DEVELOPMENT OF AN INPUT SWITCHED CONTINUOUS INPUT CURRENT BUCK BOOST SINGLE PHASE AC-DC CONVERTER

By

MD. MONABBER ALAM

MASTER OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY (BUET)

DECEMBER 2014

DEVELOPMENT OF AN INPUT SWITCHED CONTINUOUS INPUT CURRENT BUCK BOOST SINGLE PHASE AC-DC CONVERTER

By

MD.MONABBER ALAM

A thesis submitted
to
The Department of Electrical and Electronic Engineering in partial fulfillment for the degree of
Master of Science in Electrical and Electronic Engineering

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

DECEMBER 2014

Declaration

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Signature of the Candidate

……
(Md. Monabber Alam)

The thesis titled **"DEVELOPMENT OF AN INPUT SWITCHED CONTINUOUS INPUT CURRENT BUCK BOOST SINGLE PHASE AC-DC CONVERTER"** submitted by Md. Monabber Alam, Student No.: 0409062137, Session: April, 2009, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of MASTER OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING on December 13, 2014.

BOARD OF EXAMINERS

1. _____

Dr. Mohammad Ali Choudhury — Chairman (Supervisor)
Professor
Department of Electrical and Electronic Engineering,
Bangladesh University of Engineering and Technology,
Dhaka –1205, Bangladesh.

2. _____

Dr. Taifur Ahmed Chowdhury — Member (Ex-officio)
Professor and Head
Department of Electrical and Electronic Engineering,
Bangladesh University of Engineering and Technology,
Dhaka–1205, Bangladesh.

3. _____

Dr. A. B. M. Harun-ur-Rashid — Member
Professor
Department of Electrical and Electronic Engineering,
Bangladesh University of Engineering and Technology,
Dhaka–1205, Bangladesh.

4. _____

Dr. Md. Ashraful Hoque — Member (External)
Professor
Department of Electrical and Electronic Engineering,
International University of Technology,
Gazipur, Bangladesh.

Dedication

To my Parents

Acknowledgement

I thank and praise Almighty Allah for giving me the ability to complete this thesis successfully.

I would like to express my gratitude and deep appreciation to my supervisor, Dr. Mohammad Ali Choudhury, Professor, Department of Electrical and Electronic Engineering, BUET, for his helpful suggestions, encouragement, guidance and individual assistance and constant supervision that have enabled me to finish this work.

I am grateful to the Head of the Departmental of Electrical and Electronic Engineering of BUET, for rendering me all support and departmental assistance during my M.Sc. study at BUET. I would like to convey my thanks to all faculty and other members of the department for their support during the research work.

I acknowledge gratefully the kind presence of Professor Dr. A. B. M. Harun-ur-Rashid and Professor Dr. Md. Ashraful Hoque in my thesis defense and giving me their valuable guidance and insightful suggestions for further improvement of the thesis.

Last but not the least, it would be unjust if I do not mention about the contribution of my family members who have always encouraged me and rendered their supports to continue my study and research.

Abstract

The input current of uncontrolled diode rectifier with **o**utput filter capacitor is non-sinusoidal. The output voltage of controlled rectifier is controllable but the input current is non-sinusoidal. To overcome the problem of non-sinusoidal input current of single phase diode bridge rectifier, various input current shaping and power factor correction [PFC] methods are available. These are Buck, Boost, Buck-Boost, Ĉuk, Sepic, Inverse Sepic or Zeta converter controlled rectifiers. Various Isolated Converters like Flyback, Forward, Push-Pull, Full-Bridge and Half-Bridge converters are also used for the same purpose. A Buck Boost circuit provides output voltage that may be less than or greater than the input voltage. The output voltage is negative with respect to input and input current is discontinuous. For discontinuous input current, filtering needs large size of inductor and capacitor. Switching is possible both at the output and input sides of the rectifier. Both output switched and input switched Conventional Buck Boost Single Phase AC-DC Converters are available in literature. In such converters input current is discontinuous, input current THD is high and input power factor is low. To overcome the problem of discontinuous input current, high input current THD and low input power factor, three AC-DC converter topologies are proposed and studied. These are Output Switched Modified Buck Boost Single Phase AC-DC Converter, Input Switched Modified Buck Boost Single Phase AC-DC Converter (One Switch and Two Inductors) and Input Switched Modified Buck Boost Single Phase AC-DC Converter (One Switch and One Inductor). These three proposed topologies are studied with and without input filter between the source and the rectifier. Comparing various results of the previous and proposed works it is found that for proposed output switched and input switched topologies with one inductor THD of input current is reduced, input power factor is improved and found near unity and efficiency is also improved compared to previous conventional Buck Boost topology based single phase AC-DC converter.

List of Abbreviation

SMPS	Switch Mode Power Supply
IGBT	Insulated Gate bipolar Transistor
PWM	Pulse Width Modulation
Rms	Root mean square
THD	Total Harmonic Distortion
SCR	Silicon Control Rectifier
Fig	Figure
V_{in}	Input voltage
T_{ON}	Turn on time.
T_{OFF}	Turn off time.
T	$T_{ON} + T_{OFF}$.= Time period
D	Duty cycle = T_{ON} / T.
I_a	Average load current
f	Switching frequency
L	Inductor
C	Filter capacitance
I_O	Output Current

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CHAPTER-1
INTRODUCTION

1.1 Introduction

A single-phase full wave rectifier converts an alternating signal (AC) into a unidirectional signal (DC). The output DC should have minimum amount of harmonic contents. The input current should be as sinusoidal as possible and in phase with the input voltage so that the power factor becomes near unity.

Single-phase full wave rectifiers in bridge configuration have the demerits of poor power quality in terms of non-sinusoidal input current, injected current harmonics caused voltage distortion and poor power factor at input ac mains, slow varying rippled dc output at load end and low efficiency [1-8]. Normal rectifiers also have high input current THD. Various methods have been proposed to solve these problems. One solution is to use input filter. The size of the inductor and capacitor as filter required in such solution are large. It improves THD but power factor remains low. To overcome the problems, switch mode regulators (active filtering) have been proposed.

Conventionally a single-phase AC-DC switch mode converter is made of a bridge rectifier followed by a DC-DC converter [9-16]. The most common of these is a single-phase rectifier followed by a boost DC-DC converter. In principle, it is a combination of diode bridge rectifier and step-up dc chopper with filter and energy storage elements. The bridge rectifier converts AC to uncontrolled DC, and the DC-DC converter provides controlled and regulated DC output. The output DC-DC converter acts as high frequency output current/voltage chopper, which is reflected at the input as high frequency chopped AC [9-10]. High frequency chopped input current is then filtered by a small filter to obtain near sinusoidal input current with high power factor [9-10].

The DC-DC converter at the output of the bridge rectifier is usually Boost type, but Buck, Buck-Boost and Ĉuk converters may be employed for the same purpose with different input/output voltage gain relationships [16-20]. The DC-DC converters use unidirectional switch for the switching purpose. In the boost-regulated AC-DC conversion, the boost rectifier must be operated in critical mode [21-23], where, the power switch should be turned ON at the instant of boost diode's current reaches zero. This needs variable

switching frequency operation of the DC-DC converter as the load or the input voltage changes. Another approach for boost-regulated rectifier involves controlling to a constant level the average current of the boost diode [21-23]. In order to keep the average current constant through the boost diode, the duty cycle must be modulated over the line cycle. This method requires current sensor in the scheme.

However, Boost regulated rectifiers have disadvantages. For example, these rectifiers suffer from high voltage and current stresses and only output voltage greater than the input voltage can be obtained. Output voltage which is lower than the input voltage is also needed in practical uses. The Buck-Boost and Ĉuk rectifiers can step up/down the output voltage.

Bridge-less configurations [24-25], two-switch rectifiers [9] and input switched AC-DC converters [26-31] are also reported in literatures for AC-DC conversion having the above advantages and disadvantages of Boost regulated rectifier.

In this research, a new single-phase AC-DC converter topology based on Buck-Boost conversion is investigated. Buck-Boost topology based AC-DC converter will chop input ac current by a single bidirectional switch (composed of a unidirectional switch enclosed in a bridge diode circuit) which will differ from the DC-DC converter regulated rectifiers or bridgeless rectifiers in two sense. The first is the use of a single bidirectional switch composed of a unidirectional switch enclosed in a bridge rectifier. The second is the input current switching. The second feature will ensure high frequency switching of input ac almost in phase with input ac voltage. The adoption of modified Buck-Boost topology will provide continuous input current of the converter unlike conventional Buck Boost topologies. This will result in shaping of input current to near sinusoid by use of small filter and ensures good input power factor.

Proposed Buck-Boost topology based AC-DC converter will provide step-up/step-down output dc voltage with the duty cycle control of the switch of the converter. The circuits can be considered for AC-DC conversion with low distortion and high input power factor.

1.2 Problems of Rectifiers

1.2.1 Single Phase Uncontrolled Rectifier with Output Filter Capacitor

A rectifier is a circuit that converts an alternating signal (AC) into a unidirectional signal (DC). Output of a rectifier is normally uncontrolled or fixed. Single-phase full wave bridge rectifiers have the demerits of poor power quality in terms of non-sinusoidal input current, injected current harmonics, caused voltage distortion and poor power factor at input AC mains and slow varying rippled DC output at load end and low efficiency [1-8]. These rectifiers also have high input current THD. L, C and LC type filters are used to smooth out the DC output voltage of the rectifier and these are known as DC filters. A single phase uncontrolled rectifier with output filter capacitor is shown in Fig 1.1, the typical output voltage waveform is shown in Fig 1.2 and the typical input current waveform is shown in Fig 1.3.

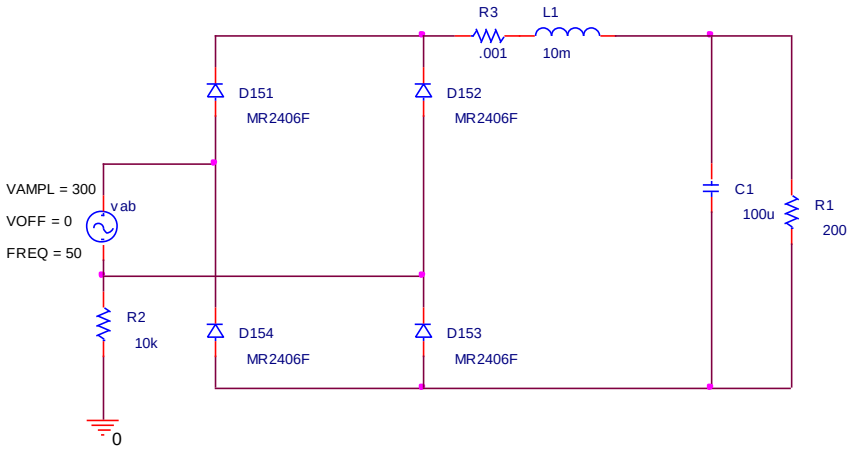

Fig 1.1: A single phase uncontrolled rectifier with output filter capacitor

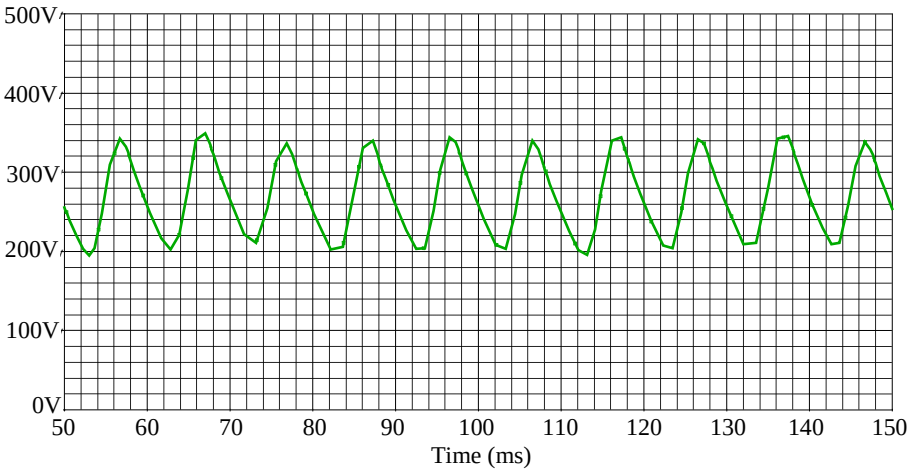

Fig 1.2: Typical output voltage waveform of the circuit of Fig 1.1

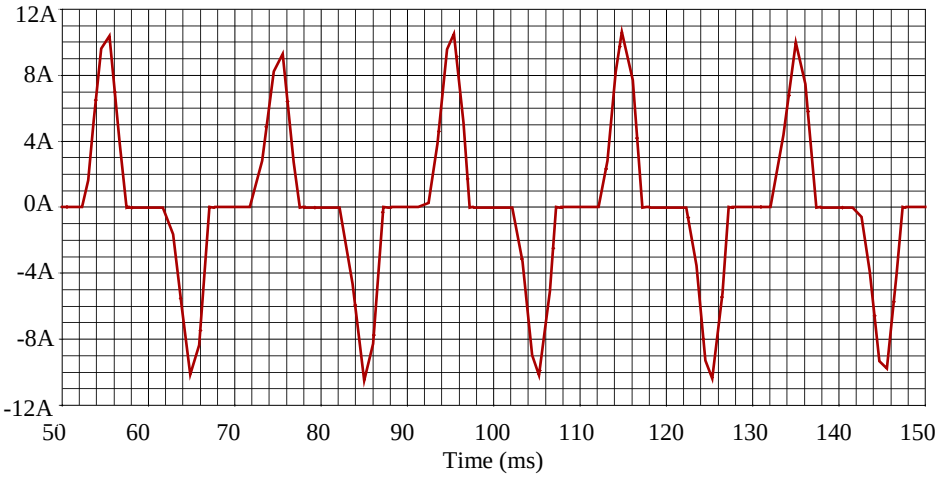

Fig 1.3: Typical input current waveform of the circuit of Fig 1.1

1.2.2 Single Phase Controlled Rectifier

Output of a single-phase full wave bridge rectifier is normally uncontrolled or fixed. But in practical work controlled output are also needed. Therefore uncontrolled DC output of a bridge rectifier is controlled by using switches like thyristors, bipolar junction transistors (BJTs), metal-oxide-semiconductor field effect transistors (MOSFETs), and insulated gate bipolar transistors (IGBTs) [1-8]. The problems associated with the single phase uncontrolled rectifier remains in case of controlled rectifier too. A single phase controlled rectifier is shown in Fig 1.4, the typical output voltage waveform is shown in Fig 1.5 and the typical input current waveform is shown in Fig 1.6.

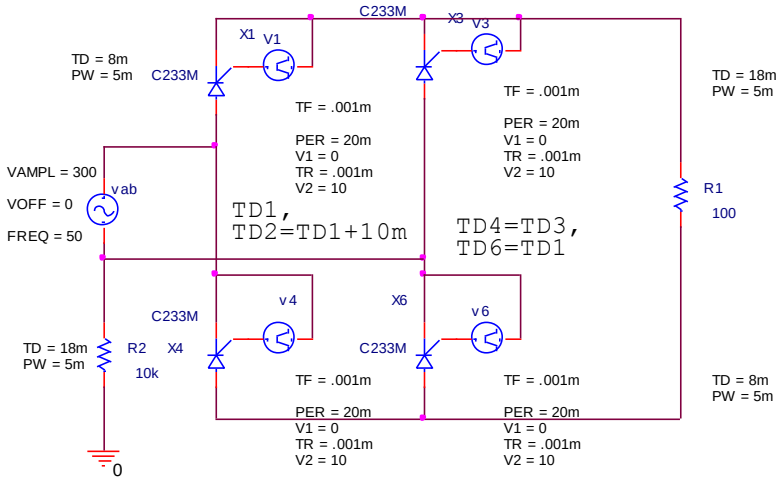

Fig 1.4: A single phase controlled rectifier

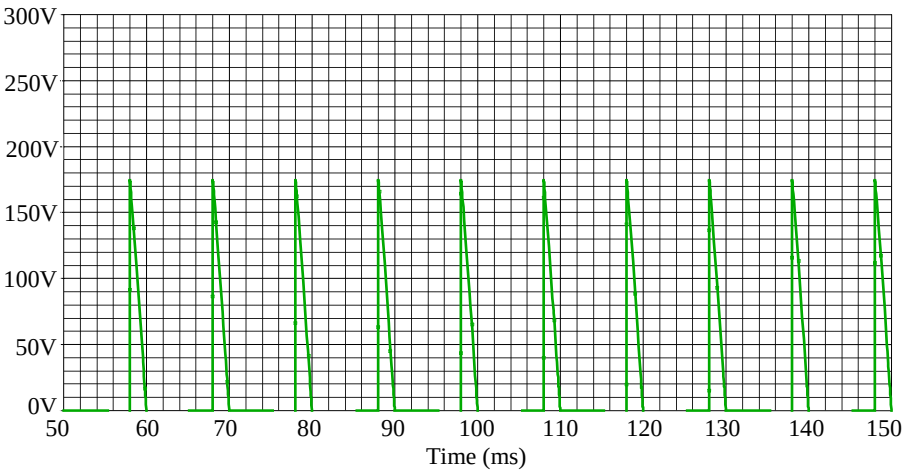

Fig 1.5: Typical output voltage waveform of the circuit of Fig 1.4

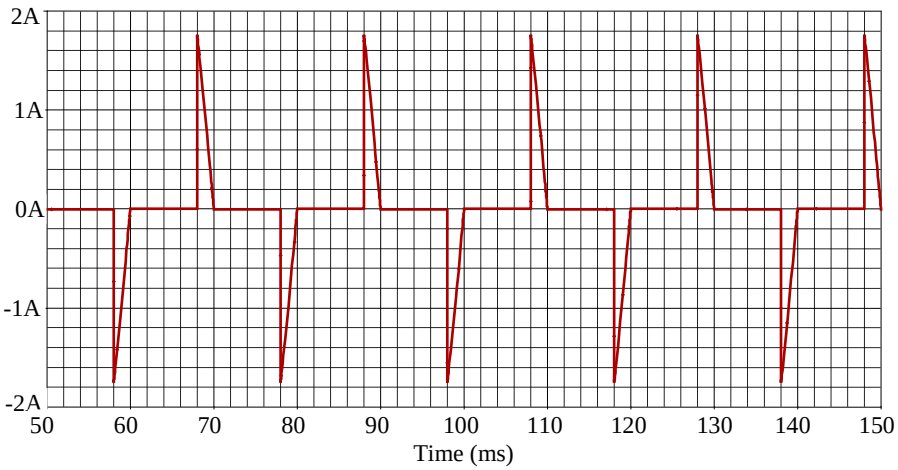

Fig 1.6: Typical input current waveform of the circuit of Fig 1.4

1.2.3 Three Phase Uncontrolled Rectifier

Fig 1.7 shows a three-phase uncontrolled diode bridge rectifier. This rectifier also has the problems of non-sinusoidal input current, injected current harmonics, caused voltage distortion and poor power factor at input AC mains, high input current THD and low efficiency. The typical output voltage waveform of a three-phase uncontrolled diode bridge rectifier is shown in Fig 1.8 and the typical input current waveform is shown in Fig 1.9.

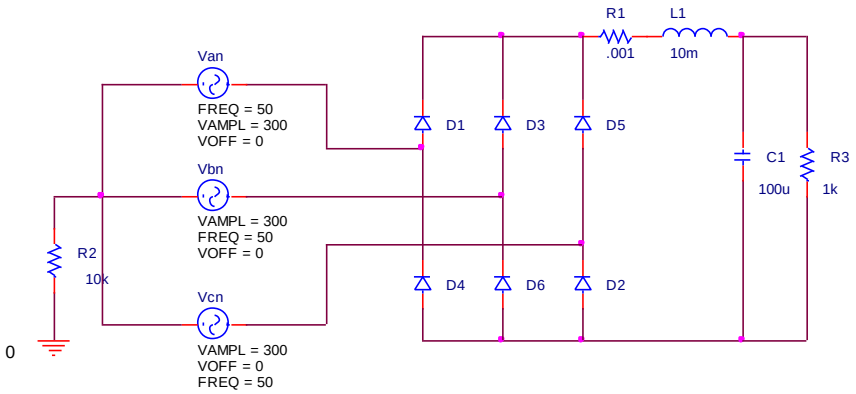

Fig 1.7: A three-phase uncontrolled rectifier

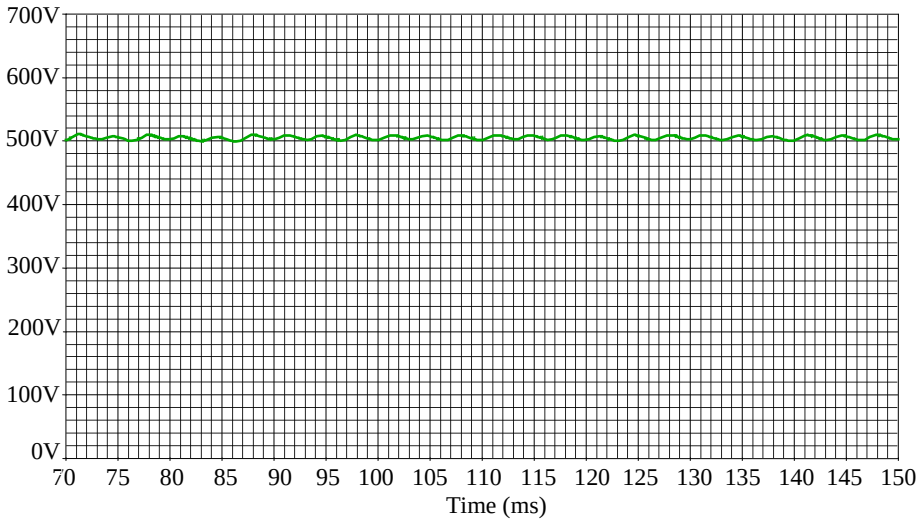

Fig 1.8: Typical output voltage waveform of the circuit of Fig 1.7

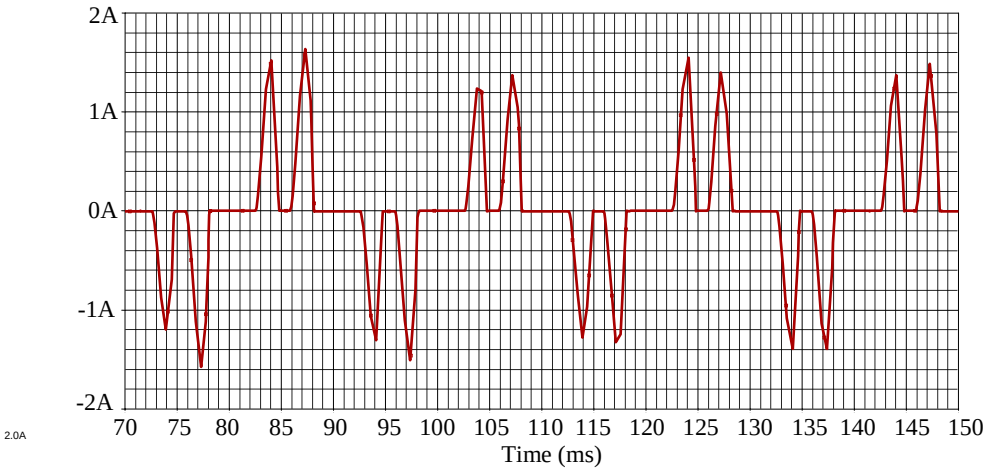

Fig 1.9: Typical input current waveform of the circuit of Fig 1.7

1.2.4 Three Phase Controlled Rectifier

Fig 1.10 shows a three-phase phase controlled rectifier. Problems of non-sinusoidal input current, injected current harmonics, caused voltage distortion and poor power factor at input AC mains, high input current THD and low efficiency remains in this rectifier also. The typical output voltage waveform of a three-phase phase controlled rectifier is shown in Fig 1.11 and the typical input current waveform is shown in Fig 1.12.

