HIGH-EFFICIENCY SINGLE PHASE PASSIVE LC^3 COMPONENT AC-DC BUCK-BOOST CONVERTER

by

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Declaration of Authorship

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List of Acronyms

SMPS	Switch Mode Power Supply
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
THD	Total Harmonic Distortion
PF	Power Factor
CCM	Continuous Conduction Mode
PWM	Pulse Width Modulation
RMS	Root Mean Square
f_s	Switching Frequency
D	Duty Cycle
T_{on}	Turn on time
T_{off}	Turn off time
PI	Proportional-Integral

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Abstract

The demand for electrical energy has grown over the last few decades, putting a strain on our non-renewable energy resources. Thus, modern appliances' design employs power electronics to consider issues like energy sustainability and energy savings. Widespread use of DC loads has made AC-DC converters essential. Conventional AC-DC converters consist of diodes for uncontrolled and thyristors for controlled power flow; therefore suffer from high Electromagnetic Interference (EMI), lower efficiency, decreased Power Factor (PF), and high Total Harmonic Distortion (THD). In this research work, A new single-phase AC-DC Buck-Boost converter is proposed comprising a compact passive LC^3 configuration. The proposed converter can achieve higher efficiency while maintaining low THD and a close to unity input power factor. The converter circuit includes a bridge rectifier with an LC^3 configuration and a conventional Buck-Boost converter. The inductance is kept above the critical value for the converter to operate in continuous conduction mode. Proportional-Integral (PI) based feedback control augmented the performance of the converter. The simulation result solidified the effectiveness of the proposed converter and its control system. The inclusion of a comparative analysis justifies the compatibility of the converter. The proposed converter achieved a 3% increase in efficiency, a 48% increase in power factor, and an overall 40% decrease in a total harmonic distortion compared to a conventional Buck-Boost circuit's relevant performance.

Chapter 1

Introduction

1.1 Overview

Power electronics combines Power, Electronics, and Control. Power is related to the static and rotating power equipment for the generation, transmission, and distribution of electric energy. Control relates the steady-state and dynamic attributes of closed-loop systems. Electronics contain solid-state devices and circuits for signal processing to meet the preferred control purposes. Power electronics is defined as the employment of solid-state electronics for the control and conversion of electric power. There are many ways to illustrate power electronics as the art of transforming electrical energy into different forms in a clean, efficient, and robust manner for energy utilization to meet the desired needs. Figure 1.1 shows the fundamental concept of power electronics through a block diagram.

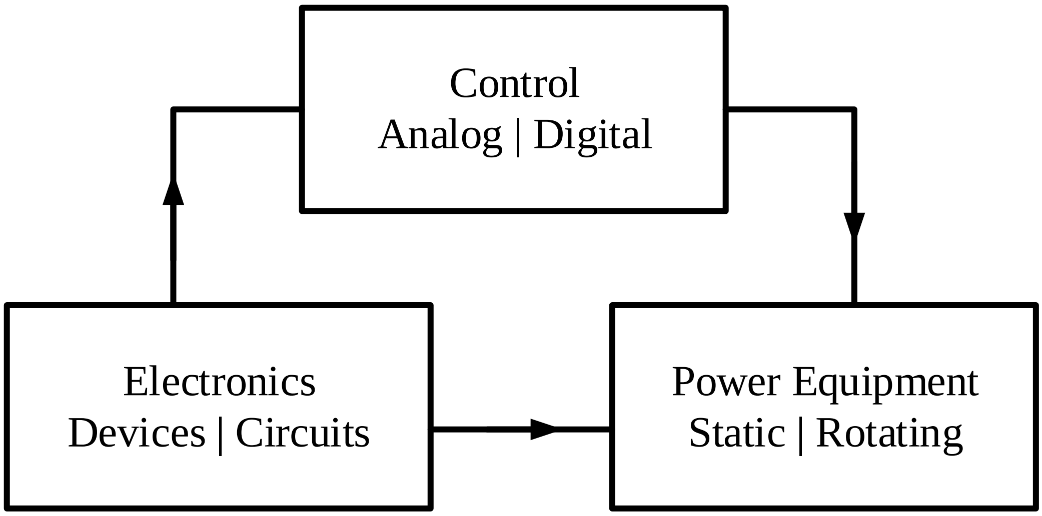


Figure 1.1 Fundamental concept of Power Electronics

Development in power electronics has established one of the great success stories of the 20th century. With the improvement of manufacturing technology, the cost of semiconductor devices has decreased. It is often said that solid-state electronics brought in the first electronics revolution, whereas solid-state power electronics is the second electronics revolution. It is interesting to note that power electronics blend the mechanical, electrical, and electronic eras. High-level productivity of the industries and product quality enhancement are not possible by using non-power electronic systems. Today, power electronics are an indispensable tool in any country's industrial economy. It is necessary that some converters are to be used to improve the quality of the power supply. Power semiconductor devices make it possible for utilities to use various power control equipment to raise power quality levels and enhance performance and efficiency [1, 2]. The continuous development of communication technologies requires high-performance communication power. High efficiency, high power density high reliability of the communication power module become the inevitable trend of the development of communication power [3, 4]. Power electronics deals with the control and adaptation of electrical power by utilizing solid-state devices. Converters form a prominent part of power electronics. Power electronic converters are essential in applications that require modification of the electrical energy form with classical electronic devices. Voltage converters convert and regulate the voltages to our desired shape. Modern DC converters use a switch-mode power supply (SMPS). They mainly comprise semiconductor switches, such as power MOSFET, power BJT, IGBT, thyristors, and storage components with little resistance like inductors and capacitors. Power converters should incur low power loss during conversion to ensure high efficiency. The above-mentioned applied field necessary involves the requirement of highly efficient regulation of system voltage and current. This regulation of voltage can be achieved through the use of transformers and converters. DC-DC and AC-DC power converter have grown popular over the years and become an integral part of the power supply system. The converter carries the power transfer from the input to output, or vice versa, and is comprised of power semiconductor devices acting as switches, plus passive devices (inductors and capacitors) [5-7]

1.2 Basic Operation of Power Electronics

Power electronic circuits are brought into play to control the power conversion from AC or DC sources to AC or DC loads, and occasionally with bidirectional capabilities [4, 8]. This conversion is accomplished in most power electronics systems with two functional modules called the control and power stages. Figure 1.2 shows the topology for a single source and single load converter application and includes a power processor (the power stage) and a controller (the control stage). The converter handles the power transfer from the input to output, or vice versa, and is constituted of power semiconductor devices acting as switches, plus passive devices (inductor and capacitor). The controller is responsible for operating the switches according to specific algorithms monitoring physical quantities (usually voltage and currents) measured at the system input or output.

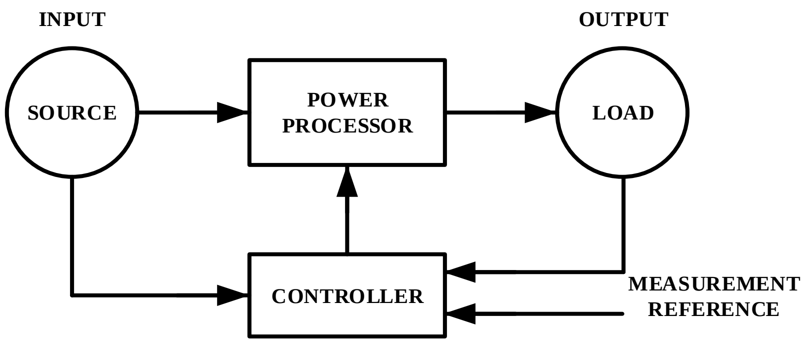


Figure 1.2 A general power electronics system

1.3 Types of Power Electronics Devices

The conversion of electric power is necessary for controlling the electric power, and the switching characteristics of the power devices permit these conversions. The static power converters perform these functions of power conversions. A converter may be considered as a switching matrix in which one or more switches are turned on and connected to the supply source to obtain the desired output voltage or current. The power electronics circuits can be categorized into six types:

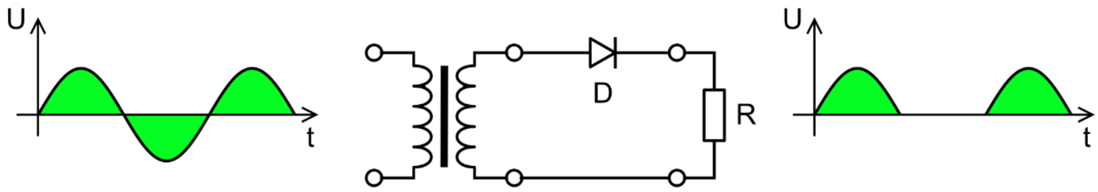
- Rectifiers as diodes
- DC-DC converters (DC choppers)
- DC-AC converters (Inverters)
- AC-DC converters (Controlled rectifier)
- AC-AC converters (AC voltage controllers)
- Static switches

1.3.1 AC-DC Converter

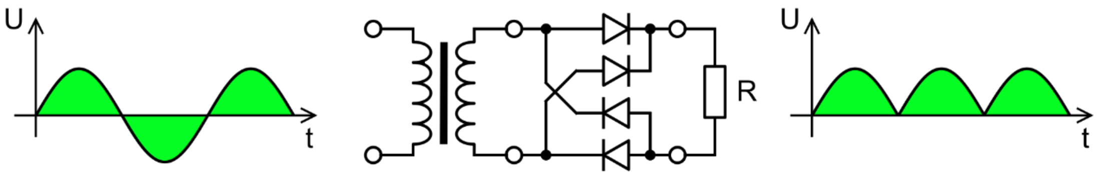
AC-DC converters or namely rectifiers, convert alternating voltage/current to direct voltage/current. The simplest converters use diodes for the rectification of the AC signal. There are two types of rectifiers-

- Half wave rectifier
- Full-wave rectifier

Both of the rectifiers in Figure 1.3 [9] use diodes to restrict the flow of current in one of the two half-cycles of an AC signal based on their polarity, allowing the output current to flow in one direction only.



(a)



(b)

Figure 1.3 AC-DC converter (a) Half Bridge Rectifier (b) Full Bridge Rectifier [9]

1.3.2 DC-DC Converter

DC converters, also known as regulators, regulate the DC voltage level. They convert the DC voltage from one level to another. Such converters are used in batteries of cellular phones and laptops primarily. The following devices can convert DC to DC:

- Linear regulator
- Voltage regulator
- Motor–generator
- Rotary converter
- Switched-mode power supply

Modern electronic converters use switching techniques. SMPS DC-DC converters store energy temporarily for the input voltage level and release that energy at the output terminals at different levels. This energy may be stored in a magnetic field of inductors and transformers or capacitors' electric fields. Thus voltage is increased or decreased. Voltage conversions by switching are more power-efficient (75%-98%) than linear voltage regulation, where unwanted power gets released as heat [10].

1.4 Design of Power Electronics Equipment

The design procedure of power electronics equipment can be explained in four parts:

1. The design of power circuits
2. Protection of power devices
3. Determination of control strategy
4. Design of logic and gating circuits

Before building a prototype, the designer has to investigate the effects of the circuit parameters and device limitations and should adjust the design if required. After constructing and testing the prototype, the designer validates the method and approximates more precisely some of the circuit parameters.

1.5 Power Electronics Applications

Some of the emerging applications of power electronics are briefly presented here to introduce the field's breadth of activity.

A hybrid electric vehicle typically has two significant power electronic systems and dozens or even hundreds of smaller designs. One of these two hefty units is the inverter system controlling the electric drive motor, and another is a rectifier system managing the battery charging. Minor systems contain motor controllers in electric power directing units, lighting electronics for high-intensity headlamps, controllers for the wide-ranging small motors that trigger everything from DVD players to windshield wipers, and power supplies for the host of microcontrollers inserted in a modern-day car. The continuous development of plug-in hybrid and electric vehicles will increase the efficiency and refinement of battery chargers and drive motor controllers.

Usually, the inverter rating of a hybrid car is around 50 KW. Overall, electric automobiles have an inverter rating of about 200 KW. From there, hybrid and electric drive power levels increase up to multi-megawatt inverters for powering up high-speed trains.

On the other hand, designers have been working on small power electronics systems that pull out energy from several peripheral sources for residential demands. These energy harvesting applications will lead to an arising growth area. For instance, a corrosion sensor is constructed into a highway bridge that collects energy from vibration. This energy is converted and preserved, then used for sporadic communication with a central monitoring computer. The standard power levels may not be as much as 0.001 W.

Solar, wind, and other renewable energy resources are strongly related to power electronics. A typical solar panel generates about 30V DC, with tolerances from 20 to 40 or more. The randomly charging DC source should be converted to regulated ac voltage that synchronizes to the electricity grid and transports energy. Solar inverter efficiency, reliability, and cost are significant factors in successful energy innovation. A dual application, meaning that energy flows in the opposite direction but that many other characteristics are shared, is that of solid-state lighting. In that care, flexible control of a DC must be provided from an ac grid source. For wind energy, a typical large-scale wind turbine can produce 2 MW of high-frequency ac power. The frequency and voltage vary rapidly according to wind speed. This power must be converter to fixed frequency and voltage for grid interconnection.

1.6 Research Objective

A large portion of modern appliances that render us a flexible lifestyle employs the technology of power electronics. In recent times, the use of DC loads is expanding in the power system. These loads require AC-DC converters that convert the AC voltage from the mains supply or AC power distribution system to DC and feed it into the DC loads. Diode rectifier or thyristor rectifier were traditional AC-DC converters. Such converters consist of active electrical components like diodes for uncontrolled and thyristors for controlled power flow. These components have few downsides like high harmonic, high electromagnetic interference (EMI), low efficiency, low power factor, and large size of filters.

