DESIGN AND CONTROL OF BI-DIRECTIONAL AC-DC CONVERTER FOR ENERGY STORAGE SYSTEM

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Final Year Project Report

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DESIGN AND CONTROL OF BI-DIRECTIONAL-AC-DC CONVERTER-FOR ENERGY STORAGE SYSTEM

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Of the requirement for the degree of

B.S. Electrical Engineering

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Declaration

We, hereby declare that the project work entitled "Design and Control of Bi-directional AC-DC Converter for Energy-Storage-System" submitted to the Department of Electrical Engineering and Applied Sciences (FEAS), Riphah International University, has not been copied out from any source. It is also stated that we produced this, project and the accompanying report totally via our own efforts, guided by our supervisor's honest direction. No part of the work described in this report has been submitted in support of any-other degree or certification granted by this or any other university or institute-of learning; if this is discovered, we will be held accountable.

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Riphah International University, Pakistan, has recognized their project under the supervision of their project adviser and with the approval of the project examination commiittee as partial-fulfilment of the criteria for the four-year degraee of **B.S. Electrical Engineering.**

(Dr. Haris Shehzad)

Designation, Project Advisor

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Dedication

<u>THIS WORK IS DEDICATED TO OUR LOVED PARENTS AND TEACHERS.</u>

WHO, RIGHT FROM THE TIME OF OUR BIRTH, HAVE BEEN

WORKING ON US TO MAKE US ENABLED HUMAN BEINGS

Acknowledgement

First of-all, we would like to thank Almighty Allah the most beneficent and the most merciful for whatever success we have achieved in our project. We have furthermore thanked our supervisor Dr. Haris Shehzad for guiding us at every single step of this project. And for giving us an opportunity to work on this interesting project. It was only due to his guidance and belief in us that led to the completion of our project. And especially thankful to Sir Engr. Adil Zohaib from the Department of Electrical Engineering who guided us a lot. I would also like to thank the staffs of my electrical department who have helped us in many ways. And of course, our parents, who love us and guide us for our better future and always believed us.

Abstract

The energy storage system is an essential part in different power systems, like uninterruptable power supplies (UPS), micro-grids, electric-vehicles (EV), etc. By preserving and providing electricity when it is needed, the energy storage system enhances the performance (efficiency) of power consumption. The need for an energy storing system arises from the fact that it addresses the issues of power that is generated and used at the same time; it can preserve power and utilize it when it is needed. Energy storing system(ESS) has allowed us to utilize renewable energy(RE) efficiently and reliably. A bi-directional power converter is necessary to fully utilize the energy storage system. This device regulates the flow of power from the-grid to the battery (charging mode) andfrom the battery to the grid (discharge mode) (discharging mode). Bi-directional AC-DC converters are critical for bridging the gap between the AC grid and a storage device.

The design difficulties of single-phase bi-directional AC_DC converters for charge/discharge management of energy storage systems(ESS) are discussed in this research paper. This project includes two converters: a bidirectional AcDc converter and a bidirectional DcDc converter. A non-inverting buck-boost architecture will be used to create a bi-directional DcDc converter. The DcDc converter will function as a buck-converter when we want to store electricity and as a boost-converter when we needed. The AcDc converter will be worked in charging mode as a bridge-diode rectifier.The 4 switches of the dcac converter will be controlled using the PWM technique in the discharging-mode. An efficient inverter has been designed for micro-grid systems which are simulated by MATLAB/Simulink.

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LIST OF ABBREVIATIONS

D	*Duty cycle*
R	*Resistor*
L	*Inductor*
C	*Capacitor*
D1,2	*Diodes*
IL	*Inductor current*
Vb	*Battery voltage*
Vo	*Output voltage*
ΔiL	*Change in inductor current*
po	*Output power*
vs	*Source voltage*
Is	*Source current*
f	*frequency*
Id	*Diode current*
Ic	*Capacitor current*
VL	*Inductor voltage*
S1,2,3	*Switches*

ESS	*Energy Storage System*
f	*frequency*
Id	*Diode current*
vs	*Source voltage*
C	*Capacitor*
Vd	*DC Voltage*

Chapter One

1 INTRODUCTION

1.1 Background

Massive usage of natural fuels like oil, coal, and gas pollutes the environment and has a significant greenhouse effect throughout the planet. In the center of the fossil fuel supply and global energy demand, on the other side, there is a massive denial. Some barriers to human growth have become more severe, such as energy scarcity and air pollution.

As a result, the recyclable renewable energy source of wind and solar wave may be used for high step-up operation. This type of renewable energy can provide DC voltages. So we need to convert this DC voltage in to AC voltage by using AC-DC converter because our devices use AC voltage. But the drawback of wind energy conversion system is unpredictable energy, as same as solar energy.

In these DERS, the output voltage is very low. In order to increase the output voltage (AC), two different methods are used. One is convert low output DC voltage in to AC by using unidirectional DC-AC converter then use step-up transformer to stepup the ac voltage level. And the 2nd method is to use DcDc converter with high gain to stepup the DC then convert it in AC Voltage.

High-gain DC–DC converters are in high demand in a variety of applications, including renewable energy, energy storage systems(ESS), and electric vehicle applications. By preserving and providing electricity when it is needed, the energy storage system enhances the performance (efficiency) of power consumption. Due to its inconsistency in availability, the battery energy storage system (BEES) with effective charging methods played a significant part in DRES-based power generation.

Transformer less energy storage system (ESS) required two converters in charging time one can convert AC-DC and other can transform high voltage in to low voltage (Buck converter) to charge our battery. In discharging mode, a DcDc (Boost) converter required to convert low voltage level to high voltage DC, which is subsequently converted to AC for everyday use by a DCAC converter. The above all discussed AC-DC and DC-AC both converters are unidirectional because they can work only in one direction.

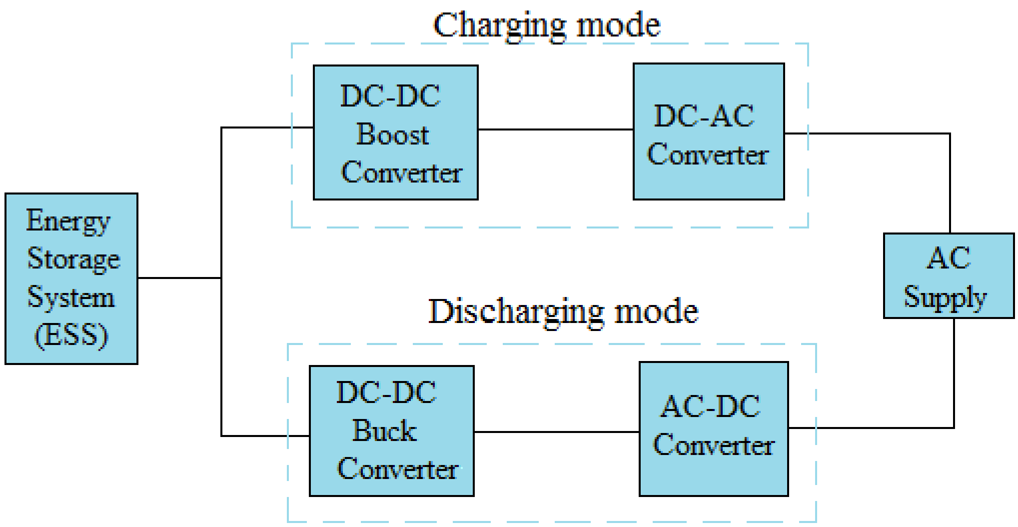

Fig 1.1 Unidirectional converter for energy storage system

In the past few years, the following types of DC-DC converters topologies are focused:

(a) Fly back Converter

(b) Push pulls Converter

(c) Interleaved Boost Converter

(d) Forward converter

These type of converters used in uninterruptable power supplies (UPS), energy storage systems (ESS), Electric vehicles (EV). Etc.

To utilize the energy storage system effectively, we required a bi-directional AcDc power converter. This converter enables the transfer of power from the ac-main to the battery which is known as charging mode and from the battery to the ac-main which is known as discharging mode. It has the ability to work in both ways. So we can use one bi-directional AC_DC converter instead of two unidirectional converters.

1.2 Problem statement

- The control algorithm of unidirectional acdc converter is less stable, inefficient and ripple in the dc current and voltage.

- Unidirectional converters have more power processing stages than bidirectional converters.

- Due to the large number of switches in unidirectional, it has more switches losses which effect on its cost and efficiency as well.

- In unidirectional converters, two converters are required (one is AC-DC and second is DC-AC) It raises the price, weight, complexity and size of whole system.

- Due to overcome these draw backs of conventional converters, we design a bidirectional AC-DC converters which is more efficient.

1.3 Objectives

The objectives-of the proposed research works are

- Design and control of bidirectional converter.

- Improve the efficiency of ESS.

- Minimize power processing stages.

- Reduce the weigh, size, and cost.

- Simplify (reduce complexity) the converter.

1.4 Organization of thesis

Chapter 1: In this chapter, a brief introduction about AC_DC and DC_DC Converters and Problem statement, Objective is discussed.

Chapter 2: In this chapter, a detail reviewof literature along with ACDC, DCAC and DCDC converters for Energy storage systems (ESS), uninterruptable power supplies (UPS) Applications is discussed.

Chapter 3: In this chapter, Conventional circuits are discussed.

Chapter 4: In this chapter, a new proposed Bi-directional AC_DC converter consist of Non- inverting Bi-directional DC_DC (Buck-Boost) converter and their Simulation Results Using MATLAB/SIMULINK are discussed

Chapter 5: This chapter gives the conclusion about the proposed Converter and its application.

Chapter 6: In this chapter, references are mentioned.

Chapter Two

2 LITERATURE SURVEY

The mercury arc valve was the first high-power electrical gadget. Semiconductor switching components and power transistors are used in modern systems to convert energy (like power-MOSFETs and IGBTs). In comparison to electronic systems requiring signal and data transmission and processing, power electronic equipment processes a huge quantity of electrical energy. AC/,DC converters (rectifiers) are the most typical power electronic devices in many consumer electronic-devices, such as televisions etc. The kind of input and output power may be used to categories power transformation systems. It can be classified into four types which are followings:

- AC DC
- DC AC
- DC DC
- AC AC

The evolution of power electronics began in 1902 with the invention of mercury arc rectifiers by PeterCooper Hewitt, which are used to transform alternating current into direct current. Uno Lame has created a mercury valve with graded electrodes that may be used to transmit high-voltage direct current electricity. In 1933, the selenium rectifier was created.

In 1959, Mohamed Atalla and Dawon Kahng discovered the MOSFET thus realizing a step-forward in power electronics technology. By the help of many generations of MOSFET transistors, power supply designers have been able to attain previously unthinkable levels of performance and density with bipolar transistors. Power MOSFETs were accessible in the 1970s as a result of advancements in MOSFET technology (which was originally utilized in the manufacture of integrated circuits). Power MOSFET is the most typical power gadgets on the earth. It has the advantages of low gate drive power, fast switching speed, easy drive, easy biasing and so on. They are used in power converters.

In 1982, insulated gate bipolar transistors (IGBTs) were first introduced. IGTs the power handling capabilities of bipolar transistors (BJT) with the benefits of power MOSFETs.

Qun Zhao et al. (2001) proposed a Continuous-Current Mode (CCM) boost converter. When the switch is operated, the current through the boost rectifier is equal to zero, and the drop rate of current is controlled by the leaky inductor. This is accomplished by diverting current to a branch with a rectifier and linked winding.. Furthermore, the high duty ratio causes significant current ripple and diode reverse recovery problems. As a result, conduction losses rise.

K. Al-Haddad et al. (2005) suggested a mathematical model of DC/DC switch-mode converters that can operate in both CCM and DCM operating modes. The notion of switching functions underpins the modelling approach. The models are expressed by time-variant equations, which are very easy to execute on a computer. The-proposed modeling approach is appliedto the conventional buck and Cùck converters for illustration purpose.

Vahid Samavatian et al. (2015) proposed a magnetically coupled inter-leaved converter which is superior to the conventional interleaved cascaded buck-boost converter. This method yields non-pulsing input & output currents, as well as excellent efficiency and reduced switch voltage stress. Input and output current ripple, low power density, internal voltage oscillation, and low converter efficiency are the primary disadvantages.

Liao et al. (2012) proposed buck-boost converter for running electric mobility system. His converter does not require a diode and saves money by combining two non-inverting buck-boost converters with an interleaved action. The current stress and current ripple at the diode's output are reduced as a result of this interleaved operation. The input voltage variation is not entirely accomplished using an interleaved non-inverting buck-boost converter with minimal output current ripple. When the operation mode (buck or boost) is changing, all topology suffer from high ripple current, low efficiency and internal dynamic oscillations. But, this transition is not continuous in conventional converter.

Ching-Tsai et al. (2010) describe a chuck-type converter that minimizes input and output ripple. Then, to get a greater voltage conversion ratio, a chuck-type converter is employed. It prevents the converter from running at a high duty ratio. Capacitors are used for decreasing the voltage stress of diode and active switch.. A large output voltage at smaller duty cycle is produced in the Discontinuous Conduction Mode (DCM) operation when compared to Continuous Conduction Mode (CCM). But, the output voltage is quite variable to the change in duty_cycle. The feedback circuit design is difficult in chuck converter. Thereby, the efficiency is poor in DCM. Hence, only CCM is used in fuel cell application. The main drawbacks of this converter are coupled inductors and commutation losses due to leakage inductance.

2.1 Types of AC-DC converters

In power electronics, converter is used to transform the electric-energy form one form to another form. Peter Cooper Hewitt in 1902 proposed a rectifier which converts ac to dc. An ac*dc converter changes an ac input to a dc output. From an ac source to a dc load, average power is transsferred. The term "rectifier" refers to a device that transforms alternating electricity into direct current.

2.1.1 Half-Wave Rectifier

A rectifier transform ac current to dc current. The goal of a rectifier might be to generate a voltage or current waveform with a specific dc component, or it can be to provide a completely dc output. The average current from the supply will not be zero in this case. Transformer performance may be hampered by this nonzero average current. This circuit has a restricted number of practical uses.

