INPUT SIDE CONTROLLED SINGLE PHASE RECTIFIER WITH IMPROVED POWER QUALITY

A thesis submitted to the Department of Electrical and Electronic Engineering, Bangladesh University of Engineering and Technology in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING

By

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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

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APPROVAL CERTIFICATE

The thesis titled "**INPUT SIDE CONTROLLED SINGLE PHASE RECTIFIER WITH IMPROVED POWER QUALITY**" submitted by **Samia Islam**, Student ID: **100706101**, Session: October 2007, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Science in Electrical and Electronic Engineering on 7 July, 2012.

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ABSTRACT

A new topology of single-phase Ĉuk ac-dc converter with low input current THD and high input power factor has been proposed and studied. The input to the converter is ac and the rectifier’s input is chopped at high frequency during positive and negative cycles by a bi-directional switch in Ĉuk conversion mode to get step-up/step-down ac-dc conversion. For the proposed topology, the Total Harmonic Distortion of the input current has been found to be less than10% and input power factor is more than 0.7. The efficiency of the proposed circuit has been found to be higher than 70%. The obtained voltage gain is found to be step down for duty cycle lower than 0.5 while that for duty cycle higher than 0.5 is step up in nature. Moreover, the proposed topology has been studied for different types of load circuits.

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LIST OF ABBREVIATIONS

AC	Alternating Current
D	Duty Cycle
DC	Direct Current
DCM	Discontinuous Current Mode
DPA	Distributed Power Architecture
EMI	Electromagnetic Interference
FET	Field Effect Transistor
FFT	First Fourier Transform
GTO	Gate Turn-off Thyristor
IC	Integrated Circuit
IEEE	Institute of Electrical and Electronic Engineering
IGBT	Insulated Gate Bipolar Transistor
LCD	Liquid Crystal Display
OP AMP	Operational Amplifier
PF	Power Factor
PFC	Power Factor Correction
PWM	Pulse Width Modulation
RMS	Root Mean Square
SMPS	Switch Mode Power Supply
THD	Total Harmonic Distortion

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CHAPTER-I

INTRODUCTION

1.1 Background

A rectifier is a power processor that converts an alternating signal (AC) into a unidirectional signal (DC). It should give a DC output with a 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 will be near unity.

In practice, in a single phase full wave rectifier, two problems occur during AC-DC conversion. Firstly, the input current is not sinusoidal and secondly, the input power factor is very low. Also these rectifiers have high input current THD. To overcome these problems use of input filter was introduced. But to do so, very large inductor is required. It reduces THD but cannot improve the power factor and efficiency. Switch mode regulators can be the solution for these problems.

Switch mode power supplies are lighter in size than other power supplies. For this Buck, Boost, Buck-Boost and Ĉuk topologies are usually used. Boost topology is used for most cases to overcome the aforementioned problems. However, it has some disadvantages. For example, these rectifiers suffer from high voltage and current stresses. In case of Boost regulated rectifiers, 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 cases. The Buck-Boost and Ĉuk rectifiers can step up/down the output voltage. Ĉuk topology can be considered for step up/down regulated rectifier.

The input current can be shaped to sinusoidal with low harmonics and power factor may be to near unity by Ĉuk regulation of single phase rectifier.

In the present study, a new single phase ac-dc rectifier circuit based on Ĉuk converter will be investigated. The topology to be proposed will have a single bi-directional switch at the input side of the rectifier in contrast to the switch at the output side of the rectifier.

1.2 Review of the Literature

Generally, to reduce dc voltage ripple of the output voltage in the single phase diode rectifier, a large electrolytic capacitor filter is used. The capacitor produces pulsating current when the input ac voltage is greater than the capacitor voltage and for this THD becomes high and the power factor becomes poor. To overcome these problems, passive filtering methods and active wave shaping techniques have been used.

The conversion of AC power to DC power is done by using a diode rectifier and a DC capacitor connected to the rectifier output as shown in the Fig 1.1. But it has some disadvantages that include

a. High-input current harmonics
b. Low rectifier efficiency because of large rms value of the input current
c. Input ac mains voltage distortion because of the associated peak currents and
d. Maximum input power factor of approximately 0.50 while a larger filter inductor is required for a high-input power factor.

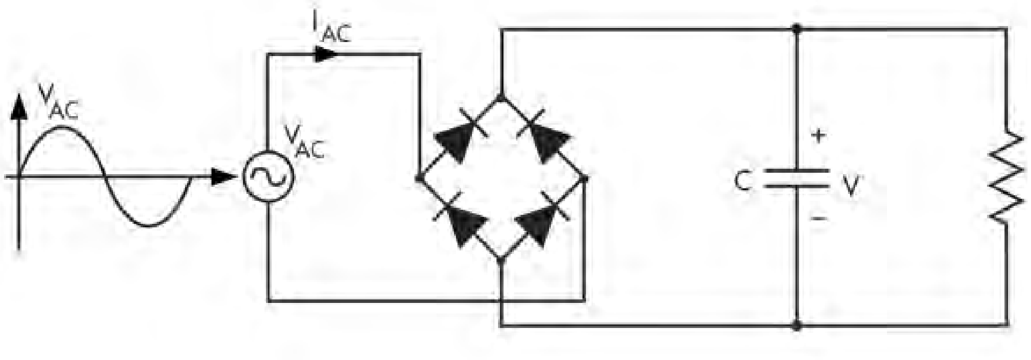

Fig. 1.1 Conventional Single Phase AC-DC Diode Rectifier Topology

To overcome the above mentioned problems many methods have been proposed. These can be classified as active, passive and hybrid methods. In the past, three passive wave shaping methods have been used to improve power factor and reduce total harmonic distortion [1]. Those are input passive filter method, resonant passive input filter method and ferro resonant transformer method.

Among the proposed wave shaping methods, the method proposed by P. D. Ziogas [2] as shown in Fig. 1.2 is superior to others. This method improves the power factor efficiently. But the disadvantage of the topology is input current's total harmonic distortion remains high. Then P. D. Ziogas proposed another method of using of an input Lr-Cr parallel resonant tank to remove the third harmonic component from the input current.

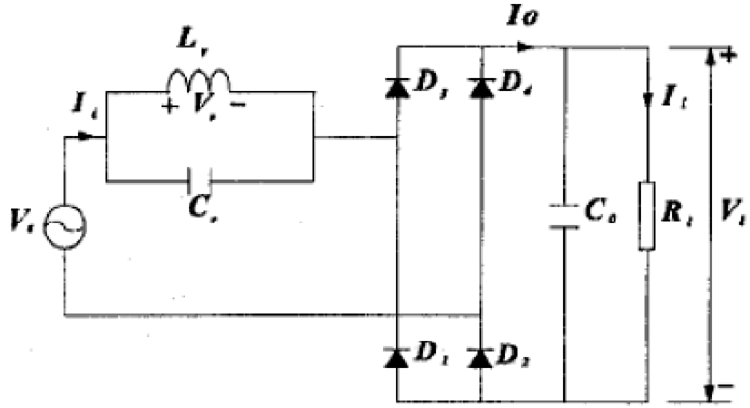

Fig. 1.2 Single Phase AC-DC Rectifier Topology with Input Resonant LC Filter [2]

As the main reason of the low input power factor (i.e. the third harmonic component) is removed, input power factor increases substantially. The advantages of the Ziogas method over the conventional method were comparatively low input current THD, higher input power factor and high efficiency of the rectifier.

In P. D. Ziogas method [2] a single phase rectifier was designed for 5 kW load specification from a 208 V rms, single phase source with 60 Hz frequency. The power factor was found to be 0.957 which is better than 0.623, the power factor of conventional topology. The total harmonic distortion of the method was found 20% compared to 116% for the conventional method. So the total harmonic distortion level improved from the conventional topology.

To solve the problem of high THD associated with the method of P. D. Ziogas and to improve power factor, a capacitor C_b is placed in parallel; between the parallel resonant tank and the rectifier bridge as shown in Fig. 1.3. This capacitor helps to compensate the reactive power and absorbs the distortion power. The method is named as improved passive wave shaping method and it was proposed by Yancho et al. in 1996 [3].

Presenting the rather small impedance to the higher order harmonics the capacitor C_b filters out these components. So the improved method has a better filter feature and higher input power factor than the novel method. In this method [3], the single phase rectifier was designed for 5 kW load specification from a 220 V rms with 5% output voltage ripple and its frequency was 50 Hz. The power factor was 0.9852 and the total harmonic distortion decreased from 20% to 14.9%.

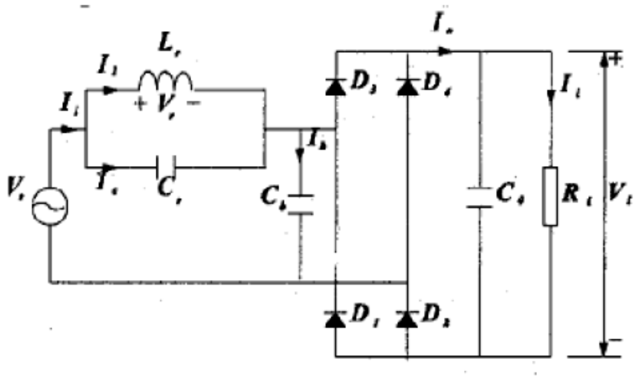

Fig. 1.3 Passive Wave Shaping Topology with Input Resonant LC Filter [3]

The advantages of the improved method over P. D. Ziogas method include: lower input current total harmonic distortion due to filter feature of capacitor C_b, higher input power factor and increased rectification efficiency.

The passive methods are simple and rugged but it is of bulky size and heavy weight and the high power factor cannot be achieved. Therefore, it is not applicable for the current trends of harmonic norms. Basically, it is applicable for power rating of lower than 25W. So for the cases of high power ratings, the active methods using high frequency switching technique are preferred to shape the input current. However, there are disadvantages associated with active wave shaping methods such as: expensive, reliability and implementation difficulty.

In 1991, an active power factor correction method for power supplies with three phase front end diode rectifiers as shown in Fig. 1.4 was proposed and analyzed by A. R. Prasad and P. D. Ziogas [4]. Figure 1.5 represents single phase equivalent circuit of Figure 1.4. This method involves the use of an additional single switch boost chopper. The combined front end converter draws sinusoidal ac currents from the ac source with nearly unity power factor while operating at a fixed switching frequency. In this study, it was found that the converter performance can improve substantially if the active input power factor correction stage is used to regulate the dc bus voltage. These improvements include component count reduction, simplified input synchronization logic requirements, and smaller reactive components. In this method the rectifier was designed for 1 kW rated power with 50 V rms voltage source at 60 Hz frequency and the boost switching frequency was 24 kHz. This method does not deal with total harmonic distortion but the power factor is near unity.

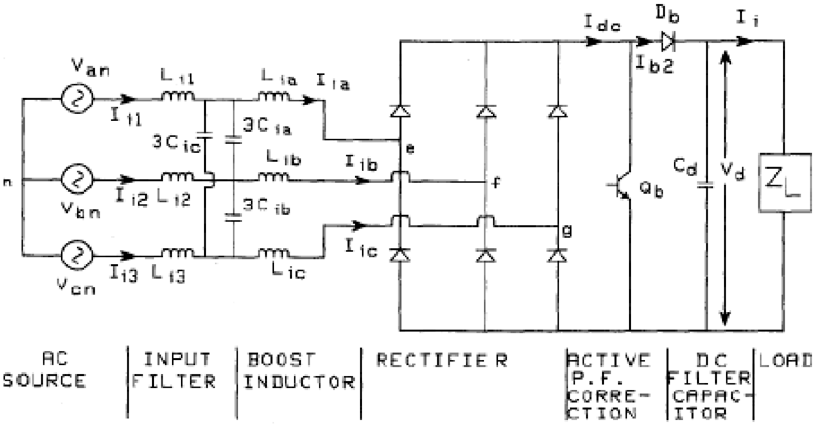

Fig. 1.4 Active PFC Technique for Three Phase Diode Rectifiers [4]

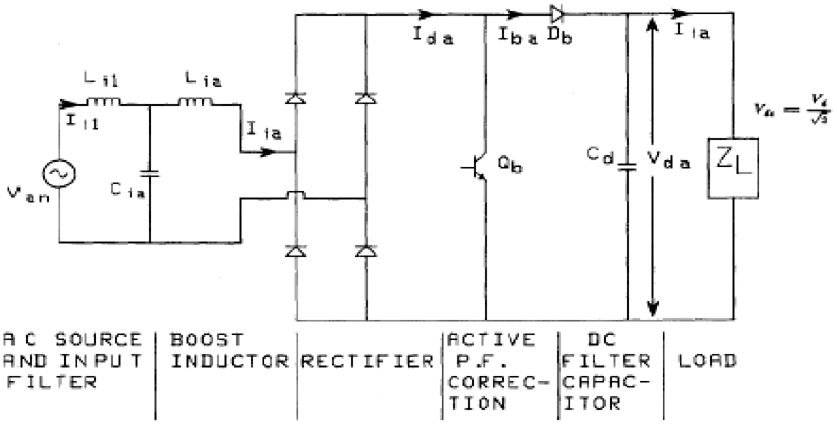

Fig. 1.5 Single Phase Equivalent Circuit of Fig 1.4 [4]

M. A. Khan in 2007 [5] designed a single phase rectifier with switching on AC side for high power factor and low total harmonic distortion which was based on the analysis of the active power factor correction of three phase diode rectifiers by A. R. Prasad and P. D. Ziogas [4]. In this method a single MOSFET is used on the ac side to provide alternative path for input current flow and hence make it continuous. The rectifier is connected to the ac mains through a series combination of inductor and capacitor, which keeps the input current smooth and in phase with the supply voltage. The simulated results revealed that the total harmonic distortion is below 2% with the overall efficiency being 90%.

