ON-BOARD INTEGRATED EV CHARGER WITH REDUCED SWITCHING LOSS AND IMPROVED EFFICIENCY

A PROJECT REPORT

Submitted by

ARUNPRASATH N	**(2127200601006)**
BALASURIYA M	**(2127200601012)**
DHAANYAAKUMAAR G S	**(2127200601018)**

in partial fulfilment for the award of the degree

of

BACHELOR OF ENGINEERING

IN

ELECTRICAL AND ELECTRONICS ENGINEERING

SRI VENKATESWARA COLLEGE OF ENGINEERING

(An Autonomous Institution; Affiliated to Anna University, Chennai -600 025)

ANNA UNIVERSITY:: CHENNAI 600 025

DECEMBER 2023

SRI VENKATESWARA COLLEGE OF ENGINEERING

(An Autonomous Institution; Affiliated to Anna University, Chennai -600 025)

ANNA UNIVERSITY, CHENNAI – 600 025

BONAFIDE CERTIFICATE

Certified that this project report **“ON-BOARD INTEGRATED EV CHARGER WITH REDUCED SWITCHING LOSS AND IMPROVED EFFICIENCY”** is the bonafide work of **“ARUNPRASATH N (2127200601006), BALASURIYA M (2127200601012), DHAANYAAKUMAAR G S (2127200601018)”** who carried out the project work under my supervision.

SIGNATURE	**SIGNATURE**
Dr.KR. SANTHA	**Dr. N. SHANMUGAVADIVU**
VICE PRINCIPAL AND	**SUPERVISOR**
HEAD OF THE DEPARTMENT	
Professor,	Assistant Professor,
Department of Electrical and	Department of Electrical and
Electronics Engineering.	Electronics Engineering.

Submitted for EE18711 Project Work 1 viva-voce examination held on

______

INTERNAL EXAMINER **EXTERNAL EXAMINER**

ABSTRACT

For applications involving the battery charging of vehicles, there is a constant need for on-board chargers that are dependable, effective, compact, and lightweight. Specifically, on-board integrated chargers are created employing the idea of hardware reuse in order to increase the power level of the on-board chargers. By integrating the charger component with the propulsion circuitry, on- board battery chargers can reduce their weight, volume, space, and cost. It is possible to use the EV's traction components in the charging circuit because they are not activated during the charging process. The stator windings of a three- phase traction AC motor can be used as a grid-interfacing inductor filter at the front-end AC-to-DC converter during the charging mode. The PWM voltage source converter and the bidirectional DC-DC converter are both used while charging. When the system is in drive mode, the PWM scheme is employed to provide the desired motor speed and torque. The proposed system comes with a Zero-Voltage Switching (ZVS) bidirectional DC-DC converter, which will reduce switching losses and increase the overall system efficiency.

ACKNOWLEDGEMENT

We wish to express our sincere gratitude to **Dr. S. GANESH VAIDYANATHAN**, Principal, Sri Venkateswara College of Engineering (Autonomous) for being a source of inspiration throughout our educational experience in this college.

We express our sincere thanks to **Dr. KR. SANTHA**, Vice Principal & Head of the Department, Electrical and Electronics Engineering, Sri Venkateswara College of Engineering (Autonomous) for her constant encouragement to carry out this project.

We express our deep and sense of gratitude to our respectful guide **Dr. N. SHANMUGAVADIVU,** Assistant Professor, Electrical and Electronics Engineering, Sri Venkateswara college of Engineering(Autonomous) for his support and guidance which enabled us to complete the project.

We would like to thank our project coordinator, **Ms. K. SUGANTHI**, Assistant Professor, Department of Electrical and Electronics Engineering, Sri Venkateswara College Of Engineering (Autonomous) and all professors who helped me directly or indirectly, for facilitating me in the preparation and spending their precious time in evaluating my work.

We also acknowledge with a deep sense of reverence, our gratitude towards our parents who always supported us morally as well as economically and we also thank all our friends who directly or indirectly helped us complete our project.

Place: Pennalur

Date:

TABLE OF CONTENTS

CHAPTER NO.	TITLE	PAGE NO.

CHAPTER NO.	TITLE	PAGE NO.

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	-	Alternating Current
DC	-	Direct Current
EV	-	Electric Vehicle
IBC	-	Interleaved Boost Converter
PI	-	Proportional Integral
PID	-	Proportional Integral Derivative
SOC	-	State Of Charge
VSI	-	Voltage Source Inverter
ZVS	-	Zero Voltage Switching

CHAPTER 1

INTRODUCTION

In Electric vehicle one or more electric motor is used for propulsion instead of internal combustion engine. The electric vehicle uses a large traction battery pack to power the electric motor and must be plugged into a charging station or wall outlet to charge. As these vehicles run on electricity, they emit no exhaust from a tailpipe and does not contain the typical liquid fuel components, such as a fuel pump, fuel line, or fuel tank. The recent development in infrastructure for charging electric vehicles includes both off-board and on-board chargers off- board is a fast charger that delivers high power to DC outlets but has a high cost of production, moreover fast charging drastically affects battery life when compared to on-board charging.

To eliminate the front-end converter’s filter, by using the stator winding of traction motor as inductive filter and adopting the Bi-directional Zero voltage switching DC-DC converter for reduced switching loss and increased efficiency.

1.1 OVERVIEW OF THE PROPOSED MODEL

The proposed system comes with three-level Zero Voltage Switching (ZVS) bidirectional dc–dc converter which will reduce the switching losses and will increase the overall system efficiency. The stator windings of three-phase traction AC motor can be used as a grid interfacing inductor filter at the front-end AC to DC converter during the charging mode. The PWM voltage source converter and the bidirectional DC-DC converter are both used while charging. When the system is in drive mode, the PWM scheme is employed to provide the desired motor speed and torque.

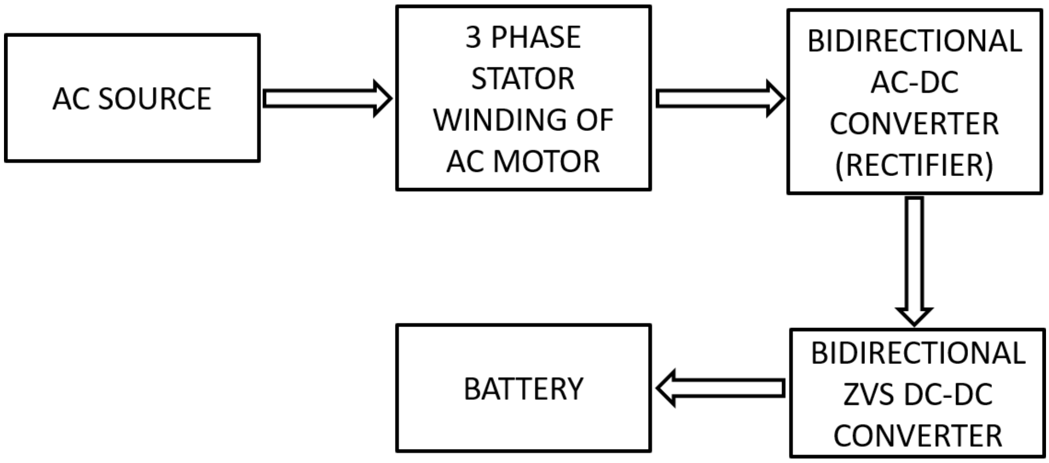


Figure 1.1 Block diagram of the proposed model during charging mode

Figure 1.1 describes the block diagram of the power flow from AC source to the battery through corresponding converters.

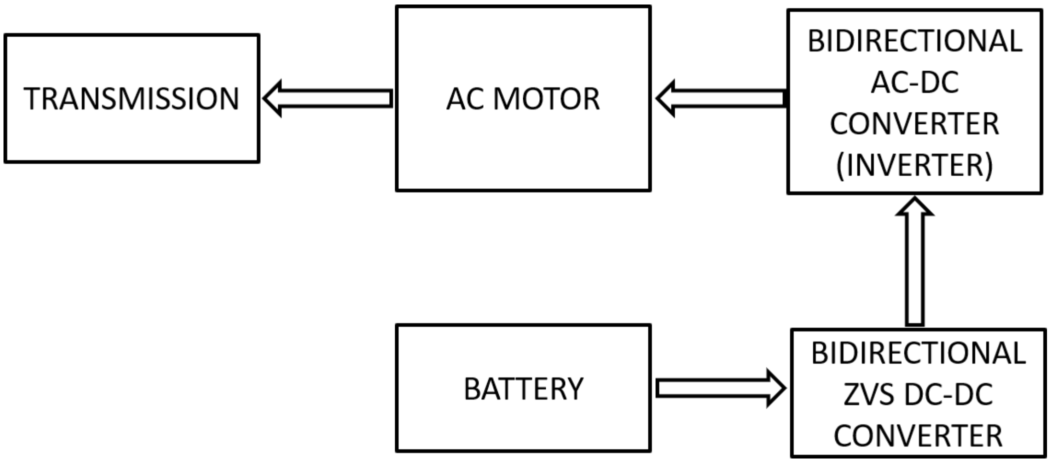


Figure 1.2 Block diagram of the proposed model during traction mode

Figure 1.2 describes the block diagram of the power flow from battery to motor through corresponding converters.