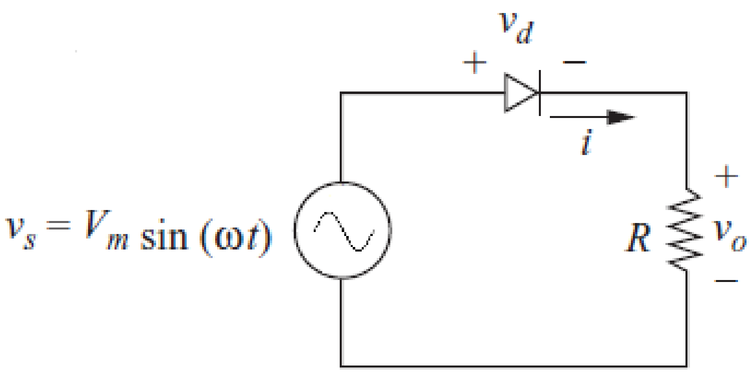

Fig2.1 Half-wave rectifier with resistive-load

2.1.2 Full-Wave Rectifiers

Full-wave-rectifier is used to generate entirely dc-voltages or currents. While the aim of a full-wave rectifier is related to a half-wave rectifier, full-wave rectifiers offer a few benefits over half-wave rectifiers. The average current in the ac source is zero in a full-wave rectifier. Which eliminates issues related with non-zero average source currents, such as those observed in transformers. Output has low ripple in a full-wave rectifier's than a half-wave rectifier's.

Bridge-rectifier

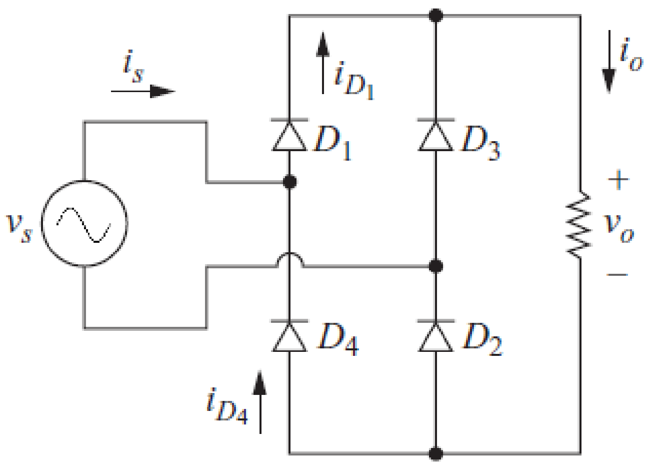

Fig2.2 Full-wave bridge-rectifier circuit

Center-taped transformer

In this type current in each half winding of the transformer secondary is reflected to the primary, yielding a source current of zero on average. Between the source and the load, the transformer offers electrical isolation. Because there are two periods of output for every time of input, the output voltage has a fundamental frequency of 2ω.

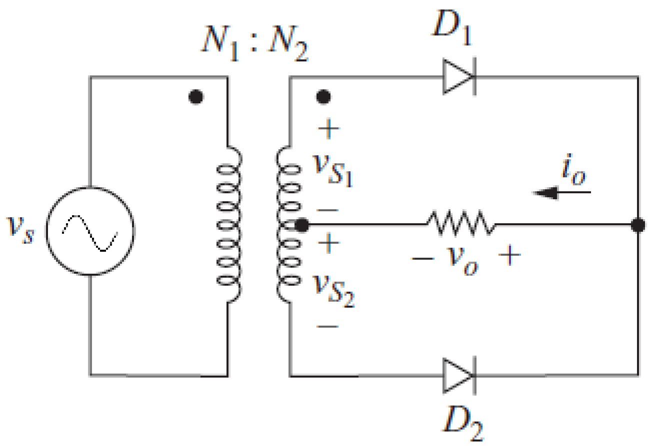

Fig2.3 Full-wave center-tapped rectifier circuit

2.2 Types of DC-AC converters

A device that transforms dc to ac voltage is called an inverter. The converter's average power flows from the dc to the ac side. Inverters are used to change a dc voltage to an ac voltage at a certain frequency and to link other energy source, such as a solar array, to the grid.

2.2.1 Half-Bridge-Inverter

The inverter is a four-switch process that changes dc to ac voltage, while the half-bridge inverter has two diodes and two anti-parallel switches. Both switches are complimentary, means that one switch is on at that time other is off and vice When switch S1 is turned on-from 0 to T/2, the diodes D1 and D2 are in reverse bias, and the S2 switch is turned off. Both diodesare in reverse bias state and the S1 switch is OFF while switch S2 is on for a time period of T/2 to T.

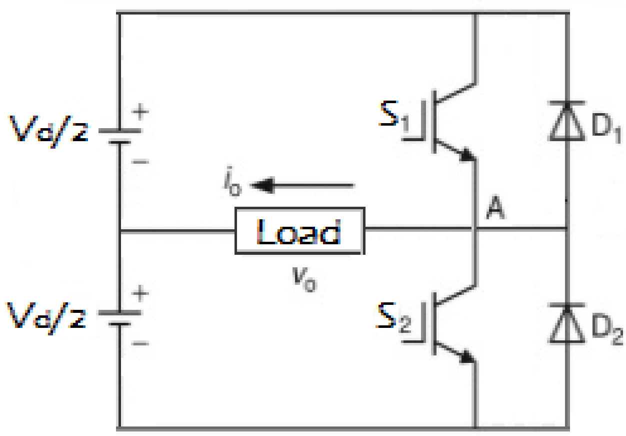

Fig2.4 Half-Bridge DC-AC Inverter

2.2.2 Full-Bridge Inverter

The full-bridge circit is the most basic circuit for converting direct to alternate current. By closing and opening of buttons in a certain order, a full-bridge inverter creates an ac output from a dc input. The output Vo polarity depend upon which buttons are working. It can be -Vdc, +Vdc, or zero. S1 and S4, as well as S2 and S3, should not be turned on at the same time. Otherwise, a short circuit would develop across the dc source. Real switches don't flip on and off at the flick of a wrist. As a result, switching transition periods must be factored into the switch control. Blanking time is the amount of time given for switching.

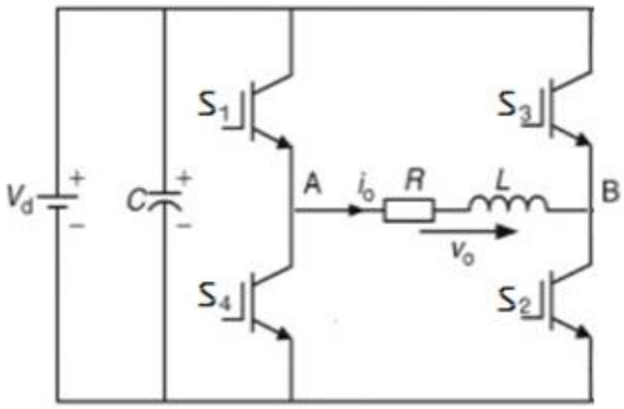

Fig2.5 Full-Bridge DC-AC Inverter

2.3 Types of DC-DC converters

In power electronics, converter is used to transform the electric energy form one form to other form. It can change voltage levels, such as low voltage to high voltage and vice versa, while maintaining the same power. When a load demands a specific dc voltage or current, but the supply is at a different or uncontrolled dc value, a DcDc converter comes in handy. Low-voltage suppliers such as solar and wind are examples of low-voltage sources that convert to high-voltage. Different types of DCDC converters include the buck, boost, Buck-Boost, and cuck converters. The most contemporary types of converters in use today are isolated and non-isolated converters, which may be split into numerous groups. Isolated converters

Isolated converters are required to provide electrical isolation between input and output. The isolated converter with minimum number of switch is more advantage. Using the transformer the low power from the source end is converted into high power to the load end.

2.3.1 Fly back Converter

Nikolas P Papa-Nikolaou et al. (2004) proposed a DCM of fly-back converter, in which the duty cycle is determined by load. In CCM, it is difficult to design topology as load changes due to small duty cycle. High power factor correction can be achieved. In DCM mode, the use of a load dependent current source with auxiliary converter is the main idea. The switched capacitor technology is used to achieve a high stepup voltage-gain. High power density and good dynamic performance are achieved by the absence of inductor. But, the efficiency is degraded and the current through the power switch is increased. A high-voltage conversion gain is attain by the switching inductor technology.

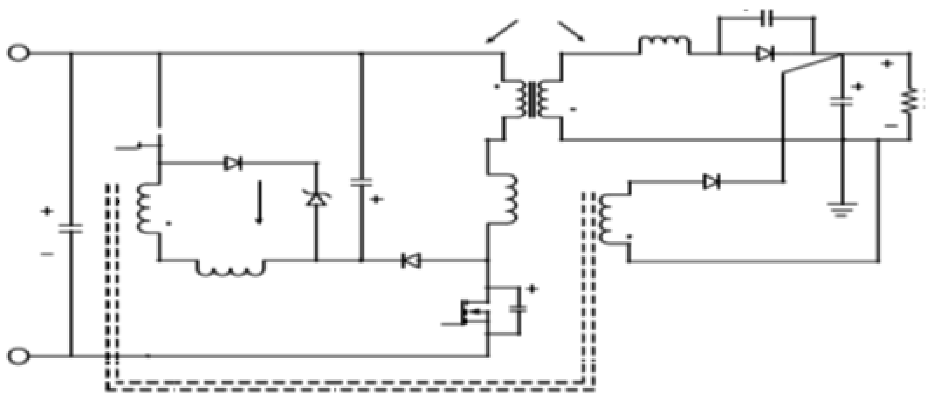

Fig2.6 fly-back converter in DC

2.3.2 Quadratic Boost Converter

Leyva J-Ramos et al. (2009) proposed quadratic boost converter, which comprises of two LC-filters which will exhibit 4th – order characteristic dynamic. The first inductor current is also used for one-cycle overload production. t has a greater noise immunity and a quicker transient response. The voltage stepup requirement is satisfied by the boost converter and fly-back converter. But in high step-up situation, a high_stepup conversion with greater efficiency can be obtained by the conventional converter due to the leakage inductance. Huge conduction-losses, diode reverse-recovery issue are caused due to the extreme duty cycle. The high turn's ratio causes a huge leakage inductance and copper losses in the winding at the same time.

2.3.3 Resonant Converter

Jaun A Martin Ramos et al. (2008) presented a high voltage power converter to reduce transformer turns ratio. High voltage transformer is also proposed. The mathematical model of the converter is also presented. The current spikes and voltage are caused and loss and noise that degrades the system achievements are increased due to the inductance and capacitance, which are create by the secondary winding of transformer, hereby, circuit components are damaged. A high voltage and high power design model is developed to test the performance.

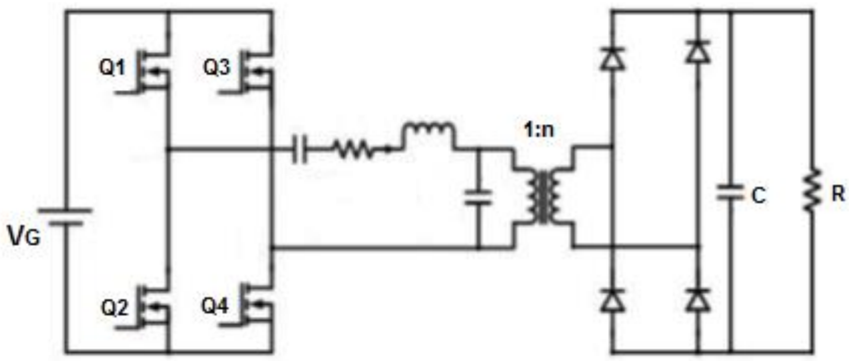

Fig2.7 PRC-LCC Resonant Topology-with a Capacitor Output-Filters

2.4 Non-isolated converters

Non-Isolated converters are required to provide electrical isolation between input and output. The non-isolated converter with minimum number of switches reduced voltage stresses and low cost is more advantage. A simplified single switch Non-Isolated DCDC Boost converter topology is proposed for DCDC conversion.

2.4.1 Cascade boost converter

Garth et al. (1971) proposed a converter for space applications. This is not suggested for high current application, because only two semiconductor devices process the output power and the resistance of the filter inductor becomes appreciable in the size of the Electromagnetic Interference (EMI) filter and energy storage inductor size can be reduced.

2.4.2 Cuck Converter

Xiaogang F et al. (2002) presented the conventional three level boost converters which are not sufficient for very high voltage gain. In this converter low current ripple and wide conversion ratio cannot be obtained, if two or more convention boost converter is cascade converter. In the cuck converter the important drawbacks are reduced efficiency and large number of components. The voltage-stress-across the boost diode and the main switch is equivalent to the output voltage in applications where the output voltage is large, resulting in the usage of many active switches and low-efficiency.

2.4.3 Switched Capacitor Boost Converter:

Ismail et al. (2008) presented switched capacitor boost converter topology, which requires various components like two inductors per cell. The major benefit is that the output voltage is larger at low duty cycle levels, resulting in less voltage stress across semiconductor components. The usage of two inductors per cell results in increase heaviness and size can cause to poor efficiency (Ismail et al. 2008).

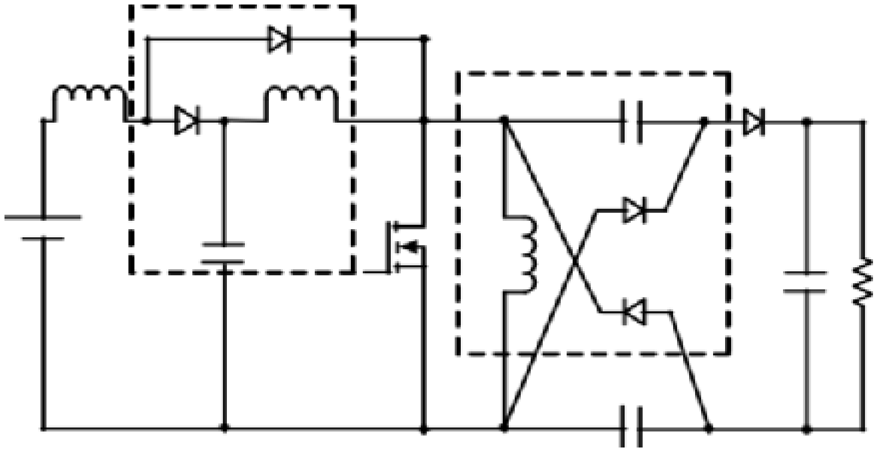

Fig2.8 Switched Capacitor Boost Converter

Chapter Three

3 CONVENTIONAL CIRCUITS

3.1 AC-DC Converter

An ac-dc converter converts an ac input to a dc output. Average-power is transferred to a dc load by an ac-supply. The term "rectifier" refers to a device that transforms alternating-electricity into direct current.

