Multifunctional Bidirectional Electric Vehicle Charger- A DC Swiftly Charging Architecture

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Submitted by

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CANDIDATE'S DECLARATION

I, RIDHIMAN KUMAR, Roll No 2K22/C&I/05.student of M.Tech Control and Instrumentation (Electrical Engineering), here by declare that the Project Dissertation titled "Multifunction Bidirectional EV Charger- A DC Swiftly Charging Architecture" which is submitted by me to the Electrical Engineering Department, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi RIDHIMAN KUMAR

Date:20.05.2024

CERTIFICATE

We certify that the Project Dissertation titled "Multifunctional Bidirectional EV Charger -A DC Swiftly Charging Architecture," submitted by Ridhiman Kumar, Roll No. 2K22/C&I/05 of the Electrical Engineering Department (MTech C&I), reflects the project work conducted under our guidance at Delhi Technological University (DTU), Delhi. This document has been presented by the student as part of the fulfilment criteria for the Master of Technology (MTech) degree. To the best of our knowledge, this work has not been submitted, either in part or in full, for award of any other degree or diploma at this university or any other institution.

Place: Delhi　　　　Dr. Ashish Rajeshwar Kulkarni　　　　Prof. Madhusudan Singh

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List of Symbols:

S_{rated}	Charging station-rated capacity
k_{load}	Overload factor
N_{Slot}	Amount of the charging slots available
P_{EV}	maximal power rate
V_{dc}	DC Bus Voltage
V^{min}_{bat}	Minimum modulation index
m_{min}	battery's minimum voltage
C_{dc}	DC capacitance.
L_{inv}	Inverter-side inductance
C_f	Filter capacitance
L_{grid}	Grid-side inductance
V_{grid}	Grid Voltage
f_{grid}	Grid Frequency
RAF	Current ripple attenuation
S_{buck}	Upper Switch
S_{boost}	Lower Switch
m_a,m_b,m_c	Amplitude Modulation Ratio a,b and c
D	Upper Switch Duty Cycle
D'	Lower Switch Duty Cycle
P_{ON}	Power in ON Stage
P_{OFF}	Power in OFF Stage
u_d	d-axis Voltage
u_q	q-axis Voltage
i^*_d	d-axis reference current
i^*_q	q-axis reference current
P	Power
Q^*	Reference Value of Reactive Power
V_{dc^*}	DC Bus Reference Voltage
I_d	Discharging current
I_{dref}	Discharging reference current

Abstract:

The growing prevalence of Electric Vehicles (EVs) has prompted an exploration into their viability as energy storage units within microgrids. This study aims to investigate the utilization of stationary EVs for effective surplus energy storage, employing bidirectional charging technology and employing Fuzzy Logic Control (FLC) for analyzing the charger's performance. The implementation involves DC rapid charging technology, capable of providing high power levels ranging from 120 to 240KW for level 3 fast charging, establishing a connection between EVs and a DC microgrid. To enhance the dynamic performance of the (V2G-G2V) charging stations, soft computing techniques such as fuzzy logic-based control and Proportional Integral (PI) control systems are employed. A comparative analysis of the two control systems, Fuzzy Logic Control and Proportional Integral Control, is conducted, focusing on their charging speeds in V2G and G2V modes. The simulation models are intricately designed to assess both V2G and G2V modes, resulting in a notable reduction in Total Harmonic Distortion (THD) generated by grid-injected current. This reduction in THD, a significant marker of active power management, is exemplified by the impressive decrease from 0.09% to 0.02% through the application of fuzzy logic control. These outcomes underscore the potential for both efficient and dependable operation of the proposed system.

CHAPTER 1.

INTRODUCTION

1.1 INTRODUCTION:

The transition to EVs marks a pivotal shift in the automotive industry towards sustainable and eco-friendly transportation solutions. But as EVs become more and more common, an effective system for charging them is needed to keep up with the demands of modern transportation while handling issues like grid stability, charging time, and integrating renewable energy. In this context, multifunctional bidirectional EV chargers equipped with DC swiftly charging architecture emerge as a promising solution to enhance charging efficiency, enable vehicle-to-grid (V2G) capabilities, and accelerate the transition to sustainable transportation systems.

1. **Challenges in EV Charging Infrastructure**: The exponential growth of EV adoption brings forth challenges in the existing charging infrastructure, particularly regarding charging speed and grid integration. Traditional charging methods, predominantly AC chargers, face limitations in delivering rapid charging speeds required for widespread EV adoption. Moreover, the intermittent nature of renewable energy sources complicates their integration into the grid, posing challenges for stable energy supply during peak charging periods.
2. **Role of Bidirectional Charging**: Bidirectional charging technology facilitates Electric Vehicle (EV) batteries not only to draw energy from the grid but also to contribute stored energy back to the grid when required. This two-way capability, commonly referred to as V2G, presents significant potential for enhancing grid stability, managing loads efficiently, and engaging in energy arbitrage., realizing the full benefits of V2G requires advanced charging architectures capable of efficiently managing power flows in both directions while ensuring the longevity and safety of EV batteries.
3. **Advancements in DC Swiftly Charging Architecture**: The evolution of EV charging technology has seen a shift towards direct current (DC) fast charging solutions, offering significantly faster charging speeds compared to AC chargers. Within this landscape, the concept of swiftly charging architecture aims to further enhance charging efficiency by optimizing charging protocols, battery management strategies, and thermal control systems. DC's swiftly charging architecture seeks to minimize charging times while

mitigating risks associated with battery degradation and overheating, thus enhancing the overall user experience and promoting EV adoption.

The multifunctional bidirectional EV charger with DC swiftly charging architecture represents a significant advancement in EV charging technology, offering enhanced efficiency, grid flexibility, and sustainability. By addressing the challenges of rapid charging and grid integration, these systems pave the way for a future where EVs play a central role in building resilient and eco-friendly transportation ecosystems.

1.2 Current Infrastructure of Electric Vehicles and Rationale for Using DC- Microgrid:

The infrastructure for electric vehicles (EVs) has seen significant growth over the past decade. Key components of this infrastructure include:

1.Charging Stations: Public and private charging stations are crucial for the widespread adoption of EVs. These stations are classified into different levels based on their charging speeds:

- Level 1: Standard 120V AC outlets, suitable for overnight charging.
- Level 2:240V AC outlets, providing faster charging times, typically found in residential, commercial, and public locations.
- DC Fast Charging (Level 3):High-power DC charging stations that can charge an EV battery to 80% in 20-30 minutes.

2.Grid Connectivity: EVs rely on the power grid for charging. The integration of Evs into the grid presents challenges and opportunities, including the need for grid modernization to handle increased demand and the potential for EVs to act as distributed energy resources (DERs).

3.Energy Sources: The sustainability of EVs is closely linked to the sources of electricity used for charging. Renewable energy sources, such as solar and wind, are increasingly being integrated into the grid to reduce the carbon footprint of EVs.

4.Technological Advancements: Innovations in battery technology, such as improvements in energy density, charging speed, and cost reduction, are critical for the future growth of EV infrastructure.

Despite these advancements, several challenges remain, including the need for more extensive charging networks, improved grid management, and the integration of renewable energy sources.

Rationale for Using DC Microgrids

The concept of DC microgrids offers several advantages over traditional AC systems, particularly in the context of EV infrastructure:

Efficiency: DC microgrids eliminate the need for multiple AC/DC conversions, which are typically required in conventional power systems. This reduces energy losses and improves overall system efficiency [1].

Reliability: DC microgrids can operate independently of the main grid, providing enhanced reliability and resilience, especially in areas prone to grid outages. This is particularly beneficial for critical applications such as EV charging stations [2].

Integration with Renewable Energy Sources:DC microgrids facilitate the direct integration of renewable energy sources, such as solar panels and wind turbines, which naturally generate DC power. This seamless integration further enhances system efficiency and reduces the carbon footprint of EV charging [3].

Cost-Effectiveness: By reducing the need for AC/DC conversion equipment and simplifying the overall infrastructure, DC microgrids can be more cost-effective to deploy and maintain [4].

Key Applications: DC microgrids are particularly suited for various applications beyond EV infrastructure. These include remote and rural electrification, military and disaster recovery operations, and integration with energy storage systems. The flexibility and scalability of DC microgrids make them an attractive option for diverse energy needs [5].

1.3 Objectives of the Present Work:

The primary objective of this project is to address the gaps in existing studies. This infrastructure, located within a dedicated micro-grid building, streamlines the efficient transfer of electricity between EVs and the micro-grid, facilitating high-power, bidirectional charging. Leveraging Level 3 technology for DC rapid charging, coupled with the integration of a PV array into the micro-grid through the DC bus, enhances the system's environmental sustainability and capacity to support a variety of renewable energy sources. This comprehensive approach broadens the system's ability to accommodate diverse forms of renewable energy in charging infrastructure . The following are major contribution in this project.

1. Create a versatile bidirectional electric vehicle (EV) charging circuit with multiple functions.
2. Conduct a mathematical modeling of the charging circuit.
3. Conduct analysis of charging circuit using MATLAB & harmonic studies.
4.Implement control logic utilizing fuzzy logic control and PI control
5. Investigate and explain the reason for the lower THD achieved with Fuzzy Logic Control compared to PI Control.
6. Implementation of hardware circuit using Arduino UNO.

1.4 Outline of Thesis:

This Thesis includes six chapters.

Chapter 1 presents a brief introduction of the EV technology, risk and challenges of EV infrastructure.

Chapter 2 presents the literature survey of the EV charges and it's technologies, the previous research which is being done by my researchers.

Chapter 3 presents the proposed bidirectional converter circuits and anlaysis of Battery charging and Discharging parameter.Converter is designed and implemented.

Chapter 4 presents the circuit diagram of proposed EV charger and it's analysis on MATLAB.

Chapter 5 presents the hardware implement of the proposed EV charger using Arduino UNO

Chapter 6 presents the conclusion and future scope of the project.

CHAPTER 2.

LITERATURE REVIEW

This literature review aims to provide insights into the multifunctional bidirectional EV charger with DC swiftly charging architecture. Key developments, difficulties, and prospects will be highlighted as it examines the state of research and development in this field at present. By examining the architecture, control strategies, integration with renewable energy sources, and experimental validation of bidirectional EV chargers, this review seeks to contribute to the understanding of the evolving landscape of EV charging infrastructure and its implications for sustainable transportation.

The increasing adoption of EVs globally has highlighted the need for advanced charging infrastructure to support their widespread use. One promising solution is the development of multifunctional bidirectional EV chargers capable of swiftly charging EVs while also enabling V2G functionalities. This literature review aims to explore the present state of research and development in this area, focusing on the architecture of DC swiftly charging systems in bidirectional EV chargers.

2.1 Evolution of EV Charging Architecture:

The burgeoning adoption of electric vehicles (EVs) is driven by concerns over rising fossil fuel prices and escalating carbon dioxide (CO2) emissions [6]. However, these EVs rely on existing utility power grids for charging, placing significant strain on the infrastructure, particularly at the distribution level.

2.1 Shifting Towards DC Grid-Based Charging

DC grid-based EV charging offers seveeal advantages over traditional AC distribution systems:

- **Enhanced Reliability:** DC grids provide greater reliability compared to AC grids.
- **Improved Efficiency:** Power conversion losses are minimized in DC systems.
- **Simplified Integration:** DC grids facilitate easier interconnection with renewable energy sources (RESs) like solar and wind power.

- **Energy Storage Integration:** Integrating energy storage units (ESUs) becomes more straightforward with DC grid

2.1.2 The Role of Renewable Energy and Energy Storage

Storing RES-generated power in local ESUs presents an alternative approach to managing grid demand during peak charging periods. Additionally, effective energy management and control strategies become crucial for powering EV battery charging units within microgrids.

2.1.3 Dedicated Topologies, Controls, and Standards

EV charging stations necessitate dedicated converter topologies and control strategies to meet established charging levels and safety standards. The specific microgrid architecture and control strategies employed depend on the available combination of EVs, ESUs, and RESs, ensuring optimal operation at the charging point.

2.1.4 Reviewing Existing Solutions

This review paper delves into various RES-connected architectures and control strategies currently employed in EV charging stations [6]. It highlights the significance of different charging station architectures and analyzes the latest power converter topologies proposed in research literature.

2.1.5 Comparative Analysis

The paper presents a comprehensive comparison of microgrid-based charging station architectures. This includes their energy management systems, control strategies, and charging converter controls [6].

2.1.6 Beyond Architecture: Levels, Standards, and Controls

Furthermore, the discussion expands to encompass the different levels and types of EV charging stations, along with the control systems and connector types utilized. An experimental energy management strategy (EMS) is presented, demonstrating control over power flow between available sources and charging terminals for maximizing renewable energy utilization.

2.1.7 Challenges, Opportunities, and Selection Considerations

The review concludes by exploring the challenges and opportunities associated with EV charging infrastructure. It also provides valuable insights into the key parameters to consider when selecting appropriate charging stations.

2.2 Architecture of Bi-Directional EV Chargers: Leveraging V2G and G2V Technologies

The growing popularity of electric vehicles (EVs) has spurred significant advancements in vehicle-to-grid (V2G) and grid-to-vehicle (G2V) technologies. The architecture of a bi-directional EV charger that facilitates this two-way power flow [7].

2.2.1 Bi-Directional Power Flow with Buck and Boost Converters

The proposed bi-directional charger employs a combination of buck and boost converters, constructed using semiconductor devices. This configuration enables the seamless exchange of electricity between the EV battery and the grid in both directions.

2.2.2 Benefits of Bi-Directional Charging

Bi-directional charging offers a multitude of advantages for the power grid:

- **Peak Load Shaving:** Bi-directional chargers can help reduce peak electricity demand during high-usage periods.
- **Load Leveling:** They can contribute to smoothing out fluctuations in grid load, promoting overall system stability.
- **Voltage Regulation:** Bi-directional chargers can assist in maintaining voltage stability within the grid.
- **Enhanced Power System Stability:** By facilitating the exchange of power between EVs and the grid, bi-directional chargers contribute to a more robust and resilient power system.

2.2.3 Proposed On-Board Charger (OBC) Architecture

Th architecture designed for EVs, incorporating V2G, G2V, and vehicle-to-load (V2L) functionalities [57].

- **G2V Mode:** In this mode, the charger utilizes sinusoidal and unity power factor (UPF) currents to draw power from the grid and charge the EV battery.
- **V2G Mode:** During V2G operation, the charger enables the EV to feed excess battery power back into the grid, enhancing grid stability.
- **V2L Mode:** V2L functionality allows the EV to serve as a mobile power source, supplying electricity during power outages or in off-grid locations.

2.2.4 Design Considerations and Simulation Validation

The study delves into the critical factors influencing filter design on the AC side of the charger. This optimization ensures optimal performance across all three operating modes (G2V, V2G, and V2L) [7].

2.3 DC Swiftly Charging Architecture with Enhanced Power Balancing

2.3.1 Addressing Range Anxiety with High-Power DC Charging

The growing popularity of electric vehicles (EVs) necessitates significantly reduced charging times to alleviate "range anxiety" among drivers. High-power charging stations equipped with fast chargers are crucial to meet this demand. While charging stations employing the neutral-point-clamped (NPC) converter offer advantages, they suffer from unbalanced power distribution across the bipolar DC bus.

2.3.2 Proposed Solution: Comprehensive DC Power Balance Management (PBM)

This paper introduces a novel approach to address the power imbalance issue in high-power DC fast charging stations based on NPC converters. It proposes a comprehensive DC power balance management (PBM) system in conjunction with a high-power three-level DC-DC converter [8].

The PBM system incorporates two key components:

- **Active DC Power Balance Management (APBM):** This strategy assists the central NPC converter in actively balancing power, eliminating the need for additional balancing circuits.
- **Passive DC Power Balance Management (PPBM):** This strategy mitigates fluctuating neutral-point currents, ensuring the balanced operation of the fast chargers.

Additionally, it analyses the power balance limitations of APBM and circulating currents within the PPBM system.

2.4 Control and Management Strategies for Bi-Directional EV Charging Stations

2.4.1 Integrating Renewables, Storage, and Bi-Directional Power Flow

EV charging stations are evolving beyond simply delivering power from the grid to EVs. This paper proposes a micro-grid structure for charging stations that integrates new energy sources (renewables) and energy storage systems [8]. This approach enables bi-directional energy transfer, allowing EVs to not only be charged but also feed power back into the grid during peak demand periods.

2.4.2 Core Bi-Directional Converters and Control Strategies

It consists of core bi-directional converters that facilitate this energy flow:

- **DC/DC Converters:** These converters are responsible for regulating the DC voltage between the DC bus and the battery storage system. The paper details a current-limited closed-loop control strategy for effective DC/DC converter operation.
- **Bi-Directional AC/DC Converters:** These converters handle the conversion between AC grid power and DC power for charging EVs. The control strategies employed depend on the converter's operating mode:
    - **Rectifier Mode:** When operating as a rectifier, a double-loop control strategy is implemented, with an outer voltage loop and an inner inductor current loop. This ensures stable power conversion from the AC grid.
    - **PQ Control Inverter Mode:** In this mode, the converter acts as an inverter, regulating both real and reactive power output. A double-loop control strategy with an outer voltage loop and an inner inductor current loop is again employed.
    - **Droop Control Inverter Mode:** This mode allows the converter to participate in frequency and voltage regulation within the micro-grid. A double-loop control strategy with an outer voltage loop and an inner capacitor current loop is utilized for this purpose.

2.5 Integration with Renewable Energy Sources

The future of electric vehicles (EVs) hinges on fast-charging stations powered by renewable energy sources (RES), particularly solar photovoltaic (PV) systems. However, integrating PV systems, EVs, and the electrical grid introduces challenges in maintaining high-quality power delivery [9].

The model is validated for bi-directional power flow in a Hybrid DC Fast Charging (HDCFC) station, where solar insolation (the amount of solar radiation reaching the Earth's surface) is constantly changing.

2.5.1 Maximizing Renewable Energy Utilization

The HDCFC station controller design prioritizes charging EVs using solar power to minimize dependence on the electric grid. It achieves this by maintaining a constant DC link voltage while maximizing energy extraction from the PV system.

2.5.2 Dynamic Performance and Tracking Capability

The smooth transition between power sources highlights the superior performance of the hybrid charger, particularly its ability to maximize the benefit of PV during high solar insolation periods.