1.2 OBJECTIVE OF THE PROJECT

Adopting the Bi-directional Zero voltage switching DC-DC converter for reduced switching loss and increased efficiency. Eliminating the front-end converter's filter, by using the stator winding of traction motor as inductive filter.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

The various data collected from the below literature is useful in various ways in the development of this project. The same way each page has its advantage and disadvantages. Literature survey helps in analysing the characteristics for various converters for electric vehicle. Also, various schemes which can be used to control the speed control and the operation of stator winding as filter. Proper analyzing of various proposals help in the innovation of key areas of improvement.

2.2 LITERATURE REVIEW

N.P.Subramaniam et al. (2010) have developed a soft switching implementation without additional device, high efficiency, simple control Zero Voltage Switching (ZVS) bidirectional isolated DC-DC converter is presented in this paper. The proposed bi-directional DC-DC converter for fuel cell electric vehicle driving system. In the ZVS bidirectional DC-DC converter low-voltage side half-bridge with MOSFET and high voltage side half bridge with IGBT were developed.

G. Pellegrino et al. (2010) presented a model in which the battery charger is derived from the power hardware of the scooter, with the ac motor drive that operates as three-phase boost rectifier with power factor correction capability. The control of the charger is also integrated into the scooter control firmware that is implemented on a fixed-point DSP controller. Current-controlled or voltage-controlled charge modes are actuated according to the requirements of the battery management system, that is embedded into the battery pack.

L. De Sousa et al. (2010) proposed a concept of electric powertrain system which is configurable as a battery charger without additional power components. The interest of this particular solution is the full magnetic decoupling between the rotor and the stator during the charging mode which avoid a clutch system, and prevent the rotor from vibrating. A combined multiphase electric drive and fast battery charger for Electric Vehicles.

Amol S. Kamble et al. (2018) described a concept in split three-phase induction motor each phase winding carries same current, as well as each phase winding produced same magnetic field of the same magnitude but opposite in direction, so resultant is zero. The dual active bridge dc to dc converter used for controlling charging and discharging of the battery.

Tuopu et al. (2019) have presented a review of On-Board Integrated Charger for Electric Vehicles and A New Solution. Based on permanent magnet motor (PM) and induction motor (IM), the last type can also integrate both the converter and the motor windings. Two motor windings are used as filter inductors and two inverters are served as rectifier. The other two inverters and two windings are used as second stage dc/dc converter, which can control the output voltage.

Jyoti Gupta et al. (2020) modified the two conversion stage of an on-board charger is a front-end ac–dc voltage source converter with unity power factor correction feature followed by a dc–dc converter. The rectified output voltage (Vdc) of VSC is divided in two equal parts using split dc link capacitors (C1, C2) and fed to three-level bidirectional dc–dc converter.

S. Sharma et al. (2020) presented an equivalent inductance for the stator windings for increasing the filter effect to reduce the noise generated by the Pulsating Magnetic Field (PMF) in the motor, The same driving inverter is reconfigured to work as a bidirectional ac/dc converter and machine windings are also integrated in the charging circuitry.

2.3 CONCLUSION

Thus, considering the above papers, we analyzed the advantages and disadvantages of each technique for our project. We eliminated some problems and got some knowledge from the above works. This literature survey is useful to complete our simulation work.

CHAPTER 3

BI-DIRECTIONAL CONVERTER

3.1 INTRODUCTION TO CONVERTER

The primary task of power electronics is to process and control the flow of electric energy by supplying voltages and currents in a form that is optimally suited for user loads. Modern power electronic converters are involved in a very broad spectrum of applications like switched-mode power supplies, active power filters, electrical-machine-motion-control, renewable energy conversion systems distributed power generation, flexible AC transmission systems, and vehicular technology, etc.

The Bidirectional DC-DC converter is used to step-up and step-down the voltage using buck and boost converters from AC source to battery to store the regulated voltage and from battery to the power train. There are various bidirectional DC-DC converters available as follows.

3.2 CONVENTIONAL THREE-LEVEL DC-DC CONVERTER

The conventional three-level dc-dc converter is shown in Figure 3.1. Typical gating signals for the four converter switches are shown in Figure 3.2. Equivalent circuit diagrams that show the modes of operation for a half-switching cycle for the three-level converter are shown in Figure. Switch pairs S1 and S2 or S3 and S4 are turned on simultaneously; when either S1 or S4 is turned off, the converter enters a freewheeling mode of operation. The discharging of switch output capacitances is initiated by the turning off of either S2 or S3. The converter has the following modes of operation:

Mode 1: During this mode, switches S1 and S2 are on, half the dc bus voltage, Vin/2, is impressed across the transformer primary, and energy is transferred to the output.

Mode 2: During this mode, switch S1 is turned off and the voltage of CS1 increases from zero to Vin/2 while the voltage of (CS3+CS4) decreases from Vin to Vin/2. Switches S3 and S4 are each exposed to a voltage of Vin/4.

Mode 3: During this mode, the converter is in a freewheeling mode of operation as current freewheels through S2 and D1. It should be noted that the voltage across S1 during this mode is Vin/2.

Mode 4: The converter enters this mode when S2 is turned off. The transformer primary current discharges the output capacitances of switches S3 and S4 so that current flows through the body diodes of these devices. The mode ends when S3 and S4 are turned on and the converter enters Mode 1 but with S3 and S4 on instead of S1 and S2.

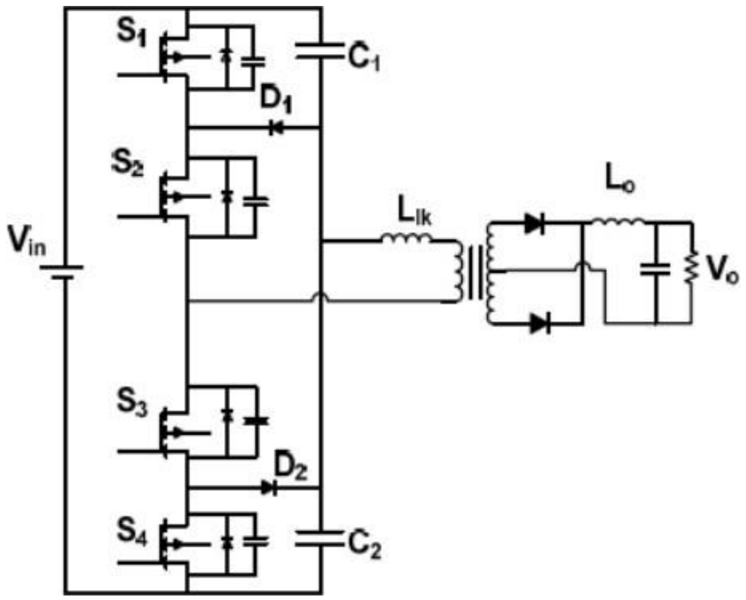


Figure 3.1 Conventional Three level DC-DC Converter

Even though Three-level DC-DC Converters have some advantages it possess some Demerits also notably

1. Switching converters are prone to noise.
2. They can be expensive.
3. Choppers are inadequate due to unsteady voltage and current supply.
4. In conventional three-level converter with PSPWM scheme, the lagging-leg switches have narrow ZVS range due to the limited energy stored in primary leakage inductance.
5. High circulating current losses in the freewheeling interval.
6. The main drawbacks of conventional high boost converters are the increased size of passive elements, cost and decreased efficiency.

3.3 THREE-LEVEL DC-DC CONVERTER WITH ZVS FOR TWO SWITCHES

In the converter shown in Figure, a flying capacitor has been added between top and bottom switches to make a path for the discharging of the output capacitance of S1 and S4 so that these switches can turn on with ZVS.

Mode 1: During this mode, switches S1 and S2 are ON and energy from dc bus capacitor C1 is transferred to the output load.

Mode 2: In this mode, S1 is OFF and S2 remains ON. Capacitor Cs1 charges and capacitor Cs4 discharges through Cf until Cs4, the output capacitance of S4, clamps to zero. This mode ends when S4 turns on with ZVS.

Mode 3: In this mode, S1 is OFF, the primary current of the main transformer circulates through diode D1 and S2 and the load inductor current freewheels in the secondary of the transformer.

Mode 4: In this mode, S1 and S2 are OFF and the current in the transformer primary charges capacitor C2 through the body diode of S3 and switch S4. This mode ends when switches S3 and S4 are switched on and a symmetrical period begins. In this mode, the load inductor current continues to transfer energy from input to the output.

The main advantage of this converter is that the converter just uses a flying capacitor to guarantee ZVS for at least two top and bottom switches and thus the converter needs less circulating current to make ZVS for the other switches. Typical waveforms of the converter are shown in figure.

