DESIGN AND IMPLEMENTATION OF PFC FULL BRIDGE PHASE SHIFT CONVERTER FOR EV BATTERY CHARGING

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by

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Certified that **Avinash Singh Gautam** (23/C&I/07) has carried out his research work presented in this thesis entitled "**DESIGN AND IMPLEMENTATION OF PFC FULL BRIDGE PHASE SHIFT CONVERTER FOR EV BATTERY CHARGING**" for the award of Master of Technology from Department of Electrical Engineering, Delhi Technological University, New Delhi under our supervision. The thesis embodies results of original work, and studies carried out by the student himself and the contents of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

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ABSTRACT

The research work describes the design and implementation of a PFC full bridge phase shift converter for EV battery charging. It has a Power factor correction (PFC) unit at front end using boost converter followed by a phase-shift full-bridge (PSFB) converter. The PFC boost stage enables the charger to reach a nearly ideal power factor with an input current THD below 5%. The PSFB converter delivers power transfer to the load from the external power source to the battery. An optimized power conversion approach in the system decreases both voltage and current ripples and improves stability and reliability of the battery charging operation. A proto-type converter circuit is designed and experimentally tested to verify the performance of the converter. The PSFB converter technology enables high-quality power delivery and energy-efficient transfer and thus represents an effective solution for electric vehicle charging needs.

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Parameters	**Definitions**
V_{out}	Output Voltage
V_{in}	Input Voltage
D	Duty ratio
ΔI_L	Output ripple current
f_s	Switching Frequency
I_{out}	Output Current
ΔV_{out}	Output Ripple Voltage
C_{dc}	Output Capacitor of PFC Boost Converter
N_r	Transformer Turns Ratio
N_p	No. of Primary Turns
N_s	No. of Secondary Turns
C_b	DC link capacitance
K_p	Proportional gain
$e(\tau)$	Instantaneous error at time t
V_{ref}	Reference Voltage
V_{out}	Output Voltage

CHAPTER 1

INTRODUCTION

1.1 Introduction

In recent years, significant global concern has been expressed regarding environmental degradation caused by the continuous reliance on fossil fuels. This concern has arisen due to the increased emission of greenhouse gases, elevated levels of urban air pollutants, and the unsustainable nature of fossil fuel dependence. As the transportation sector has been identified as a major contributor to carbon dioxide (CO_2) emissions, targeted efforts have been made to reduce its environmental impact. In response, electric vehicles (EVs) have been adopted as a sustainable alternative to conventional internal combustion engine vehicles. Through the use of EVs, zero tailpipe emissions can be achieved, energy efficiency can be improved, and integration with various forms of clean and renewable energy can be facilitated [1] [2].

On the other hand, the rise in electric mobility has been accompanied by new challenges, particularly the need to establish reliable and scalable EV charging infrastructure [3]. It has become essential for EV charging to be supported by systems that provide appropriate charging speed, ensure user safety, and comply with existing power quality standards [4]. Therefore, the development of EV chargers that are energy efficient, electrically safe, capable of handling grid fluctuations, and able to maintain stable power output has been recognized as a critical area of research.

The interaction of EV chargers with the electrical grid has been identified as one of the primary design considerations. If not properly designed, a charger can generate distorted current waveforms on the AC side [5], resulting in elevated total harmonic distortion (THD) and a poor power factor [6]. These conditions can degrade overall power quality, lead to non-compliance with grid regulations, reduce system efficiency, and adversely affect the performance of other sensitive equipment connected to the same supply [7]. Consequently, the ability of the charger to regulate its power factor and minimize harmonic content has been regarded as a crucial requirement for any modern charging system [8].

These challenges have been addressed by researchers through the implementation of two-stage power conversion architectures [9], which have been recognized for their efficiency and flexibility. In this dissertation, the design and realization of a two-stage AC-DC EV charger have been presented [10]. In the first stage of the system, a Power Factor Correction (PFC) boost converter has been employed to rectify the AC input while shaping the input current to follow the sinusoidal voltage waveform [11]. The ability to generate harmonic currents within acceptable limits has been considered essential [12], as it ensures compliance with relevant standards, such as IEC 61000-3-2 [13]. Furthermore, the boost converter has been configured to maintain a stable and sufficiently high DC link voltage, which is then supplied to the second stage of the system [14].

The Phase-Shifted Full-Bridge (PSFB) converter has been utilized to step down the high DC voltage to a suitable level for battery charging, while simultaneously providing galvanic isolation between the AC mains and the battery system [16]. A high-frequency transformer within the PSFB network has been employed to ensure safe and reliable operation. When both power stages are integrated, the EV charger is capable of delivering accurately regulated and electrically isolated DC power to the vehicle's battery [17].

1.2 Motivation

The increasing global demand for electric vehicles (EVs) has led to a growing need for efficient, robust, and grid-compatible charging systems. This trend motivated the present research work, as the development of high-performance EV chargers has become essential to support the shift toward sustainable transportation. A key objective was to ensure compliance with international standards such as IEC 61000 (which addresses electromagnetic compatibility and harmonic distortion) and IEC 61851 (which defines the technical requirements of EV charging systems) [18]. The primary aim of the proposed charger design was to achieve reliable operation, efficient energy transfer, and user safety under diverse grid and load conditions. A major consideration was the realization of a high power factor on the AC side. By ensuring the alignment of current and voltage waveforms, reactive power consumption could be minimized and total harmonic distortion (THD) reduced, thereby improving power quality and lessening stress on the upstream grid [19]. To accomplish this, a Power Factor Correction (PFC) boost converter was incorporated to synchronize the input current waveform with the AC voltage waveform, ensuring regulatory compliance and enhancing system efficiency.

Further motivation was drawn from the need to deliver a flexible and accurate DC output suitable for various EV battery systems [21]. Whether constant current, constant voltage, or multi-stage charging profiles were required, the proposed system was designed to adapt dynamically to changing battery conditions and motor demands [22]. Robustness against short-term disturbances, load fluctuations, and sudden demand shifts was also addressed [23]. Galvanic isolation between the AC grid and the EV battery was achieved through the implementation of a Phase-Shifted Full-Bridge (PSFB) DC-DC converter, which included a high-frequency transformer to ensure electrical separation and compliance with safety norms [20].

1.3 Objectives

In this dissertation, a two-stage AC-DC converter topology has been designed and simulated for electric vehicle (EV) charging applications, involving a Power Factor Correction (PFC) boost converter followed by a Phase-Shifted Full-Bridge (PSFB) DC-DC converter. A near-unity power factor has been targeted at the input side by controlling the PFC boost stage, ensuring that harmonic distortion levels meet IEC 61000-3-2 standards. A stable and sufficiently high DC link voltage has been maintained between the two stages to support consistent downstream converter operation. Galvanic isolation between the grid and the EV battery has been provided through a high-frequency transformer in the PSFB stage, supporting safety and compliance with electrical norms.

A regulated and low-ripple DC output has been aimed for, allowing flexible battery charging under various profiles such as constant current (CC), constant voltage (CV), or multi-stage modes. The charger system has been modeled, simulated, and assessed using MATLAB/Simulink under different grid and load conditions. Closed-loop control strategies and PWM logic have been implemented using simulation control blocks to reflect realistic dynamic behavior. The system's performance in terms of power quality, efficiency, and reliability has been thoroughly evaluated based on the simulation outcomes and checked against standard performance requirements.

1.4 System Overview and Scope

The electric vehicle (EV) charger system is designed by carrying out a simulation which focuses on three main subsystems: the Power Factor Correction (PFC) Boost Converter, the Phase-Shifted Full-Bridge (PSFB) DC-DC Converter, and the circuit used to control the gates for switching.

The first important part is identified as the PFC Boost Converter, which is used to change the main AC power into a more usable high-voltage DC. The primary function of an inverter is defined as converting DC voltage into a stable AC output while ensuring that the input current is made to follow the AC voltage waveform. Syncing these groups of frequencies results in less distortion, a better power factor, and compliance with the required grid quality rules set by IEC 61000-3-2. Within the simulator, the PFC stage is analyzed under different load conditions [34], and it is checked to confirm that near-unity power factor is maintained to reduce reactive power use and improve energy efficiency [35].

The high voltage DC from the PFC stage is taken by the PSFB DC-DC Converter and changed to a regulated DC level needed for battery charging [36]. The ability of the converter to separate the grid-side circuitry from its output is considered very important. Using an RF transformer model, this isolation is provided to separate the vehicle and the user from any grid-related electrical errors or transients [37]. High voltage is effectively reduced by the PSFB converter for high-power applications, and steady temperature and stability are maintained by the system when it is permanently switched on.

The gate signal control logic is represented in digital form during simulation, and the theoretical role of setting the switching states for MOSFET devices is played by it. The role of gate drivers is duplicated by them to ensure that the timing of switching is correct. In a usual hardware system, voltage expansion, isolation, and dead time are managed by physical gate drivers [39]. However, since logical logic is used in the simulation, timing control and logical blocks are employed to prevent two switches from operating simultaneously, ensure accurate dead-time insertion, and replicate fault protection measures [40]. Such features are required to prevent short circuits and improve the safety and long-term reliability of the simulated switching system.

1.5 Scope of Work

In this field, EV chargers need to be understood by engineers on both theoretical and practical levels. Then, the process is started by designing the two main converter stages, such as the PFC converter and the PSFB converter, on paper. Theory is used by engineers to analyze power, design equipment, and assess the control process during the making of these converters. After the first design requirements are set, the system can be simulated on MATLAB/Simulink.