2.5.3 Comprehensive Analysis

This study delves into the overall system's dynamic performance, including total harmonic distortion (THD) and power flow control across different operating modes. This comprehensive analysis provides valuable insights into the system's efficiency and effectiveness.

2.6 Case Studies and Experimental Validation in EV Charging Stations

2.6.1 Validating Bi-Directional Charging with Fault Tolerance

This section explores the importance of case studies and experimental validation in EV charging station development. While case studies offer real-world insights, experimental validation provides a controlled environment to assess performance and ensure reliability.

One such example is presented in [10], where researchers propose a bi-directional multilevel DC-DC power converter for EV battery charging. The paper delves into the operating principle of the converter, analyzes its functionality, and critically validates its performance through experimentation under various conditions.

2.6.2 Focus on Fault Tolerance

The study goes beyond standard operation by investigating the converter's behavior under fault conditions. The bi-directional multilevel DC-DC converter is integrated into a bipolar DC grid, and experiments simulate open-circuit failures in each wire of the grid (positive, negative, and neutral).

The results demonstrate the converter's resilience: the EV battery charging process continues uninterrupted even during these fault scenarios. This highlights the effectiveness of the proposed control algorithms and converter topology in maintaining reliable charging operation.

2.6.3 Experimental Details and Validation Scope

The experiments cover a wide range of scenarios, including steady-state and transient operation under normal conditions, as well as various open-circuit fault conditions in the bipolar DC grid.

The experimental analysis conclusively shows that the converter guarantees uninterrupted and successful EV battery charging even in the presence of faults within the bipolar DC grid. This comprehensive validation approach offers valuable insights into the converter's robustness and suitability for real-world applications.

2.7 Literature Review:

Microgrids play a pivotal role in modern energy systems by addressing challenges in integrating intermittent renewables for sustainable energy [11]. One essential challenge is efficiently storing surplus energy during peak demand, a task that EV batteries can effectively handle [11]. However, implementing V2G in the primary power grid presents challenges related to control complexities and the need for a substantial EV fleet, as discussed in [11]. It also highlights key discoveries and advancements in the field. Diverse V2G applications within the broader power grid have been explored, such as regulation, spinning reserves, peak shaving, and valley filling [11]. Given that many vehicles remain idle for around 22 hours daily, there's a unique opportunity to integrate them as energy storage assets in microgrids. The Grid-to-Vehicle (G2V) concept allows storing excess microgrid energy in EVs during idle periods, discharging it back when needed through V2G technology. This approach aligns well with microgrid environments, avoiding the complexities of the conventional power grid and the need for a large EV fleet [11]. Research has also investigated the feasibility of V2G technology as a foundation for supporting power generation from variable renewable sources like solar and wind [12]. The SAE (Society of Automotive Engineers) has established standards for 3 EV charging methods: Level 1, Level 2, and Level 3 (DC fast Charging) [12-15]. While Level 1 charging is common, Level 3 (DC fast charging) stands out for its rapid charging capabilities, making it suitable for V2G applications in microgrids. It enhances sustainability by integrating with various renewable energy sources using the DC bus in Level 3 stations [16].Despite being in the early stages within microgrid facilities [17-20], V2G technology has mainly focused on the main power grid. Current systems mainly use AC charging methods (Level 1 and Level 2) due to limitations posed by onboard charger power ratings and grid adaptation complexities for bidirectional energy flow [21]. Thus, there's a need for research to devise technically viable charging station layouts for smooth V2G integration with microgrids. The introduction of DC rapid charging stations with integrated V2G capabilities in microgrid environments presents an innovative solution. This infrastructure incorporates a solar PV array into a DC bus, enhancing the microgrid's energy supply. It enables high-power, bidirectional EV charging through off-board chargers, facilitating efficient V2G and G2V operations. Rigorous MATLAB/Simulink simulations validate the effectiveness of this advanced model. The study offers a comprehensive overview of the design, implementation, and simulation findings, demonstrating that the proposed DC rapid charging station infrastructure with V2G capabilities can function in microgrid environments. These findings have significant implications for advancing V2G technology in microgrid environments, promoting sustainable energy management and the use of green energy sources. In the last few years, there has been substantial interest in V2G technology, recognizing the potential of EVs as valuable assets in microgrid energy management. This section reviews the existing body of knowledge on V2G technology, evaluating its applicability across various power grid settings, including both the conventional power grid and microgrids. These studies demonstrate how electric vehicles can enhance grid stability and reliability by providing essential ancillary services. Overcoming these challenges requires a phased, long-term integration approach. Overcoming these challenges requires a phased, long-term integration approach. The Energy stored in EV batteries can be employed for valley filling and peak shaving , aiding the balance of the power supply and demand [22]. Microgrids, with their more contained and manageable environment compared to the conventional power grid, simplify the coordination needed for implementing V2G systems. Early experiments have assessed the feasibility of V2G system integration within microgrid settings, concluding that V2G technology holds promise for enhancing energy management and sustainability in these environments [23]. A notable challenge in V2G research related to microgrids has been the predominant focus on Level 1 & Level 2 AC charging devices [24-27]. The onboard charger's power rating places limitations on these systems, reducing the amount of energy that can be exchanged between electric vehicles and the microgrid [28-29]. To overcome this limitation, there is a pressing need to design charging station structures that are technically feasible and capable of facilitating uninterrupted bidirectional energy flow, while also accommodating larger power transfers. It is discovered that EV responses vary based on several drop characteristics [30]. Some EVs decrease the power drawn from the grid [30]. Previous research used Level 1 and Level 2 AC charging schemes, leading to power distribution losses, but Level 3 charging architectures are now used for bidirectional energy flow in V2G and G2V technology [31]. According to an earlier study, with the exception of September, October, and November, there are times when PV generation exceeds load demands in most months. Golf buggies that aren't in use at these times can be charged with this extra energy, and then discharged based on locational requirements [32]. Bidirectional power transfer between EVs and the grid is made possible by V2G, but EVs must be able to charge in both directions. The main benefit is grid balancing, which is particularly advantageous when combined with renewable energy, as demonstrated by earlier studies [33]. The mobility industry has shifted towards being less polluting, sustainable, and highly effective. As renewable energy sources become more prevalent in big cities, EV charging stations can help the current grid function better [34]. Most private vehicles are idle assets, lying idle for about 22 hours a day. EVs can help with microgrid energy management by storing excess energy (G2V) and reintroducing it to the grid when required (V2G). V2G applied to the general power grid has limitations, such as being hard to manage, needing many EVs, and being slow to deploy [35]. The area that the PV plant covers, the efficiency of the solar panels, and changes in sun irradiation all affect how much power the facility can produce. A V2G system model was previously developed for a 24-hour scenario, taking into account unusual operating situations such as high wind speeds, sudden variations in load demand, and partial shading of photovoltaics [36]. Peak load shaving is a technique used by EMS as part of Demand Side Management (DSM) in microgrid systems operating off-grid and without connection to the electric grid in situations where there is a shortage of power supply, such as when there is no energy produced by RES or stored in batteries [37]. Since EVs are only used 5% of the time, there is a chance that they could be utilized in the microgrid as electrical energy storage components [38]. Electrical energy storage devices will be essential in a microgrid system that primarily uses renewable energy sources to ensure that power is maintained at night, when PV is not exposed to sunlight, and in the event of low wind, which prevents wind power plants from operating at full capacity [38]. In earlier studies, researchers suggested that since EVs had a quick battery response to rapidly stabilize frequency, they may be utilized in the V2G infrastructure for frequency control [39]. To control fluctuations in frequency, EV-based storage is used as a power system [39]. V2G's performance can be optimized by Markov Decision Processes (MDP), formulating the optimal policy through the value iteration algorithm [40]. In this case, the Reinforcement Learning (RL) approach can be applied because it is easy to obtain the mobility of electric vehicles (EVs), their State of Charge (SOC), and the estimated/actual demands of microgrids (MGs) [40]. EV operates as an injecting source in V2G mode and as an electrical load in G2V mode. Having each of the EV's wheels powered by an electric motor enhances its usefulness in managing system moments to stabilize vehicle motion. Although consumers are unable to store energy from EVs directly, V2G makes use of the energy that is stored in EV battery banks to return power exports to the grid, generating income [41]. Battery charging operates in G2V mode, and parking sector energy consumption is covered by the utility [41]. By charging an EV during off-peak hours or consuming extra energy from RES, such as a home wind or PV system, an EV can serve as a backup energy source for a home [41]. In the previous research, the development of V2G technology provided an idea to maintain the frequency stability of the power system, using the "source-load" dual characteristics of EVs to quickly eliminate frequency fluctuations in power supply quality [42]. The rapid development of new power sources in the last ten years, such as photovoltaic power generation technology and wind power technology, has greatly affected the power quality of the power grid [42]. Establishing a general and accurate V2G technology model is essential for analyzing V2G technology's impact on power grid frequency control. In 1995, American energy expert Amory Blovins first proposed the concept of V2G. The research team led by Professor Kempton has carried out more in-depth research and experimental verification of V2G technology, making breakthrough progress [42]. In October 2007, a relatively simple V2G technology model was successfully established, connecting an EV to the power grid and receiving dispatching instructions [42]. However, the net present cost of EVs must be analyzed.

A case study of the Ecuadorian archipelago of the Galapagos Islands, which has been cut off from the main grid, was examined in earlier research in order to assess the planning model of EV [43]. Increased population as well as tourism have boosted transportation along with electricity demand, increasing concerns on the islands [43]. EVs are the only solution to curb environmental-related problems [43]. A time series load flow test for summer and winter load profiles must be completed for electricity generation in order to integrate renewable energy sources and EVs into a microgrid. [44]. Voltage profiles were evaluated within a 24-hour period for different generators and EV penetration to analyze less significant voltage drops with increased distributed generator penetrations [44]. When compared to uncontrolled charging regimes, energy losses in dual-tariff EV charging regimes are less significant. In order to improve the voltage profile, loading circumstances are crucial. Energy losses are greater at the minimal summer load profile than they are under the maximum winter loading conditions [44].It has been discovered in earlier studies that EV responses vary according to many droop attributes [45]. Certain EVs "reduce the amount of power from the grid used [40]. Unlike the simple PI controller used in synchronous frame control, a resonant controller is required for inverter-based control. In order for the controller to follow the reference signal, the goal is to obtain infinite gain at a specific frequency [45]. The unpredictable nature of solar energy can be lessened by utilizing EVs and V2G technologies. An initial investigation of the potential impact of V2G technology to reduce PV production uncertainties on the Campus" is carried out using an optimization technique, which compares estimations and true measurements [46]. In earlier studies, EVs are interfaced to the microgrids via "a DC fast charging station with off-board charges and a grid-connected inverter. In order to guarantee efficient power transfer and compliance with pertinent regulations, the control system should be built to enable bi-directional power transmission between EVs and the grid [47]. Due to their ability to facilitate the integration of intermittent renewable energy sources, energy storage" devices are essential parts of a microgrid [47]. Control is dependent on the battery and voltage sensors, whereby variations in the EV's battery voltage level cause mode switching [48]. The system's overall complexity can be decreased because the battery voltage is the primary factor that determines when to switch between different modes [48]. The number of EVs, driven kilometers, and energy consumption per kilometer of the vehicles all affect how much G2V energy is needed to finish all of the daily travel. Until mainstream EVs are equipped with faster charging capabilities, Level 3 AC charging installations must be completed. Furthermore, even after making all of the daily excursions, a fully charged EV battery still has a significant amount of energy left in it [49]. A power grid's ability to function properly rests heavily on its ability to maintain “load/generation balance at all times. The system maintains the equality of generated power and demand while it works at a nominal frequency. The system frequency varies with each imbalance in load and generation [50]. The system operator must provide distinct services from different generating units on the market in order to maintain the load/generation” balance [50]. Primary and secondary load control can be used to maintain constant frequency; EV charging can supply the necessary reserves [50]. In order to maximize profits for car owners, the “charging/discharging current of every vehicle should be regulated based on an energy management strategy that addresses aspects like microgrid, power demand, SOC of battery, driving plan, and current power” cost [51]. V2G is permitted to run within a predetermined SOC range due to its simplicity; however, in order to maintain a good driving range and avoid battery overcharging, low and high SOC should be avoided [51].

By integrating V2G with MG, it is easier to control the grid frequency during sudden events by utilizing the extra vehicle battery power that is available. During periods of low demand, solar and wind power supply the necessary power, while diesel generators provide extra power during periods of high demand [52]. Smart Grids will develop sensor-specialized controllers and faster communication paths to provide consumers with power that is more reliable, flexible, and reasonably priced [53]. When managing a microgrid in its grid-connected state, the concepts of smart grid and microgrid merge, necessitating the use of a smart-control architecture to regulate bidirectional power flow between the two [53]. Because load-shedding allows producers to keep within the maximum demand specified in the contract and optimizes work, it is advantageous to both energy producers and consumers [53]. In previous research, a novel modulation technique for V2G converter provided an open-loop sinusoidal input current, with the adjustment of phase shift given to the grid [54]. V2G mode is intended to support the microgrid by supplying electricity during the car's idle condition, resolving peak load situations, attaining grid frequency balance, offering demand response services, and improving system performance during peak load times [55]. Active power regulation, current harmonic filtering, and power adjustment for renewable energy sources are all provided by the V2G system [50]. However, current demand response management algorithms are not effectively exploiting V2G control algorithms due to the features of EVs, which can travel across different regions and act as energy transporters among various grids [56]. V2G can be used as "a new perception of PHEV to the power grid, incorporating new technologies allowing duplex power flow between electrical power and the battery [57]. Local aggregators facilitate communication between the grid and consumers/prosumers" to enable V2G power transfer. Smart meters in vehicles supply power to data centers so that peak shaving is possible [57]. The construction of a smart grid system and the concept of V2G promote good interaction between EVs and power systems. It should be used as a controllable load and distributed generation to provide the load to the grid. Through reasonable planning and control, when the load fluctuates, it provides auxiliary frequency to the grid, respectively [58]. Investing in EVs and improved infrastructure for EV charging will lead to increased interest in people buying EVs, reducing environmental pollution if system costs improve, especially with high diesel and gasoline costs and investments in PV energy generation [59].

2.8 Research Gap Identified:

Fuzzy Logic Control can be used to utilize this EV Charger as an AI control with better performance of THD [60]. This research's primary aim is to address the gaps in existing studies. This infrastructure, located within a dedicated micro-grid building, streamlines the efficient transfer of electricity between EVs and the micro-grid, facilitating high-power, bidirectional charging. Leveraging Level 3 technology for DC rapid charging, coupled with the integration of a PV array into the microgrid through the DC bus, enhances the system's environmental sustainability and capacity to support a variety of renewable energy sources. This comprehensive approach broadens the system's ability to accommodate diverse forms of renewable energy.

CHAPTER 3.

Architecture of Charging Station and modelling of charger circuit.

3.1 Charging Station:

A typical Electric Vehicle (EV) charger system is depicted in the Fig 3.1 . This diagram illustrates the integration of off-board chargers connecting Electric Vehicle (EV) batteries to a direct current (DC) bus. The system incorporates crucial components such as LCL filters and step-down transformers in conjunction with a grid-connected inverter, referred to as the Grid-Connected Inverter (GCI). These elements collectively function to regulate the utility grid and the voltage of the DC bus, ensuring efficient and controlled energy flow.

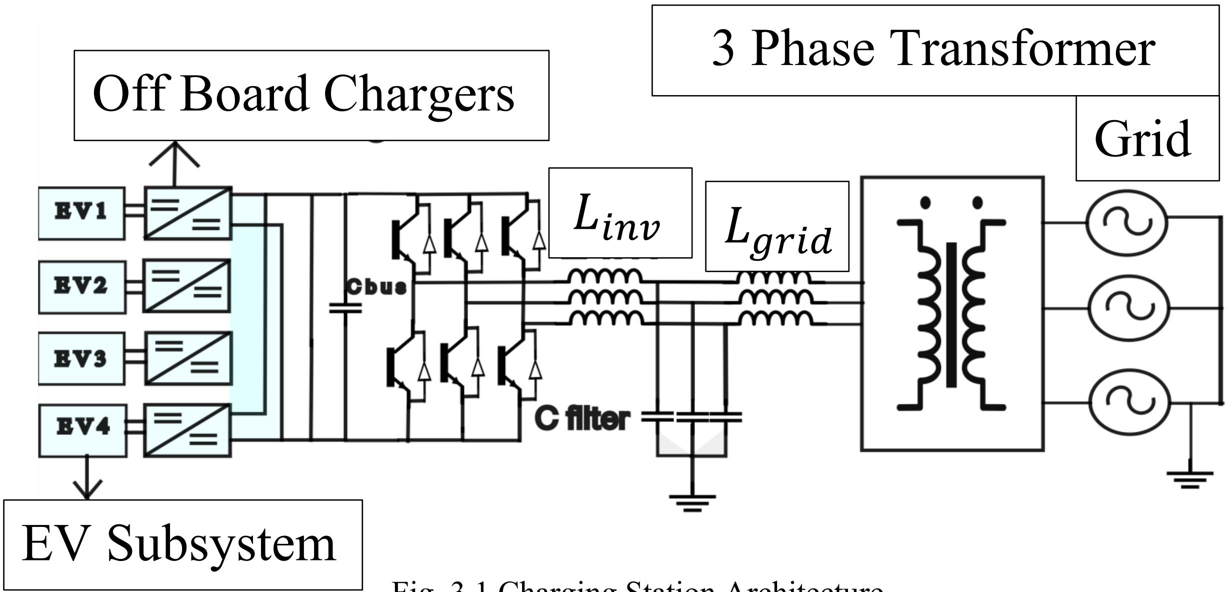

Fig. 3.1 Charging Station Architecture

At the heart of the system is the off-board charger embedded within the Electric Vehicle Supply Equipment (EVSE). This charger employs a bidirectional DC-DC converter, a vital component enabling V2G functionality. V2G operation occurs through two distinct modes: Charging Mode, also known as the Buck Mode, and Discharging Mode, referred to as the Boost Mode. In the Charging Mode, the grid voltage is lowered to facilitate battery charging, while in the Discharging Mode, the battery voltage is raised to match that of the DC bus, enabling seamless V2G energy transfer.