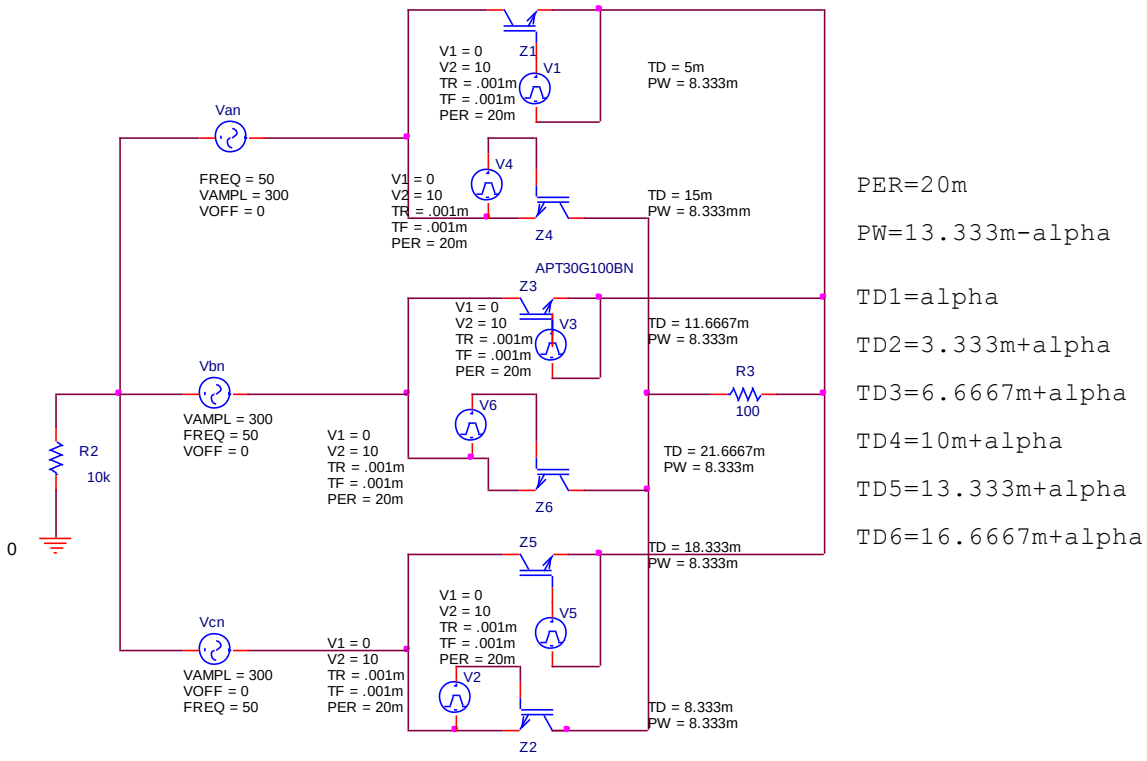

Fig 1.10: A three-phase phase controlled rectifier

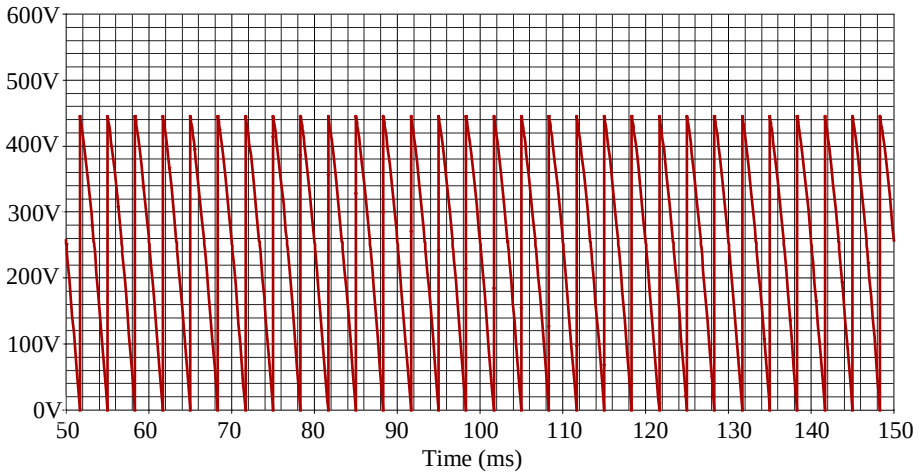

Fig 1.11: Typical output voltage waveform of the circuit of Fig 1.10

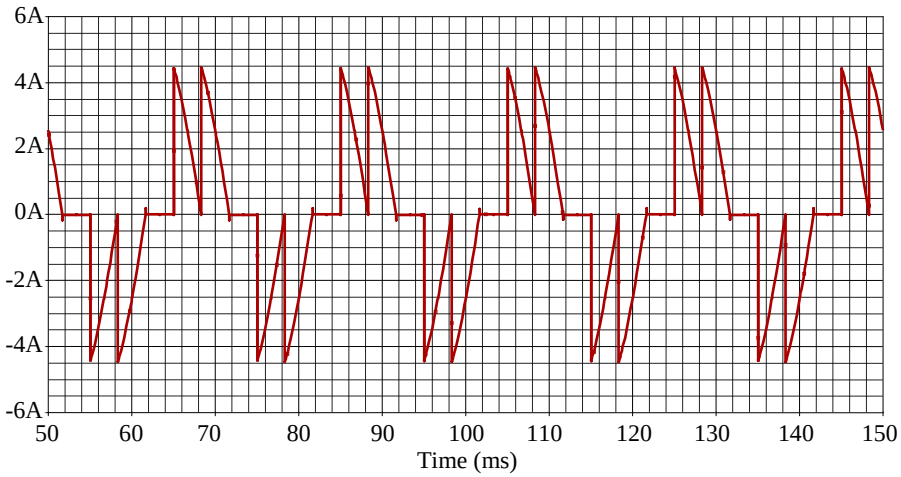

Fig 1.12: Typical input current waveform of the circuit of Fig 1.10

1.3 Conventional Input Current Shaping and Power Factor Correction [PFC] of a Single Phase Diode Bridge Rectifier

The problem of non-sinusoidal input current with high THD and low input power factor of uncontrolled single phase diode bridge rectifier with output voltage filter may be mitigated by using:

i) Passive filter and

ii) Active filter techniques

In the passive filter technique, tuned and un-tuned LC filters are used which are bulky and expensive [10]. In active filter technique harmonic injection with passive filter and DC-DC

converter (either at the input or at the output of the rectifier) with passive input filter are used [10]. Input DC-DC converter regulated rectifier, input switching is relatively new method. Use of a DC-DC converter between the rectifier and load is common and conventional method to shape the input current to chopped sine wave. In both input and output dc-dc converter switched rectifier power factor correction (PFC) techniques, DC-DC converters available in literature are investigated and they are being used in many applications. Proper feedback and input current tracking with the input voltage waveform mechanisms are incorporated to ensure near unity power factor with very low input current THD and high efficiency. The following DC-DC converters (either in continuous inductor current or discontinuous inductor current mode of operation) are used for input current shaping and input power factor improvement,

Non Isolated Converters:

a) Buck Converter,
b) Boost Converter,
c) Buck-Boost Converter,
d) Ĉuk Converter,
e) Sepic Converter,
f) Inverse Sepic or Zeta Converter,

Isolated Converters:

g) Flyback Converter,
h) Forward Converter,
i) Push-Pull Converter,
j) Full-Bridge Converter and
k) Half-Bridge Converter

1.3.1 Power Factor Correction [1-10]

Appliances connected to supply mains interact with the utility and the grid to a large extent. Passive linear loads normally draw current linearly and do not affect the operation of other equipment connected to the same mains. Power electronic devices switch the current on and off and these cause disturbances in power lines in the form of current harmonics. Harmonics are generated by the switching action in the equipment and interfere

with sensitive devices in the network. Regulations exist that specify acceptable levels of harmonics from power electronic equipment and other phenomenon in power lines. Utility companies do not like this harmonics in their lines because it causes them to supply extra power to the equipment and install extra thick cabling to account for circulating current. Some of the power electronic topologies, mainly DC-DC converters, offer the characteristic of making any switching load appear as resistive load. In other words, these controllers draw the line current proportional to the line voltage. Various power electronic converters for power factor correction in single phase rectifiers to achieve good power factor are briefly mentioned in the following sections. Generally, mains-connected power supplies consist of a bridge rectifier followed by a DC link capacitor. The capacitor is used to make the voltage constant it draws current from the mains only when the instantaneous mains voltage is greater than the capacitor voltage. Large pulses of current are drawn from the line over a very short time.

1.3.2 Concept of PFC

PFC is an abbreviation for power factor correction. Any electrical system can be simplified as shown in Fig 1.13.

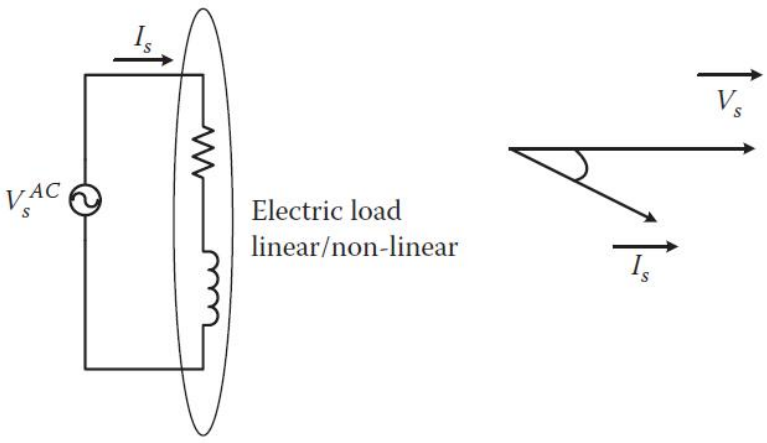

Fig 1.13: Simplified electrical system

Fig 1.14: Effect of load on the line current wave shape

Depending on the loading on the utility, the current shape will be different. The load can be linear, such as in resistive heaters, or it can be nonlinear. Fig 1.14 shows the effect of load on the line current wave shape, and thus the effect on power quality. For sinusoidal voltage and current, the input power factor is given by,

$$\cos\text{Ø} = V_S/I_S$$

where, Ø is the angle between the voltage V_S and I_S (input voltage and input current). Modern appliances load consist of switching power supplies in them. They have diode rectifiers on their front ends. The current waveforms are no longer sinusoidal for them, and thus the definition of power factor is changed for them. It is given by,

$$\text{PF} = \frac{\text{DPF}}{\sqrt{1+THD^2}}$$

where, DPF is displacement power factor and THD is total harmonic distortion. Definition of both is given by,

$$\text{DPF} = \cos\Phi_1 = \frac{V_S}{I_{S1}}$$

where I_{S1} is fundamental component of the supply current,

$$THD = \frac{I_{distortion}}{I_{S1}}$$

Nonlinear loads, such as power electronic equipment and magnetic circuits operating near and in saturation regions cause problems like,

a. Produce harmonics and cause electromagnetic interference (EMI)
b. Harmonic currents cause extra losses and need extra VAR from the system
c. Need over-dimensioning of parts (Transformers, Generators, Transmission and distribution lines and neutral conductors)

d. Reduce capability of power lines and equipment

Power factor improvement makes the load look more like a resistive. Modern PFC circuits can achieve power factor very near to unity. PFC circuits have following advantages,

a. Better source efficiency
b. Lower line and equipment cost installation cost because of standard size (not oversized to supply extra VARs)
c. Low EMI
d. Reduce peak current levels
e. Ability to act as filter
f. May use common input filter for paralleled supplies

PFC circuits come with extra costs because of,

a. Complexity of design
b. More parts in the system
c. More parts require a more cost and higher utility cost.

Harmonic standards developed by the Institute of Electrical and Electronics Engineers (IEEE) and the International Electro technical Commission (IEC) are enforced in many parts of the world. IEEE and international harmonic standards can be grouped into three main categories [70-72]:

1. Customer system limits
    a. IEEE 519-1992
    b. IEC 1000-3-2 (compatibility levels)
    c. IEC 1000-3-6
2. Equipment limits
    a. IEC 1000-3-2
    b. IEC 1000-3-4
    c. New task force in IEEE (harmonic limits for single phase loads)
3. How to measure harmonics
    a. IEC 1000-4-7

1.4 High Switching Frequency Topologies for PFC of Single Phase Rectifier

1.4.1 Output DC-DC Converter Regulated Single Phase Rectifiers

High frequency PFC topologies are becoming common in PFC circuits. High frequency circuits offer advantages of low weight, accurate voltage control, low line harmonic distortion, wide operating voltage range, and easy design. As already mentioned, the pre-regulator can be any one of the basic DC-DC converter topologies. Their block diagrams with typical waveforms with feedback control circuit are given in the following sections. The regulators are designed to draw input currents proportional to the instantaneous input voltage. Though the circuits are complex, power factor of almost unity is achievable with these high frequency topologies. All the topologies can operate in both discontinuous conduction mode (DCM) as well as in continuous conduction mode (CCM) mode.

1.4.1.1 Buck Converter as Power Factor Corrector

For the buck converter the output voltage is always less than the peak input voltage. Power factor correction is therefore not achieved when the instantaneous input voltage is lower than the required output voltage. This topology, on its own, is not suitable for PFC. The input current is switched directly, which may give rise to EMI problems (Fig 1.15 and 1.16).

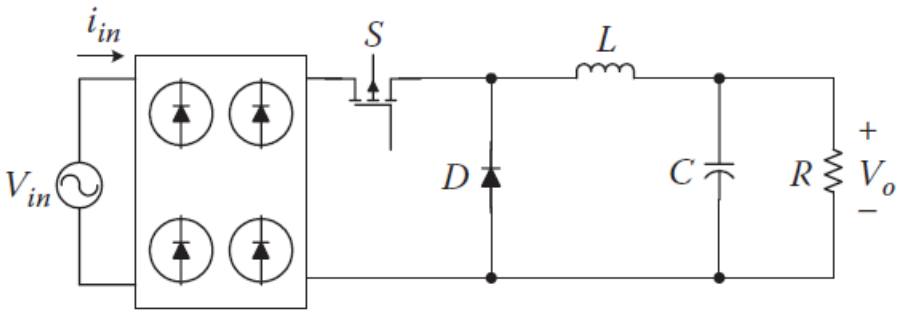

Fig 1.15: Output Buck Converter Regulated Single Phase PFC Rectifier Circuit [1-8, 34-39]

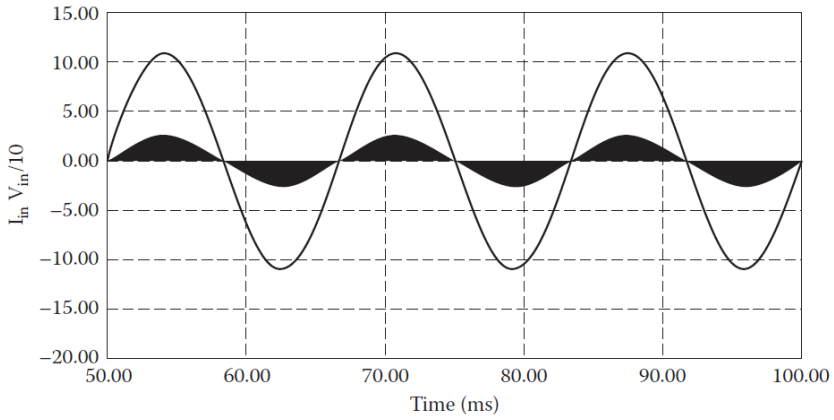

Fig 1.16: Typical Waveforms of Circuit of Fig 1.15 [1-8, 34-39]

1.4.1.2 Boost Converter as Power Factor Corrector

Boost regulator at the output of rectifier is the most popular for PFC. The input current from the mains is not chopped directly in this topology, which helps with EMI. Drive circuit of a boost regulated PFC is simpler than the other topologies. The advantages of the boost converter are: EMI performance, voltage rating less than other topologies, absorbs line transients, and easy drive circuits. The disadvantages are, no PFC control when input voltage is higher than the output voltage and cannot limit the inrush currents (Fig 1.17 and 1.18).

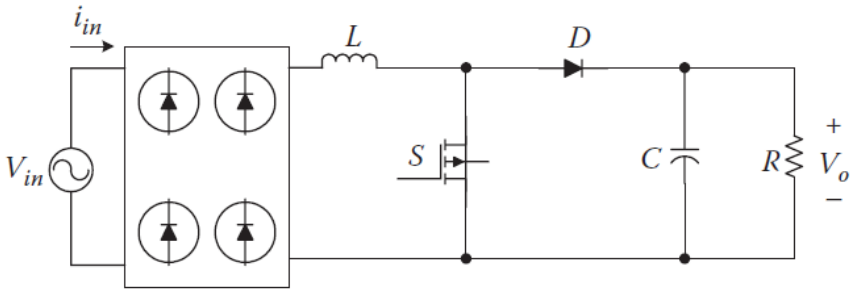

Fig 1.17: Output Boost Converter Regulated Single Phase PFC Rectifier [1-8, 40-49]

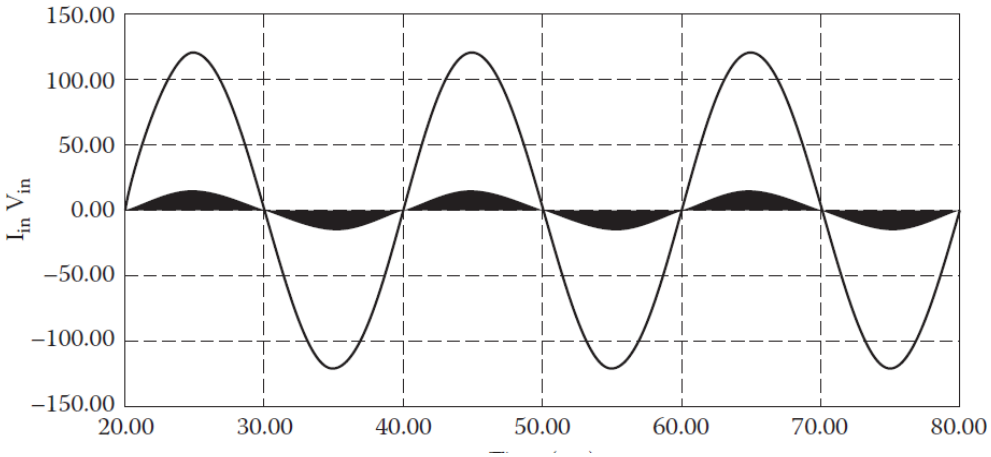

Fig 1.18: Typical Waveforms of Circuit of Fig 1.17 [1-8, 40-49]

1.4.1.3 Buck-Boost Converter as Power Factor Corrector

In Buck Boost Regulated topology, current drawn by the converter is proportional to the input voltage and hence input current follows the input voltage. This topology is suitable for the application where a wide range of output voltage is necessary. The topology has limitations like output voltage being of opposite polarity of input and complex drive circuit requiring drive reference isolation. The power stage circuit of the buck-boost converter is shown in Fig 1.19. Typical simulation result showing input voltage and current is shown in Fig 1.20.

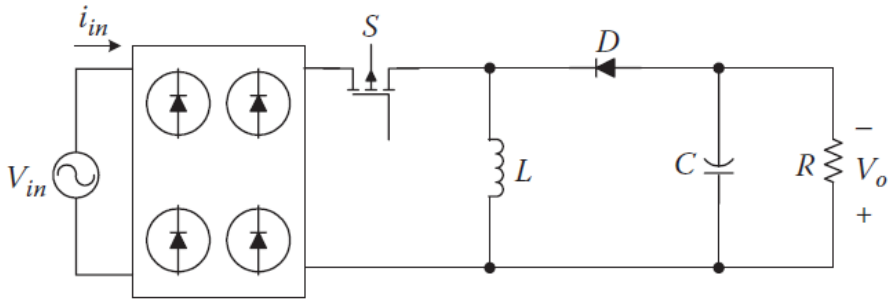

Fig 1.19: Output Buck Boost Converter Regulated Single Phase PFC Rectifier [1-8, 50-53]

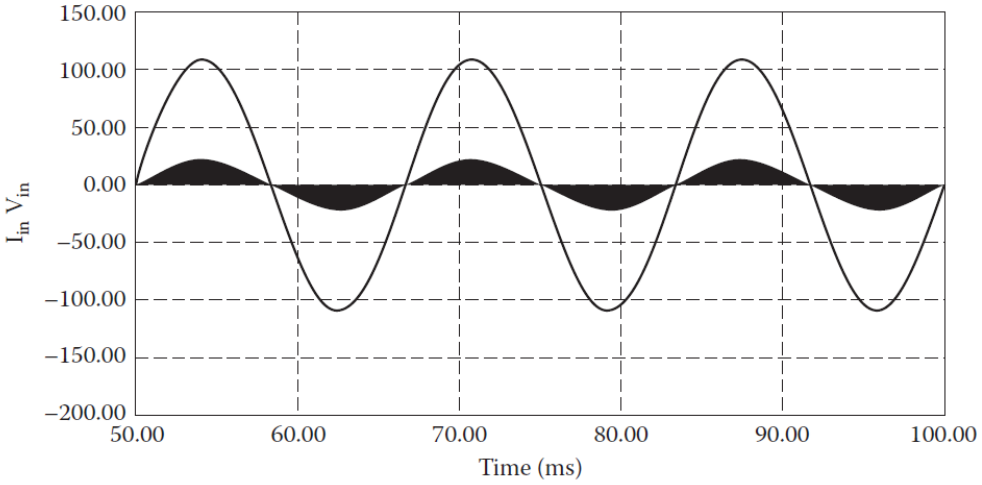

Fig 1.20: Typical Waveforms of Circuit of Figure 1.19 [1-8, 50-53]

1.4.1.4 Ćuk Converter as Power Factor Corrector

Ćuk converter regulated topology has two inductors, one at input and the other at output. If it is operated in DCMDCM mode, it is possible to achieve good power factor. The output voltage can be varied independently in a specified limit (Fig1.21 and 1.22).

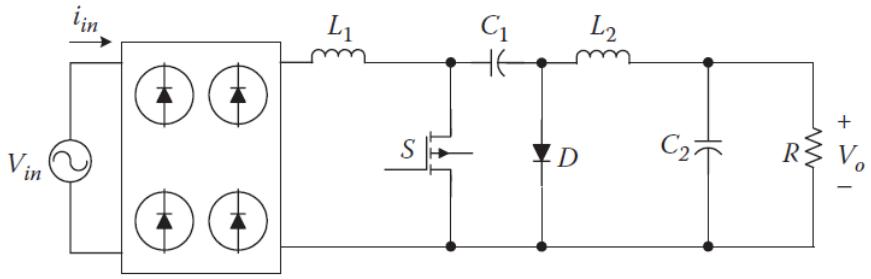

Fig 1.21: Output Ĉuk Converter Regulated Single Phase PFC Rectifier [1-8, 54-55]

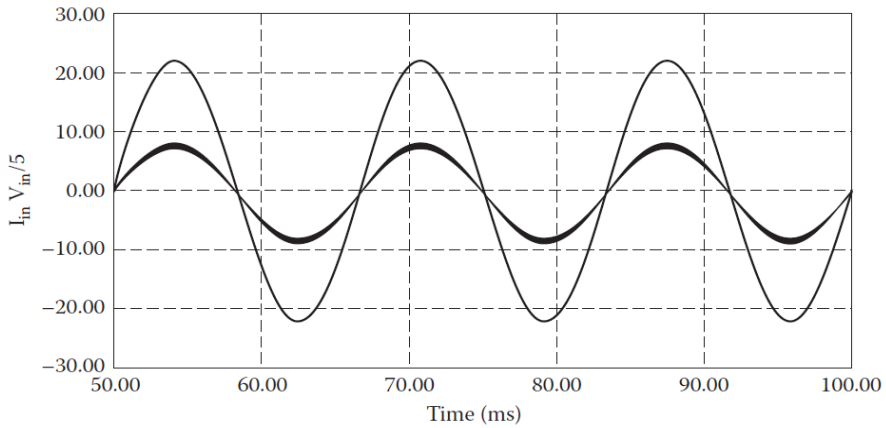

Fig 1.22: Typical Waveforms of Circuit of Fig 1.21 [1-8, 54-55]

1.4.1.5 SEPIC Converter as Power Factor Corrector

The SEPIC converter regulated single phase PFC rectifier is shown in Fig 1.23 and typical waveforms of the circuit are shown in Fig 1.24.

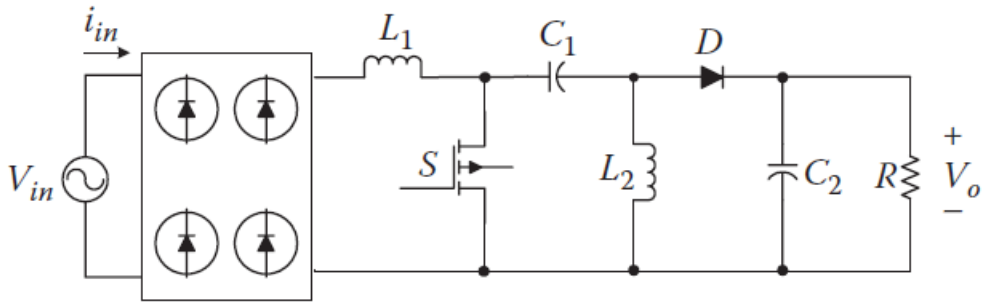

Fig 1.23: Output SEPIC Converter Regulated Single Phase PFC Rectifier [56-60]

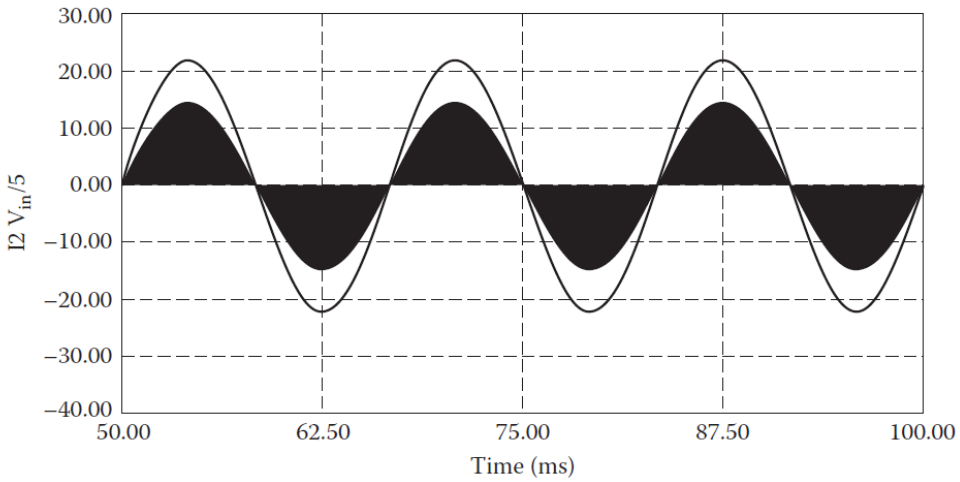

Fig 1.24 Typical Waveforms of the Circuit of Fig 1.23 [56-60]

1.4.1.6 Zeta Converter as Power Factor Corrector

In Zeta converter regulated single phase PFC rectifier, relationship between input and output voltage is similar as with buck-boost and Ćuk, The input inductor inherently makes this topology suitable when isolation is necessary. The ideal voltage and current gain equations for the zeta are the same as that of the Ćuk converter and buck-boost converter. Zeta converter is the dual of the SEPIC converter. Thus, it gives same performance as the SEPIC converter. The typical waveforms the zeta converter of Fig 1.25 is shown in Fig 1.26.