Time-based simulations are conducted, harmonic distortion is reviewed, loops are tested, and thermal results for hardware are predicted before hardware production. After all the simulations are confirmed, the schematics are compiled and the layout is created for the PCB. The power driver and gate driver circuits are also included, as they ensure safety and high-speed operation of the transistors. Code Composer Studio (CCS) is then used to develop and test the control algorithm once the hardware is manufactured. The PWM signal is generated, feedback is gathered, and the converters are adjusted with the help of the code. When the system is running, various tests on the power flow are performed to check its stability and overall robustness.

During development, professionals monitor and ensure that parameters such as efficiency, input power factor, the ability to regulate power and how much heat it generates are all in an acceptable range and meet design standards.

1.6 Literature Review

A comprehensive body of research has been explored in recent years to understand and refine electric vehicle (EV) charging systems. As the world steadily shifts towards sustainable modes of transport, there has been a noticeable rise in the simulation-based development of EV chargers. Theoretical frameworks have been established largely through modeling and simulation environments [36], where systems are analyzed and validated without the need for physical prototypes. This literature review draws upon numerous such studies, emphasizing how simulation has been used to investigate, improve, and optimize charger behavior in line with emerging global standard.

The literature has been primarily focused on studying various power conversion techniques, control strategies, and topology configurations through tools such as MATLAB/Simulink. By using these platforms, theoretical constructs could be tested in a highly controlled, repeatable, and flexible manner. Complex behaviors under transient conditions, fault occurrences, and variable load scenarios were able to be examined in greater depth, and the limitations of hardware constraints were effectively bypassed [42].

It has been recognized that simulation-based research plays a pivotal role in the early stages of charger design. Control systems such as feedback loops, PWM modulation, and switching sequences have been thoroughly examined in these environments, providing valuable insights into system dynamics and regulation efficiency [43]. Rather than being restricted by hardware limitations, these systems were represented logically—allowing focus to remain solely on control accuracy, timing coordination, and system stability.

Additionally, it was consistently noted that the modeling of gate-driving functions—such as dead-time control and timing precision—was carried out virtually [44]. Though in practice these are managed via driver ICs, the same functional behavior could be emulated within the simulation framework [45]. This allowed the switching behavior of semiconductors to be studied under theoretical conditions, ensuring that results mirrored real-world responses while remaining within the scope of a software-based environment.

Studies have also emphasized that certain charger topologies exhibit superior performance under simulation. Among them, the two-stage architecture has repeatedly been validated for its modularity, clarity of control, and efficiency [46]. This configuration, which includes a Power Factor Correction (PFC) stage followed by a Phase-Shifted Full-Bridge (PSFB) DC-DC converter, has become widely accepted across simulation-based research for its ability to isolate and optimize each function individually.

1.6.1 Two-Stage Charger Architecture

The two-stage architecture has been presented in literature as a highly adaptable and efficient configuration for EV chargers. In the simulation environment, this architecture is not only easier to analyze but also allows each stage to be designed, tuned, and evaluated independently. The separation of the input stage (PFC) and output stage (DC-DC) has enabled simulation researchers to focus on specific performance metrics relevant to each functional block.

The PFC stage, often modeled as a boost converter, has been shown in simulations to significantly improve the power factor, sometimes nearing unity. This improvement has been credited with reducing current harmonics, improving input current waveform shaping, and aligning better with international standards such as IEC 61000-3-2. In the absence of hardware concerns, simulations could precisely tune PFC parameters to study their impact on input quality and downstream conversion efficiency.

Interleaved and bridgeless topologies within the PFC stage have also been widely studied through simulation. These designs were implemented virtually to evaluate their influence on input current ripple, switching losses, and electromagnetic behaviour [48]. It was found that interleaving helped distribute the energy processing load more uniformly, while bridgeless designs minimized conduction paths—both contributing to a more stable and efficient simulated system.

Furthermore, the modular nature of the two-stage architecture has supported iterative simulation design. Control strategies could be independently modeled for the PFC and DC-DC stages, enabling specific behaviors—such as input voltage adaptation, output voltage tracking, and fault mitigation—to be tested under diverse virtual scenarios. Because each stage was simulated in isolation and then as part of a larger model, optimization was made more systematic and predictable.

1.6.2 Phase-Shifted Full-Bridge (PSFB) Converter

The PSFB converter has been examined extensively in the context of the second stage of EV chargers [50]. Through simulation, this converter has been validated as a suitable method for stepping down high-voltage DC into a controlled, lower-voltage output suitable for battery charging. Its operation has been modeled to demonstrate both efficiency and flexibility, especially under varying load and voltage conditions.

In theoretical studies, the galvanic isolation provided by the PSFB's transformer has been virtually simulated to prevent disturbances on the grid side from affecting the battery side. The control mechanism, involving a variable phase shift between switching elements, has allowed precise regulation of the output power. This method, implemented within simulation tools, has been shown to offer excellent performance for dynamic charging needs.

What has also been consistently observed is the PSFB's ability to operate at high frequencies, allowing the use of compact components in simulation and faster system response times. These high-frequency switching conditions have contributed to a deeper understanding of ripple reduction, efficiency enhancement, and control resolution. With the absence of hardware constraints, simulation has enabled this converter's full range of operating parameters to be thoroughly explored.

In particular, phase-shift modulation has been modeled to investigate its effects on soft switching, duty cycle variation, and thermal behavior—all within a logical simulation framework. The studies have emphasized how load adaptability and output regulation remain robust even under extreme virtual test cases. As a result, the PSFB has been consistently highlighted in literature as a top candidate for inclusion in simulation-based charger models.

CHAPTER 2

MATHEMATICAL MODELLING

2.1 Introduction

As the adoption of electric vehicles (EVs) continues to grow, the need for high-performance charging infrastructure that complies with global power quality and safety standards has been recognized. In this dissertation, a converter system has been proposed to address these challenges using a two-stage simulation-based architecture. By adopting this structure, the behavior of the power conversion stages has been thoroughly analyzed and validated entirely through simulation. The system has been designed with the intent to serve various charging environments—including residential setups, commercial installations, renewable energy systems, and modern smart grids—highlighting the need for flexibility, modularity, and adaptability to evolving loads and grid conditions. To meet these demands, key performance parameters such as high power factor, low harmonic distortion, voltage stability, output isolation, and compatibility with a range of battery chemistries and capacities have been targeted.

In the proposed approach, a reliable two-stage EV charger topology has been modeled and studied. In the first stage, a Power Factor Correction (PFC) boost converter has been employed to convert AC input into a regulated high-voltage DC output [5]. By using this topology, the system draws minimal reactive power, reduces total harmonic distortion (THD), and complies with the IEC 61000-3-2 power quality standard. Following this, a Phase-Shifted Full-Bridge (PSFB) DC-DC converter has been implemented to provide galvanic isolation and to step down the high DC voltage to battery-compatible levels. Stable and efficient power delivery has been ensured by the PSFB stage, even under variable load conditions, and the design has been made compatible with different battery configurations.

The entire system has been simulated and analyzed using MATLAB/Simulink. Instead of implementing hardware-based control, all feedback loops, timing signals, and logic operations have been digitally modeled and executed within the simulation environment. Pulse-width modulation (PWM) signals, phase-shifting control, feedback regulation, and protective mechanisms against overvoltage and overcurrent have been configured through digital control blocks. This simulation-based method has allowed detailed investigation of charger behavior under steady-state, transient, and fault conditions without the cost and complexity of physical prototyping. Through this modeling, the viability and performance of the two-stage EV charger system have been confirmed, supporting its theoretical foundation and opening pathways for further development. This section provides a detailed explanation of the system topology, control strategies, subsystem requirements, and the rationale behind each design stage.

2.2 System Architecture

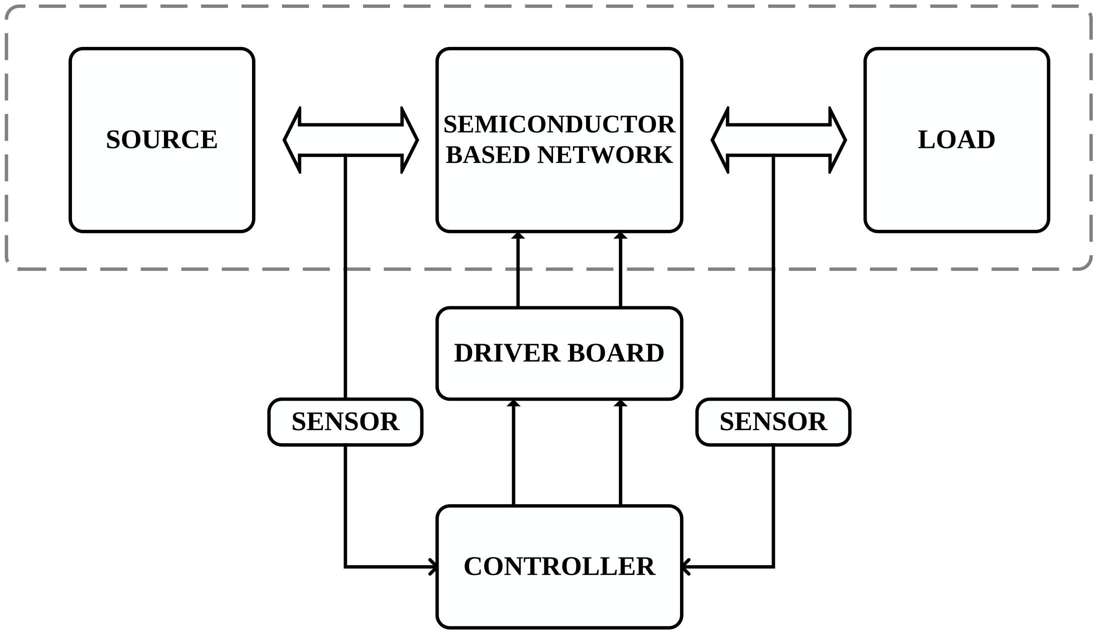

Fig.2.1: Block Diagram of PFC Boost Converter

This architecture diagram represents a control system typically used in power electronic converters or smart power distribution systems. The architecture has been divided into three major blocks: the Source to Load path (upper section), the Control and Sensing loop (middle and bottom), and the Semiconductor-based switching network. Each of these blocks is interconnected to enable closed-loop operation and efficient control of power flow.