To regulate and optimize the charging and discharging processes, sophisticated control strategies are implemented. Proportional-Integral (PI) controllers play a pivotal role in ensuring constant current regulation. These controllers are crucial for maintaining the efficacy of the charging and discharging operations, providing a stable and controlled flow of energy between the EV batteries and the DC bus.
Off-board chargers are crucial for enabling effective DC rapid charging. These chargers, which serve as the link between the electric car and the charging infrastructure, are designed specifically to connect with the Electric car Supply Equipment. The off-board charger's inbuilt bidirectional DC-DC converter is a critical piece of technology that enables V2G functioning. This converter allows for seamless transitions between charging and discharging processes by dynamically controlling voltage levels.

The integration of LCL filters and step-down transformers with the grid-connected inverter, or GCI, is crucial for managing the voltage levels of both the utility grid and the DC bus. The LCL filter helps mitigate harmonic distortions, ensuring a cleaner and more stable power flow. Step-down transformers are employed to adjust voltage levels as needed, providing a versatile and adaptive solution for interfacing with the diverse components of the charging system.

Efficient DC rapid charging is a pivotal aspect of this proposed EV charger system, and it is achieved through the orchestrated operation of the off-board chargers, bidirectional DC-DC converter, and control strategies. The bidirectional DC-DC converter is especially noteworthy as it enables the seamless transition between charging and discharging modes, unlocking the full potential of V2G functionality.

Control strategies, particularly those implemented through PI controllers, are essential for maintaining the stability and efficiency of the charging and discharging processes. The constant current regulation ensured by these controllers is critical for preventing fluctuations and disruptions in the energy flow, thereby contributing to the overall reliability of the EV charger system.

The proposed EV charger system represents a sophisticated and integrated solution for efficient DC rapid charging and seamless integration with microgrids using Simulink MATLAB. The off-board chargers, bidirectional DC-DC converter, LCL filters, step-down transformers, and control strategies collectively form a robust infrastructure capable of optimizing energy transfer, ensuring stability in charging and discharging processes and unlocking the full potential of V2G functionality. This system aligns with the evolving landscape of electric vehicles and their integration into sustainable energy ecosystems, making significant strides toward the realization of more efficient and environmentally friendly transportation solutions.

3.2 Circuit Description:

The Bidirectional EV Charger circuit consists of following sections:

1. Grid Connected LCL filter.
2. Grid Connected Inverter (GCI).
3. Bidirectional DC Converter (BDC).

3.2.1 Grid Connected LCL filter

The grid-connected inverter (GCI) is a crucial component in the integration of a microgrid with the utility grid. It serves as the intermediary device that facilitates the exchange of energy between the microgrid and the main power grid. To achieve this, the GCI incorporates an LCL filter and a step-up transformer.

The LCL filter is employed to address harmonic distortion issues that may arise during the energy exchange process. Harmonic distortions can lead to disruptions and inefficiencies in the power flow, impacting the stability as well as the reliability of the overall system. The LCL filter effectively mitigates these distortions, ensuring a cleaner and more stable power transfer between the microgrid and the utility grid.

Additionally, the GCI utilizes a step-up transformer as part of its configuration. The step-up transformer plays a crucial role in adjusting voltage levels between the utility grid and the DC bus. This adaptive voltage adjustment is essential for harmonizing the different voltage requirements of the microgrid and the main power grid, facilitating seamless energy exchange. It ensures efficient energy exchange while addressing harmonic distortion concerns through the LCL filter and adjusting voltage levels using the step-up transformer. This integrated approach contributes to the reliability, stability, and overall performance of the interconnected microgrid and utility grid system.

3.2.2 Mathematical Modelling of LCL filter:

LCL filter consists of inductance L_{grid} being the inductance of the grid side, C_f is being defined as the capacitance filter and L_{inv} is being defined as the inductance of the inverter side as defined below:

$$S_{rated} = \frac{k_{load} \cdot N_{Slot} \cdot P_{EV}}{cos\phi} \tag{3.1}$$

where S_{rated} is defined as the charging station-rated capacity, $cos\phi$ is denoted as the power factor, N_{Slot} is signified as the amount of the charging slots available for the individual EVs, P_{EV} is represented as the maximal power rate of an individual EV and k_{load} is denoted as an overload factor for control overloading in transients.

If N_{Slot} = 2, k_{load} = 1.875, P_{EV} = 40kW and $cos\phi$ = 0.6 then

$$S_{rated} = \frac{k_{load} \cdot N_{Slot} \cdot P_{EV}}{cos\phi} = \frac{1.875.2.40kW}{0.6} = 250 \text{ kVA}$$

3.2.3 *DC BUS capacitance* calculation:

The grid voltage is typically used to determine the DC link voltage. The grid in this work is with a transformer connected, the DC bus voltage selection is unaffected by the grid voltage level. Nonetheless, that the battery's minimum voltage $V^{min}{}_{bat}$ and minimum modulation index m_{min}, as shown in the equation below, provides an upper bound for the DC bus voltage: V_{dc}

$$V_{dc} \leq \frac{V^{min}{}_{bat}}{m_{min}} \tag{3.2}$$

If $V^{min}{}_{bat}$ =. 450 V m_{min} = 0.3 then $V_{dc} \leq \frac{V^{min}{}_{bat}}{m_{min}} = \frac{450}{0.3} = 1500 \text{ V}$

The stability of the DC bus is directly impacted by the magnitude of the DC capacitance. Essentially, it needs to sustain the DC current ripple. There can be a lot of EV chargers linked to the DC bus, so the ripple current can get very high. This means that a large capacitance is needed. You can see the proposed formula below.

$$C_{dc} = \frac{S_{rated}}{{V_{dc}}^2}\frac{2\eta . T. \Delta r. \cos\phi}{\Delta x} = \frac{250kW}{(1500^2)} . \frac{1.6.1127.69.0.83}{1} = 133\text{uF} \tag{3.3}$$

Where C_{dc} is the DC-link Capacitor value, η is the Efficiency(%), T is the Period of one cycle, Δr is the ripple factor and Δx is the change in resistance or deviation in the some parameter related to system dynamics.

3.2.4 Inverter Side Inductance:

Fig.1 demonstrates the LCL filter configuration where the inverter-side inductance L_{inv}, filter capacitance C_f and grid-side inductance L_{grid} are determined as follows,

$$L_{inv} = \frac{V_s^2}{S_{rated}THD \cdot 2 \cdot \pi \cdot f_{sw}} \cdot \sqrt{\frac{\pi^2}{18} \cdot \left(\frac{3}{2} - \frac{4\sqrt{3}}{\pi} \cdot m_a + \frac{9}{8} \cdot m_a^2\right)} \quad (3.4)$$

$$L_{inv} = \frac{(415)^2}{250kVA.\,5\%.\,2.3.14.10Khz} \cdot \sqrt{\frac{\pi^2}{18} \cdot \left(\frac{3}{2} - \frac{4\sqrt{3}}{\pi} \cdot 0.25 + \frac{9}{8} \cdot (46.4)^2\right)} = 0.25mH$$

Where f_{sw} is switching frequency, m_a is modulation index of a

$$L_{grid} = \frac{RAF + 1}{RAF \cdot C_f \cdot 2 \cdot \pi \cdot f_{sw}^2} \quad (3.5)$$

$$L_{grid} = \frac{RAF+1}{RAF \cdot C_f \cdot 2 \cdot \pi \cdot f_{sw}^2} = \frac{100+1}{100 \cdot 7.42nF \cdot 2 \cdot \pi \cdot (10)^2} = 0.25mH$$

$$C_f \le \frac{0.05S_{rated}}{2\pi . f_{grid} . V^2{}_{grid}} = \frac{0.05.250.1000}{6.28.50.171225} = 0.00742\ uF\ or\ 7.42\ nF \quad (3.6)$$

where C_f is the capacitor filter, *RAF* is the current ripple attenuation factor and f_{sw} is the switching frequency.

3.3 Constant current control strategy for Battery Charger:

Fig 3.2, the battery charger control scheme. It is used to regulate the current in charge and discharge mode of battery. It integrates both FLC and PI control. To determine the polarity of the current signal and whether the system should be in the charging or discharging mode, the controller first compares the reference battery current to zero. Following the establishment of the mode, a PI controller processes the error that results from comparing the measured current to the reference current. This PI controller generates switching pulses, ensuring that S_{buck} /S_{boost}, remains inactive throughout the charging process, and S_{buck}, is disabled throughout the discharging process.

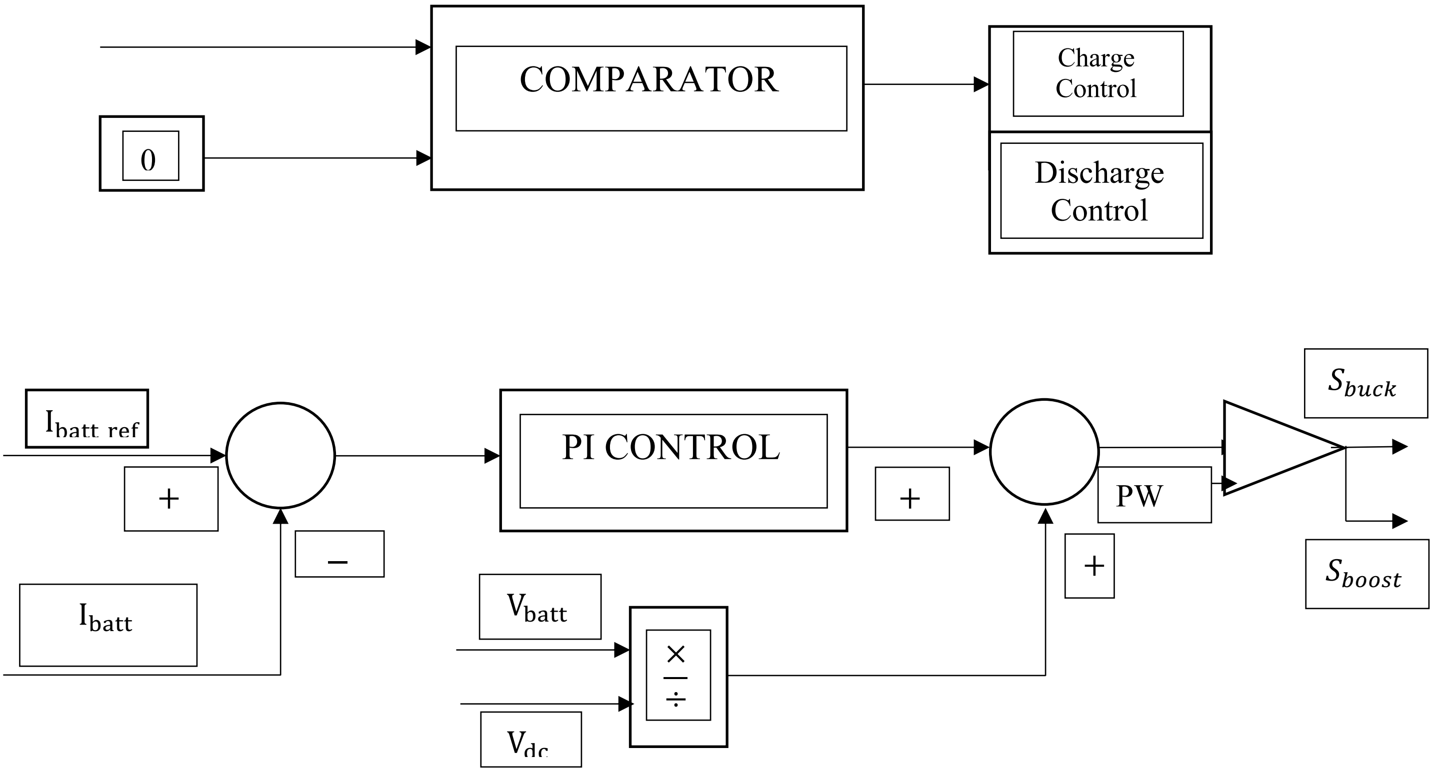

Fig 3.2 Constant current control strategy using PI Control

3.4 Grid Connected Inverter (GCI):

The system starts with a three phase AC-input, Typically sourced from the Grid or an alternative AC power source, which is then passed through a bridge rectifier to convert an AC waveform into a pulsating DC waveform. Following rectification a series of Insulated Gate Bipolar Transistors (IGBTs) or metal oxide semiconductor field effect transistors (MOSFETs), designated as S1, S2, S3, S4, S5 and S6. Are controlled to alternate between the opened and closed states forming an inverter or converter circuit. To mitigate harmonics and smooth the pulsating DC waveform, an LCL filter consisting of an inductor (L) and capacitor (C) and an additional inductor (L), is employed reducing Total Harmonic Distortion (THD) and contributing to a cleaner DC Signal. A PWM control strategy is utilized to regulate these switches, controlling output waveform by adjusting the duty cycle of switches, thus ensuring the precise output voltage regulation.

During Positive half cycle, S1, S3 and S5 are operated to facilitate the flow of current, converting the rectified pulsating DC into a smoother waveform before it reaches filtering stage. Their operation in conjunction with switches S2,S4 and S6. Which handles negative half cycle, ensures the balanced and consistent conversion process.

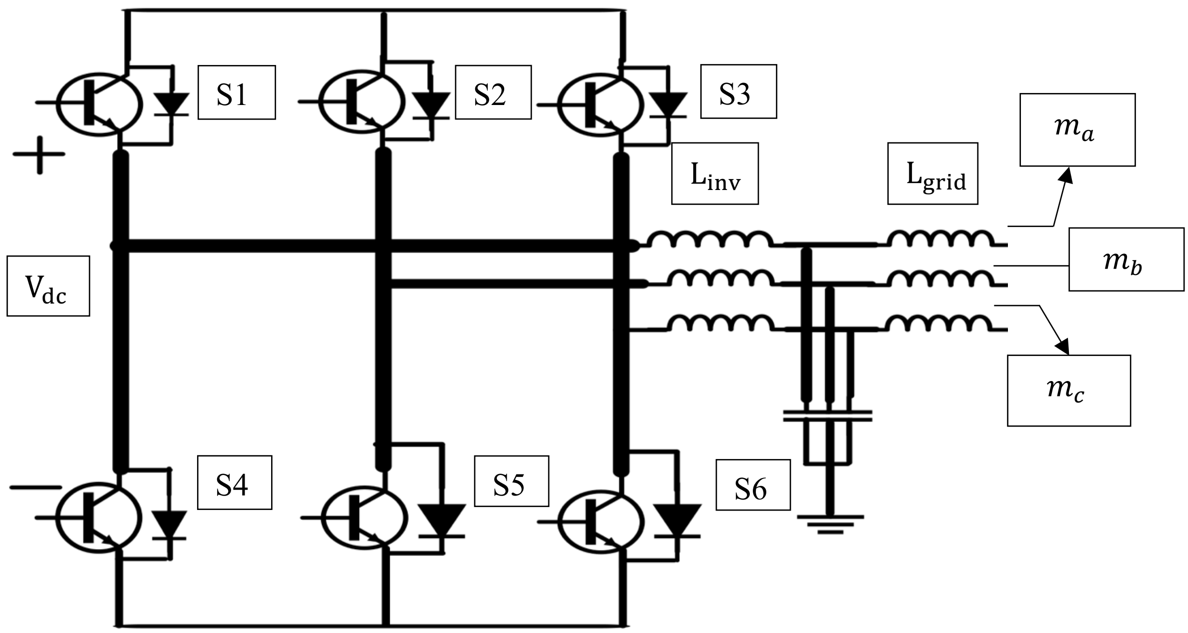

Fig 3.3 Three-Phase GCI

3.4.1 Control Strategy (PWM Control):

PWM (Pulse Width Modulation) control is often utilized to regulate the switches and control the output waveform. By adjusting the duty cycle of the switches, the efficient voltage reaching the DC link can be controlled, allowing for precise output voltage regulation. Breif explaination is given in below sections.

3.4.1.1 Mathematical Analysis of Inverter Control Strategy:

The voltage source's control approach is explained in this subsection. The following equations might be applicable based on Fig. 5:

$$V_A = U_A - L.\frac{di_A}{dt} - R.i_A - \frac{1}{C}.\int i_A.dt \quad (3.7)$$

$$V_B = U_B - L.\frac{di_B}{dt} - R.i_B - \frac{1}{C}.\int i_B.dt \quad (3.8)$$

$$V_C = U_C - L.\frac{di_C}{dt} - R.i_C - \frac{1}{C}.\int i_C.dt \quad (3.9)$$

where R, C, and L are the resistance, capacitance, and inductor of the line between the grid and inverter in the LCL filter circuit. The following formula, known as the dq frame, is used to remove steady-state error:

$$\begin{bmatrix} u_d \\ u_q \end{bmatrix} = \begin{bmatrix} e_d \\ e_q \end{bmatrix} + L.\frac{d}{dt}.\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \omega.L.\begin{bmatrix} -i_q \\ i_d \end{bmatrix} + R.\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{1}{C}.\int \begin{matrix} i_d \\ i_q \end{matrix} \quad (3.10)$$

By using the PLL (Phase Locked Loop) algorithm to synchronize the inverter with the power grid, the q-axis grid voltage i.e.($u_q = 0$). The following is another way to rewrite equation (3.10):

$$\begin{cases} u_d = E_S - \omega L_{i_q} + \Delta u_d \\ u_q = \omega L_{i_q} + \Delta u_q \end{cases} \quad (3.11)$$

Where:

$$\begin{cases} \Delta u_d = L.\dfrac{di_d}{dt} + Ri_d + \dfrac{1}{c}.\displaystyle\int i_d.dt \\ \Delta u_q = L.\dfrac{di_q}{dt} + Ri_q + \dfrac{1}{c}.\displaystyle\int i_q.dt \end{cases} \tag{3.12}$$

The q and d-axis currents are driven to their reference values by two PI controllers:

$$\begin{cases} \Delta u_d = k_{p,d}(i^*{}_d - i_d) + k_{i,d}\displaystyle\int (i^*{}_d - i_d).dt \\ \Delta u_q = k_{p,q}(i^*{}_q - i_q) + k_{i,q}\displaystyle\int (i^*{}_q - i_q).dt \end{cases} \tag{3.13}$$

where $i^*{}_d$ and $i^*{}_q$ are the d and q-axis reference currents respectively. The following equations provide the transmitted active and reactive power in the dq reference frame (taking into consideration that $u_q = 0$):

$$\begin{cases} P = \dfrac{3}{2}.e_d * i_d \\ Q = -\dfrac{3}{2}.e_q * i_q \end{cases} \tag{3.14}$$

Here, the d and q-axis reference currents can be adjusted to control the active and reactive power, respectively. The d-axis current is managed by the PI controller in order to keep the DC bus voltage steady:

$$i^*{}_d = k_p(V_{dc^*} - V_{dc}) + k_i\int (V_{dc^*} - V_{dc}).dt \tag{3.15}$$

where V_{dc^*} is the DC bus reference voltage value (400 V). Similarly, the q-axis current can be adjusted to regulate the reactive power in the following way:

$$i^*{}_q = k_p(Q^* - Q) + k_i\int (Q^* - Q).dt \tag{3.16}$$

where Q^* is the reference value of reactive power.