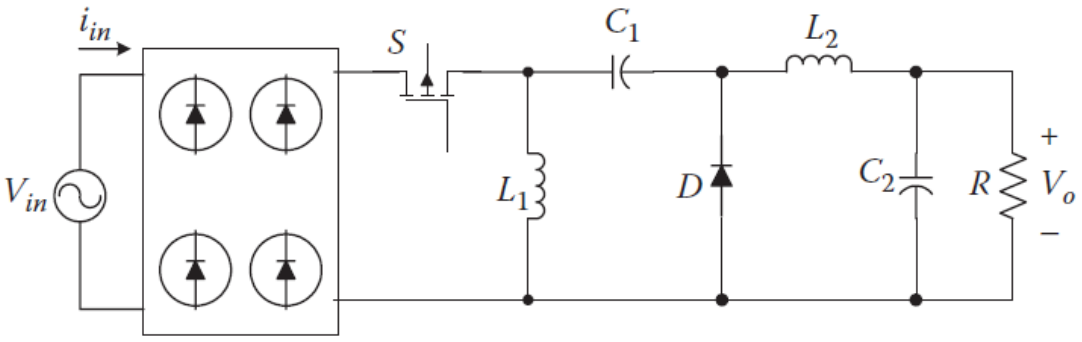

Fig 1.25: Output ZETA Converter Regulated Single Phase PFC Rectifier

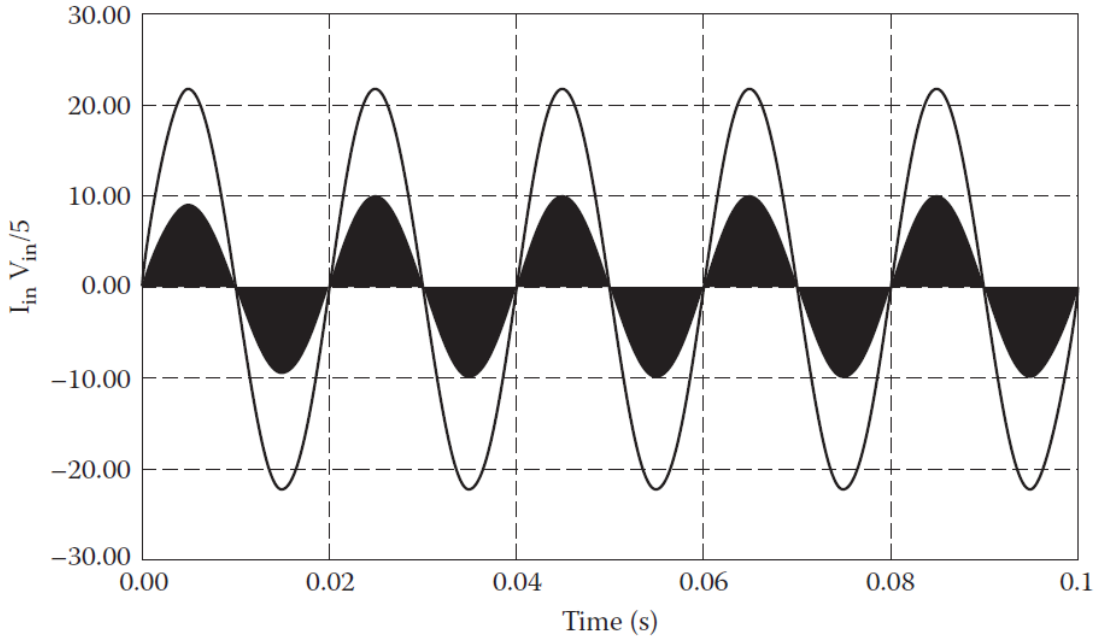

Fig 1.26: Typical Waveforms of the Circuit of Fig 1.25

1.4.1.7 Flyback Converter as Power Factor Corrector

In flyback converter regulated single phase PFC rectifier, output voltage can be made greater or less than the input voltage. This can be done by duty ratio and transformer turns ratio (Fig 1.27 and 1.28).

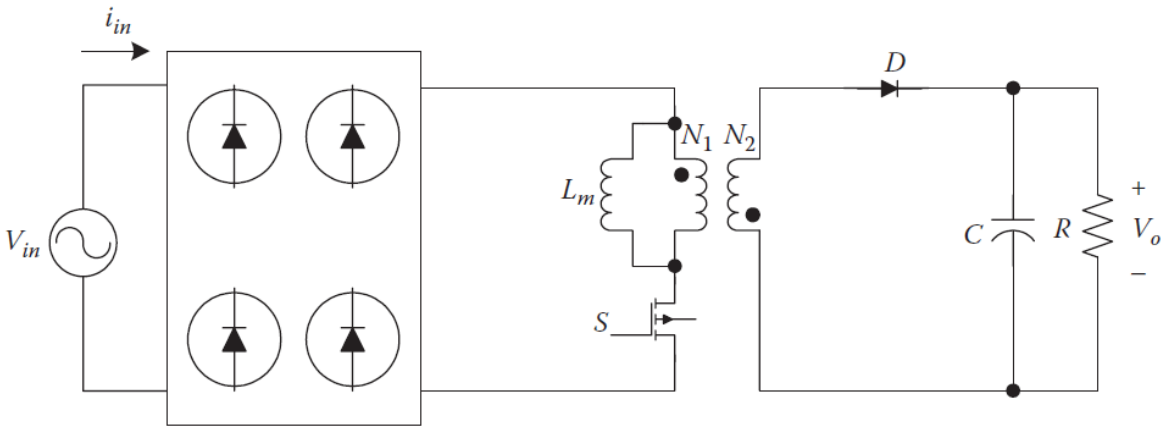

Fig 1.27: Output Flyback Converter Regulated Single Phase PFC Rectifier [61-64]

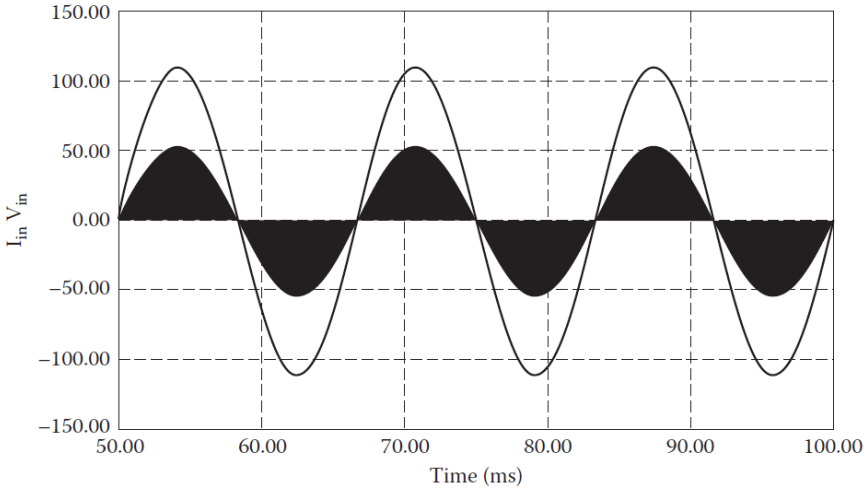

Fig 1.28: Typical Waveforms of Circuit of Fig 1.27 [61-64]

1.4.1.8 Forward Converter as Power Factor Corrector

The forward converter regulated single phase PFC rectifier is shown in Fig 1.29 and the typical waveforms of the circuit are shown in Fig 1.30. In this topology it is possible to achieve isolation between input and output. But it is necessary to have third winding to discharge magnetizing current.

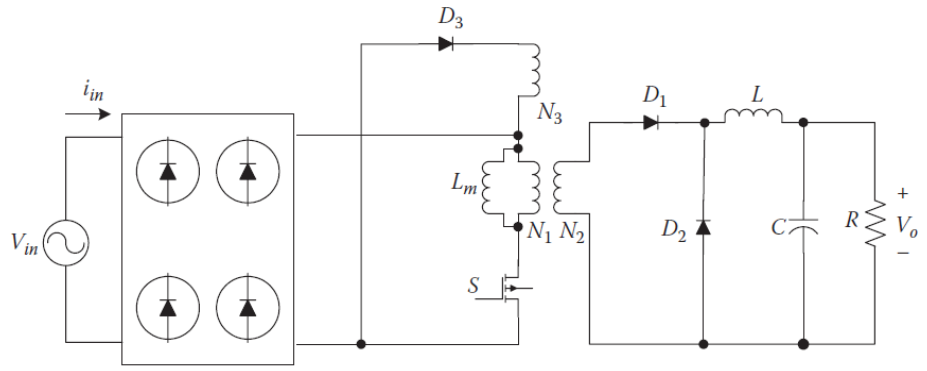

Fig 1.29: Output Forward Converter Regulated Single Phase PFC Rectifier [66]

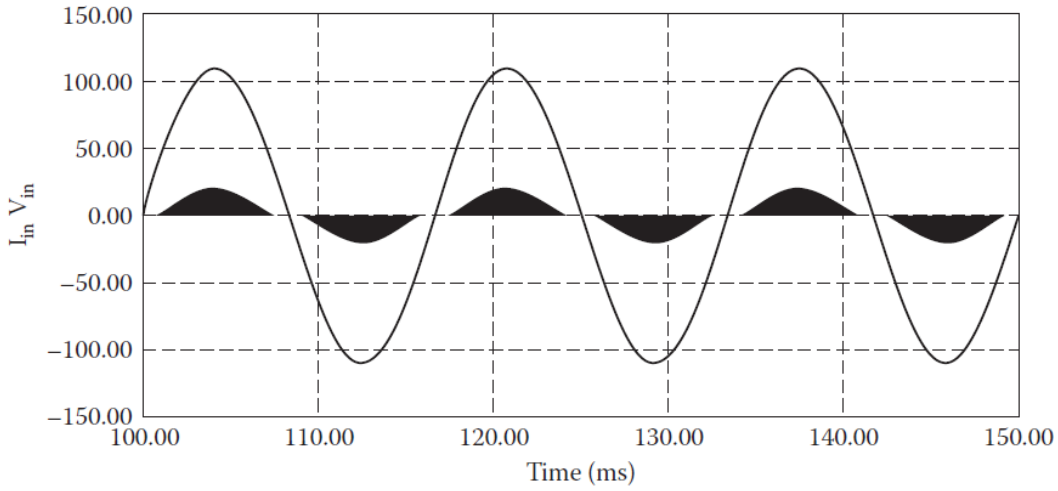

Fig 1.30 Typical Waveforms of Circuit of Fig 1.29 [66]

1.4.2 Input DC-DC Converter Regulated Single Phase PFC Rectifiers [73]

Recently several input switched single phase PFC rectifiers have been reported in literature. Also many bridgeless single phase PFC rectifiers have been reported. Some of the input switched (regulated) single phase PFC rectifiers are diagrammatically shown from Figs 1.31-1.42 with their typical input/output waveforms [73]. These are input Buck, Boost, Ćuk, Sepic and Zeta converter regulated single phase PFC rectifiers.

1.4.2.1 Input Buck Regulated Single Phase PFC Rectifier [26-31, 73]

Fig 1.31 is the input Buck regulated single phase PFC rectifier and Fig 1.32 presents the output of the circuit. Waveforms represent the input voltage and the input current without any input filter. Figs indicate that inphase input current switching is possible with the circuit which is necessary for power factor correction.

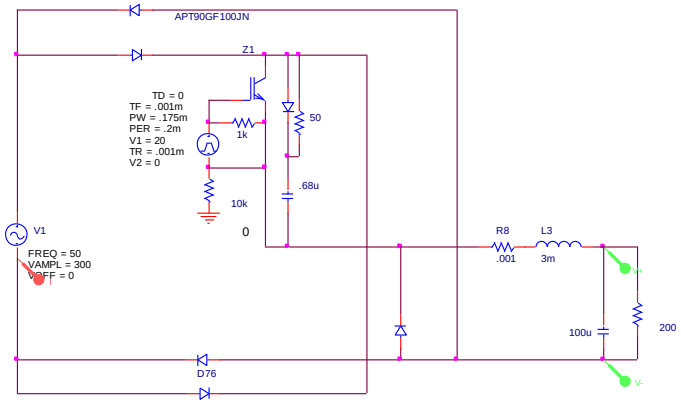

Fig 1.31: Input Buck Converter Regulated Single Phase PFC Rectifier [73]

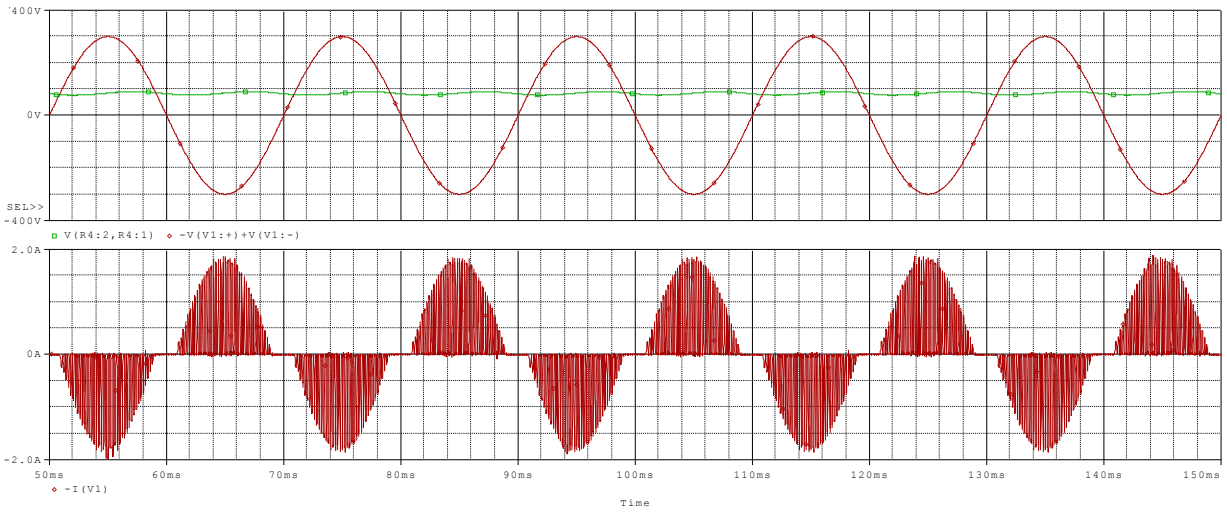

Fig 1.32: Typical Waveforms of the Circuit of Fig 1.31 [73]
Upper: Input and Output Voltages; Bottom: Input Current

1.4.2.2 Input Boost Regulated Single Phase PFC Rectifier [73]

Fig 1.33 is the input Boost regulated single phase PFC rectifier. The configuration uses a bidirectional switch for input current shaping of the boost rectifier. Fig 1.34 presents the typical input voltage/current and output voltage waveforms of the circuit of Fig 1.33.

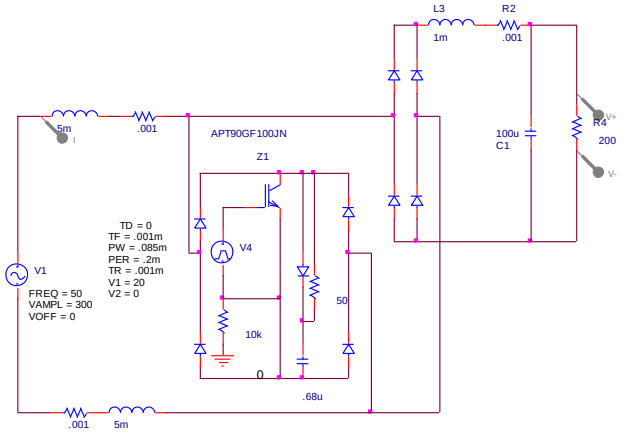

Fig 1.33: Input Boost Converter Regulated Single Phase PFC Rectifier [73]

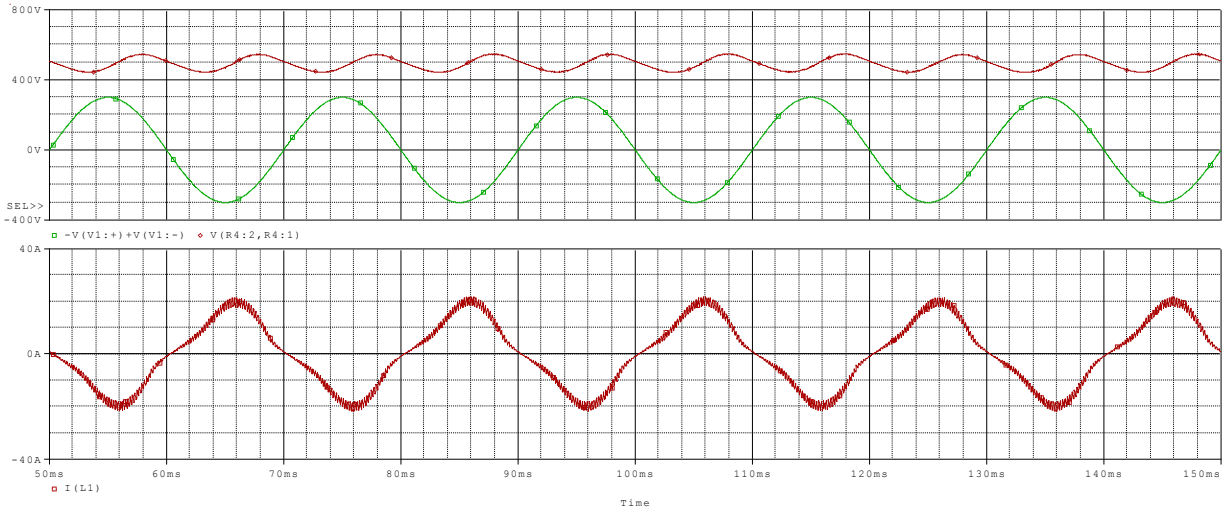

Fig 1.34: Typical Waveforms of the Circuit of Fig 1.33 [73]
Upper: Input and Output Voltages; Bottom: Input Current

1.4.2.3 Input Buck-Boost Regulated Single Phase PFC Rectifier [73]

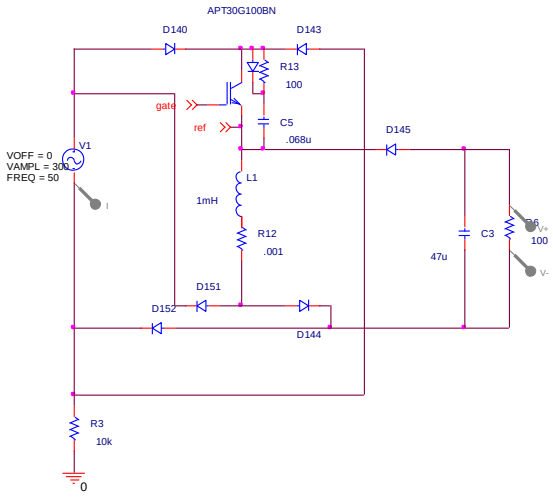

Fig 1.35: Input Buck Boost Converter Regulated Single Phase PFC Rectifier [73]

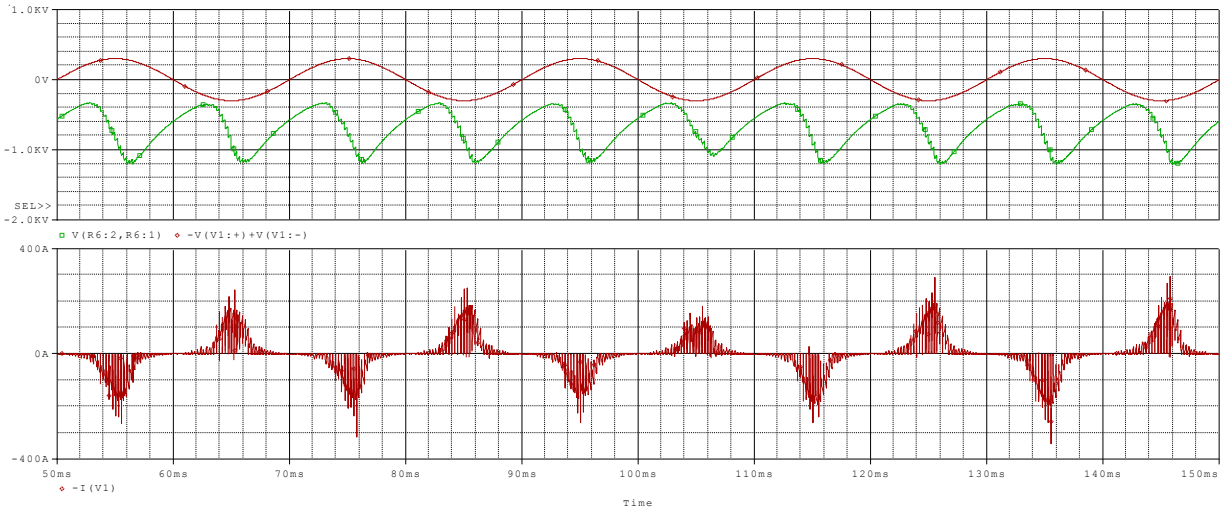

Fig 1.36: Typical Waveforms of the Circuit of Fig 1.35 [73]
Upper: Input and Output Voltages; Bottom: Input Current

1.4.2.4 Input Ĉuk Regulated Single Phase PFC Rectifier [73]

Fig 1.37 is the input Ĉuk regulated single phase PFC rectifier. The configuration uses a bidirectional switch for input current shaping of the Ĉuk rectifier. Fig 1.38 presents the typical input voltage/current and output voltage waveforms of the circuit of Fig 1.37.

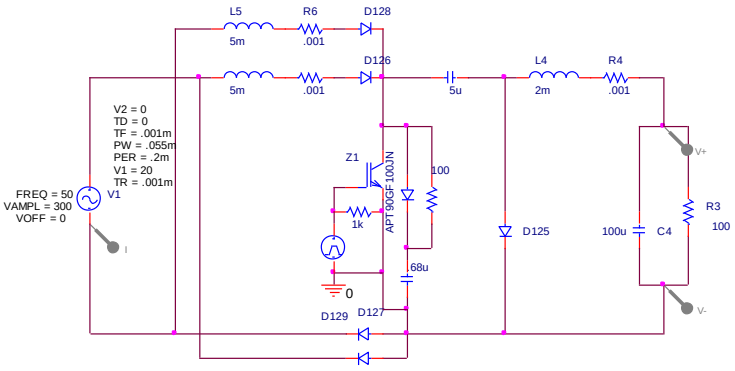

Fig: 1.37: Input Ĉuk Converter Regulated Single Phase PFC Rectifier [73]

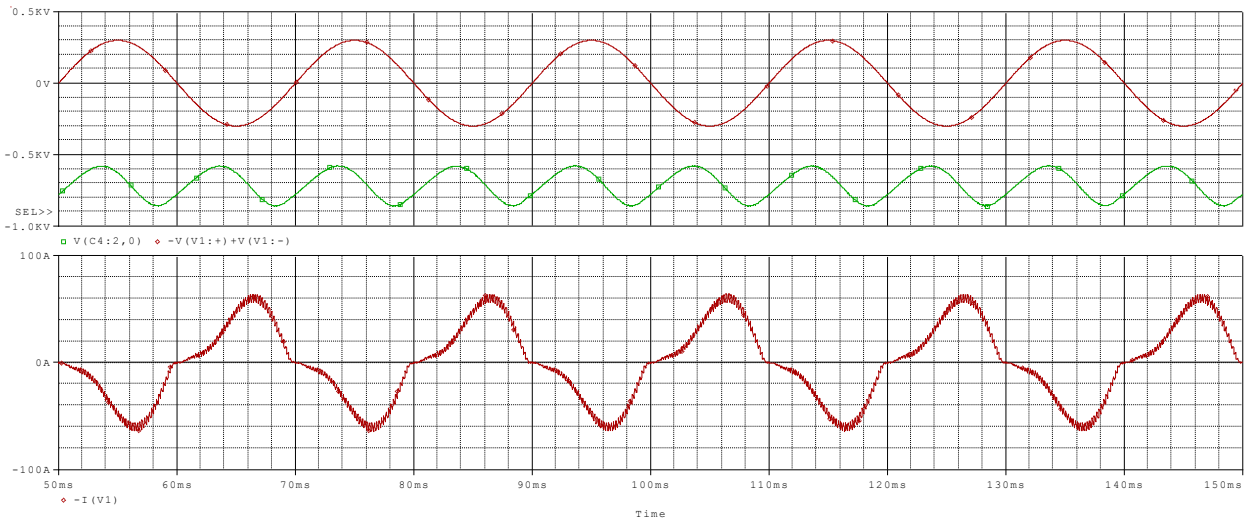

Fig 1.38: Typical Waveforms of the Circuit of Fig 1.25 [73]
Upper: Input and Output Voltages; Bottom: Input Current

1.4.2.5 Input SEPIC Regulated Single Phase PFC Rectifier [73]

Fig 1.39 is the input Sepic regulated single phase PFC rectifier. The configuration uses a bidirectional switch for input current shaping of the Sepic rectifier. Fig 1.40 presents the typical input voltage/current and output voltage waveforms of the circuit of Fig 1.39.