Numerous approaches have been employed to overcome these complications. One of these techniques includes switching-mode regulators that employ a diode rectifier followed by a DC-DC converter [12-13]. An example of such a method is a Boost converter with a diode rectifier. Boost converters are limited to step-up voltage operations. For voltage step-down, these converters are needed to be cascaded with another DC-DC converter. Thus the circuit complexity and expense rises. Therefore, more straightforward configurations are introduced for step-down applications. Such converters like Buck, Buck-Boost, Ĉuk, and SEPIC are employed with different voltage relationships [14-16]. A Buck-Boost converter can step down and step up the input voltage. The conventional Buck-Boost converter has several setbacks, which are needed to be focused on. However, by addressing these problems, the efficiency of the converter decreases. The input current of this converter is discontinuous with significant high-frequency contents that increase EMI [17]. An input filter is required to reduce the effects of EMI and the current ripple [18]. Such filters have several setbacks too. The resulting converter becomes bulky. Although line current harmonics are reduced, a large phase shift in the fundamental component causes a low power factor. For overcoming this problem, active PFC solutions are employed that can attain low harmonic distortion and high power factor [19]. Such techniques involve using switching devices such as IGBTs and MOSFETs, which can control the line current's shape. An exciting solution can be the use of a two-switched Buck-Boost converter [20]. However, with an increased number of switches, conduction loss also increases.

1.7 Thesis Outline

This thesis work proposes a single-phase AC-DC Buck-Boost converter cascaded with a compact passive LC^3 configuration. The proposed circuit satisfies low THD and high PF [21]. The proposed converter can attain a high power factor, low THD, adjustable step-up/step-down output voltage with higher efficiency. The operation is conducted in continuous conduction mode (CCM). The proposed Buck-Boost AC-DC converter provides step-up or step-down output DC voltage, respectively, with the switch's duty cycle control. The efficiency is variable with the change in the duty cycle. For verifying the proposed circuit design and its control schemes, simulations are carried out using the PSIM software. Comparative analysis, along with a closed-loop analysis of the circuit is presented.

In chapter 2, the theoretical settings behind our proposed converter have been discussed. The fundamentals of SMPS systems, different types of switch-mode regulators, performance parameters related to the converter have been described. Our work intends to augment the performance of the conventional AC-DC Buck-Boost converter. The traditional AC-DC Buck-

Boost converter's basic operation principle has been discussed to get familiarized with the Buck-Boost operation.

In chapter 3, the configuration and operation analysis of the proposed converter is discussed. A novel single-phase LC^3 component AC-DC Buck-Boost converter is presented, which operates at higher efficiency, lesser THD, and improving the input power factor. Additionally, closed-loop feedback control is established to enhance these performance parameters further.

In chapter 4, the proposed converter, both with and without the feedback control, is simulated in PSIM software. The PSIM simulation includes a comparative analysis of the performance parameters among the conventional AC-DC Buck-Boost converter, proposed LC^3 component AC-DC Buck-Boost converter without feedback control, and the converter with feedback control. Finally, a PCB design of our converter is constructed in Proteus software to assist in the hardware implementation of the converter in future works.

Chapter 5 includes the summary of our thesis project and the future work related to our project that we intend to accomplish for the even better performance of our converter.

Chapter 2

Theoretical Background

2.1 Synopsis

Our research deals with a Buck-Boost converter that uses MOSFET as a switch. It is a combination of a full-bridge rectifier (AC-DC) and Buck-Boost regulator (DC-DC) working in continuous conduction mode (CCM). We chose Buck-Boost regulator for-

- Higher efficiency
- Output short circuit protection would be easy to implement
- Under a fault condition of the transistor, the variation in fault current is limited by the inductor.

Since the converter discussed is an SMPS circuit with AC input and constitutes reactive elements, like inductors and capacitors, it affects essential circuit parameters like efficiency, THD, power factor, etc.

A brief about the significant terms mentioned above will acquaint us with a conventional Buck-Boost converter's operation and behavior.

2.2 Switch Mode Power Supplies

2.2.1 SMPS configuration

It is an electronic circuit that converts electrical power efficiently using switching devices. The incorporated switching components are turned ON and OFF at high frequencies, expending very little time in high dissipation transitions to minimize energy loss. SMPS can transfer power from DC or AC source to DC source, providing conversion of both voltage and current characteristics. The voltage regulation is obtained by controlling the ratio of the transistor switch's on-off time (duty cycle). Figure 2.1 represents the schematic diagram of a sample SMPS system [5].

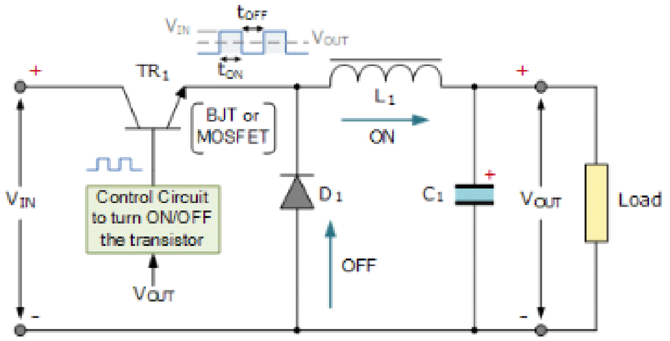


Figure 2.1 Sample SMPS schematic diagram [5]

2.2.2 SMPS Operation

The basic functionality of an SMPS system is shown in Figure 2.2

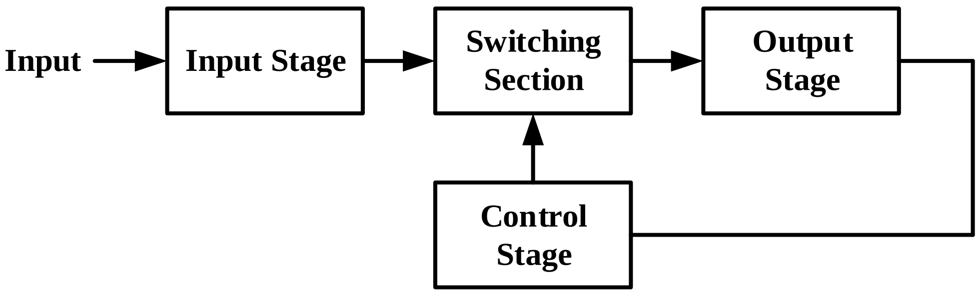


Figure 2.2 SMPS working block

Input stage: For an AC input, the voltage is first converted to DC using a rectifier (through the diode). The DC voltage obtained is unregulated and sent to the central switching section of SMPS.

Switching section: A transistor, like MOSFET, switches according to PWM and sends the output to a transformer. In simpler circuits, inductors are used in place of transformers.

Output stage: The signal from the switching section undergoes rectification and filtering. The regulated output is then fed into a feedback circuit.

Control unit: A feedback circuit monitors the output voltage and compares it with a reference voltage.

2.2.1 *Duty Cycle*

The fraction of a period/cycle for which a signal is active. It, therefore, determines the ON time of the transistor, and varying this fraction renders pulse width modulation (PWM). Let's assume, in Figure 2.3 for a total period T, the switch remains ON for time T_{on} and remains OFF for time T_{off}. So, total time $T = T_{on} + T_{off}$ and switching frequency $F = \frac{1}{T}$.

$\therefore$ Duty Cycle, $D = \frac{T_{on}}{T}$

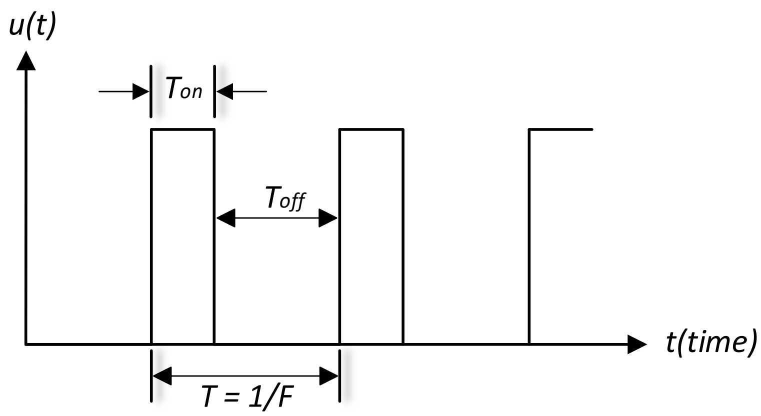


Figure 2.3 Duty cycle diagram

2.2.2 *MOSFET*

MOSFET (Metal-Oxide-Semiconductor Field-Effect-Transistor) is a field-effect transistor. It is a unipolar, three-terminal device. The terminals are gate, drain, and source. The potential voltage variance between the gate and source determines the conduction state of a MOSFET. When operating under cutoff and saturation modes, they can be used as switches. MOSFET has high thermal stability and a faster switching speed than BJT. Therefore they make suitable options for switching circuits.

2.2.3 Continuous Conduction Mode (CCM)

Under CCM, the current never falls to zero in the circuit. Certain parts of the circuit keep conducting while other parts do not, and hence the current flow remains continuous throughout the circuit. For example, in a Buck-Boost regulator during

- Switch ON - MOSFET and inductor conduct
- Switch OFF – diode, inductor, capacitor, and output load conduct

2.2.4 Switch Mode Regulators

Some basic switch-mode circuit topologies are:

- Buck regulator
- Boost regulator
- Buck-Boost regulator
- CUK regulator
- SEPIC regulator
- ZETA regulator

Buck regulator: These are DC regulators that lower the rectified DC voltage, according to the duty cycle of the switching device M, without changing the polarity. A stepped-down voltage is obtained at the output terminals—figure 2.4 displays a Buck regulator configuration.

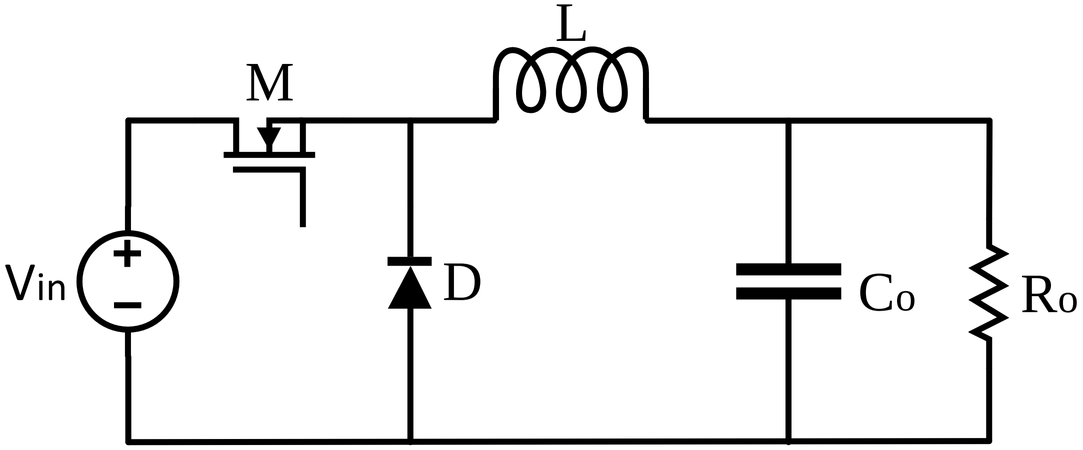


Figure 2.4 Buck regulator circuit diagram

Boost regulator: According to the switching device's duty cycle, boost regulators increase the DC voltage without changing the polarity. In boost regulators, the switch is connected parallel to the output terminal or load—figure 2.5 displays a Boost regulator configuration.

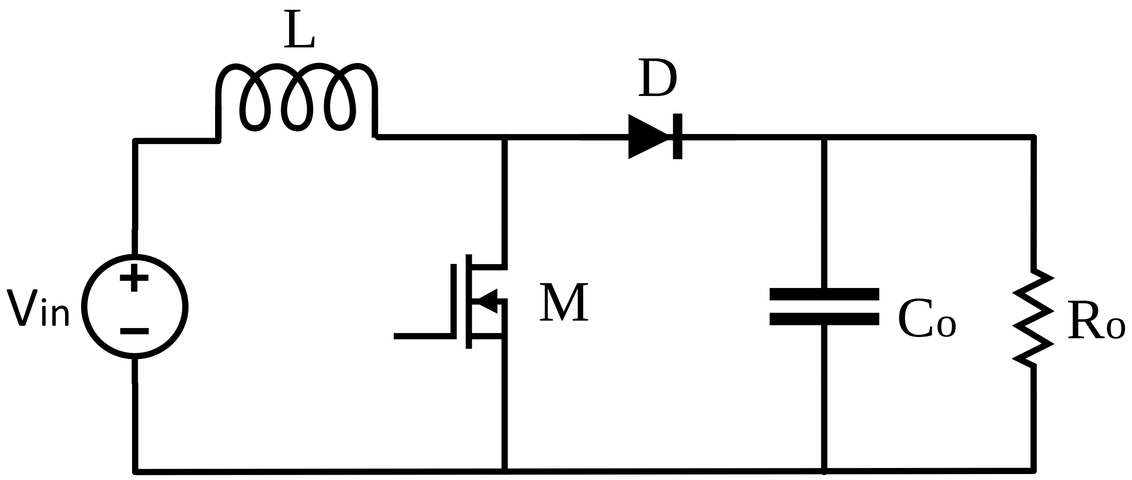


Figure 2.5 Boost regulator circuit diagram

Buck-Boost regulator: It combines the above two regulators and provides both steps up and step down of the input DC voltage according to the duty cycle ratio. The voltage obtained at the output is of opposite polarity to the input—figure 2.6 displays a Buck-Boost regulator configuration.