\

3.4.2 Inverter Control Scheme.

For EV battery management, the off-board charger and FLC play a pivotal role, encapsulated in Fig. 3.4. Instead of conventional PI controllers, FLC is employed for real-time adjustments in charging and discharging rates. FLC relies on linguistic rules and membership functions to generate precise control signals for bidirectional DC-DC converters, considering parameters like battery current and voltage errors. Off-board chargers and FLCs are essential in EV battery systems. FLC, unlike conventional PI controllers, excels in real-time adjustment of charge and discharge rates, due to its interest in complex, nonlinear interactions using language codes and member functions are applied FLC is equally applicable to bidirectional DC-DC converters considering variables such as battery current and voltage errors This flexibility makes the FLC ideal for responding to dynamic situations and unpredictable schedules. The off-board charger intelligently uses FLC to optimize EV battery charging and discharging rates, matching microgrid conditions, battery charge levels, and utility grid requirements Adaptive control ensures efficient charging during power overload available with controlled discharge when high demand.

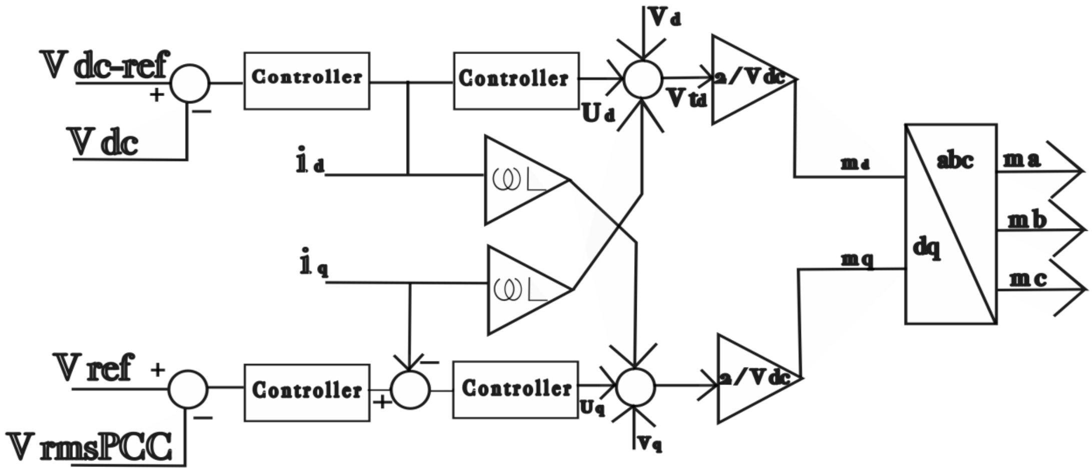

Fig 3.4 Inverter Control Strategy

FLC extends its influence to grid-connected inverters, facilitating power transmission between microgrids and utility grids. FLC’s adaptability is enhanced by unpredictable changes in demand or renewable energy production, ensuring uninterrupted microgrid operation. FLC integration optimizes V2G and G2V system operation, monitoring current, voltage, and power switching for optimal charger operation, battery health monitoring, and grid integration This provides energy consumption efficiency, reducing losses, reducing THD, and improving system response, ultimately grid performance is consistent power actions and increases the Circuit's efficiency. Inverter control strategy Simulink Model is shown in Fig. 3.5.

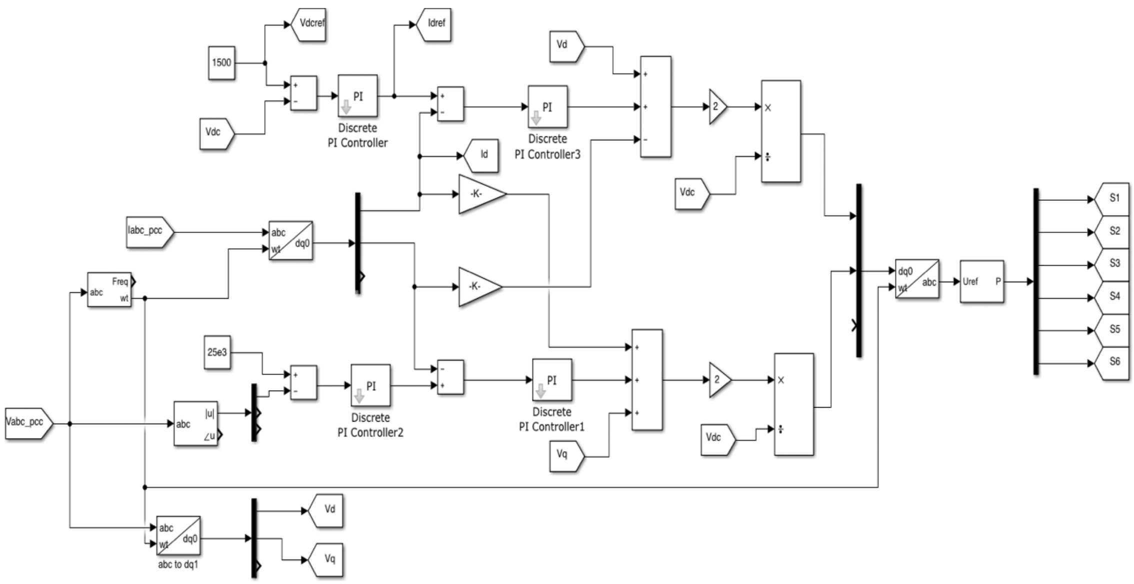

Fig 3.5 Simulink model of Inverter Control Strategy

3.5 Bidirectional DC Converter (BDC):

An essential element of an off-board charger with V2G capability is a bidirectional DC-DC converter. This converter serves as an intermediary between the EV battery system and the DC distribution line. Illustrated in Figure 3.6 is the layout of the converter, comprising two IGBT/MOSFET switches continually controlled by synchronized control signals. A Simulink Model of Bidirectional DC Converter is shown in Fig 3.7 .

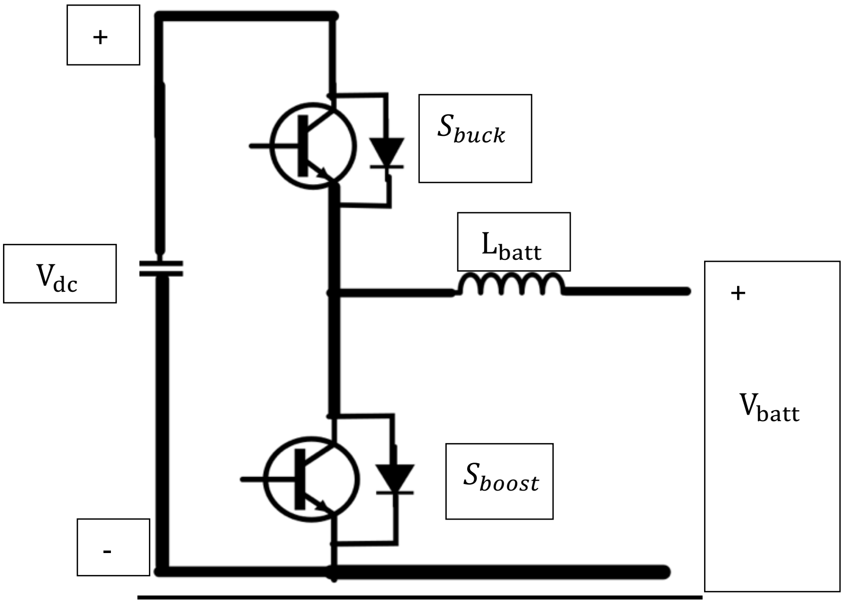

Fig 3.6 Bidirectional DC Converter for Battery charging and discharging

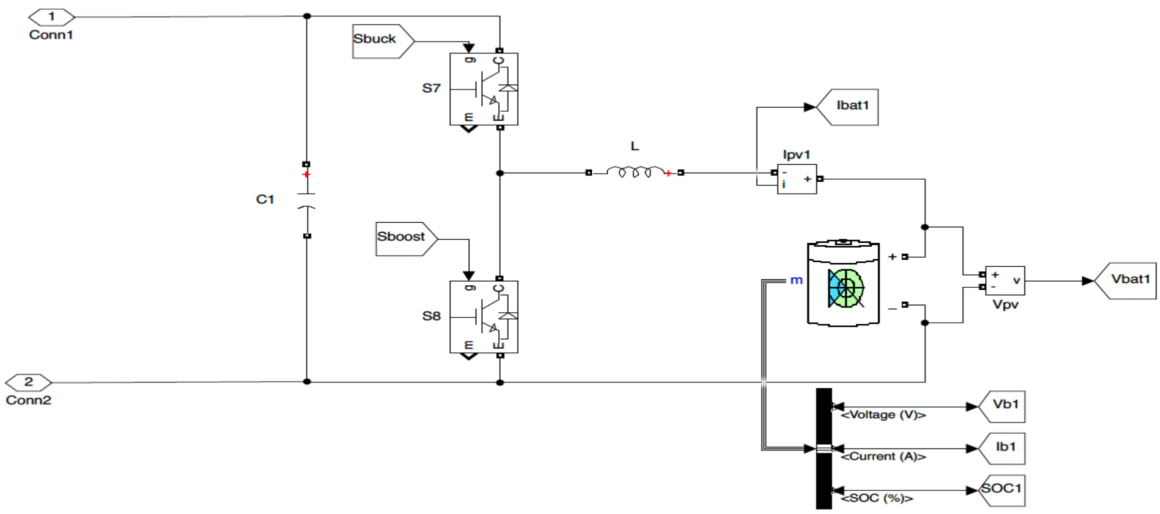

Fig. 3.7 Simulink Model of Bidirectional DC Converter

3.5.1 Buck mode of operation (Charging Mode)

The converter operates as a buck converter when the upper switch is in the active position i.e. S_{buck},lowering the input voltage V_{batt} to the battery charging voltage. When the switch is in the ON position, power from the G2V is used to depict the charging process as current passes via the switch and inductor to the battery. The circuit is closed when the switch is in the OFF position because the current goes back via the bottom switch's diode and inductor.
The following formulae can be used to calculate the battery voltage if D represents the upper switch's duty ratio:

During ON State ($\boldsymbol{S_{buck}}$):
During this time the upper switch is closed, and the current flows through the switch and inductor to the battery. The power flowing through this time is given by:

$$P_{ON} = V_{batt}.I_{avg}.D \tag{3.17}$$

Where I_{avg} is the average value of the current flowing through the inductor.
During OFF State:
Current passes through the lower switch's diode and inductor in the return path when the upper switch is in the OFF position. The power during this phase is determined by:

$$P_{OFF} = -V_{batt}.I_{avg}.(1-D) \tag{3.18}$$

Equating the power during ON-state and OFF-state:

$$P_{ON} = P_{OFF} \tag{3.19}$$

$$V_{batt}.D = -V_{batt}.(1-D) \tag{3.20}$$

$$V_{batt}.(2.D-1) = 0 \tag{3.21}$$

If $V_{batt} = 0$
Then we get eqs. (3.20) and (3.21) as:
For (3.20): D – 1 = 0, i.e. D = 1;
For (3.21): (2.D – 1) = 0, i.e. $D = \frac{1}{2}$

$$\text{If } D = 1 \text{ then } P_{ON} = V_{batt}, \ P_{OFF} = 0. \tag{3.22}$$

$$\text{If } D = \frac{1}{2} \text{ then } P_{ON} = \frac{V_{batt}}{2}, \ P_{OFF} = \frac{-V_{batt}}{2}. \tag{3.23}$$

3.5.2. Boost mode of Operation:

When the bottom switch is turned on, the converter functions as a boost converter, increasing the voltage from the battery to the DC bus voltage. (S_{boost}) When the switch is turned on, current flows through the inductor and then through the capacitor and antiparallel diode of the upper switch, completing the circuit, V_{batt}. When the batter is in discharge mode, the V2G, $V_{dc}$is the source of net power flow in this situation. The output voltage in the boost mode is delivered as long as the capacitor is big enough to keep the DC voltage steady.

During the ON state:

When the bottom switch is turned on, current flows through the inductor before passing through the upper switch's antiparallel diode and capacitor to complete the circuit. The power flowing through this time is given by:

$$P_{ON} = V_{batt}.I_{avg}.D' \quad (3.24)$$

where D' represents the lower switch's duty cycle.

During OFF state:

During this time, the bottom switch is off, and the current flows through the upper switch's antiparallel diode and the capacitor to maintain the circuit. The power flowing during this time is negligible since the capacitor is big enough to maintain a consistent DC voltage.

Output Voltage V_{dc} is given by the following formula:

$$V_{dc} = \frac{V_{batt}}{1 - D'} \quad (3.25)$$

3.5.3 Simulation results of Battery Charging and Discharging for (BDC):

Fig 3.8 Depicts the Battery Voltage parameters like Battery Voltage, Battery Current and SOC (%) during the charging and discharging process. From t = 0 to t =4 battery voltage remains constant during the charging process, but from t = 4 to t = 6 battery voltage increases from 540 to 550 Volts. From t =0 to t =1 the battery current during charging process is the same. But from t = 1 to t = 4 battery current increases upto 100 A but from t = 4 battery current decreases but remains constant after t = 4 till t = 6. During discharging process from t = 0 to t = 1 the battery voltage decreases from 550 volt to 500 volt which indicates that the vehicle is in the discharging process and it continues to be in the same state from t = 1 to t = 6. From t = 0 to t = 4 battery current during discharging process remains the same but from t = 4 it decreases at fast pace, but from t = 4 to t = 6 it remains to be constant as shown in Fig. 3.8.

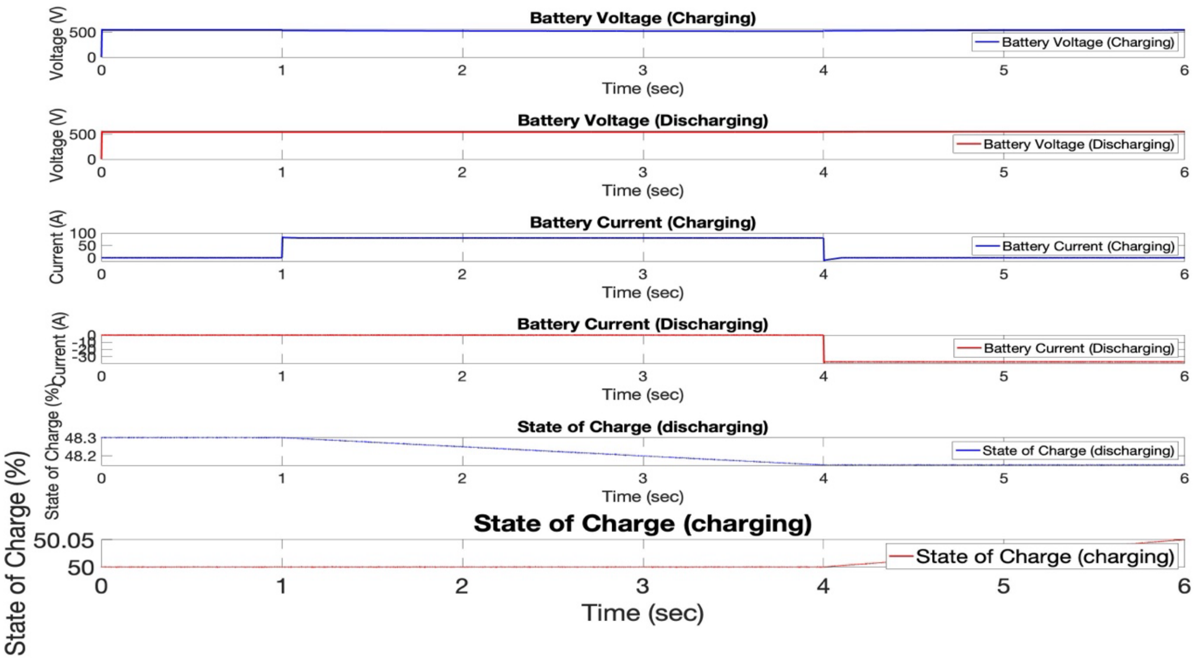

Fig. 3.8 Simulation results of Battery Charging and Discharging for (BDC)

3.6 Conclusion

This chapter explored the design and functionality of a DC rapid charging system for Electric Vehicles (EVs) within a microgrid environment. The system leverages off-board chargers equipped with bidirectional DC-DC converters, enabling seamless Vehicle-to-Grid (V2G) integration.

Key findings include:

- **Efficient DC Rapid Charging:** The system facilitates efficient DC rapid charging through a coordinated approach involving off-board chargers, bidirectional DC-DC converters, and control strategies. The bidirectional DC-DC converter is particularly noteworthy for its ability to transition between charging and discharging modes, maximizing V2G potential.
- **Control Strategies for Stability:** PI controllers play a vital role in maintaining constant current regulation during charging and discharging processes. This ensures stability and prevents disruptions in energy flow, contributing to the overall reliability of the EV charger system.
- **Microgrid Integration:** The proposed system represents a sophisticated and integrated solution for DC rapid charging that seamlessly integrates with microgrids using Simulink MATLAB. This integration is facilitated by components like LCL filters and step-down transformers, ensuring efficient energy transfer and grid stability.
- **Future of Electric Vehicles:** This system aligns with the evolving landscape of electric vehicles and their integration into sustainable energy ecosystems. It represents a significant step towards the realization of more efficient and environmentally friendly transportation solutions.

In conclusion, this chapter has presented a novel DC rapid charging system for EVs that offers efficient charging, seamless V2G integration, and compatibility with microgrids. The system holds promise for advancing the future of electric mobility and promoting sustainable energy practices.

CHAPTER 4.