3.1.1 Introduction

With a defined dc component, a full-wave-rectifier is used to generate entirely dc-voltages or currents. While the motive of a full-wave rectifier is alike to that of a half-wave rectifier, full-wave rectifiers offer a few benefits over half-wave rectifiers. The average current in the ac source is zero in a full-wave rectifier. Which eliminates issues related with non-zero average source currents, such as those observed in transformers. Output has low ripple in a full-wave rectifier's than a half-wave rectifier's.

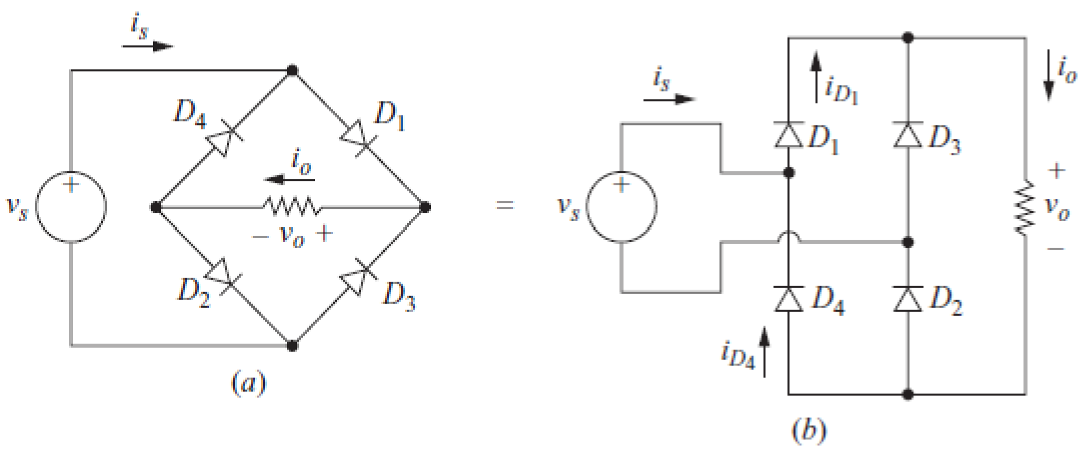

Fig3.1 Conventional AC-DC Rectifier

3.1.2 Principle of Operation

In a full bridge rectifier, diode1,2 operate together, whereas diode3,4 operate together. The Kirchhoff-voltage law in the close loop with the source, diode1,3 loop shows that diode1,3 are unable to be switched on at the same time. Diode2,4 unable to operate at the same time the current is a load can be zero and positive but never be negative. When diode1,2 are turned on, the voltage drop across the load is +ve . When the diode3,4 turned on, the voltage drop across the load is -ve. The greatest voltage across a reverse-biased diode is the source's peak value. This is demonstrated by Kirchhoff's voltage law. The fundamental frequency of the output voltage is 2f, because two periods of the output occur for every period of the input.

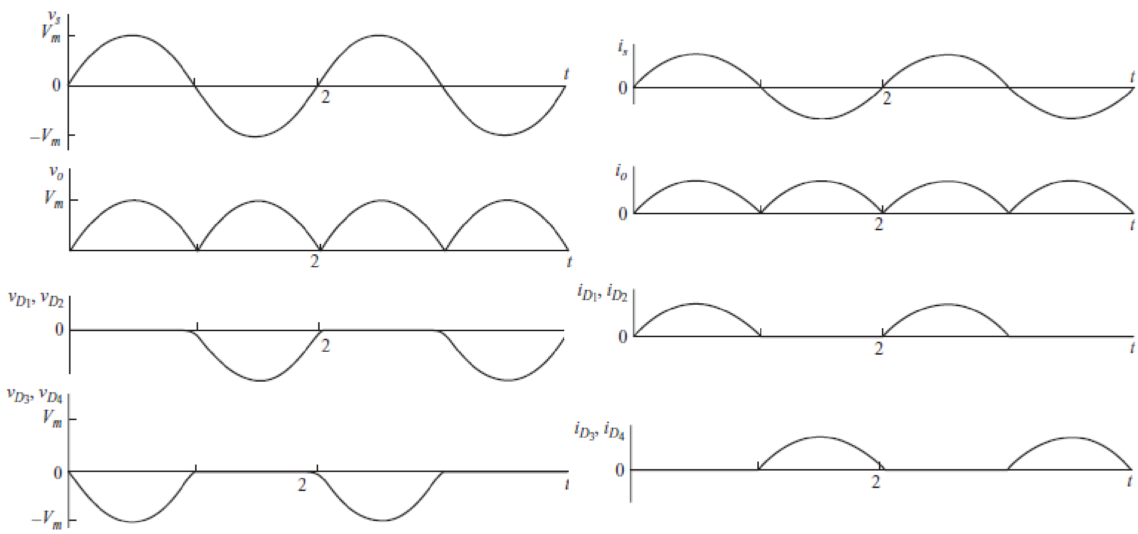

Fig3.2 input and output wave forms (voltage and currents)

3.1.3 Converter Voltages and Currents

For the bridge rectifier voltage across a resistive load is given by:

$$v_o(\omega t) = \begin{cases} V_m \sin \omega t & \text{for } 0 \leq \omega t \leq \pi \\ -V_m \sin \omega t & \text{for } \pi \leq \omega t \leq 2\pi \end{cases}$$

The Load current is simply the voltage of the resistor is divided by resistance.

$$Vo = \frac{1}{\pi}\int_0^\pi Vm.\sin\ \omega t.d(\omega t) = \frac{2Vm}{\pi}$$

$$Io = \frac{Vo}{R} = \frac{2Vm}{\pi R}$$

The absorbed power can be calculated from $I^2 rms.R$.

$$Irms = \frac{\text{Im}}{\sqrt{2}}$$

3.2 DC-AC Converter

Full-Bridge DCAC converter is basically a voltage-source inverter. Unlike the Half Bridge Inverter this does not require a three-wire DC input source. The output-frequency may be adjusted by adjusting the MOSFETs' turn ON and turn OFF times.

3.2.1 Introduction

The fundamental circuit for converting dc to ac is the full-bridge converter. By closing and opening switches in a certain order, a full-bridge inverter produces an ac output from a dc input.

3.2.2 Principal of operations

The full-bridge converter's simplest switching method provides a square-wave output-voltage. When S1iand S2 are closed, the load is connected to +Vdc, and when S3iand S4 are closed, the load is connected to -Vdc. Square wave output can be obtain by the periodic-switching of the load voltage in between +Vdc and -Vdc. Although this polarity changing output a non-sinusoidal, for some applications, it may be a suitable ac waveform. The load's current is determined by the load components. The current waveform for a resistive load is identical to the output-voltage waveform. Because of the inductor's filtering feature, an inductive load's current will have a more sinusoidal nature than the voltage. Assume that switches S1 and S2 close at t = 0 for an RL load with a square-wave output voltage.

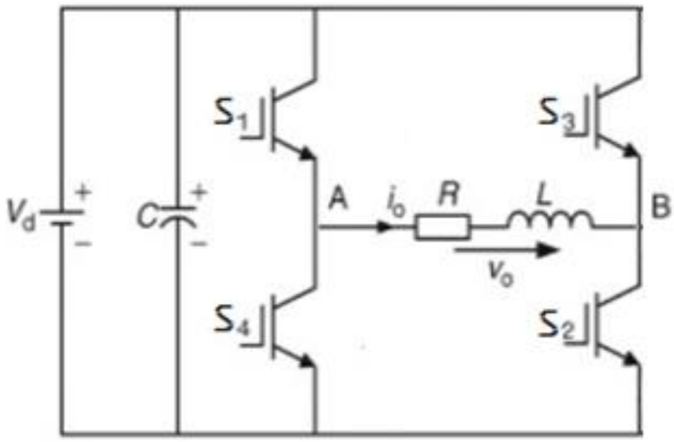

Fig3.3 Full-Bridge DC-AC Inverter

$$i_o(t) = i_f(t) + i_n(t)$$

$$= \frac{V_{dc}}{R} + Ae^{-t/\tau} \qquad \text{for} \qquad 0 \le t \le \frac{T}{2} \tag{3.21}$$

Constant A calculated by using the condition i=0 value of τ = L/R. At t = T/2, S1 and S2 off, and S3 and S4 on. The voltage at the Resistive-inductive load drops to -Vdc, and the current takes on the shape.

$$i_o(t) = \frac{-V_{dc}}{R} + Be^{-(t-T/2)/\tau} \qquad \text{for} \qquad \frac{T}{2} \le t \le T \tag{3.22}$$

From the initial condition, the constant "B" is calculated. Before a steady-state achieves by the current, a transient occurs when circuit is activated and the initial current in an inductor is zero.

$$i_o(0) = \frac{V_{dc}}{R} + Ae^0 = I_{min}$$

$$A = I_{min} - \frac{V_{dc}}{R}$$

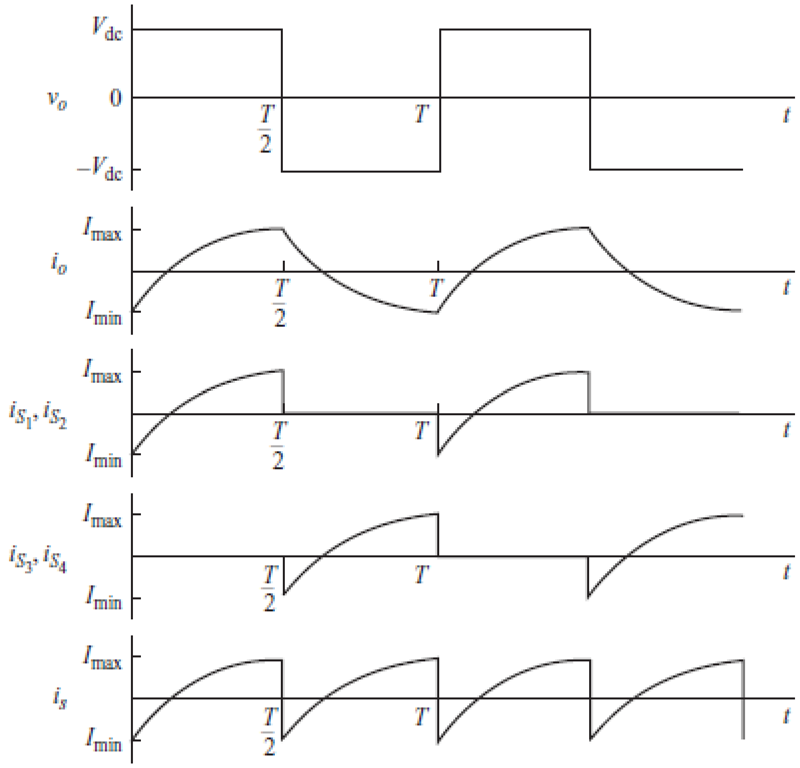

Fig3.4 Voltage and current waveforms for RL load.

Eq. (3.22) is judge at t = T / 2.

$$i_o(T/2) = \frac{-V_{dc}}{R} + Be^0 = I_{max}$$

$$B = I_{max} + \frac{V_{dc}}{R}$$

In steady-state, the current wave-forms expressed by Eqs. (3.21) and (3.22) becomes

$$i_o(t) = \begin{cases} \frac{V_{dc}}{R} + \left(I_{min} - \frac{V_{dc}}{R}\right)e^{-t/\tau} & \text{for } 0 < t < \frac{T}{2} \\ \frac{-V_{dc}}{R} + \left(I_{max} + \frac{V_{dc}}{R}\right) - e^{(t-T/2)/\tau} & \text{for } \frac{T}{2} < t < T \end{cases} \quad (3.23)$$

An equation is obtained for Imax by calculating the first part of Eq. (3.23) at-t=T / 2

$$i(T/2) = I_{max} = \frac{V_{dc}}{R} + \left(I_{min} - \frac{V_{dc}}{R}\right)e^{-(T/2\tau)} \quad (3.24)$$

By the symmetry,

$$I_{\min} = -I_{\max}$$

Substituting –Imax for Imin Eq. (3.24) and solving-for Imax,

$$I_{\max} = -I_{\min} = \frac{V_{dc}}{R}\left(\frac{1-e^{-T/2\tau}}{1+e^{-T/2\tau}}\right) \qquad (3.25)$$

Because the square of each of the current half-cycle is similar, just the first half-cycle

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T i^2(t)\,d(t)} = \sqrt{\frac{2}{T}\int_0^{T/2}\left[\frac{V_{dc}}{R} + \left(I_{\min} - \frac{V_{dc}}{R}\right)e^{-t/\tau}\right]^2 dt} \qquad (3.26)$$

3.3 DC-DC Boost Converter

3.3.1 Introduction

The converter which has greater output DC-voltage then the input is known as boost-converter. This circuit "boosts" the source voltage to a higher regulated value, allowing a single power supply to provide several driving voltages. The output voltage of a boost circuit can range from the power supply voltage to many times that of the power supply voltage. To produce a steady input current, the inductor L is utilized. A MOSFET can be used as a solid-state switch in PWM mode.