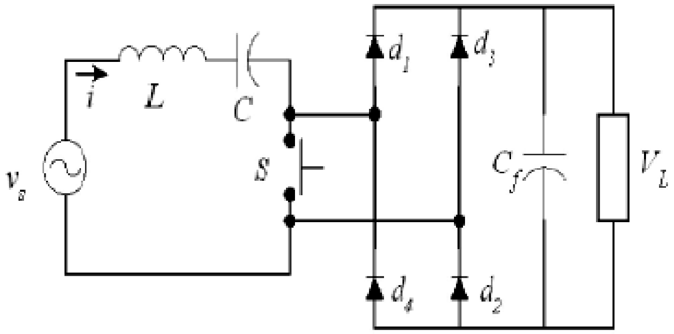

Fig. 1.6 Single Phase Rectifier with Switching on AC Side [5]

As depicted in Fig 1.6, the single phase rectifier circuit was designed for 220 V rms source with 50 Hz frequency at 1 kW load specification and several combinations of L and C at various switching frequencies were used to calculate the efficiencies and the percentage of total harmonic distortions. It was found that for the aforementioned specifications with the combination of 50 mH inductance and 20 μf the efficiency was found to be 91.12% and the total harmonic distortion was 2.8%.

In 2008, Esam H Ismail, Ahmad J Sabzali and Mustafa A Al-Saffar [6] proposed Buck Boost type unity Power Factor rectifier with extended voltage conversion ratio. It was done by cascading a front end buck boost converter with an output buck converter as shown in Fig 1.7 [6]. The buck boost converter was selected due to its capabilities of providing a step down voltage conversion and a high power factor when it operates in the Discontinuous Current Mode (DCM). On the other hand, buck converter at the output stage was selected due to its step down capability. Hence a high step down ratio was achieved. The characteristic include the absence of inrush current problem and the ability to protect against over load current. Proposed converter is a modified version of its dc-dc version presented in [7] by adding an additional diode D_L in series with L_1

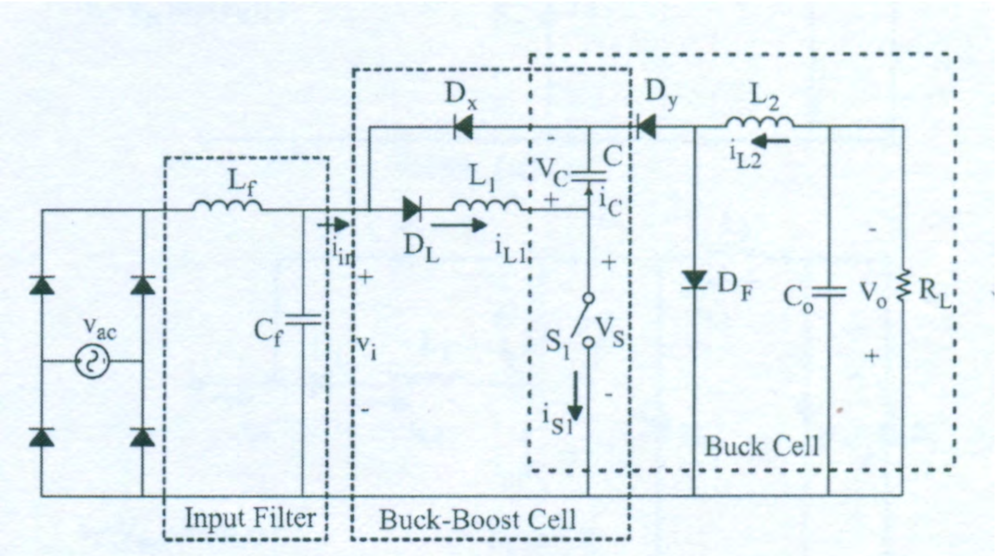

Fig. 1.7 Scheme with Extended Voltage Conversion Ratio [6]

In PSpice simulation, 15% THD of input current, 77% efficiency with laboratory prototype and nearly unity power factor are found. For the simulation, input voltage 110 V rms at 50 Hz, output voltage 20V ± 2%, maximum load power 50W and minimum switching frequency 60 kHz were used. Circuit components values were $L_1 = 100$ µH, $L_2 = 47$ µH, C = 680 µF, $C_0 = 100$ µF, duty cycle, D = 0.22. Input filter parameters were set to 2 mH and 0.68 µF.

In February 2011, Hung-Liang Cheng, Yao-Ching Hsich and Chi-Sean Lin proposed a novel single stage AC-DC converter with symmetrical topology as shown in Fig. 1.8 [8]. To raise the power capability for higher power applications, full bridge resonant converter integrated with two buck boost type PFC circuits was adopted in this proposal. Two PFC circuits double the power handling capabilities. So a high power factor was gained by operating the PFCs at DCM. The advantages of this circuit include less component count of power switches and less conducting losses.

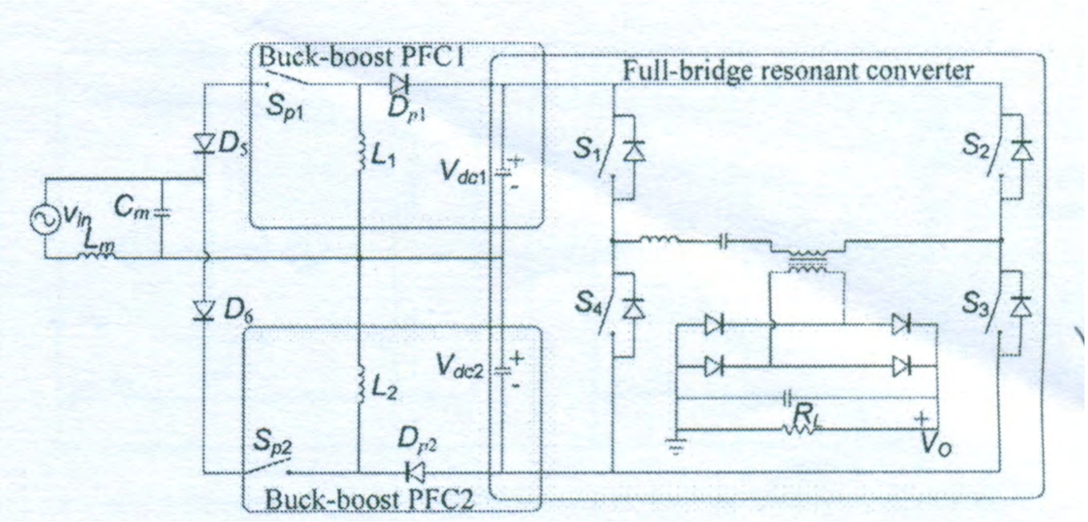

Fig.1.8 Scheme with Symmetrical Topology [8]

The prototype circuit of 200 W output power was built and tested with circuit parameters proposed in the simulation. Output voltage=200 V, power factor = more than 0.99, THD = 6.8% and efficiency =88% are found in the test result.

In general modern power supplies connected to ac mains inject harmonic in the utility due to various static power converter associated with them. These harmonic currents cause problems such as voltage distortion, heating, noise and reduce the capability of the line. This fact and the need to comply with standards have forced to use power factor correction in power supplies.

Unity power factor and tight output voltage regulation are achieved commonly by two stage approach. This is a good option for ac-dc converters due to the following reasons.

1) Sinusoidal input current guarantees the compliance of Regulation
2) It gives good performance under universal line voltage
3) It offers many possibilities of implementation and
4) The penalty on the efficiency due to the double energy processing is compensated by the fact that the voltage on the storage capacitor is controlled.

Although unity power factor is the ideal objective, it is not necessary for meeting the Regulations. For example, both IEEE 519 and IEC 1000-3-2, allow the presence of harmonics in the line current [9], [10]. This fact has lead to the publication of a great number of papers in the last years, proposing solutions that obtain some advantages over the two stage approach.

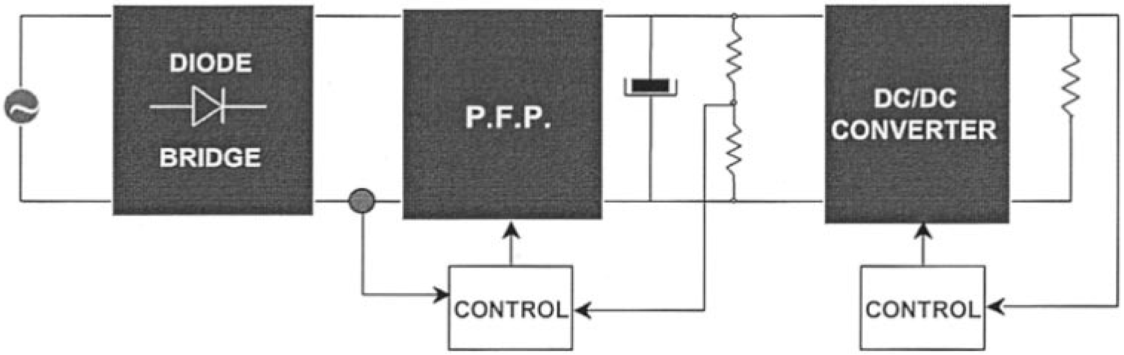

Fig. 1.9 Two Stage ac-dc PFC converter [11]

Several dc-dc converters are suitable to work as a “power factor pre-regulator (pfp)” or “resistor emulator” in AC–DC applications [12]. In general, these converters require two control loops (input current and output voltage) to achieve this goal (Fig. 1.9). When the input current is sinusoidal (at 50/60 Hz), the input power is pulsating (at 100/120 Hz) and, since the power demanded by the load is constant, it is necessary to include an element to store the energy. This element is usually a capacitor, but it should be dimensioned for twice the line frequency (100/120 Hz). Therefore, it is a large component. A second DC–DC converter is required to regulate the output voltage. Therefore, the penalty for the highest quality waveform (sinusoidal) and tight output voltage regulation is

1) Two control loops in the pre-regulator
2) A big storage capacitor
3) An additional dc–dc converter with its own control circuit

However, in general terms, the “two stage approach” is a good option for power factor correction taking into account the advantages of this scheme. The inconveniences may be overcome using a multi-level converter [13], where a double number of devices is used but with lower voltage stress. On top, the sinusoidal waveform usually involves a high-cost circuit. An intermediate quality level is composed by those solutions that comply with the regulations without achieving unity power factor. Among them, there are “single stage converters” that offer some advantages, but its field of application is limited to low power (up to 300 W, approximately). If there is not any requirement about the line current, the simplest solution composed by a diode bridge and a filter capacitor can be used as a first stage.

In general the classification is done as shown below as made in reference [11] as the pfc solution of diode rectifiers.

The solutions were classified in two groups, according to the input current shape: sinusoidal or non-sinusoidal. Many proposed solutions for ac-dc power factor correction have been analyzed. They have been classified according to the line current waveform and their performance. If the purpose is to obtain a sinusoidal line current, the classical two-stage approach is an option, mainly if universal line voltage operation is required. It is desirable to include ZVS if it is feasible to implement it in any or both PFP and dc-dc converter. In general terms, the solutions based on a better energy management (either processing less energy or process it with higher efficiency) do not offer great advantages, unless the efficiency were the unique parameter to consider. Passive solutions are adequate in the low power range for simplicity. Single stage solutions are a good option to meet the low frequency harmonic Regulations in low power applications with low cost. The solutions derived from the two-stage approach with slight modifications usually have a higher number of components and, therefore, a higher cost.

Solutions with sinusoidal line current are valid considering any standard or recommendation. However, the feasibility of the second group of converters (non-sinusoidal current) depends on each particular Regulation and its evolution along the years. Therefore, some converters useful today might not be used tomorrow and vice versa.

A. Sinusoidal Line Current

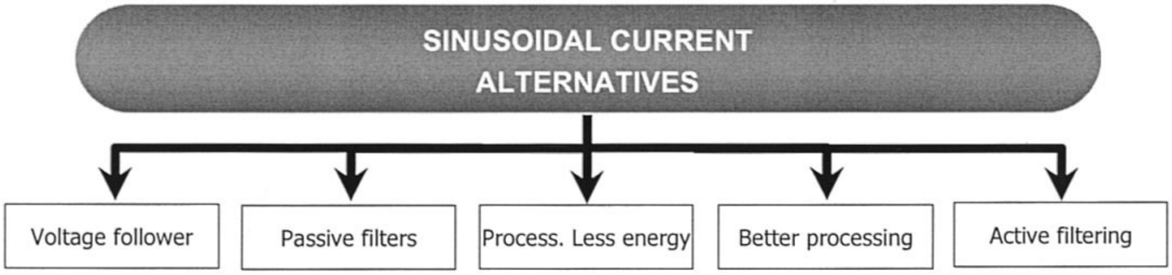

Fig. 1.10 Alternatives to the two stage approach

B. Nonsinusoidal Line Current

Since Regulations allow harmonic currents, designers may take advantage of that, simplifying the circuitry and using new topologies, mainly in low power applications.