MATLAB Modelling, Simulation and Performance Analysis of EV Charger with Fuzzy Logic Controller

4.1 General

In this chapter, MATLAB simulation and analysis of EV Charger and their control through fuzzy logic are discussed. The proposed research included extensive simulations to evaluate the V2G-G2V infrastructure's performance with both the traditional PI controller and the freshly developed FLC. The effectiveness of the V2G-G2V infrastructure was evaluated with the aid of these controllers. The outcomes of these simulations were evaluated side by side and contrasted with one another. The simulations were executed with the help of MATLAB/Simulink, and the outcomes were studied in order to come to a conclusion about the effectiveness and accomplishments of every control system.

4.2 Grid to Vehicle (G2V) and Vehicle to Grid (V2G) operations of vehicle:

Figure 4.2 provides a visual representation of the G2V and V2G charging functions, illustrating the dynamic role of EVs in managing energy during periods of peak electricity demand. This graphical representation serves as a valuable insight into how EVs can function as energy storage devices, actively contributing to grid stability. The whole circuit MATLAB model is shown in Figure 4.1.

In the G2V charging function, EVs are depicted as actively absorbing excess power from the microgrid. This process occurs during peak electricity demand, strategically utilizing the EVs as reservoirs for surplus energy. By integrating G2V functionality, these vehicles play an important role in supporting grid stability. The absorption of excess power by EVs acts as a buffer, making sure of a steady and controlled flow of electricity within the microgrid. This, in turn, contributes to the efficient management of the grid, preventing fluctuations and disruptions during high-demand periods.

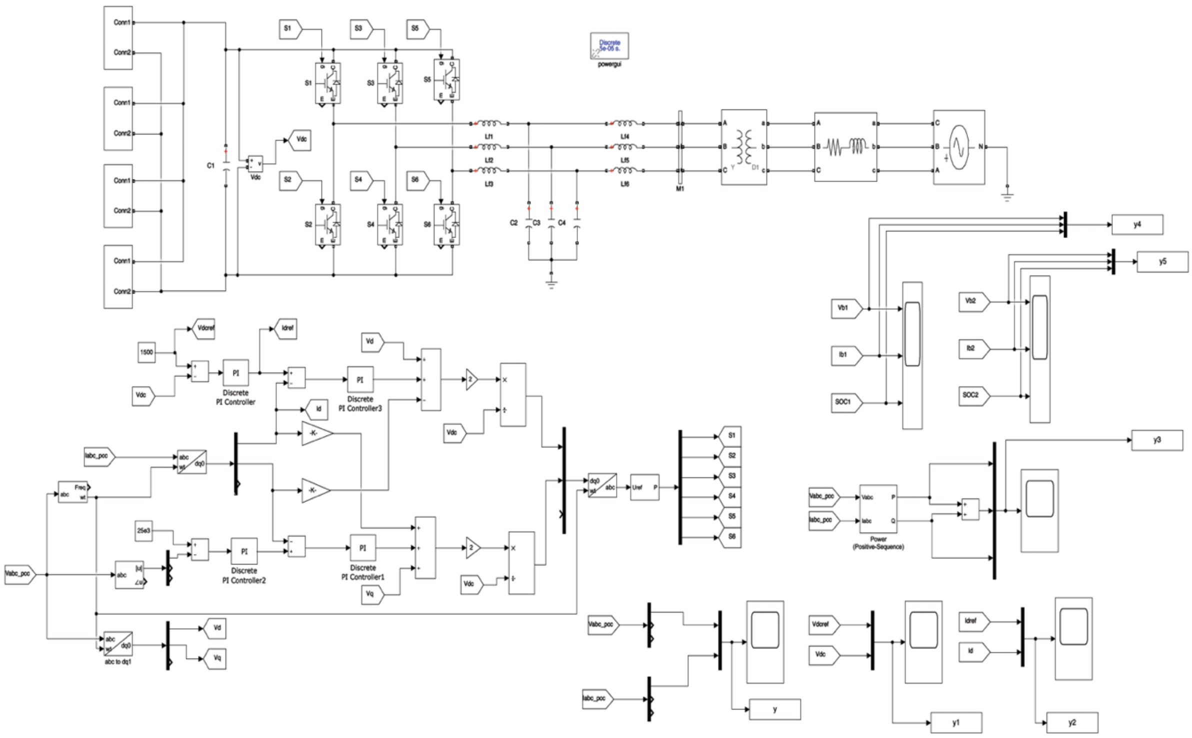

Fig.4.1 EV Charger Circuit Implemented on Simulink MATLAB.

Conversely, the V2G charging function, also illustrated in Figure 4.3, showcases how EVs release stored energy back to the grid when required. This bidirectional energy flow enables EVs to not only act as consumers but also as contributors to the energy ecosystem. During periods of low electricity demand or when the grid requires additional power, EVs seamlessly discharge stored energy. This V2G capability improves the overall flexibility and reliability of the grid, showcasing the potential for EVs to actively participate in grid support functions.

The significance of these charging functions is underscored by their ability to aid grid stability. The absorption of excess power during peak demand and the controlled release of stored energy during low demand contribute to a balanced and stable electricity flow. This is particularly crucial in mitigating the challenges associated with fluctuations in demand and maintaining a reliable power supply.

Integral to the effectiveness of these charging functions is the implementation of FLC. FLC plays a pivotal role in orchestrating the G2V and V2G processes, ensuring that the energy exchange between EVs and the grid is optimized for stability and efficiency. Fuzzy Logic Control provides a sophisticated and adaptive approach to managing the charging and discharging of EVs, considering the complex and dynamic nature of grid conditions.

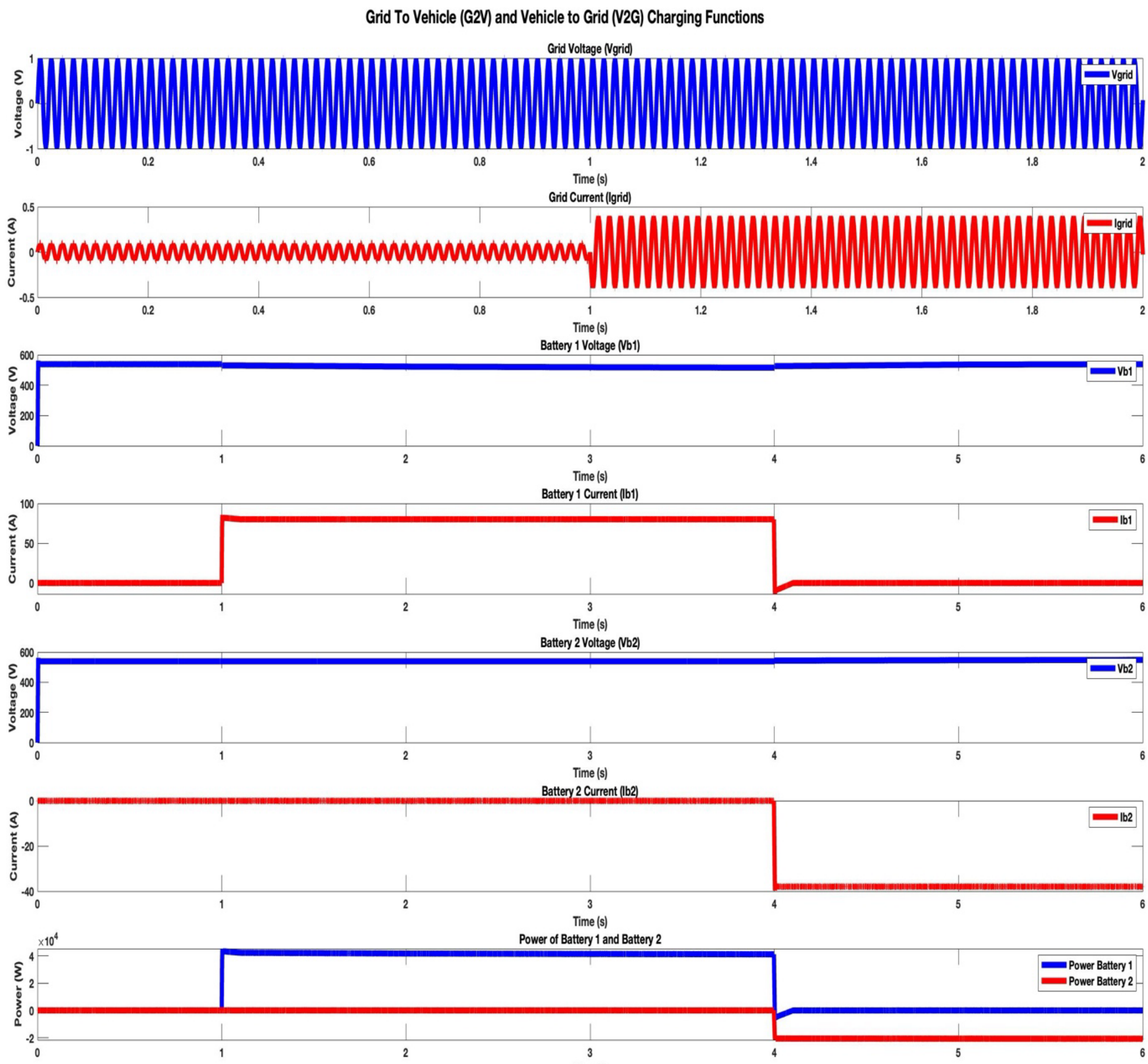

Fig. 4.2 V2G and G2V charging functions.

Figure 4.2, aligns with the broader goals of sustainable and smart energy systems.At t = 1.02 grid voltage and current are inverted as shown in Fig.4.2. At t = 0.2 power is in the value of 48 kw and voltage is 450 V.The ability of EVs to seamlessly integrate with microgrids, acting as both consumers and contributors, exemplifies a forward-thinking approach to energy management. This not only optimizes the usage of renewable energy sources but also addresses challenges associated with peak demand, ultimately enhancing the resilience and sustainability of the overall energy infrastructure.

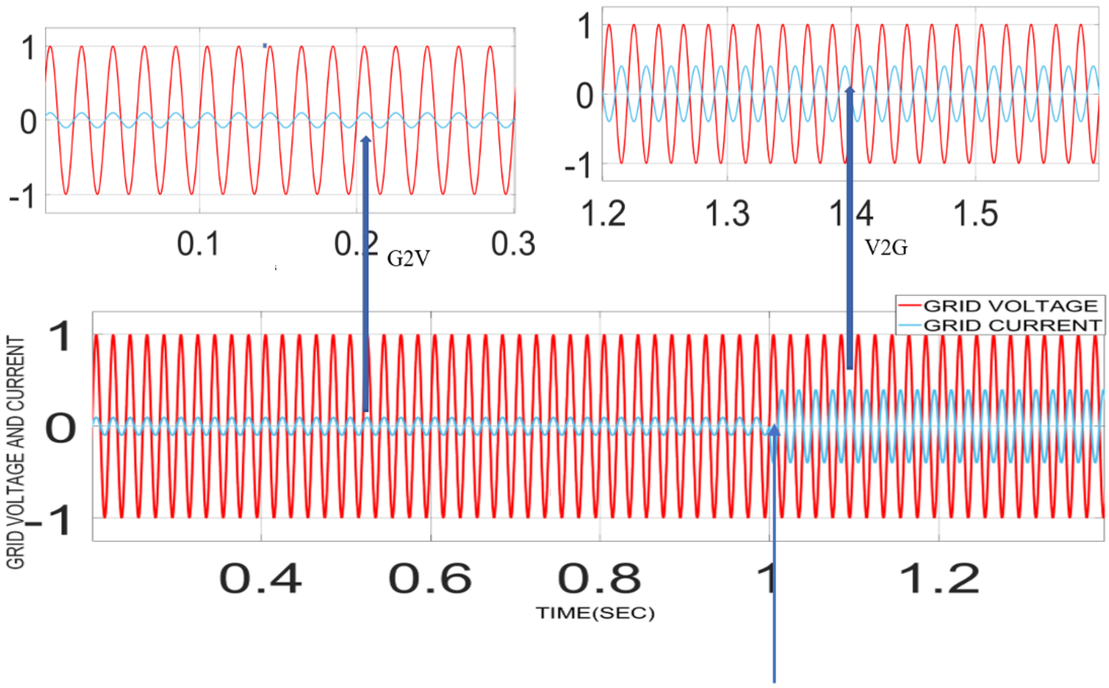

Fig. 4.3 Working of Bidirectional EV charger G2V and V2G

4.3 Regulation of Battery Charging Current:

Figure 4.4 presents control scheme for current regulation of battery charging and discharging currents (I_d) concerning the reference current (I_{dref}). This graphical representation serves as a crucial insight into the precision and effectiveness of FLC in monitoring and controlling the battery currents, showcasing its ability to ensure accurate current management.

In essence, Figure 4.4 serves as a visual narrative of the FLC's prowess in accurately regulating battery currents in response to changes in the reference current. The controller's ability to promptly adapt to variations, maintain stability during constant reference periods, and ensure precision in current management reaffirms its significance in enhancing the overall performance as well as reliability of the battery system. This nuanced and responsive control mechanism positions FLC as a valuable asset in optimizing energy utilization and supporting the40 seamless operation of battery systems.

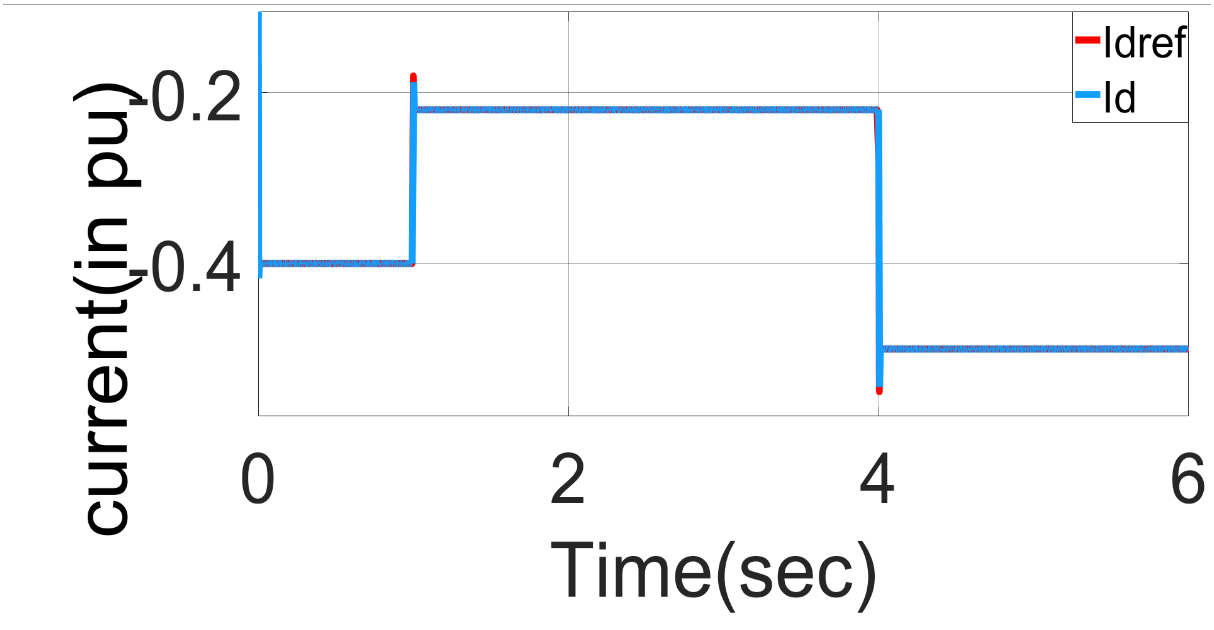

Fig. 4.4 Control scheme for current regulation of battery charging and discharging currents

In the Figure 4.5 , the graph illustrates the dynamic relationship between the actual battery currents and the reference current I_{dref} over a specific time span, depicting the process of constant current charging up to 80% of the battery and subsequent voltage control, while considering the grid voltage.

Initially, at time t = 0, both I_d and I_{dref} are aligned, indicating a stable condition where the actual current matches the desired reference value. This synchronization underscores the ability of the FLC (Fuzzy Logic Controller) to maintain precise control over the battery currents from the outset, ensuring efficient charging. At this stage, the grid voltage supplies power to the battery system, initiating the charging process.

As time progresses to t = 1, there is a subtle increase in the reference current I_{dref} ,suggesting a deliberate adjustment in the desired current level to accommodate the increasing battery voltage. Despite this adjustment, the actual current I_d remains consistent with the reference, showcasing the FLC's ability to adapt to changes in the reference value while adhering to the constant current charging principle. During this period, the grid voltage continues to provide power to meet the charging requirements of the battery system. Between t = 1 to t = 4, both I_{dref} and I_d remain constant, indicating a period of sustained stability in the system. Despite potential fluctuations in the grid voltage or other external factors, the FLC ensures that the actual current maintains alignment with the reference, ensuring steady charging progress. Throughout this phase, the grid voltage remains consistent, providing a reliable power supply to support the charging process.

At t = 4, a subtle decrease is observed in the reference current I_{dref}, reflecting an adjustment to control the charging voltage as the battery approaches 80% of its capacity. Once again, the FLC promptly responds to this change, ensuring that the actual current I_d aligns with the adjusted reference value. This responsiveness highlights the FLC's adaptability to dynamic conditions, maintaining precision in regulating battery currents and controlling voltage fluctuations during the charging process. Table 1 shows the constant charging at 80 % condition.

Table 1 shows the constant charging at 80 % condition.