In the upper portion, power is supplied by the Source and transferred through the Semiconductor-Based Network to the Load. This path is used for power conversion or conditioning, and it is implemented using semiconductor devices such as MOSFETs or IGBTs. The entire system (inside the dashed box) represents the power processing module.

In the lower portion, Sensors are used to measure electrical quantities (like voltage and current) from both the source side and load side. These measurements are fed to the Controller, which processes the data and generates appropriate control signals. These signals are then sent to the Driver Board, which amplifies and conditions them to drive the switches in the semiconductor network. By doing so, real-time control is achieved, and the desired operation maintained. Throughout this architecture, the data flow and control signals have been handled in a closed-loop manner, ensuring accuracy and efficiency in system performance.

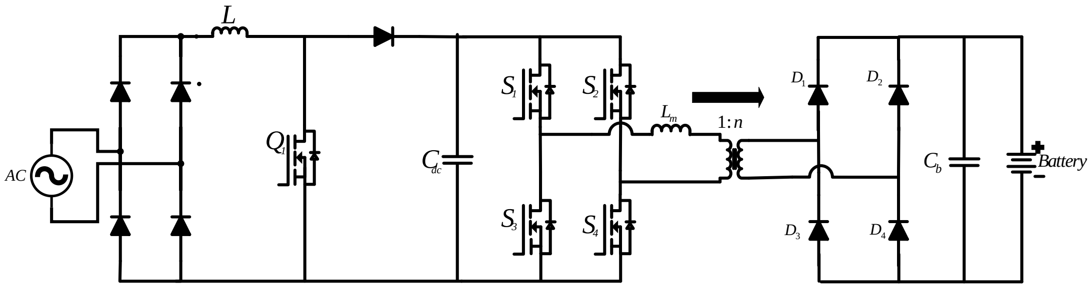

Fig.2.2: Block Diagram of the Proposed Two-Stage EV Charger Architecture

2.2.1 Input Stage and Power Factor Correction (PFC) Using Boost Converter

In the initial stage of the electric vehicle (EV) charger, an alternating current (AC) input is supplied from the grid. This input is first rectified using a diode bridge rectifier, through which the AC is converted into an unregulated direct current (DC) voltage. This rectified voltage is then processed through a boost converter, in which a boost inductor L and a switching device Q are used to step up the voltage to a desired DC level. The current drawn from the AC source is shaped by the boost converter to follow the waveform of the voltage, allowing the power factor to be improved significantly. Through this process, compliance with power quality standards such as IEC 61000 and IEEE 519 is ensured. A bulk capacitor C_{dc} is placed at the output of the boost stage to filter the voltage ripple and to provide a stable DC link for the following power stage. The control of this stage is handled by feedback loops that are implemented using sensors and a controller, by which continuous adjustment of the duty cycle of the switch is made.

2.2.2 Isolation and DC-DC Conversion Using PSFB Topology

Following the boost stage, the regulated DC voltage is transferred to a Phase-Shifted Full-Bridge (PSFB) converter, where electrical isolation and voltage level conversion are performed. The PSFB stage is composed of four active switches S_1 to S_4, which are controlled through a phase-shifted modulation scheme. A high-frequency transformer is used in this stage to provide galvanic isolation and to adjust the output voltage level based on the battery specifications. The primary side of the transformer is energized by the full-bridge converter, and the secondary side is connected to a full-bridge rectifier composed of four diodes D_1 to D_4.

These diodes rectify the alternating waveform produced at the transformer secondary to generate a unidirectional DC output. The rectified voltage is then smoothed using an output capacitor C_b, which is used to reduce voltage fluctuations and provide a consistent voltage at the battery input. The voltage conversion ratio is determined by the transformer turns ratio 1:n, which is selected based on the desired output voltage range.

All in all, thanks to the PFC and PSFB, this charger circuit converts AC power well, improves the quality of the electricity, separates the charging process and adjusts to various kinds of battery voltages, so it is a good fit for modern EV charging.

2.3 PFC Boost Converter Design and Implementation

The PFC (Power Factor Correction) Boost converter comes first in the EV charger and converts AC from the utility grid to a regulated DC output while also enhancing the power factor. The main reason for using this converter is to make sure the current from the AC source is sinusoidal and in time with the voltage waveform which meets the requirements set by IEC 61000-3-2. Because it is easy to set up and operate, has steady input current and can supply a higher voltage than the highest input AC voltage, the boost topology is used. At this step of design, suitable values for the inductor, switch (usually a MOSFET), diode and output capacitor are selected so that the criteria of voltage ripple, efficiency and heat dissipation are met. To give better results and harmonic distortion, the PFC boost converter works in continuous conduction mode (CCM). The feedback loop of the electronic circuit uses a PI controller to adjust the converter’s output voltage and input current. As a result of the design, the output from the converter is different for different situations, but remains stable at 400 V DC, making the interface between the grid and charger rest, stable and energy efficient.

2.3.1 Introduction to PFC Boost Converter

Now, PFC boost converters are important for supporting Electric Vehicle (EV) chargers and their associated devices. A power converter is required to produce DC output, adjust the input AC voltage and ensure the output current is sinusoidal and following the power grid’s input. This is necessary so that EV chargers meet important international standards for power quality such as IEC 61000-3-2 [14][21].

In battery charging, the PFC boost converter is first step, converting AC into the right type of power for use in future converters. The chapter goes into detail about the circuit and how to use a PFC boost converter in EV charging, as well as the vital equations that control its behaviour.

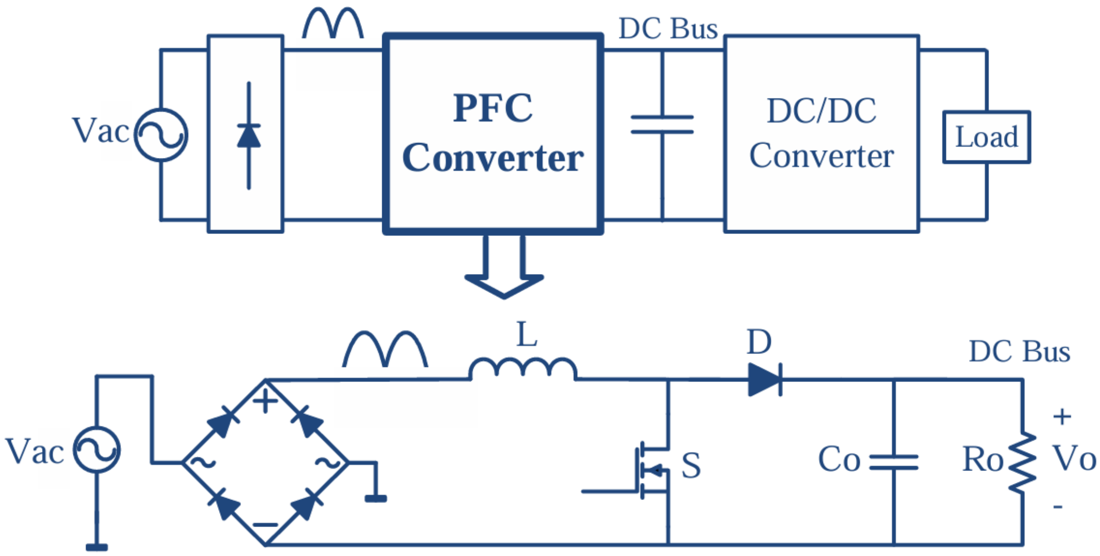

Fig.2.3. (a) Block Diagram, (b) Circuit Diagram

2.3.2 Importance of PFC Boost Converter in EV Charger

At the beginning of the EV charger, a PFC unit is required, as its inclusion is known to enhance system performance, support more effective power utilization, and ensure that regulatory standards are met. In this context, it is typically operated with a very high power factor, often close to unity, which is considered highly beneficial [51][21]. By aligning the current and voltage drawn from the source, the PFC stage ensures that the majority of the input power is used efficiently, with minimal losses caused by reactive components. As a result, better energy efficiency is achieved, and the electrical grid is maintained in a more stable and reliable state.

In addition, in various countries and regions, compliance with grid regulations is considered essential due to strict requirements related to Total Harmonic Distortion (THD) and power factor. When the boost stage in the PFC is properly applied, issues such as penalties, disturbances to nearby electrical equipment, and difficulties in obtaining certifications are effectively avoided. By ensuring alignment with utility standards, the system is made more suitable for large-scale implementation.

The PFC mode is used to ensure that the converter operates efficiently. By regulating the amount and type of current fed into the converter, the volume of losses occurring during the operation of upstream components is reduced. As a result, less heat is produced, allowing the overall setup to remain both reliable and more compact. In addition, the PFC stage is employed to suppress electromagnetic interference and minimize current harmonics, which leads to a significant reduction in total harmonic distortion (THD) [7][5]. This allows the system to meet EMC requirements, enhancing its reliability in sensitive environments where nearby electronics could otherwise be affected [20].

A significant role is played by the PFC boost converter in consistently regulating the voltage. The fluctuating AC source is converted into a smooth DC current—typically within the range of 380–400 V—which is then delivered to the subsequent DC-DC stage, such as a PSFB converter. By maintaining a steady DC bus voltage, the efficient functioning of the entire charging system is supported, while the appropriate voltage and current are provided for charging the EV battery. As a result, the inclusion of a PFC boost converter in the EV charger system enhances overall efficiency, improves safety, and helps reduce potential issues.