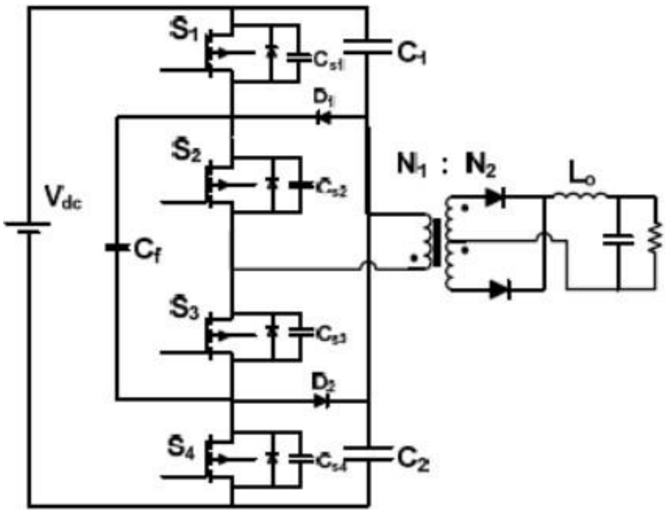


Figure 3.2 Three level Isolated ZVS DC-DC Converter

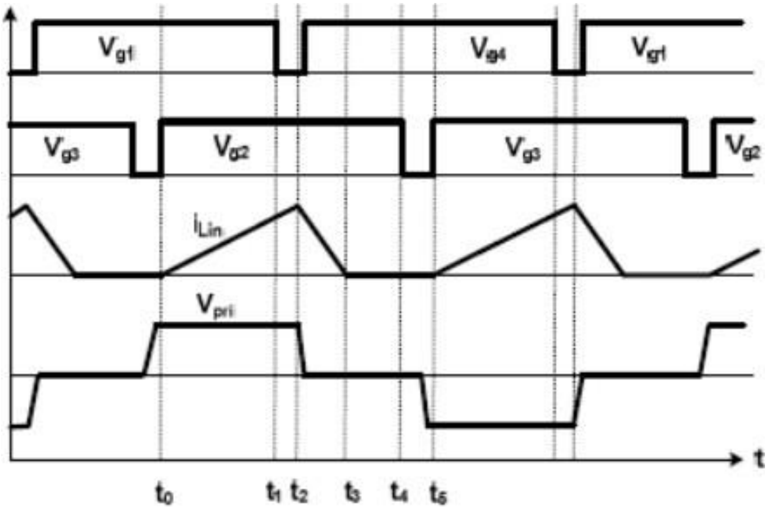


Figure 3.3 Waveform for Three level Isolated ZVS DC-DC Converter

Though the three-level isolated ZVS DC-DC Converter have some merits like

1. The voltage stress across the switches is half of the input voltage.

2. The converter can achieve low switching losses and high circuit efficiency.

3. All the main switches achieve zero-voltage turn-on and quasi zero-voltage turn-off, and the auxiliary switches realize zero current turn-on and zero-voltage turn-off; thus, the efficiency will be high.
4. The auxiliary currents generated by the ACACs are controllable.
5. The ITLDC [Isolated Three level DC-DC] can realize ZVS during the whole charging process; thus, the efficiency will be high.

The isolated ZVS DC-DC converter have some demerits such as,

1. The switching frequency with wide input voltage and load current variations is much wider. Thus, the magnetic components are difficult to be designed at the optimal point.

2. The secondary rectifier voltage waveforms are still two-level, which needs a large output filter to minimize the output current ripple, and a large input EMI filter is also required [^10^].

3. The ZVS load range is narrow, which results in high power loss especially under the light load condition [^10^].

4. The main drawback of these converters is hard switching operation, which results in low power transferring efficiency.

3.4 ZVS DC-DC CONVERTER

The Bidirectional DC–DC converter with soft-switching capabilities. The main characteristic of this converter is that it can be operated in both boost and buck modes. The major advantages of this converter are high efficiency and reduced switching loss in high-power and high-voltage applications. The soft-switching capability is obtained by additional dual auxiliary resonant circuits connected to the conventional non-isolated bidirectional DC–DC converter. Except for the auxiliary switches, all main switches turn on with zero-voltage switching in this proposed bidirectional DC–DC converter. The auxiliary switches turn off with zero current transition. In this model we only deploy the Buck mode of this converter during charging operation and the sequence of operation is listed below,

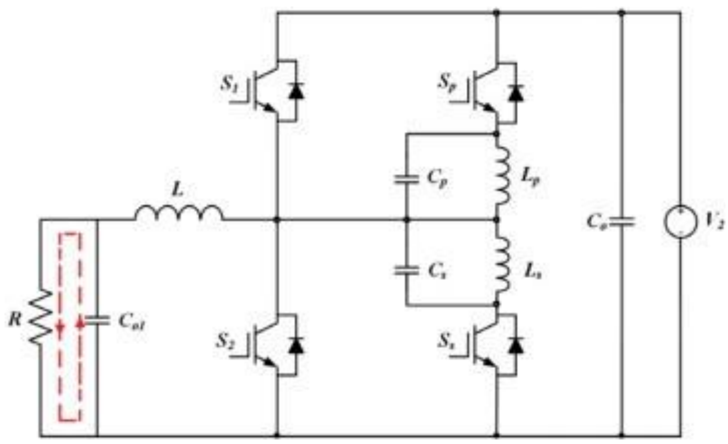


Figure 3.4 Proposed ZVS DC-DC Converter

3.4.1 Buck Mode

The time intervals t_2–t_3 and t_3–t_4, t_4–t_5 and t_5–t_6 are categorised into two states: states 3 and 4, respectively. States 1 and 3 are resonant while the rest are non-resonant. When this converter is operating in buck mode the IGBT$_s$ S_2, S_s are kept turned-off for the entire operation. The IGBT S_1 acts as a buck switch and the auxiliary IGBT S_p can be turned on to achieve soft-switching operation. Nevertheless, the auxiliary IGBT S_p can be turned on for a small period of time, the gate pulse V_{gp} is applied prior to that of S_1. The eight intervals of buck operations are described as below:

Interval (t_0–t_1): This stage begins when all switching devices are in turned off condition, since L_p and C_p are resonating with each other. The L_p and C_p are resonating until t_1, as the resonant capacitor C_p starts charging in the reverse direction up to $0.26 \times V_{in}$ and then discharges completely at t_1. At t_1, iL_p reaches a constant value, that is, output current:

$$V_{Cp}(t) = -Z \sin \omega(t - t_0)\ i_{Lp}(t) = i_{Lp}(t_6) \cos \omega(t - t_0) \tag{1}$$

$$V_{Cp}(t) = -(\alpha I_{in}/V_o) \sin \omega(t - t_0) \tag{2}$$

Interval (t_1–t_2): From the previous stage, all switches are in turned off condition, since there is no power delivered to the load until t2:

$$i_{Lp} = 0 \tag{3}$$

$$V_{Cs} = 0 \tag{4}$$

Interval (t_2–t_3): This interval begins when S_p is turned on. The voltage across S_1 starts decreasing smoothly and reduces to zero at t_3. The current through L_p linearly decreases to $-I_m$. The capacitor C_p begins to charge and is fully charged at t_3, which is equal to $0.8 \times V2$, as both L_p and C_p are resonating with each other.

$$V_{Cp}(t) = Z \sin \omega(t - t_2)\ i_{Lp}(t) = i_{Lp}(t_2) \cos \omega(t - t_2) \quad (5)$$

$$V_{Cp}(t) = (\alpha I_{in}/V_o) \mathrm{Sin}\ \omega(t - t_2) \quad (6)$$

Interval (t_3–t_4): At t_3, body diode of S_1 starts conducting to allow the resonant tank current since S_p is still in conduction. The current through L_p reaches I_k and at t_4, the capacitor Cp discharges completely:

$$i_{Lp}(t) = I_k\ V_{Cp} = 0 \quad (7)$$

Interval (t_4–t_5): During this interval, the current through L_p is maintained at $+I_m$ and V_{Cp} remains zero.

Interval (t_5–t_6): When the gate pulses V_{g1} is applied to S_1, this interval begins. Since S_1 body diode is still conducting and voltage across S_1 is zero, ZVS is obtained. At t_5, S_1 body diode stops conducting and current through S_p becomes zero. The i_{Lp} remains constant, which is equal to maximum output current:

$$i_{Lp}(t) = I_k \quad (8)$$

$$V_{Cp} = 0 \quad (9)$$

Interval (t_6–t_7): At t_6, S_p is turned off and S_1 starts conducting and then i_{S1} reaches the level of output current at t_7.