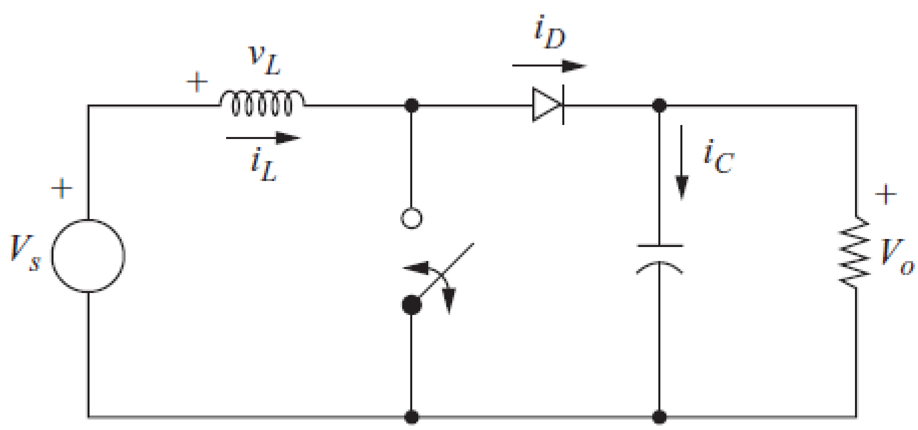

Fig3.5 Boost Converter Circuit

3.3.2 Principal of Operations

The inductor is linked to the power source when switch S is switched on. The voltage across VL rises to the power supply voltage Vi very quickly, while the current through the inductors starts increasing linearly and inductor preserve this energy in the form of magnetic field. The current falls when the switch is switched off, and the energy preserved in the inductor is transferred to the capacitor using the diodeD. To boost the output voltage, the induced voltage VL across the inductor is reversed, and the inductor voltage is added to the power supply voltage. The current that was flowing via S is now going to the load through L, D, and C. As a result, the inductor's preserved energy is deliver to the load.

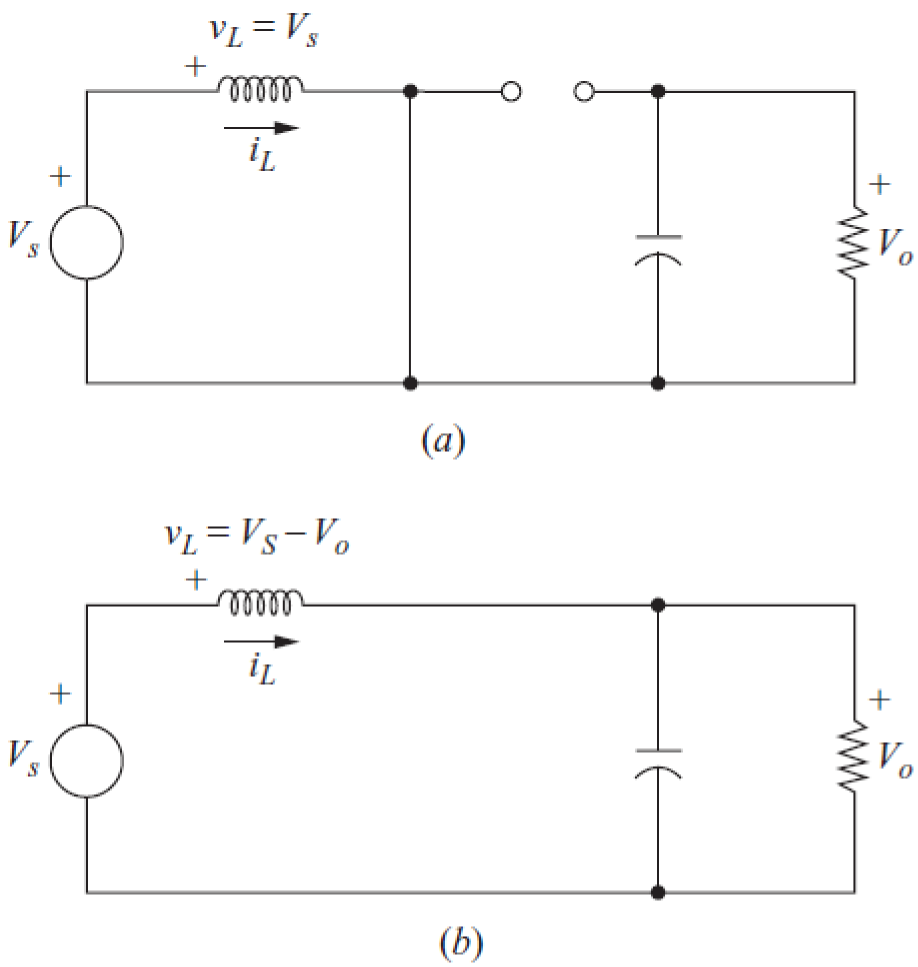

Fig3.6 (a) circuit for the closed switching-interval (b) circuit for-the open-switching interval

Analysis for closed switch

By Kirchhoff's voltage law path comprising the source, inductor, and button as follows:

$$VL = Vs = L\frac{diL}{dt} \quad \text{Or} \quad \frac{diL}{dt} = \frac{Vs}{L} \tag{3.31}$$

Change in inductor-current is determined by the bellow equation:

$$\frac{\Delta iL}{\Delta t} = \frac{\Delta iL}{DT} = \frac{Vs}{L}$$

$$(\Delta iL)closed = \frac{VsDT}{L} \tag{3.32}$$

Analysis for Switch-Open

The voltage drop across the inductor is: (3.33) if the output Vo is constant.

$$VL = Vs - Vo = L\frac{diL}{dt} \tag{3.33}$$

$$\frac{diL}{dt} = \frac{Vs - Vo}{L}$$

Change in current is determined by bellow equation:

$$\frac{\Delta iL}{\Delta t} = \frac{\Delta iL}{(1-D)T} = \frac{Vs - Vo}{L}$$

$$(\Delta iL)open = \frac{(Vs - Vo)(1-D)T}{L} \tag{3.34}$$

3.3.3 Converter Voltages and Currents

The net change-in current of inductor for steady-state-operation, must be zero. Using Eqs. (3.32) and (3.34),

$$(\Delta iL)open + (\Delta iL)closed = 0$$

$$\frac{VsDT}{L} + \frac{(Vs - Vo)(1-D)T}{L} = 0$$

$$Vo = \frac{Vs}{1-D} \tag{3.35}$$

$$Po = \frac{Vo^2}{R} = VoIo \qquad \therefore Vs \cdot Is = Vs \cdot IL \tag{3.36}$$

$$IL = \frac{Vs}{(1-D)^2 R} = \frac{Vo^2}{Vs \cdot R} = \frac{Vo \cdot Io}{Vs} \tag{3.37}$$

3.3.4 Expression of Inductances L

During the closed switch first interval the current in the inductor increases linearly and at the time of open switch 2nd interval inductor current starts decreases linearly as shown below:

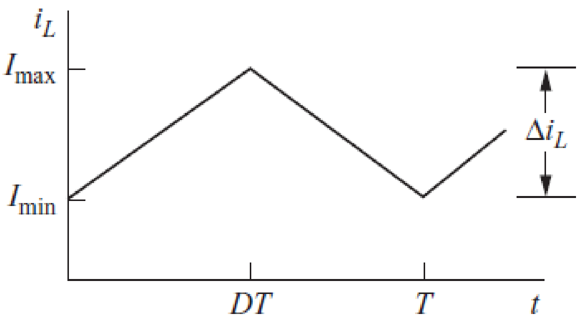

Fig3.7 Inductor Current Waveform

Inductor current slope in closed switch interval $0 \le t \le DTs$, is:

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

Changing in inductor current during $0 \le t \le DTs$

$$\frac{\Delta iL}{\Delta t} = \frac{\Delta iL}{DT} = \frac{Vs}{L} \tag{3.31}$$

$$\Delta iL = \frac{VsDT}{L}$$

$$L = \frac{VsDT}{\Delta iL} \tag{3.38}$$

Bu putting T=1/F the equation (3.39) becomes:

$$L = \frac{VsD}{\Delta iL \cdot f}$$

3.3.5 Output Capacitor Capacitance

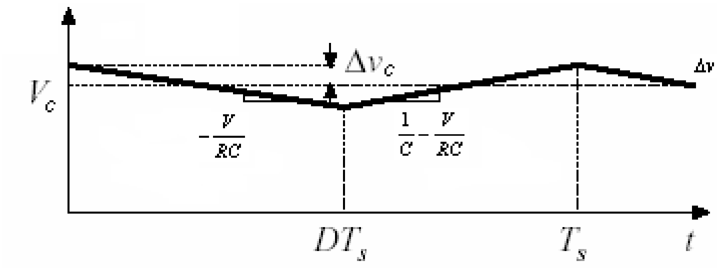

Fig3.8 Capacitor Voltage Waveform

Capacitor voltage slope in closed switch interval $0 \le t \le DTs$, is:

$$\frac{dv}{dt} = \frac{Vo}{RC} \tag{A}$$

Changing in capacitor voltage during $0 \le t \le DTs$

$$\Delta vo = \frac{Vo}{RC} DTs \tag{B}$$

$$\frac{\Delta vo}{Vo} = \frac{DT}{RC}$$ By re-arranging Eq. (B)

$$C = \frac{Vo \cdot DT}{R \cdot \Delta vo} \tag{3.39}$$

Bu putting T=1/F the equation (3.39) becomes:

$$C = \frac{Vo \cdot D}{R \cdot \Delta vo \cdot f}$$

3.4 DC-DC Buck Converter

3.4.1 Introduction

Buck-converters are DcDc power converters with a lower output than the input. This circuit allows a single power supply to generate several driving voltages by "bucking" the source voltage to a higher controlled voltage. The output voltage of a buck circuit might differ from the power source voltage. The solid-state switch that operates in PWM mode can be a MOSFET.

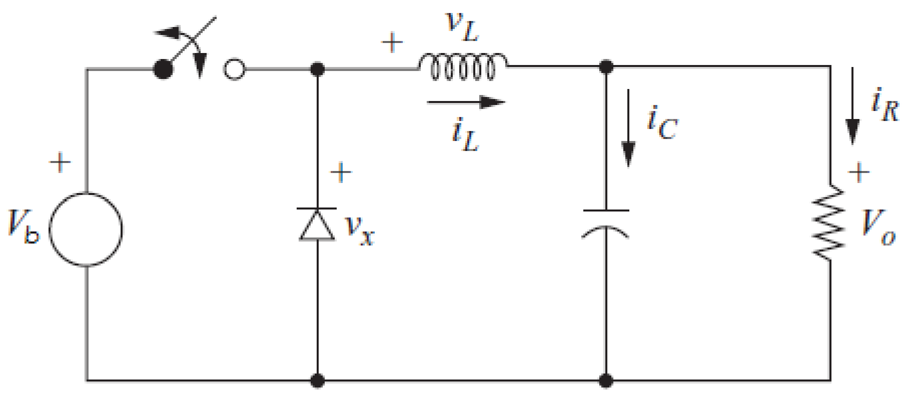

Fig3.9 Buck Converter Circuit

3.4.2 Principal of Operations

The inductor is linked to the power source Vb when the switch S is switched on. Current flows to capacitor at that moment, charging it up. The voltage-across the capacitor is not the full voltage of the source Vb because the voltage across the capacitor cannot rise rapidly and the charging current is limited by the inductor. As a result, diode D is reverse biased. When the switch S is disabled. Because an inductor's current cannot change instantly, it produces a voltage VL across it. Because the diode D is now forward-biased when button is switched off, this voltage is permitted to charge the capacitor C and power the load through the diode D, output current throughout the switching cycle. These two stages keep repeating, giving in a constant output Vo.

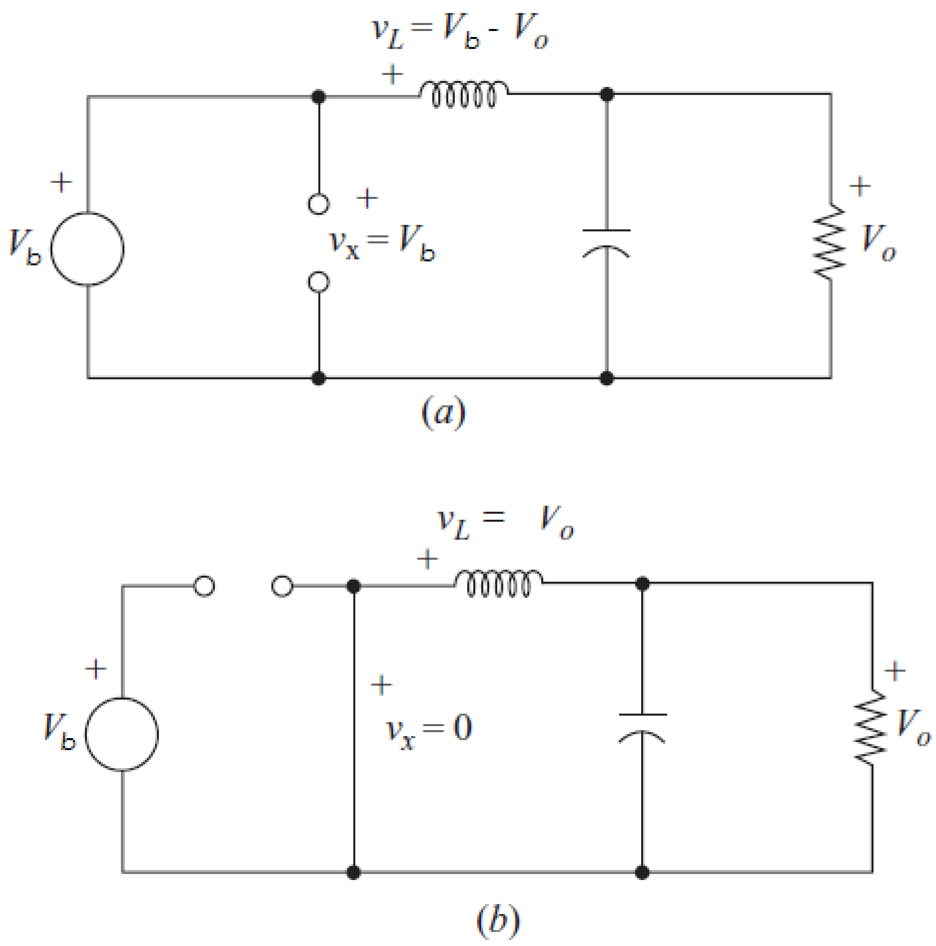

Fig3.10 (a) circuit for the closed switching-interval (b) circuit for the open switching interval

Analysis of the closed-switch

By Kirchhoff's voltage law path comprising the source, inductor, and button as follows:

$$VL = Vb - Vo = L\frac{diL}{dt} \quad \text{or} \quad \frac{diL}{dt} = \frac{Vb - Vo}{L} \tag{3.41}$$