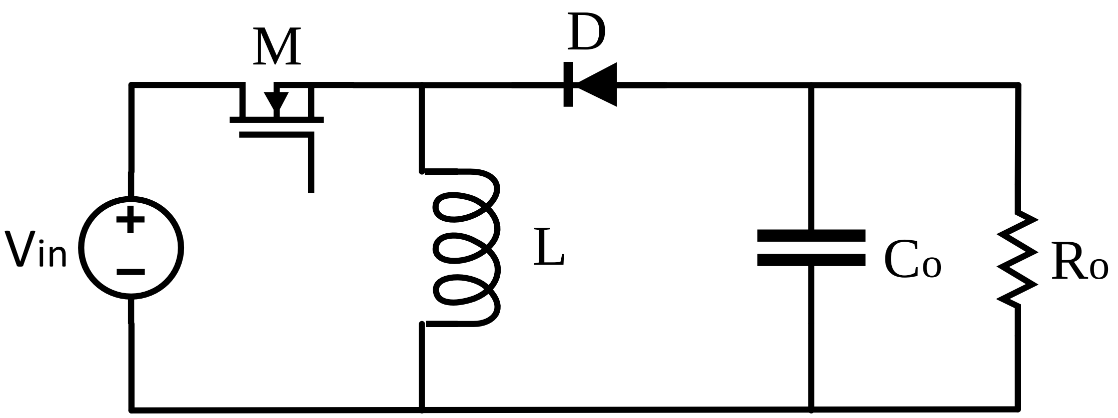


Figure 2.6 Buck-Boost regulator circuit diagram

2.3 Performance Parameters

2.3.1 Efficiency

For an AC-DC converter, the ratio of output power (DC) and input power (AC) is termed efficiency. Let's assume,

The average value of the output (load) voltage, V_{dc}

The average value of the output (load) current, I_{dc}

The output DC power,

$$P_{DC} = V_{DC}I_{DC}$$

The root-mean-square (RMS) value of the source voltage, V_{rms}

The RMS value of the source current, I_{rms}

The input source AC power,

$$P_{AC} = V_{rms}I_{rms}$$

∴ The efficiency (or rectification ratio) of an AC-DC converter,

$$\eta = \frac{P_{DC}}{P_{AC}}$$

It should be noted that η is not the power efficiency. It is the conversion efficiency which is a measure of the quality of the output waveform. For a pure dc output, the conversion efficiency would be unity. Theoretically, output voltages and currents are changed by switching ideally lossless storage components, capacitors, and inductors, between different electrical configurations using a perfectly conducting transistor (provides zero resistance when active and carries zero current when OFF). Thus all the input power is transferred to the load's output power, causing an efficiency of 100%. Practically, such ideal characteristics cannot be obtained, so efficiency cannot be 100%. The prominent power losses occur for the following-

1. Inductor core loss
2. MOSFET switching loss- increases with switching frequency
3. Voltage drops at diodes

These energy losses are responsible for the low efficiency of the converter circuit.

2.3.2 Power Factor

In AC electrical power system, the ratio of real power and apparent power is known as the power factor. Real power is the actual value power consumed by the converter as an average over one line cycle.

$$P_{real} = VIcos\theta$$

Apparent power is described as the RMS (Root Mean Square) product value of voltage and current.

$$P_{apperant} = V.I$$

Where V, I is the RMS value of the AC voltage and current, respectively. θ is the phase angle difference between voltage and current waveforms. Thus, power factor is expressed as,

$$P_{apperant} = \frac{P_{real}}{P_{apperant}} = \frac{VIcos\theta}{V.I} = cos\theta$$

For the AC-DC Buck-Boost converter, the input side's power factor is considered as only the input portion is AC.

2.3.3 Total Harmonic Distortion

The harmonic factor (of the nth harmonic), which is a measure of individual harmonic contribution, is defined as

$$HF_n = \frac{V_{on}}{V_{o1}} \qquad \text{For n >1}$$

Where, V_{o1} is the root-mean-square (RMS) value of the fundamental component and V_{on} is the RMS value of the harmonic component.

The total harmonic distortion, which is a measure of closeness in shape between a waveform and its fundamental component, is defined as

$$THD = \frac{1}{V_{o1}}\left(\sum_{n=2,3\ldots}^{\infty} V^2{}_{on}\right)^{1/2}$$

The extent of harmonic distortion existing in a signal. Same as the power factor, the AC signal is accountable for THD. Thus, for our converter, only the THD of the input side current is observed.

2.3.4 Parameter Standards

The acceptable range of the performance parameters discussed above, according to IEEE standards, are-

Efficiency > 85%

Power factor > 0.9

THD < 5% (maximum 20%)

2.4 Converter Overview

2.4.1 AC-DC Buck-Boost Converter

In the case of DC-DC conversion, different converters are used to obtain regulated output voltage from the unregulated source. As for switching mode power supplies, these converters' basic functionality is to either step-up or step-down the input voltage. The converter intended for stepping down the voltage is known as the Buck converter. Again, the converter designed for stepping up the voltage is known as the Boost converter. Some converters can achieve both step-down and step-up operations by controlling the switching states. The switching conditions can be controlled by tweaking the PWM signal's duty cycle passed to the switch. One of the converters which can perform both of these operations is the Buck-Boost converter. It can operate as a step-down converter or a step-up converter depending upon the duty cycle, D.

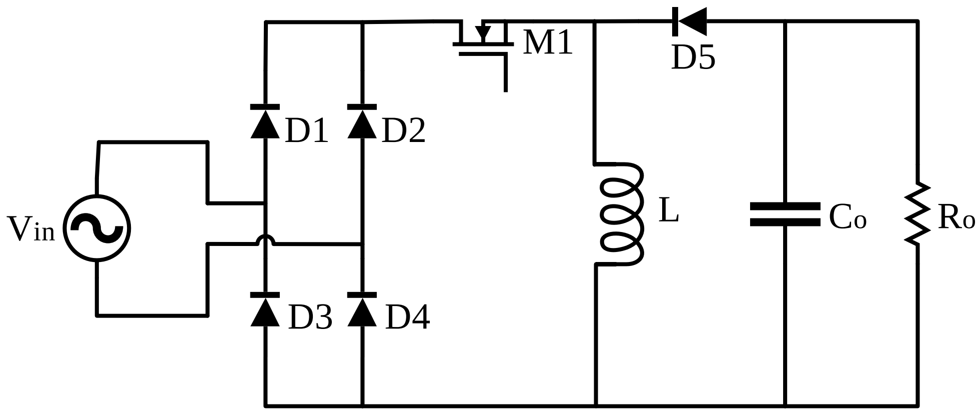


Figure 2.7 AC-DC Buck-Boost Converter (Using full-wave bridge rectifier)

The basic configuration of an AC-DC Buck-Boost converter is shown in Figure 2.7. The converter includes a single-phase AC source, followed by an AC-DC converter (Full-wave bridge rectifier), a MOSFET switch M_1, a diode D_5, an inductor L, an output capacitor C_o and the load as a resistor R_o. The full-bridge rectifier converts the incoming AC supply into a rectified DC supply. The MOSFET M_1 functions as a voltage-controlled switch that operates at lesser power loss than other switches. The switch can be controlled by using a PWM signal. Between two types of PWM signals, one time-based and another frequency-based, it is preferable to use a time-based PWM signal for the Buck-Boost converter. For time-based modulation, it is easier to implement, and frequency remains constant.

2.4.2 Full Bridge rectifier operation

A rectifier circuit consists of one or more diodes, converting an AC signal into a one-directional DC signal. Such rectifiers can be employed as AC-DC converters. The waveform of the output voltage will appear in the same shape as the input. However, the negative portion of the output voltage will have a positive value. A single-phase full-wave bridge rectifier in Figure 2.8(a) comprises four diodes (D_1 – D_4). During the positive half-cycle of the AC input, diode D_1 and D_4 conducts and pass the positive portion of the AC signal across the output capacitor C_o and load R_o. In the negative half-cycle, diode D_2 and D_3 operate and convert the negative part of the AC signal into a rectified wave and pass it across the output. Figure 2.8(b) shows the AC supply waveforms from the input source and the rectified output waveform after full-bridge rectification. Full-wave bridge rectifiers are suitable for industrial applications up to 100KW, and these are simple to use in commercially available units.

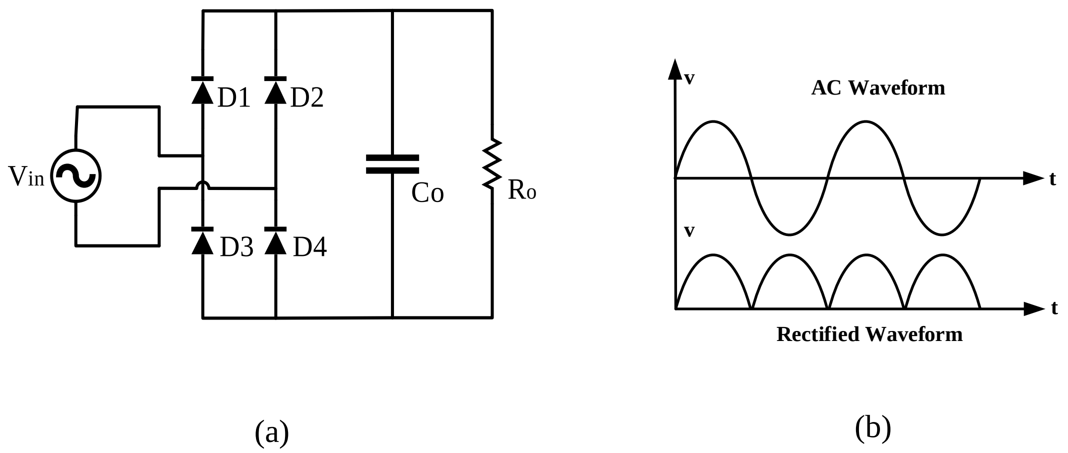


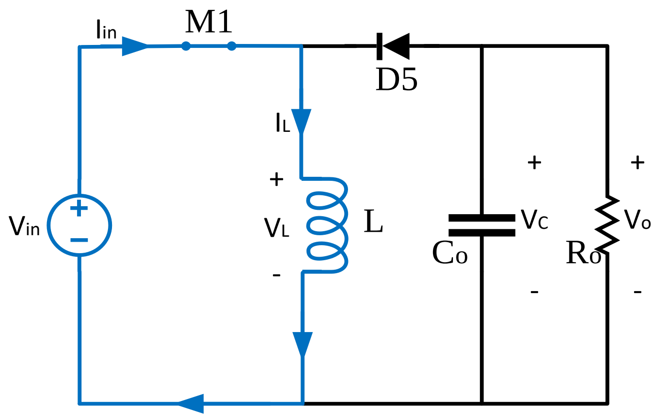
Figure 2.8 Full-wave bridge rectifier (a) Configuration (b) Waveforms

2.4.3 Basic Buck-Boost operation

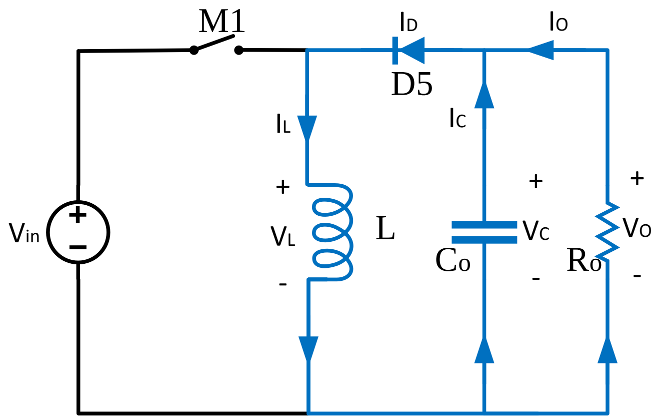
The principle of Buck-Boost conversion is changing the DC output voltage level, whether increasing the output voltage or decreasing it. The rectifier circuit delivers a rectified form of current to the converter side. So, it can be said that, after rectification, a DC-DC conversion takes place at the Buck-Boost converter. Depending upon two switching states, switch ON and switch OFF, the DC-DC Buck-Boost converter has two operations modes.

- In Mode 1, Figure 2.9 (a), the switch M_1 is ON, acting as a short circuit path. From the input, current flows through the switch M_1, then through the inductor L, and returns to the source. As the diode D_5 is in reverse bias with the current flow, it acts as an open circuit. Here inductor L is getting charged due to the current flow from the input. After one cycle, capacitor C_o will discharge, and current will flow through the load resistor, R_o.

- In Mode 2, Figure 2.9 (b), the switch M_1 is OFF, acting as an open circuit path. Although the source is disconnected, inductor L discharges and keeps current flow in the output capacitor C_o and the load resistor R_o. As diode D_5 is now in forward bias with the current flow, it acts as a short circuit, and the current flows through the diode without resistance.



(a)



(b)

Figure 2.9 Principle of operation for Buck-Boost converter (a) Mode 1: Switch M_1 being ON, (b) Mode 2: Switch M_1 being OFF

In the course of Mode 1, in steady-state operation, applying KVL (Kirchhoff's Voltage Law),

$$V_{in} = V_l$$

Where V_{in} is the input voltage, and V_l is the voltage drop across inductor L. Again, for the average inductor current i_L can be expressed as $V_l = L\frac{di_L}{dt}$

$$\therefore V_l = L\frac{di_L}{dt} = V_{in}$$

Let’s say, the total period is T, and duty cycle is D

As the switch M1 is closed for a time $T_{on} = DT$ so, we can say that $\Delta t = DT$,

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{Dt} = \frac{V_{in}}{L}$$

$$\therefore (\Delta i_L)_{closed} = \left(\frac{V_{in}}{L}\right)DT$$

Again, in the course of Mode 2, in steady-state operation, applying KVL,

$$\therefore V_L = V_o$$

Where V_o is the output voltage, and V_l is the voltage drop across inductor L.