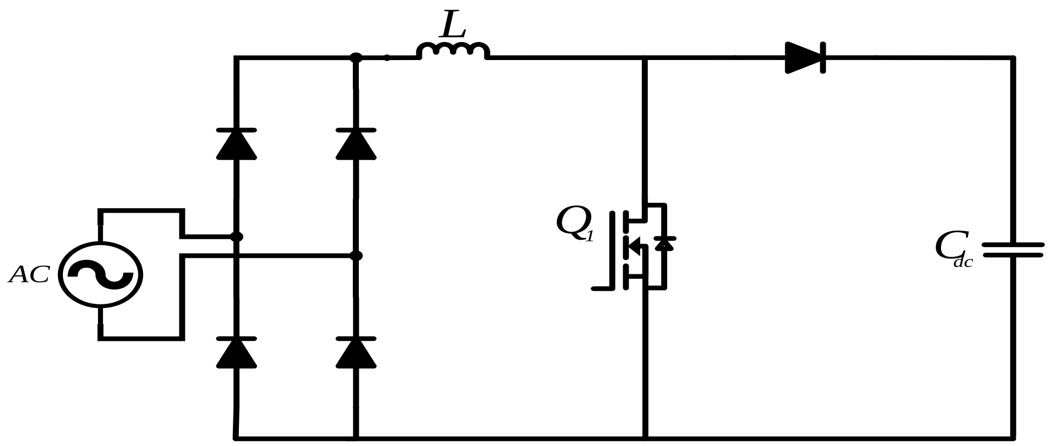

Fig.2.4 PFC Boost Converter Circuit Diagram

2.3.3 Design Equations for PFC Boost Converter

PFC boost converters are designed by selecting components in a way that the expected performance outcomes are achieved. To guide this process, a set of key equations is employed to determine important parameters such as the output voltage, inductance, capacitance, and current ripple [4][5].

1. Output Voltage: The output voltage V_{out} of a boost converter is given by the relationship between the input voltage V_{in} and the duty cycle D is expressed as:

$$V_{out} = \frac{V_{in}}{1-D} \tag{2.1}$$

2. Inductor Selection: The value of the boost inductor L is crucial for controlling the current ripple and energy transfer efficiency. The inductor value can be determined using the equation:

$$L = \frac{V_{in} \times D}{\Delta I_L \times f_s} \quad (2.2)$$

Where:

- f_s is the switching frequency,
- ΔI_L is the peak-to-peak ripple current in the inductor.

3. Capacitor Selection: The output capacitor C_{dc} smooths the output voltage by filtering out high-frequency ripple. The capacitor is selected based on the allowed output voltage ripple ΔV_{out}, and the output current I_{out}. The equation for C is:

$C_{dc} = \frac{I_{\text{out}}}{f_s \times \Delta V_{\text{out}}}$ I_{out} is the output currentΔV_{out} is the allowable output voltage

4. Current Ripple: The current ripple ΔI_L in the boost converter depends on the value of inductor, switching frequency, and duty cycle. The ripple current can be calculated using:

$$\Delta I_L = \frac{V_{in} \times D}{L \times f_s} \quad (2.3)$$

Where:

- D is the duty cycle,
- L is the inductor value,
- f_S is the switching frequency.

5. Power Factor: The PFC boost converter's power factor PF can be improved when the input current orients the waveform of the input voltage. It involves changing the duty cycle and modifying the current shape with the help of feedback.

6. The simulation results showed that the system could maintain a high power factor (greater than 0.98) and low total harmonic distortion under various load conditions. The ripple voltage was also well within the acceptable limits for the following DC-DC stage.

2.3.4 Boost Parameters

Table 2.1: Boost Parameters

Parameters	Values
Input voltage, V_s	230V
Output voltage, V_o	400V
Load current, I_L	3.75A
Duty cycle, D	0.4
Inductance, L	2.34mH
Capacitance, C	1000µF
Switching frequency, f_s	20kHz

2.4 PSFB Converter Design and Implementation

In this section, the focus is placed on the design process and functional understanding of the Phase-Shifted Full-Bridge (PSFB) DC-DC converter, which is regarded as a vital component of the two-stage EV charger system. This converter is chosen for its capability to manage high power levels while ensuring galvanic isolation and regulated output voltage. To ensure that performance, safety, and reliability standards are met, a thorough analysis is conducted. The overall approach is shaped by established power electronics principles and is further validated through simulation tools, by which real-world behavior under varying load conditions is carefully examined.

2.4.1 Introduction to PSFB Converter

The PSFB converter is recognized for its high efficiency and reliable performance in large DC-DC systems. Due to its greater efficiency, provision of galvanic isolation, and effective operation across a wide voltage range, it is considered well-suited for EV charging applications [23][27]. In such systems, the AC output from the grid is first converted into a stabilized high-voltage DC signal (up to 400 V DC) by the Power Factor Correction (PFC) boost converter, after which the second stage is operated by the PSFB converter.

The PSFB converter is tasked with isolating the grid from the battery and reducing the DC voltage to ensure safe charging of the EV battery. A galvanic isolation is provided by the high-frequency transformer within the PSFB, which prevents direct connection between the input and output, thereby protecting both the user and the system [6][16]. As a result of this isolation, neither the vehicle nor its battery is exposed to faults at the DC level caused by power surges originating from the AC grid.

The structure of the PSFB converter is composed of four power MOSFETs arranged in a full-bridge, or H-bridge, configuration. The main feature of this converter is defined by its ability to delay switching between one leg of the full bridge and the other using a phase-shift control technique. The amount of energy transferred to the output is determined by this delay, which also affects the output voltage.

In this chapter, the design, working principle, and implementation of the PSFB converter within the EV charger are explored in detail. Standards for critical features, such as the transformer's turns ratio, output filter components, and switching levels, are outlined. Additionally, the essential design equations are presented, which connect the input voltage, duty cycle, and output parameter values, providing a clear understanding of the converter's operation.

2.4.2 Importance of PSFB Converter in EV Charger

The PSFB converter is placed as the second stage in an EV charger, providing the necessary insulation after the AC power has been rectified, the power factor corrected, and the DC voltage converted by the PFC boost converter. Its role in the EV charger is considered essential, as it not only changes the voltage but also offers important electrical and operational benefits. During this stage, galvanic isolation is provided by the PSFB converter, ensuring that no direct current flows from the grid to the battery charging circuit.

Power is isolated within the system by the transformer, which acts as a safeguard protecting against faults, electrical noise, or failures [24][27]. In the event of a malfunction occurring in either the power grid or the battery, the problem is prevented from spreading due to this isolation, thereby enhancing the safety and reliability of the overall system. Furthermore, a wide range of input voltages is accommodated by the PSFB converter, allowing adaptation to variations in the grid voltage [23][6]. Thanks to this flexibility, the charger is able to handle diverse power grid conditions and locations, ensuring greater robustness and wider applicability.

It is also considered important that the output voltage is regulated by the PSFB converter with high accuracy. Safe and efficient battery charging is ensured by maintaining precise control over the output voltage, which prevents undercharging—leading to capacity loss—and overcharging, which can cause damage due to overheating. Fast charging is recommended only under controlled conditions to preserve battery health and extend its lifespan. Thanks to the PSFB topology, ripple is minimized more effectively. Because high-speed operation and unwanted current separation are enabled by the converter, less stress is placed on the battery, resulting in improved charging performance [10][16].

Heating and internal damage to the battery are reduced by decreased ripple currents during high-current charging [16][24]. Because of these benefits, the PSFB converter is considered an ideal choice for safe, reliable, and high-power EV charging.

2.4.3 PSFB Converter Circuit Diagram

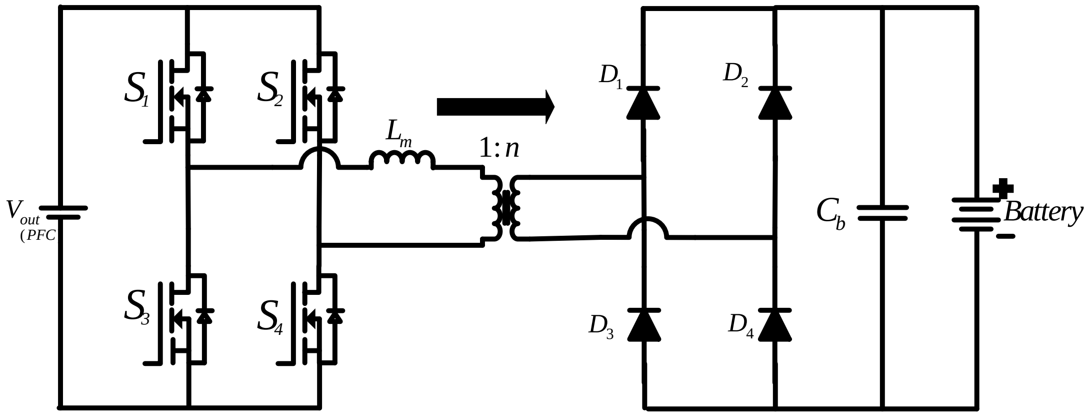

Fig.2.6: Phase Shift Full Bridge Converter

The PSFB converter is characterized by the inclusion of four MOSFET cross-linked switches arranged in a full-bridge configuration, along with a transformer that provides isolation protection. Four major components are used to make up the PSFB converter.

The input DC voltage, which is received from the PFC boost converter, forms the first element of the PSFB converter. Since the DC link is established in the PFC boost stage, this voltage—typically ranging from 300 V to 400 V—represents the DC link voltage. Although the exact value of the DC voltage may vary depending on the setup, it is ensured that it never exceeds or falls below the limits the converter can handle. This voltage is considered crucial, as it determines the starting point for voltage reduction needed in applications such as battery charging. To maintain optimal converter performance under any grid condition, the input DC voltage is kept within a proper range [4][22].