Change in an inductor-current is determined by following equation:

$$\frac{\Delta iL}{\Delta t} = \frac{\Delta iL}{DT} = \frac{Vb - Vo}{L}$$

$$(\Delta iL)closed = \left(\frac{Vb - Vo}{L}\right)DT \tag{3.42}$$

Analysis of the Open-Switch

The voltage drop across the inductor is: (3.43) if the output Vo is constant

$$VL = -Vo = L\frac{diL}{dt} \quad \text{Or} \quad \frac{diL}{dt} = \frac{-Vo}{L} \tag{3.43}$$

Change in an inductor-current is determined by following equation:

$$\frac{\Delta iL}{\Delta t} = \frac{\Delta iL}{(1-D)T} = \frac{-Vo}{L}$$

$$(\Delta iL)open = -\left(\frac{Vo}{L}\right)(1-D)T \tag{3.44}$$

3.4.3 Converter Voltages and Currents

The net change-in current of inductor for steady-state-operation, must be zero. Using Eqs. (3.42) and (3.44),

$$(\Delta iL)open + (\Delta iL)closed = 0$$

$$\left(\frac{Vb - Vo}{L}\right)DT - \left(\frac{Vo}{L}\right)(1-D)T = 0$$

$$Vo = Vb \cdot D \tag{3.45}$$

The average inductor current must be the same as the average current in the load resistor.

$$IL = IR = \frac{Vo}{R} \tag{3.46}$$

3.4.4 Expression of Inductances L

During the closed switch first interval the current in the inductor increases linearly and at the time of open switch 2nd interval inductor current starts decreases linearly as shown below:

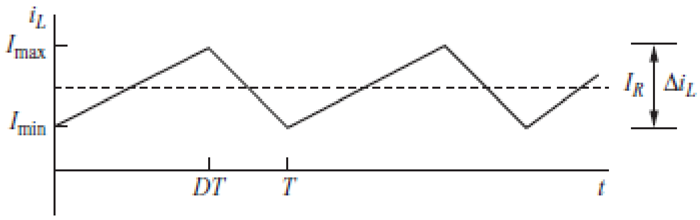

Fig3.11 Inductor Current Wave-form

Inductor current slope in closed switch interval $0 \le t \le DTs$, is:

$$\frac{diL}{dt} = \frac{Vb - Vo}{L} \tag{3.41}$$

Changing in inductor current during $0 \le t \le DTs$

$$\frac{\Delta iL}{\Delta t} = \frac{\Delta iL}{DT} = \frac{Vb - Vo}{L}$$

$$\Delta iL = \left(\frac{Vb - Vo}{L}\right)DT \tag{3.42}$$

$$L = \left(\frac{Vb - Vo}{\Delta iL}\right)DT$$

Bu putting T=1/F the above equation becomes:

$$L = \left(\frac{Vb - Vo}{\Delta iL \cdot f}\right)D \tag{3.47}$$

By rearranging the above equation we end up with inductor formula:

$$L = \frac{Vo(1 - D)}{\Delta iL \cdot f}$$

3.4.5 Output Capacitor Capacitance C

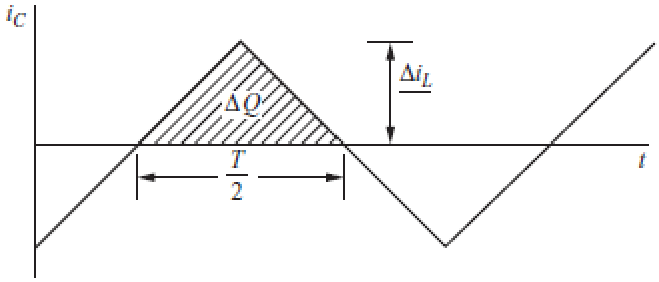

Fig3.12 Capacitor Current Wave-form

Figure show the

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

$$\Delta Q = \frac{1}{2}\left(\frac{T}{2}\right)\left(\frac{\Delta iL}{2}\right) = \frac{T \cdot \Delta iL}{8} \tag{3.48}$$

$$\Delta Vo = \frac{T \cdot \Delta iL}{8C}$$

By putting the value of ΔiL in the above equation we end-up with

$$\Delta Vo = \frac{Vo(1-D)}{8LCf^2} \tag{3.49}$$

An expression forripple voltage is:

$$\frac{\Delta vo}{Vo} = \frac{1-D}{8LCf^2} \tag{3.50}$$

$$C = \frac{1-D}{8L(\Delta Vo/Vo)f^2} \tag{3.51}$$

Chapter Four

4 PROPOSED BIDIRECTIONAL AC-DC CONVERTER

4.1 Introduction

The energy storing system improves the performance (efficiency). Energy storing system(ESS) has allowed us to utilize renewable energy(RE) efficiently and reliably. The reason for the requirement for energy storing system is that it tackles the issues of power that is produced and absorbed at a similar time; it can save power and use it when it is required. It implies that when there is more supply (power) than demand, for example, during the night when low-price power plants are working, the surplus power generation can be utilized to power storage gadgets. It can store power and utilized it when it is required. To utilize the energy storage system effectively, a bi-directional_power converter is required. This gadget controls the flow of power from the ac-main to the battery and from the battery to the ac-main.

A Bidirectional AC-DC converter plays an important role in applications like uninterrupted power supplies (UPS), electric vehicles (EV), energy storage systems (ESS), and micro-grids. A bidirectional AC-DC convertor consists of two parts which are bidirectional ACDC converter and a bi-directional buck-boost DcDc converter. The whole is split into two operation modes one is charging mode and the second one is discharging mode.

The proposed bidirectional DCDC converter is a non-inverting, non-isolated converter. The boost type and buck type DcDc converters are commonly used in transformer-less non-isolated power conversion systems. The use of a high-frequency-transformer-based technology to provide isolation between the source and load sides is appealing. However, the transformer-less topologies are far more appealing in terms of increasing overall performance (efficiency), size, weight, and cost.

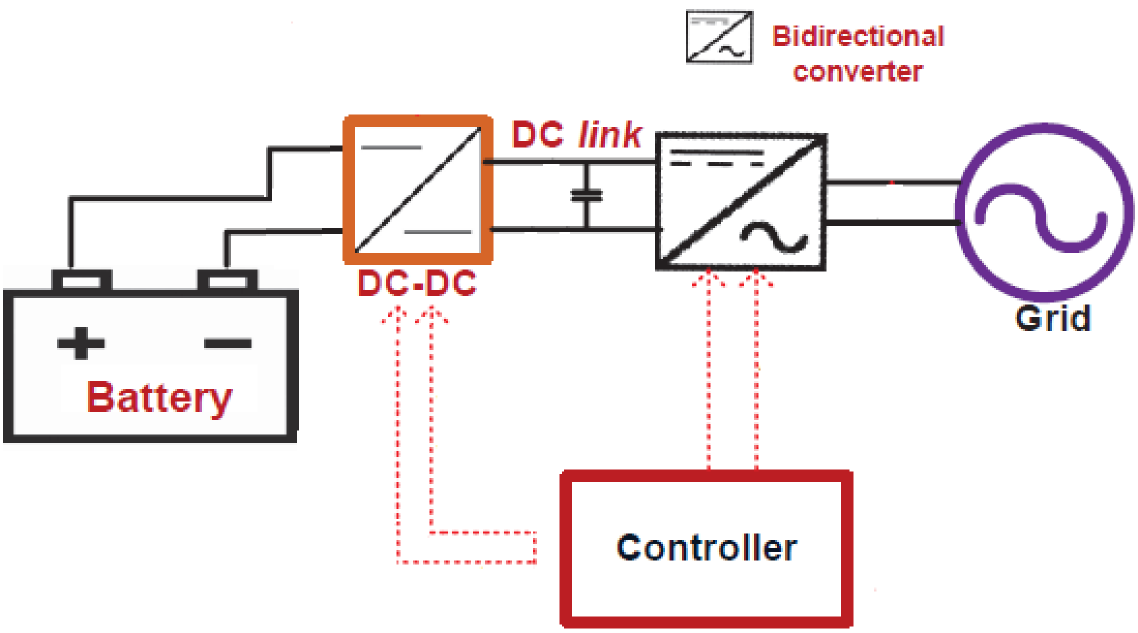

Fig4.1 Block diagram of Bidirectional-AC-DC-converter

4.2 System Model

This project proposes a bi-directional converter with a non-isolated and non-inverting buck-boost DCDC converter. The entire mechanism is seen in Figure 4.2.

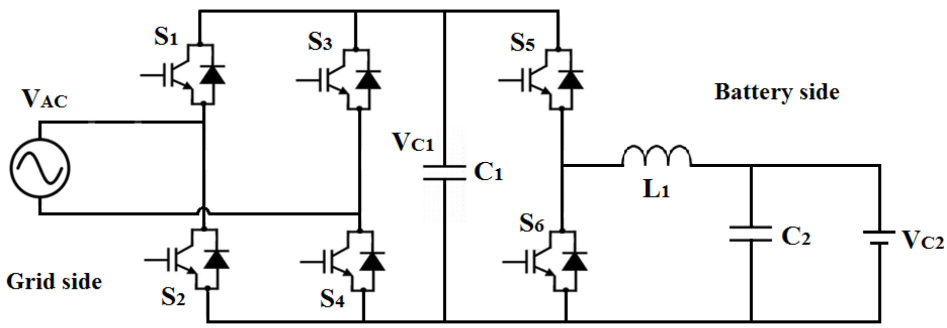

Fig4.2 The circuit diagram of a Bi-directional AC_DC converter.

For a simple and low-cost design, the suggested converter adopts a transformer-less topology. A transformer-less architecture enhances efficiency, decreases gross weight, and simplifies control when compared to traditional systems with a transformer on the AC grid side. The integration of an Energy Storage System with a household electric system is proposed in this research using a bidirectional ACDC converter and a buck-boost type bidirectional DCDC converter. The converter's mathematical model will be expressed as a charging and discharging mode. Each mode will be separated into two parts: AcDc and DcDc.

The AC-DC component will function as a diode-bridge rectifier when the reverse diodes of bidirectional switches are used in the charging mode (MOSFET). The DC-DC portion is a buck type step-down voltage converter in charging mode. In discharging mode, the DC-AC component will act as an inverter and will be controlled via pulse width modulation (PWM). In discharging mode, the DC-DC section O is employed..

4.3 Operating-Modes of-Proposed System

The suggested converter's operational principle, which uses two ways of charging and discharging, is discussed

4.3.1 Operating Mode 1

Assume mode 1 is the charging mode, in which electrical energy is transferred from the AC grid to the battery. Bidirectional AC-DC converters are arranged as diode bridge rectifiers in this mode, while bidirectional DC-DC converters are buck type step-down voltage converters.

Rectifier Model in Charging Mode

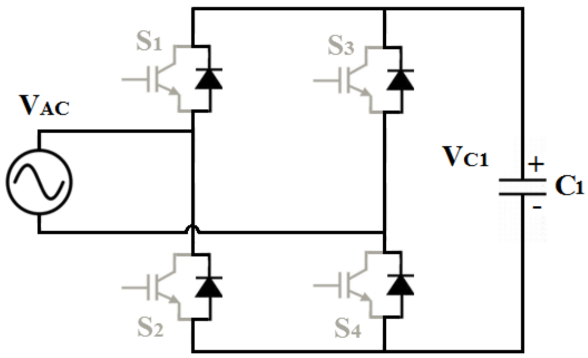

Fig4.3 circuit diagram of diode bridge rectifier.

Figure 4.3 shows how the bidirectional AC-DC converter acts as a bridge-diode for rectifier employing the bidirectional AC-DC converter's reverse diode (MOSFETs).

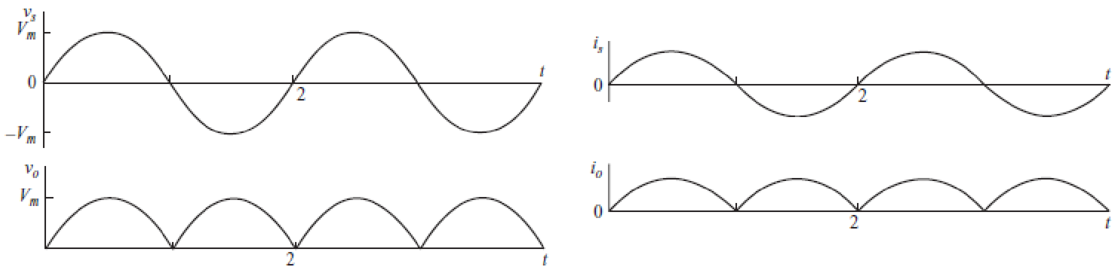

Fig4.4 Input and output waveform of diode bridge rectifier

Buck Model in Charging Mode

The buck structure has three states based on the continuous current of the inductor: continuous, discontinuous, and critical. In a bi_directional DcDc system, the current in an inductor remains constant. When employed in step-down mode, the electrical component is considered an ideal device. Two states of the circuit are evaluated in a single PWM cycle. Switch S5 is active in buck mode, however switchiS6 is always off. The operation of buck mode is shown in Figure 4.5.

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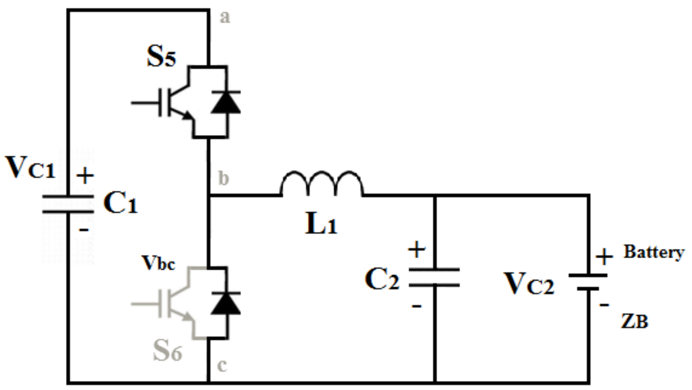


Fig4.5 (a) equivalent circuit of buck mode

In the **first mode of operation**, when S5 is switch on and S6 is switch off, the inductor is connected to the power supply Vc1. The inductor current gradually increases, but the voltage of the electric capacitor remains constant. During the switching cycle, the voltage across the capacitor is not the entire value of the power source Vc1. And the anti-parallel diode with S6 becomes reverse biased.