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

As the switch M1 is open for a time $T_{off} = T - T_{on} = T - DT = (1-D)T$ we can say that $\Delta t = (1-D)T$,

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

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

Over one complete cycle, the total change of the inductor current is zero.

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

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

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

Thus, duty cycle D will control the Buck-Boost operation. If D is more significant than 0.5, the output voltage is larger than the input, executing Boost operation. If D is less significant than 0.5, the output is smaller than the input, performing Buck operation. For D = 0.5, the output voltage is equivalent to the input voltage.

Chapter 3

Proposed Circuit

3.1 Proposed Converter

3.1.1 Proposed Buck-Boost Configuration

The proposed single-phase passive LC^3 component AC-DC Buck-Boost converter is demonstrated in Figure 3.3. Starting from a single-phase sinusoidal AC source, followed by a full bridge rectifier, afterward an inductor-capacitor combination, namely LC^3 topology, and finally the conventional Buck-Boost converter. The proposed configuration consists of a MOSFET switch M_1, five diodes (D_1-D_5), two inductors (L_1, L_2), four capacitors (C_1-C_3, C_0), and resistor R_0. The arrangement of inductor L_1 and three capacitors C_1-C_3 creates the LC^3 topology. Diode D_5, MOSFET M_1, inductor L_2, output capacitor C_0, and load resistor R_0 constructs the Buck-Boost configuration. This new configuration will contribute to improving the performance parameters of the conventional converter. It will operate at higher efficiency, provide lower Total Harmonic Distortion (THD) at the input side, and improve the input power factor making it closer to unity. The converter operates at continuous conduction mode (CCM). The converter works as an SMPS circuit with MOSFET as the switch. The PWM signal's duty cycle to transistor controls the regulator's output voltage part of the circuit. For a duty ratio > 0.5, DC voltage is stepped up. For a duty ratio of < 0.5, DC voltage is stepped down. Feedback can be used to control the duty ratio for the variable load.

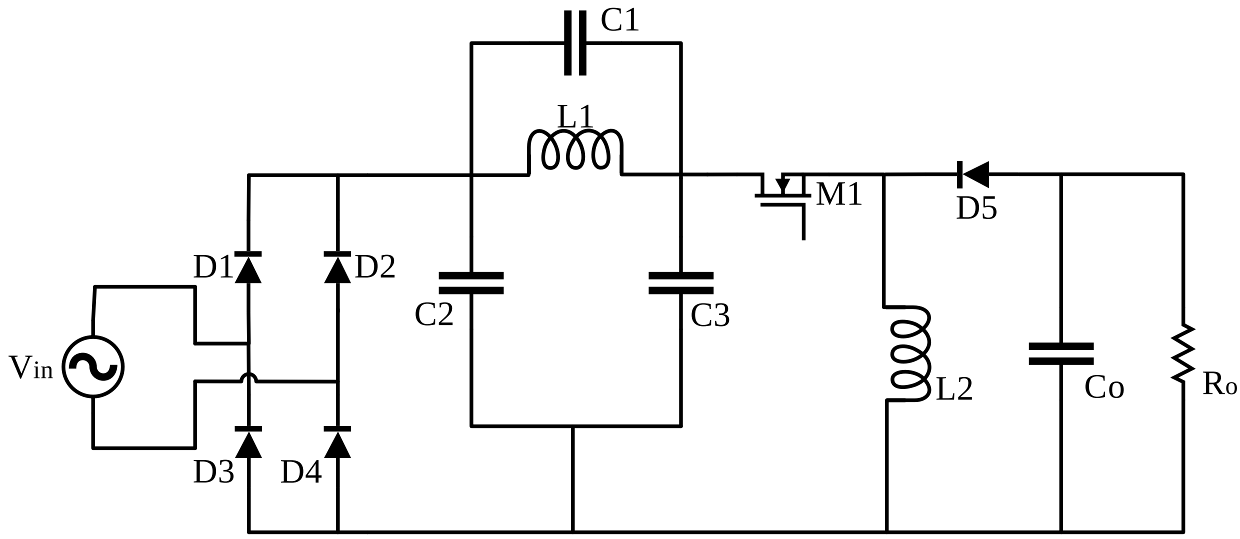


Figure 3.1 Proposed passive LC^3 component AC-DC Buck-Boost Converter

3.1.2 *LC^3 Topology*

LC^3 denotes a combination of one inductor and three capacitors. Arrangement of compact passive components consisted of one inductor L_1 and three capacitors C_1, C_2, and C_3, as shown in Figure 3.4. The idea of LC^3 originated from the construction of an LED driver, which has a similar configuration. LED driver is a self-contained power supply regulating the required power of an array of LEDs. Through the driver, a constant voltage is supplied at the LEDs. Usually, the LEDs have low voltage capacity, so the driver is also used for low voltage applications. In our proposed circuit, this topology is used for the performance enhancement of the traditional Buck-Boost converter. The inductor L_1 opposes the change of current distortion, reducing the Total Harmonic Distortion of the input side current. Again, the three capacitors (C_1, C_2, and C_3) absorb the reactive power and increase the input power factor of the circuit. The overall efficiency of the converter also increases with the implementation of the LC^3 topology. Thus, connecting this topology with the existing Buck-Boost converter will perk up the converter's performance parameters.

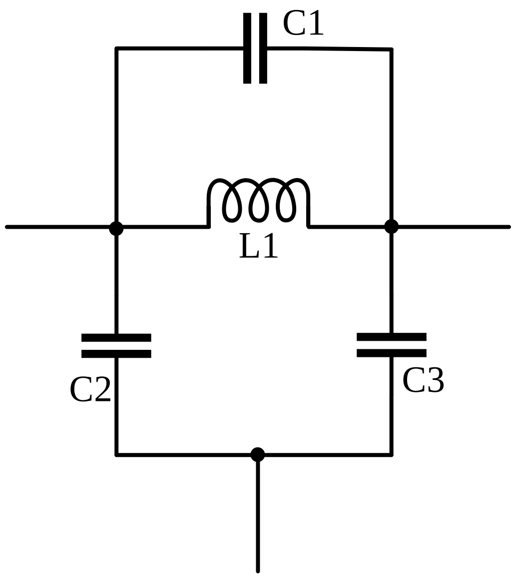


Figure 3.2 LC^3 topology for intended converter

The current flow in the LC^3 topology components, depending upon two switch modes, ON and OFF, are shown in Figure 3.3.

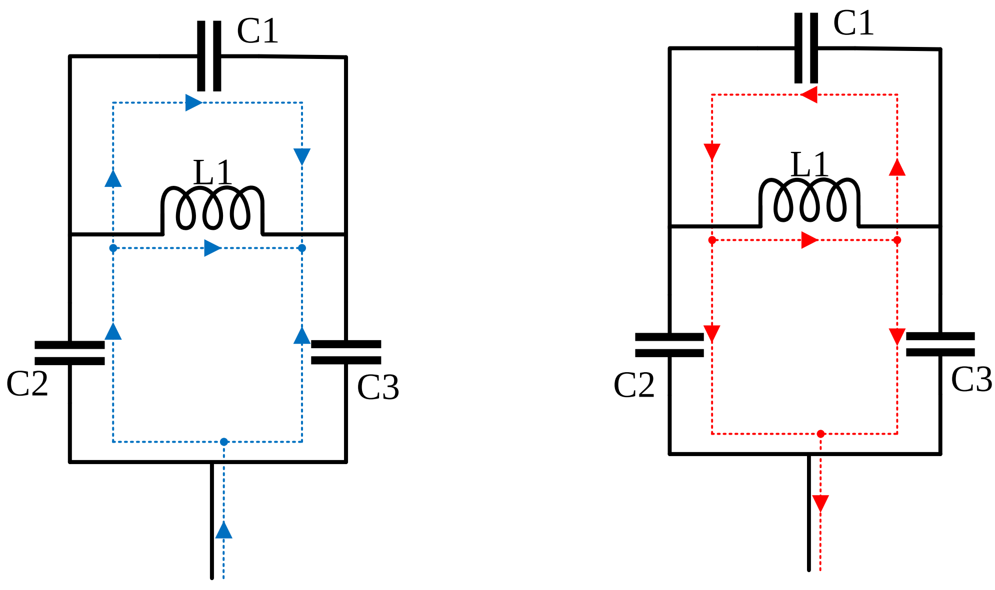


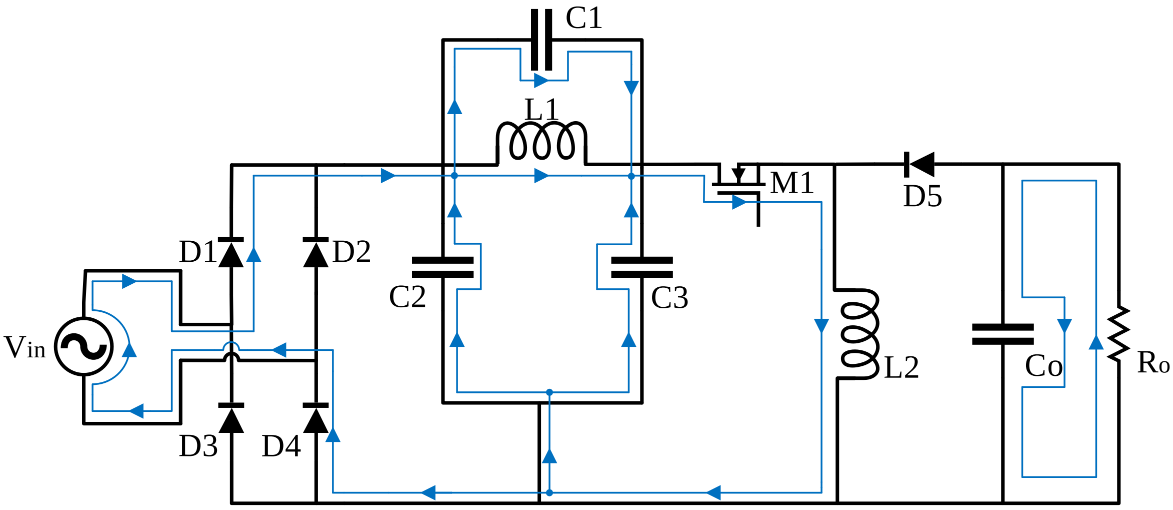
Figure 3.3 Current flow diagram of LC^3 topology (a) Switch being ON, (b) Switch being OFF

The current directions through LC^3 inductor L_1 in Figure 3.3 during both switch ON and OFF states remain unchanged as the inductor is opposing the current direction change.

3.1.3 Converter Operation Analysis

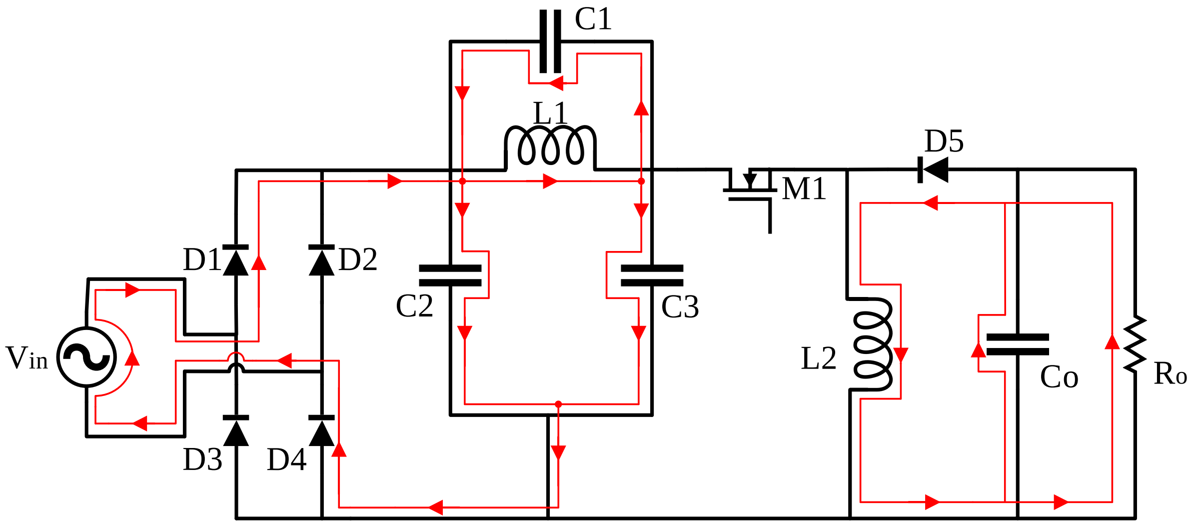
The proposed circuit operates in four modes.