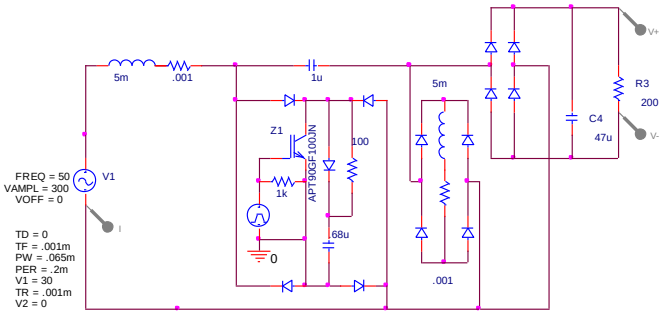

Fig 1.39: Input SEPIC Converter Regulated Single Phase PFC Rectifier [73]

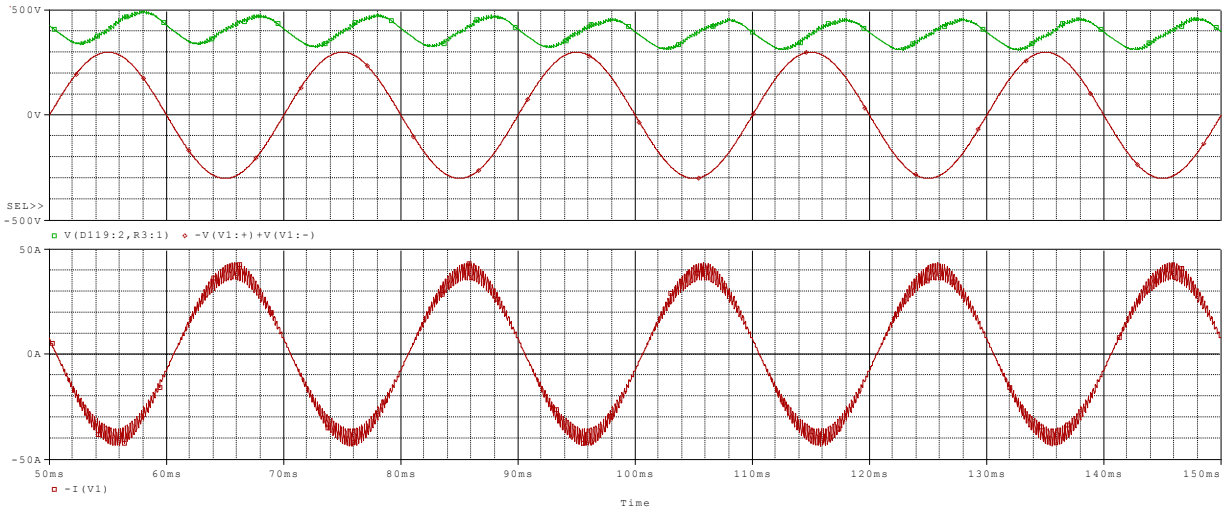

Fig 1.40: Typical Waveforms of the Circuit of Fig 1.39 [73]
Upper: Input and Output Voltages; Bottom: Input Current

1.4.2.6 Input ZETA (Inverse SEPIC) Regulated Single Phase PFC Rectifier [73]

Fig 1.41 is the input Zeta regulated single phase PFC rectifier. The configuration uses a bidirectional switch for input current shaping of the Zeta rectifier. Fig 1.42 presents the typical input voltage/current and output voltage waveforms of the circuit of Fig 1.41.

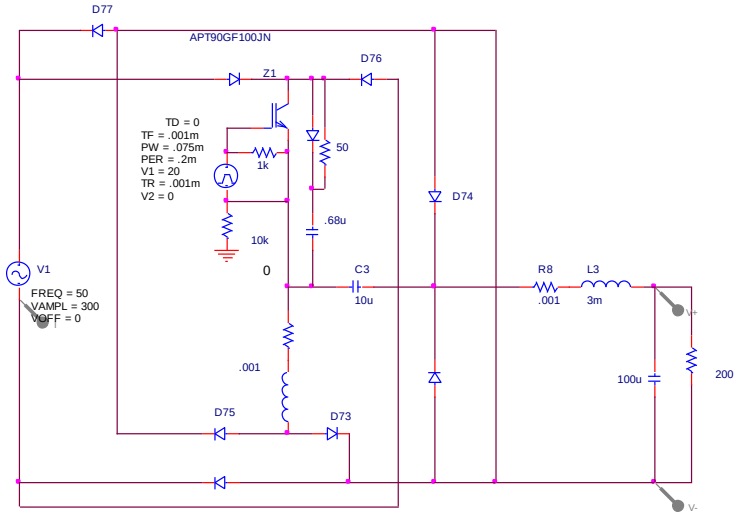

Fig 1.41: Input ZETA (Inverse SEPIC) Converter Regulated Single Phase PFC Rectifier [73]

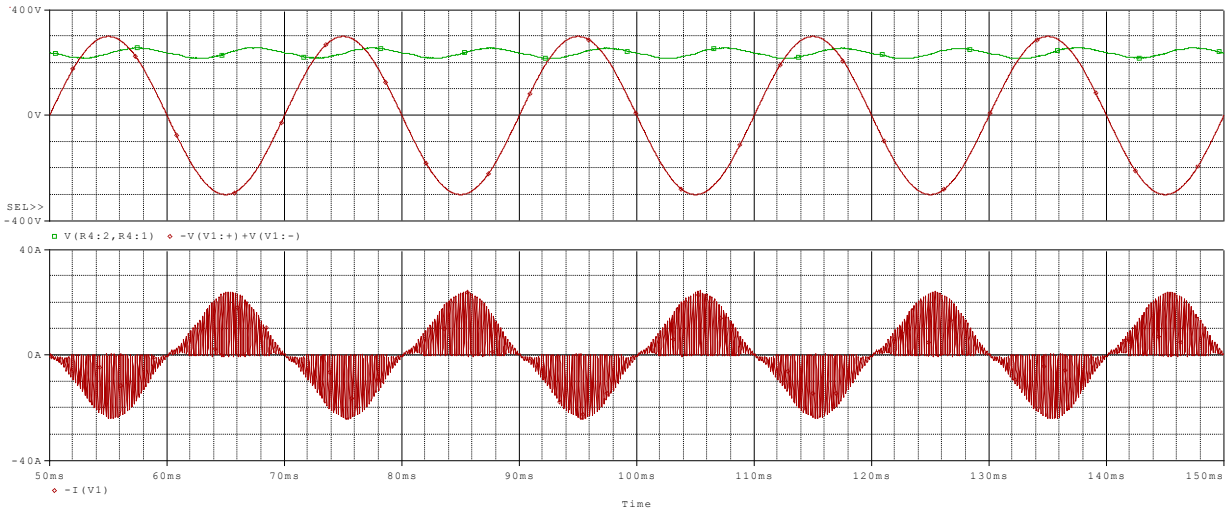

Fig 1.42: Typical Waveforms of the Circuit of Fig 1.41 [73]
Upper: Input and Output Voltages; Bottom: Input Current

1.5 Topic Identification and Objective of the Research

The conventional output Buck-Boost DC-DC converter regulated PFC circuit and its typical waveforms are shown in Figs 1.19-1.20. Recently input switched rectification and bridgeless rectifiers have been investigated as shown in section 1.4.2. The investigation indicated that these PFC rectifiers perform better in terms of input pf and input current THD. In line with these new developments Buck-Boost input regulation has been investigated for PFC in single phase rectifiers. Both bridge and bridgeless circuits were investigated. They provide input pf and input current THD improvement. But since the input current of conventional Buck-Boost converter is discontinuous, it is problematic for input switching (due to source inductor current being chopped abruptly) and the input current filter required is also large. To avoid both problems in this research a modified Buck-Boost converter topology which has continuous input current has been adopted. The adoption of modified Buck-Boost topology will provide continuous input current of the converter. This will result in shaping of input current to near sinusoid by use of small filter and ensures good input power factor. Same Buck-Boost converter topology can also be used at the output of single phase rectifier for input pf and input current THD improvement. In this thesis both input and output switching is studied and compared.

Proposed Buck-Boost topology based AC-DC converter will provide step-up/step-down output dc voltage with the duty cycle control of the switch of the converter.

The objectives of the proposed work are:

1. To develop and design of a scheme for high input power factor, high efficiency single switch AC-DC converter.
2. To design the circuit parameters to achieve low THD, high input power factor and good efficiency.
3. To analyze the performances of proposed circuit/circuits by simulation.
4. To compare the performances of the proposed scheme/schemes with conventional switch mode AC-DC Buck Boost converter (rectifier followed by modified and conventional Buck Boost DC-DC converter).

The outcome of this research will be a single switch AC-DC Buck Boost converter with near unity input power factor, high efficiency and low THD of the input current.

1.6 Outline of the Thesis

Chapter I introduces the thesis topic. Here, the problems of single phase and three phase rectifiers have been narrated. Then to overcome the problems of rectifier several input current shaping and PFC methods of a single phase diode bridge rectifier have been discussed. This chapter also contains the topic identification and objectives of this research work.

Chapter II provides discussion on problem of buck boost converter and the solution of discontinuous input current. In this chapter conventional and proposed topologies of buck boost converters are discussed. Then various simulation results of conventional and proposed topologies of buck boost converters are compared and discussed.

Chapter III draws a conclusion of this work. This chapter puts forward suggestions for future scopes of works related to this thesis.

CHAPTER-2
DISCONTINUOUS INPUT CURRENT BUCK BOOST SINGLE PHASE PFC RECTIFIER

2.1 Introduction

The output of a Buck Boost converter may be less than or greater than the input voltage. The output voltage is negative and the input current is discontinuous. As a result power factor correction and input current THD reduction by this conversion technique needs large input filter in both output and input control. For discontinuous input current filtering becomes difficult; large size of inductor and capacitor are required.

A conventional Buck Boost DC-DC circuit and a modified Buck Boost DC-DC circuit are studied. Output Switched Conventional Buck Boost Single Phase AC-DC Converter and also Input Switched Conventional Buck Boost Single Phase AC-DC Converter are found in literature and both are studied.

2.2 Buck Boost DC-DC Circuit (Conventional with Discontinuous Input Current)

A conventional Buck Boost DC-DC circuit is shown in Fig 2.1. A Buck Boost circuit provides output voltage that may be less than or greater than the input voltage. So it can be used in both step up and step down operation. But this converter has following demerits:

a. Input current is discontinuous and

b. For discontinuous input current filtering input current needs large inductor and capacitor.

The typical output voltage waveform of a conventional Buck Boost DC-DC circuit of Fig 2.1 is shown in Fig 2.2 and the typical input current waveform is shown in Fig 2.3. Fig 2.3 indicates the discontinuous nature of the input current of a Buck Boost DC-DC converter.

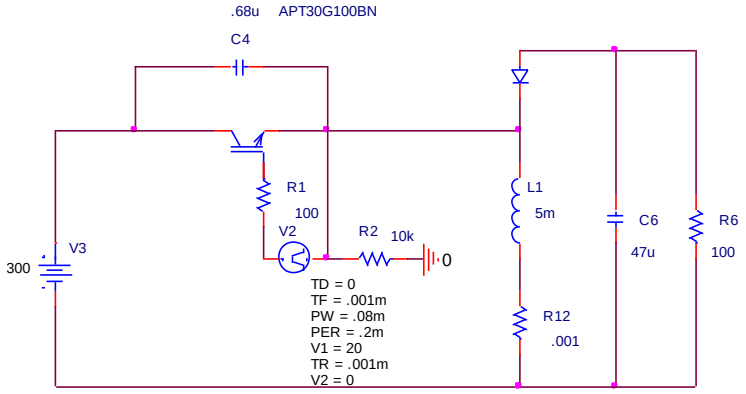

Fig 2.1: A conventional Buck Boost DC-DC circuit

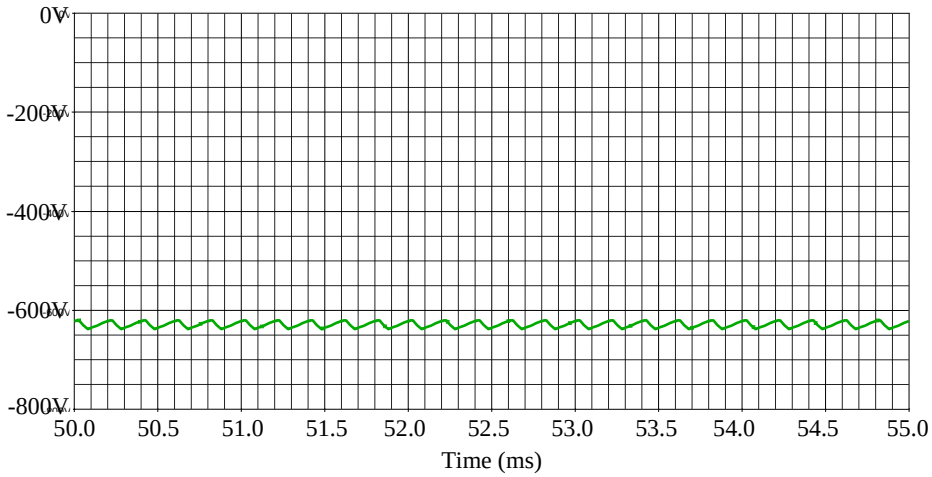

Fig 2.2: Typical output voltage waveform of the circuit of Fig 2.1

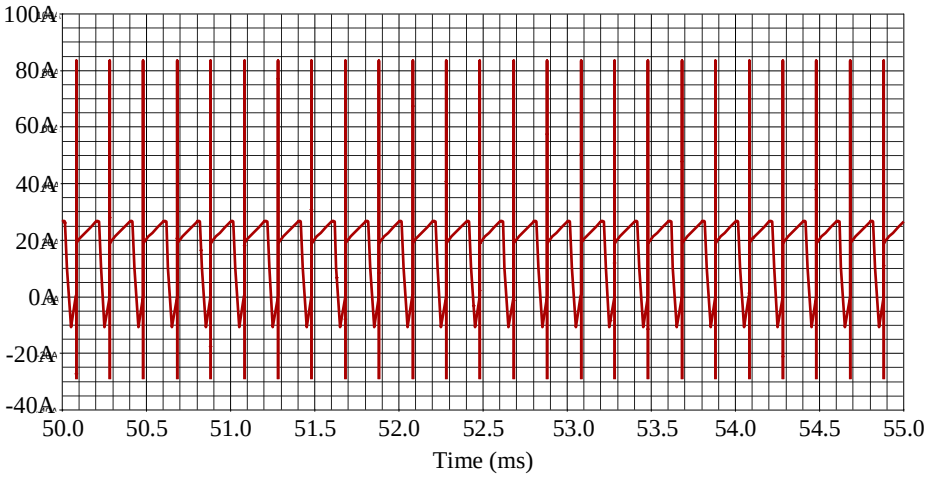

Fig 2.3: Typical input current waveform of the circuit of Fig 2.1

2.3 Modified Buck Boost DC-DC Converter (Continuous Input Current)

To make the input current of a conventional Buck Boost DC-DC circuit continuous a modified Buck Boost DC-DC circuit may be used which is shown in Fig 2.4. The typical output voltage waveform of the circuit of Fig 2.4 is shown in Fig 2.5 and the typical input current waveform is shown in Fig 2.6.

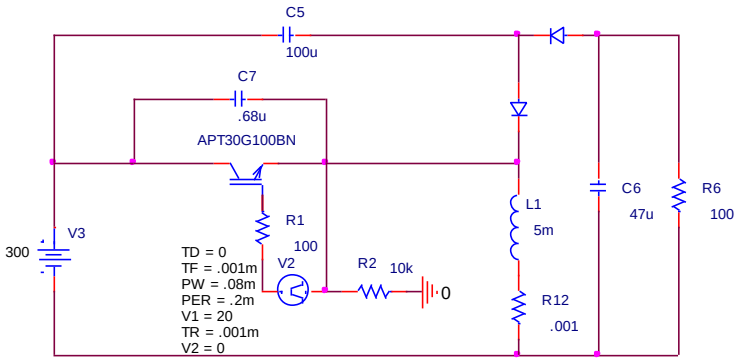

Fig 2.4: Continuous input current Buck Boost DC-DC circuit

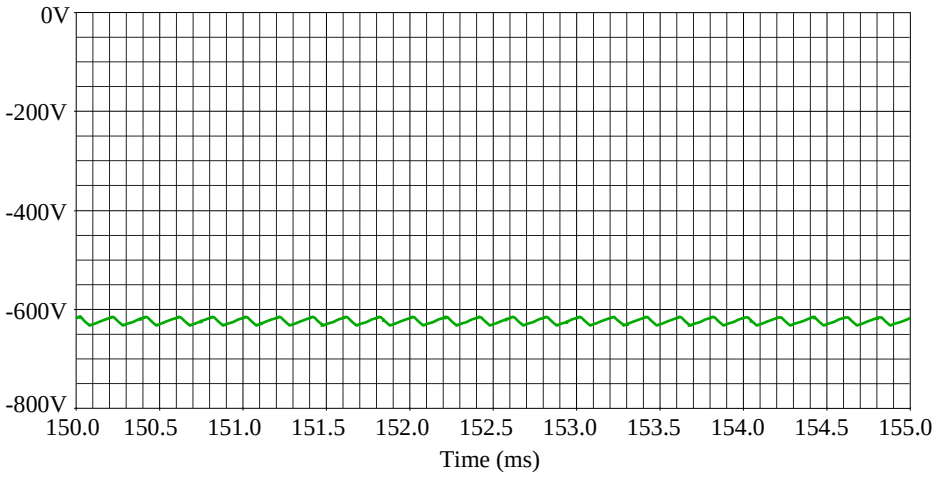

Fig 2.5: Typical output voltage waveform of the circuit of Fig 2.4

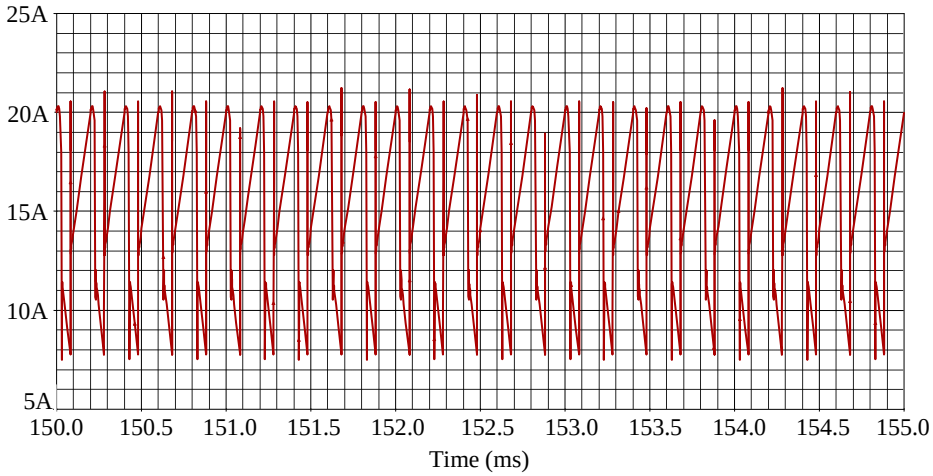

Fig 2.6: Typical input current waveform of the circuit of Fig 2.4

2.4. Previous Works

2.4.1.1 Conventional Buck Boost Output Regulated Single Phase AC-DC Converter (Discontinuous Input Current)

In an Output Switched Single Phase AC-DC converter a Buck Boost DC-DC circuit is placed between the output of the bridge rectifier and the DC output as shown in Fig 2.7, where one switch and one inductor are used and the switching is done at the output of the rectifier. In this converter input current is discontinuous. The typical output voltage waveform of the circuit of Fig 2.7 is shown in Fig 2.8 and the typical input current waveform is shown in Fig 2.9. The Fourier transform of the input current waveform is shown in Fig 2.10.

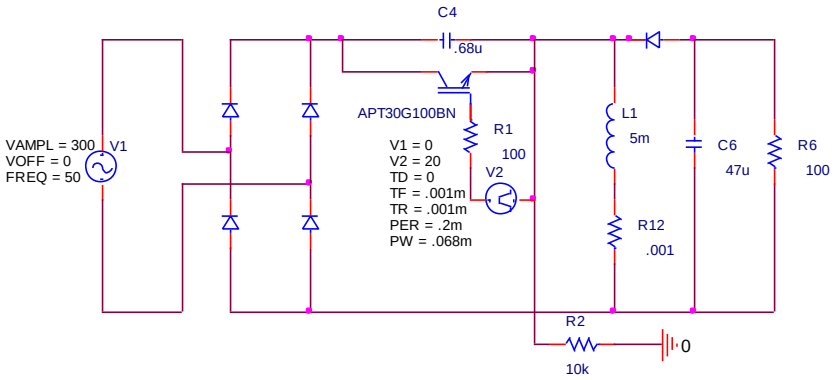

Fig 2.7: Conventional Buck Boost Output Regulated Single Phase AC-DC Converter (Discontinuous Input Current)

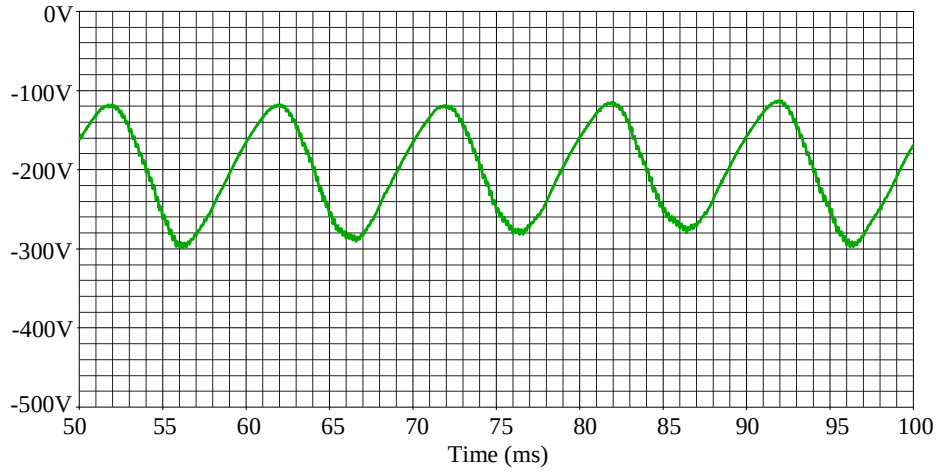

Fig 2.8: Typical output voltage waveform of the circuit of Fig 2.7

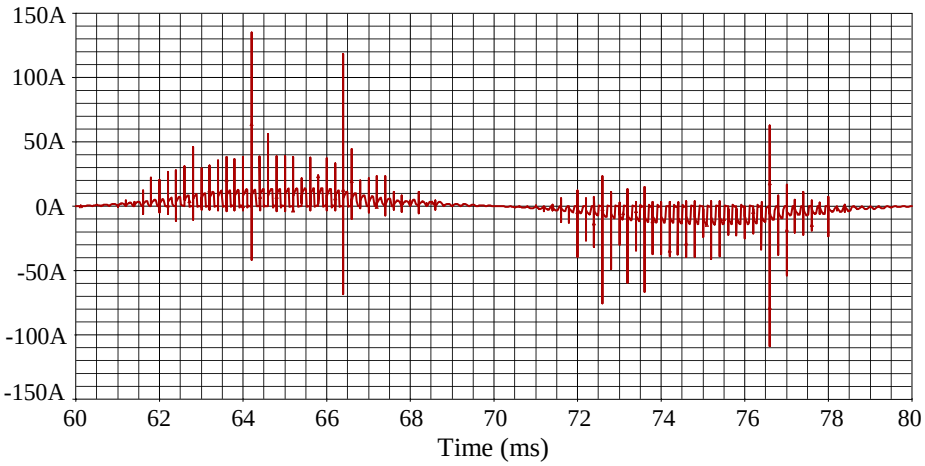

Fig 2.9: Typical input current waveform of the circuit of Fig 2.7

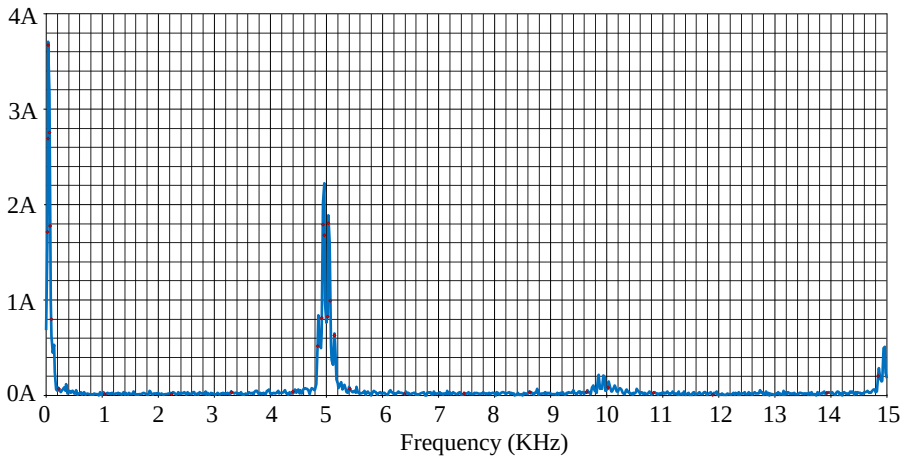

Fig 2.10: Fourier transform of the input current waveform of Fig 2.9

2.4.1.2 Conventional Buck Boost Input Regulated Single Phase AC-DC Converter (Discontinuous Input Current)

In a single phase AC-DC rectifier switching is possible in input side also. In this topology a conventional Buck Boost DC-DC circuit is placed at the input. A Conventional Buck Boost Input Regulated Single Phase AC-DC converter (Discontinuous Input Current) is shown in Fig 2.11 where one switch and one inductor are used. Still input current is discontinuous and the filtering problem remains. The typical output voltage waveform of the circuit of Fig 2.11 is shown in Fig 2.12 and the typical input current waveform is shown in Fig 2.13. The Fourier transform of the input current waveform is shown in Fig 2.14.