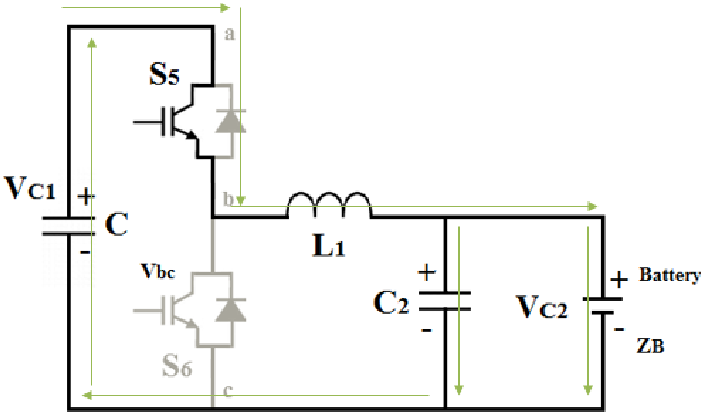


Fig4.5 (b) shows S5 on, S6 off

$$\frac{\Delta iL}{\Delta t} = \frac{\Delta iL}{DT} = \frac{Vc1 - Vc2}{L} \tag{4.1}$$

$$(\Delta iL)closed = \left(\frac{Vc1 - Vc2}{L}\right)DT \tag{4.2}$$

In the **second mode of operation**, when the switch S5 is turned off. Current change instantly because to its nature, therefore the inductor produces a voltage VL across it. Because the diode is now forward biased when the switch is switched off, this voltage is permitted to charge the capacitor C2 and power the load through the anti-parallel diode with S6, maintaining the current output current constant during the switching cycle.

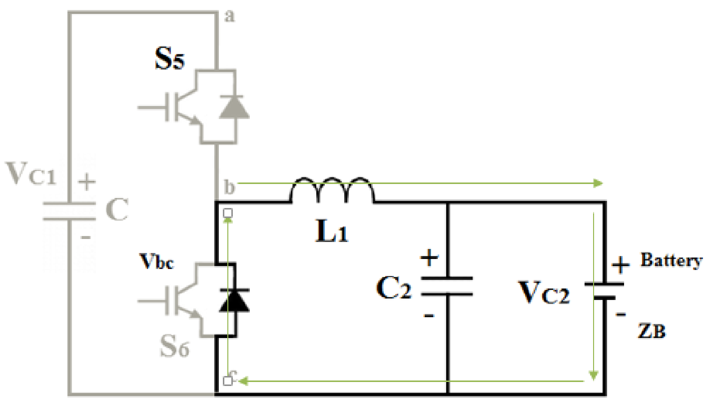


Fig4.5 (c) shows S5 off, S6 off

$$\frac{\Delta iL}{\Delta t} = \frac{\Delta iL}{(1-D)T} = \frac{-Vc2}{L} \tag{4.3}$$

$$(\Delta iL)open = -\left(\frac{Vc2}{L}\right)(1-D)T$$

(4.4)

The stored current IL happens periodically in inductance when the circuit operates in a steady-state mode.

$$(\Delta iL)open + (\Delta iL)closed = 0 \qquad (4.5)$$

$$\left(\frac{Vc1-Vc2}{L}\right)DT - \left(\frac{Vc2}{L}\right)(1-D)T = 0$$

Eq. (4.6) represents transfer function of a buck converter.

$$Vc2 = Vc1 \cdot D \qquad (4.6)$$

4.3.2 Operating mode 2

The mode 2 is the discharging mode in which electrical energy flowing from ESS to AC grid. In this mode bi-directional AC_DC will be working as an inverter and will be controlled by the pulse-width/modulation (PWM) method and bi-directionalDC_DC converter is a boost-type stepup voltage converter.

Inverter Model in Discharging Mode

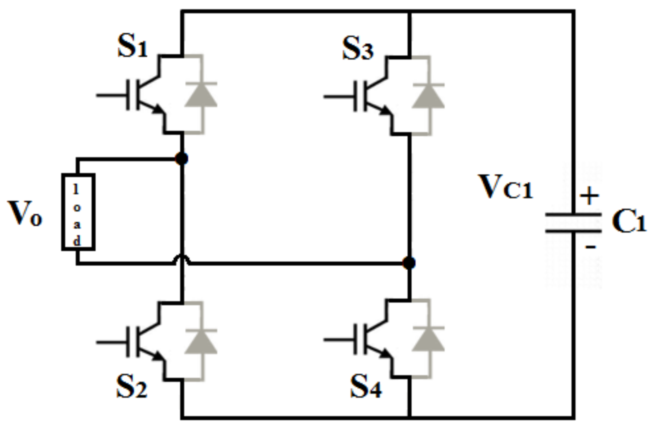


Fig4.6 circuit diagram of inverter mode.

The PWM technique will be used to control the inverter model, which comprises of four common switches. When S1 and S4 are working, the load is connected to +Vdc, and when-S2 and S3 are working, the load is connected to -Vdc. A square-wave output is produced across the-load when the load voltage is switched between +Vdc and -Vdc on a regular basis.

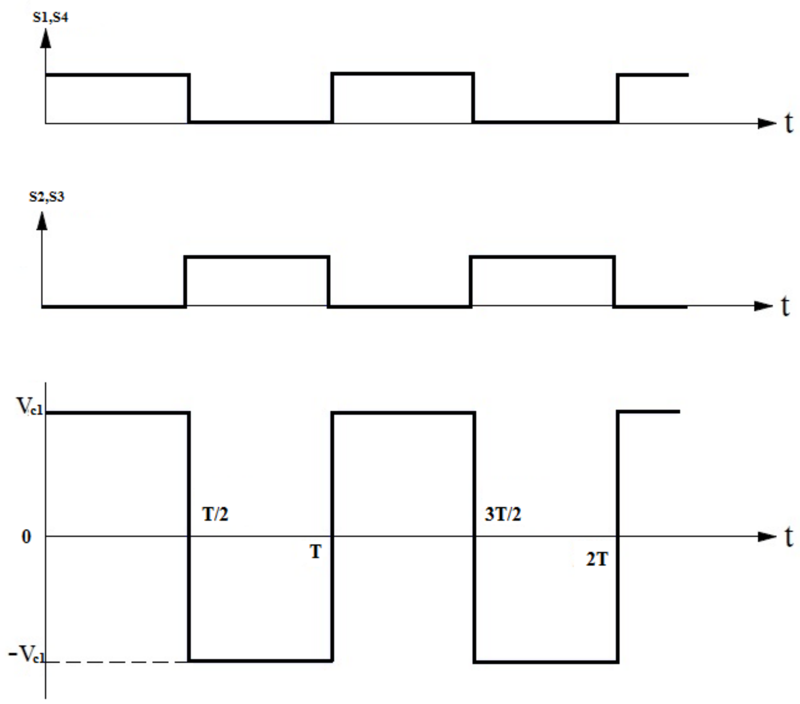


Fig4.7 Switching strategy and output relation

Boost Model in Discharging Mode

There are three states in the boost structure: continuous, discontinuous, and critical. The inductor current is constant in a bidirectional DcDc converter system. Two states-of the circuit are evaluated in a single PWM cycle. Switch S6 is active in boost mode, whereas switch S5 is always off. The operation of boost mode is depicted in Figure 4.8.

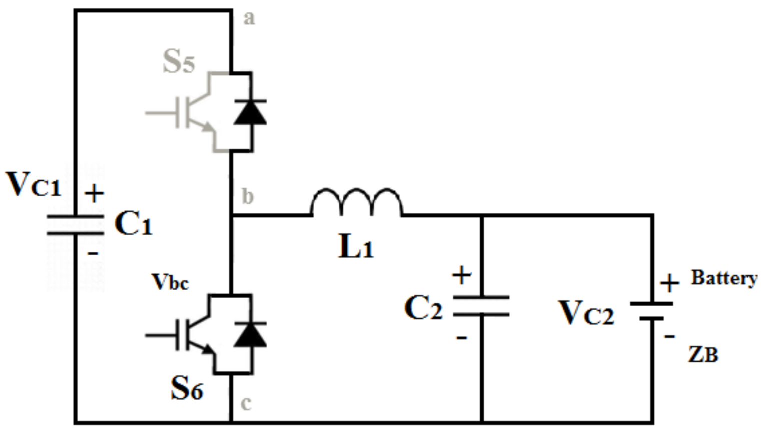


Fig4.8 (a) equivalent circuit of boost mode

The inductor is linked to the power source Vc2 in the first mode of operation, when S6 is turned on and S5 is turned off. The voltage across VL jumps to the power supply voltage Vc2 almost instantaneously, but current in inductor rises linearly and stores energy in the magnetic field. As a result, the S5 anti-parallel diode becomes reverse biased.

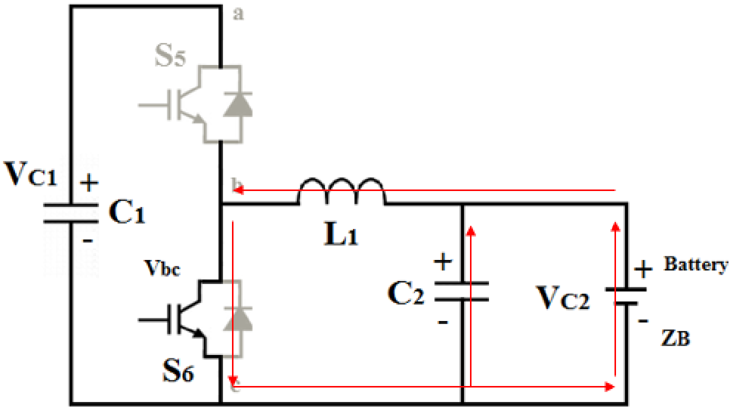


Fig4.8 (b) shows S6 on, S5 off

$$VL = Vc2 = L\frac{diL}{dt} \tag{4.8}$$

$$\frac{\Delta iL}{\Delta t} = \frac{\Delta iL}{DT} = \frac{Vc2}{L} \tag{4.9}$$

$$(\Delta iL)closed = \frac{Vc2 \cdot DT}{L} \tag{4.10}$$

In second mode of operation, when the button S6 is off. Through the anti-parallel diode of switch S5, the current fall in and the energy preserved in the inductor is transferred to the capacitor (diode forward biased). To increase the output voltage, the induced voltage VL across the inductor is reversed, and the inductor voltage is added to the power supply voltage. The diode gets reverse biased when S6 is turned on again, the capacitor C1 energy gives the load voltage, and the cycle continues.

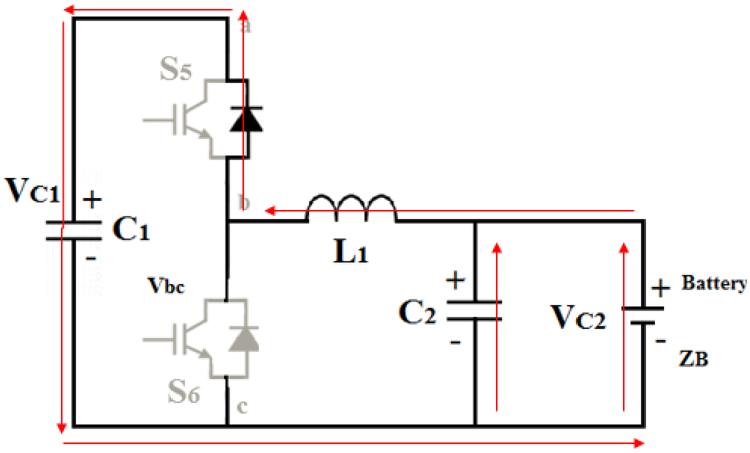


Fig4.8 (c) shows S6 off, S6 off

$$VL = Vc2 - Vc1 = L\frac{diL}{dt} \tag{4.11}$$

$$(\Delta iL)open = \frac{(Vc2 - Vc1)(1 - D)T}{L} \tag{4.12}$$

When this circuit is working in a stable-state of operation the net change in inductor current is zero.

$$(\Delta iL)open + (\Delta iL)closed = 0 \tag{4.13}$$

$$\frac{Vc2 \cdot DT}{L} + \frac{(Vc2 - Vc1)(1 - D)T}{L} = 0 \tag{4.14}$$

Eq. (4.15) represents transfer function of a boost converter.

$$Vc2 = \frac{Vc1}{1 - D} \tag{4.15}$$

4.4 Results

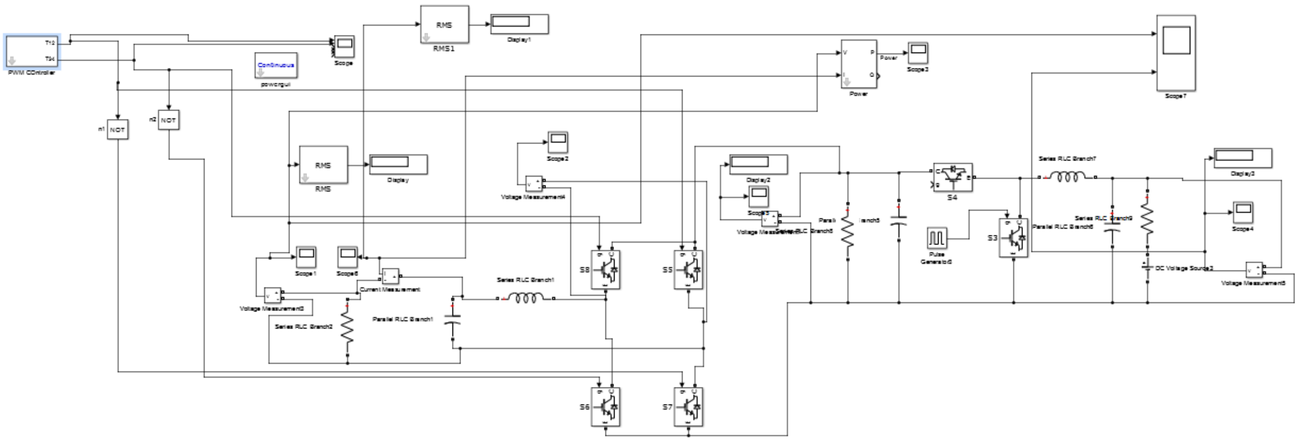


Fig4.9 Proposed bi-directional AC-DC converter with non-isolated bidirectional DC-DC-converter