- In Mode 1 Figure 3.4 (a), at positive half-cycle and the switch M_1 is ON, the current flow follows the path through diode D_1, LC^3 topology, switch M_1, Buck-Boost inductor L_2, and then splitting into two portions, one course coming back into the LC^3 topology and another returns to input through diode D_4. Due to the current flow through the LC^3 topology, inductor L_2 is getting charged.
- In Mode 2 Figure 3.4 (b), during the positive half-cycle and the switch M_1 is OFF, current flows through diode D_1, LC^3 topology, and returns to input through diode D_4. This charges the components of the LC^3 topology. Again, inductor L_2 is now discharging, so current flows through output capacitor C_o, load resistor R_o and diode D_5.
- In Mode 3 Figure 3.4 (c), during the negative half-cycle and the switch M_1 is ON, the current flow follows the path through diode D_2, LC^3 topology, switch M_1, Buck-Boost inductor L_2, and then splitting into two portions, one part coming back into the LC^3 topology and another returns to input through diode D_3. Due to the current flow through the LC^3 topology, inductor L_2 is getting charged. Again, capacitor C_o is discharging, so current flows through load resistor R_o.
- In Mode 4 Figure 3.4 (d), during the negative half-cycle and the switch M_1 is OFF, current flows through diode D_2, LC^3 topology, charging the LC^3 components, and returns to input through diode D_3. Due to inductor L_2 discharging current flows through output capacitor C_o, load resistor R_o and diode D_5. This charges up the capacitor C_o.



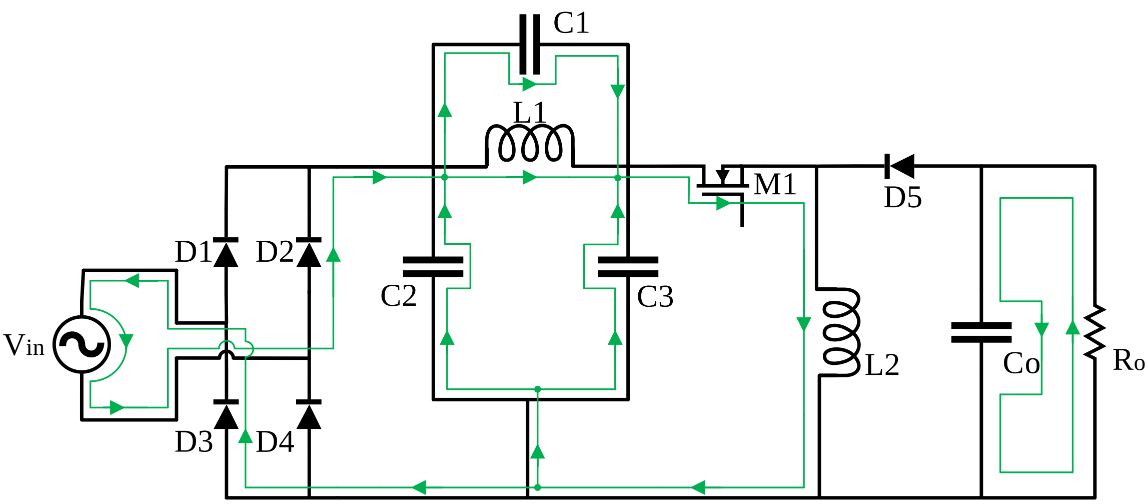
C1
L1
M1
D5
D1
D2
C2
C3
Vin
D3
D4
L2
Co
Ro

(a)



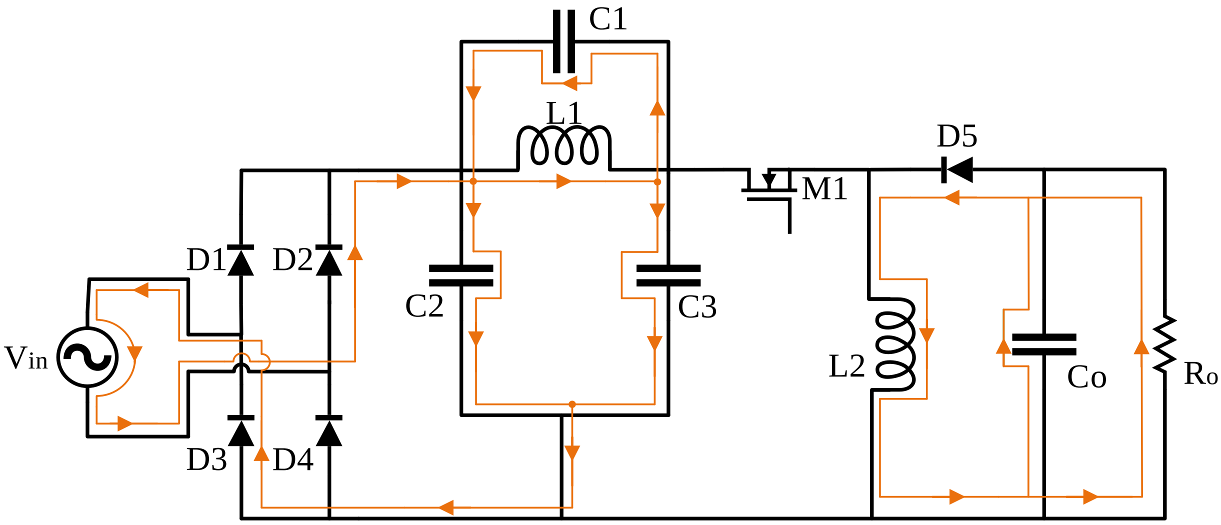
C1
L1
D5
M1
D1
D2
C2
C3
Vin
L2
Co
Ro
D3
D4

(b)



C1
L1
M1
D5
D1
D2
C2
C3
Vin
L2
Co
Ro
D3
D4

(c)



(d)

Figure 3.4 Principle of operation of LC[3] AC-DC Buck-Boost Converter: (a) Mode 1: During positive half cycle & switch M_1 being ON; (b) Mode 2: During positive half cycle & switch M_1 being OFF; (c) Mode 3: During negative half cycle & switch M_1 being ON; (d) Mode 4: During negative half cycle & switch M_1 being OFF

In every mode, the current direction through the LC^3 inductor L_1 remains unchanged. Here, the inductor is opposing the change of current direction, which is also responsible for lessening the input THD. However, the current through the LC^3 capacitors (C_1, C_2, and C3) changes with the ON and OFF states of the switch M_1.

3.3 Feedback Control

3.3.1 Feedback Configuration

For further enhancement of the converter, closed-loop feedback control is established. The configuration of the feedback control converter is demonstrated in figure 3.5. The feedback path consists of a voltage sensor (V_S), passed through an absolute block (|X|), and then a multiplying block connected with a 3V external DC supply. The connection goes to a summation block from the multiplier, followed by the PI controller, a limiting block, an operational amplifier connected with a triangular AC supply, and a current sensor (C_S)

connected alongside the switch M_1. The PI controller aids the feedback path to increase the input power factor closer to unity and reduce the THD of the input current.

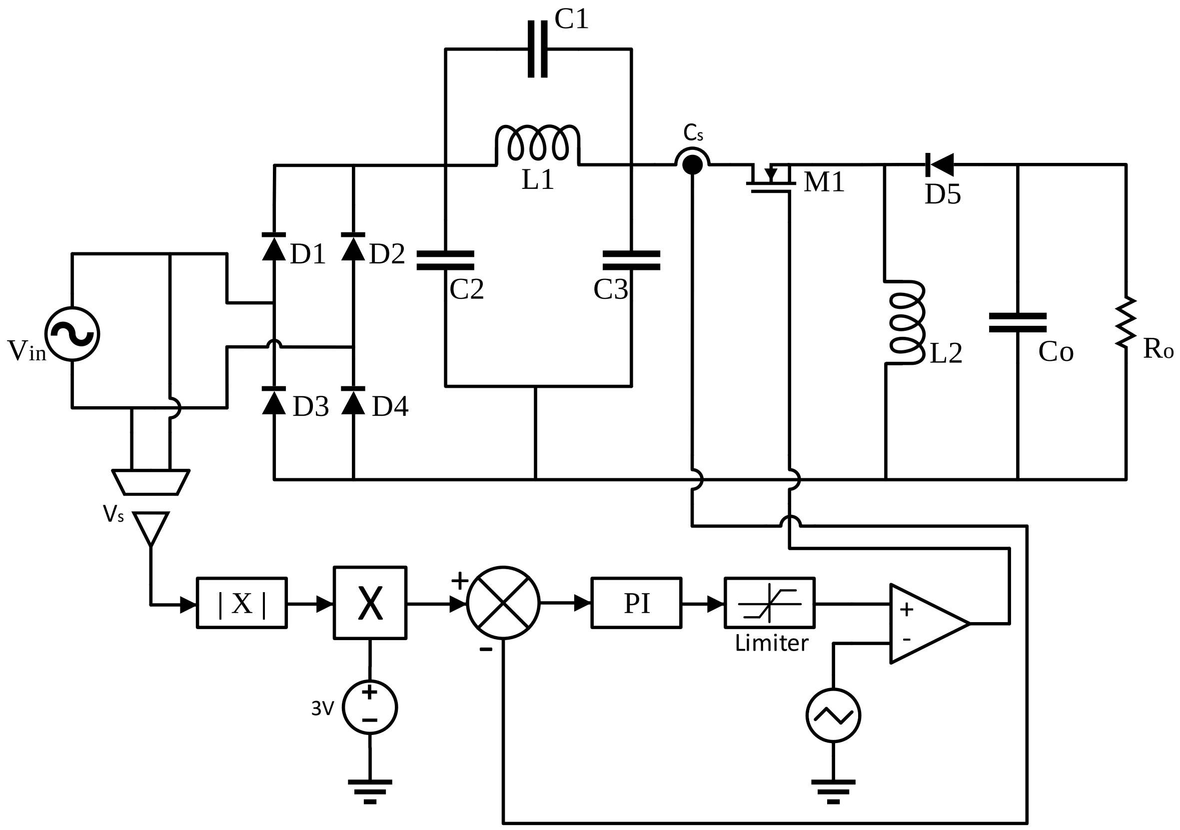


Figure 3.5 Closed-loop feedback control implementation for LC^3 AC-DC Buck-Boost converter

3.3.2 Feedback Components Analysis

Voltage Sensor (V_s*):* Used for calculating and monitoring the amount of voltage in the circuit. The voltage sensor can determine the AC voltage or DC voltage level. In our proposed converter, the input voltage is passed through the voltage sensor V_s, where the output is a current signal passed to an absolute value block.

Absolute value block (|X|*):* Converts the input AC signal into a rectified signal by taking the signal components' absolute values.

DC scaler and Multiplier: An external DC voltage supply to scale the rectified signal to the desired form, which will later be used for necessary comparison. The amount of DC supply is considered 3V after performing successive approximations, leading to the converter's best possible results. The DC voltage is multiplied with the incoming rectified signal through a multiplier block.

Summation block: Performs the summation of two incoming signals. At the positive terminal, a scaled rectified current is added, and at the negative terminal, the LC^3 induction current coming from the current sensor Cs is subtracted.

PI Controller: A proportional-integral controller (PI controller) is a control loop mechanism employing feedback. PI controller continuously calculates an error value $E_r(t)$ as the difference between the desired set-point (SP) and a measured process variable (PV) and applies a correction based on the proportion and integral terms. $u(t)$ is considered as the controller output.

$$E_r(t) = SP - PV$$

$$u(t) = U_{bias} + k_c E_r(t) + \frac{k_c}{\tau_I} \int_0^t e(t)dt$$

Here U_{bias} is a constant. When at first the PI controller is switched to go from manual to automatic, this constant value is set as the value of $u(t)$. This provides a “bumpless” transfer if the error is zero when the controller is turned on. PI controller has two tuning parameters, which are controller gain k_c and the integral time constant τ_I. The value of k_c is the multiplier of proportional error and integral term, and a higher value makes the controller more aggressive at responding to errors away from the set-point.

Comparator and limiter: The Op-amp comparator compares one analog voltage level with another analog voltage level, or some preset reference voltage, $Vref$ and produces an output signal based on this voltage comparison. In other words, the op-amp voltage comparator compares the magnitude of two voltage inputs and determines which is the larger of the two. For $Vref$ a triangular wave voltage source is connected at the negative terminal of the op-amp, providing a 10V peak to peak triangular AC supply to the comparator. A limiter block has been connected between the PI controller and the comparator. It sets the limiting value of the comparator from 0 to 10 to obtain the desired optimum result.

*Current sensor (*Cs*):* It's a device that detects electric current in a wire and generates a signal proportional to the current. The generated signal can show the measured current in an ammeter or can be applied for control purposes. In our proposed converter, the generated signal is an analog current signal used to compare the input current signal. The signal is passed to the negative terminal of the summation block of the feedback control. This connection forms the feedback path of the converter circuit.

3.3.3 Feedback Operation Analysis

In the closed-loop feedback control circuit, a scaled rectified current is taken from the input side and compared with the LC^3 induction current of our proposed converter. The PI controller functions as an error minimizer. It reduces the distortion difference between the current coming from the input and the current coming from the LC^3 topology. The comparison is made by the op-amp, which works as a comparator. The limiter sets the limiting value of the comparator at 0 to 10. We have chosen appropriate scaling factors to get the optimum results from the converter. These scaling factors were obtained after performing successive approximations. With the feedback control, the converter is operating at an even higher efficiency. The PI controller's implementation helps to reduce the input side THD and increase the input power factor. Thus the feedback control improves the performance parameters of our LC^3 Buck-Boost converter.