Interval (t_7–t_8): During this interval, the power is delivered to the load via L–S_1–R:

$$i_{Lp}(t) = I_k\ V_{Cp} = 0 \quad (10)$$

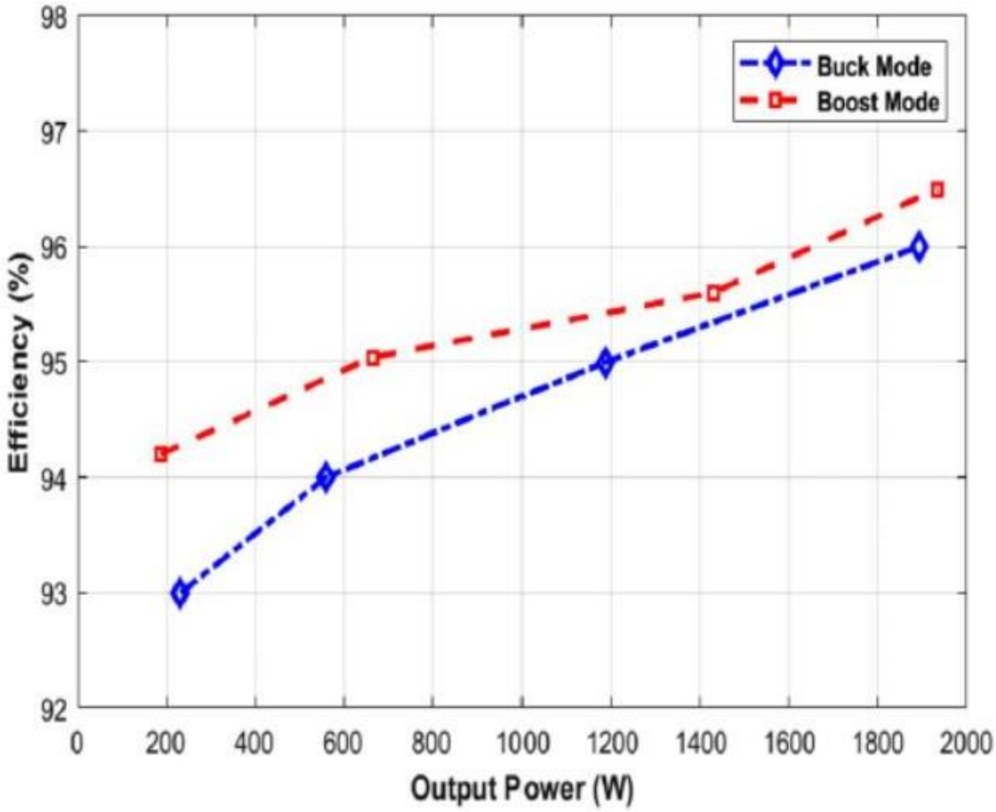


Figure 3.5 Efficiency graph of Proposed ZVS DC-DC Converter

From Figure 3.5 we can infer that efficiency of Proposed ZVS DC-DC Converter on Buck Mode - 96% and Boost Mode – 96.5% respectively.

3.5 BIDIRECTIONAL AC-DC CONVERTER

A bidirectional AC-DC PWM (Pulse Width Modulation) converter is a power electronic device that can operate in both rectification (AC to DC) and inversion (DC to AC) modes. These converters are commonly used in applications where power needs to flow bidirectionally, such as in energy storage systems, electric vehicles, and grid-tied renewable energy systems.

3.5.1 Modes of Operation

3.5.1.1 Rectification (AC to DC):

During rectification, the bidirectional AC-DC converter converts AC power from the source (grid) into DC power for storage or use in a DC load. This process typically involves a rectifier circuit, which can be implemented using diodes, thyristors, or controlled rectifier circuits.

3.5.1.2 Inversion (DC to AC):

In inversion mode, the bidirectional converter converts stored DC power into AC power. This is essential in applications such as grid-tied inverters, where stored energy needs to be fed back into the AC grid. Inversion is accomplished using an inverter circuit, often employing switches like Insulated Gate Bipolar Transistors (IGBTs) for high-power applications.

3.5.2 Control Strategies

The bidirectional AC-DC converter plays a crucial role in managing power flow between AC and DC systems. Pulse Width Modulation (PWM) control strategies for bidirectional AC-DC converters involve adjusting the duty cycle of the switching signals to regulate the power flow between AC and DC systems efficiently. In rectification mode, PWM is used to control the rectifier, managing the conversion of AC to DC while maintaining desired voltage or current levels. In inversion mode, PWM controls the inverter, regulating the conversion of DC to AC. Common strategies include Voltage Control, where the converter adjusts the output voltage to match a reference; Current Control, which maintains a specified current in the system; and Power Control, where the converter manages the power flow bidirectionally. Advanced control algorithms may be employed for improved performance, allowing seamless transitions between modes, precise regulation, and response to dynamic load changes in applications like renewable energy integration and electric vehicle systems.

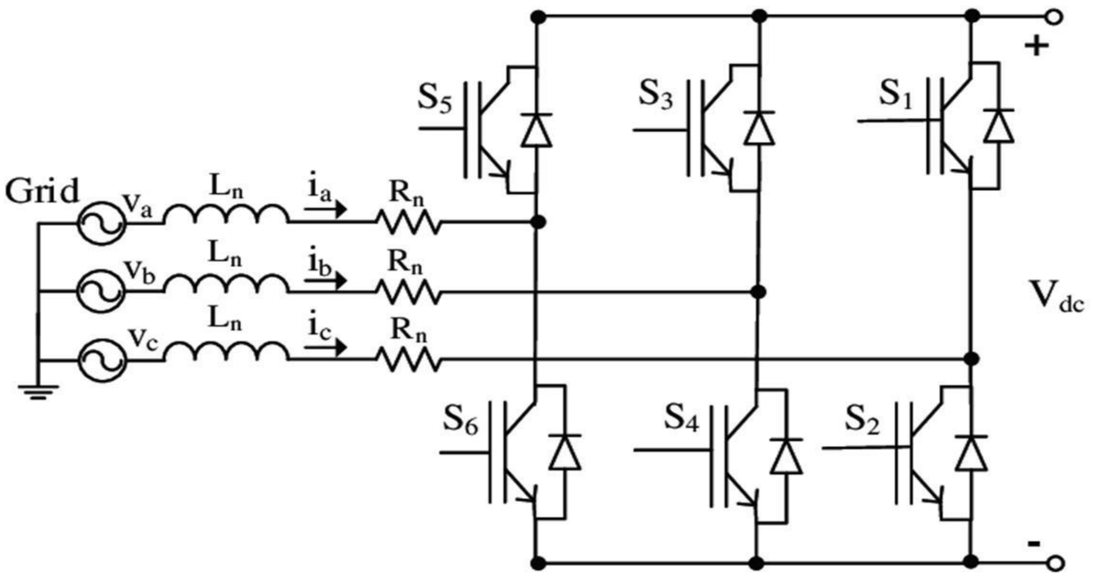


Figure 3.6 Bi-directional AC-DC Converter

3.5.2.1 Advantages

- ✓ Bidirectional Power Flow
- ✓ Power Flow Control
- ✓ Regenerative Braking in Electric Vehicles
- ✓ Grid Support Functions
- ✓ Load Balancing in Microgrids
- ✓ Smart Grid Applications
- ✓ Efficient Energy Transfer

3.5.2.2 Disadvantages

- ❖ Complexity and Cost
- ❖ Efficiency Challenges

3.5.3 Components And Topologies

The specific design and features of a bidirectional AC-DC PWM converter will depend on the application requirements and system specifications. Engineers often use simulation tools and mathematical models to optimize the converter design for a given application. The Bi-directional AC-DC of our circuit uses IGBT as switches since it has various advantages like,

- ✓ High Power Handling Capacity
- ✓ High Switching Frequency
- ✓ Low Conduction Losses
- ✓ Fast Switching Speed
- ✓ Voltage Rating
- ✓ Reliability
- ✓ High Short-Circuit Withstand Capability
- ✓ Good Thermal Performance

CHAPTER 4

SYSTEM ANALYSIS

4.1 INTRODUCTION

EV battery chargers are classified into on-board and off-board chargers with unidirectional and bidirectional power flow. Battery chargers' connections are of two types within the vehicle (on-board) and outside the vehicle (off-board). For charging the battery, two charging connectors are accessible. Off-board is a fast charger that provides high power to dc outlets but its manufacturing cost is high. As compared to on-board charging, fast charging reduces the battery life considerably. Unlike off-board, on-board chargers are lighter in weight, smaller in size and volume. Typically, two conversion stage of an on-board charger is a front-end AC-DC voltage source converter with unity power factor correction feature followed by a DC-DC converter . Achieving high power level with aforesaid chargers is very difficult because of its large passive components. For unidirectional power flow, the vehicle batteries could be charged through a unidirectional charger but the injection of power back to the grid is not possible. These chargers typically utilize diode bridge rectifier with filter components and DC-DC converter.

4.2 OFF-BOARD EV CHARGERS

Offboard chargers for Electric Vehicles (EVs) play a crucial role in providing a convenient and efficient means of charging EVs outside of their home charging stations. These chargers are typically installed in public spaces, commercial areas, and along transportation routes, offering a reliable infrastructure for EV users. Offboard chargers come in various power levels, commonly ranging from Level 2 (AC charging) to Level 3 (DC fast charging), providing flexibility to accommodate different charging needs. Level 2 offboard chargers use Alternating Current (AC) and are often found in locations like shopping centres, workplaces, and parking lots. They typically deliver power at a rate of up to 22 kW, making them suitable for overnight charging or extended stays.

Level 3 offboard chargers, also known as DC fast chargers, provide a higher charging rate, typically ranging from 50 kW to 350 kW or more. These chargers are strategically placed along highways and major routes to enable quick charging stops, allowing EV users to replenish their batteries in a relatively short amount of time.

Offboard chargers incorporate advanced technologies such as smart charging capabilities, real-time communication, and payment systems. Many are equipped with connectors compatible with various EV models, ensuring broad accessibility. The deployment of offboard chargers is a critical aspect of developing a comprehensive charging infrastructure, promoting widespread adoption of EVs. Governments, businesses, and utilities are investing in expanding the offboard charging network to address range anxiety concerns and support the growing number of electric vehicles on the road. As the EV market continues to expand, advancements in offboard charging technology, increased charging speeds, and enhanced user experience are expected to further accelerate the transition to electric mobility.