4.4.1 Charging Mode

For resistive load

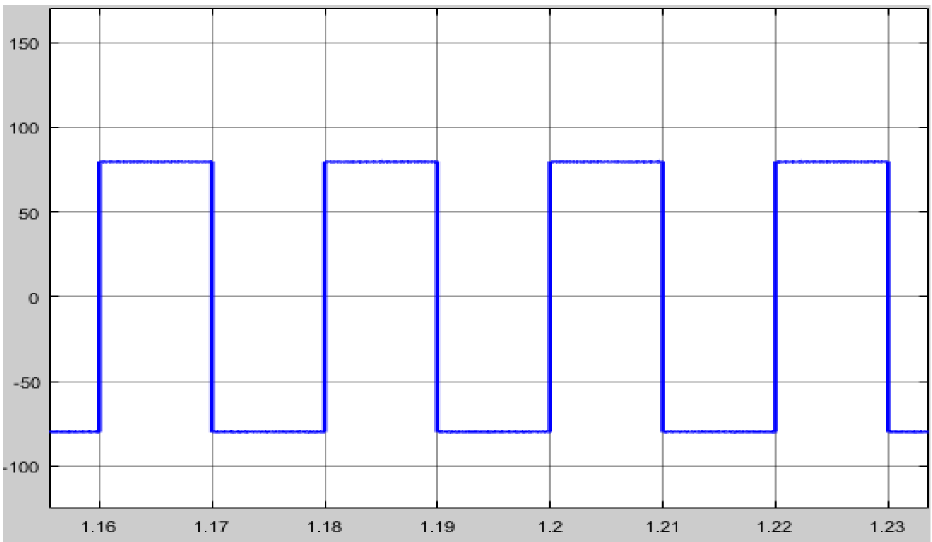


Fig4.10 voltage across the load (R=10 ohm)

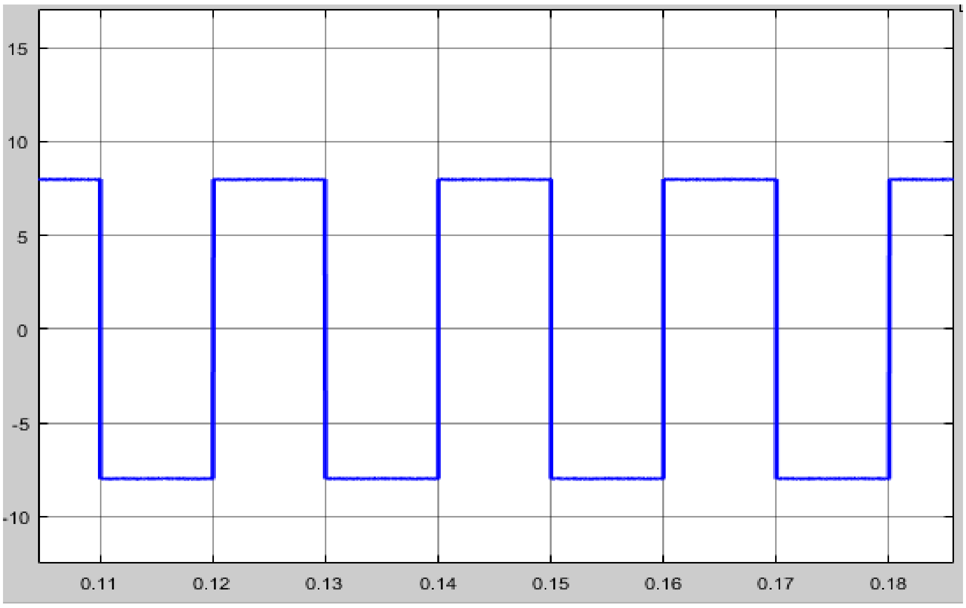


Fig4.11 Load current (R=10 ohm)

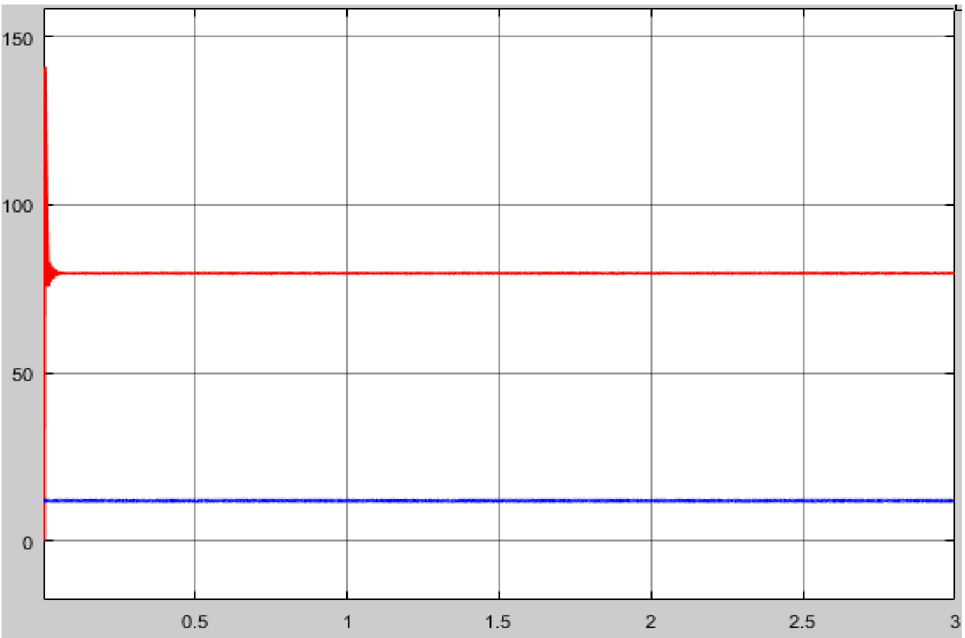


Fig4.12 Bidirectional DC-DC Converter output in discharging mode (R=10ohm)

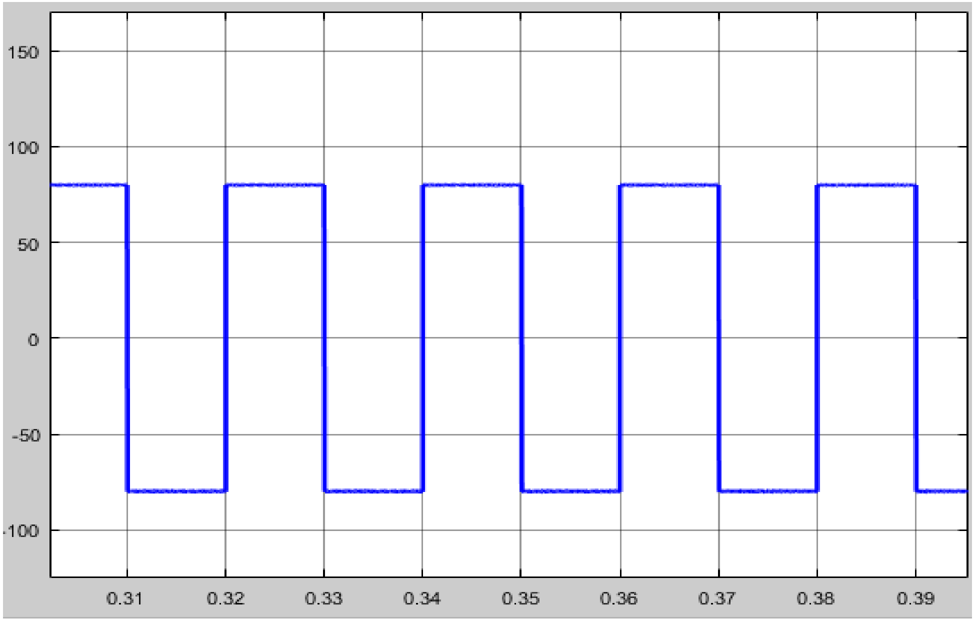


Fig4.13 voltage across the load (R=100 ohm)

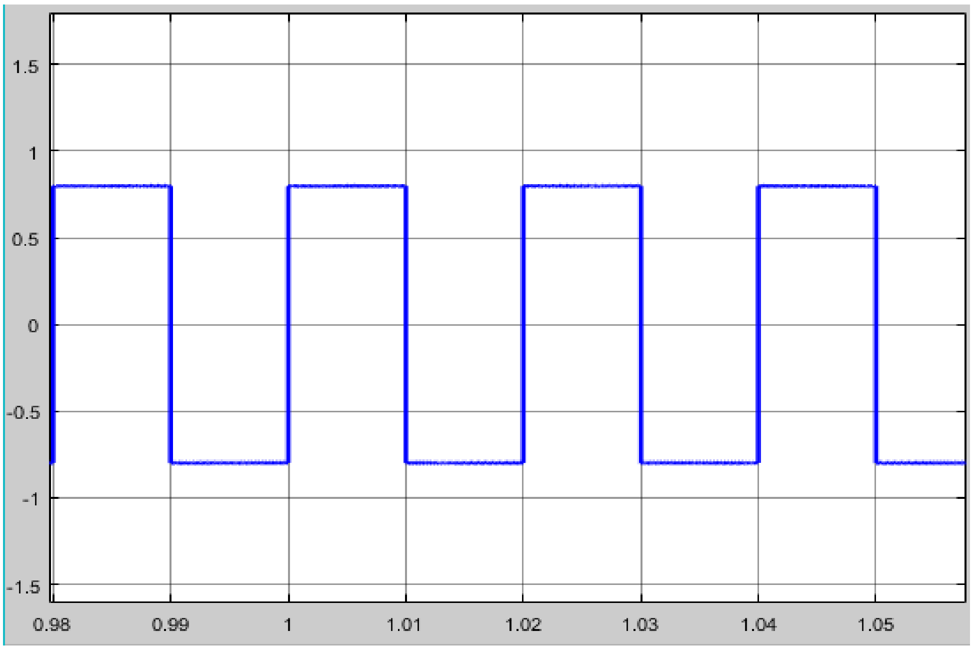


Fig4.14 Load current (R=100 ohm)

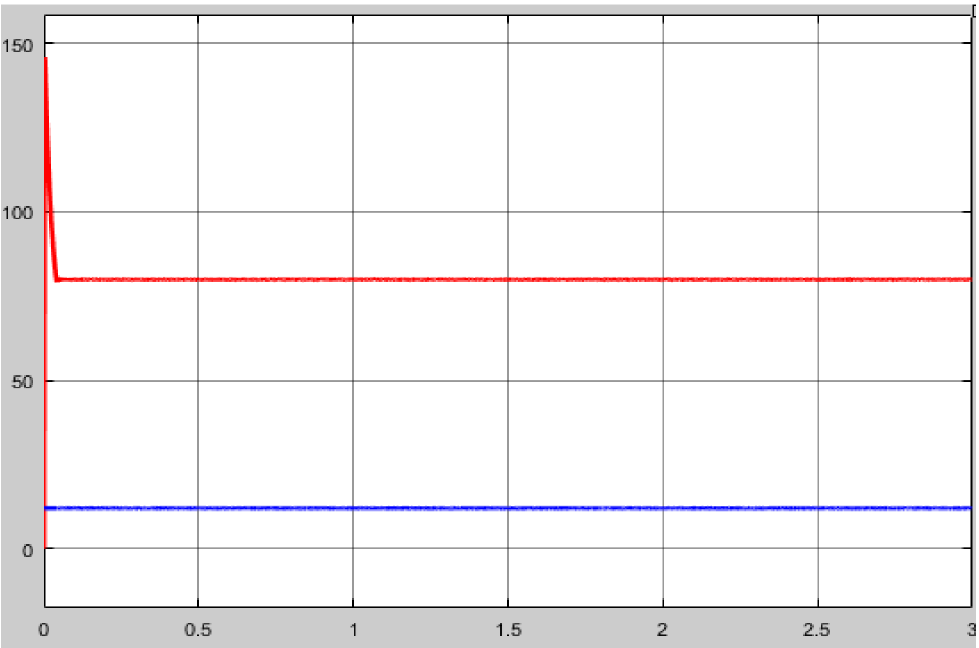


Fig4.15 Bidirectional DC-DC Converter output in discharging mode (R=100ohm)

For RL load

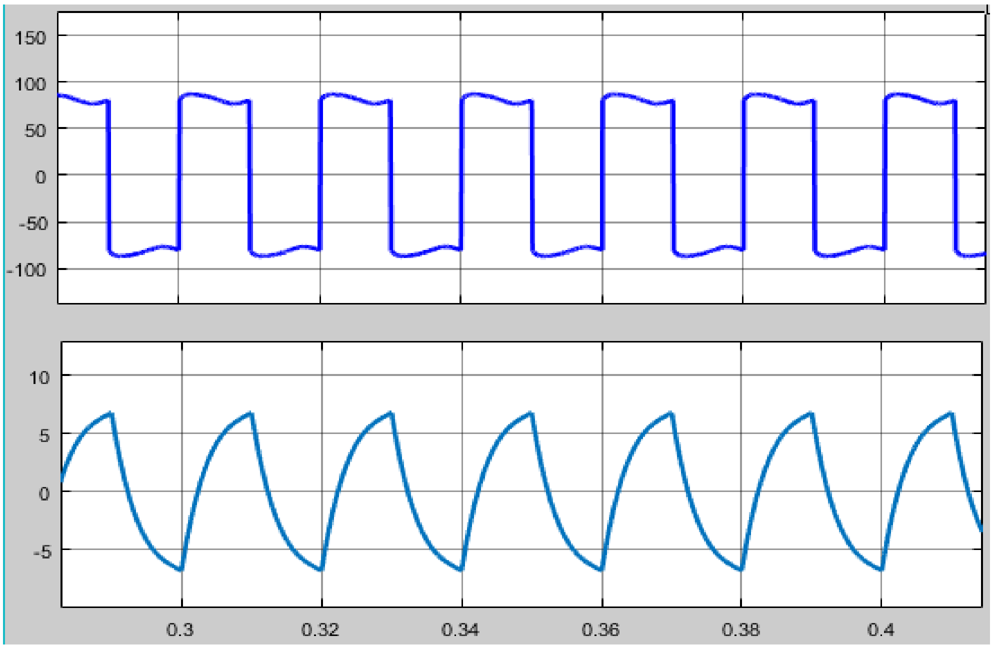


Fig4.16 Output voltage and current waveform with RL load

4.4.2 Charging mode

Red waveform shows the 12V dc output of the bidirectional ACDC converter in charging mode.