Time (t)	Reference Current (I_{dref})	Actual Current (I_d)	Grid Voltage (Vgrid)	Battery Voltage (Vbat)	Phase
t = 0	Aligns with I_d	Aligns with I_{dref}	Supplies power	Low	Initialization
t = 1	Slight Increase	Follows I_{dref} increase	Supplies power	Starts rising	Adjustment
t = 1 to t = 4	Constant	Constant (follows I_{dref})	Supplies power	Steady increase	Constant Current Charging
t = 4	Slight Decrease	Follows I_{dref} decrease	Supplies power	Nearing 80%	Transition to Voltage Control

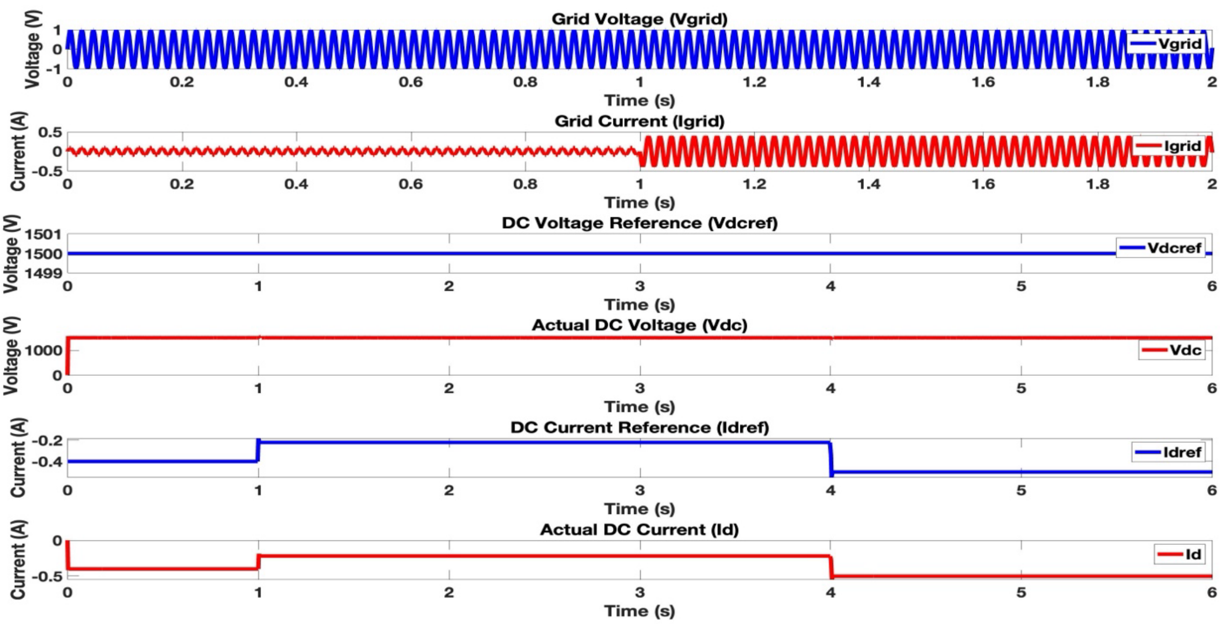

Fig. 4.5 Variation of control signals for regulation of battery current.

4. 4 Regulation of DC Bus Voltage:

Fig 4.5 provides a detailed portrayal of the dynamic alterations in the DC bus voltage (V_{dc}) concerning the reference voltage (V_{dcref}) throughout the operations of the microgrid, which encompass both V2G and G2V functions. The graph serves as an illustrative representation of how the Fuzzy Logic Controller (FLC) adeptly manages V_{dc} to closely align with V_{dcref}, showcases its precision in voltage control. This nuanced control mechanism is instrumental in elevating the overall performance and reliability of the system, ensuring a steady power flow between EVs and the microgrid. The value of V_{dc} is 1500V and V_{dcref} is 1550V.

Initiating the analysis at t = 0, both $V_{dc}$and $V_{dcref}$are observed to be constant, indicating a state of equilibrium where the actual DC bus voltage aligns precisely with the reference voltage. This synchronous relationship underscores the FLC's ability to maintain a stable voltage output from the outset, contributing to the consistency and reliability of the microgrid operations.
As the timeline progresses to t = 1, a deliberate increase is noted in both $V_{dc}$and V_{dcref}.This adjustment adheres to the rule that the values of $V_{dc}$and V_dcref must be closely aligned, with minimal divergence between them. This slight increase in both values reflects the FLC's dynamic response to changes in the microgrid's operational requirements, ensuring that the actual DC bus voltage closely tracks the reference voltage.
In the subsequent period from t = 1 to t = 4, both $V_{dc}$and V_{dcref}maintain a constant value. This phase signifies a sustained period of stability in the microgrid operations. The FLC's effectiveness is evident as it ensures that the DC bus voltage consistently matches the reference voltage, demonstrating the controller's role in providing a reliable and unwavering power flow.
At t = 4, a temporary decrease is observed in both $V_{dc}$and V_{dcref}. However, this deviation is transient, and from t = 4 to t = 6, both voltages return to a constant value. This responsiveness of the FLC to variations in the reference voltage contributes to the adaptability and resilience of the microgrid, enhancing its ability to navigate changing conditions while maintaining optimal voltage control.In essence, the graphical representation in Figure 8 offers a compelling narrative of the FLC's capacity to intricately manage DC bus voltage, ensuring close alignment with the reference voltage. This precision in voltage control significantly contributes to the overall robustness and dependability of the microgrid, fostering a consistent power flow between EVs and the microgrid infrastructure. The FLC's dynamic response to variations in

operational requirements positions it as a pivotal component in optimizing energy utilization and sustaining the efficient

4.5 Analysis of Power Flow in G2V and V2G:

The power profile depicted in Figure 4.6 provides a dynamic visualization of the power exchange between EVs and the microgrid throughout V2G and G2V operations. The graph serves as an illustrative representation of the integral role played by the FLC in orchestrating a controlled and seamless power flow. This controlled power exchange not only ensures efficient energy transfer but also aligns with the microgrid's requirements, emphasizing the FLC's pivotal role in optimizing power dynamics.

Beginning the examination at t = 0 to t = 4, the graph reveals a period during which the grid power remains constant. This stability underscores the FLC's ability to maintain a consistent power supply from the grid during this timeframe. However, at t = 4, a noticeable increase in grid power is observed, followed by a subsequent decrease. This fluctuation indicates the FLC's adaptability to changes in power demand, dynamically adjusting the grid power output. Remarkably, from t = 4 to t = 6, the grid power stabilizes once again at a constant level.

Simultaneously, at t = 1, there is a net increase in EV power, which remains constant up to t = 4. This sustained period of constant EV power output highlights the FLC's capability to regulate and stabilize power generation from EVs during this timeframe. However, at t = 4, a decrease in net EV power is evident, followed by consistent power output from t = 4 to t = 6.

Examining the power at the PCC (Point of Common Coupling), at t = 0, the net power at PCC decreases and remains constant up to t = 4. This signifies a controlled and consistent power transfer at the PCC during this period. Intriguingly, from t = 4 to t = 6, there is an increase in net power at PCC, followed by a sustained constant level.

The FLC's adaptability is paramount in enabling effective power management, enhancing system responsiveness to changing demand, and renewable energy production. The controller's dynamic response to fluctuations in grid power, EV power, and power at the PCC exemplifies its ability to optimize the power flow within the microgrid. This adaptability is crucial in navigating varying demand scenarios and aligning power generation with renewable energy availability.

The FLC's role in achieving a controlled and smooth power flow, as evidenced by the fluctuations and stabilizations in grid power, EV power, and power at the PCC, underscores its significance in optimizing energy transfer. This adaptive and responsive power management contributes to the overall efficiency as well as the sustainability of the microgrid, showcasing the FLC as a linchpin in the dynamic landscape of smart energy systems.

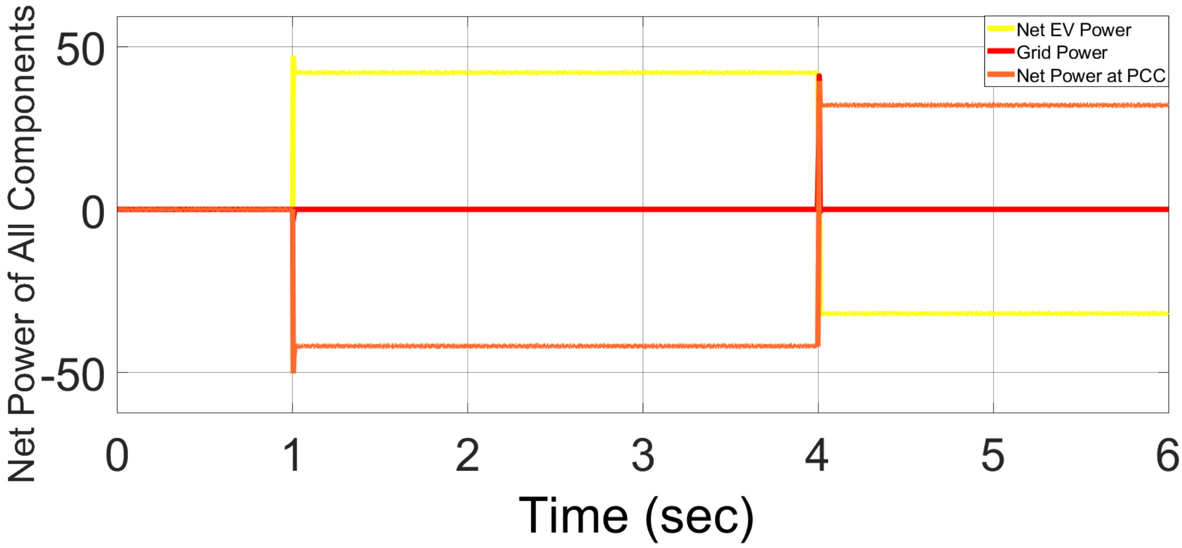

Fig.4.6 Power Profile of All Components

4.6 Fuzzy Logic Control:

Uncoordinated fluctuations in power loading or discharging within transmission networks can lead to alterations in the voltage profiles of nodes. For instance, the unregulated loading or discharging of energy may cause increases or decreases in node voltages beyond the standard Comprehensive Environmental Assessment (CEA). To address this issue, this study employs a Fuzzy Logic Controller (FLC) as shown in Fig. 4.7 to regulate frequency and manage voltage profiles.

In the loading station, each electric vehicle (EV) considers entry parameters like current SOC and voltage profiles. EV loads are adjusted based on high and low SOC voltages, as well as the SOC voltage in conjunction with node voltages. Instances may arise where both high and low SOC, as well as node voltages, need adjustments. In such cases, a controlled charge or discharge rate becomes imperative. The FLC proves highly adept at handling these diverse scenarios, ensuring that variations in node voltages remain within the prescribed standards. This adaptive approach of the FLC effectively mitigates the impact of uncoordinated power dynamics on the transmission network, maintaining stability and compliance with necessary voltage standards.

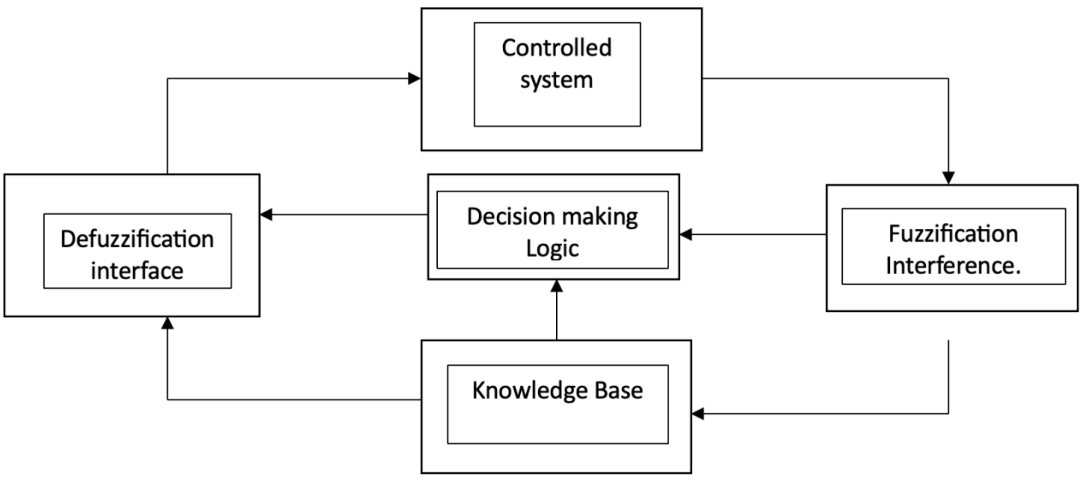

Fig.4.7 FLC Control applied in the circuit.

4.6.1 Design of Controller using Fuzzy:

"The control output u(t) signifies the standardized representation of the control output, while u(v) denotes the output variable. The input voltage is influenced by 7 linguistic variables: which are Negative Big(NB), Negative Medium (NM), Negative Side(NS), Zero(S), Positive Side(PS), Positive Medium(PM), and Positive Big(PB)".

$$u(t) = \frac{\sum_{i=1}^{n} u_i . \mu_v(u_i)}{\sum_{i=1}^{n} \mu_v(u_i)} \quad (4.1)$$

Both voltage and State of Charge (SOC) serve as inputs for the load station controller, influencing the power output utilized for constructing analogous membership functions.
Here the Fuzzy Logic Rule Base being applied in the Project as shown in Table 2 below.

Table 2: RULE BASE FOR FUZZY LOGIC APPLIED

Logic	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NB	NM	Z
NM	NB	NB	NB	NB	NM	Z	PM
NS	NB	NB	NB	NM	ZE	PM	PB
Z	NB	NB	NM	ZE	PM	PB	PB
PS	NB	NM	ZE	PM	PB	PB	PB
PM	NM	ZE	PM	PB	PB	PB	PB
PB	ZE	PM	PB	PB	PB	PB	PB

4.6.2 THD Analysis:

Illustrated in Figure 10 is the THD (Total Harmonic Distortion) of the grid current waveform, a critical parameter in assessing grid stability and safeguarding equipment from potential damage. The waveform, as depicted, exhibits a remarkably low THD of 0.02%, signifying a high-quality and stable electrical output. The significance of monitoring and controlling THD lies in its direct impact on the integrity of the grid and the well-being of connected equipment. The Fuzzy Logic Controller (FLC) plays a pivotal role in achieving this exceptional waveform quality through intelligent and adaptive control decisions.

The THD of the grid current waveform is a key metric in evaluating the purity of the electrical signal. A high-quality waveform, as indicated by the low 0.02% THD, is indicative of minimal harmonic distortions in the current. These distortions, if left unaddressed, can lead to a destabilized grid and potentially cause damage to sensitive equipment connected to the system. Therefore, maintaining a low THD is imperative for making sure the overall stability as well as reliability of the electrical grid.

The FLC, being intelligent and adaptive controller, serves as the driving force behind the control decisions that contribute to the exceptional waveform quality. Through its decision-making process, the FLC dynamically responds to variations and fluctuations in the electrical system, mitigating the presence of harmonic distortions. This adaptability allows the FLC to optimize the current waveform, resulting in a cleaner and more stable electrical output. The reduction in harmonic distortion achieved by the FLC has profound implications for power quality and system efficiency. Harmonic distortions can introduce unwanted frequencies into the electrical system, leading to issues such as voltage fluctuations, increased heating in equipment, and decreased overall system performance. By minimizing THD, the FLC enhances power quality, ensuring a smoother and more reliable flow of electrical energy within the grid.

Moreover, the intelligent decision-making capabilities of the FLC enable it to proactively address variations in system conditions. This adaptability is crucial for maintaining stable electrical output under changing loads and operational scenarios. As a result, the FLC not only minimizes THD but also contributes to the overall efficiency and resilience of the power system.

The low THD showcased in the graph is a testament to the FLC's intelligent decision-making, adaptability, and significant role in enhancing power quality and system efficiency. This capability is vital for ensuring the stability of the grid and preventing damage to equipment, underscoring the importance of intelligent control mechanisms in modern power systems.

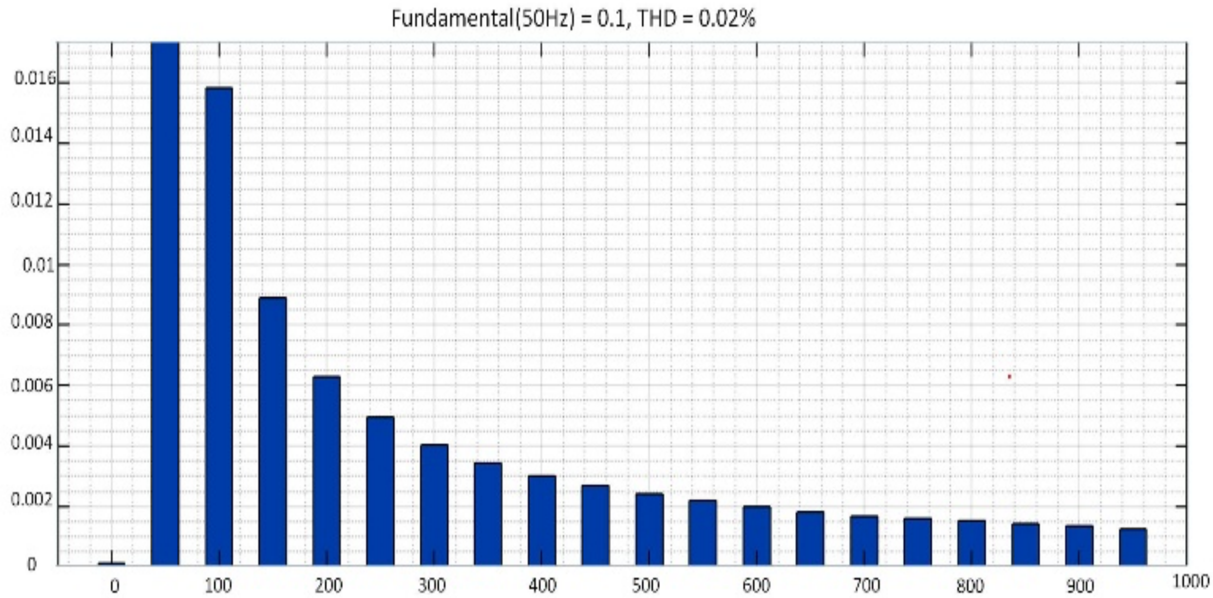

Fig 10 THD using Fuzzy Logic Control (FLC)

Table 1 shows the differences between PI and Fuzzy Logic Controllers in terms of THD. The FLC reduced THD from 0.09% (PI Controller) to 0.02%. The Fuzzy Logic Controller reduces harmonic distortion and boosts power quality.

Table 3 Performance Comparison

Controller Type	**THD (%)**
PI Controller	0.09%
Fuzzy Logic Controller	0.02%

4.7 Conclusion:

This chapter demonstrated that Fuzzy Logic Control (FLC) significantly improves EV charger performance within a V2G-G2V infrastructure. FLC excels at regulating currents, voltages, and power flow, leading to more stable and efficient energy exchange between EVs and the grid. Compared to a PI controller, FLC reduces THD in the grid current, ensuring a cleaner and more reliable power supply. FLC presents a promising control technique for EV chargers, paving the way for a more sustainable and resilient energy future.

CHAPTER 5.