A full-bridge configuration is considered an essential part of the PSFB converter, consisting of four MOSFETs (S1, S2, S3, and S4) arranged in a full-bridge pattern. The switches are divided into two sets—(S1, S2) and (S3, S4)—with each pair operating in opposite switching actions. Power is efficiently transferred due to the ability of full-bridge transformers to allow current flow in both directions. At any given time, only one set of MOSFETs is kept conducting while the other remains idle, with the switching roles reversed during the next cycle. This arrangement enables effective use of the AC waveform, reducing losses typically observed in half-bridge converters.

In the PSFB converter, the inputs and outputs are isolated by the transformer, which also reduces the voltage to the level required for charging the battery. Fault currents are blocked by the transformer, protecting connected devices and safely separating the high-voltage grid from the charger system. Additionally, the necessary output voltage of 300 V to 400 V on the secondary side is provided by the transformer's turns ratio. By adjusting the turns ratio and duty cycle, the output voltage of the converter is matched to the input voltage as needed.

In the PSFB converter, the AC voltage is converted into DC by the primary-side rectifier, while the output rectifier performs the same function on the secondary side. Generally, a bridge rectifier system consisting of four diodes is used in the PSFB converter. The current is directed by the diodes to flow in the correct direction, transforming the AC waveform from the transformer into a steady DC output. This DC voltage correction is essential to ensure proper battery charging. Given the high switching frequencies involved, diodes that are suitable for fast switching are carefully selected to maintain efficient operation.

The DC output voltage is smoothed by the output capacitor to ensure uniformity. After rectification, some ripple remains due to the switching process, but this ripple is reduced by the capacitor, which removes high-frequency fluctuations. This allows the DC voltage to be safely and smoothly applied for battery charging. The capacitor's size is determined based on the allowable ripple and the power requirements of the EV charger. With the capacitor in place, the output voltage is kept stable, helping to ensure a fault-free charging process for both the battery and the charger.

2.4.4 Design Equations for PSFB Converter

To design a PSFB converter, certain equations are used to control its output voltage, duty cycle, and transformer turns ratio. The most important design equations are provided here for reference.

1. Output Voltage: The output voltage V_{out} of the PSFB converter is related to the input voltage V_{in} and the transformer turns ratio N_r by the following equation:

$$V_{out} = D \times V_{in} \times \frac{N_s}{N_p} \tag{2.4}$$

Where:

- V_{in} is the input voltage from the PFC converter,
- N_r is the transformer turns ratio,

- D is the duty cycle of the converter.

2. Transformer Turns Ratio: The turns ratio of the transformer N_r is chosen to step down the voltage to the desired level for battery charging. The turns ratio can be calculated as:

$$N_r = \frac{N_p}{N_s} \tag{2.5}$$

The turns ratio is a critical parameter as it directly affects the output voltage and current.
To determine the appropriate ratio, the following equation is used:

$$N_r = \frac{V_{\text{in}}}{D \times V_{\text{out}}} \tag{2.6}$$

3. Output Ripple Current: The current ripple at the output is influenced by the switching frequency f_s, inductance of the transformer, and the output capacitance. The equation for the output current ripple ΔI_{out}:

$$\Delta I_{out} = \frac{V_{out} \times (1 - D)}{L \times f_s} \tag{2.7}$$

Where:

- $L_{transformer}$ is the inductance of the transformer winding,
- f_s is the switching frequency.

2.4.5 PSFB Parameters

Table 2.2: PSFB Parameters

Parameters	Values
Input voltage, V_s	400V
Output voltage, V_o	56V
Load current, I_L	15A
Duty cycle, D	0.4
Inductance, L	3mH
Capacitance, C	1000µF
Switching frequency, f_s	20kHz

CHAPTER 3

CONTROLLER DESIGN

3.1 Introduction

Many issues are encountered in EV charging systems, such as fluctuating input from the grid, batch charging challenges, and risks to sensitive vehicle electronics when galvanic isolation is not provided. Because of these challenges, close control of voltages and currents is required by regulators, along with the reduction of ripple effects and the alignment of the current waveform with the input voltage to improve power factor. Compliance with IEC standards 61000 and 61851 mandates that chargers maintain a power factor close to unity and keep total harmonic distortion very low.

For this reason, a PI structure is employed in the dissertation as the basic control approach for both the PFC boost converter and the PSFB DC-DC converter stages. The PI controller is widely chosen because a good balance is offered between performance and simplicity. Unlike some other control techniques, extensive computation or costly hardware is not required by PI controllers, making them well-suited for use in both simulation and embedded platforms.

The reference value is compared with the actual system value by the PI controller, and a control signal is generated based on this information, taking into account the accumulated error over time. This approach allows quick adjustment to sudden changes and ongoing drifts, enabling the system to reach a steady state rapidly and maintain stability throughout operation. The reliability of PI controllers has been confirmed by both industrial and academic researchers, who have found that EV chargers respond quickly to input changes while providing consistent power.

n this chapter, the theoretical background of PI control is presented, along with its application in a two-stage EV charger system. The main function of the first stage, which includes a PFC boost converter, is to regulate the DC link voltage and improve the power factor through the use of a PI controller. Another PI controller is employed in the second stage, known as the PSFB DC-DC converter, to maintain a stable voltage at the battery terminals by controlling the power delivered through adjustments in the phase shift of the bridge switches. Models for both controllers were developed and fine-tuned using MATLAB/Simulink to achieve excellent performance during simulations involving various load and supply changes.

3.2 Overview of PI Control

The Proportional-Integral (PI) controller is widely used in many industrial and power applications due to its nature as a linear feedback control system. Equal importance is placed on ease of use and good performance, making it a reliable method for managing voltage, current, and various parameters in EV chargers. Since it is based on a simple mathematical model, the setup, tuning, and testing of the PI controller are made straightforward in systems that are linear or nearly linear.

At the center of the PI controller, the error signal—defined as the difference between the setpoint and the actual process output—is continuously monitored. To bring this error to zero, a control signal is generated based on the proportional and integral terms.

3.2.1 Proportional Action (P-Term)

The proportional component provides an output that is directly proportional to the current error. It is defined mathematically as:

$$P = K_p \cdot e(t) \tag{3.1}$$

where:

- P is the proportional output,
- K_p is the proportional gain,
- $e(\tau)$ is the instantaneous error at time t.

The proportional term causes a correction that increases as the magnitude of the error grows. The larger the error, the stronger the corrective action is applied. However, the steady-state error may not be completely eliminated by proportional control alone, especially in systems experiencing constant disturbances or slowly changing inputs. Because of this, the integral term is needed to address such issues.

3.2.2 Integral Action (I-Term)

The integral component accounts for the accumulation of past error over time and is defined as:

$$I = K_i \int_0^t e(\tau) d\tau \tag{3.2}$$

where:

- I is the integral output,

- K_i is the integral gain,
- $e(\tau)$ is the error at any previous time τ.

The steady-state error is removed by the integral action, which continuously accumulates the error over time. If any residual error remains uncorrected by the proportional term, the controller output is gradually increased by the integral term until the error is driven to zero. Because of this, the PI controller is made particularly effective for applications requiring high precision, such as the regulation of output voltage in power converters.

3.2.3 PI Controller Equation

Mathematically, the PI control function is expressed as:

$$u(t) = K_p \cdot e(t) + K_i \int_0^t e(\tau) d\tau \qquad (3.3)$$

Where:

- $u(t)$ is the control output (such as a duty cycle or phase shift),
- $e(\tau)$ is the instantaneous error between reference and actual values,
- K_p is the proportional gain (affects system speed),
- K_i is the integral gain (removes offset error).

PI controllers are preferred in power converters due to their balance between simplicity and effectiveness. Unlike PID controllers, they omit the derivative term, making them less susceptible to noise—a valuable feature in switching power systems. Proper tuning of K_p and K_i ensures optimal system performance, including fast settling, minimal overshoot, and stable steady-state operation.

3.3 PI Control for the PFC Boost Converter

The initial stage in an EV charger is taken by the PFC boost converter, which is tasked with ensuring efficient power conversion and adherence to proper power quality guidelines. Grid alternating current is converted into direct current by this stage, while the shape and phase of the input (AC) current are preserved. To handle changes in electricity demands and incoming sources, a good control strategy is applied, ensuring continuous cooperation between the system and the grid.

In this stage, a PI (Proportional-Integral) controller is employed to regulate the output voltage of the boost converter. The control scheme is designed using a closed-loop voltage control configuration, where the actual output voltage is continuously monitored and compared with a fixed reference value. The voltage error that results is processed by the PI controller, and the duty cycle of the PWM (Pulse Width Modulated) signal—used to control the switching of the boost converter's power switch (typically a MOSFET)—is then adjusted accordingly.

3.3.1 Working Principle of the Control Loop

The operation is begun by rectifying the AC supply voltage through a diode bridge, which converts it into a pulsating DC voltage. This voltage is then used as the input to the boost converter. The voltage is stepped up by the boost converter and delivered to the DC-link capacitor. The output voltage across the capacitor is sensed and fed back to the PI controller for regulation.

The error signal is computed as the difference between the reference DC-link voltage V_{ref} (400 V) and the actual measured output voltage V_{out}.

$$e_{PFC}(t) = V_{ref} - V_{out}(t) \tag{3.4}$$

This error is used by the PI controller to generate the control signal, which determines the required duty cycle D(t) for the PWM signal:

$$D(t) = K_p \cdot e_{PFC}(t) + K_i \int_0^t e_{PFC}(\tau) d\tau \tag{3.5}$$

Where:

- K_p is the proportional gain that reacts to the instantaneous deviation,
- K_i is the integral gain that eliminates steady-state error.