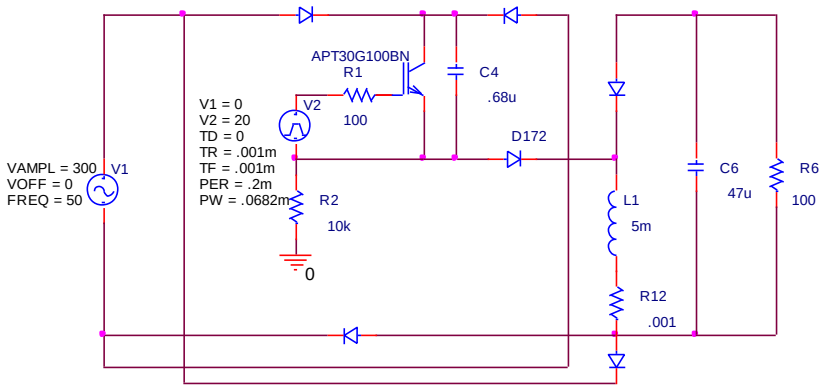

Fig 2.11: Conventional Buck Boost Input Regulated Single Phase AC-DC Converter (Discontinuous Input Current)

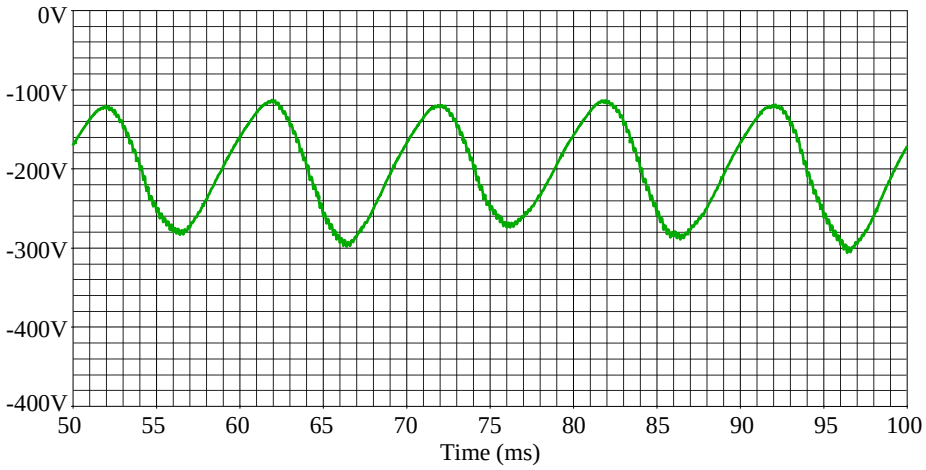

Fig 2.12: Typical output voltage waveform of the circuit of Fig 2.11

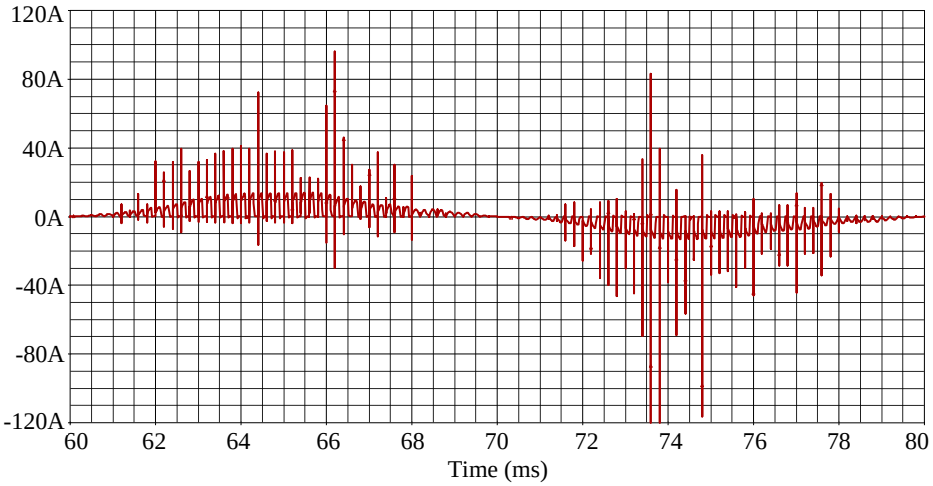

Fig 2.13: Typical input current waveform of the circuit of Fig 2.11

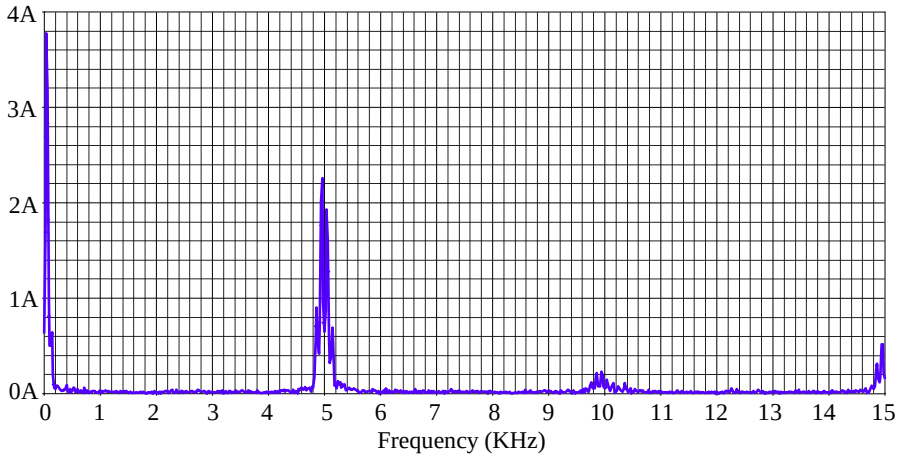

Fig 2.14: Fourier transform of the input current waveform of Fig 2.13

2.4.1.3 Conventional Buck Boost Output Regulated Single Phase AC-DC Converter with Input Filter (Discontinuous Input Current)

A Conventional Buck Boost Output Regulated Single Phase AC-DC Converter with Input Filter is shown in Fig 2.15 where a LC filter is used between the source and the input of the rectifier. The typical output voltage waveform of the circuit of Fig 2.15 is shown in Fig 2.16 and the typical input current waveform is shown in Fig 2.17. The Fourier transform of the input current waveform is shown in Fig 2.18.

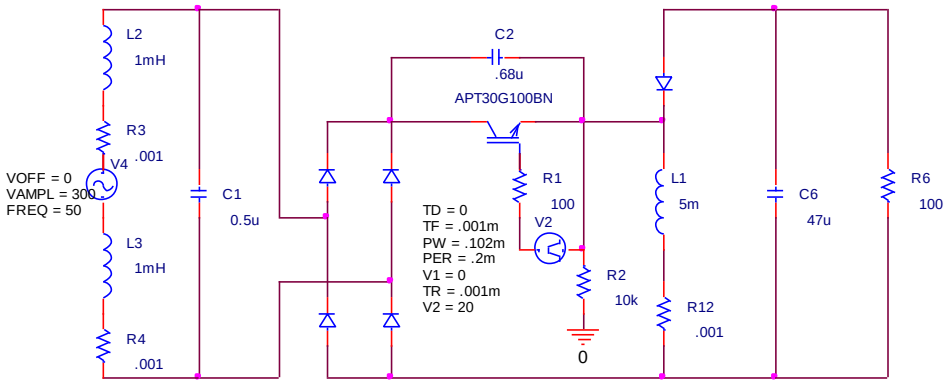

Fig 2.15: Conventional Buck Boost Output Regulated Single Phase AC-DC Converter with Input Filter (Discontinuous Input Current)

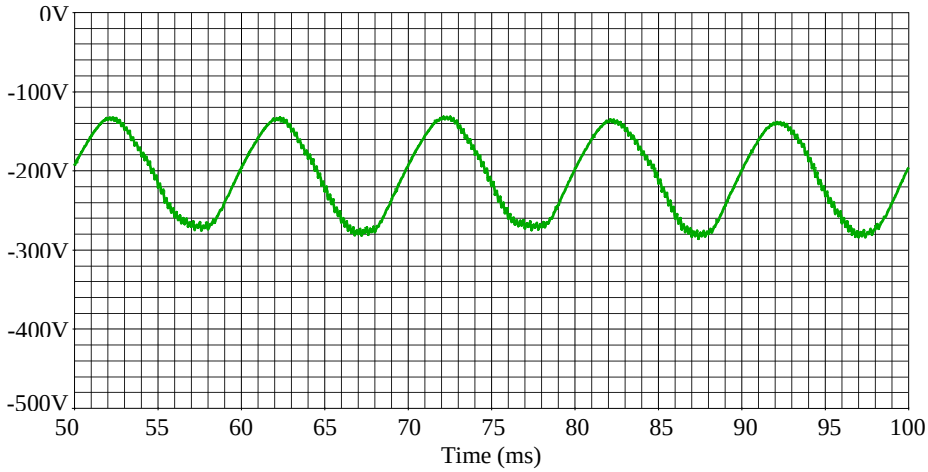

Fig 2.16: Typical output voltage waveform of the circuit of Fig 2.15

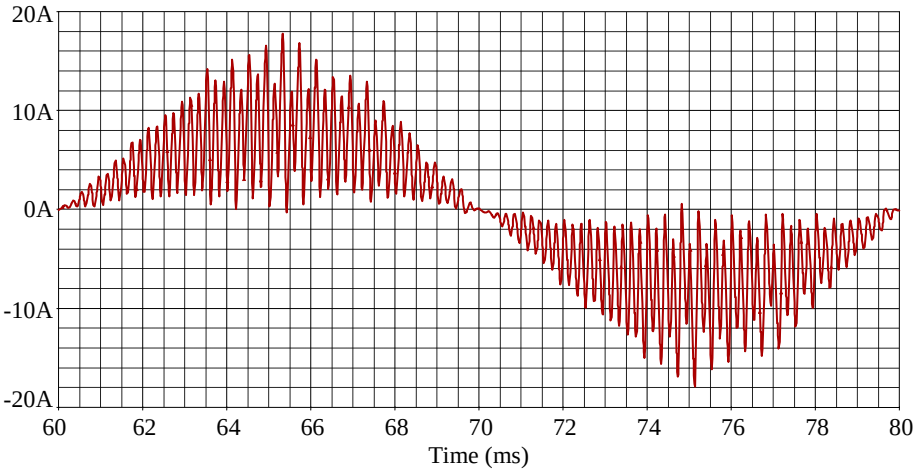

Fig 2.17: Typical input current waveform of the circuit of Fig 2.15

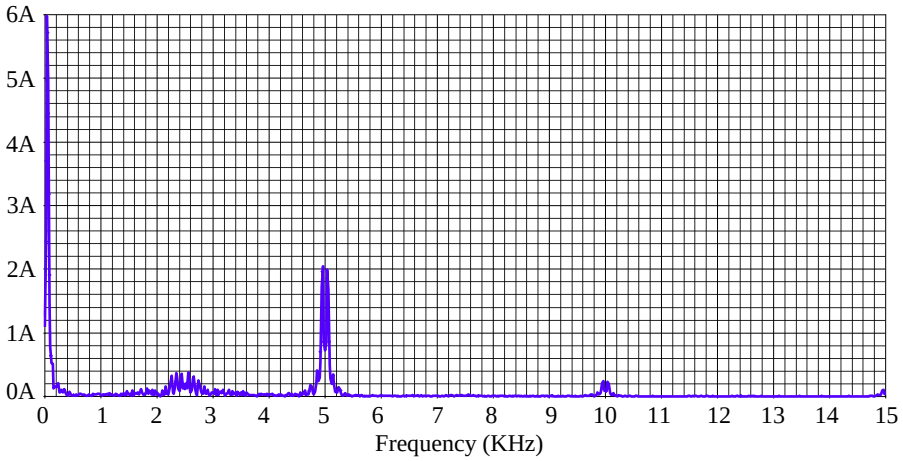

Fig 2.18: Fourier transform of the input current waveform of Fig 2.17

2.4.1.4 Conventional Buck Boost Input Regulated Single Phase AC-DC Converter with Input Filter (Discontinuous Input Current)

A Conventional Buck Boost Input Regulated Single Phase AC-DC Converter with Input Filter (Discontinuous Input Current) is shown in Fig 2.19 where a LC filter is used between the source and the input of the rectifier. The typical output voltage waveform of the circuit of Fig 2.19 is shown in Fig 2.20 and the typical input current waveform is shown in Fig 2.21. The Fourier transform of the input current waveform is shown in Fig 2.22.

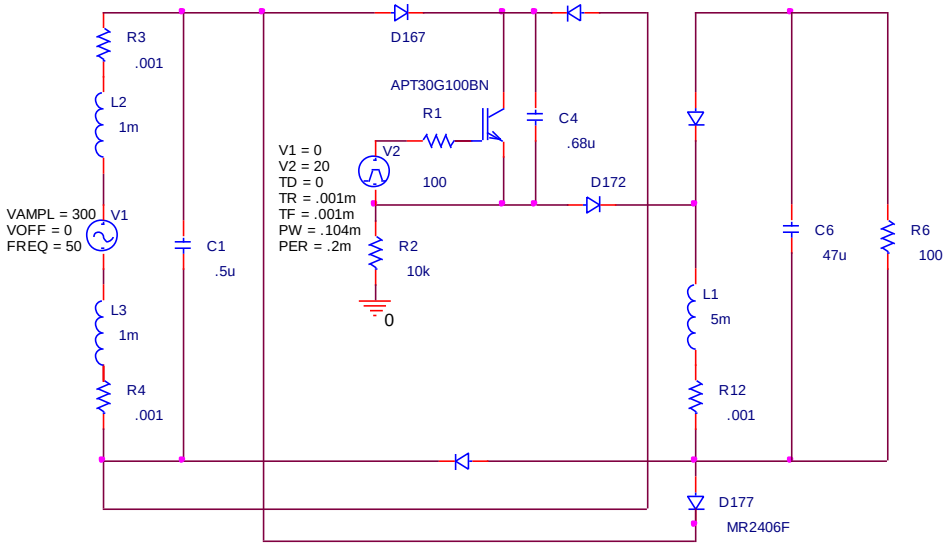

Fig 2.19: Conventional Buck Boost Input Regulated Single Phase AC-DC Converter with Input Filter (Discontinuous Input Current)

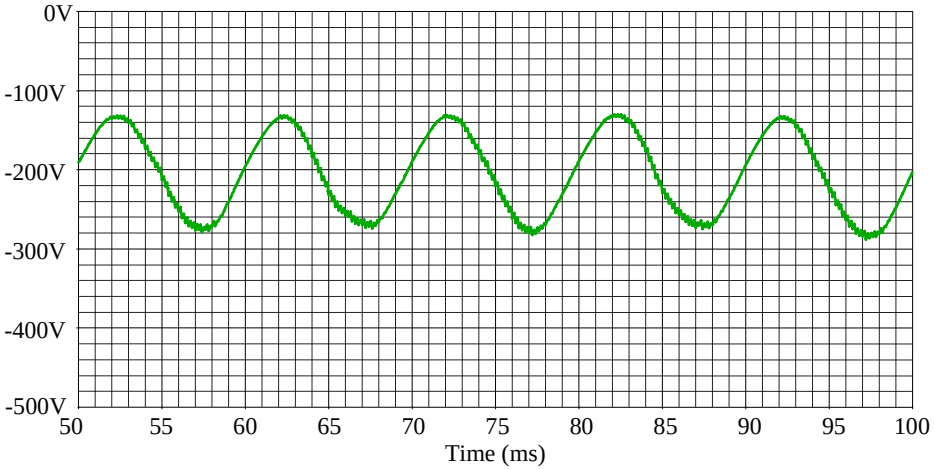

Fig 2.20: Typical output voltage waveform of the circuit of Fig 2.19

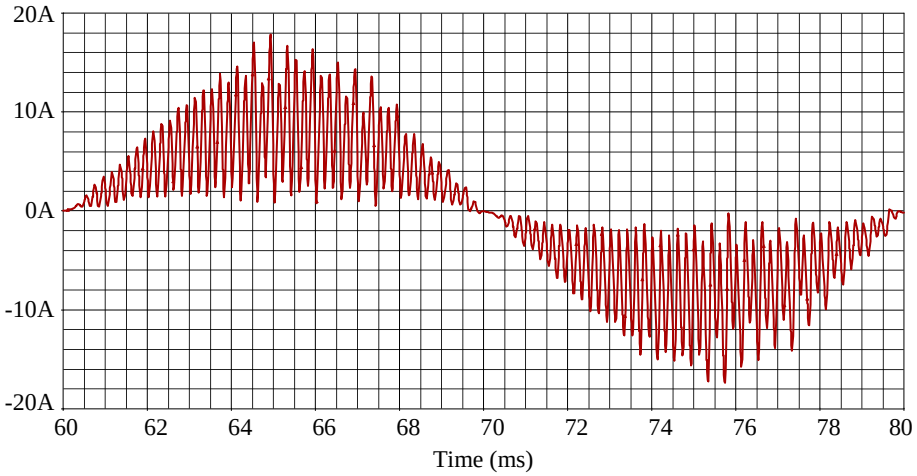

Fig 2.21: Typical input current waveform of the circuit of Fig 2.19

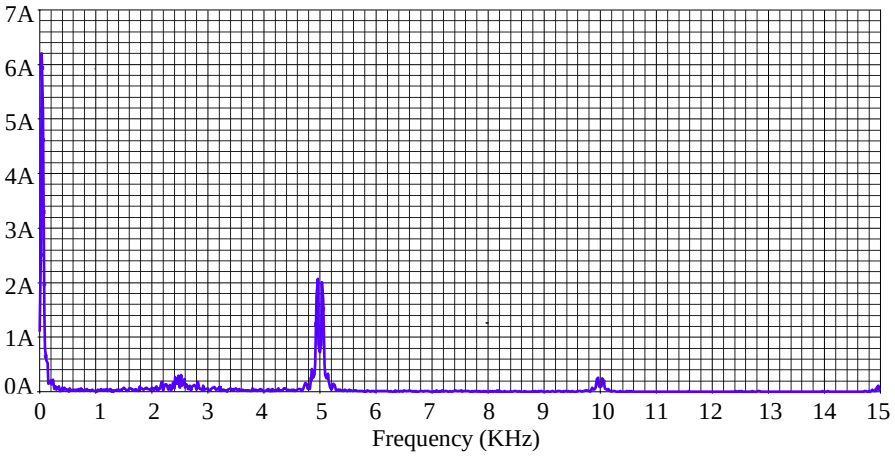

Fig 2.22: Fourier transform of the input current waveform of Fig 2.21

CHAPTER-3
CONTINUOUS INPUT CURRENT BUCK BOOST SINGLE PHASE PFC RECTIFIER

3.1 Introduction

To overcome the problem of discontinuous input current conventional Buck Boost circuit can be modified so that current becomes continuous. This may allow use of filter of small inductor and capacitor. Switching can be done in input or in output side of the rectifier. In input switching the Buck Boost circuit is placed between the source and the rectifier, whereas in output switching the Buck Boost circuit is placed between the rectifier and the load.

In this work Output Switched Modified Buck Boost Single Phase AC-DC Converter and also Input Switched Modified Buck Boost Single Phase AC-DC Converter are investigated.

3.2 Proposed Work

3.2.1.1 Modified Buck Boost Output Regulated Single Phase AC-DC Converter (Continuous Input Current)

A topology of an Output Switched Buck Boost Single Phase AC-DC converter with continuous input current is proposed here. The circuit of the proposed topology is shown in Fig 3.1. One switch and one inductor are used and the switching is done at the output of the rectifier.

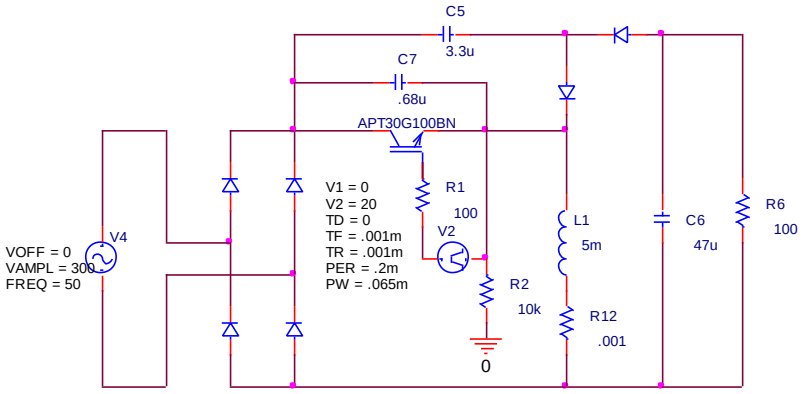

Fig 3.1: Modified Buck Boost Output Regulated Single Phase AC-DC Converter (Continuous Input Current)

Circuit operations in positive half cycle are shown in Fig 3.2 and Fig 3.3. Circuit operations in negative half cycle are shown in Fig 3.4 and Fig 3.5. As the switching device of the circuit is switched at high frequency during the positive half cycle of the supply, the conduction path is shown in Fig 3.2 when the switch is ON. The conduction path when the switch is OFF during the positive cycle of the supply is shown in Fig 3.3.

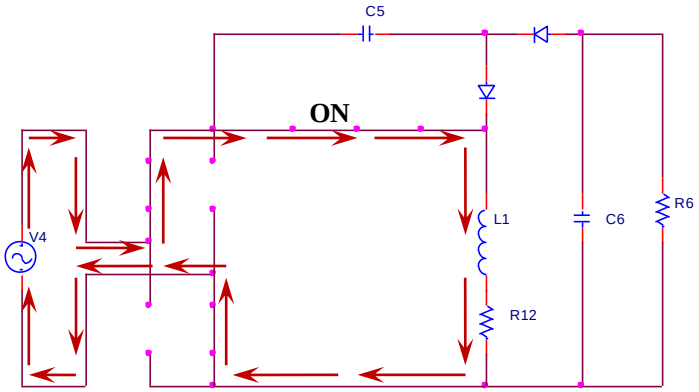

Fig 3.2: Conduction path of the circuit of Fig 3.1 (+ve half cycle, switch ON)

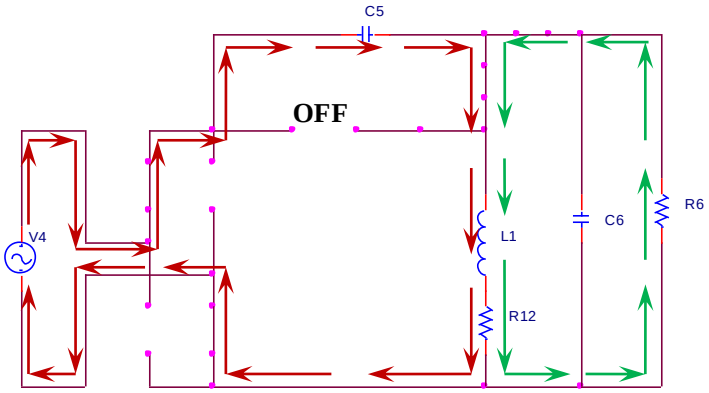

Fig 3.3: Conduction path of the circuit of Fig 3.1 (+ve half cycle, switch OFF)

During negative half cycle, as the switching device turns ON and OFF at high frequency, the conduction paths are shown in Fig 3.4 when the switch turns ON and in Fig 3.5 when the switch turns OFF.