Simulation and Analysis of Bi-Directional EV Charger Using Arduino UNO in Proteus

5.1 General

This chapter presents the hardware implementation of the Multifunctional Bidirectional Converter (BDC) with Arduino UNO-based microcontroller. The implementation of the circuit is shown in Fig. 5.1 in which two microcontrollers are used for the Inverter Control, Charging and Discharging Control. But before the implementation, the Components used in the circuit along with the working are shown below and then after that switching frequency analysis of three phase inverter and three phase analysis will be done.

5.2 Components used in circuit.

The below schematic i.e. Fig. 5.1 consists of following components which are used in circuit:

5.2.1. Optocoupler Circuit for Conversion Process:

- The optocoupler circuit is essential for isolating the control signals from the Arduino UNO to the high-power components of the inverter as shown in Fig. 18.
- It typically consists of an LED on the Arduino side and a phototransistor on the inverter side, separated by an optically transparent barrier.

When the Arduino sends a signal, it illuminates the LED, which in turn activates the phototransistor, mimicking the signal on the other side while keeping the two sides electrically isolated. This isolation protects the Arduino from potential high-voltage spikes or noise generated by the inverter circuit, ensuring reliable operation and safety.

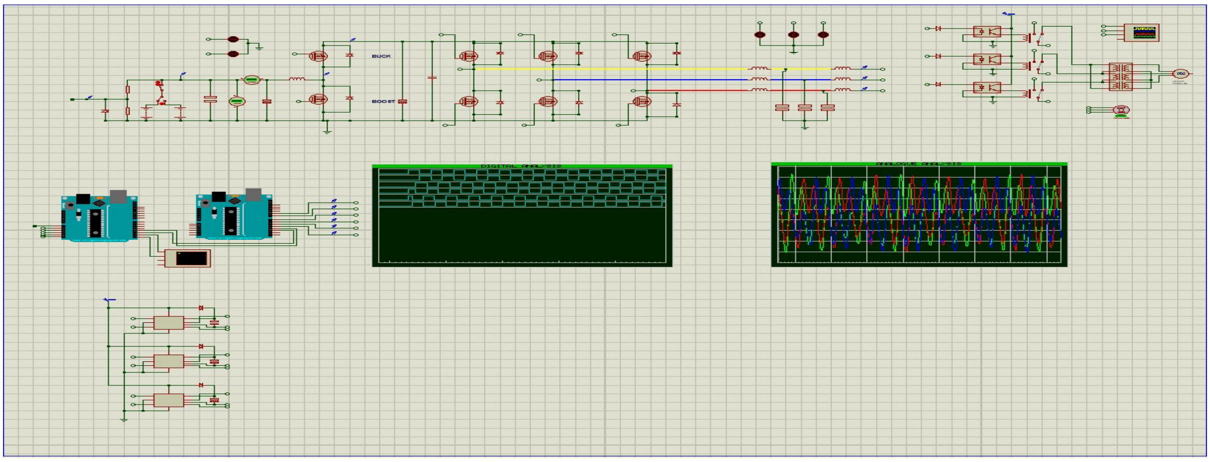

Fig. 5.1 Schematic Diagram of Circuit with Arduino UNO

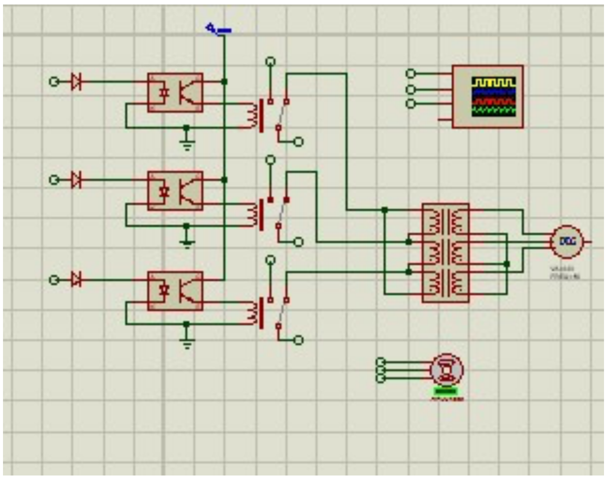

Fig.5.2 Optocoupler circuit for conversion process

5.2.2. Inverter Control:

- Inverter control manages the switching of power transistors or MOSFETs in the three-phase inverter circuit as shown in Fig. 5.3.
- The Arduino UNO generates PWM signals to control the speed and direction of the motor or load connected to the inverter.
- By adjusting the duty cycle of the PWM signals, the Arduino regulates the output voltage and frequency of the inverter, thus controlling the speed and torque of the motor.
- Feedback mechanisms, such as current or voltage sensors, are employed to adjust the PWM signals dynamically, ensuring stable operation and optimal performance.

5.2.3. Charging Control:

- Charging control oversees the charging of batteries or capacitors used in the system as shown in Fig. 5.3.
- The Arduino monitors the voltage and current levels of the batteries or capacitors and adjusts the charging parameters accordingly.
- It employs charging algorithms to ensure efficient charging while preventing overcharging, which can degrade battery life or cause safety hazards.
- Components like voltage regulators, current sensors, and charging ICs are integrated to manage the charging process effectively and safely.

5.2.4. Discharging Control:

- Discharging control regulates the discharge process of batteries or capacitors when the load is connected to the inverter as shown in Fig. 5.3.
- The Arduino manages the discharging process by adjusting the load connected to the inverter based on the system's power requirements.
- It prevents over-discharge, which can damage the batteries or capacitors, by monitoring their voltage levels and disconnecting the load when necessary.

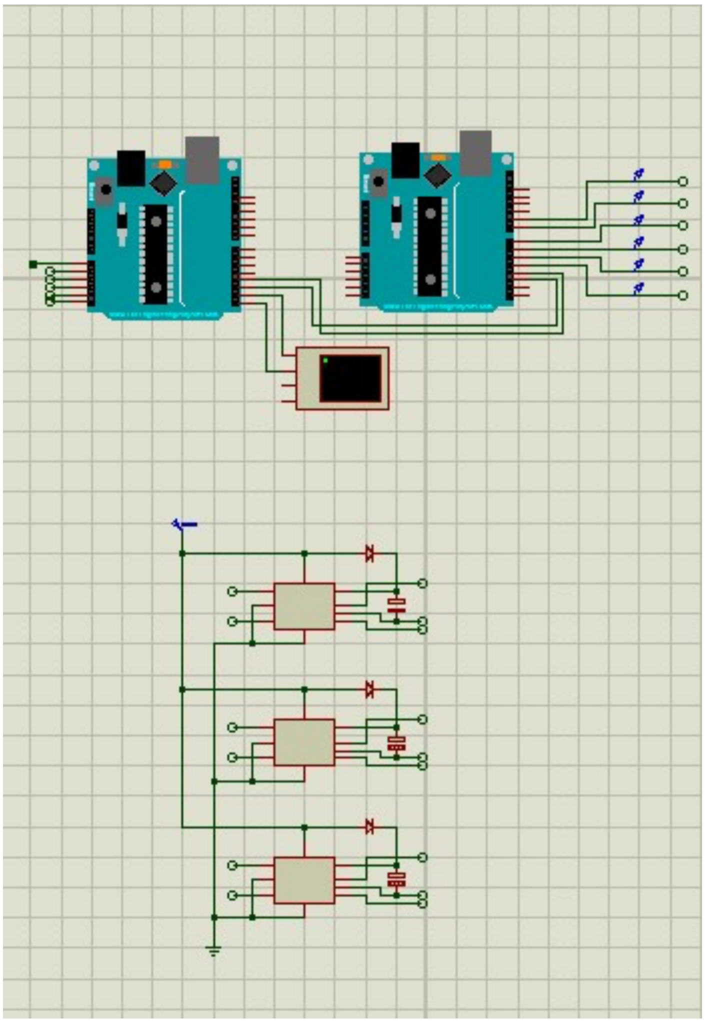

Fig.5.3 Inverter control, charging, and discharging control

5.2.5. Proposed Circuit:

- The proposed circuit encompasses the entire system design, integrating all the a fore mentioned sections into a cohesive unit.
- It considers factors such as component placement, wiring, and safety measures to ensure the reliable and efficient operation of the system.
- Additional features or enhancements are incorporated based on specific requirements, such as communication interfaces for remote monitoring and control or fault detection mechanisms.

Fig. 20 shows the proposed circuit which is developed with the Arduino UNO along with the LCL Filter being connected to the grid and the inverted output is being supplied via the three-phase connection of the MOSFETs and the output of the Three Phase MOSFET is being converted via the DC-DC Converter which is then being supplied to the charger as shown in Fig.20.

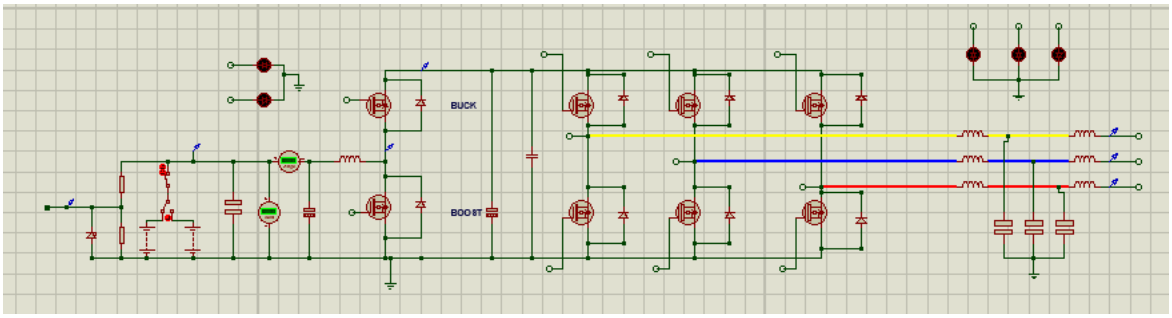

Fig. 5.4 Proposed circuit

5.2.6 Circuit Analysis Output:

Circuit is analysed in the two different operating conditions which are the Inverter control Mode and charging and discharging control mode as shown in below given sections for porposed circuit as shown in Fig. 5.4 .

5.3 Inverter Control

In the inverter control circuit designed with an Arduino Uno for a bidirectional converter (as shown in Figure 5.1), the Arduino serves as the brain of the system, orchestrating the switching of IGBT diodes or MOSFETs to control power flow. The circuit utilizes digital pins D4, D5, D6, D7, D8, and D9 for this purpose, with D5, D6, D7, and D9 configured as digital PWM pins for precise control over pulse width modulation. When AC power is supplied, an optocoupler activates, providing 5V to power the Arduino. Upon initialization, the Arduino sets the designated pins accordingly. It then runs a control algorithm to determine the switching pattern for the three-phase circuit, taking into account parameters such as commutation delay and dead time delay. By generating PWM signals on the appropriate pins, the Arduino controls the switching of the diodes or MOSFETs, adjusting output voltage and frequency as needed. Optional feedback sensors can provide data for dynamic adjustments, while safety features ensure protection against abnormal conditions. When the AC supply is disconnected, the Arduino halts PWM signal generation, ending the inverter operation. This control circuit offers flexibility and customization, making it suitable for various applications such as renewable energy systems, motor drives, or uninterruptible power supplies. Additionally, by leveraging the Arduino's programmability, digital PWM pins, and feedback capabilities, it provides precise control over power flow while ensuring safety and reliability. In Figure 5.1, the Arduino on the right side of the picture acts as the three-phase inverter controller, transmitting signals to Arduino Uno 2 for the charging and discharging circuit.

5.4. For charging and discharging control.

In the charging and discharging process, the second Arduino Uno receives signals from the first Arduino Uno and executes operations based on the circuit's operating conditions. Two different batteries are involved in this scenario. Initially, the first Arduino Uno monitors the voltage of the batteries and determines whether the power supply in the grid is in negative or positive polarity, indicating the required operating condition for the circuit. If the switch is in the upper position, indicating battery 1, it will engage in Grid-to-Vehicle (G2V) or Vehicle-to-Grid (V2G) operations. However, certain operations involved in EV charging, such as managing communication protocols like CAN bus or handling high-power charging currents, may require specialized hardware or dedicated EV charging controllers. The second Arduino Uno monitors the PWM signals generated by the switches for charging and discharging. If the switch is in the lower position, indicating battery 2, it engages in G2V operation. Arduino 2 continues to monitor PWM signals, adjusting charging and discharging based on battery conditions, such as whether they are fully charged or not. This dual Arduino setup, supplemented with specialized hardware where necessary, enables efficient control and management of battery operations, ensuring optimal performance and utilization within the circuit.

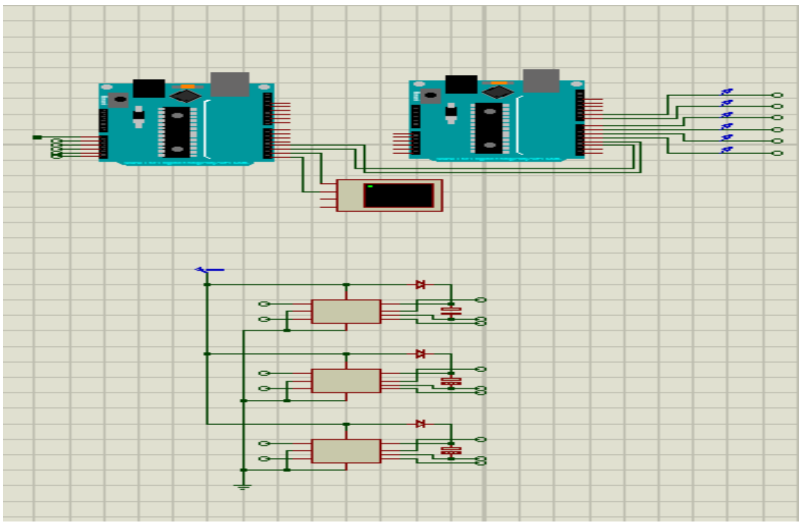

Fig. 5.5 Inverter control, charging, and discharging control

5.5 Results and Discussions

As shown in Fig. 5.6 AH, AL, BH, BL, CH, CL are the outputs being generated by Arduino Uno for the three-phase AC analysis, predicting whether the output is in the form of 1 or 0 in the time interval of 1 second between 0 seconds to 10 seconds" suggests that the Arduino Uno is generating control signals for a three-phase AC system.

In a three-phase AC system, there are three phases: phase A, phase B, and phase C. Each phase has two outputs, one representing the high state (AH, BH, CH) and the other representing the low state (AL, BL, CL). These outputs are typically used to control switches, such as IGBTs or MOSFETs, in an inverter circuit.

During the time interval from 0 seconds to 10 seconds, the Arduino generates these control signals in a cyclical manner, with each cycle lasting for 1 second. The values of 1 or 0 indicate whether the respective output is in the high state (1) or the low state (0) at a given moment in time.

Overall, this line describes the generation of control signals by the Arduino Uno to manage the switching of the three-phase AC system, ensuring proper operation and control of the power flow.

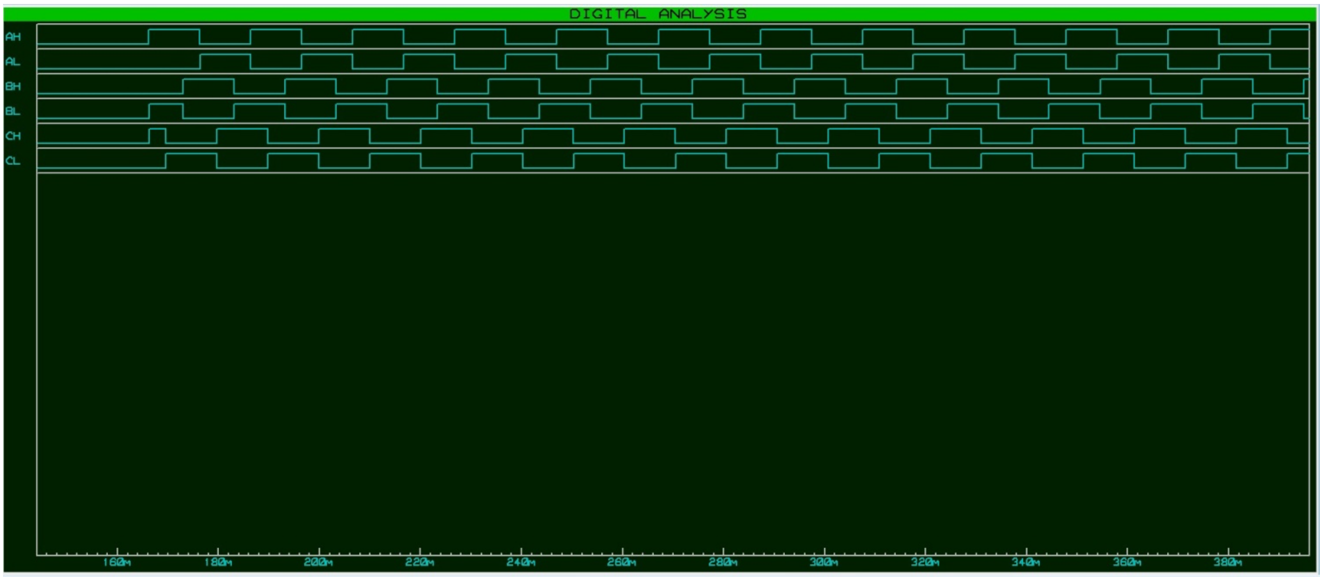

Fig. 5.6 Switching frequency analysis 3-phase inverter

Fig 5.7 is the output of the G2V and V2G analysis being carried out by the Arduino Uno for controlling the voltage and current among the three-phase switches and controlling and monitoring the voltage and current for buck and boost regulation up to 12V DC" indicates that the following figure displays the results of Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) analysis performed by the Arduino Uno. In this analysis, the Arduino Uno is responsible for controlling the voltage and current among the three-phase switches in the system. It manages the power flow between the grid and the vehicle during G2V and V2G operations. Additionally, the Arduino Uno monitors and regulates both the voltage and current for buck and boost regulation, ensuring that the output remains within the desired range, specifically up to 12V DC.

But the sinusoidal output observed in the figure below does not occur at regular time intervals, and distortions are evident in the waveform. These irregularities make it challenging to predict whether the system is in working condition or not with certainty. Despite efforts to control voltage and current, the presence of waveform distortions indicates potential issues or inefficiencies in the system's operation. These distortions could arise from various factors such as harmonic distortion, switching losses, or mismatches in component characteristics. As a result, additional analysis and troubleshooting may be required to ensure the system operates reliably and efficiently.