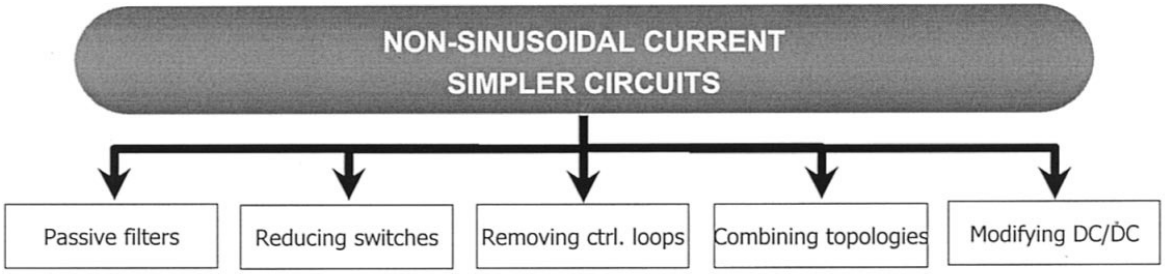

Fig. 1.11 Alternatives to the two stage approach for non-sinusoidal line current

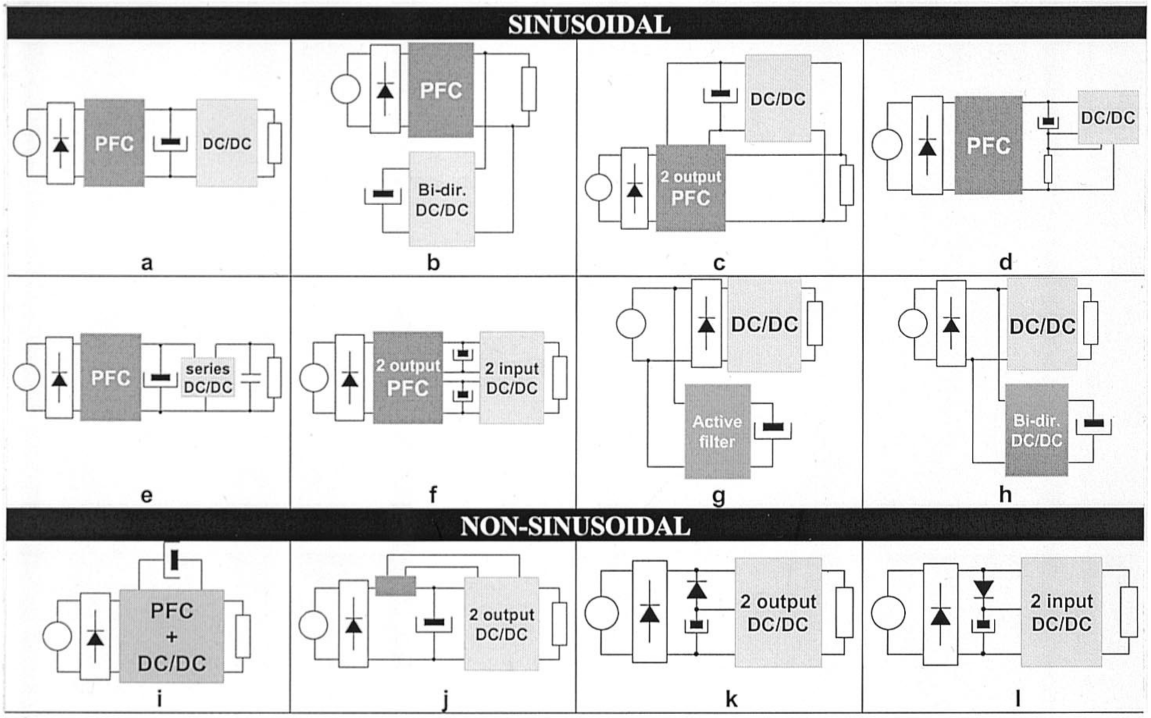

Fig. 1.12 Approaches proposed for power factor correction

1.3 Motivation and Objectives

A new single phase AC-DC rectifier circuit based on Ĉuk converter is investigated which is derived from its counterpart topology used in dc-dc conversion. The input to the converter is AC and the switch used is a bi-directional switch made of a unidirectional switch combined with four diodes. Since the input is AC, the circuit topology will be modified at both input and output side so that volt-amp balancing of Ĉuk conversion takes place in both the positive and negative cycle of the ac supply voltage. Total Harmonic Distortion (THD) cof the input current is low and efficiency of the proposed circuit is high. It ensures high frequency switching of input ac almost in phase with the input ac voltage without any additional control scheme and results in better input power factor. The rectifier being based on Ĉuk topology, therefore, it has step up/step down controllability of the output voltage. For output voltage control, the duty cycle of the high frequency gate pulse of the bi-directional switch has to be changed.

The objectives of the present study are:

1. To develop and design a scheme for high input power factor, high efficiency single switch ac-dc Ĉuk converter,
2. To choose the circuit parameters to achieve low THD, high input power factor and efficiency.
3. To analyze the performances of proposed circuit by simulation and
4. To compare the performances of the proposed scheme with conventional switch mode ac-dc Ĉuk regulated conventional diode bridge rectifier.

The outcome of this thesis is a Single Switch ac-dc Ĉuk converter with near unity input power factor, high efficiency and low THD of the input current.

1.4 Simulation Environment

To successfully meet project goals, PCB designers and electrical engineers need powerful, intuitive, and integrated technologies that work seamlessly across the entire PCB design flow. Cadence OrCAD solutions offer fully integrated front-end design, analog/signal integrity simulation, and place-and-route technologies that boost productivity and shorten time to deliver the electronic circuit.

OrCAD Capture provides fast and intuitive schematic design entry for PCB development or analog simulation using PSpice. The component information system (CIS) integrates with it to automatically synchronize and validate externally sourced part data. Easy-to-use and powerful, Cadence OrCAD Capture is widely used schematic design solution, supporting both flat and hierarchal designs from the simplest to complex designs. Seamless bi-directional integration with OrCAD PCB Editor enables data synchronization and cross-probing/placing between the schematic and the board design. OrCAD Capture allows designers to back annotate layout changes, make gate/pin swaps, and change component names or values from board design to schematic using the feedback process. It also comes with a large library of schematic symbols and can export net lists in a wide variety of formats.

OrCAD Capture CIS integrates the OrCAD Capture schematic design application with the added capabilities of a component information system (CIS). CIS allows designers to search, identify, and populate the design with preferred parts. With easy access to component databases and part information, designers can reduce the amount of time spent researching needed parts.

OrCAD boosts schematic editing and efficiency of complex designs, through hierarchical and variant design capabilities. It integrates with a robust CIS that promotes the use of preferred, current parts to accelerate the design process and reduce project costs. It also provides access to more than two million parts with Cadence Active Parts, offering greater flexibility when choosing design components.

1.5 Layout of the Thesis

Chapter I introduces the thesis topic. Here, an overview of the gradual development of the AC-DC converter has been described. Thereafter, a review of a good number of literatures on the related fields studied so far has been made. This chapter also contains the motivation that drives the study of ac-dc converter and work on this thesis topic.

Chapter II provides discussion on various switch mode topologies. At the outset this chapter discusses different stages of AC-DC conversion process starting with basic diode rectifier. Then it describes different types of SMPS technique.

Chapter III addresses the basic concept of harmonics and power factor. it introduces concept of total harmonic distortion, causes of in efficiency and inter relationship between THD, power factor and efficiency.

Chapter IV describes the proposed single phase Ĉuk topology based on AC-DC converter. It presents the results of the analysis of conventional and proposed topologies of AC-DC Ĉuk converter converters at different switching frequencies and duty cycles. Graphical presentations of the analysis and observations have also been discussed in this chapter.

Chapter V concludes the work of the thesis. This chapter puts forward suggestions for future scopes of works related to this thesis.

CHAPTER-II

SWITCH MODE CONVERTER TOPOLOGIES

2.1 Introduction

Virtually every piece of electronic equipment in the world today is powered from a DC source. This source may be either a battery or a power supply. Most electronic equipments require not only DC power source, but one that is well-filtered and well-regulated. There are three types of electronic power conversion devices in common use today: the AC/DC power supply, the DC/DC converter, and the DC/AC inverter. Each has its own specific areas of application. Of these three, AC/DC power supplies and DC/DC converters are the most commonly used power supplies. Power supplies have evolved through the years from the large rack mounted units employing vacuum tubes or high voltages to today's compact solid state power supplies with their lower, and relatively safe, DC voltages. Since power supplies and DC/DC converters are so widely used in electronic equipment, these devices now encompass a worldwide segment of the electronics market in excess of US$5 billion annually. Furthermore, this market is growing in step with the total worldwide electronic market. Power converters have not only evolved into compact solid-state devices, but the basic technology has advanced from linear power supplies to modern switching power supplies which are smaller and lighter, and obviously more efficient than their linear counterparts. Linear power supplies employ conventional 50/60 Hz power transformers followed by a rectifier, filter, and linear regulator. These supplies are about 40 to 55% efficient. Switching power supplies directly rectify and filter AC line voltage without first using a 50/60 Hz transformer. Then the filtered DC is chopped by the power switch, the output may be finally rectified and filtered again. Because of the fast switching, which is from 20 kHz to 500 kHz, the transformer and the capacitors are much smaller than their 50/60Hz counterparts. Switching power supplies are from 60 to 80% efficient. DC/DC converters, similar to switching power supplies in their operation, are used to change one DC voltage to another, and are usually well-regulated. These devices are important where electronic equipment must be operated from a battery or other DC source. Power supply technology has changed rapidly over the past decade, and modern switching power supplies and DC/DC converters are much more difficult devices to design and produce reliably than were the simpler linear power supplies of the past.

More systems now utilize Distributed Power Architecture (DPA) which provides an intermediate DC voltage from which the final DC circuit voltages are derived. These DC/DC converters may or may not require isolation, but retain the need for generating specific and regulated DC voltage outputs. Sophisticated battery powered equipment such as laptop computers also require conversion, regulation and control of the DC battery voltage in order to meet the needs of the internal circuitry.

2.2 Switch Mode Topologies

Switch Mode Power Converters operate by transferring energy from the input to the output. For a given power level, the energy transferred per cycle is inversely proportional to the operating frequency. Since this transferred energy is stored in capacitors or inductors during portions of the operating cycle and is transferred through a transformer in many cases, the size of these circuit elements will be smaller when a higher operating frequency is selected. So the highest possible operating frequency would appear to be advantageous.

Unfortunately, high frequency operation comes at a cost - impacts on the efficiency of the converter. The FETs, bipolar transistors and switching diodes used in power converters have two types of losses - static conduction losses and switching losses. Static losses are not affected by the selection of operating frequency. The switching losses are influenced by the operating frequency.

Since the energy losses per second will be proportional to the operating frequency, the overall transition power losses will increase with operating frequency and at some point the converter efficiency will degrade unacceptably. This effect is somewhat offset by using various resonant switching techniques to minimize losses, but eventually the parasitic losses associated with less than ideal components and packaging techniques will impose an upper limit on useful operating frequency.

These design trade-offs are depicted in a general way in Fig. 2.1. As can be seen, there is an optimal range of operating frequency for each design. The lower operating frequency is most often limited by either the converter becoming too large or by the desire to keep the operating frequency above the audible frequency range. For these reasons, 25 kHz is the lowest operating frequency that is practical. The upper limit on operating frequency is determined by efficiency, availability of specialized components and the advanced packaging and manufacturing techniques required for high frequency operation. This upper limit is now in the range of 3 MHz. Most of today's converters operate somewhere in the range of 100 kHz to 2 MHz. However, power converters requiring more than 1 kW power conversion would need low frequency switching in the range of 5-10 kHz to reduce switching loss and tackle other difficulties of high power converter implementation.

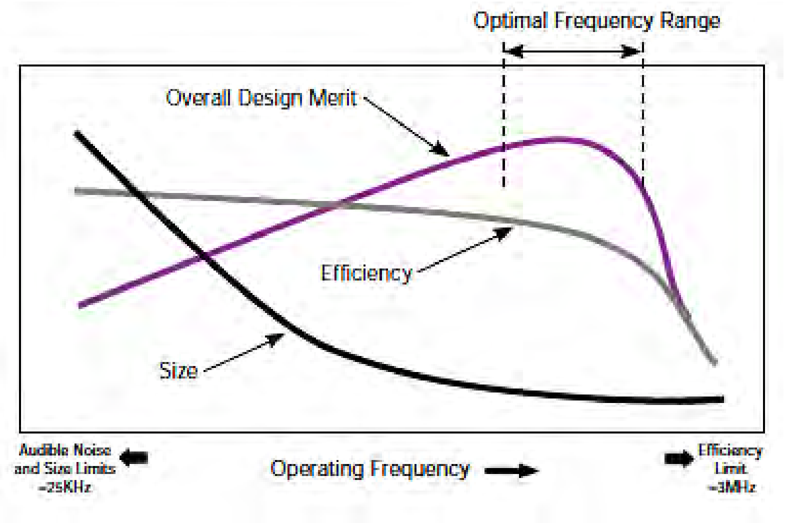

Fig. 2.1 Operating Frequency of Switch Mode Converters [14]

2.2.1 Topology Tree

Figure 2.2 represents a 'topology tree' which defines relationships between different topologies. Switch mode converters are sub-divided into resonant variable frequency and pulse width modulated topologies. Pulse width modulated topologies are in wider use. Pulse width modulated topologies are further divided into direct and indirect types. Direct converters transfer energy from the input to the output during the 'on time' of the converter switch(s). Indirect converters accomplish the energy transfer during the 'off time' of the power switches. Some of the major benefits or areas of application are shown for each major topology in the tree.