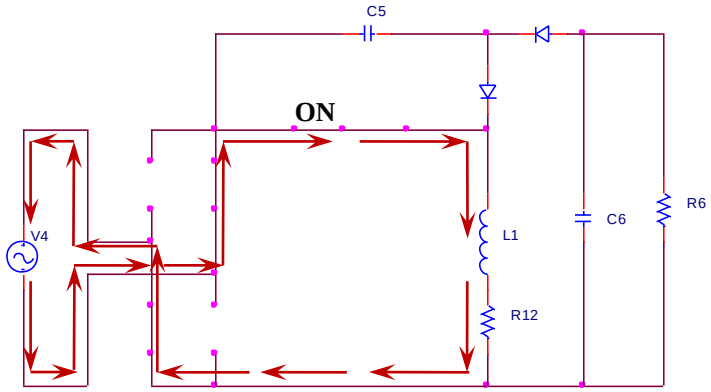

Fig 3.4: Conduction path of the circuit of Fig 3.1 (-ve half cycle, switch ON)

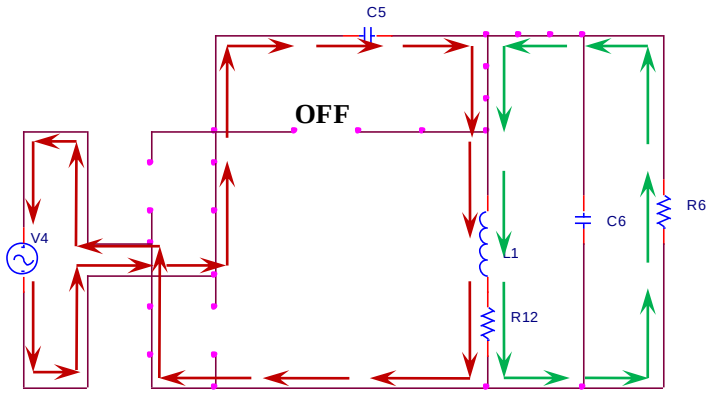

Fig 3.5: Conduction path of the circuit of Fig 3.1 (-ve half cycle, switch OFF)

When the switch is turned on, primary current ramps up and in both positive and negative cycle energy is stored in the inductor L1. Energy to the load is supplied by the charge in capacitor C6. When switch turns off, stored energy in L1 provides energy to load circuit and recharges C6.

The typical output voltage waveform of the circuit of Fig 3.1 is shown in Fig 3.6 and the typical input current waveform is shown in Fig 3.7. For this topology input current is found continuous, so the problem of filtering is overcome. The Fourier transform of the input current waveform is shown in Fig 3.8.

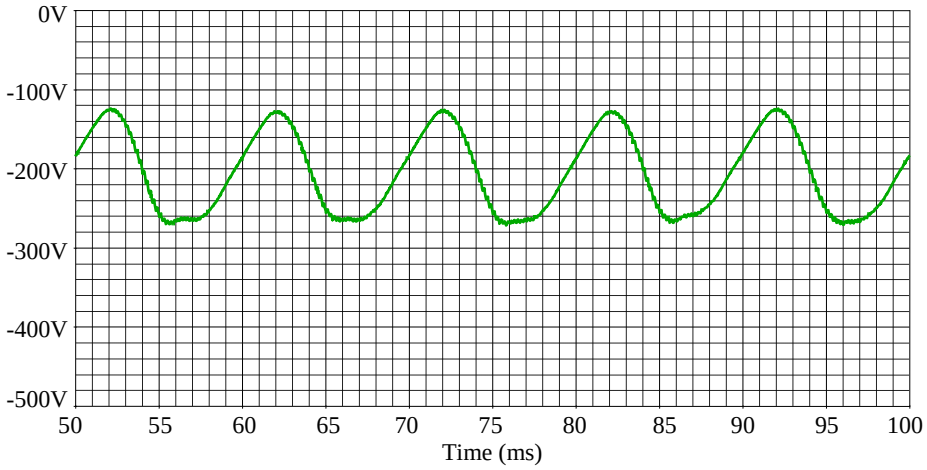

Fig 3.6: Typical output voltage waveform of the circuit of Fig 3.1

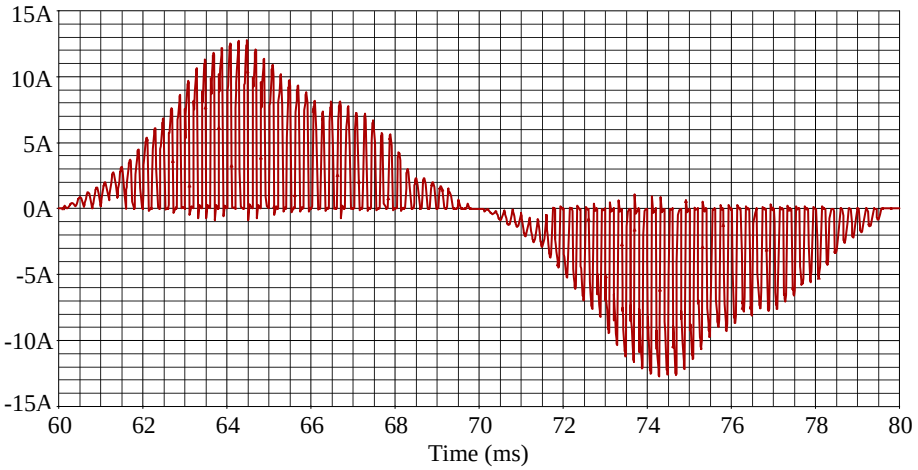

Fig 3.7: Typical input current waveform of the circuit of Fig 3.1

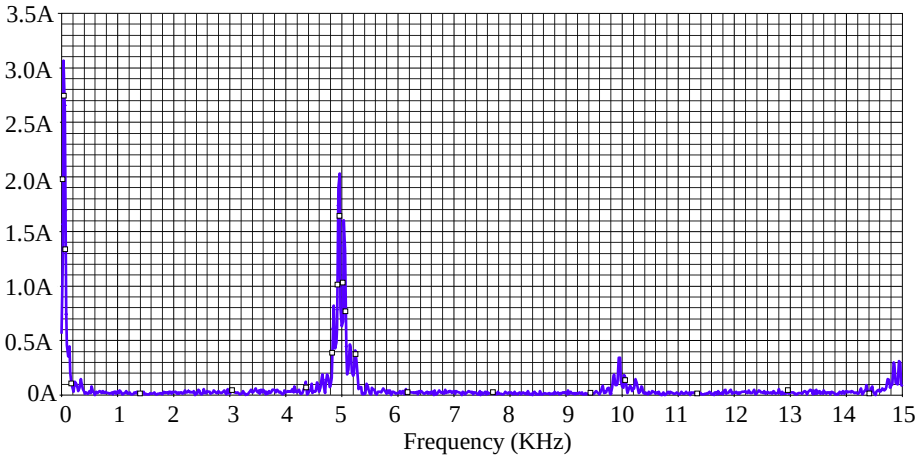

Fig 3.8: Fourier transform of the input current waveform of Fig 3.7

3.2.1.2 Modified Buck Boost Input Regulated Single Phase AC-DC Converter (Continuous Input Current, Circuit-I)

A topology of an Input Switched Buck Boost Single Phase AC-DC converter with continuous input current is proposed here. The circuit of the proposed topology is shown in Fig 3.9. One switch and two inductors are used and the switching is done at the input of the rectifier.

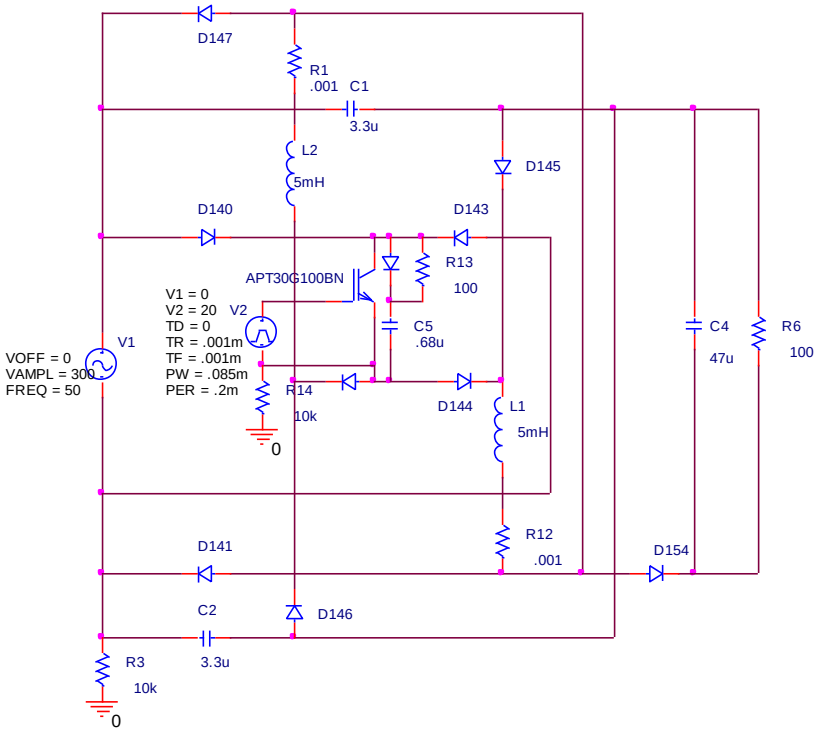

Fig 3.9: Modified Buck Boost Input Regulated Single Phase AC-DC Converter (Continuous Input Current, Circuit-I)

Circuit operations in positive half cycle are shown in Fig 3.10 and Fig 3.11. Circuit operations in negative half cycle are shown in Fig 3.12 and Fig 3.13. As the switching device of the circuit is switched at high frequency during the positive half cycle of the supply, the conduction path is shown in Fig 3.10 when the switch is ON. The conduction path when the switch is OFF during the positive cycle of the supply is shown in Fig 3.11.

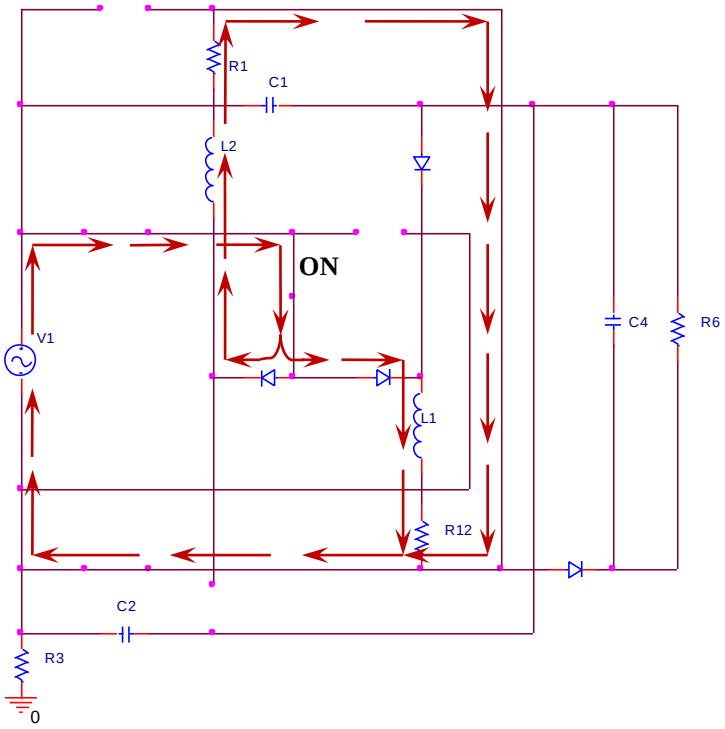

Fig 3.10: Conduction path of the circuit of Fig 3.9 (+ve half cycle, switch ON)

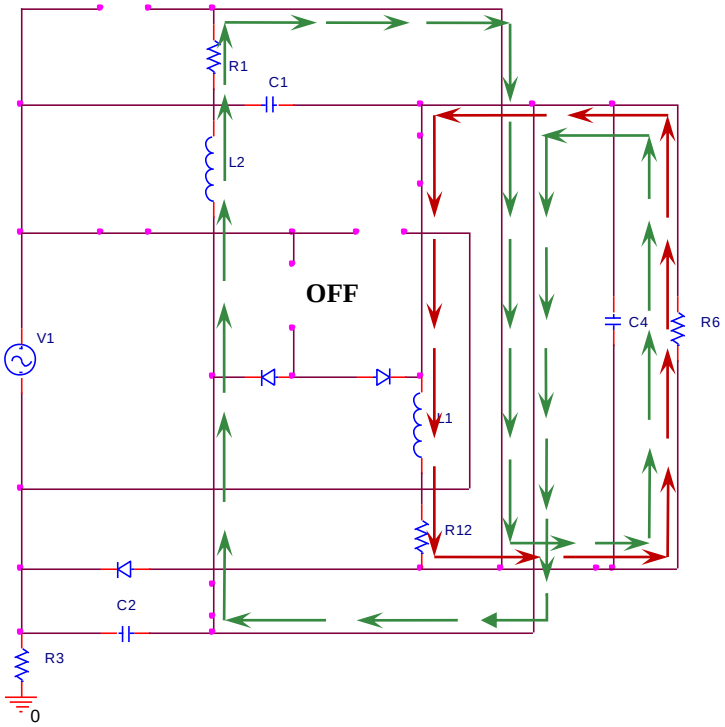

Fig 3.11: Conduction path of the circuit of Fig 3.9 (+ve half cycle, switch OFF)

During negative half cycle, as the switching device turns ON and OFF at high frequency, the conduction paths are shown in Fig 3.12 when the switch turns ON and in Fig 3.13 when the switch turns OFF.

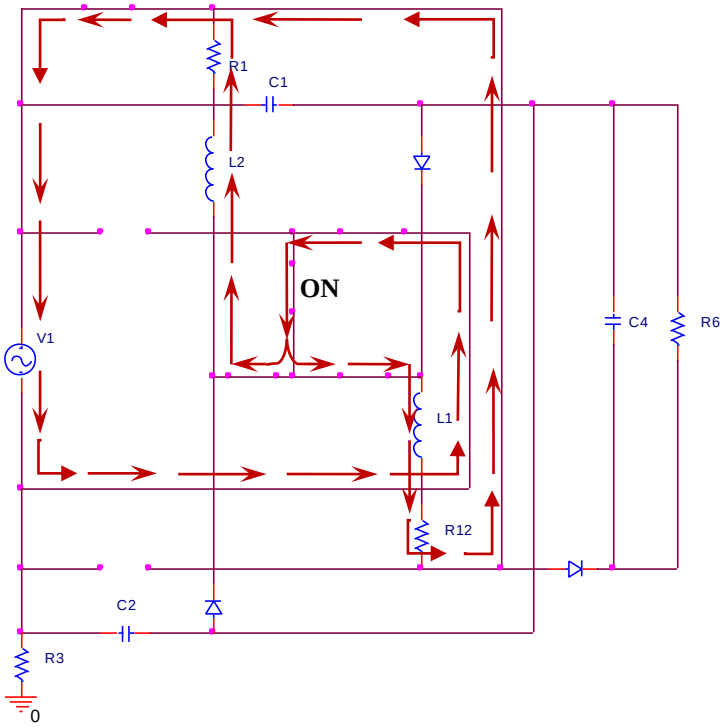

Fig 3.12: Conduction path of the circuit of Fig 3.9 (-ve half cycle, switch ON)

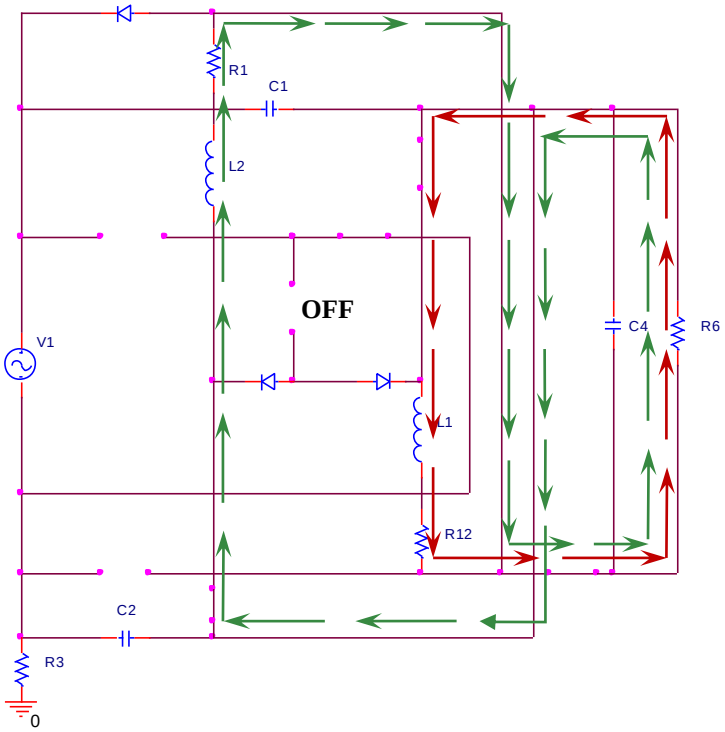

Fig 3.13: Conduction path of the circuit of Fig 3.9 (-ve half cycle, switch OFF)

When the switch is turned on, primary current ramps up and in both positive and negative cycle energy is stored in the inductor L1 and L2. Energy to the load is supplied by the charge in capacitor C4. When switch turns off, stored energy in L1 and L2 provide energy to load circuit and recharges C4.

The typical output voltage waveform of the circuit of Fig 3.9 is shown in Fig 3.14 and the typical input current waveform is shown in Fig 3.15. For this topology input current is found continuous, so the problem of filtering will be less. The Fourier transform of the input current waveform is shown in Fig 3.16.

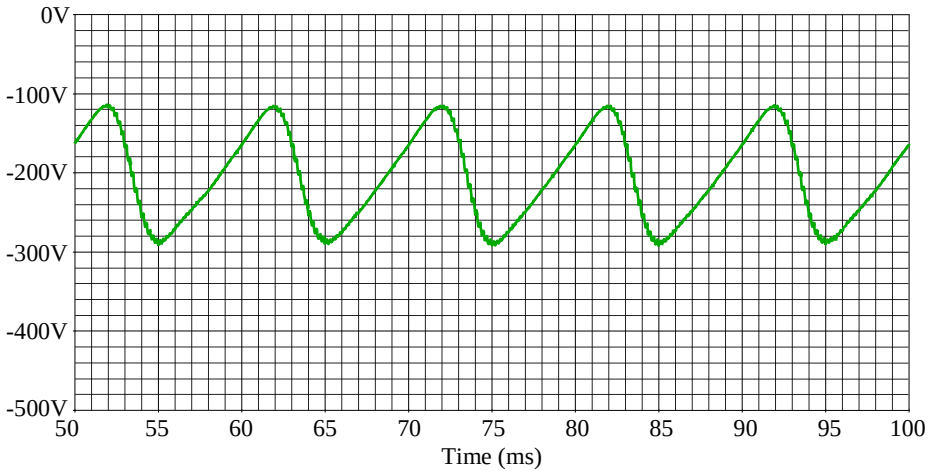

Fig 3.14: Typical output voltage waveform of the circuit of Fig 3.9

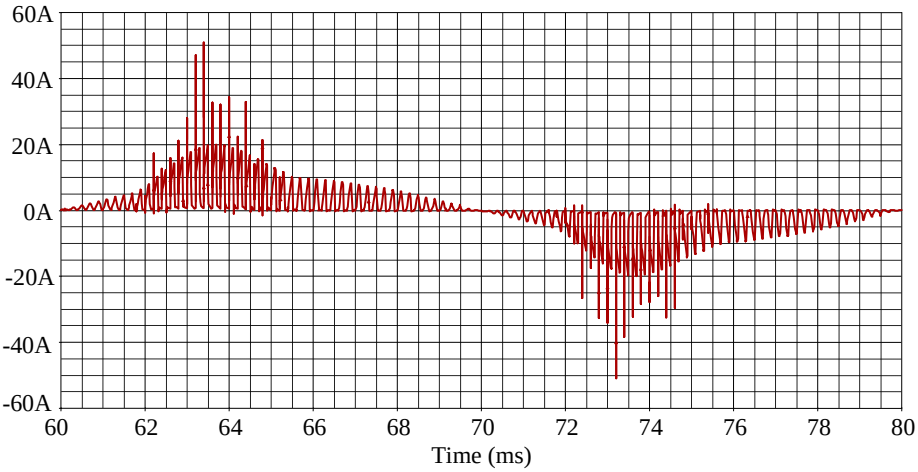

Fig 3.15: Typical input current waveform of the circuit of Fig 3.9

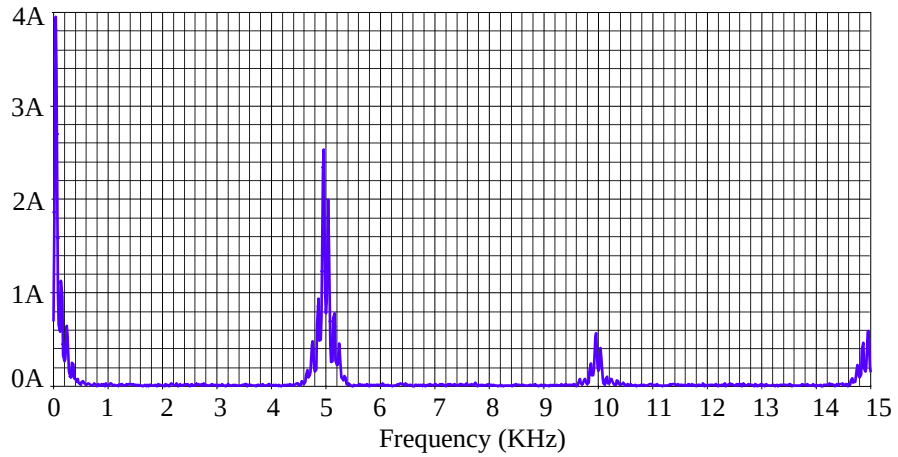

Fig 3.16: Fourier transform of the input current waveform of Fig 3.15

3.2.1.3 Modified Buck Boost Input Regulated Single Phase AC-DC Converter (Continuous Input Current, Circuit-II)

A second topology of an Input Switched Modified Buck Boost Single Phase AC-DC converter with continuous input current is proposed here. The circuit of the proposed topology is shown in Fig 3.17. One switch and one inductor are used in this topology and the switching is done at the input of the rectifier.

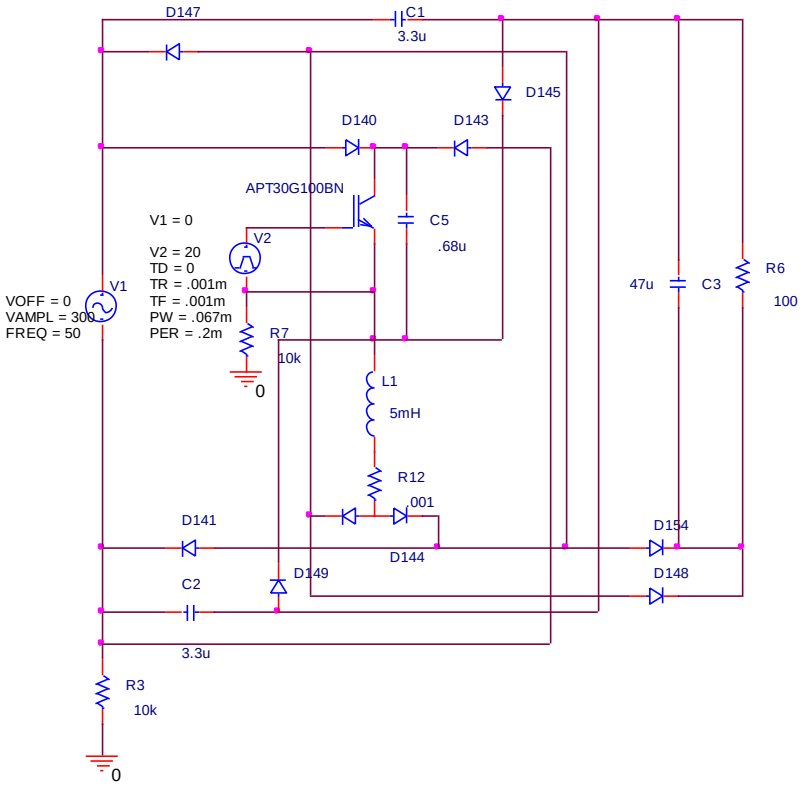

Fig 3.17: Modified Buck Boost Input Regulated Single Phase AC-DC Converter (Continuous Input Current, Circuit-II)

Circuit operations in positive half cycle are shown in Fig 3.18 and Fig 3.19. Circuit operations in negative half cycle are shown in Fig 3.20 and Fig 3.21. As the switching device of the circuit is switched at high frequency during the positive half cycle of the supply, the conduction path is shown in Fig 3.18 when the switch is ON. The conduction path when the switch is OFF during the positive cycle of the supply is shown in Fig 3.19.