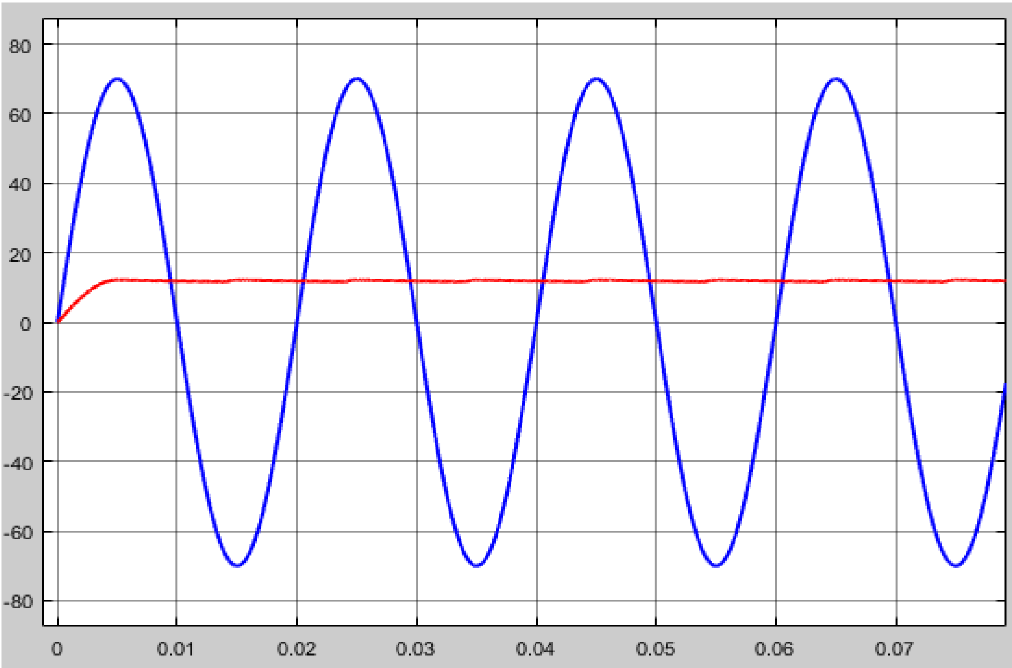
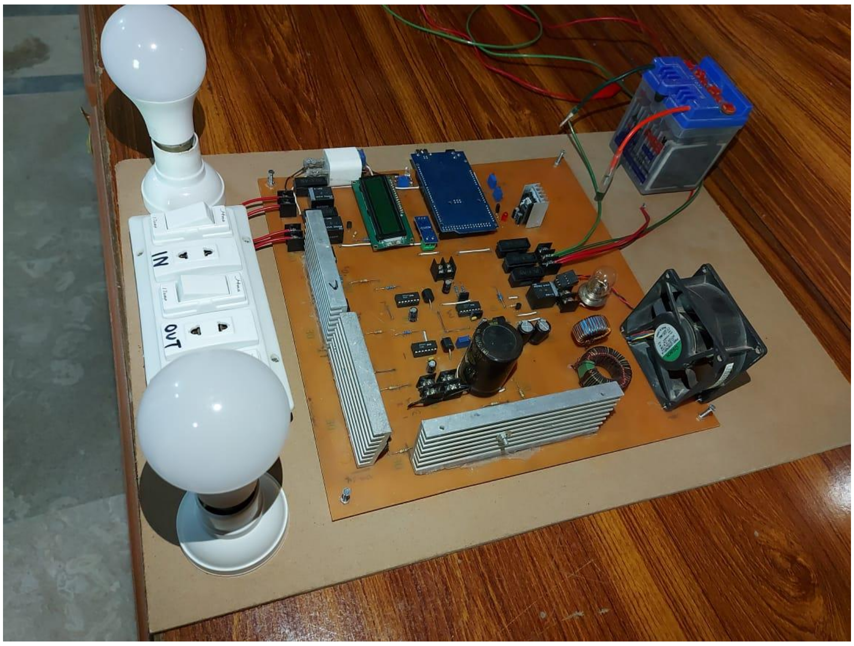
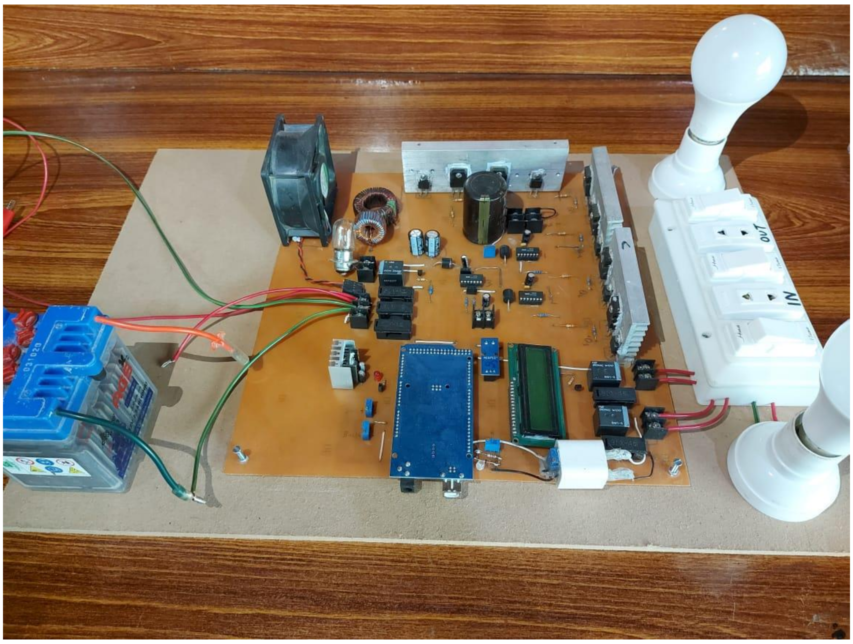
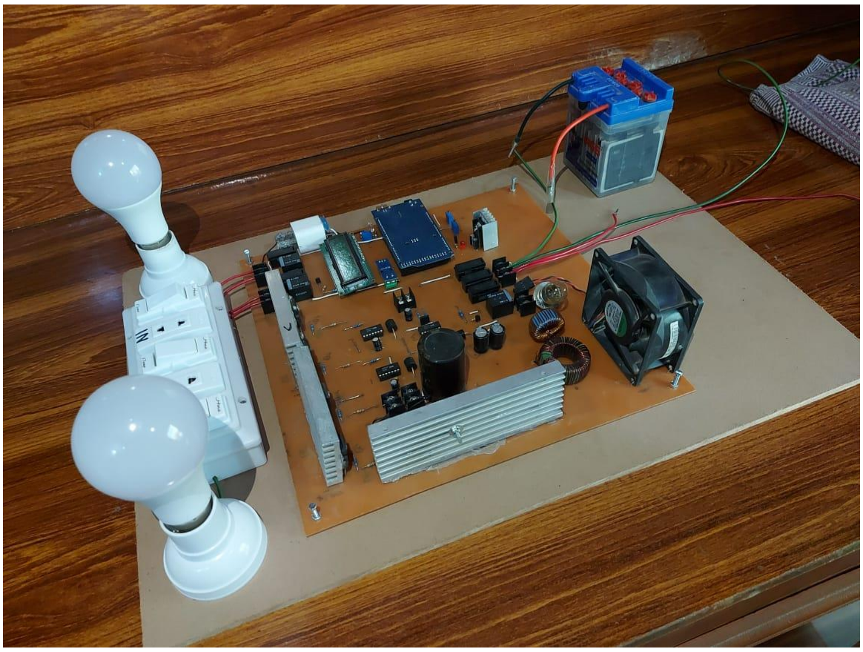


Fig4.17 Output and input voltage waveform in charging mode

4.4.3 Hardware




OUT
IN



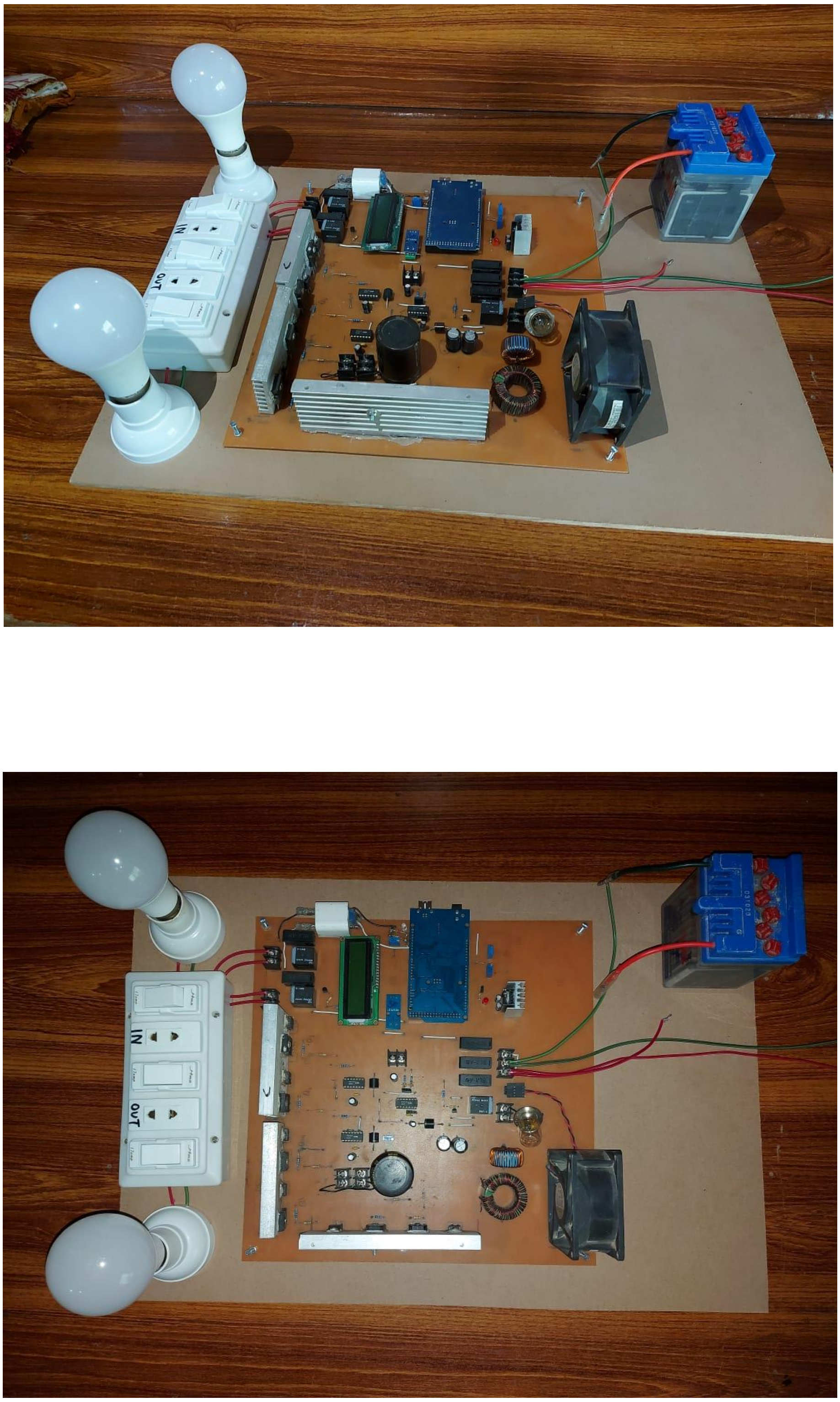


Fig4.18 Hardware of proposed system

Chapter Five

5 CONCLUSION

In this project, the proposed controller was designed to perform the combination of energy storage system (ESS) with a domestic electric system using the mathematical model of a bi-directional AcDc and bi-directional buck-boost DcDc converter. The non-isolated and non-inverting buck-boost type-topology was used to develop and build the bi-directional DcDc converter. The use of a high frequency transformer to create source and load side isolation is appealing. Transformer-free topologies, on the other hand, are considerably more appealing in terms of boosting performance (η), size, weight, and cost.

In the charging mode, the buck (step-down) mode was used, whereas in the discharging mode, the boost (step-up) mode was used. Using the reverse diode of the bi-directional switch, the AcDc converter was regulated to function as a bridge diode rectifier in charging mode. The four switches of the DcAc converter were controlled using the PWM technique in the discharging mode.

5.1 Applications

- Battery energy storage systems ESS
- Uninterruptible power supplies
- DC micro-grids
- Chargers for electric vehicles

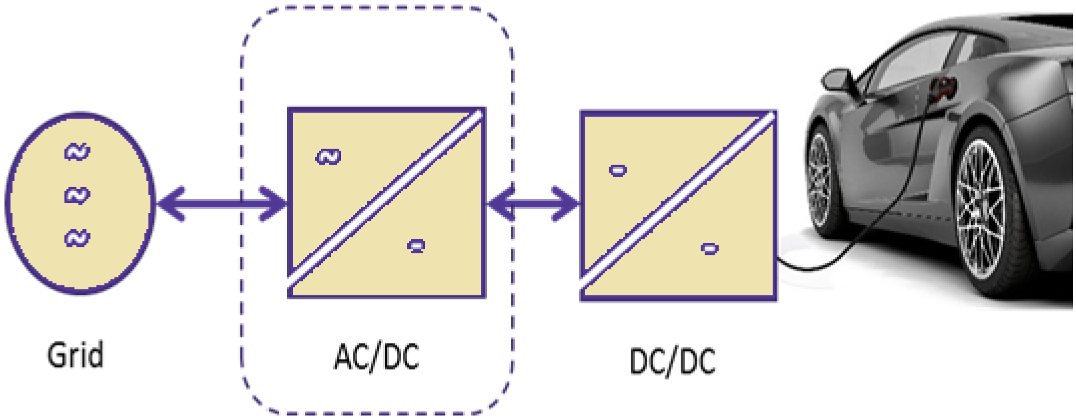


Fig4.19 Application of Proposed converter as an Electric vehicle charger

Chapter Six

6 REFERENCES

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