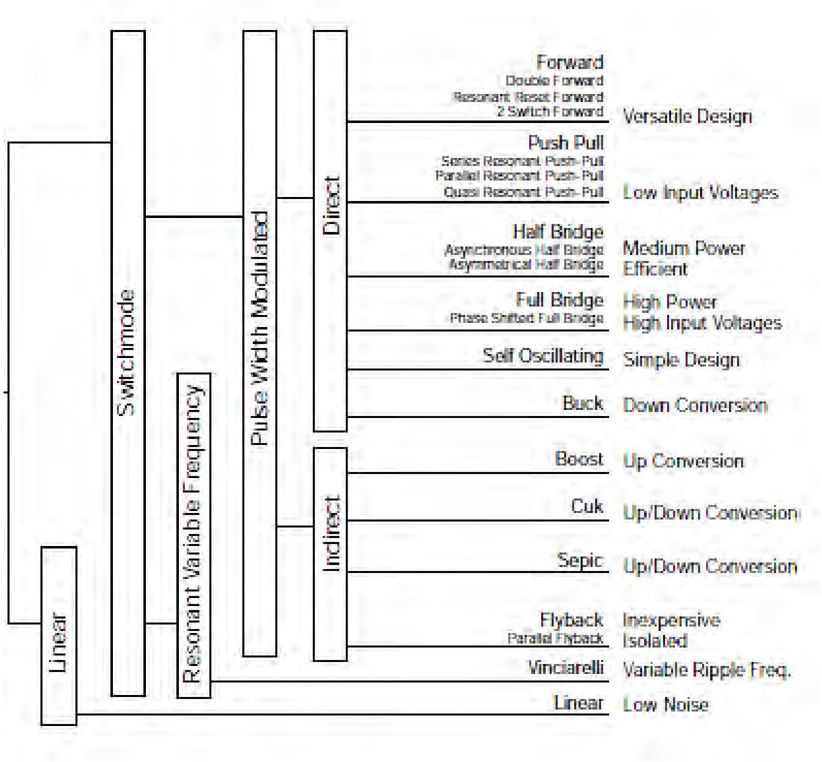

Fig. 2.2 Topology Tree [14]

Basic switching power converter topologies are

a) Buck

b) Boost

c) Buck-Boost and

d) Cûk topology

2.2.2 Buck Converter

The buck topology shown in Figure 2.3 is one of the most basic topology. It is a non-isolated down converter that operates in the direct mode. Load current conducts through the single switch element during the on-time and through the output diode D_1 during the off-time. Advantages of the buck are simplicity and low cost. Disadvantages include a limited power range and a DC path from input to output in the event of a shorted switch element, which makes secondary circuit protection difficult.

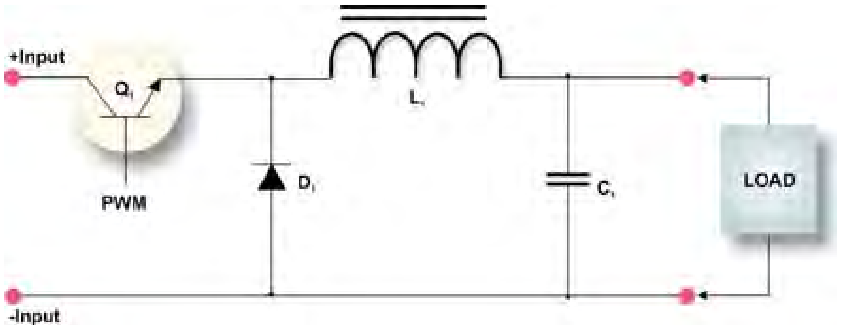

Fig. 2.3 Simplified Buck Converter [15]

Basic characteristics of Buck Converters are mentioned in Table 2.1

Table 2.1: Basic Characteristics of Buck Converters

Useful Power Level	1-50 Watts
Switch Voltage Stress	V_{in}
Switch Power Stress	P_{in}
Transformer Utilization	N/A
Duty Cycle	<1.0
Output Ripple Frequency	Switching Frequency of the Converter
Relative Cost	Low

2.2.3 Boost Converter

The boost topology shown in Fig. 2.4 is a form of non-isolated up converter. It is classified as an indirect converter since the energy transfer to the output occurs when the switch element is in the off state. During the on-time of the switch element, energy is accumulated in the input inductor as it is connected across the input voltage source by Q_1. During this time, the load current is drawn from the output capacitor, which is isolated from the reverse biased diode D_1. When Q_1 turns off, the energy stored in L_1 is released into the output through D_1 adding to the input voltage source and setting the output voltage to the desired value as a function of the converter's duty cycle (D).

Advantages of the boost topology are simplicity, low cost and the ability to achieve step up conversion without a transformer. Disadvantages are a limited power range and a relatively high output ripple due to all of the off-time energy coming from the output capacitor C_1.

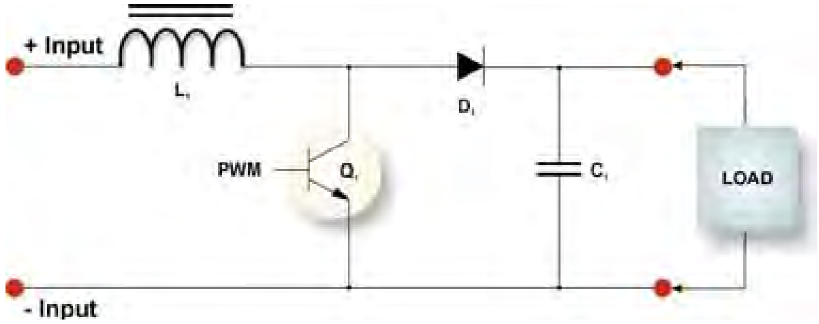

Fig. 2.4 Simplified Boost Converter [15]

Basic characteristics of Boost Converters are shown in Table 2.2

Table 2.2: Basic Characteristics of Boost Converters

Useful Power Level	1 to 50 Watts
Switch Voltage Stress	V_{out}
Switch Power Stress	P_{in}
Transformer Utilization	N/A
Duty Cycle	<1.0
Output Ripple Frequency	Switching Frequency of the Converter
Relative Cost	Low

2.2.4 Buck-Boost Converter

The Buck Boost converter is shown in Fig. 2.5. This is a transformer-isolated topology operating in the indirect conversion mode. Single inductor nonisolated Buck Boost conversion is also possible. When the power switch Q_1 is turned on, primary current ramps up and energy is stored in the core of transformer T_1. During this time interval, diode D_1 is reversed biased and energy to the load is supplied by the charge in capacitor C_1. When Q_1 turns off, the negative current transition on the primary is reflected to the secondary so that D_1 becomes forward biased and current is conducted to the load and also to recharge C_1.

This topology is a common and cost-effective means of generating moderate levels of isolated power in AC/DC converters. Additional output voltages can be generated easily by adding additional secondary windings. However, there are some disadvantages. Regulation and output voltage ripple are not as tightly controlled as in some of the other topologies and the stresses on the power switch are higher. Basic characteristics of Buck Boost converters are shown in Table 2.3.

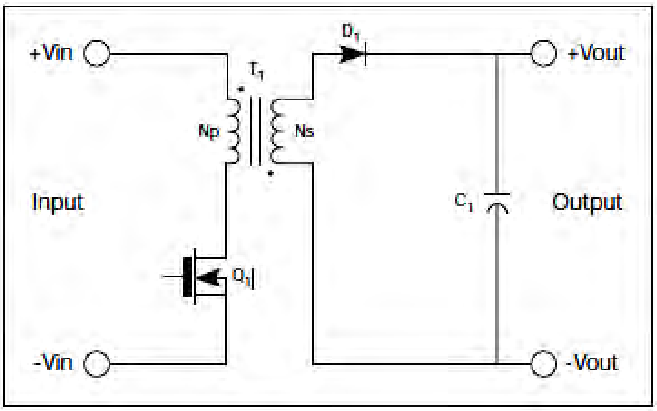

Fig. 2.5 Simplified Buck Boost Converter [14]

Table 2.3: Basic Characteristics of Buck Boost Converters

Useful Power Level	5 to 150 Watts
Switch Voltage Stress	$V_{in} + (N_p/N_s)\ V_{out}$
Switch Power Stress	P_{in}
Transformer Utilization	Poor/Specialized Design
Duty Cycle	<0.5
Output Ripple Frequency	Switching Frequency of the Converter
Relative Cost	Low to Moderate

2.2.5 Ĉuk Converter

The Ĉuk is an indirect converter most commonly used in a non-isolated configuration as shown in Figure 2.6. It has the useful property of acting as either a down converter or an up converter as a function of the duty cycle (D). Its operation is more complex to understand than the other non-isolated converters presented in that energy is transferred first to C_1 from inductor L_1 during the off-time of the switching device and then into the output filter L_2, C_2. Besides the advantage of offering either up or down conversion, the topology is somewhat unique in that the primary and secondary are connected through a capacitor. Although this does not represent galvanic isolation and will not meet some safety requirements, it is still a useful property in that any failure of the power switch will not impose overvoltage conditions onto the secondary.

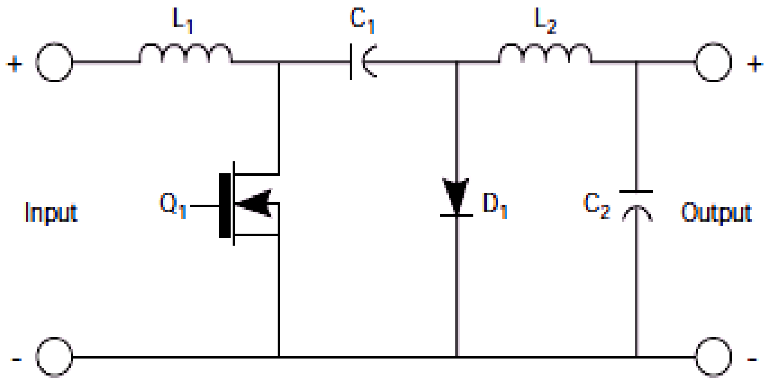

Fig. 2.6 Simplified Ĉuk Converter [14]

Basic characteristics of Ĉuk Converters are shown in Table 2.4

Table 2.4: Basic Characteristics of Ĉuk Converters

Useful Power Level	10 to 100 Watts
Switch Voltage Stress	$V_{in}/(1-D)$ (can be high)
Switch Power Stress	P_{in}
Transformer Utilization	N/A
Duty Cycle	<1.0
Output Ripple Frequency	Switching Frequency of the Converter
Relative Cost	Low to Moderate

2.3 Choice of Topology

AC-DC converters essentially operate from the rectified AC power line voltage, hence the topologies that are optimized for high voltage input is preferred. This is true for both single phase and three phase AC inputs and for all international power line voltages. Where galvanic isolation of the secondary voltages from the power line circuit is a requirement isolated topologies are normally employed. Non-isolated topologies are acceptable for low power sealed equipment with no user access. A high voltage non isolated front-end power supply normally uses boost topology.

Choice of topology actually depends on the purpose of the converters. Main criteria are: desired output voltage, efficiency, allowable PF and THD.

equencies and duty cycles. Graphical presentations of the analysis and observations have also been discussed in this chapter.

Chapter V concludes the work of the thesis. This chapter puts forward suggestions for future scopes of works related to this thesis.

CHAPTER-III

HARMONICS AND POWER FACTOR

3.1 Harmonics

Harmonics can be defined as sinusoidal components of a periodic wave having frequencies which are an integral multiple of the fundamental frequency. The supply fundamental frequency is 50 Hz. Therefore, harmonic frequencies are 100 Hz, 150 Hz, 200 Hz, 250 Hz and so on.

Usually these frequencies are specified by their harmonic number or multiple of the fundamental frequency. For example, a harmonic with a frequency of 150 Hz is known as the third harmonic (50×3=150). In this case, for every cycle of the fundamental waveform, there are three complete cycles of the harmonic waveforms. The even multiples of the fundamental frequency are known as even harmonics while the odd multiples are known as the odd harmonics.

3.1.1 Effects of Harmonics

The problem with harmonics is distortion in waveform. Relationship between the fundamental and distorted waveforms can be calculated a by finding the square root of the sum of the squares of all harmonics generated by a single load, and then dividing this number by the nominal 50 Hz waveform value.

To achieve this mathematically Fast Fourier Transform (FFT) theorem is used. This calculation method determines the total harmonic distortion (THD) contained within a nonlinear current or voltage waveform. Electronic equipment generates more than one harmonic frequency. For example, computers generate 3rd, 9th, and 15th harmonics. These are known as triplen harmonics. They are of concern to engineers and building designers because they do more than distort voltage waveforms. Overheating the wiring, transformer etc. are caused by them which results user equipment failure..

Harmonics can cause overloading of conductors and transformers and overheating of utilization equipment such as motors. Triplen harmonics can especially cause overheating of neutral conductors on 3-phase, 4-wire systems. While the fundamental frequency and even harmonics cancel out in the neutral conductor, odd order harmonics are additive. Even in a balanced load condition, neutral currents can reach to magnitudes as high as 1.73 times the average phase current. This additional loading creates more heat. Due to overheat the insulation of the neutral conductor breaks down.

In some cases, it can break down the insulation between windings of a transformer. In both cases, the result is a fire hazards and short circuits. This potential damage can be prevented by using sound wiring practices.

Harmonics are an increasing problem in electric power systems because of the expanding demand of nonlinear load such as power electronic equipment. Harmonics can cause a number of unwanted effects. Electric utility transmission and distribution equipment may be adversely affected by ac line harmonics which may cause higher transformer loss, capacitor failure or failure of protective relay operation. When connected to an ac line which has severe harmonics sensitive electronic loads may also malfunction. The power line harmonics current can be coupled in to the communication circuits by either induction or direct conduction and cause interference with communication circuits.

Major sources of harmonics in utility or industrial systems include rectifiers, motor drives, UPS and Arc furnaces. For this research, the harmonics due to rectifier loads are considered and analyzed. The wide spread application of power electronics is resulting in an increasing number of electrical load which include rectifiers to produce dc power. Inverter motor drives, uninterruptible power supplies and computer power supplies generally use rectifier at their inputs.

3.2 Power Factor

Power Factor (PF) is defined as the ratio of the real/working power to apparent power or the cosine (for pure sine wave for both current and voltage) that represents the phase angle between the current and voltage waveforms. The power factor can vary between 0 and 1, and can be either inductive (lagging) or capacitive (leading). In order to reduce an inductive lag, capacitors are added until PF equals 1. In sine wave voltage and current when the current and voltage waveforms are in phase, the power factor is 1. The whole purpose of making the power factor equal to one is to make the circuit look purely resistive.

Real power (watts) produces real work; this is the energy transfer component. Reactive power is the power required to produce the magnetic fields (lost power) to enable the real work to be done. Apparent power is considered the total power that the power company supplies. This total power is the power supplied through the power mains to produce the required amount of real power. Figure 3.1 shows the power factor triangle for sinusoidal voltage and current.