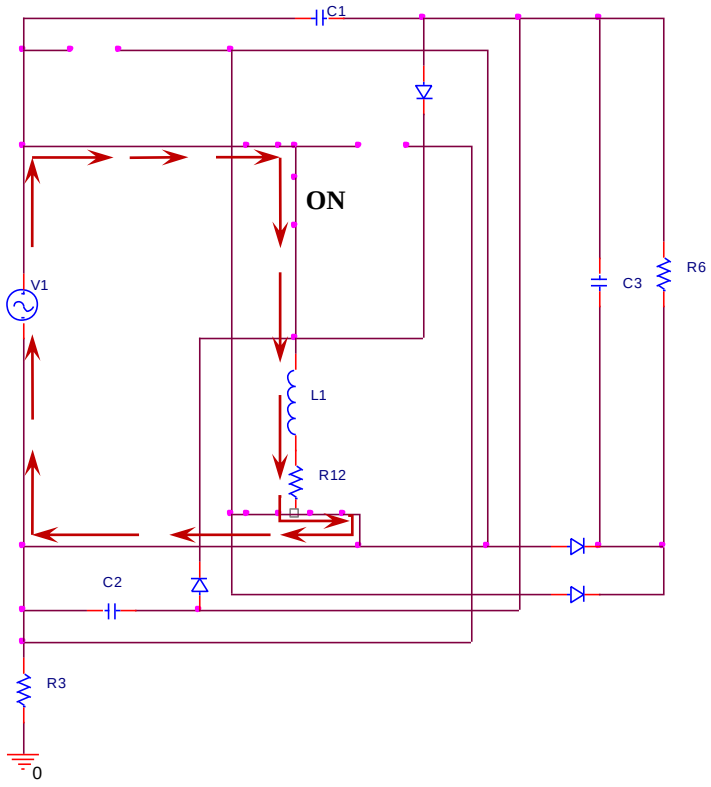

Fig 3.18: Conduction path of the circuit of Fig 3.17 (+ve half cycle, switch ON)

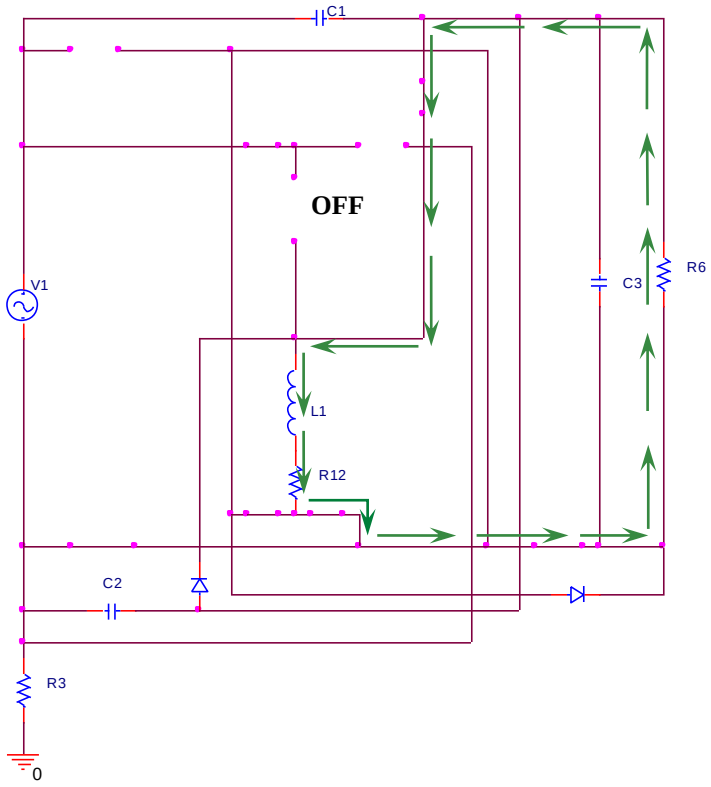

Fig 3.19: Conduction path of the circuit of Fig 3.17 (+ve half cycle, switch OFF)

During negative half cycle, as the switching device turns ON and OFF at high frequency, the conduction paths are shown in Fig 3.20 when the switch turns ON and in Fig 3.21 when the switch turns OFF.

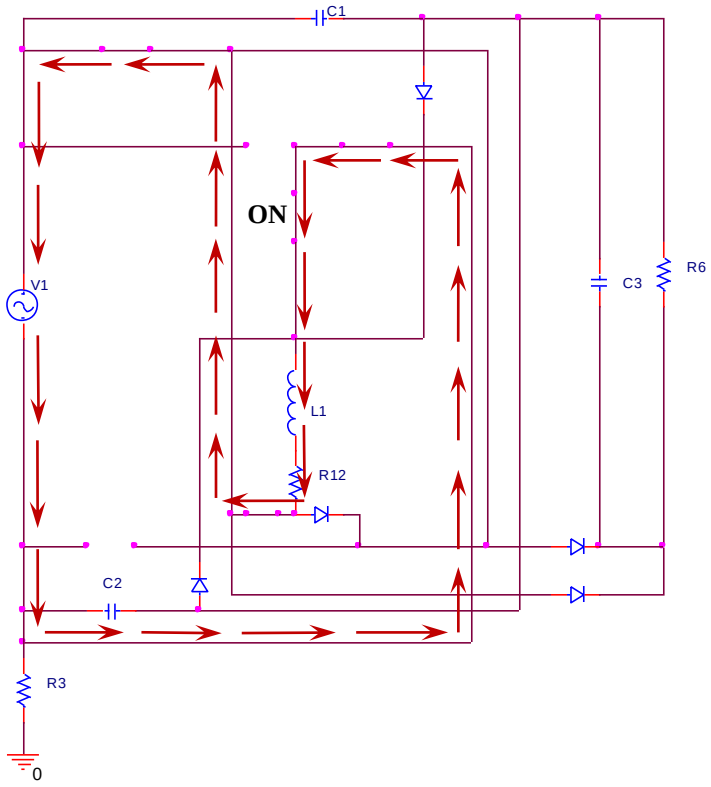

Fig 3.20: Conduction path of the circuit of Fig 3.17 (-ve half cycle, switch ON)

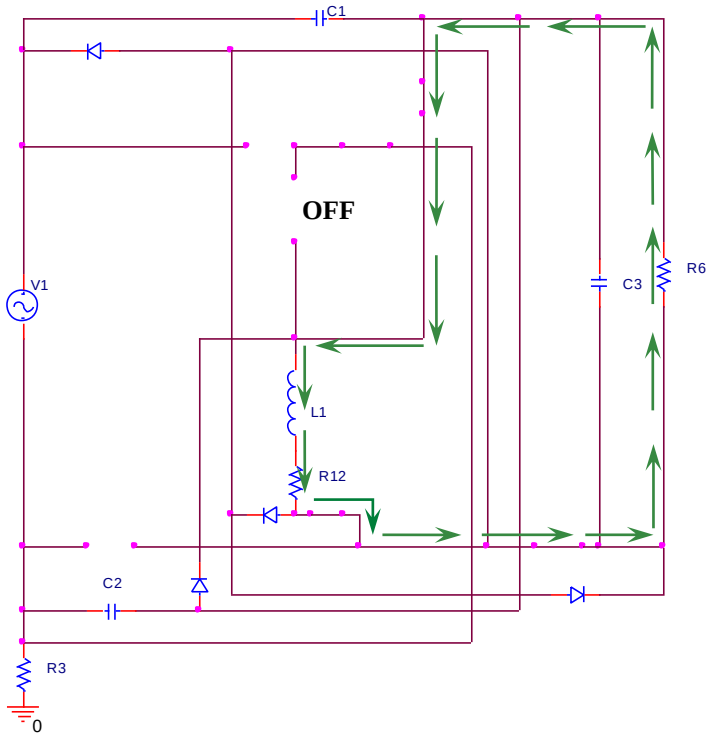

Fig 3.21: Conduction path of the circuit of Fig 3.17 (-ve half cycle, switch OFF)

When the switch is turned on, primary current ramps up and in both positive and negative cycle energy is stored in the inductor L1. Energy to the load is supplied by the charge in capacitor C3. When switch turns off, stored energy in L1 provides energy to load circuit and recharges C3.

The typical output voltage waveform of the circuit of Fig 3.17 is shown in Fig 3.22 and the typical input current waveform is shown in Fig 3.23. For this topology input current is found continuous, so the problem of filtering will become less. The Fourier transform of the input current waveform is shown in Fig 3.24.

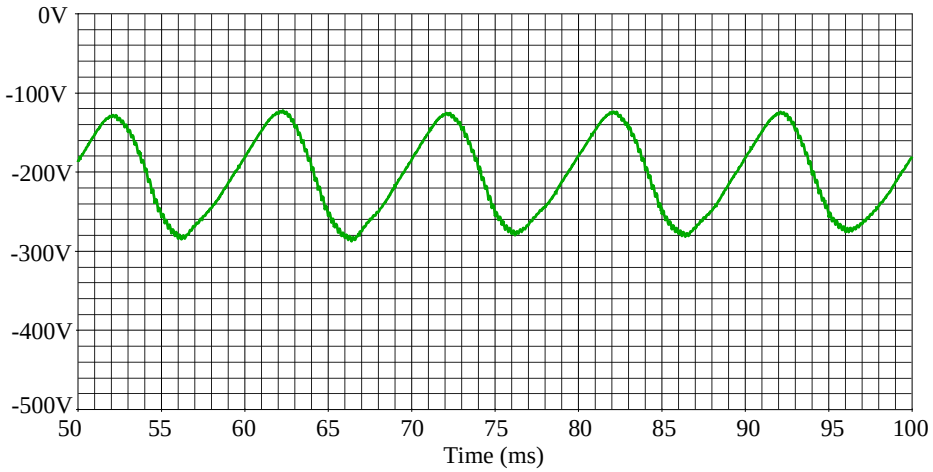

Fig 3.22: Typical output voltage waveform of the circuit of Fig 3.17

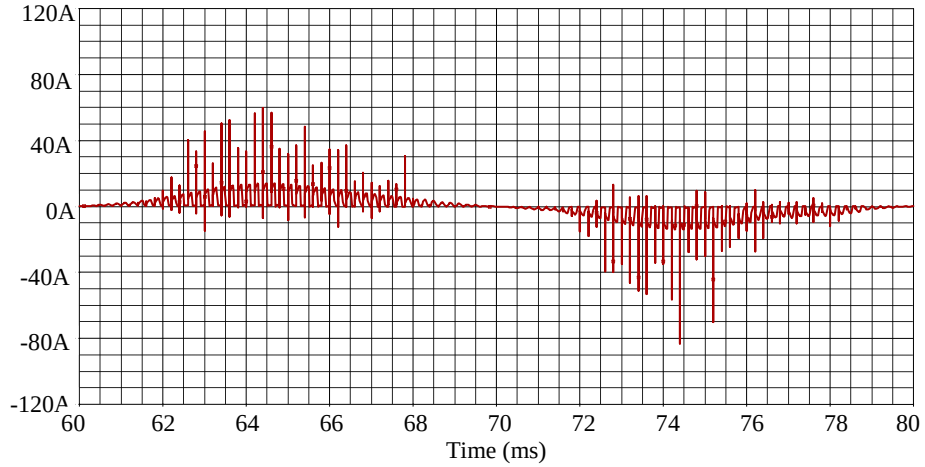

Fig 3.23: Typical input current waveform of the circuit of Fig 3.17

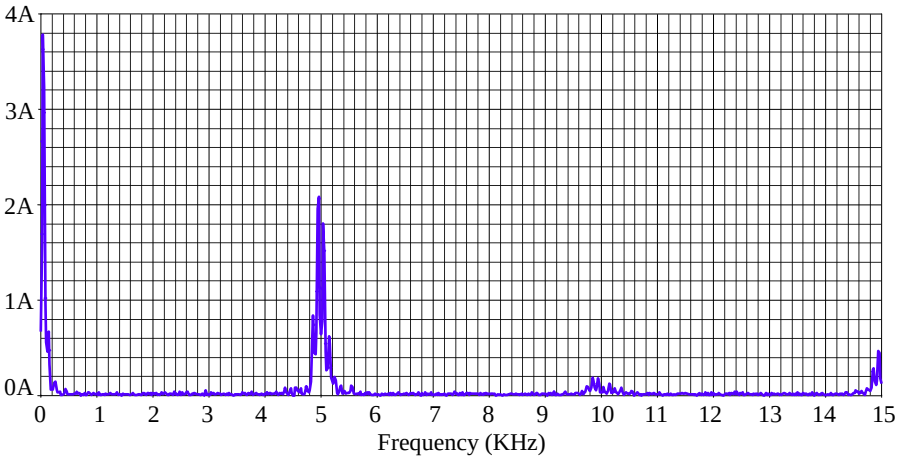

Fig 3.24: Fourier transform of the input current waveform of Fig 3.23

3.2.1.4 Modified Buck Boost Output Regulated Single Phase AC-DC Converter with Input Filter (Continuous Input Current)

An input filter is added with the proposed **M**odified Buck Boost Output Regulated Single Phase AC-DC converter of Fig 3.1 and presented. The circuit of the proposed topology is shown in Fig 3.25. One switch and one inductor are used and the switching is done at the output side. An LC filter is used between the source and the rectifier. The typical output voltage waveform of the circuit of Fig 3.25 is shown in Fig 3.26 and the typical input current waveform is shown in Fig 3.27. For this topology input current is found continuous and approaching sinusoidal. The Fourier transform of the input current waveform is shown in Fig 3.28.

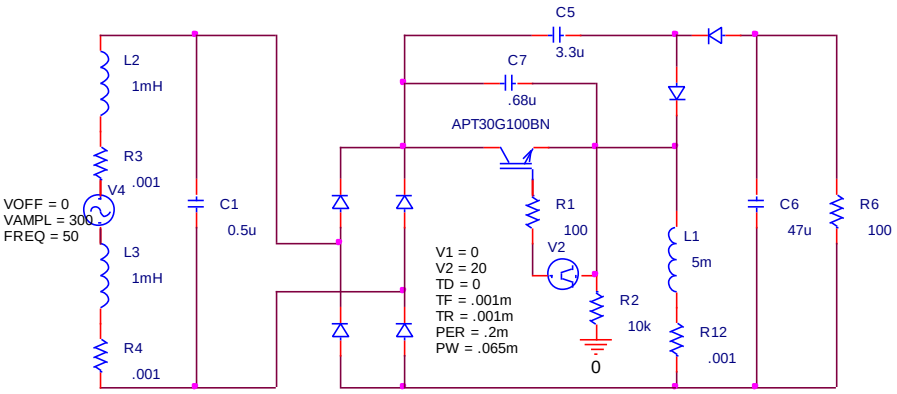

Fig 3.25: Modified Buck Boost Output Regulated Single Phase AC-DC Converter with Input Filter (Continuous Input Current)

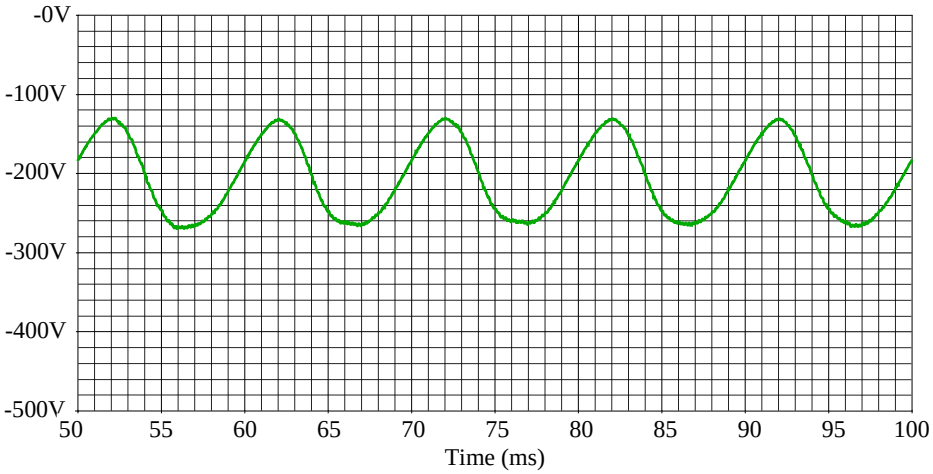

Fig 3.26: Typical output voltage waveform of the circuit of Fig 3.25

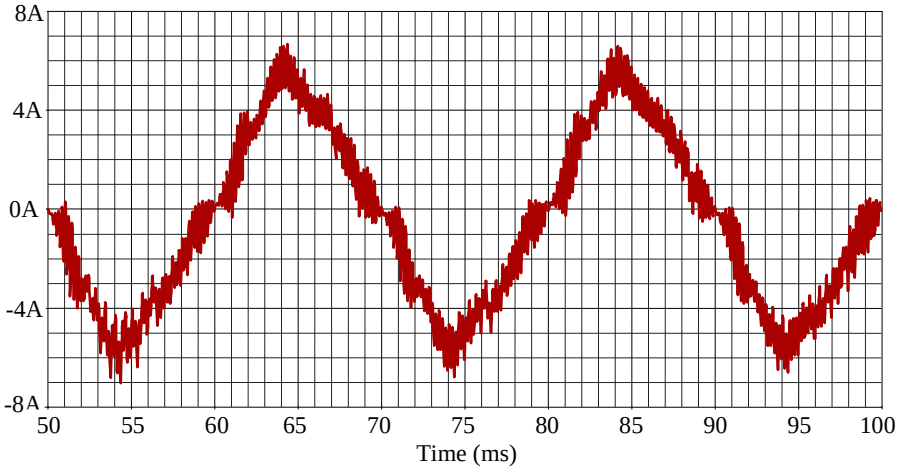

Fig 3.27: Typical input current waveform of the circuit of Fig 3.25

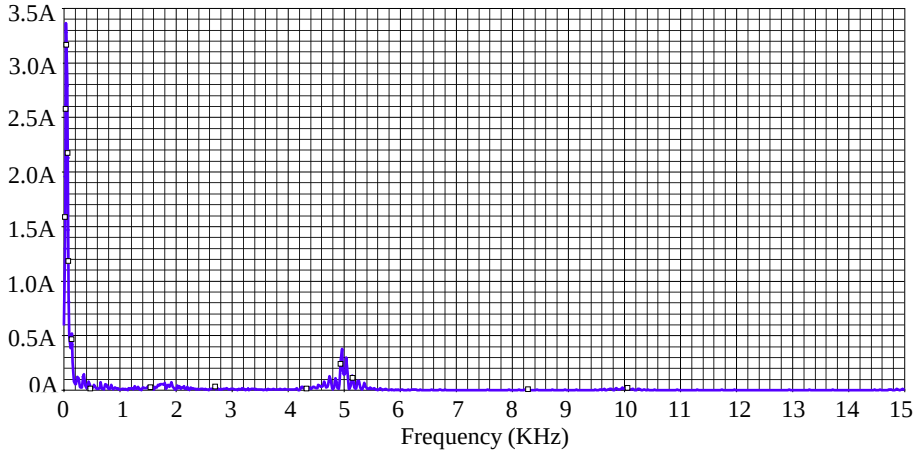

Fig 3.28: Fourier transform of the input current waveform of Fig 3.27

3.2.1.5 Modified Buck Boost Input Regulated Single Phase AC-DC Converter with Input Filter (Continuous Input Current, Circuit-I)

An input filter is added with the proposed **M**odified Buck Boost Input Regulated Single Phase AC-DC converter of Fig 3.9 and presented. The circuit of the proposed topology is shown in Fig 3.29. One switch and two inductors are used and the switching is done at the input side. An LC filter is used between the source and the rectifier. The typical output voltage waveform of the circuit of Fig 3.29 is shown in Fig 3.30 and the typical input current waveform is shown in Fig 3.31. For this topology input current is found continuous and approaching sinusoidal. The Fourier transform of the input current waveform is shown in Fig 3.32.

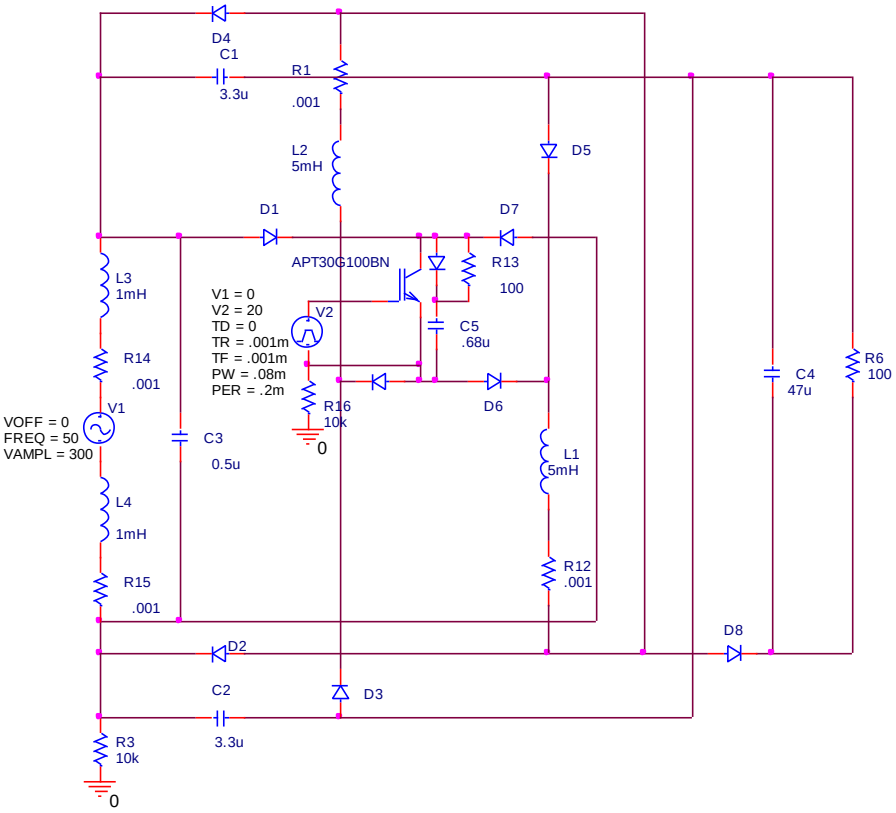

Fig 3.29: Modified Buck Boost Input Regulated Single Phase AC-DC Converter with Input Filter (Continuous Input Current, Circuit-I)

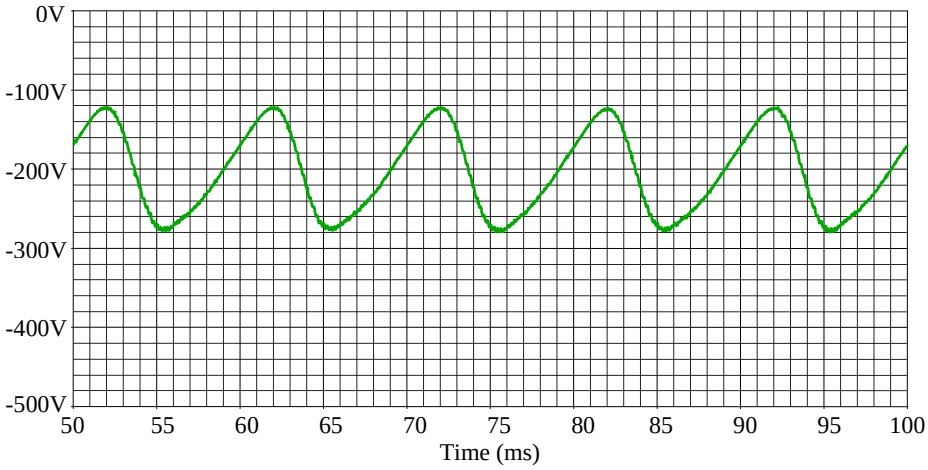

Fig 3.30: Typical output voltage waveform of the circuit of Fig 3.29

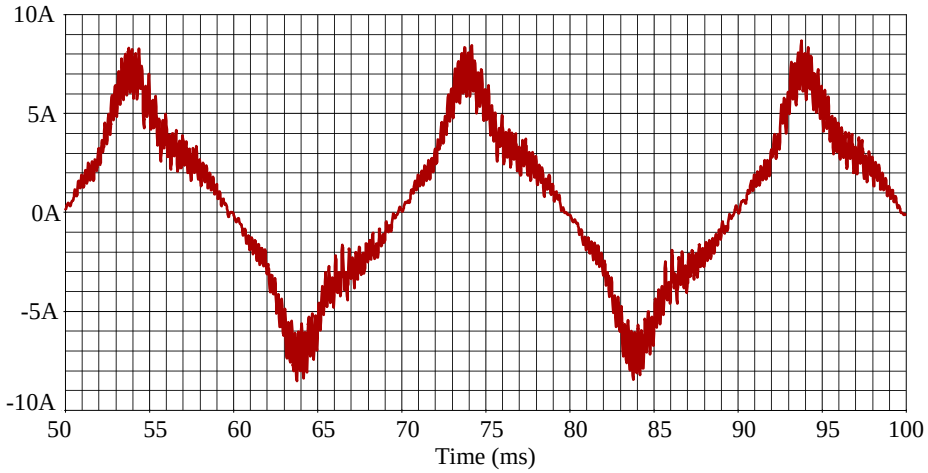

Fig 3.31: Typical input current waveform of the circuit of Fig 3.29

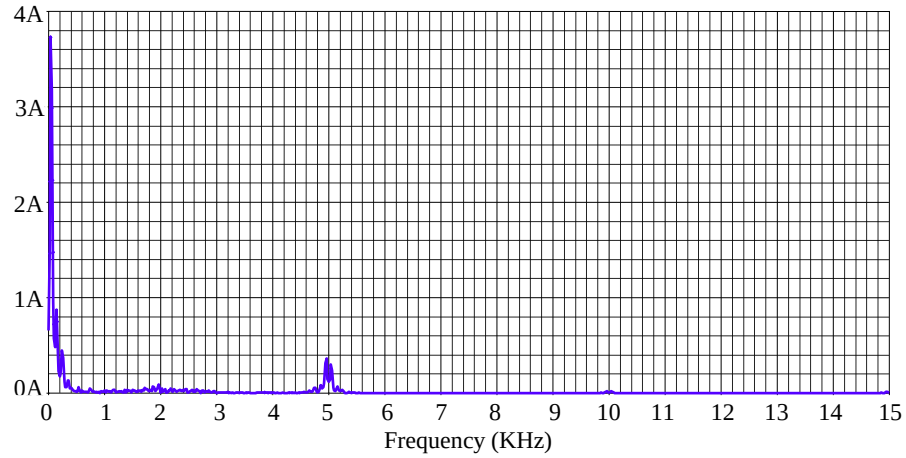

Fig 3.32: Fourier transform of the input current waveform of Fig 3.31

3.2.1.6 Modified Buck Boost Input Regulated Single Phase AC-DC Converter with Input Filter (Continuous Input Current, Circuit-II)

An input filter is added with the proposed **M**odified Buck Boost Input Regulated Single Phase AC-DC converter of Fig 3.17 and presented here. The circuit of the proposed topology is shown in Fig 3.33. One switch and one inductor are used and the switching is done at the input side. An LC filter is used between the source and the rectifier. The typical output voltage waveform of the circuit of Fig 3.33 is shown in Fig 3.34 and the typical input current waveform is shown in Fig 3.35. For this topology input current is found continuous and near sinusoidal. The Fourier transform of the input current waveform is shown in Fig 3.36.