Chapter 4

Simulations and Results

4.1 Assumptions and Parameters

The single-phase passive LC^3 component AC-DC Buck-Boost converter operations were simulated using the software PSIM (version 12.0.1). For theoretical analysis, the following assumptions were made:

- All the components are presumed to be ideal.
- The input voltage V_{in} is considered as a purely sinusoidal source.
- Converter operation is conducted in Continuous Conduction Mode.
- The value of output capacitor C_o is chosen large enough to avoid ripple in output voltage (V_o as pure DC voltage)

The parameters used for the simulation of the proposed converter is shown in Table 4.1

Table 4.1 Design parameter specifications

Parameter	Value
Input Voltage, V_{in}	100V
Input Frequency, f	50Hz
Rectifier, D_1-D_4	Full Bridge Rectifier
LC^3 Inductor, L_1	1mH
LC^3 Capacitors, C_1–C_3	10μF
Switching Device	MOSFET
Switching frequency, f_s	5000Hz
Buck-Boost Inductor L_2	5mH
Output Capacitor, C_o	330μF
Load Resistor, R_o	100Ω

4.2 Waveforms of voltages and currents

For observing the voltage and current waveforms through the components and the input, output sides, voltmeters were connected across the branches, and ammeters were connected in series. The PSIM simulation for both the traditional Buck-Boost converter and the proposed Buck-Boost converter was conducted at a duty cycle of 70%. For the proposed converter, waveforms are observed for both with and without the feedback control.

4.2.1 Conventional Buck-Boost Converter waveforms

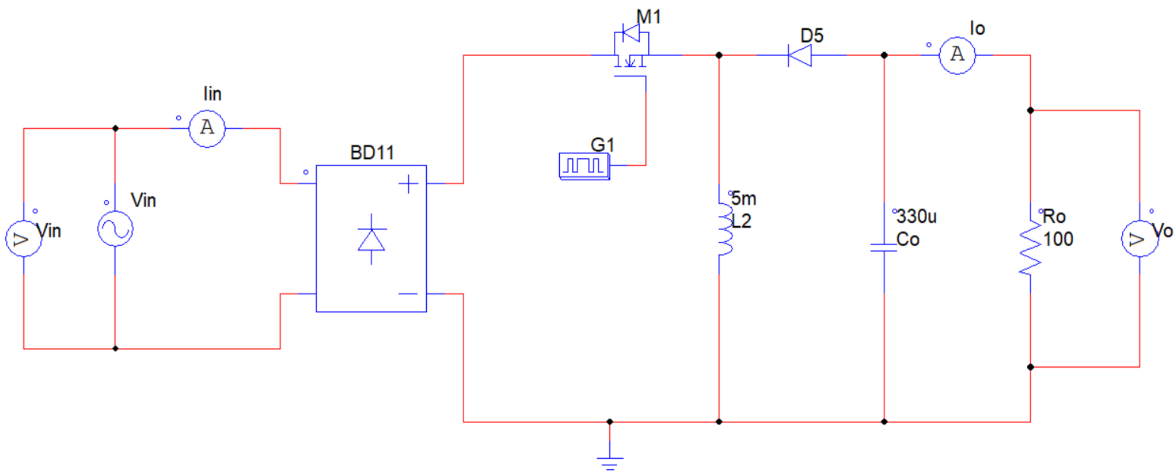


Figure 4.1 Conventional AC-DC Buck-Boost converter constructed in PSIM

Figure 4.1 displays the conventional AC-DC Buck-Boost converter simulated in PSIM. The circuit consists of sinusoidal AC source Vin, A bridge rectifier BD11, MOSFET switch M1, a gating block G1, to supply PWM signal to the switch, diode D5, inductor L2, output capacitor Co, and load resistor Ro. The component values are assigned as per the assumptions mentioned in Table 4.1. Voltmeters are connected across the input-output components to measure voltage, and ammeters are connected in branches to calculate the branch currents. Tweaking the switching point values in the gating block will provide the PWM signal with desired duty cycle to the switch.

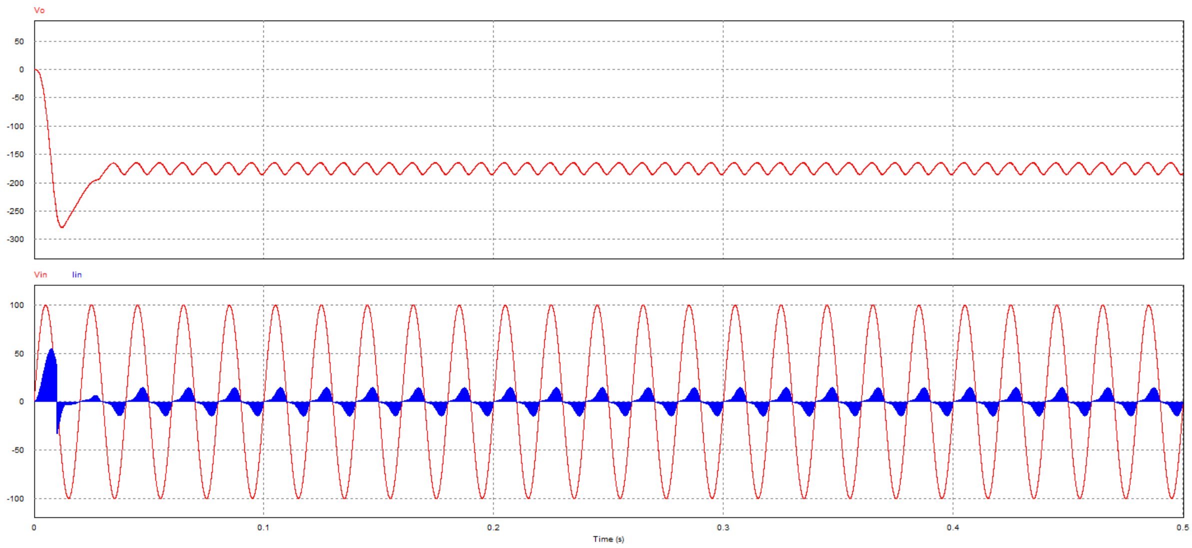


Figure 4.2 Output voltage and Input voltage-current waveforms for conventional AC-DC Buck-Boost converter simulated in PSIM

Figure 4.2, the obtained voltage and current waveforms of the conventional AC-DC Buck-Boost converter can be observed. These waveforms are for the converter operating at a 70% duty cycle. The input voltage waveform is made of a 100V sinusoidal AC supply. The input current waveform contains a significant amount of distortion, causing the input THD to be higher. The output voltage waveform shows a negative DC voltage having an overshoot at the beginning, which gradually produces a constant ripple with an average voltage of -174.5V.

4.2.2 Proposed LC³ Component AC-DC Buck-Boost Converter waveforms

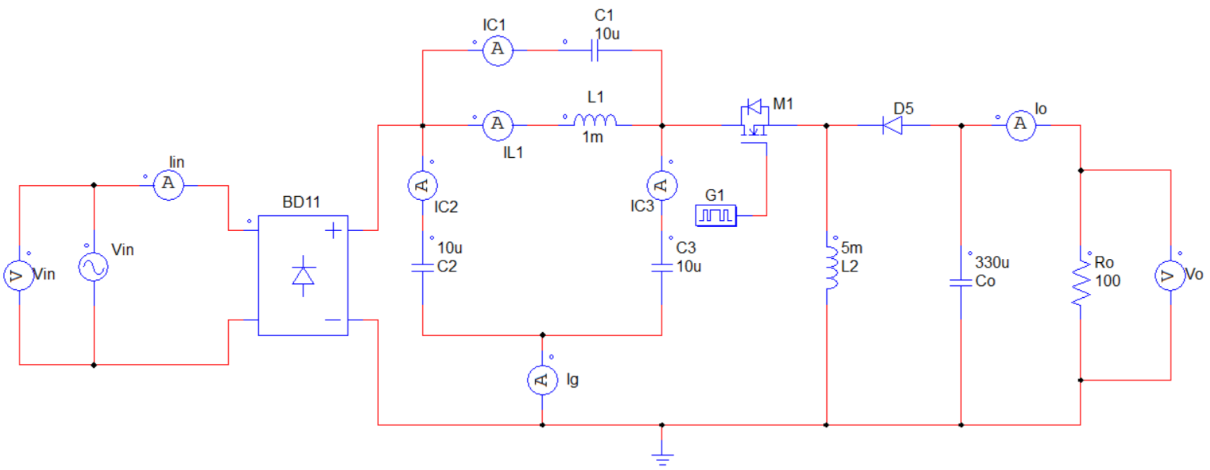


Figure 4.3 LC³ Component AC-DC Buck-Boost converter constructed in PSIM

Figure 4.3 demonstrates the proposed LC^3 component AC-DC Buck-Boost converter simulated in PSIM. Along with the traditional Buck-Boost converter components described earlier, this circuit contains the LC^3 topology connected between the bridge rectifier and the Buck-Boost configuration. The component values are assigned as per the assumptions mentioned in Table 4.1. Ammeters are connected in each branch of the LC^3 topology to observe the current flow through the LC^3 inductors and capacitors.

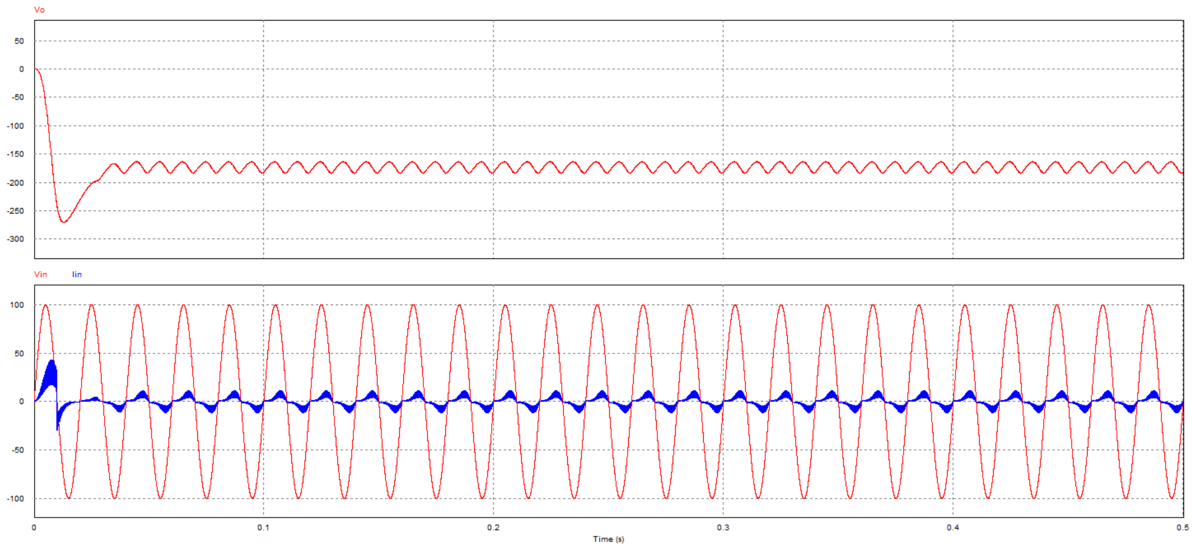


Figure 4.4 Output voltage and Input voltage-current waveforms for LC^3 Component AC-DC Buck-Boost converter simulated in PSIM

Figure 4.4 displays the simulated voltage and current waveforms of the LC^3 component AC-DC Buck-Boost converter. These waveforms are for the converter operating at a 70% duty cycle. The input current waveform for the proposed converter shows that it has lesser distortion in the waveform. Thus THD of the input current has been decreased by using the LC^3 configuration. However, the output voltage still contains an overshoot at the beginning of the waveform. At a 70% duty cycle, the converter provides an average voltage of -173.1V by performing Boost operation.

4.2.3 *Feedback controlled LC^3 Component AC-DC Buck-Boost Converter waveforms*

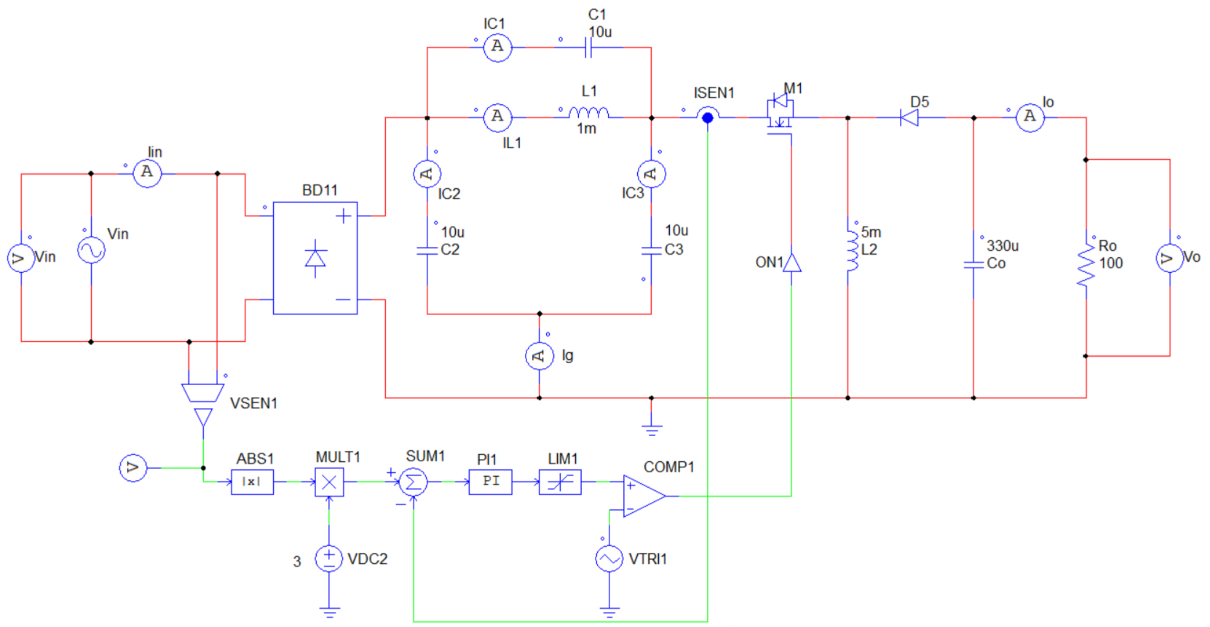


Figure 4.5 Feedback Controlled LC^3 Component AC-DC Buck-Boost converter constructed in PSIM

Figure 4.5 demonstrates the closed-loop feedback control for our proposed LC^3 component AC-DC Buck-Boost converter simulated in PSIM. The feedback path consists of a voltage sensor VSEN1, absolute block ABS1, external DC supply VDC2 for scaling purpose, a multiplier MULT1, a summation block SUM1, proportional-integral controller PI1, limiting block LIM1, a comparator COMP1, reference voltage supplier at comparator VTRI1, an ON-OFF switch controller ON1, and a current sensor ISEN1. In Figure 4.5, the red wire lines signify power circuits, whereas the green wire lines signify the control circuit. The DC scaler value has been taken as 3V after performing successive approximations. The PI controller has the gain value set to 0.8, and a time constant of value 0.0001 is chosen. For reference voltage at the comparator, a triangular AC supply with 10V peak-peak and 20000Hz frequency is connected at the op-amp's negative terminal. The rest of the component values are assigned as per the assumptions mentioned in Table 4.1.