4.3 ON-BOARD EV CHARGERS

Electric Vehicle (EV) onboard chargers play a critical role in the charging infrastructure of electric vehicles, facilitating the transfer of electrical energy from the grid to the vehicle's battery. These chargers are typically integrated into the vehicle, providing a convenient and efficient means for EV users to recharge their batteries at home or at public charging stations. Onboard chargers are characterized by their power output, measured in kilowatts (kW), which influences the charging speed.

Modern EV onboard chargers utilize advanced power electronics and control systems to manage the charging process effectively. They employ technologies such as Pulse Width Modulation (PWM) to control the voltage and current supplied to the battery, ensuring safe and optimized charging. Bidirectional capabilities may also be incorporated, allowing the charger to function not only as a power receiver but also as an energy exporter, enabling vehicle-to-grid (V2G) applications. The power level of onboard chargers can vary, with Level 1 chargers typically providing around 2-3 kW for standard household outlets and Level 2 chargers offering higher power levels, often between 7-22 kW, suitable for residential and public charging stations. Some high-power EVs may also feature DC fast-charging capabilities, bypassing the onboard charger for direct high-voltage DC charging.

Efficiency is a key consideration in onboard charger design, impacting both the charging speed and energy consumption. Additionally, safety features such as overcurrent protection, temperature monitoring, and secure communication protocols are integrated to ensure reliable and secure charging processes. As the electric vehicle market continues to grow, advancements in onboard charger technology focus on increasing charging speeds, improving efficiency, and enhancing compatibility with diverse charging infrastructure standards. These developments contribute to the overall accessibility, convenience, and sustainability of electric transportation.

4.3.1 Advantages of On-Board EV Charging

- ✓ AC charging is more widely available than DC fast charging, making it easier to find a charging station.
- ✓ AC charging is generally cheaper than DC fast charging.
- ✓ Level 1 charging can be done from any standard household outlet.
- ✓ Level 2 charging is faster than level 1 charging and can fully charge most EVs in a few hours.
- ✓ Most EV owners begin their charging at home which eliminates waiting time at charging stations.

4.4 EXISTING MODEL

The existing on-board charger model comprises different stages, like: first, the AC power from the grid is given to the front-end filter of the front-end AC- DC converter, which is a unidirectional power conversion process. As the rectified output DC voltage is not the rated battery voltage, which is needed to be made nominal, where the action of the bi-directional DC-DC converter comes into action. The nominal output from the bi-directional DC-DC converter is stored in the battery while in charging mode, but during the motoring operation, the DC power from the battery is given to the same bi-directional DC-DC converter to convert the voltage to the motor-rated voltage. For motoring and regenerative braking, a bi-directional power electronic motor drive is employed. The main demerit of this system includes multiple power conversions at different voltage levels, which may result in a decrease in efficiency and increased losses. Our main motive is to remove multiple power conversion stages and incorporate the charging circuitry and motor control circuit.

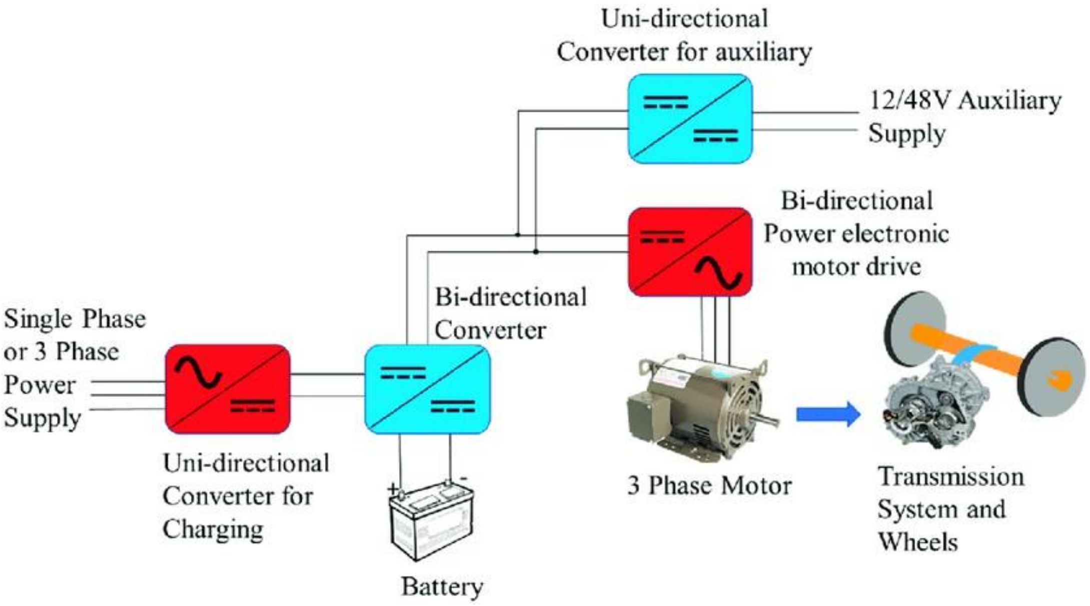


Figure 4.1 Existing model of On-Board EV charger

4.5 PROPOSED MODEL

The bidirectional charging system consists two stages of operation to improve power factor using PWM voltage source converter and regulate the battery current/voltage using ZVS bidirectional DC-DC converter. The PWM scheme is used in drive-mode operation of the system to generate torque and desired motor speed. In the battery charging mode, the PWM scheme with current control is employed to charge the battery with unity power factor operation. While operating in charging and discharging modes, it should draw a sinusoidal current with minimum phase angle to improve reactive power and maximize active power. This circuit provides fast controlling and high-power density as compared to unidirectional charger, which accounts more components, more cost and greater challenge for implementation. To reduce size, weight, and cost, windings of electric motor, inverter, and other hardware components are utilized for charging system Also the front-end filter size is reduced by using the stator winding of the AC propulsion motor as grid interfacing filter thus, integrated drive system with battery charger topology have been introduced. During charging process, few mandatory features of integrated on-board chargers are less harmonic content in supply current, unity power factor operation and there is no development of unwanted torque in motor.

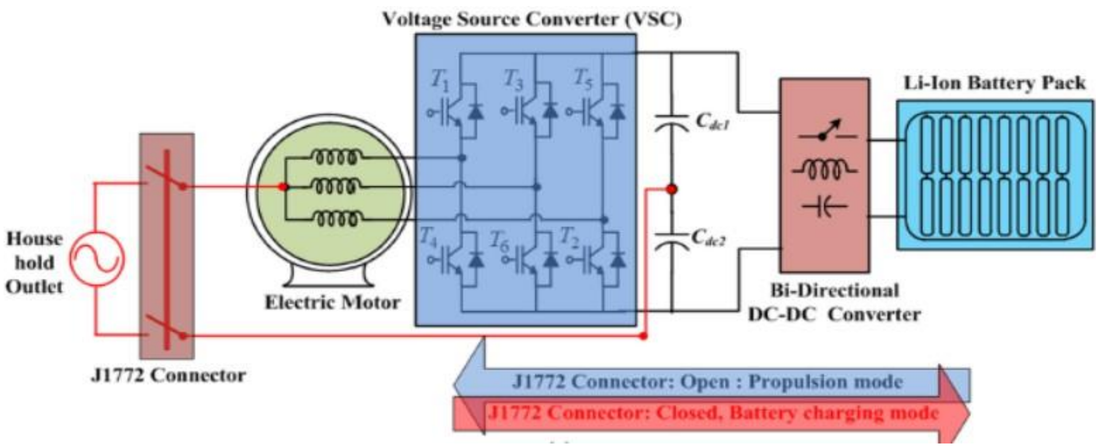


Figure 4.2 Proposed model of On-Board EV charger

4.5.1 Operation of Proposed Model

The operation of the proposed model can be divided into two modes.

4.5.1.1 Charging Mode:

During the charging process, the power flow will be: from the household outlet (i.e., the AC source), the AC power is given to the 3-phase winding of the traction AC motor, which acts as a front-end AC filter, then the AC power is given to the bi-directional AC-DC converter, which converts the input AC power to DC power(here the AC-DC converter acts as a rectifier). Now the rectified DC is not the battery-rated voltage. So, there comes the action of a bi-directional DC- DC converter, which converts the DC power to battery-rated DC and can be stored in a battery.

4.5.1.2 Traction Mode:

During the motoring process, the power flow will be: from the battery (i.e.) DC source, the DC power is given to the bi-directional ZVS DC-DC converter as input, then the output nominal DC power is given to the bi-directional AC-DC converter, which converts the input DC power to motor-rated AC power(here the AC-DC converter acts as an inverter). Now the inverted reted AC is given to the 3-phase motor for traction. Here, the bi-directional AC-DC converter is controlled by a PWM control scheme.

4.6 EV CHARGER PORTS

Electric Vehicle (EV) charging stations use different types of charging ports and connectors to accommodate various charging standards and power levels. The two main types of charging ports are AC (Alternating Current) and DC (Direct Current), each with specific connector standards. Here are some common types of charger ports used in EV chargers:

- **Type 1 (J1772):**

Specification: Type 1, also known as J1772, is a standard primarily used in North America and Japan for AC charging. It has a single-phase AC power delivery.

Application: Level 1 and Level 2 charging for electric vehicles.