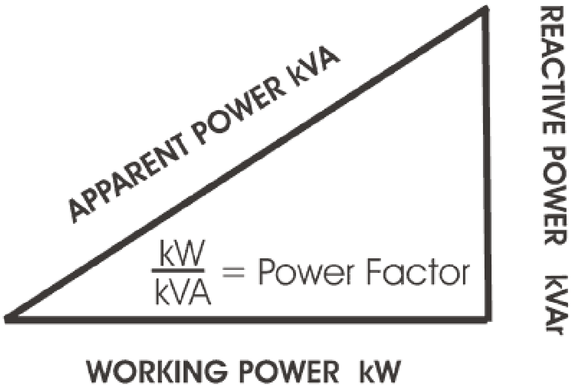

Fig. 3.1 Power Factor Triangle (lagging)

The previously-stated definition of power factor related to phase angle is valid when considering ideal sinusoidal waveforms for both current and voltage; however, power supplies draw a non-sinusoidal current.

Power factor depends on: harmonic content and displacement angle between fundamental current and voltage.

3.2.1 Advantages of High PF

The advantages of having high power factor are:

a) Voltage distortion is reduced,
b) All the power is active,
c) Smaller rms current,
d) Higher number of loads can be fed and
e) Helps to preserve environment.

3.3 Power Factor Correction

Power Factor Correction (PFC) circuit helps to minimize the input current distortion and make the current in phase with the voltage. When the power factor is not equal to 1, the current waveform does not follow the voltage waveform. This causes not only power losses but also results harmonics that travel down the neutral line and disrupt other devices connected to the line. The closer the power factor is to 1, the closer the current harmonics will be to zero since all the power is contained in the fundamental frequency.

Switch Mode Power Supplies (SMPS) generally do not use any form of power factor correction. The input capacitor C_{IN} (as shown in Fig. 3.2) charges only when V_{IN} is close to V_{Peak} or when V_{IN} is greater than the capacitor voltage V_{CIN}.

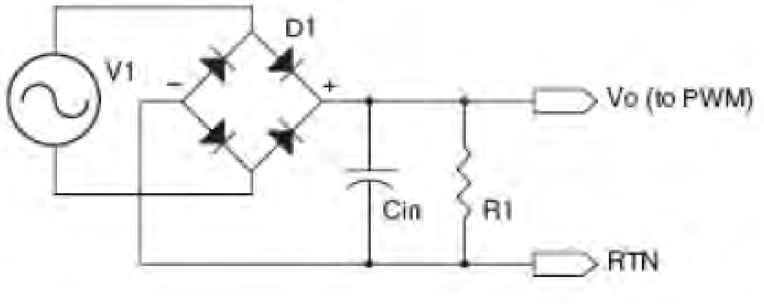

Fig. 3.2 SMPS input without PFC [16]

If C_{IN} is designed using the input voltage frequency, the current will look much closer to the input waveform, however, any little interruption on the mainline will cause the entire system to react negatively. That's why in designing a SMPS, the hold-up time for

C_{IN} is designed to be greater than the frequency of V_{IN}, so that if there is a glitch in V_{IN} and a few cycles are missed, C_{IN} will have enough energy stored to continue to power its load.

In a non-PFC circuit, C_{IN} charges only during a small percentage of the overall cycle time. After 90 degrees, the half cycle from the bridge drops below the capacitor voltage (V_{CIN}); which back biases the bridge, inhibiting current flow into the capacitor. From Fig. 3.3, it is evident that the input current spike of the inductor is very big. All the circuitry in the supply chain (the wall wiring, the diodes in the bridge, circuit breakers, etc) must be capable of carrying this huge peak current.

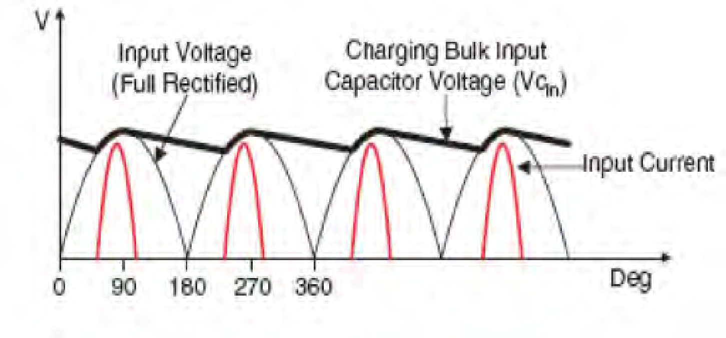

Fig. 3.3 Voltage and Current Waveforms in a Simple Rectifier Circuit [16]

During these short periods the C_{IN} must be fully charged, therefore large pulses of current for a short duration are drawn from V_{IN}. Smoothing out the huge peak current is achieved by using power factor correction circuit.

To follow V_{IN} more closely and to avoid these high amplitude current pulses, C_{IN} must charge over the entire cycle rather than just a small portion of it. Today's non-linear loads make it impossible to know when a large surge of current will be required, so keeping the inrush to the capacitor constant over the entire cycle is beneficial and allows a much smaller C_{IN} to be used. This method is called power factor correction.

3.3.1 Need for Power Factor Correction

The input stage of any AC-DC converter comprises of a full-bridge rectifier followed by a large filter capacitor. The input current of such a rectifier circuit creates of large discontinuous peak current pulses that result in high input current harmonic distortion. The high distortion of the input current occurs because the diode rectifiers conduct only for a short period. This period corresponds to the time when the mains instantaneous voltage is greater than the capacitor voltage. Since the instantaneous mains voltage is greater than the capacitor voltage only for very short periods of time, when the capacitor is fully charged, large current pulses are drawn from the line during this short period of time.

A schematic diagram of a typical single phase diode rectifier filter circuit is shown in Fig. 3.4 while Fig 3.5 shows the typical simulated line voltage and current waveforms. The typical input current harmonic distortion for this kind of rectification is usually in the range of 55% to 65% and the power factor is about 0.6. The actual current wave shape and the resulting harmonics depend on the line impedance.

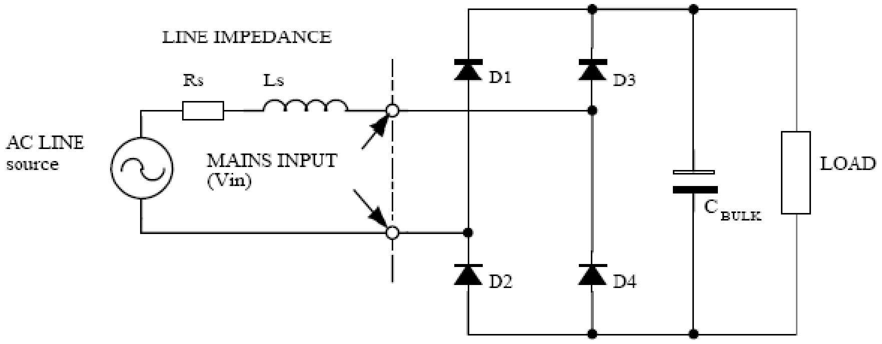

Fig. 3.4 Single Phase Diode Rectifier with Capacitor Filter Circuit [17]

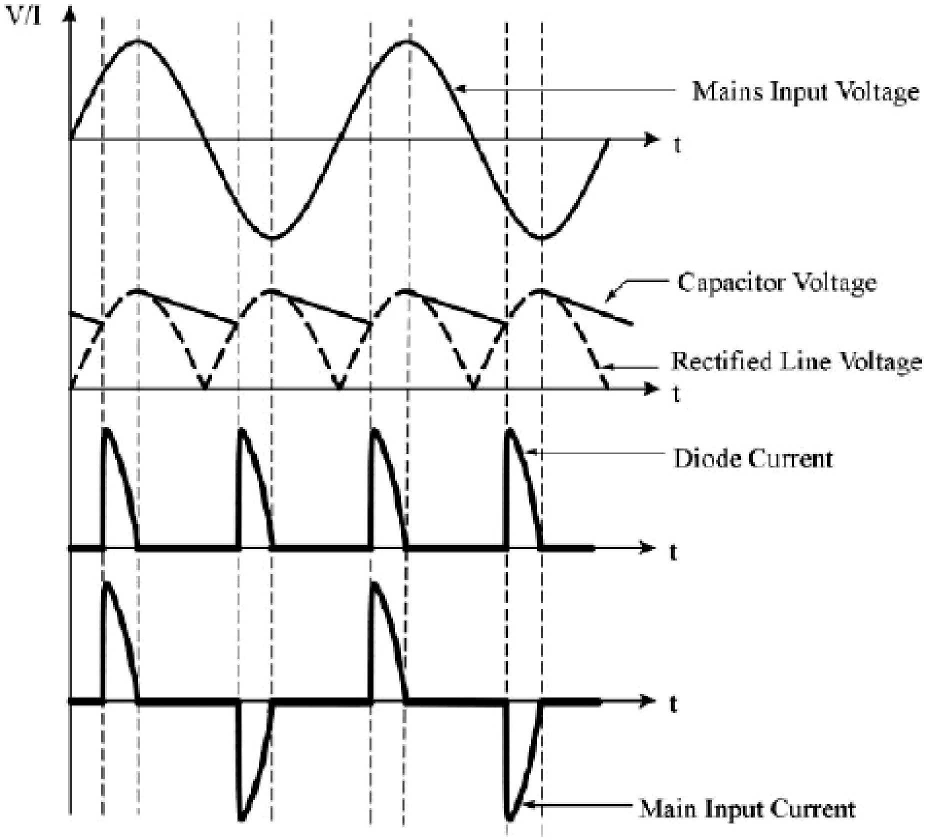

Fig. 3.5 Typical Line Current and Voltage Waveforms [17]

Conventional AC rectification is a very inefficient process which results waveform distortion of the current drawn from the mains. A circuit similar to that shown in Fig 3.4 is used in most mains-powered AC-DC converters. At higher power levels (200 to 500 watts and higher) severe interference with other electronic equipment may become apparent due to these harmonics sent into the power line. Another problem is that the power utility line cabling, the installation and the distribution transformer, must all be designed to withstand these peak current values resulting in higher electricity costs for any electricity utility company. Thus, summarizing, conventional AC rectification has the following main disadvantages:

a) It creates harmonics and electromagnetic interference (EMI)
b) It has poor power factor
c) It produces high losses
d) It requires over-dimensioning of parts/components and
e) It reduces maximum power capability from the line.

3.3.2 Passive Power Factor Correction

The power line disturbances caused by the proliferation of phase controlled and diode rectifier circuits were of concern even in late 70s [18] [19]. The passive power factor correction techniques were presented in early literature [19]. Passive techniques still remain attractive for low power PFC applications [20]. It has been reported [20] that power factor as high as 0.98 can be achieved using passive PFC techniques. Few of the passive PFC circuits are discussed in the subsequent paragraphs.

3.3.3 Inductive Filter

Figure 3.6 depicts a conventional rectifier circuit with inductive filter which has an inductor inserted between the output of the rectifier and the capacitor. The inclusion of the inductor results in larger conduction angle of the current pulse and reduced peak and rms values. For low values of inductance the input current is discontinuous and pulsating. However, even for infinite value of the inductance; the PF cannot exceed 0.9 for this kind of arrangement. [19]

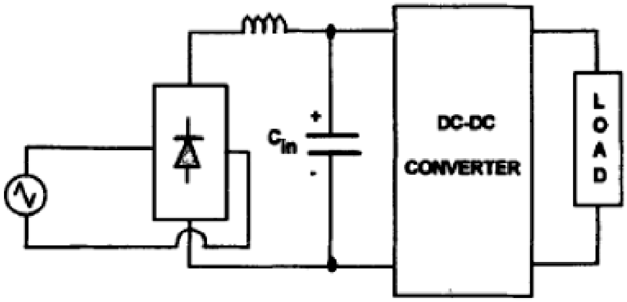

Fig. 3.6 Conventional Rectifier Circuit with Inductive Filter [21]

Addition of first stage LC filter as shown in Fig. 3.7 (line inductance not shown) causes higher order harmonics of the line frequency to undergo greater attenuation (typically 80 dB) and results in better harmonic performance. It is reported [1] that even for a relatively small value of the inductance; PF of 0.86 is attainable, a considerable improvement over the non capacitance case.

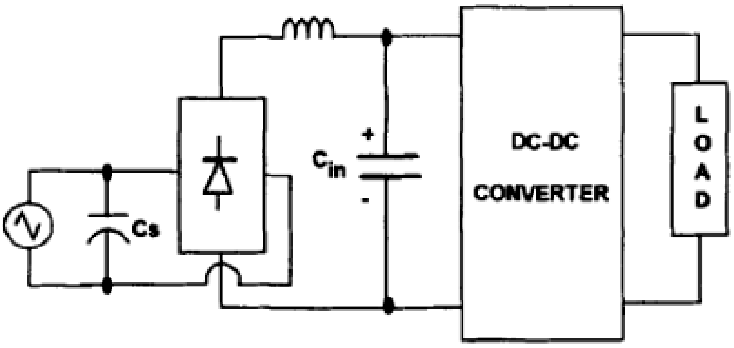

Fig. 3.7 Rectifier Circuit with Input LC Filter [21]

3.3.4 Resonant Input Filter

The input series filter arrangement for power factor correction [2] is shown in Fig.3.8, which results in good power factors as high as 0.94. The harmonic performance is also good. This circuit arrangement is popularly used in applications where the supply frequency is high. The disadvantage with this type of arrangement is the use of large size of elements and large rms currents in the both filter capacitors

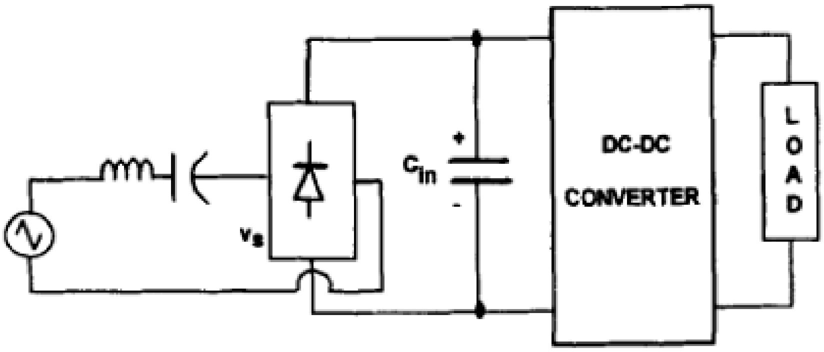

Fig. 3.8 Rectifier Circuit with Series Resonant Input Filter [21]

In Fig. 3.9, the use of parallel resonant input filter has been shown which also improves PF. With this arrangement power factor close to 0.95 is achieved. The filter is tuned to offer very high impedance to the third harmonic component (the most predominant). The high value parallel resistor is added to damp out circuit oscillations.