The duty cycle is adjusted by the controller, which directly influences the amount of energy transferred to the output capacitor during each switching cycle. As a result, the output voltage is stabilized at the desired level by the PI controller, even when input voltages or load conditions fluctuate.

3.3.2 Improvement in Power Factor

A key feature of this control approach is the indirect influence on the input current waveform. Although the output voltage is primarily regulated by the PI controller, the converter is made to draw a current from the grid that is proportional to the sinusoidal voltage waveform. This happens because the voltage regulation indirectly determines the amount of current needed by the converter at each moment. As a result, a sinusoidal and phase-aligned input current waveform is achieved, ensuring effective power factor correction. The benefit of a high power factor (close to 1) includes reduced reactive power draw from the grid, lower total harmonic distortion (THD), improved energy efficiency, compliance with international standards like IEC 61000-3-2.

3.4 Choice of PI Controller Over PID Controller

The derivative term found in a full PID (Proportional-Integral-Derivative) controller is often excluded in power electronic systems for practical reasons. Sensitivity to noise, which is common in fast-switching environments like DC-DC converters, is increased by the derivative action. In many power converter applications, priority is given to steady-state performance and disturbance rejection rather than extremely fast transient responses. Additionally, added complexity from the derivative term is not accompanied by a significant improvement in performance in most cases. Therefore, a PI controller is preferred as a reliable and efficient solution for EV charger applications, where precise regulation of voltage and current is required while keeping system noise and complexity to a minimum.

3.5 Simulation Behavior and Observations

The MATLAB/Simulink simulation results demonstrate that the PI controller maintains the DC-link voltage very close to the 400 V reference, even during line or load disturbances. The system shows minimal overshoot during startup and rapidly settles to the steady-state value. Additionally, the input current waveform is observed to follow the sinusoidal voltage waveform closely, validating the effectiveness of the control in achieving high power factor.

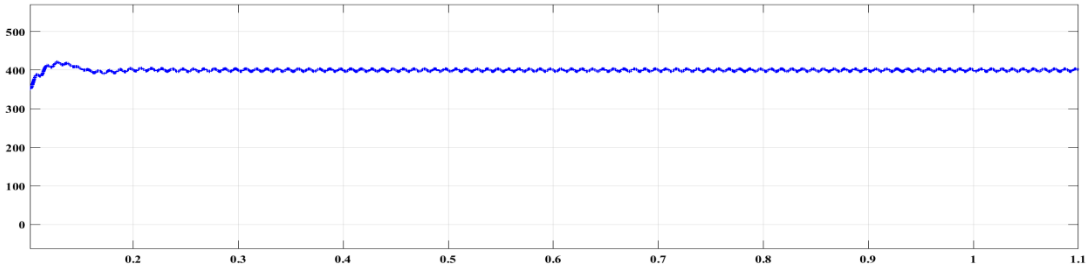

Fig.3.1: PFC Output

This confirms that the PI controller not only stabilizes the voltage but also helps meet grid standards by improving the quality of the power drawn from the utility. The control structure is simple yet powerful, making it suitable for implementation in both simulation and future real-time embedded systems.

3.6 PI Control for the PSFB Converter

The second stage of the two-stage EV charger system is formed by the Phase-Shifted Full-Bridge (PSFB) DC-DC converter. A critical role is played by this converter in stepping down the regulated high-voltage DC—typically around 400 V—provided by the PFC boost converter, to a lower voltage level compatible with the battery, usually 56 V. Galvanic isolation between the grid-side and vehicle-side circuits is also provided by the PSFB converter. This isolation is considered essential for ensuring user safety and protecting the system, as any faults or transients occurring on the grid are prevented from directly impacting the electric vehicle's battery and its sensitive electronics.

A stable and accurately regulated output voltage is maintained in the PSFB stage to ensure reliable battery charging, as fluctuations in the charging voltage can lead to reduced battery life, thermal stress, or potential safety risks. This challenge is addressed by implementing a PI controller, through which the converter's output voltage is regulated by controlling the phase shift between the legs of the full-bridge topology.

3.6.1 PSFB Converter Operation and Control Requirement

Four switches (MOSFETs or IGBTs) are used in the PSFB converter, arranged in a full-bridge configuration. A high-frequency AC signal is generated by the switching bridge and applied to the primary side of a transformer. On the secondary side, which typically features a center-tapped arrangement with diodes, this AC signal is rectified back into DC. The output is then filtered through an LC filter before being supplied to the load, which is the EV battery.

The unique feature of the PSFB converter lies in the control of output power through variation of the phase shift (ϕ) between the two legs of the bridge. At zero phase shift, no voltage is applied across the transformer primary, and consequently, no power transfer occurs. As the phase shift is increased, the effective duty cycle of the converter is raised, allowing more energy to be delivered to the output. Therefore, precise regulation of the output voltage is achieved by controlling the phase shift, even when input voltage and load conditions vary.

3.6.2 PI Control Strategy

To achieve closed-loop voltage regulation, the output voltage V_{bat} (t) is continuously sensed and compared with the desired reference value $V_{bat,ref}$The difference between them is the control error:

$$e_{PSFB}(t) = V_{bat,ref} - V_{bat}(t) \qquad 3.6$$

This error signal is then fed into the PI controller, which generates the required phase shift control signal (t) as follows:

$$D(t) = K_p e_{PSFB}(t) + K_i \int_0^t e_{PSFB}(\tau) d\tau \qquad 3.7$$

This controller ensures the output voltage stays stable under different input and load conditions while also shaping the input current waveform to follow the input voltage, resulting in improved power factor and reduced harmonic distortion.

Where:

- ϕ is the phase shift between the full-bridge switch pairs,
- K_p is the proportional gain,
- K_i is the integral gain.

The proportional term ensures that the converter reacts quickly to sudden voltage changes or transients, while the integral term ensures that even small, persistent errors are corrected over time, thereby eliminating steady-state offset.

This PI-controlled phase shift directly regulates the amount of power transferred to the output. An increase in the phase shift leads to more energy being delivered per switching cycle, and a decrease in phase shift reduces the energy delivered. This mechanism provides fine-grained control over the output voltage, ensuring it remains stable and within safe limits for the battery under all operating conditions.

3.6.3 Advantages of PI Control in PSFB

The use of a PI controller in the converter helps make the EV charger system more reliable and efficient. A key advantage is provided by the smooth and continuous control of the output voltage, which is achieved by carefully adjusting the delay of the switching legs in the full-bridge circuit. As a result, the power level delivered by the converter is automatically regulated to maintain the desired output voltage, even when input voltage or battery demand changes. Additionally, both the output voltage ripple and the energy consumption are reduced by the gradual adjustment of the phase shift, leading to an improvement in the overall system efficiency.

It is considered valuable that stability is maintained by the system even when rapid changes occur, such as unexpected increases in load. The proportional part of the PI controller provides immediate response, while accuracy over time is ensured by the integral part. Because of this, both precision and responsiveness are achieved simultaneously. The implementation of the PI controller is simplified, and minimal processor power is required, making it suitable for both simulation and practical use in embedded systems. Due to its simplicity, fewer complex algorithms are needed for effective operation. Overall, the power delivered by the PSFB converter is kept stable, secure, and of high quality through PI control, which is essential for electric vehicle charging systems.

3.7 PI Controller Design and Tuning

The adjustment of a PI (Proportional-Integral) controller is considered important for ensuring the stability, accuracy, and responsiveness of a power converter system. The quality of voltage regulation, ripple control, and the handling of disturbances from the input or load are all influenced by how effectively the PI controller is tuned within the context of an EV charger that incorporates both a PFC boost converter and a PSFB DC-DC converter.

3.7.1 Design Objectives

The inclusion of a PI controller in an EV charger is primarily intended to ensure reliable, safe, and efficient voltage control at each stage of the converter system. During the PFC boost stage, the DC-link voltage is maintained at a steady level, and the input current is shaped to be sinusoidal and synchronized with the input voltage. This approach enables the power factor to be improved and its essential standards to be met.

In the DC-DC converter stage of the PSFB, the output voltage is intended to be kept constant, isolated, and properly regulated so that safe battery charging can be ensured. At every stage, a fast response to changes in load or supply is expected from the control system, and the output voltage ripple is intended to be minimized while steady-state errors are to be avoided. These objectives are required to be fulfilled without the introduction of system instability, excessive overshoot, or prolonged settling times. Moreover, it is necessary for the control strategy to be suited for both simulation modeling and practical deployment in operational systems. For these purposes, a PI controller has been selected owing to its simplicity, ease of tuning, and well-established ability to deliver fast and dependable voltage regulation in power converter applications

3.7.2 Tuning Methodology

The tuning of the PI controller in this dissertation was carried out using a simulation-based iterative approach within the MATLAB/Simulink environment. The main goal of the tuning process was to achieve an optimal balance between fast dynamic response and stable steady-state performance. Initially, the proportional gain (K_p) was increased gradually from a low value while observing the system’s response to step changes in input voltage or load conditions. A suitable K_p was selected when the system exhibited a fast rise time without excessive overshoot or oscillations. Once a satisfactory proportional response was obtained, the integral gain (K_i) was introduced to eliminate any remaining steady-state error. The value of K_i was adjusted carefully to ensure that the system could correct offset over time without causing instability or integral windup.

To make sure every change was correct, simulations were run testing the response of the controller to startup, variations in load and voltage changes. Controller performance was improved by adjusting parameters according to settling time, peak overshoot, steady-state accuracy and the waveform quality of the input current. Following this careful process, the PI controller was able to keep the voltage steady and respond quickly to faults without compromising operation on either converter stage.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

The results of a simulation of the two-stage EV charger system, which incorporates a Power Factor Correction boost converter followed by a PSFB isolated DC-DC converter, are presented in this chapter. The model was developed and tested using MATLAB/Simulink, primarily to evaluate voltage regulation, current waveforms, system performance, and stability under both dynamic and steady-state conditions. Particular attention was given to assessing how well power stability is maintained, how accurately power adjustment is achieved, and how reliable the charging process remains. Input voltage and current waveforms, output voltage and current from the power factor correction stage, and the battery's state of charge were carefully analyzed to evaluate the effectiveness of the PI control method at each stage.