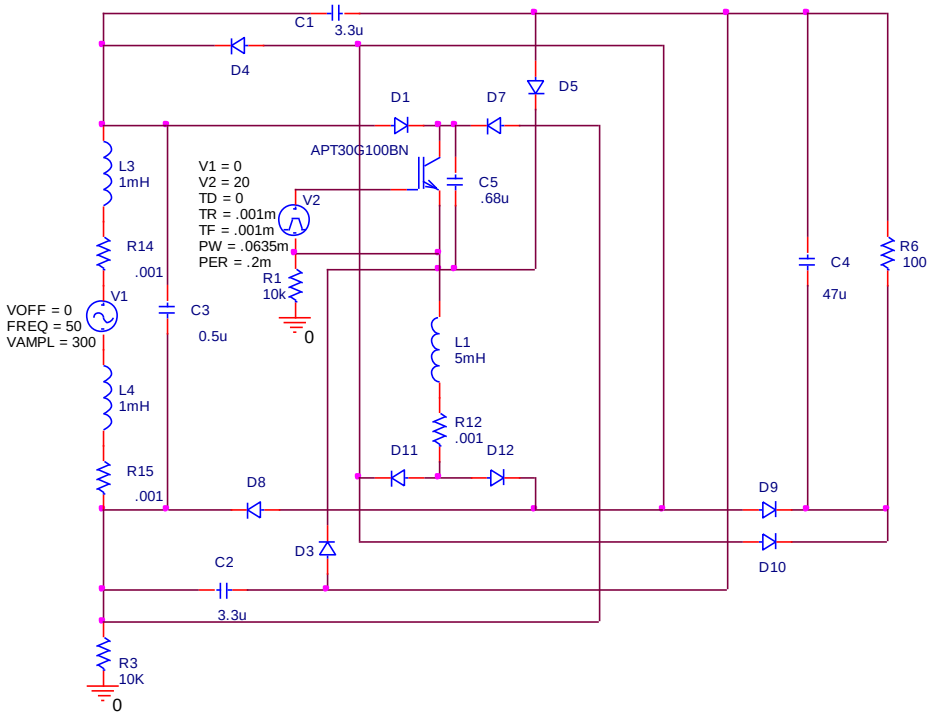

Fig 3.33: Modified Buck Boost Input Regulated Single Phase AC-DC Converter with Input Filter (Continuous Input Current, Circuit-II)

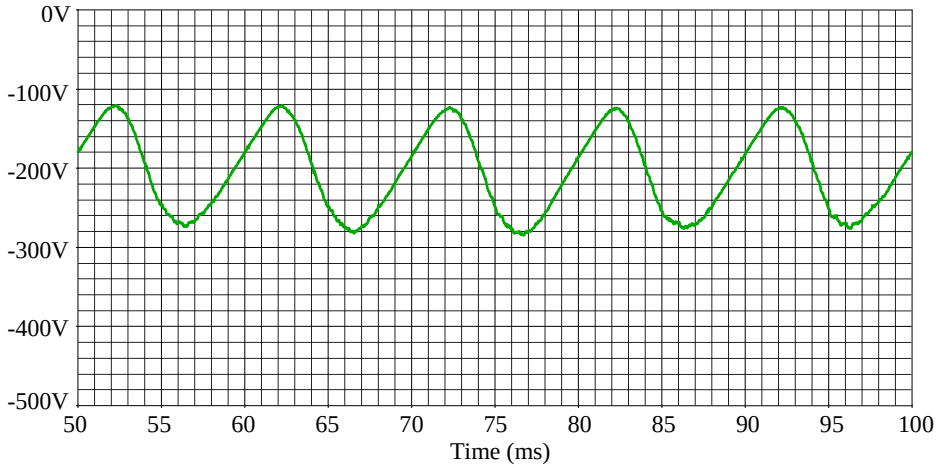

Fig 3.34: Typical output voltage waveform of the circuit of Fig 3.33

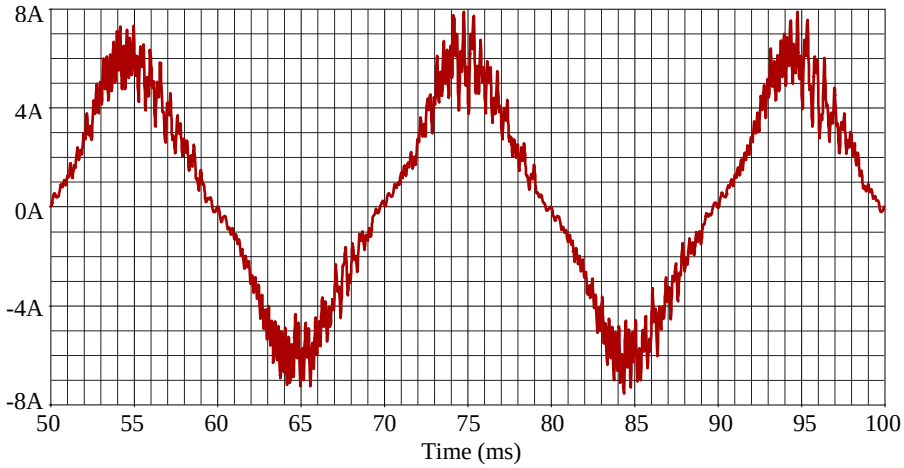

Fig 3.35: Typical input current waveform of the circuit of Fig 3.33

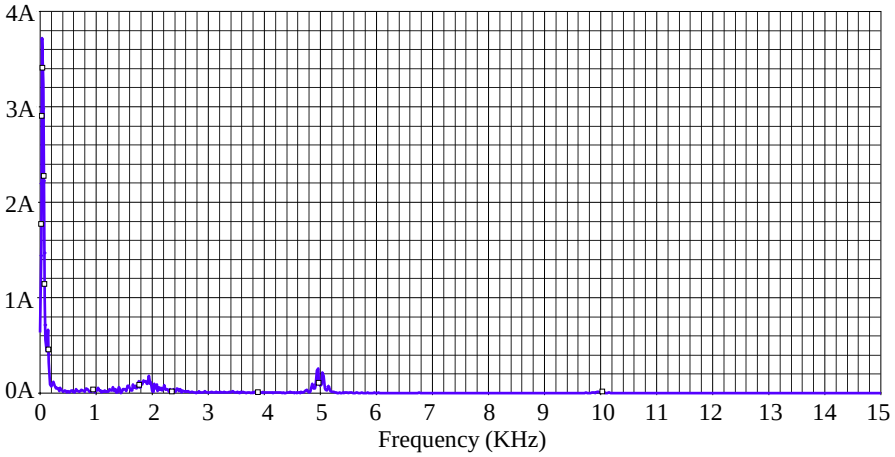

Fig 3.36: Fourier transform of the input current waveform of Fig 3.35

3.3.1 Simulation Results

Pspice simulation of conventional and proposed single phase Buck Boost AC-DC converters are conducted. Typical wave shapes of output voltage, input current and Fourier Transform of input current of previous works and proposed works are shown in paragraph 2.4.1 and 3.2.1 respectively. Performance analysis of both previous and proposed works are carried out. Input power factor, THD of input current and efficiency of conventional and proposed circuits are calculated from the simulation waveforms while voltage gain of each circuit was kept 1. Table 3.1 shows the results of output switched conventional and modified single phase Buck Boost AC-DC converter (without input filter). Table 3.2 shows the results of output switched conventional and modified single phase Buck Boost AC-DC converter with input filter. Table 3.3 shows the results of input switched conventional and modified single phase Buck Boost AC-DC converter (without input filter and one inductor). Table 3.4 shows the results of input switched conventional and modified single phase Buck Boost AC-DC converter with input filter (one inductor). For the Input Switched Modified Single Phase Buck Boost AC-DC Converter with Input Filter (one inductor) efficiency and voltage gain are also calculated against various duty cycles which are shown in Table 3.5. Then graphs of Efficiency Vs Duty Cycle and Voltage Gain Vs Duty cycle are drawn and shown in Fig 3.37 and Fig 3.38 respectively for the input switched modified single phase Buck Boost rectifiers (one inductor and with input filter)

Table 3.1: Buck Boost Output Regulated Single Phase AC-DC Converter (without input filter)

Topology	**Input Power Factor**	**Total Harmonic Distortion of Input Current (%)**	**Duty Cycle (D)**	**Efficiency (%)**
Conventional (1 inductor)	0.69	240.82	0.34	50.37
Modified (1 inductor)	0.70	206.98	0.325	62.98

Table 3.2: Buck Boost Output Regulated Single Phase AC-DC Converter
(with input filter)

Topology	Input Power Factor	Total Harmonic Distortion of Input Current (%)	Duty Cycle (D)	Efficiency (%)
Conventional (1 inductor)	0.88	16.16	0.51	33.46
Modified (1 inductor)	0.98	11.42	0.325	58.62

Table 3.3: Buck Boost Input Regulated Single Phase AC-DC Converter
(without input filter)

Topology	Input Power Factor	Total Harmonic Distortion of Input Current (%)	Duty Cycle (D)	Efficiency (%)
Conventional (1 inductor)	0.70	364.30	0.341	50.24
Modified (1 inductor)	0.73	33.72	0.335	51.29

Table 3.4: Buck Boost Input Regulated Single Phase AC-DC Converter
(with input filter)

Topology	Input Power Factor	Total Harmonic Distortion of Input Current (%)	Duty Cycle (D)	Efficiency (%)
Conventional (1 inductor)	0.89	16.51	0.52	31.80
Modified (1 inductor)	0.98	15.88	0.3175	51.93

Table 3.5: Modified Buck Boost Input Regulated Single Phase AC-DC Converter with Input Filter, Circuit-I (One Inductor)

Duty Cycle (D)	Voltage Gain (Vo-rms/Vin-rms)	Efficiency (%)
0.2	0.717	42.94
0.3	0.943	50.20
0.4	1.263	57.29
0.5	1.664	61.20
0.6	2.192	86.89
0.7	2.876	64.04
0.8	3.771	61.18
0.9	4.855	49.01

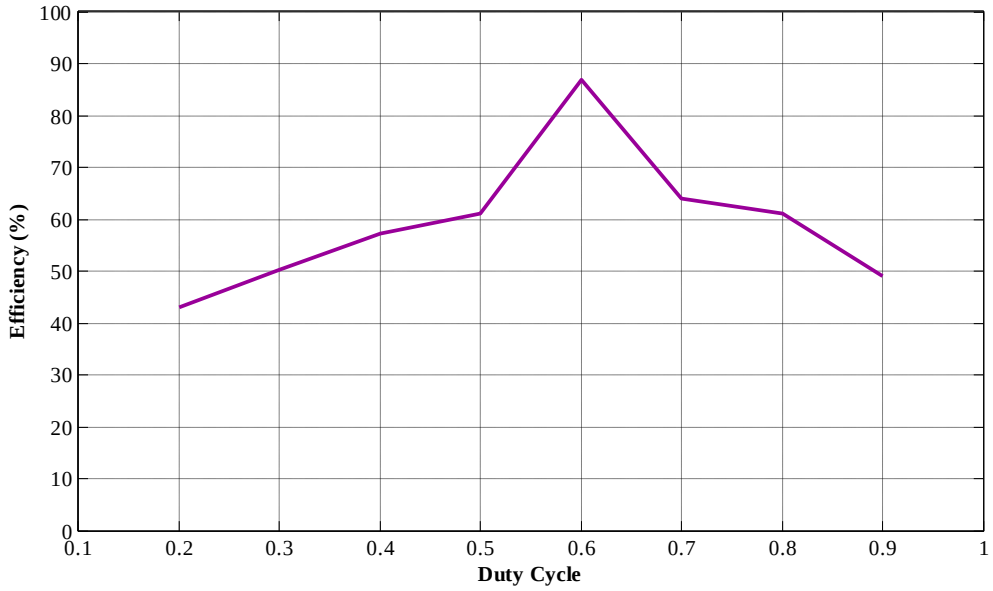

Fig 3.37: Efficiency Vs Duty Cycle Representing Results of Table 3.5

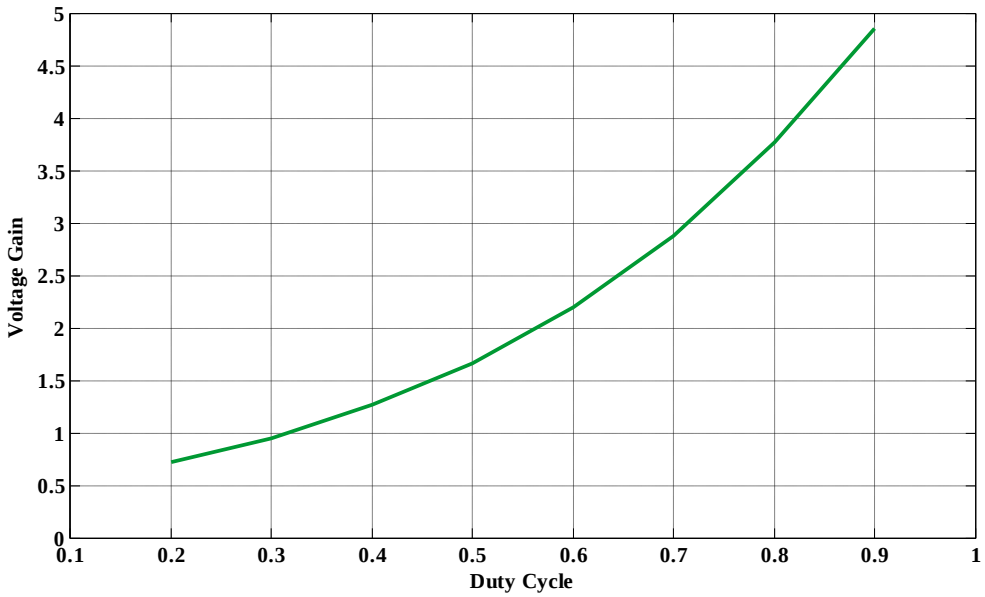

Fig 3.38: Voltage Gain Vs Duty Cycle Representing Results of Table 3.5

3.3.2 Discussions

From Table 3.1, for voltage gain of 1, in case of output regulated single phase Buck Boost rectifier input power factor of modified topology has 0.70 against 0.69 of conventional topology (1 Buck Boost inductor, without input filter). Table 3.2 presents the result of same circuits with input filter showing input pf of 0.98 in case of modified topology against 0.88 of conventional topology. It indicates that modified topology performs better in case of output regulated rectifiers in terms of input power factor.

Also same tables (Table 3.1 and 3.2) show THD of input current of conventional circuit being 240.82 percent against 206.98 percent of modified output regulated topology for circuit without input filter. When the circuits are provided with input filter the THD of input current of conventional circuit is 16.16 against 11.42 of modified topology, indicating better performance of the modified topology.

From Table 3.3, for voltage gain of 1, in case of input regulated single phase Buck Boost rectifier input power factor of modified topology has 0.73 against 0.70 of conventional topology (1 Buck Boost inductor, without input filter). Table 3.4 presents the result of same circuits with input filter showing input pf of 0.98 in case of modified topology

against 0.89 of conventional topology. It indicates that modified topology also performs better in case of input regulated rectifiers in terms of input power factor.

In the same tables (Table 3.3 and 3.4) it is found that THD of input current of conventional circuit being 364.30 percent against 33.72 percent of modified output regulated topology for circuit without input filter. When the circuits are provided with input filter the THD of input current of conventional circuit is 16.51 against 15.88 of modified topology, again indicating better performance of the modified topology.

Efficiency of the Conventional Buck Boost Output Regulated Single Phase AC-DC Converter is found 50.37% (Table 3.1), whereas in case of the Modified Buck Boost Output Regulated Single Phase AC-DC Converter it is 62.98% (Table 3.1). So in Modified Buck Boost Output Regulated Single Phase AC-DC Converter efficiency is 12.61% more than that of the Conventional Converter.

Using input filter with the Conventional Buck Boost Output Regulated Single Phase AC-DC Converter efficiency is found 33.46% (Table 3.2), whereas using the same input filter with the Modified Buck Boost Output Regulated Single Phase AC-DC Converter Efficiency is found 58.62% (Table 3.2). So using the same input filter in Modified Buck Boost Output Regulated Single Phase AC-DC Converter efficiency is 25.22% more than that of the Conventional Converter. So filtering becomes easier in case of the Modified Buck Boost Output Regulated Single Phase AC-DC Converter.

Efficiency of the Conventional Buck Boost Input Regulated Single Phase AC-DC Converter is found 50.24% (Table 3.3), whereas in case of the Modified Buck Boost Input Regulated Single Phase AC-DC Converter (with one inductor) it is 51.29% (Table 3.3). So the efficiency is still better in case of Modified Buck Boost Input Regulated Single Phase AC-DC Converter (with one inductor) than that of the conventional converter.

Using input filter with the Conventional Buck Boost Input Regulated Single Phase AC-DC Converter efficiency is found 31.80% (Table 3.4), whereas using the same input filter with the Modified Buck Boost Input Regulated Single Phase AC-DC Converter (with one inductor) efficiency is found 51.93% (Table 3.4). So using the same input filter efficiency is 20.13% more in case of Modified Buck Boost Input Regulated Single Phase AC-DC Converter (with one inductor) than that of the conventional converter.

So from the above discussion it is found that the efficiency is more in Modified Buck Boost Single Phase AC-DC Converters (in both input and output regulation) than in conventional converters while voltage gain is 1 (input and output voltages have same rms value).

In the graph of Efficiency Vs Duty Cycle (Fig 3.37) of the Modified Buck Boost Input Regulated Single Phase AC-DC Converter with Input Filter (One Inductor) it is found that efficiency increases gradually with the increase of Duty Cycle up to 0.5, and then it increases sharply from 0.5 to 0.6. Again the efficiency decreases sharply after Duty Cycle 0.6 to 0.7 and then decreases gradually with further increase of Duty Cycle.

In the graph of Voltage Gain (Vo-rms/Vin-rms) Vs Duty Cycle (Fig 3.38) of the Modified Buck Boost Input Regulated Single Phase AC-DC Converter with Input Filter (One Inductor) it is found that voltage gain (Vo-rms/Vin-rms) increases gradually with the increase of Duty Cycle which is quite normal and satisfactory.

CHAPTER-4
CONCLUSION

4.1 Summary of the Thesis

A single phase full wave uncontrolled diode rectifier with **o**utput filter capacitor has been studied. The input current was found non-sinusoidal and discontinuous. The output voltage was not controllable. Then a single phase full wave controlled diode rectifier has been studied. The output voltage was controllable but the input current remained non-sinusoidal and discontinuous. Three phase full wave uncontrolled and controlled diode rectifiers have been studied. The input current remained non-sinusoidal and discontinuous.

To overcome the problem of non-sinusoidal and discontinuous input current of single phase diode bridge rectifier various conventional input current shaping and power factor correction [PFC] methods have been studied. Various Non Isolated DC-DC converters (either in continuous inductor current or discontinuous inductor current mode of operation) like Buck, Boost, Buck-Boost, Ĉuk, Sepic, Inverse Sepic or Zeta converters used for input current shaping and input power factor improvement are discussed. Various Isolated Converters like Flyback, Forward, Push-Pull, Full-Bridge and Half-Bridge converters can be used for the same purpose are also discussed.

A Conventional Buck Boost DC-DC Circuit is studied. A Buck Boost circuit provides output voltage that may be less than or greater than the input voltage. So it can be used in both step up and step down operation. The generated output voltage is negative with respect to input and input current is discontinuous. For discontinuous input current filtering becomes difficult; large size of inductor and capacitor are required. To make the input current of a Conventional Buck Boost DC-DC circuit continuous a Modified Buck Boost DC-DC circuit has been proposed earlier and is studied during this research.

For AC-DC conversion to get the desired and controlled output, a Buck Boost DC-DC circuit is introduced between the bridge rectifier and the DC output capacitor. Switching is possible both in output and input side of the rectifier. Both output switched and input switched Conventional Buck Boost Single Phase AC-DC Converters are studied. In this converters input current is found discontinuous, input current THD is high and input power

factor is very low. Due to discontinuous input current filtering needs large size capacitor and inductor.

To overcome the problem of discontinuous input current (high input current THD and low input power factor) in this thesis three AC-DC converter topologies are proposed and studied. These are Modified Buck Boost Output Regulated Single Phase AC-DC Converter (Proposed with Continuous Input Current, One Switch and One Inductor), Modified Buck Boost Input Regulated Single Phase AC-DC Converter (Proposed with Continuous Input Current, One Switch and Two Inductors) and Modified Buck Boost Input Regulated Single Phase AC-DC Converter (Proposed with Continuous Input Current, One Switch and One Inductor). These three proposed topologies are studied using input filter between the source and the rectifier.

Comparing various results of the previous and proposed works it is found that for proposed output switched and input switched topology with one inductor THD of input current is reduced, input power factor is improved and found near unity and efficiency is also increased. The proposed single phase input switched modified Buck Boost topology based rectifiers have been found to perform better than their counterpart based on conventional Buck Boost topologies.

4.2 Future Works

The outcome of this thesis indicates that there are scopes of extending this work in future. Only simulation study is performed in this research work. The proposed both Output and Input Switched Modified Buck Boost Single Phase AC-DC Converter topologies may be implemented practically to investigate their actual potential. Such practical implementation would give further insight regarding the cost effectiveness of the proposed schemes compared to conventional converters of the similar types.

Proposed converter topologies may be studied to improve quality of the gating signals at different duty cycle. Switching losses and EMI interference were not considered here. These can be investigated too in future works.

To maintain the power factor near unity at all duty cycle and output voltage, feedback control may be used. This will keep the THD and efficiency at acceptable levels. Proper feedback control design and implementation is necessary for exact low input current THD,

near unity input power factor, regulated output and high efficiency. It is worth mentioning that absence of feedback circuit could not attain high efficiency of the circuits in this study.

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