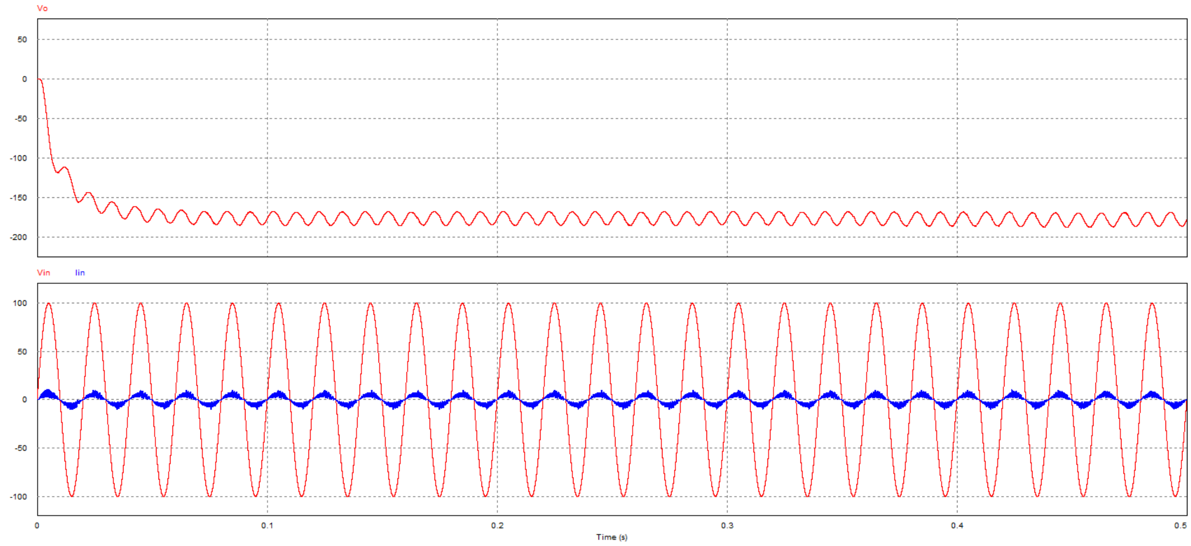


Figure 4.6 Output voltage and Input voltage-current waveforms for Feedback Controlled LC^3 Component AC-DC Buck-Boost converter simulated in PSIM

Figure 4.6 displays the LC^3 component AC-DC Buck-Boost converter's obtained voltage and current waveforms after implementing the closed-loop feedback control. The simulation was performed to get the best possible outcomes from the converter. The input current waveforms have become more sinusoidal in shape, having lesser distortions than non-feedback control. The lesser distortions imply that due to feedback control, the THD of the input current has been further reduced. The feedback control eliminates unwanted overshoots from the output voltage waveform previously seen in the non-feedback proposed converter.

4.3 Comparative Analysis

4.3.1 Efficiency Comparison

The proposed converter has higher efficiency when compared with the conventional Buck-Boost converter. It can be observed from Figure 4.7 that the efficiency of the proposed converter increase with duty cycle and stabilizes at a maximum efficiency of 97.02%

Table 4.2 Efficiency vs. Duty Cycle of Conventional and LC^3 Component Buck-Boost Converter

Duty Cycle	Conventional Buck-Boost			LC^3 Component Buck-Boost		
	Pin	Pout	Efficiency%	Pin	Pout	Efficiency%
10%	1.705	1.178	69.09%	2.466	1.834	74.36%
15%	3.730	2.915	78.17%	4.552	3.845	84.46%
20%	6.868	5.743	83.61%	7.153	6.350	88.76%
25%	11.476	10.009	87.21%	11.531	10.496	91.03%
30%	18.037	16.187	89.74%	17.917	16.623	92.78%
35%	27.218	24.928	91.59%	27.013	25.382	93.96%
40%	39.898	37.092	92.97%	39.622	37.582	94.85%
45%	57.395	53.973	94.04%	56.865	54.359	95.59%
50%	81.437	77.257	94.87%	80.749	77.570	96.06%
55%	114.689	109.551	95.52%	113.508	109.441	96.42%
60%	160.820	154.438	96.03%	158.512	153.237	96.67%
65%	225.923	217.879	96.44%	221.892	215.001	96.89%
70%	317.653	307.314	96.75%	311.513	302.217	97.02%

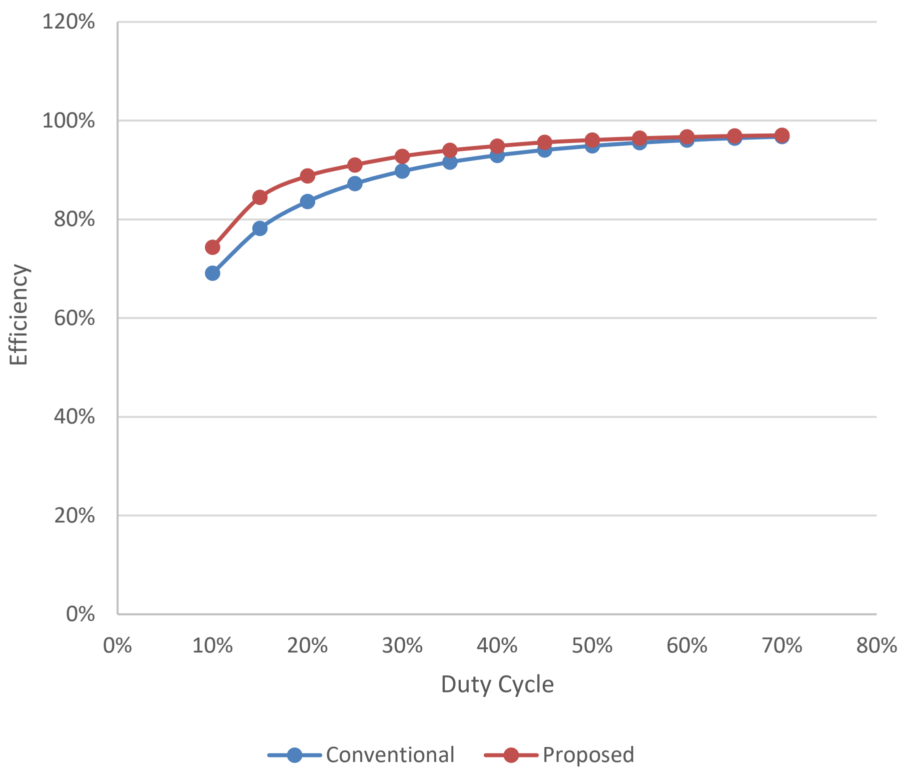


Figure 4.7 Efficiency Comparison

Figure 4.7 shows the comparison of efficiency between the conventional Buck-Boost converter and the LC^3 component Buck-Boost converter. The efficiency is relatively higher in the LC^3 component Buck-Boost converter than the conventional Buck-Boost Converter. For example, at a 10% duty cycle, the efficiency is 69.09% in the traditional Buck-Boost converter, whereas, in the LC^3 component Buck-Boost converter, it is 74.36%. The graph shows that, with the increase of duty cycle, the converter's efficiency also increases. But after around 60% duty cycle, the efficiency does not increase that much. That means it’s quite persistent after a 60% duty cycle. At an even higher duty cycle, the efficiency will start decreasing due to the power losses occurring at the switch. Thus, the duty cycle range has been shown up to 70% for efficiency comparison.

4.3.2 Input Power Factor Comparison

The proposed converter has a better input power factor when compared with the conventional Buck-Boost converter. This improvement is achieved due to the implementation of the LC^3 configuration, which reduces ripple current and harmonics. From Figure 4.8, it can be observed that the input power factor of the proposed converter increases as the duty cycle increases.

Table 4.3 Input PF vs. Duty Cycle of Conventional and LC^3 Component Buck-Boost Converter

Duty Cycle	Conventional Buck-Boost PF	LC^3 Component Buck-Boost PF
10%	0.283	0.419
15%	0.334	0.477
20%	0.378	0.517
25%	0.415	0.575
30%	0.449	0.626
35%	0.479	0.669
40%	0.507	0.705
45%	0.533	0.732
50%	0.557	0.744
55%	0.580	0.750
60%	0.599	0.751
65%	0.617	0.749
70%	0.628	0.741

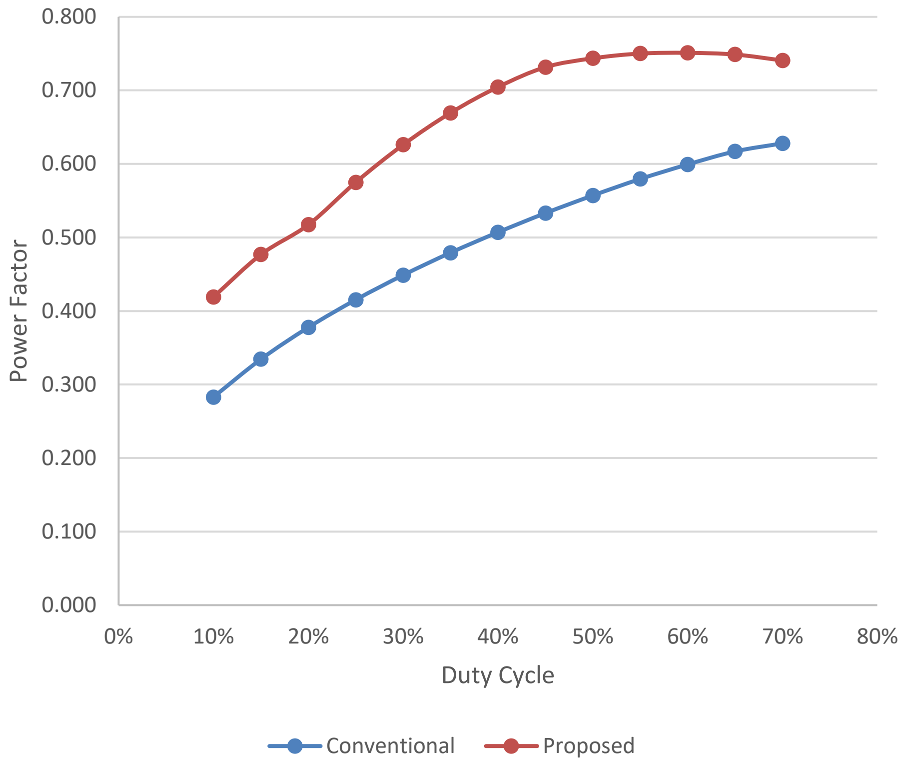


Figure 4.8 Input PF Comparison

In Figure 4.8, we have compared the input power factor with respect to duty cycle between the conventional converter circuit and the proposed converter circuit. The blue line is for the traditional converter circuit, and the red line is for the proposed converter circuit. The comparison says that the power factor is closer to the unity for the proposed converter circuit than the conventional converter circuit. For the 10% duty cycle, the power factor is measured at 0.283 in the conventional Buck-Boost converter and 0.419 in the LC^3 component Buck-Boost converter. Additionally, with the increment of the duty cycle, the PF of the converter also increases. Let's say, at 70% duty cycle, PF is 0.627 in conventional Buck-Boost converter and 0.741 in LC^3 component Buck-Boost converter. So in boost operation, PF is more improved than in Buck operation.

4.3.3 Total Harmonic Distortion Comparison

Figure 4.9 shows that the total harmonic distortion is less in the proposed converter in contrast with the conventional one. The LC^3 configuration acts as an input filter, which decreases the current ripple, thus significantly reducing the THD of the circuit. It can be observed that the THD of the proposed converter decreases with the increase in duty cycle.

