable defibrillator uses the boost converter to produce the high voltage needed to deliver a therapeutic shock from a comparatively low-voltage battery source.

Consumer Electronics:

Power Banks: The boost converters are always present in the power banks to bump up the battery voltage to the 5V needed to charge the devices via the USB ports.

Wireless Charging: The boost converters provide an increase in the input voltage to higher levels required for efficient energy transfer in the wireless charging system.

CONCLUSION:

Design an efficient and reliable DC-DC power converter. The task involved the analysis of specifications, selection of components, and computation of their parameters by simulation. It took into consideration the requirements of input and output voltage, current ratings, and efficiency goals because the design task ensured that the boost converter would be able to deliver a decent level of performance. This has been performed by the selection of appropriate inductors, capacitors, and switches for use in ensuring the

This was rather instrumental in the realization of efficient power conversion and voltage stepping. Concisely, the design task of the boost converter demonstrated the essence of rigorous analysis, calculations, and simulations in coming up with a functional and efficient power converter. The completion of the design task successfully brought forth some lessons and guidelines for engineers and researchers working on related projects thus offering the basis to design boost converters that fit specific application needs with reliable power conversion.