4.2 PFC Stage Waveform Analysis

The performance of the Power Factor Correction (PFC) stage is critical in ensuring the overall efficiency and reliability of the EV charger system. By carefully analyzing the waveforms produced during this stage, important insights can be gained about how effectively the voltage is regulated and how well the current waveform aligns with the input voltage. Such analysis helps in validating the design and control strategies employed, particularly the PI controller's role in maintaining a stable and clean output that meets required power quality standards.

4.2.1 PFC output Voltage

The PFC boost converter was designed to maintain a regulated voltage across the DC-link while correcting the power factor by shaping the input current to follow the waveform of the AC input voltage. During simulation, a clean and smooth sinusoidal input voltage waveform was observed, as expected from a typical grid supply. As a result of this, the input current was also shaped into a sinusoidal form and was kept in phase with the input voltage. This alignment demonstrated that the current waveform was effectively molded by the PI controller, leading to a power factor that was brought very close to unity.

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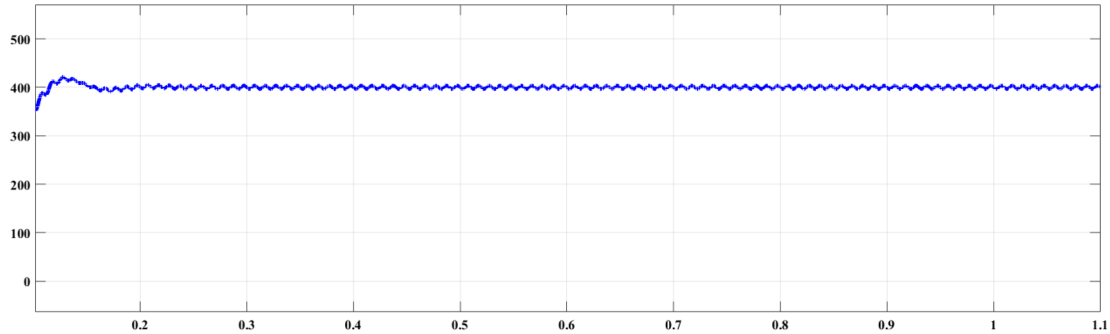

Fig.4.1: Output of PFC Boost Converter

The PFC stage is observed to produce a rectified and corrected DC output voltage from the boost converter, which is then passed on to the next stage of the charger system. The primary objective in a well-designed PFC boost converter is to raise the rectified AC input to a higher and more stable DC voltage—typically around 400 V—suitable for electric vehicle (EV) charging applications. This output voltage is maintained as the DC-link level required by the subsequent isolated DC-DC converter, namely the PSFB stage.

From the waveform, it can be observed that the voltage is boosted during the startup phase and is then maintained at a stable level, with only minimal ripple present. This steady yet rapid rise reflects the transient response of the boost converter, which is effectively managed by the PI controller to avoid overshoot and shorten the settling time. Once the reference voltage is reached, the waveform is seen to level off and remain consistently close to the target value, indicating strong steady-state regulation.

The slight variation in voltage is caused by the switching actions and has been minimized through the appropriate selection of capacitors and careful tuning of the control system. Due to the small ripple, a clean and stable voltage is received by the PSFB converter, allowing the battery to be charged in an efficient and dependable manner.

From the PFC output results, it has been observed that the converter is operating in continuous conduction mode (CCM), a mode known for delivering lower current ripple and producing high-quality waveforms—features well-suited for high-power applications. Moreover, the converter’s ability to maintain a steady output under changing conditions indicates that the control strategy has been effectively implemented and is actively managing real-time disturbances.

4.2.2 Input Current and voltage waveform

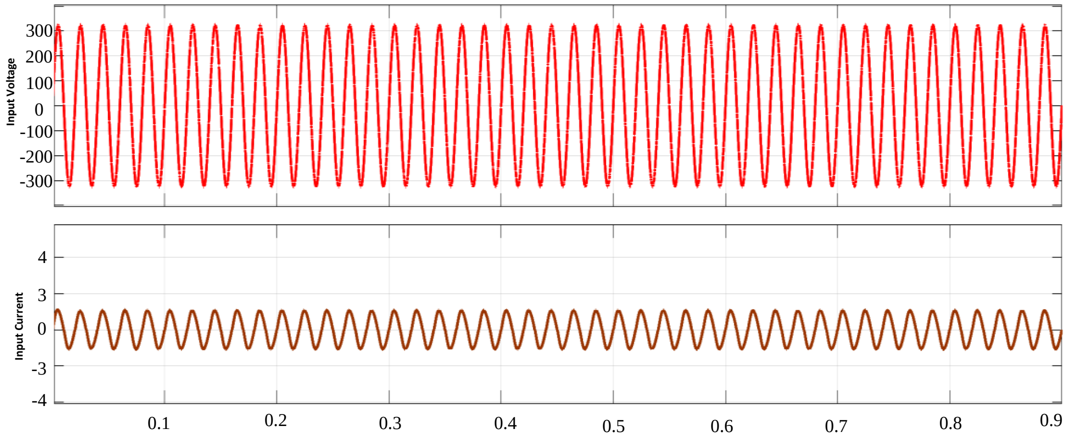

Fig.4.2: Input Current and Voltage waveform

The waveform illustrates the voltage applied to the PFC boost converter at the top, along with the corresponding input current shown at the bottom. This simulation result has been carefully examined because it helps to understand how power quality aspects—such as the alignment of input current with the AC supply—have been influenced by the action of the PFC converter.

The DC voltage shown in the figure has been derived from a 230 V RMS single-phase AC input after undergoing full-wave rectification, which results in a sine wave centered around zero voltage. The waveform has been observed to maintain a steady amplitude and consistent frequency, closely reflecting the characteristics typically associated with an AC supply provided by the grid.

Particular attention has been given to the behavior of the input current waveform, as it has been observed to closely follow the input voltage in both shape and phase. Through the action of the PI-controlled PFC boost converter, the current has been shaped to match the voltage variation effectively. A smooth and uninterrupted power flow has been achieved without noticeable distortion, which indicates that the converter has been operating in continuous conduction mode (CCM).

One of the main objectives of the PFC stage has been to bring the power factor as close to unity as possible. This has been made possible by shaping the current drawn from the supply so that it remains sinusoidal and in phase with the input voltage. From the waveform, it can be seen that effective power factor correction has been achieved—an important goal for any grid-connected power electronics system. In doing so, reactive power consumption has been minimized, and compliance with essential power quality standards such as IEC 61000-3-2 has been ensured.

Moreover, a low total harmonic distortion (THD) has been observed in the current waveform, which suggests that electromagnetic interference (EMI) has been minimized and the efficiency of energy conversion has been improved. High-frequency oscillations, harmonic distortion, or flattening at the waveform peaks have not been seen—features typically linked to poor PFC performance. Because of this, the simulation results have confirmed that the PI control loop has been successfully applied to modulate the switching of the boost converter and regulate the input current in an effective manner.

In conclusion, it can be observed from the waveform that the PFC stage of the EV charger is being operated exactly as intended. A sinusoidal input current, matching the input voltage in both frequency and phase, is being delivered while excellent current quality is maintained. As a result, improved efficiency is achieved, stress on the power grid is reduced, and compliance with regulatory standards is ensured.

4.2.3 Power Factor

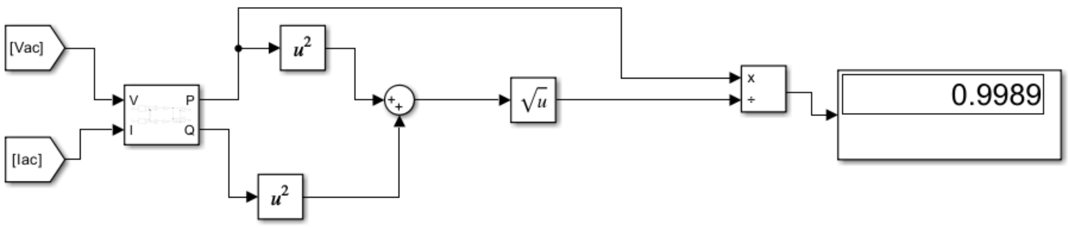

Fig.4.3: Power Factor

In the model, two input signals are used: the AC voltage V_{ac} and the AC current I_{ac}. These signals are taken directly from the input side of the PFC converter. The signals are passed into a power measurement block, which calculates real-time active power (P) and optionally reactive power (Q) and apparent power (S). However, in this structure, the apparent power is calculated manually using RMS values.

The real power (P) is measured directly as the average product of voltage and current over a full cycle. Meanwhile, the RMS values of voltage and current are obtained by squaring the V_{ac} and I_{ac} signals, integrating or averaging them over time, and then taking the square root. These operations are represented in the block diagram by the u^2 blocks (squaring), the summation and square root blocks, and finally the multiplication/division block to compute the apparent power:

$$S = V_{rms} \cdot I_{rms}$$

Then, the power factor (PF) is calculated as the ratio of real power to apparent power:

$$\text{Power Factor} = \frac{P}{S} = \frac{P}{V_{rms} \cdot I_{rms}}$$

The final value is shown in the output block, where it is observed to be approximately 0.9989 in this example, indicating an excellent power factor. Such a high power factor confirms that the input current is kept closely in phase and shape with the input voltage, thereby validating the effectiveness of the PFC boost converter and its PI control loop.