- **Type 2 (IEC 62196-2 or Mennekes):**

Specification: Type 2, or IEC 62196-2, is a European standard widely adopted for both AC and DC charging. It supports single-phase and three-phase AC power delivery.

Application: Commonly used in Europe for Level 2 AC charging, and can also support DC fast charging.

- **CHAdeMO:**

Specification: CHAdeMO is a DC fast charging standard developed in Japan.

Application: Commonly used in Asian countries and some parts of Europe and North America for fast DC charging.

- **CCS (Combo Connector):**

Specification: CCS, or Combined Charging System, is a standard combining the Type 2 connector for AC charging with additional pins for high-power DC fast charging.

Application: Common in Europe and North America, CCS supports both AC and DC charging, offering a comprehensive solution.

- **Tesla Connector (Tesla Supercharger):**

Specification: Proprietary connector used by Tesla for their Supercharger network.

Application: Exclusive to Tesla vehicles and Tesla Supercharger stations, supporting high-power DC fast charging.

- **GB/T (GB/T 20234.3):**

Specification: GB/T is a Chinese standard for EV charging, covering both AC and DC charging.

Application: Widely used in China for Level 2 AC charging and DC fast charging.

- **Tesla Destination Charger (Tesla HPWC):**

Specification: Proprietary connector used by Tesla for their Destination Charger network.

Application: Designed for slower AC charging at destinations like hotels, restaurants, and parking facilities.

Table 4.1 Charger Connectors Used In Present Day EVs

Electric car	AC Connector	DC Connector
Audi e-tron SUV and Sportback	Type 2	CCS
BMW iX	Type 2	CCS
BYD E6	Type 2	CCS
Hyundai Kona Electric	Type 2	CCS
Jaguar I-Pace	Type 2	CCS
Lexus NZ	Type 2	CHAdeMO
Mahindra e2o	IEC60309	GB/T
Mahindra eVerito	Type 2	GB/T
Mercedes-Benz EQC	Type 2	CCS
MG ZS EV	Type 2	CCS
MINI Cooper SE	Type 2	CCS
Nissan LEAF	Type 2	CHAdeMO
Porsche Taycan	Type 2	CCS
Tata Nexon EV	Type 2	CCS
Tata Tigor EV (Old)	IEC60309	GB/T
Tata Tigor EV (New)	Type 2	GB/T
Tata Tigor EV Ziptron	Type 2	CCS

CHAPTER 5

SIMULATION OF ON-BOARD INTEGRATED CHARGER

5.1 INTRODUCTION TO MATLAB AND SIMULINK

The simulation is done using the MATLAB 2022a environment. MATLAB is high performance numerical computation and visualization software. Its integrated components useful for matrix computation, numerical analysis, signal processing, data analysis and graphics in an easy-to-use environment where problems and solutions are expressed just as they are written mathematically without traditional programming.

MATLAB includes Simulink, a powerful environment for simulating nonlinear dynamics system which is a library toolbox to model electrical and mechanical power systems.

5.2 SIMULINK MODEL OF THE PROPOSED CIRCUIT

In our proposed model, Here the single-phase AC supply is given to stator inductances (L1,L2,L3) of the traction motor, where the AC supply is fed to the Bi-directional AC-DC PWM converter. The converted DC supply is fed to the ZVS Bi-directional DC-DC converter through the split DC link capacitor. Later the output voltage from the DC-DC converter is stored in the 8KW Battery.

The voltage regulator can engage in “soft switching,” which helps in avoiding switching losses that are normally seen during conventional PWM operations. Using this technique, zero-voltage switching can effectively reduce losses and this technique however, most beneficial to those operating using high-voltage inputs. Using ZVS, you can see significant improvements in efficiency using high voltage compared to their equivalents that use PWM-controlled techniques.

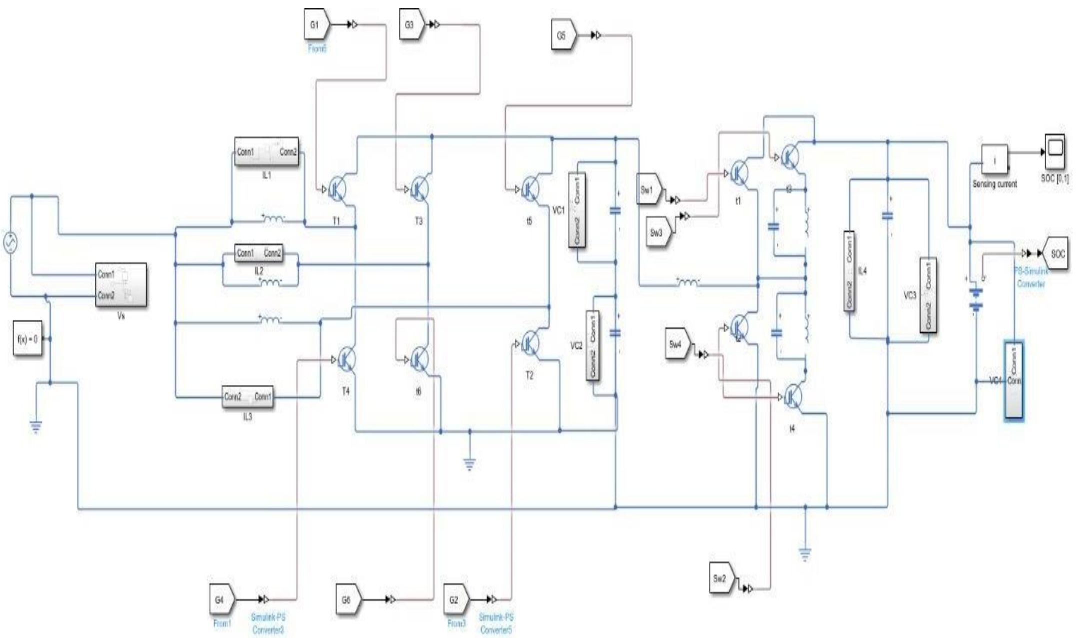


Figure 5.1 Simulink Model Of Proposed Circuit

In our model we use single phase 230V AC supply at 50HZ as input parameter. And it is given by the below waveform.

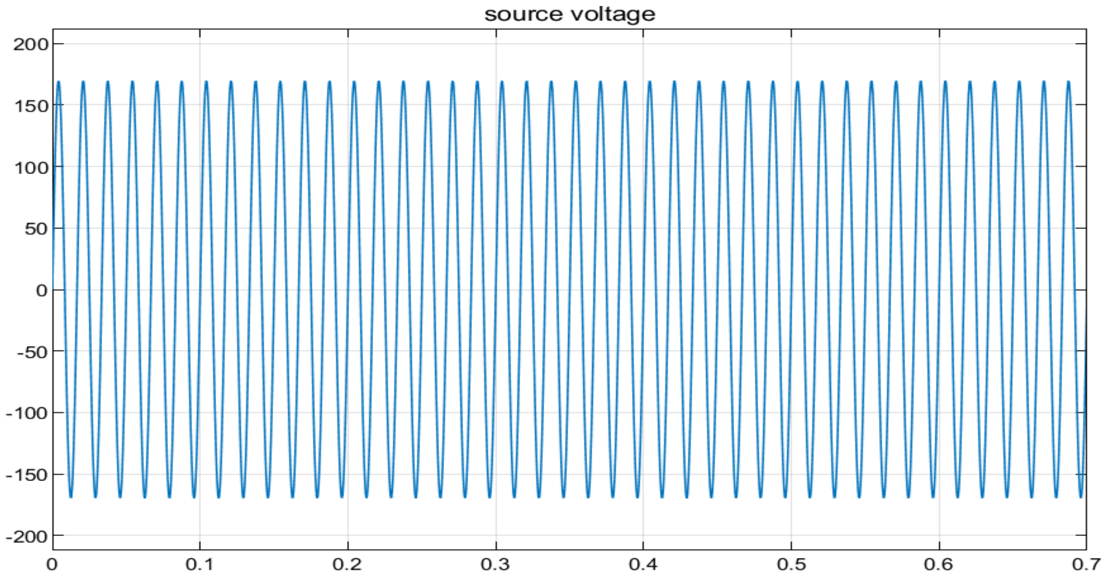


Figure 5.2 Source Voltage Waveform

5.3 SIMULINK MODEL OF ZVS CIRCUIT

Zero Voltage Switching (ZVS) is a power electronics technique that minimizes switching losses in electronic circuits. It operates by synchronizing the switching of power devices with the zero-crossing points of the input voltage waveform. By initiating the switching process when the voltage is zero, ZVS reduces the stress on the components and decreases power dissipation, enhancing overall efficiency. This method is commonly used in applications such as high- frequency converters and inverters, where minimizing switching losses is crucial for improving energy efficiency and reducing heat generation. ZVS helps optimize power delivery and is integral to the performance of various electronic systems.