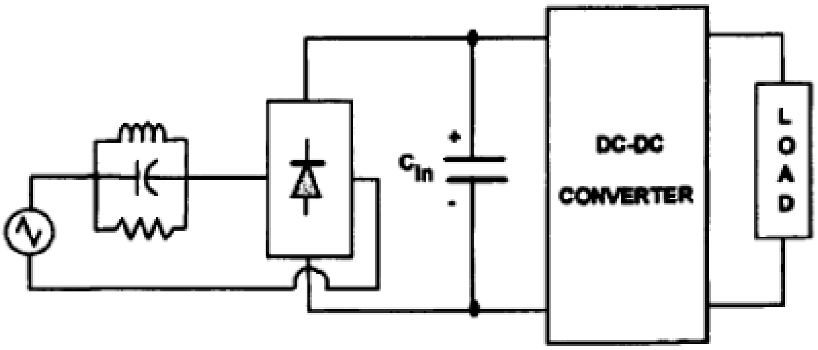

Fig. 3.9 Rectifier Circuit with Parallel Resonant Input Filter [21]

3.3.5 Active Power Factor Correction

The active PFC technique is used to shape the line current using switching devices such as MOSFETs (metal oxide semiconductor field effect transistors) and IGBTs (insulated gate bipolar junction transistors). For low and medium power ranges up to a few kilowatts (<5 kW), MOSFETs are the popular choice for PFC because of their switching speed, ease of driving and ruggedness. BJTs and more recently IGBTs are used for high voltage medium power applications which MOSFETs are unable to contend with owing to their large on-state resistances. To achieve good input current wave shaping using active techniques, typically the switching frequency should be at least an order of magnitude greater than 50th harmonic of line frequency. For 50 Hz line frequency switching speed of 2.5 kHz or more is desirable. An ideal topology of active PFC technique is shown in Fig. 3.10.

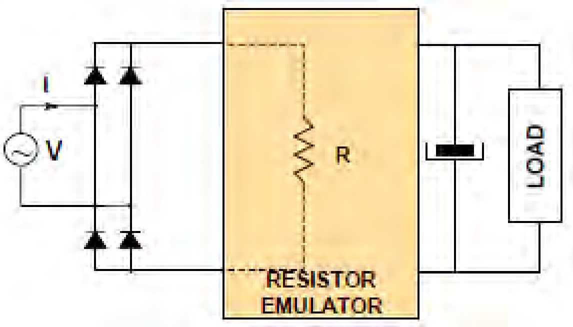

Fig. 3.10 Ideal Topology of Active PFC Technique

CHAPTER-IV

PROPOSED SINGLE SWITCH ĈUK AC-DC CONVERTER TOPOLOGY

4.1 General

The total harmonic distortion of input current for a Conventional Single Phase Diode Rectifier is more than 100% (reported value in some literature is 116%). It is very high and it needs to be reduced. Also the efficiency is very poor (about 60%). Maximum input Power factor achieved is only 0.623 which is also very low.

In Single Phase AC-DC Rectifier Topology shown in Figure 1.2 the minimum achievable total harmonic distortion of input current is 20% which is better than the conventional method. There power factor also improved from 0.623 to 0.957. The efficiency is increased. But THD is still beyond accepted standard as specified in IEEE standard 519.

In Passive Wave Shaping Topology shown in Figure 1.3 the minimum achievable input current total harmonic distortion is 14.9% which is not acceptable as specified in IEEE standard 519. The power factor is 0.9852 and which is near unity power factor. The efficiency is 60% which is poor.

The passive methods need bulky components. The results are not satisfactory also. The active wave shaping method does not deal with total harmonic distortion and the power factor is near unity.

In Fig. 1.5, it was found that the combination of 50 mH inductance and 20 μf capacitance the efficiency achieved was 91.12% and the total harmonic distortion was 2.8%. But here large input filters are required to get this result.

In the present work, a single phase AC-DC Ĉuk Converter topology with switching on AC input side have been considered and designed for 3-4 KW load specification from a 300 V max, 50 Hz single phase AC power source. The input filter parameters are: 10mH inductance and 20 μf capacitance. The designed circuits have been simulated using OrCAD software. The output voltage input current total harmonic distortion, power factor and the efficiency have been calculated and tabulated. The comparison charts have been plotted with the tabulated values.

The following discussion includes the circuit descriptions and simulation results of each simulated prototype and their calculated output voltage, input current total harmonic distortion, power factor and efficiency. All the topologies have been compared in terms of their efficiency, power factor and total harmonic distortion. Relevant discussion has been carried out for each simulated prototypes and the conclusions drawn from the simulated circuits have been presented in Chapter V.

4.2 Circuit Description

4.2.1 Circuit Diagram

Figure 4.1 represents the circuit diagram of proposed circuit diagram. In this topology an ideal switch has been used.

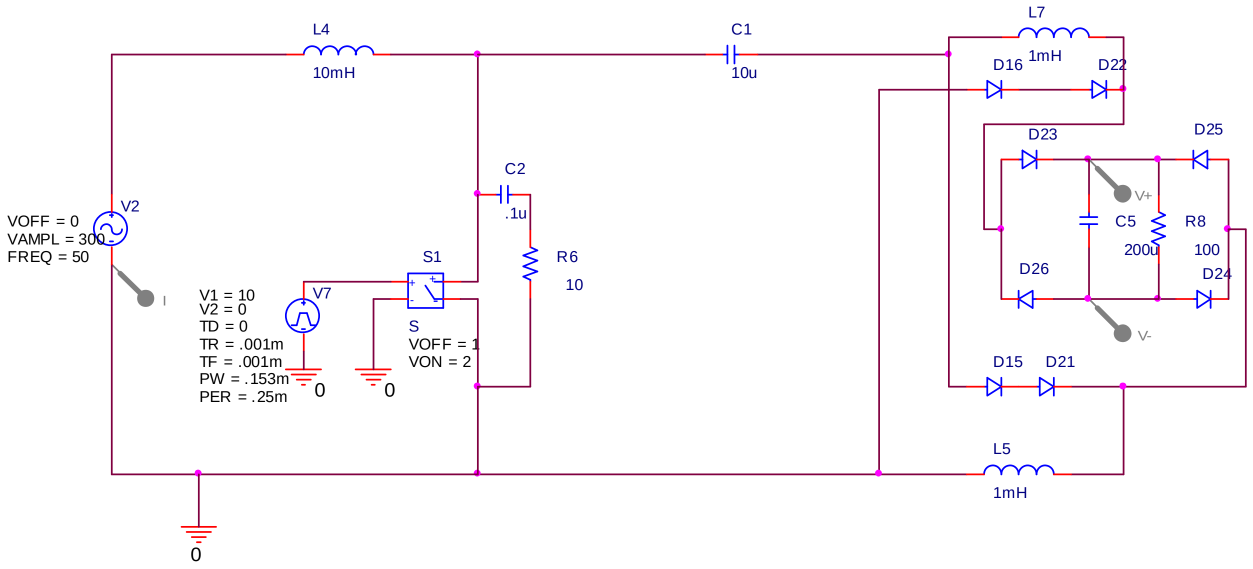

Fig. 4.1 Ĉuk rectifier with ideal switch

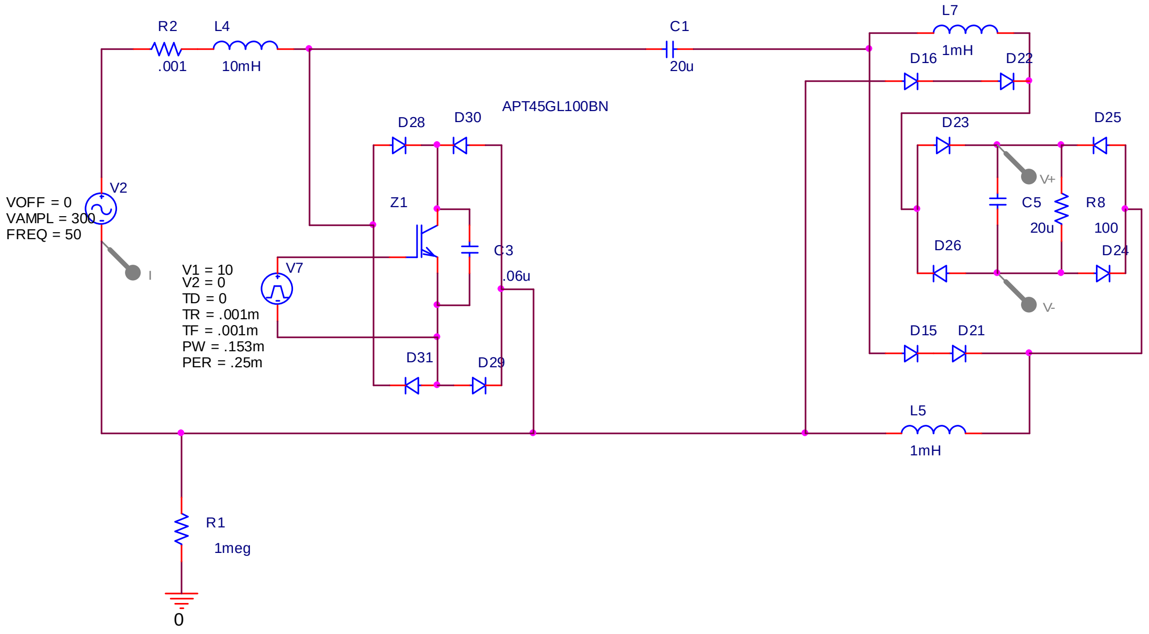

Fig. 4.2 Ĉuk Rectifier Diagram with practical Switch

The ideal switch shown in Fig 4.1 can be replaced by a IGBT as shown in Fig 4.2 which is used in practical cases.

4.2.2 Circuit Operations

Circuit operations for the proposed topology are shown in Figures 4.3 and 4.4 respectively for positive and negative half cycles.

As the switching device of the circuit is switched at high frequency during the positive half cycle of the supply, the conduction path is as shown in Fig. 4.3(a) when the switch is ON. The conduction path when the switch is OFF during the positive cycle of the supply is as shown in Fig. 4.3(b)

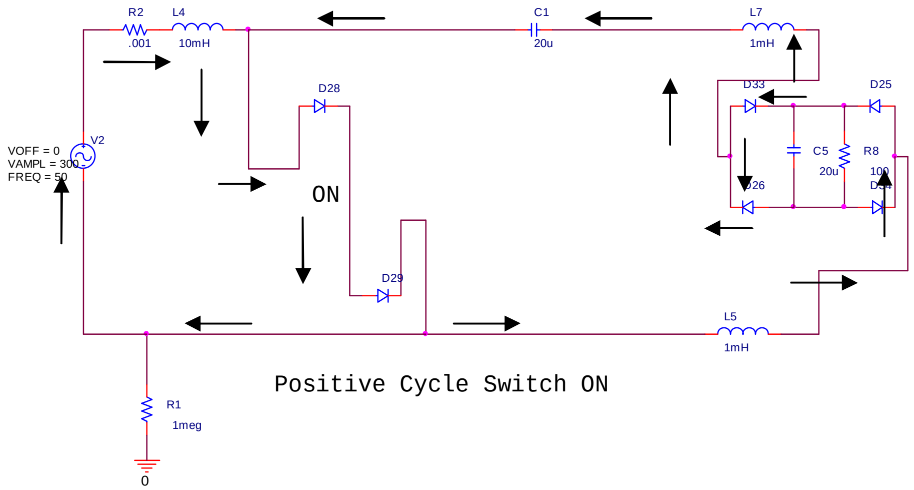

Fig. 4.3 (a) Circuit operation for positive half cycle when switch is ON

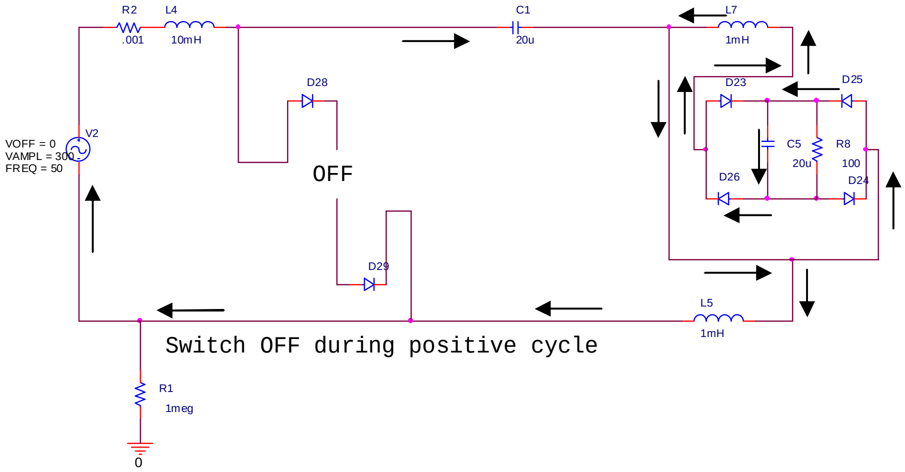

Fig. 4.3 (b) Circuit operation for positive half cycle when switch is OFF

During negative half cycle, as the switching device turns ON and OFF at high frequency, the conduction paths are as shown in Fig. 4.4(a) when the switch turns ON and as shown in Fig. 4.4(b) when the switch turns OFF.