Achieving this level of power factor is considered critical for minimizing power losses, reducing harmonic pollution on the grid, and ensuring efficient power usage. It is demonstrated by this result that the EV charger design not only achieves voltage and current regulation but also complies with international grid requirements.

4.3 PSFB Stage Waveform Analysis

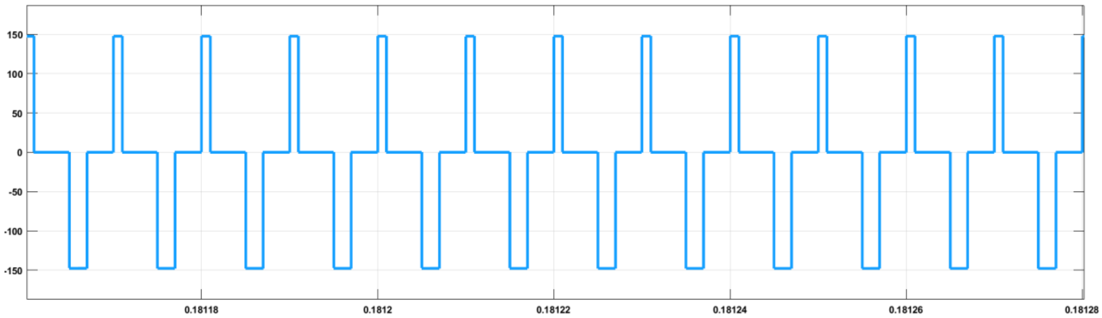

Fig.4.4: PSFB Primary waveform

The high-frequency square-wave voltage generated by the full-bridge switching network is represented by the primary side waveform. In the PSFB topology, this waveform is produced by alternating the conduction of two diagonal switch pairs (S_1 & S_4, and S_2 & S_3) with a controlled phase shift between them. The duration during which a net voltage is applied across the transformer's primary winding is modulated by this phase shift, thereby allowing the output power to be regulated.

The square shape of the waveform is recognized as typical for PSFB converters, with the peak voltage being approximately equal to the input DC-link voltage (400 V). Sharp transitions are observed, indicating that fast switching with minimal dead-time is being achieved, which contributes to high efficiency. The use of a high switching frequency also allows smaller transformers and filter components to be employed.

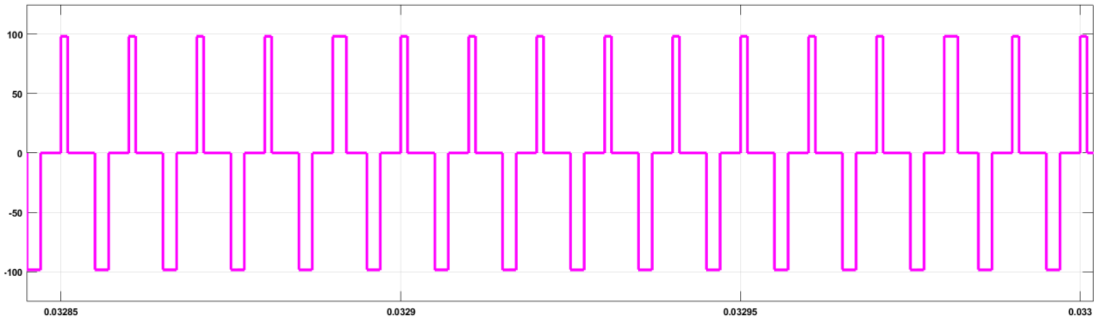

Fig.4.5: PSFB Secondary Waveform

The transformed voltage at the output side of the high-frequency transformer is represented by the secondary waveform. This waveform is modulated by the turns ratio (n:1) of the transformer, which steps down the high primary voltage to a level suitable for charging (56 V). Although the waveform retains a rectangular shape, visible modifications caused by diode rectification and load filtering are present.

The secondary waveform is typically made unipolar through the use of center-tap rectification. After rectification and LC filtering, a smooth DC voltage is delivered to the battery. Slight softening of the switching transitions on the secondary side occurs due to transformer leakage inductance and diode reverse recovery effects. However, overall, proper transformer action and timing alignment are confirmed by the waveform.

4.4 Overall output of proposed design

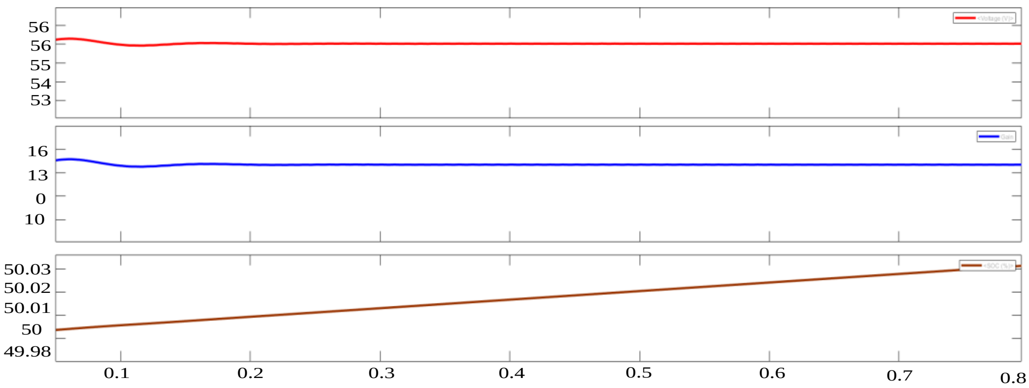

Fig.4.5: Output voltage, Current and SOC of Battery

Figure 4.5 presents the time-domain waveforms of the output voltage, output current, and the battery's state of charge (SOC) at the output side of the EV charger system. A comprehensive understanding of the PSFB converter's performance in delivering controlled and stable power to the battery is provided by these waveforms, which are observed under closed-loop regulation using a PI controller.

4.4.1 Output Voltage

The top graph displays the output voltage waveform in red. The voltage is seen to remain nearly constant at around 56 V, with only a slight dip occurring during the initial transient period (within the first 0.1 seconds) before stabilization. This transient behavior is considered normal during system startup, as the output capacitor is charged and the controller adjusts to reach the desired operating point. The quick settling time and low ripple demonstrate that the output is being effectively regulated by the PI controller, and that the converter is functioning in a stable mode. A tightly regulated output voltage is maintained to ensure safe battery charging, since even small deviations could impact battery health or charging speed.

4.4.2 Output Current

The middle graph presents the output current waveform in blue. A brief disturbance during startup is observed, followed by a rapid stabilization around 15–16 A. This steady current reflects consistent power delivery to the battery, enabling controlled charging. The smooth shape of the waveform confirms that power delivery remains stable, without oscillations or sudden drops that could suggest controller instability or switching problems. Maintaining a stable current profile is considered especially important for battery longevity, as large current spikes are known to accelerate battery cell degradation.

4.4.3 State of Charge (SOC)

The bottom graph illustrates the state of charge (SOC) of the battery in brown. A linear increase over time is observed, starting slightly below 50% and gradually reaching approximately 50.03% by 0.8 seconds. Although the change in SOC appears small within the short simulation period, this outcome is expected. The steady rise in SOC reflects the consistent power delivery from the converter and confirms that the battery charging is occurring in a controlled manner. The charging process is shown to be smooth and free from irregularities, thereby validating the effectiveness of the PSFB converter's regulation and the accuracy of the charging algorithm implemented in the simulation.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

The design, simulation, and construction of an electric vehicle (EV) charger consisting of a Power Factor Correction (PFC) boost converter and a Phase-Shifted Full-Bridge (PSFB) DC-DC converter were discussed. The system was aimed at creating a reliable charging solution that maintains a high power level, ensures electrical isolation between the supply and the EV battery, and guarantees safety. The charger was designed to improve the power factor of the AC supply and reduce total harmonic distortion (THD), thereby complying with grid standards. Equations were developed to select the optimal inductor and capacitor values, while frequency and duty cycle were taken into account to achieve optimal performance. Simulation results demonstrated that the boost stage operation stabilized the DC link voltage and provided an input current with a power factor nearly equal to unity. The PSFB converter was implemented primarily to provide galvanic isolation and regulate the output voltage. The design process included careful selection of the transformer turns ratio and switching control parameters. The PSFB converter was designed to deliver a stable output voltage for battery charging while minimizing losses and reducing output ripple.

5.2 Future Scope

To enhance the EV charger system, the power flow could be improved to support both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) modes, allowing the stored energy in the EV battery to be returned to the grid during peak demand periods. Advanced control strategies such as Model Predictive Control (MPC) or adaptive control could be implemented on the TI C2000 microcontroller to improve system responsiveness under varying operating conditions. Additionally, real-time temperature monitoring and intelligent cooling techniques could be applied to increase the reliability of power components, especially under high-power loads. Wide-bandgap semiconductor devices such as SiC and GaN MOSFETs could be used to reduce switching losses and support higher-frequency operation, resulting in a more compact and efficient converter design.

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LIST OF PUBLICATIONS

1. Avinash Singh Gautam, Prof. Madhusudan Singh, and Mr. Shreyansh Upadhyaya, " Analysis of Interleaved Boost PFC based Dual Active Bridge Converter for EV Battery Charging " in Proceedings of the IEEE International Conference on Energy, Power and Environment (ICEPE), NIT Meghalaya, India, 2025(presented and to be published).

2. Avinash Singh Gautam, Prof. Madhusudan Singh, and Mr. Shreyansh Upadhyaya, “Analysis of Boost PFC based Phase-Shift Full Bridge Converter for EV Battery Charging” in Proceedings of IEEE 5th IEEE International Conference on Sustainable Energy and Future Electric Transportation (IEEE SeFet 2025), NIT Jaipur, India, 2025 (Accepted and yet to be presented)

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Microsoft CMT <noreply@msr-cmt.org> Thu, Apr 17, 2025 at 10:49 AM
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