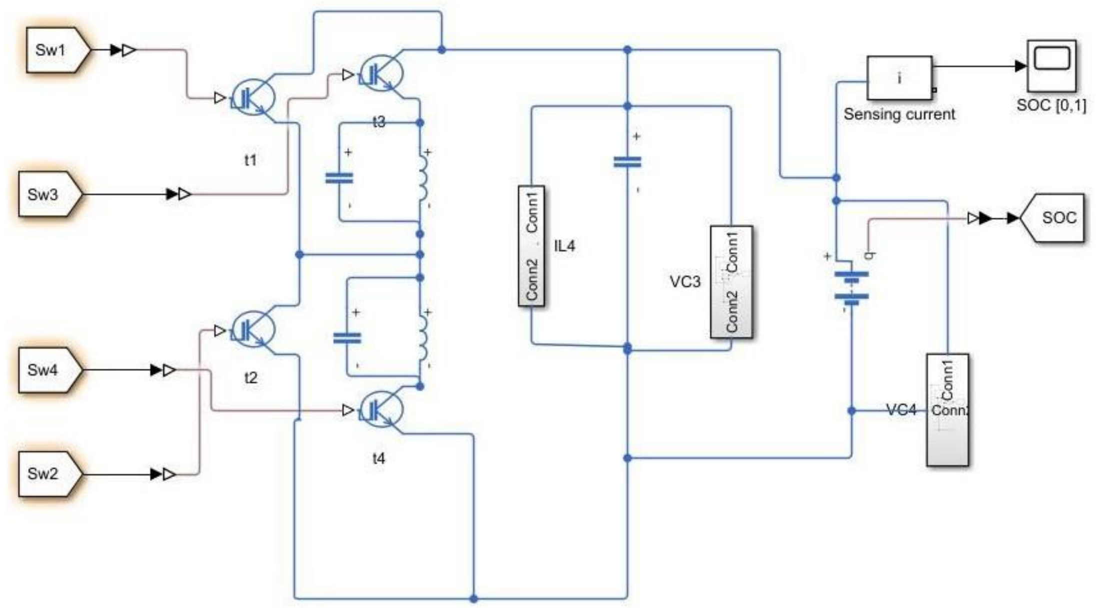


Figure 5.3 Simulink Model Of ZVS Circuit

5.4 CONTROL CIRCUIT

5.4.1 INTERLEAVED BOOST CONVERTER

The Interleaved Boost Converter is a power electronics topology designed to improve the performance of conventional boost converters by interleaving multiple channels.

In this setup, two or more boost converter channels operate in parallel, sharing the load current. Each channel is driven by a phase-shifted control signal to ensure that the current is evenly distributed among the channels. This interleaving of channels reduces input and output current ripple, minimizing the stress on components and improving overall efficiency. The interleaved design also allows for higher power handling capabilities and better thermal distribution. It's commonly employed in applications requiring high-power conversion efficiency, such as renewable energy systems and EVs.

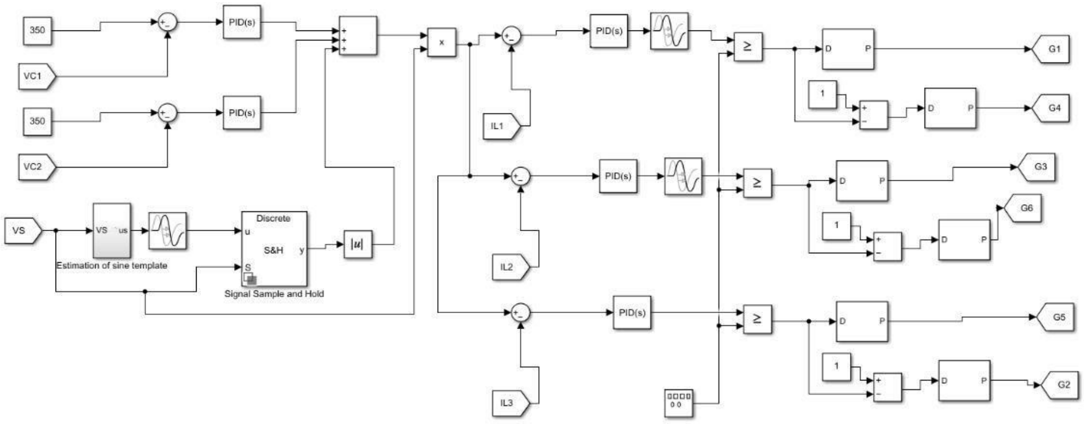


Figure 5.4 Simulink Model Of IBC Circuit

5.5 SPLIT-DC LINK CAPACITORS

A Split-DC link capacitor is used in Electric Vehicles (EVs) to enhance the performance and efficiency of the power electronics system. In EVs, the powertrain often consists of an inverter that converts DC power from the battery to AC power for the electric motor. The Split-DC link capacitor is placed between the DC bus and the inverter, providing several advantages. It helps to reduce the voltage stress on the semiconductors within the inverter, improving their reliability and lifespan. Additionally, the Split-DC link capacitor allows for bidirectional power flow, facilitating regenerative braking, where energy from braking is captured and returned to the battery. This capacitor design also aids in reducing the size and weight of the overall power electronics system, contributing to the compactness and efficiency of electric vehicles.

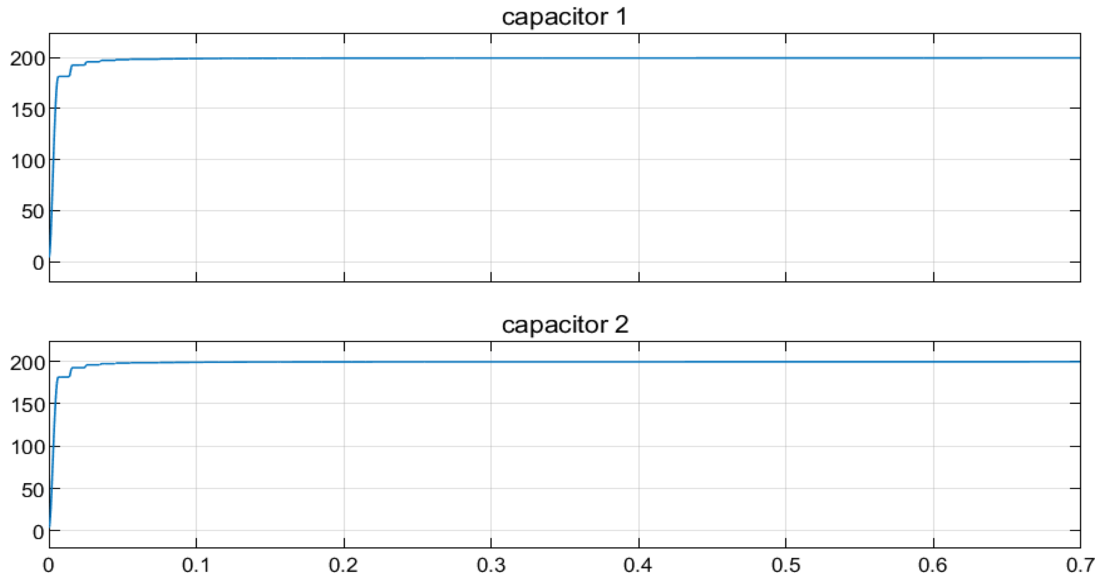


Figure 5.5 Split-DC Link Capacitor Charging Waveform

5.6 BATTERY PARAMETERS

In Electric Vehicles (EVs), the battery serves as the primary energy storage device, supplying power to the electric motor for vehicle propulsion. Typically, EVs use high-capacity lithium-ion batteries due to their energy density, efficiency, and rechargeability. These batteries store electrical energy, providing the vehicle with a reliable and efficient source of power. The Battery Management System (BMS) ensures optimal performance, monitors cell health, and regulates charging and discharging processes. Advancements in battery technology, such as solid-state batteries, aim to improve energy density, extend range, and reduce charging times, contributing to the ongoing evolution of electric vehicle technology.