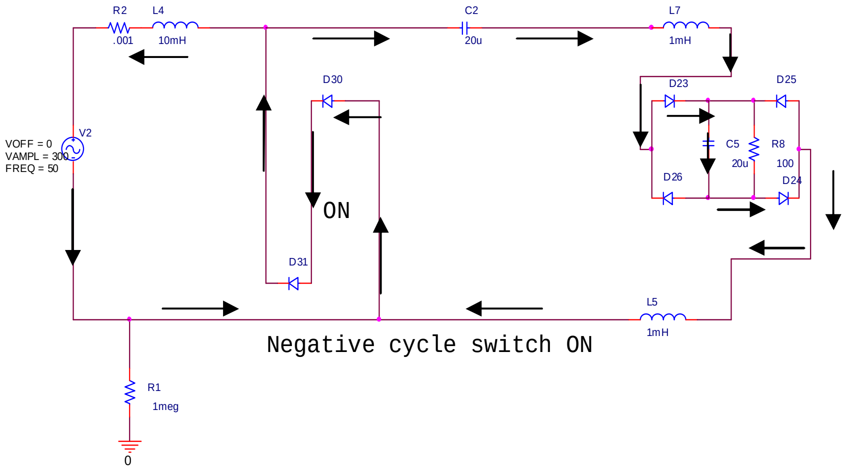

Fig. 4.4 (a) Circuit operation for negative half cycle when switch is ON

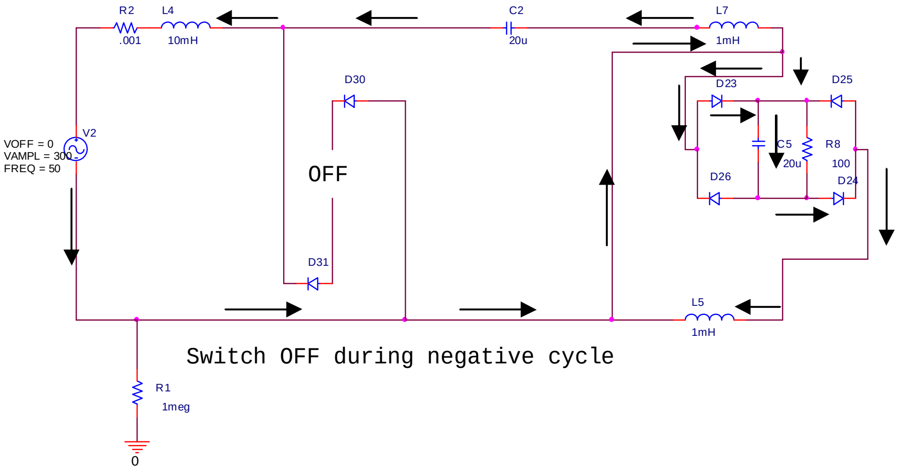

Fig. 4.4 (b) Circuit operation for negative half cycle when switch is OFF

When the switch is turned on, primary current ramps up and in both positive and negative cycle energy is stored in the inductor L_7 and L_5. Energy to the load is supplied by the charge in capacitor C_5. When switch turns off, stored energy in inductors provide energy to load circuit and recharges C_f.

4.3 Simulation Results and Discussions: Proposed Ĉuk rectifier circuit

4.3.1 Simulation Circuit

Pspice simulation circuit of the proposed single phase Ĉuk rectifier circuit is shown in Fig. 4.5. Circuit operation has been described in 4.2.2. As the bi-directional switch is turned ON and OFF, the capacitor across the load is changed positively during both positive and negative cycle of the input supply providing step up/down rectification.

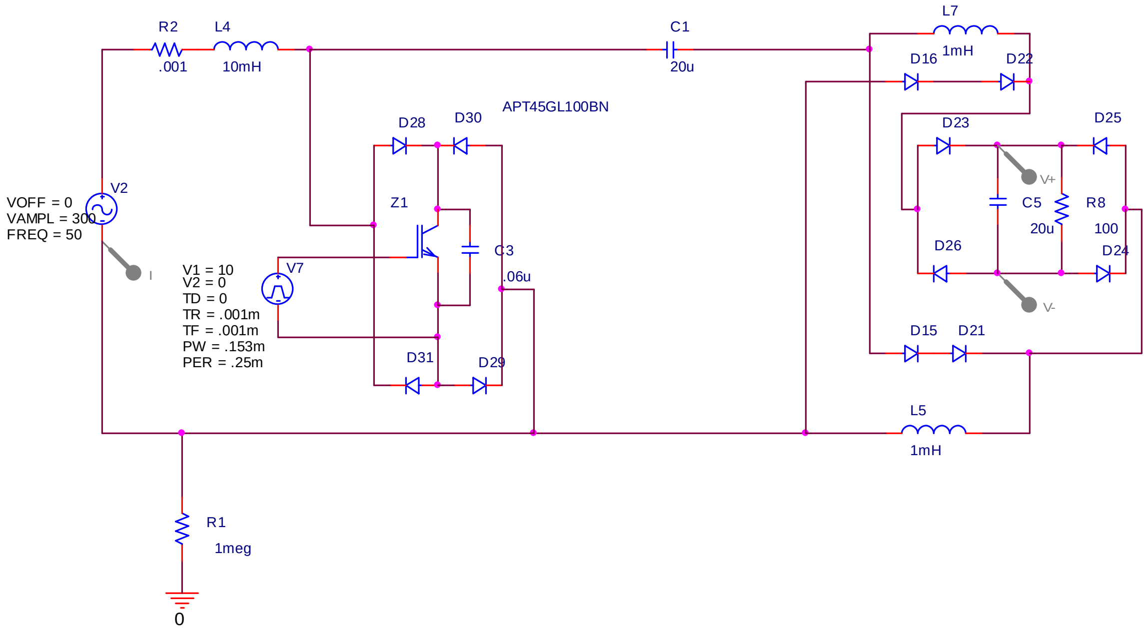

Fig. 4.5 PSpice Simulation Circuit of Proposed AC-DC Ĉuk Converter

4.3.2 Simulation Results

Performance of the single phase AC-DC Ĉuk converter of Fig. 4.5 has been carried out. The results are given in Table-4.1 which is obtained by varying duty cycle of the switching signal of the bi-directional switch of converter in Fig. 4.5. Table 4.1 shows that as the duty cycle of the switching are increased, the output dc voltage of the converter across 100Ω load increases from 250 VDC to 500 VDC. Below duty cycle 0.5, the voltage gain is step down in nature and above 0.5 duty cycle the voltage is step up in nature. The THD of the input current is less than 10% in all duty cycle, which is obtained without any additional filter. The efficiency of the circuit is above 75% for all duty cycle and the input power factor is above 0.7 for all duty cycles (above 80% for duty cycles above 50%). These results are better than the performance of single phase bridge rectifier (uncontrolled) with large filter. The results obtained in this section are for passive resistive load of 100 ohm. In the following sections, results are provided for R-L-emf load to the circuit.

Table 4.1: Simulation Results: Conventional Topology for various Duty Cycle

Input = 300Vmax Load R_L= 100 Ohm						
Period (ms)	PW (ms)	Duty cycle	Output Voltage	THD In % of input current	pf	η (%)
0.25	0.2	0.8	500	5.24	0.78	83.33
0.25	0.18	0.72	400	6.16	0.8	80
0.25	0.16	0.64	380	7.29	0.94	90.25
0.25	0.14	0.56	250	9.09	0.78	62.5
0.25	0.12	0.48	250	1.81	1.00	69

4.3.3 Wave Shapes

Typical output voltage, input voltage and input current wave shapes are shown in following Figs. 4.6-4.8. The output voltage is controllable by changing duty cycle of gate pulses.

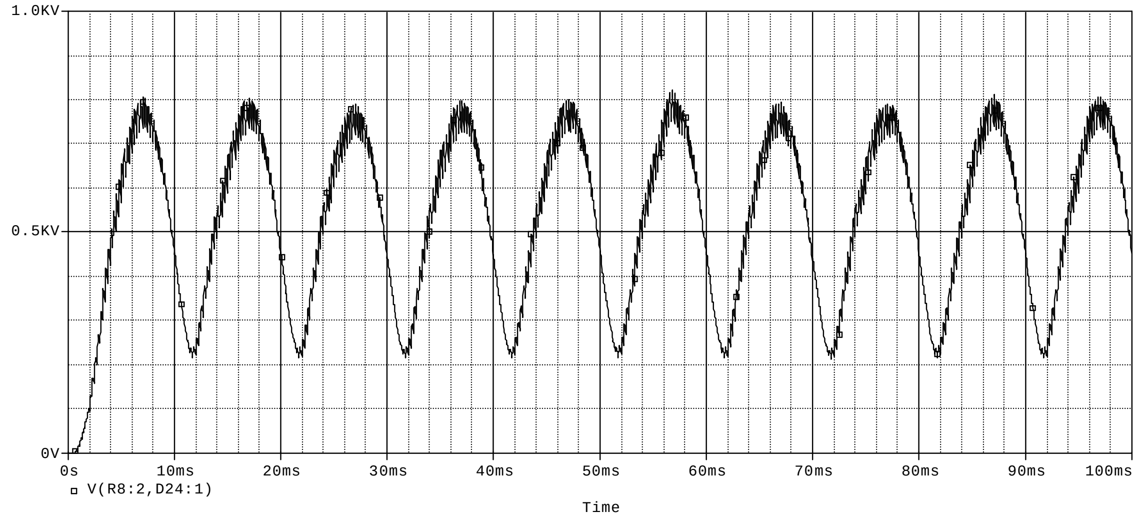

Fig 4.6 Typical Output Voltage Wave Shape at Duty Cycle 0.48

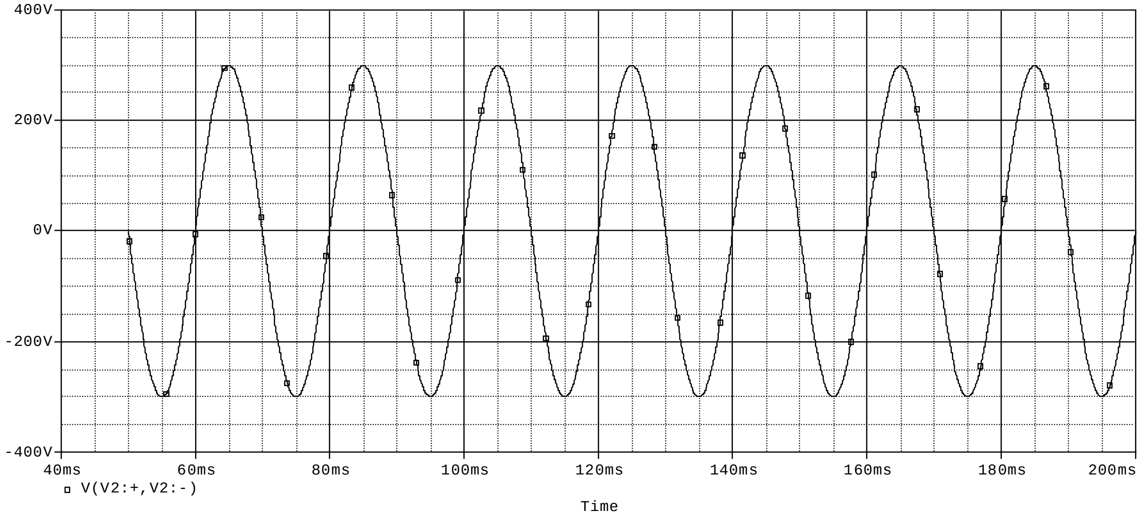

Fig 4.7 Typical Input Voltage Wave Shape at Duty Cycle 0.48

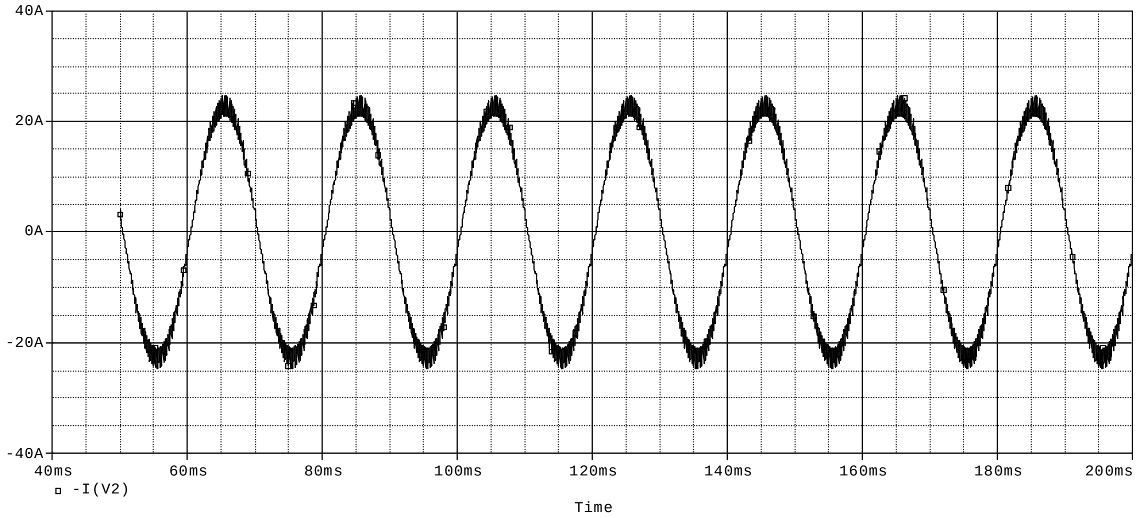

Fig 4.8 Typical Input Current Wave Shape at Duty Cycle 0.48

4.4 Proposed Topology used for R-L load

In Fig. 4.9 the proposed Ĉuk topology with for R-L load is shown. The circuit is investigated for R=10 ohm and L=10 mH as load. The results of output voltage, input current THD, efficiency and power factor are given in Table 4.2. As in the case of resistive load, output voltage increases with increase of duty cycle. The power factor for various duty cycles are above 0.7, efficiency is above 80% and input current THD is less than 10%. Typical waveforms for R-L load are shown in Fig 4.10