Table 4.4 THD vs. Duty Cycle of Conventional and LC^3 Component Buck-Boost Converter

Duty Cycle	Conventional Buck-Boost THD	LC^3 Component Buck-Boost THD
10%	316.88%	185.46%
15%	258.56%	155.52%
20%	221.61%	129.11%
25%	195.36%	104.89%
30%	175.25%	90.91%
35%	158.91%	83.10%
40%	145.11%	76.53%
45%	132.79%	70.66%
50%	121.47%	67.97%
55%	110.61%	64.60%
60%	100.20%	60.43%
65%	89.72%	55.70%
70%	79.23%	50.23%

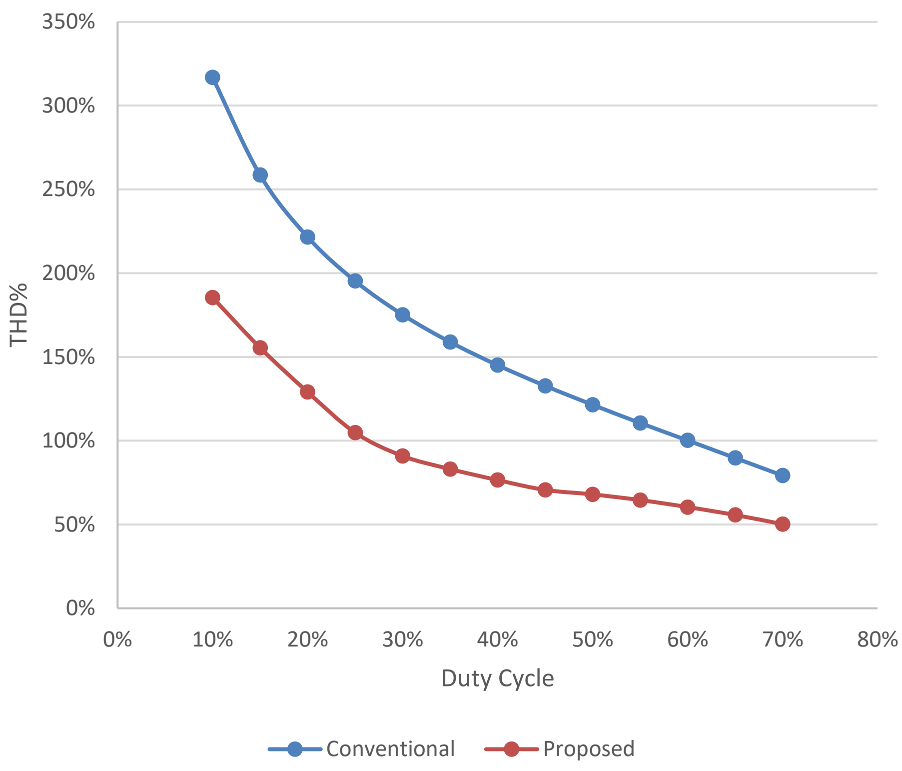


Figure 4.9 THD Comparison

Figure 4.9 shows the THD comparison between the conventional Buck-Boost converter and the LC^3 component Buck-Boost converter. THD has decreased in the LC^3 component Buck-Boost converter. For example, at a 10% duty cycle, THD is 316.88% in conventional Buck-Boost converter while it is 185.46% in LC^3 component Buck-Boost converter. THD is decreasing with increasing of duty cycle. So in boost operation, THD is quite improved than in Buck operation. For instance, at 70% duty cycle, THD is 79.23% in conventional Buck-Boost converter whereas 50.23% in LC^3 component Buck-Boost converter. The declining nature of THD shown in Figure 4.9 insists that the converter's boost operation operates at a lesser THD than the Buck operation of the converter.

4.3.4 *Feedback Control Comparison*

A closed-loop feedback control is developed, which delivers an average output voltage of 172.4V. The feedback controller further enhances the converter performance by operating at increased efficiency, improving the input power factor, and having lesser THD. Moreover, the overshoot at the output voltage is eliminated due to using the feedback control. Table 4.5 shows the parametric comparison among conventional converter, a converter with no feedback control, and converter with feedback control. The comparison is presented by taking the best results for the open-loop converter.

Table 4.5 Performance comparison among feedback control and non-feedback control converter

Parameters	Conventional converter	Proposed converter with no feedback	Proposed converter with feedback
Efficiency (%)	96.75%	97.02%	99.11%
PF	0.62799	0.7511	0.9288
THD	79.23%	50.23%	38.63%

From our simulation, it’s evident that at a duty cycle of 70%, the Buck-Boost converter shows the best performance results. For the converter without the feedback control, the simulated results with better performance parameters are observed for boost operation. The proposed converter operates, having 0.27% more efficiency than the conventional converter. With feedback, efficiency reaches 99.11%. Power factor is improving and closing nearer to unity with now being at 0.9288. THD has been reduced from 79.23% to 50.23%, and with feedback control, THD comes down to 38.63%.

4.4 PCB Design

A PCB of the proposed converter circuit is designed for practical adaptation of the converter. The design is constructed in Proteus (Version 8.8) software. The PCB board has a size of 2.4-inch width and 2.8-inch height. In practice, an optocoupler is used to pass the PWM signal generated from the signal generator. However, Proteus software doesn't contain any optocoupler package, which can be used in PCB design. Instead of the optocoupler, a 555-timer (U1, eight pins) is used in Proteus design, which has a similar pin configuration. The optocoupler provides electrical isolation for the converter while receiving PWM signal from a signal source.

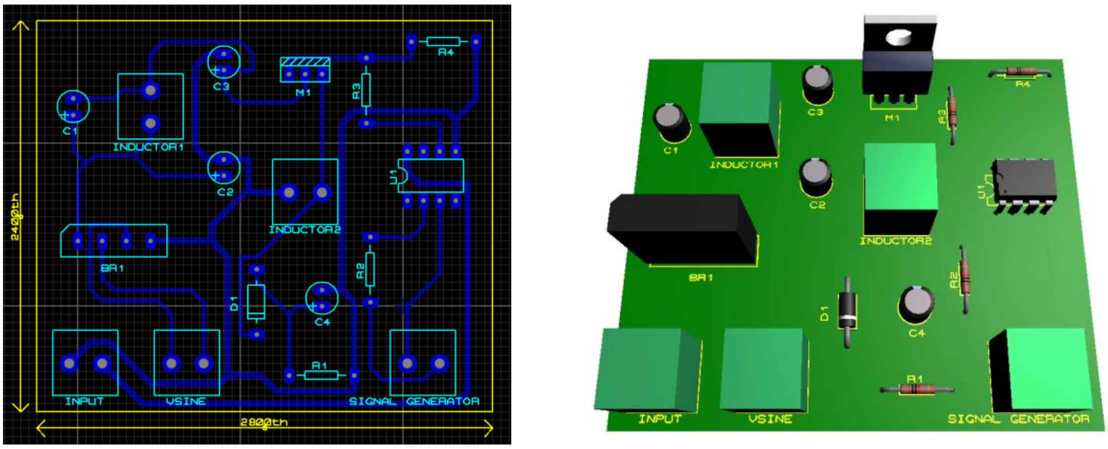


Figure 4.10 PCB layout and PCB visualization of LC^3 component Buck-Boost converter

Chapter 5

Conclusion

5.1 Summary

This thesis project aims to contribute to the ever-progressing field of power electronics. Traditional AC-DC Buck-Boost converters provide both conversion and regulation of the input AC supply. But this converter comes with some drawbacks that affect the performance parameters significantly. In this thesis, a novel AC-DC Buck-Boost converter has been discussed. The proposed converter has been derived from a conventional Buck-Boost converter along with an LC^3 configuration. Due to the implementation of the LC^3 topology, the performance parameters of the converter have been enhanced. The addition of the feedback controller further augments the performance of the proposed converter. Without feedback control, the proposed converter achieves an efficiency of 97.02%, which increases to 99.11% when the feedback controller is used. Power factor has been increased to 0.7511; with feedback control, it reaches up to 0.9288. THD has decreased to 50.23% and further comes down to 38.63% with feedback control. Therefore, we achieved around 3% increase in efficiency, about 48% increase in power factor and an overall 40% decrease in total harmonic distortion from the proposed circuit configuration in comparison to a conventional Buck-Boost circuit. The proposed converter can be applied in automated power supplies, battery-powered systems, adaptive control applications, power amplifier applications, HVDC applications like microgrids, and consumer electronics.

5.2 Future Work

The future work includes an implementation of a dual closed-loop feedback system with voltage correction. The employment of a PWM signal controller can lead to controlling of duty cycle in the feedback system. The further enhancement will be carried out to reduce THD. For observing the converter performance in practice, a hardware implementation will be conducted in the future.

References

[1] S. Singh, B. Singh, G. Bhuvaneswari and V. Bist, "Power Factor Corrected Zeta Converter Based Improved Power Quality Switched Mode Power Supply," in IEEE Transactions on Industrial Electronics, vol. 62, no. 9, pp. 5422-5433, Sept. 2015.

[2] Akter, K., G. Sarowar, and M.A. Hoque, *An Approach of improving performance of the single phase AC-DC Sepic Converter.*

[3] J. M. Ho and C. C. Wu, "A switching DC-DC converter with wide conversion range without extreme duty ratios," Proceedings of 1994 IEEE International Symposium on Industrial Electronics (ISIE'94), Santiago, Chile, 1994, pp. 92-97.

[4] D. Maksimovic and S. Cuk, "Switching converters with wide DC conversion range," in IEEE Transactions on Power Electronics, vol. 6, no. 1, pp. 151-157, Jan. 1991, doi: 10.1109/63.65013.

[5] A. Ioinovici, "Switched-capacitor power electronics circuits," in IEEE Circuits and Systems Magazine, vol. 1, no. 3, pp. 37-42, 2001, doi: 10.1109/7384.963467.

[6] V. M. Pacheco, A. J. do Nascimento, V. J. Farias, J. Batista Vieira and L. C. de Freitas, "A quadratic buck converter with lossless commutation," in IEEE Transactions on Industrial Electronics, vol. 47, no. 2, pp. 264-272, April 2000, doi: 10.1109/41.836341.

[7] V. M. Pacheco, V. J. Farias, J. B. Vieira, A. J. Nascimento and L. C. de Freitas, "A quadratic buck converter with lossless commutation," Proceedings of Applied Power Electronics Conference. APEC '96, San Jose, CA, USA, 1996, pp. 311-317 vol.1, doi: 10.1109/APEC.1996.500460.

[8] B. Axelrod, Y. Berkovich and A. Ioinovici, "Switched-capacitor (SC)/switched inductor (SL) structures for getting hybrid step-down Cuk/Sepic/Zeta converters," 2006 IEEE

International Symposium on Circuits and Systems, Kos, Greece, 2006, pp. 4 pp.-, doi: 10.1109/ISCAS.2006.1693770.

[9] Available: https://en.wikipedia.org/wiki/Rectifier [Accessed March 2021]

[10] Available: https://en.wikipedia.org/wiki/DC-to-DC_converter [Accessed March 2021]

[11] B. Singh, B. N. Singh, A. Chandra, and K. Al-Haddad, A. Pandey, D. P. Kothari, "A review of single-phase improved power quality AC-DC converters", *IEEE Transactions on Industrial Electronics*, Vol. 50, No. 5, Oct. 2003, pp 962 – 981.

[12] O. Garcia, J. A. Cobos, R. Prieto, P. Alou, and J. Uceda, "Single Phase Power Factor Correction: A Survey", *IEEE Transactions on Power Electronics*, Vol. 18, No. 3, May 2003, pp. 749-755.

[13] O. Lopez, L. Garcia De Vicuna, M. Castilla, J. Matas and M. Lopez, "Sliding-mode-control design of a high-power-factor buck-boost rectifier," in IEEE Transactions on Industrial Electronics, vol. 46, no. 3, pp. 604-612, June 1999.

[14] M. S. Patil, S. P. Patil and D. N. Kyatanavar, "Single-phase, wide line voltage range, buck power factor corrector with lower harmonic contents in compliance with IEC standard 61000-3-2," 2010 Joint International Conference on Power Electronics, Drives and Energy Systems & 2010 Power India, New Delhi, 2010, pp. 1-8.

[15] P. F. de Melo, R. Gules, E. F. R. Romaneli and R. C. Annunziato, "A Modified SEPIC Converter for High-Power-Factor Rectifier and Universal Input Voltage Applications," in IEEE Transactions on Power Electronics, vol. 25, no. 2, pp. 310-321, Feb. 2010.

[16] J. Ejury, "Buck converter design," Infineon Technologies North America (TFNA) Corn Design Note, vol. 1, 2013.

[17] Supratim Basu, "Single Phase Active Power Factor Correction Converters Methods for Optimizing EMI, Performance and Costs," PhD. Thesis, Chalmers University of Technology, Göteborg, Sweden, June 2006.

[18] K. Saifullah, M. A. A. Hysam, M. Z. U. Haque, S. Asif, G. Sarowar and M. T. Ferdaous, "Bridgeless AC-DC buck-boost converter with switched capacitor for low power applications," *TENCON 2017 - 2017 IEEE Region 10 Conference*, Penang, 2017, pp. 1761-1765

[19] EL-Kholy, E. E.. “Review of Passive and Active Circuits for Power Factor Correction in Single Phase, Low Power AC-.” (2010).

[20] G. K. Andersen and F. Blaabjerg, "Current programmed control of a single-phase two-switch buck-boost power factor correction circuit," in IEEE Transactions on Industrial Electronics, vol. 53, no. 1, pp. 263-271, Feb. 2006.

[21] E. S. Lee, B. H. Choi, J. P. Cheon, G. C. Lim, B. C. Kim and C. T. Rim, "Temperature-Robust LC3 Passive LED Drivers With Low THD, High Efficiency and PF, and Long Life," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 3, no. 3, pp. 829-840, Sept. 2015.

Published Work

Our work has been presented at an IEEE conference, and the published conference paper can found in the IEEE Xplore digital library.

M. D. Rahman, F. S. Haq, M. B. Mahboob, S. Ali and G. Sarowar, "High-Efficiency Single Phase Passive LC3 Component AC-DC Buck-Boost Converter," 2020 2nd International Conference on Advanced Information and Communication Technology (ICAICT), Dhaka, Bangladesh, 2020, pp. 325-329, doi: 10.1109/ICAICT51780.2020.9333459.