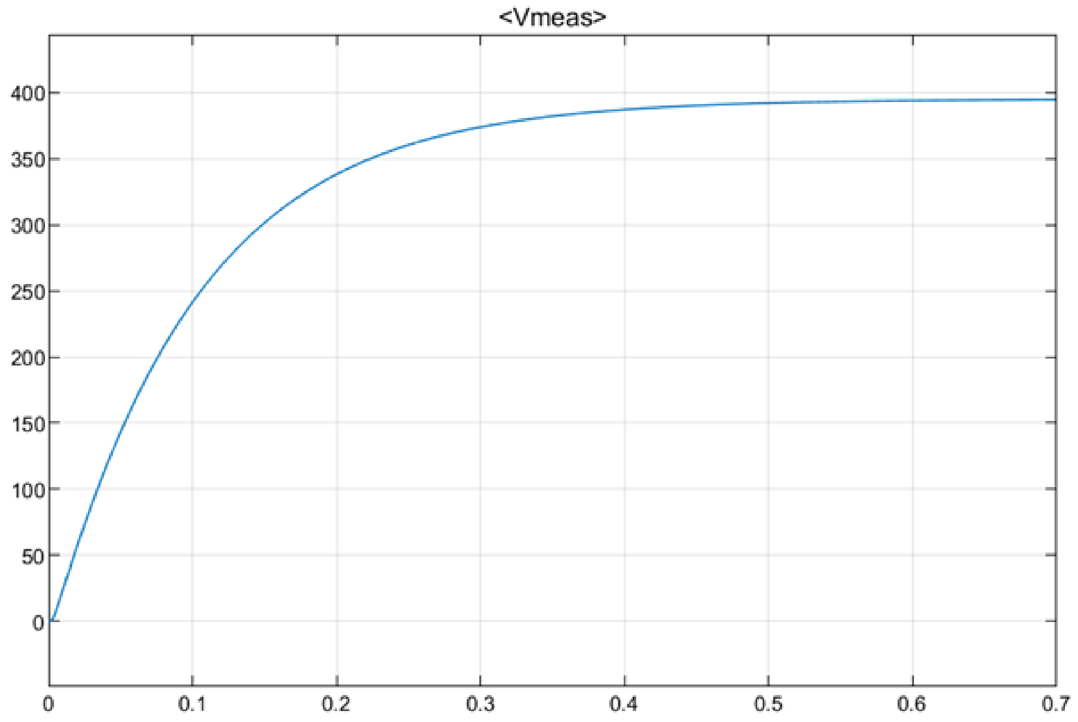
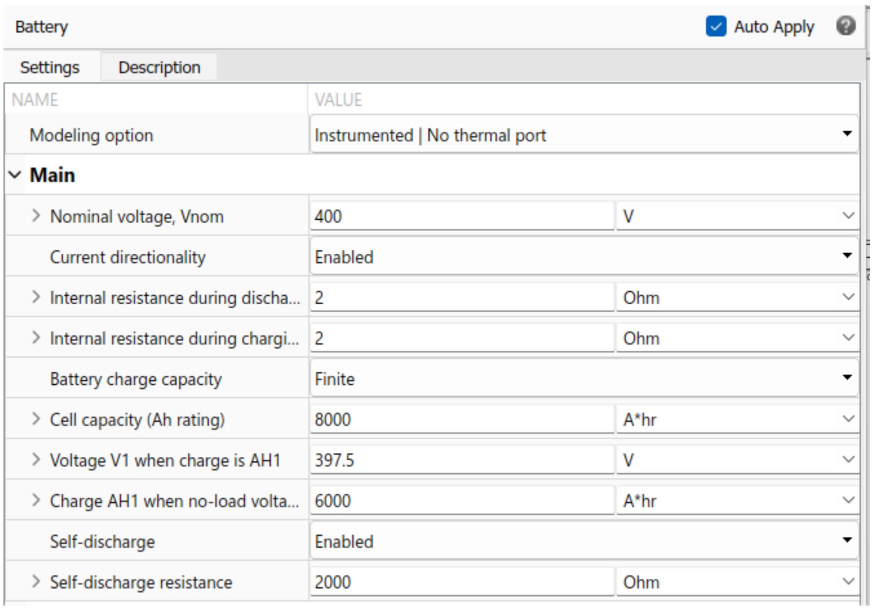


Figure 5.6 Battery Nominal Voltage Waveform

In this model we have used 8000AHr battery with nominal voltage of 400V and 20A.



Battery — Auto Apply

Settings | Description

NAME	VALUE	
Modeling option	Instrumented | No thermal port	
Main		
Nominal voltage, Vnom	400	V
Current directionality	Enabled	
Internal resistance during discha...	2	Ohm
Internal resistance during chargi...	2	Ohm
Battery charge capacity	Finite	
Cell capacity (Ah rating)	8000	A*hr
Voltage V1 when charge is AH1	397.5	V
Charge AH1 when no-load volta...	6000	A*hr
Self-discharge	Enabled	
Self-discharge resistance	2000	Ohm

Figure 5.7 Battery Specification

5.7 STATE OF CHARGE

The Battery State of Charge (SoC) in Electric Vehicles (EVs) represents the remaining energy as a percentage of the total battery capacity. It is a crucial parameter for EV management systems, informing drivers about the available driving range. Accurate SoC measurement is essential for optimizing battery performance, preventing overcharging or deep discharging, and ensuring longevity. Sophisticated Battery Management Systems (BMS) use voltage, current, and temperature data to estimate SoC. Precise SoC information enables intelligent energy management, enhancing efficiency, and supporting features like regenerative braking. Maintaining an optimal SoC is vital for maximizing the driving range and overall performance of electric vehicles.

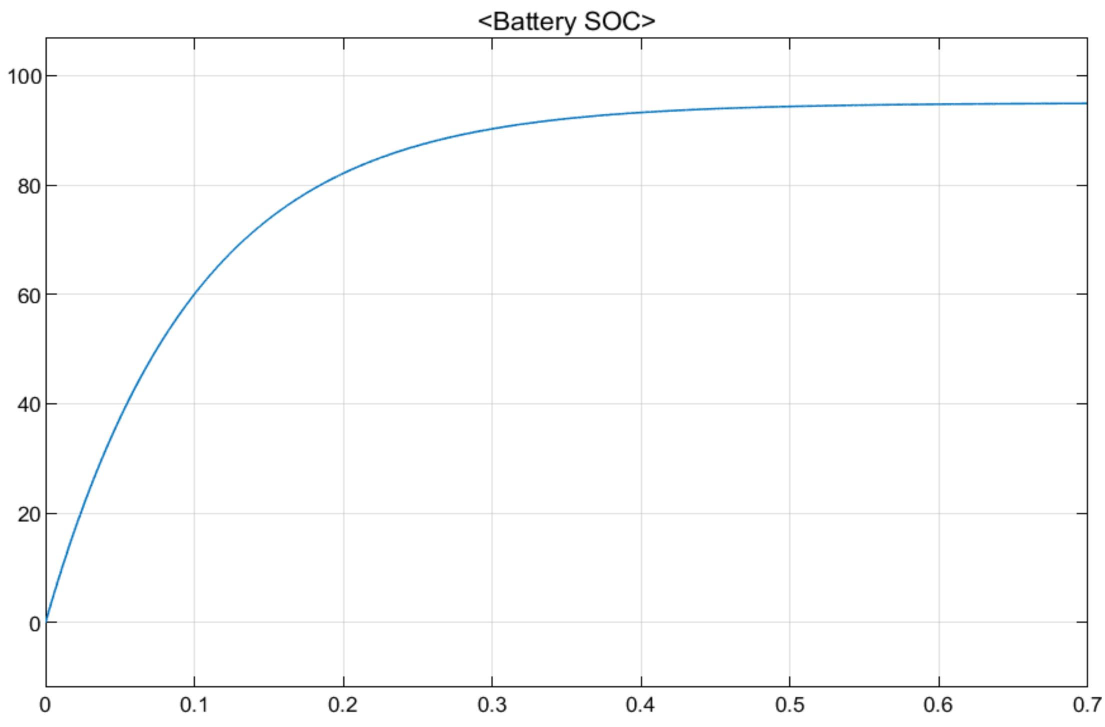


Figure 5.8 Battery State of Charge Waveform

CHAPTER 6

CONCLUSION

In this project the size of front-end filter size is reduced by using the stator winding of the traction motor as grid interfacing filter, Also ZVS Bi-directional DC-DC converter is employed instead of a conventional bidirectional DC-DC converter. By using the ZVS converter the switching loss will be reduced in the system and the efficiency of the system will be increased compared to the conventional model using three level DC-DC converter. The Total Harmonic Distortion of the source current with 230v as input voltage is calculated to be 3% with conventional converters. The THD in the presented model is found to be 2.8%. The switching loss of the conventional bidirectional DC-DC converter is found to be 0.24W. The switching loss of the ZVS bidirectional DC-DC converter is found to 0.03W. Thus using the ZVS converter reduces the switching losses in the system and which results in increase of efficiency compared to the conventional model using three level DC-DC converter.

REFERENCES

1. Bhajana, VVSK., Drabek, P., Jara, M., Popuri, M., Iqbal, A., Chitti, Babu B. (2021) 'Investigation of a bidirectional DC/DC converter with zero-voltage switching operation for battery interfaces', doi.org/10.1049/pel2.12048.

2. De Sousa, L., Silvestre, B. and Bouchez, B. (2010) 'A combined multiphase electric drive and fast battery charger for Electric Vehicles' pp. 1-6, doi: 10.1109/VPPC.2010.5729057.

3. Gupta, J., Maurya, R. and Arya, S.R. (2020) 'Improved Power Quality On-Board Integrated Charger With Reduced Switching Stress' vol. 35, no. 10, pp. 10810-10820, Oct. 2020, doi: 10.1109/TPEL.2020.2981955.

4. Kamble, A.S. and Swami, P.S. (2018) 'On-Board Integrated Charger for Electric Vehicle Based on Split Three Phase Induction Motor', pp. 1-5, doi: 10.1109/ ICETIETR.2018.8529144.

5. Na, T., Yuan, X., Tang, J. and Zhang, Q. (2019) 'A Review of On-Board Integrated Charger for Electric Vehicles and A New Solution' pp. 693-699, doi: 10.1109/PEDG.2019.8807565.

6. Pellegrino, G., Armando, E. and Guglielmi, P. (2010) 'An Integral Battery Charger With Power Factor Correction for Electric Scooter' vol.25, No.3, pp.751-759, doi: 10.1109/TPEL.2009.2033187.

7. Raju, R.G.G. and Subramaniam, N.P. (2010) 'A novel ZVS bidirectional converter for fuel cell electric vehicle driving system' pp. 339-343, doi: 10.1109/FAME. 2010.5714856.

8. Sharma, S., Aware, M.V. and Bhowate, A. (2020) 'Integrated Battery Charger for EV by Using Three-Phase Induction Motor Stator Windings as Filter' vol. 6, no. 1, pp. 83- 94, doi: 10.1109/TTE.2020.2972765.