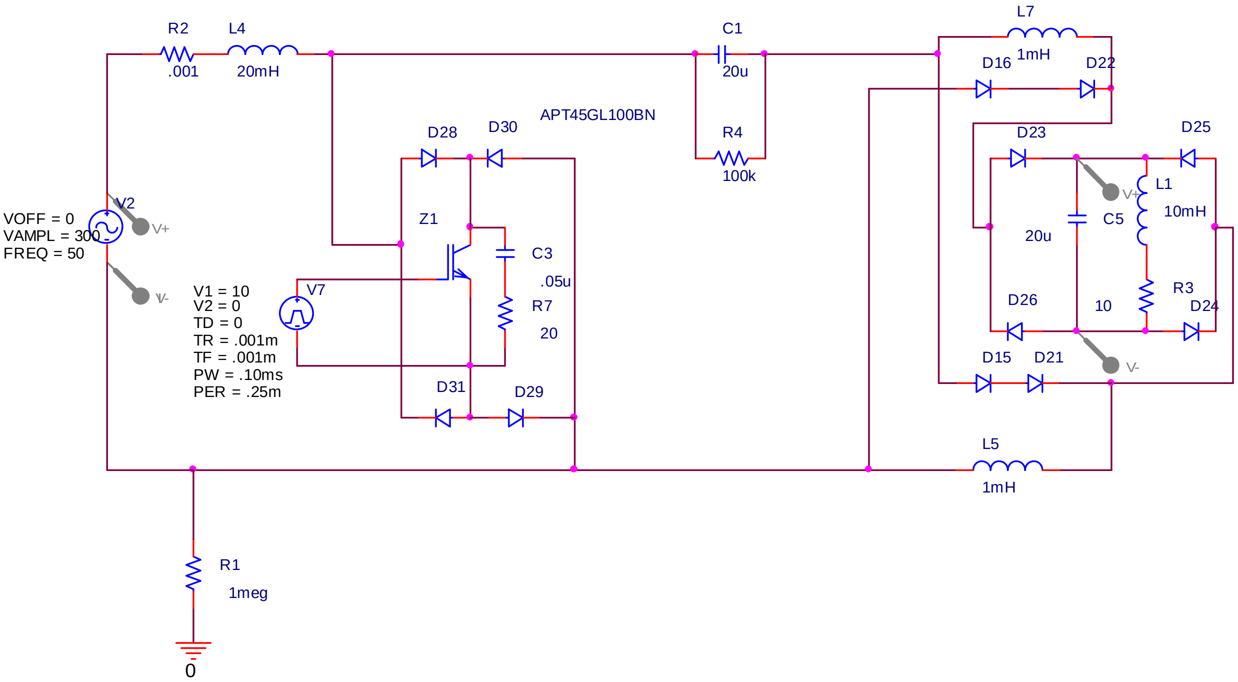

Fig 4.9: Ĉuk topology used for R-L load type circuit

Table 4.2: Simulation Results: For R-L Load for various Duty Cycle

Input = 300Vmax Load R_L= 10 Ohm						
Period (ms)	PW (ms)	Duty cycle	Output Voltage	THD In % of input current	pf	η(%)
0.25	0.2	0.8	175	4.65	0.79	99
0.25	0.18	0.72	170	3.75	0.813	99
0.25	0.16	0.64	150	4.64	0.72	97
0.25	0.14	0.56	150	4.4	0.86	98
0.25	0.12	0.48	120	4.9	0.75	90

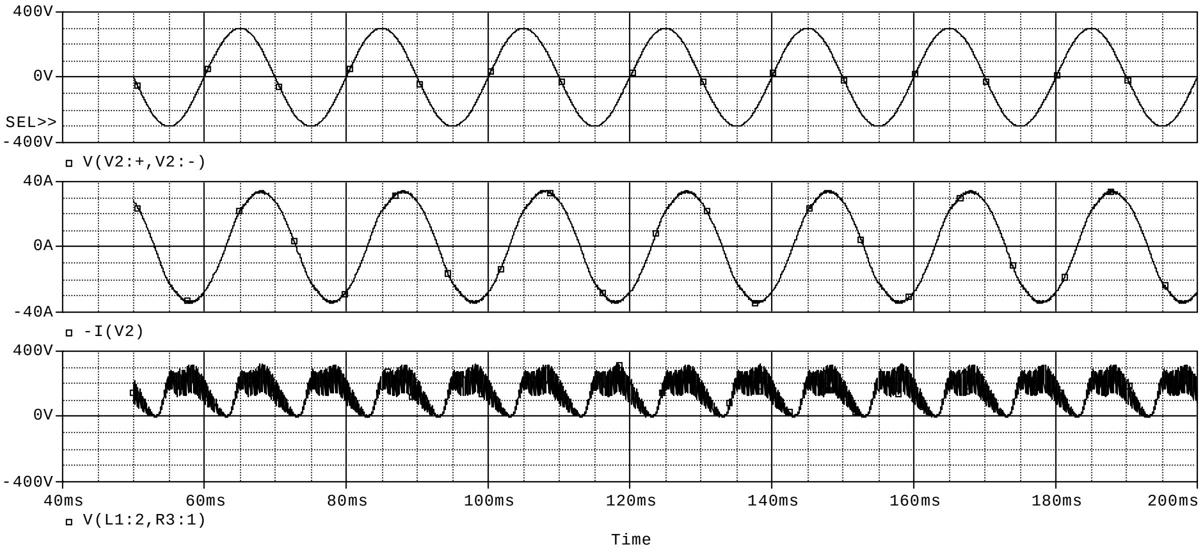

Fig. 4.10 Wave Shapes of Input Voltage, Output Voltage and Input Current for R-L load

After PSpice Simulation the following wave shapes for input current, output voltage and input voltage are found which are shown in Fig. 4.10.

4.5 Proposed Topology used for R-L-emf load

In Fig. 4.11 the proposed Ĉuk topology used for R-L-emf load is shown. The load is R=0, L=10mH and back emf=220V to the circuit. The results of output voltage, input current THD, efficiency and power factor are tabulated in Table 4.3. It is observed that the output voltage increases with the increase of duty cycle. The power factor for various duty cycles is above 0.7, the efficiency of conversion is above 80% and the input current THD is less than 10%.

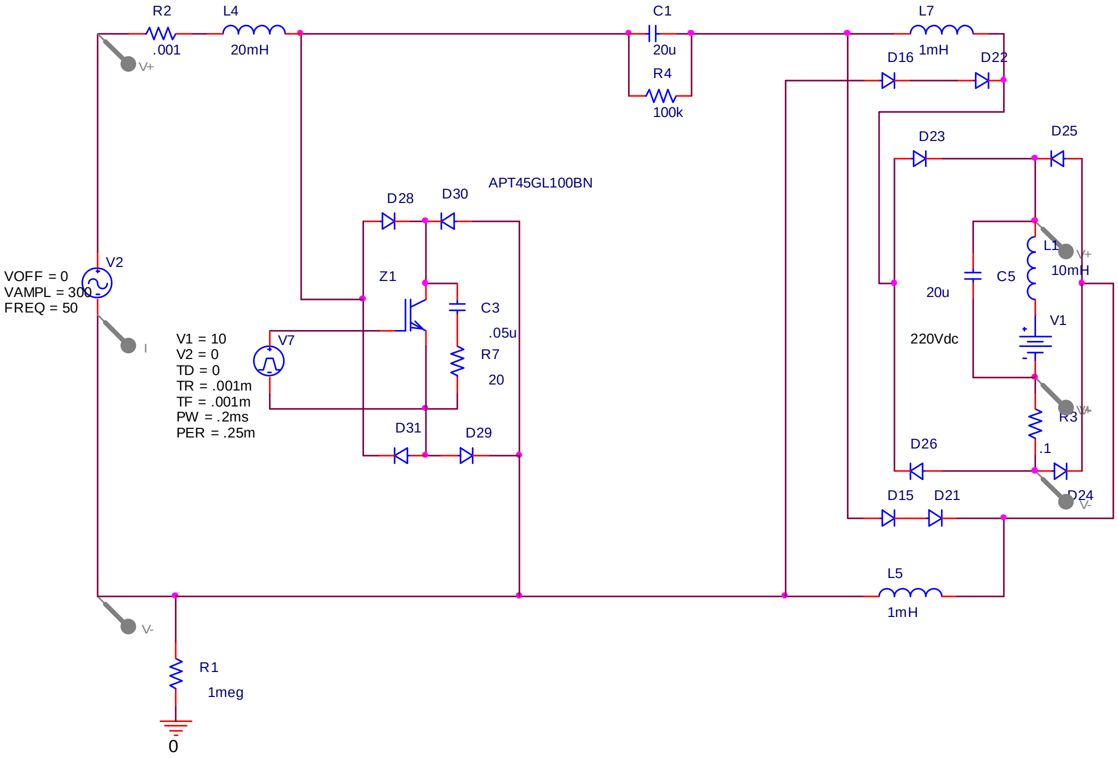

Fig 4.11 Cuk topology used for R-L-emf load type circuit

Table 4.3 Simulation Results: For R-L-emf for various Duty Cycle

Input = 300Vmax						
Period (ms)	PW (ms)	Duty cycle	Output Voltage	THD In % of input current	pf	η(%)
0.25	0.2	0.8	230	7.03	0.7	99
0.25	0.18	0.78	230	8.49	0.75	99
0.25	0.16	0.64	225	1.31	0.75	99
0.25	0.14	0.56	225	1.93	0.7	99
0.25	0.12	0.48	225	3.18	1.00	99

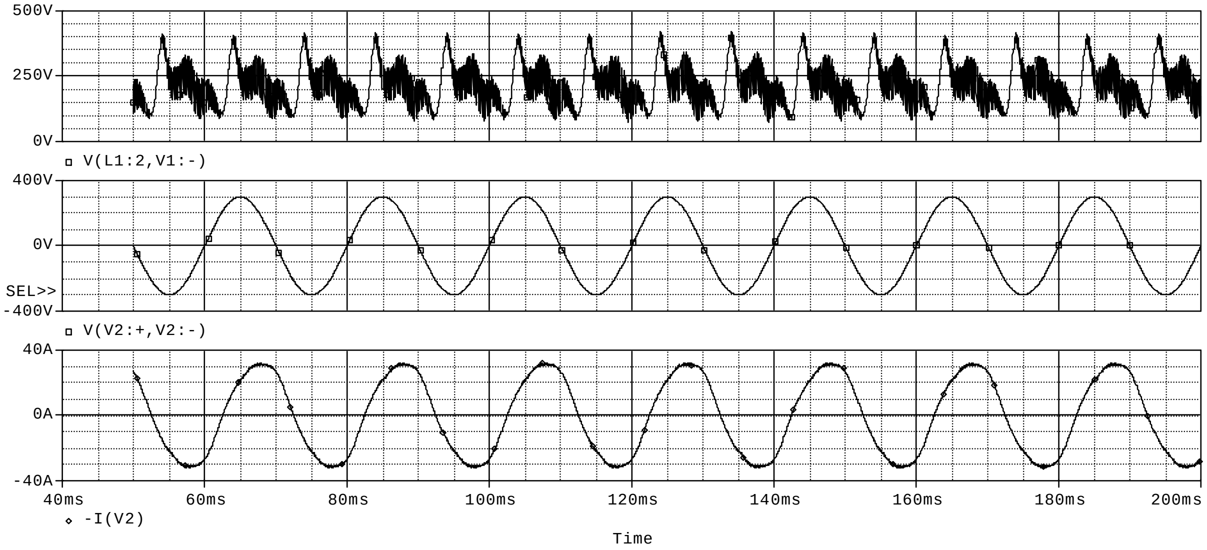

Fig. 4.12 Wave Shapes of Input Voltage, Output Voltage and Input Current for R-L-emf load

After PSpice Simulation, the following typical wave shapes for input current, output voltage and input voltage are found which are shown in Fig. 4.12.

4.6 Remarks

In the proposed Ĉuk AC-DC converter topology it is observed that the efficiency of the circuit is above 75% and the input power factor is more than 0.7 with step up/down characteristics. Also the THD of the input current is less than 10% which is overall very good.

The proposed topology is also applied for R-L and R-L-emf load type circuits. Here the THD of input current is less than 10%. The input power factor is above 0.7 and efficiency is more than 80%. It is to be noted that the whole proposed topology is very simple. The whole operation is performed without using any large filter.

CHAPTER-V

CONCLUSION

5.1 Conclusion

In this thesis a single phase ac-dc rectifier circuit based on Ĉuk topology is investigated where a bi-directional switch is used for controlling the output voltage. It has also the step up/step down characteristics as well. The Total Harmonic Distortion of the input current is less than 10% where as the input power factor is above 0.7. Also efficiency of the proposed circuit is more than 70%. The circuit diagram is very simple which has no large type filter. The bidirectional switch is made of a unidirectional switch which is combined with four diodes. Below duty cycle 0.5 the obtained voltage gain is step down and above 0.5 duty cycle it is shown step up in nature. With the increase of the duty cycle the voltage gain also increases.

The topology is also studied for different load type circuits. For those cases the input power factor is more than 0.7 and THD of input current is less than 10%. The efficiency is more than 70%.

5.2 Future work

The converter based on Ĉuk topology is designed by OrCAD. The simulation is found by using PSpice. But it has not yet been implemented in practical field. So it can be a field for future work with improvement scope.

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