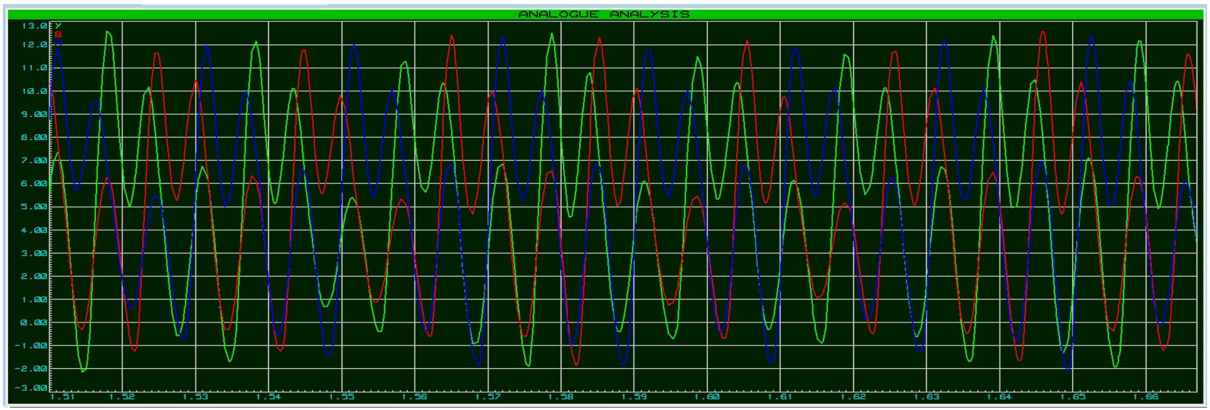

Fig.5.7 Three-Phase AC Analysis

5.6 Comparative Performance Analysis of Circuit Simulations between MATLAB and Proteus Software:

5.6.1 MATLAB AND PROTEUS CIRCUIT PERFORMANCE COMPARISON.

MATLAB IMPLEMENTATION

5.6.1.1. G2V AND V2G CHARGING VISUALIZATION

- MATLAB simulations provide visual representation of Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) charging operations as shown in Fig 4.3.

- These figures show how EVs absorb surplus electricity when demand is high and release it back into the grid as energy during low demand.

5.6.1.2. GRID STABILITY & EFFICIENCY:

- Energy supply from electric vehicles works to even out power surges within a microgrid.

- This occurs due to the ability to move electricity bidirectionally consequently ensuring there are no fluctuations or breakages during times of increased power usage.

5.6.1.3. FUZZY LOGIC CONTROL (FLC):

- FLC systems are used in optimizing G2V/V2G algorithms.

- It dynamically changes based on grid state so that EVs can trade power with the grid effectively.

5.6.1.4. SUSTAINABLE ENERGY MANAGEMENT:

- Electric vehicles play a dual role of consumers and producers in the smart grid, which fall under sustainable energy targets

- This combination enables maximization of renewable sources and overcoming challenges associated with peak demand situations.

5.6.2 Arduino Uno implementation on Proteus

Summary of findings

5.6.2.1. Distortions in the output:

- Proteus simulation with Arduino Uno result to distortions that do not perform perfect sinusoidal output.
- This is a limitation of using Arduino Uno for complex three-phase inverter circuits.

5.6.2.2. Frequency Response Analysis:

- The frequency response of the three-phase inverter was observed at 50Hz.
- However, distortion in the output obtained from monitoring signals may be an indication that using Arduino Uno for achieving more superior results is unlikely.

5.6.2.3. Recommendation for Advanced Microcontrollers:

- Changing to advanced microcontrollers such as TI-C2000 or TI-MSP430 is suggested.
- These controllers are better suited for handling complexity of this circuit, minimizing distortions and enhancing quality of outputs.

5.6.3 Comparative Analysis

5.6.3.1 Simulation Environment:

- For simulating and visualizing intricate energy management systems, MATLAB provides a powerful platform.
- But when it comes to pure hardware simulations, Proteus doesn't work well with simple microcontrollers like Arduino Uno for high-performance tasks.

5.6.3.2 Output Quality:

- Crucial clear and steady outputs can be found through running MATLAB simulations, which help understand better and optimize energy systems.
- There is substantial distortion in Proteus simulations involving Arduino Uno.

5.7 Conclusion:

The chapter demonstrates the hardware implementation of a Multifunctional Bidirectional Converter (BDC) using Arduino UNO microcontrollers. Key components include optocouplers for signal isolation, and control circuits for inverter, charging, and discharging processes.The system has performed switching frequency analysis of three phase inverter and the three phase AC analysis. The system effectively manages power flow and battery operations, but simulations reveal output distortions when using Arduino UNO, indicating its limitations for complex tasks. Advanced microcontrollers like TI-C2000 or TI-MSP430 are recommended for better performance. Comparative analysis shows that while MATLAB provides superior visualization and control optimization, Proteus simulations with Arduino UNO exhibit significant output quality issues.

CHAPTER 6

Main Conclusion and Future Scope of the work.

6.1 Main Conclusion:

This thesis presents an extensive literature review as well as identify potential gaps for future research and development in the field of multifunctional bidirectional EV chargers with DC swiftly charging architecture. Highlight the importance of continued innovation in this area to accelerate the transition towards sustainable transportation and energy systems.

This project delved into the integration of Vehicle-to-Grid (V2G) technology within microgrids, particularly focusing on providing DC rapid charging solutions for electric vehicles (EVs). The primary objective was to assess the viability of utilizing EV batteries as an energy storage solution within the microgrid context. The findings of this study underscore the significance of employing Fuzzy Logic Control (FLC) in driving the V2G-G2V system, showcasing its superior performance compared to the conventional Proportional Integral (PI) controller.

One of the notable observations of the FLC-driven V2G-G2V system was its enhanced management of power flow. In direct comparison with the industry-standard PI controller, the FLC demonstrated superior capabilities, resulting in a substantial reduction in total harmonic distortion (THD) from 0.09% to an impressive 0.02%. This reduction in THD is pivotal as it directly translates to improved circuit efficiency. The FLC's adept handling of bidirectional energy flow during V2G and G2V operations proved instrumental in optimizing charging and discharging processes based on grid dynamics.

Furthermore, the FLC showcased its adaptability by seamlessly incorporating renewable energy sources into the microgrid. This dynamic control allowed for an increase in energy consumption while ensuring the integration of clean energy alternatives. The successful implementation of V2G-G2V, guided by the FLC, contributed significantly to reducing dependence on fossil fuels. This reduction aligns with broader sustainability goals, promoting a shift towards cleaner energy sources. The implications of this study extend beyond efficiency gains. The integration of V2G-G2V, especially when guided by FLC, was found to enhance grid reliability, quality, and overall performance. The ability to actively manage energy flow bidirectionally not only optimizes the use of stored energy in EV batteries but also contributes to grid stability, a crucial factor in modern energy systems.

The dynamic control exhibited by the FLC holds particular promise for the development of smart microgrids. In the era of increasing reliance on renewable energy, the adaptability and responsiveness of FLC offer a sophisticated solution for ensuring high-quality energy management. The integration of such intelligent control systems becomes imperative for harnessing the full potential of renewable energy sources within microgrid frameworks.

In conclusion, this study serves as a testament to the potential of V2G-G2V technology, especially when coupled with DC fast charging and guided by FLC. The achieved reduction in THD and the seamless incorporation of renewable energy sources underscore the practical benefits of such systems. However, to validate the practical applicability of these findings, real-world testing in diverse microgrid applications is recommended. The success of V2G-G2V, as demonstrated in this study, not only points towards a sustainable energy future but also emphasizes the need for continued research and implementation of intelligent control systems in the pursuit of efficient and reliable microgrid operations. This holistic approach holds the key to shaping a resilient and sustainable energy landscape in the years to come.

Provide an overview of the main conclusions drawn from the literature survey and suggest future directions for study and development in the area of DC rapidly charging architecture for multipurpose bidirectional EV chargers. With the Arduino Multifunctional Bidirectional EV Charger DC Swiftly Charging Architecture, you may draw attention to how crucial it is to keep up the innovation in this field in order to hasten the shift to sustainable energy and transportation systems. Efforts are also made to utilize Arduino for implementing Multifunctional Bidirectional EV Charger DC Swiftly Charging Architecture in conjunction with IOT in the near future.

6.2 Future scope of the work:

The future scope of multifunctional bidirectional electric vehicle (EV) chargers with DC swiftly charging architecture is promising and holds significant potential for advancing electric vehicle technology and infrastructure. Following are some aspects of analysis:

1. **Increased Adoption of Electric Vehicles**: As the demand for EVs continues to rise globally due to environmental concerns and government regulations, there will be a growing need for efficient and versatile EV charging solutions. Multifunctional bidirectional chargers with DC swiftly charging architecture can address this need by offering fast and convenient charging options for electric vehicles.
2. **Enhanced Charging Infrastructure**: The deployment of multifunctional bidirectional EV chargers with DC swiftly charging architecture can contribute to the expansion and improvement of EV charging infrastructure. These chargers can be installed in various locations like homes, workplaces, public parking lots, as well as highways, providing users with more options for charging their vehicles quickly and efficiently.
3. **Vehicle-to-Grid (V2G) Integration**: When necessary, EVs with bidirectional charging capability can release energy back into the grid in addition to charging from it. This concept, known as V2G integration, enables electric vehicles to serve as mobile energy storage units and participate in grid balancing and demand response programs. The future integration of V2G technology with multifunctional bidirectional EV chargers can help improve grid stability, increase renewable energy integration, and reduce electricity costs.
4. **Smart Grid Integration**: Multifunctional bidirectional EV chargers can be integrated into smart grid systems, allowing for dynamic control and optimization of charging processes on the basis of electricity prices, grid conditions, and user preferences. Smart charging algorithms can prioritize charging during off-peak hours, manage energy flow between vehicles and the grid, and ensure efficient utilization of renewable energy resources.
5. **Advanced Communication and Connectivity**: Future multifunctional bidirectional EV chargers are likely to incorporate advanced communication and connectivity features, enabling seamless interaction with electric vehicles, charging networks, energy management systems, and other smart devices. This connectivity can facilitate

remote monitoring, diagnostics, firmware updates, and payment processing, enhancing user convenience and system efficiency.

6. **Energy Storage Integration**: Integration of energy storage systems, like batteries or supercapacitors, with multifunctional bidirectional EV chargers can further enhance their capabilities. Energy storage can help mitigate grid fluctuations, store excess renewable energy for later usage, and offer backup power during emergencies or grid outages.
7. **Standardization and Interoperability**: Future developments in the multifunctional bidirectional EV charger space may involve standardization efforts to ensure interoperability between different charger models, electric vehicles, and grid infrastructure. Standardized protocols and interfaces can promote compatibility, scalability, and widespread adoption of bidirectional charging technology.

Overall, the future scope of multifunctional bidirectional EV chargers with DC swiftly charging architecture is characterized by advancements in charging infrastructure, grid integration, communication technologies, and energy management strategies. These developments have the potential to accelerate the transition to electric mobility and pave the way for a more sustainable and resilient energy future.

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APPENDIX

Voltage-Monitor-Buck-Boost Code

```
#include "Mapf.h"

#define VBAT_SENSE_PIN A0

#define BUCK A4
#define BOOST A5

#define START_3_PHASE 2
#define STOP_3_PHASE 3

#define OPTOCOUPLER_1 A1
#define OPTOCOUPLER_2 A2
#define OPTOCOUPLER_3 A3

float battery_voltage_value = 0;
int raw_batt_vol_value = 0;
const int commutationDelay = 3333;  // microseconds

float Voltage_Sense(void);
void Grid_Switch(bool switch_val);

void setup() {

  Serial.begin(9600);
  Serial.println("Bidirectional V2G-G2V AC-DC convertor");

  pinMode(VBAT_SENSE_PIN, INPUT);

  pinMode(BUCK, OUTPUT);
```

```
  pinMode(BOOST, OUTPUT);

  pinMode(START_3_PHASE, OUTPUT);
  pinMode(STOP_3_PHASE, OUTPUT);

  pinMode(OPTOCOUPLER_1, OUTPUT);
  pinMode(OPTOCOUPLER_2, OUTPUT);
  pinMode(OPTOCOUPLER_3, OUTPUT);

  digitalWrite(BUCK, LOW);
  digitalWrite(BOOST, LOW);

  digitalWrite(START_3_PHASE, LOW);
  digitalWrite(STOP_3_PHASE, LOW);

  digitalWrite(OPTOCOUPLER_1, LOW);
  digitalWrite(OPTOCOUPLER_2, LOW);
  digitalWrite(OPTOCOUPLER_3, LOW);
}

void loop() {

  float battery_sense_val = 0;

  battery_sense_val = Voltage_Sense();

  Serial.print("Battery Voltage: ");
  Serial.println(battery_sense_val);
  delay(100);

  if(battery_sense_val < 12){
    digitalWrite(BUCK, HIGH);
    digitalWrite(BOOST, LOW);
```

```
    digitalWrite(START_3_PHASE, LOW);
    digitalWrite(STOP_3_PHASE, HIGH);

    digitalWrite(OPTOCOUPLER_1, LOW);
    digitalWrite(OPTOCOUPLER_2, LOW);
    digitalWrite(OPTOCOUPLER_3, LOW);
  }
  else if(battery_sense_val >= 12){
    digitalWrite(BUCK, LOW);
    digitalWrite(BOOST, HIGH);

    digitalWrite(OPTOCOUPLER_1, HIGH);
    digitalWrite(OPTOCOUPLER_2, HIGH);
    digitalWrite(OPTOCOUPLER_3, HIGH);

    digitalWrite(START_3_PHASE, HIGH);
    digitalWrite(STOP_3_PHASE, LOW);
  }

}

}
```

Three-Phase-Mosfet-Switching Code

```
/*   THREE PHASE MOSFET SWITCHING     */

#define START_PIN 2
#define STOP_PIN 3

#define AH 4
#define AL 5
#define BH 6
#define BL 7
#define CH 8
#define CL 9

void three_phase_dc_to_ac_convert(void);

volatile bool start_3_phase_dc_to_ac = false;
const int commutationDelay = 3333;  // microseconds
const int deadTimeDelay = 3;  // microseconds

void setup() {
  pinMode(AH, OUTPUT);
  pinMode(AL, OUTPUT);
  pinMode(BH, OUTPUT);
  pinMode(BL, OUTPUT);
  pinMode(CH, OUTPUT);
  pinMode(CL, OUTPUT);

  digitalWrite(AH, LOW);
  digitalWrite(AL, LOW);
  digitalWrite(BH, LOW);
  digitalWrite(BL, LOW);
  digitalWrite(CH, LOW);
  digitalWrite(CL, LOW);
```

```
  pinMode(START_PIN, INPUT);
  pinMode(STOP_PIN, INPUT);
  attachInterrupt(digitalPinToInterrupt(START_PIN), start_3_phase, RISING);
  attachInterrupt(digitalPinToInterrupt(STOP_PIN), stop_3_phase, RISING);
}

void loop() {

  if(start_3_phase_dc_to_ac){
    three_phase_dc_to_ac_convert();
  }
  else{
    digitalWrite(AH, LOW);
    digitalWrite(AL, LOW);
    digitalWrite(BH, LOW);
    digitalWrite(BL, LOW);
    digitalWrite(CH, LOW);
    digitalWrite(CL, LOW);
  }

}

void start_3_phase(){
  start_3_phase_dc_to_ac = true;
}

void stop_3_phase(){
  start_3_phase_dc_to_ac = false;
}

void three_phase_dc_to_ac_convert(){

  while(start_3_phase_dc_to_ac){
```

```
    digitalWrite(AH, HIGH);
    digitalWrite(BL, HIGH);
    digitalWrite(CH, HIGH);

    delayMicroseconds(commutationDelay);

    digitalWrite(CL, LOW);
    delayMicroseconds(deadTimeDelay);
    digitalWrite(CH, HIGH);

    delayMicroseconds(commutationDelay);

    digitalWrite(BH, LOW);
    delayMicroseconds(deadTimeDelay);
    digitalWrite(BL, HIGH);

    delayMicroseconds(commutationDelay);

    digitalWrite(AL, LOW);
    delayMicroseconds(deadTimeDelay);


  }

}
```

ANALYSIS OF DATA ON MATLAB CODE .m:

MATLAB CODE FOR BATTERY CHARGING AND DISCHARGING CHARACTERISTICS:

```
% Load data from the workspace

% Set the font size and line width
fontSize = 20;
lineWidth = 2;

% Create a figure for plotting
figure;

% Plot Battery 1 data
subplot(6,1,1);
plot(y4.Time, y4.Data(:,1), 'b', 'LineWidth', lineWidth);
xlabel('Time (s)', 'FontSize', fontSize);
ylabel('Voltage (V)', 'FontSize', fontSize);
title('Battery 1 Voltage (Vb1)', 'FontSize', fontSize);
set(gca, 'FontSize', fontSize);
legend('Vb1', 'FontSize', fontSize);

subplot(6,1,2);
plot(y4.Time, y4.Data(:,2), 'r', 'LineWidth', lineWidth);
xlabel('Time (s)', 'FontSize', fontSize);
ylabel('Current (A)', 'FontSize', fontSize);
title('Battery 1 Current (Ib1)', 'FontSize', fontSize);
set(gca, 'FontSize', fontSize);
legend('Ib1', 'FontSize', fontSize);

subplot(6,1,3);
plot(y4.Time, y4.Data(:,3), 'g', 'LineWidth', lineWidth);
xlabel('Time (s)', 'FontSize', fontSize);
ylabel('SOC (%)', 'FontSize', fontSize);
title('Battery 1 State of Charge (SOC)', 'FontSize', fontSize);
set(gca, 'FontSize', fontSize);
legend('SOC', 'FontSize', fontSize);

% Plot Battery 2 data
subplot(6,1,4);
plot(y5.Time, y5.Data(:,1), 'b', 'LineWidth', lineWidth);
xlabel('Time (s)', 'FontSize', fontSize);
ylabel('Voltage (V)', 'FontSize', fontSize);
title('Battery 2 Voltage (Vb2)', 'FontSize', fontSize);
set(gca, 'FontSize', fontSize);
legend('Vb2', 'FontSize', fontSize);

subplot(6,1,5);
plot(y5.Time, y5.Data(:,2), 'r', 'LineWidth', lineWidth);
xlabel('Time (s)', 'FontSize', fontSize);
ylabel('Current (A)', 'FontSize', fontSize);
title('Battery 2 Current (Ib2)', 'FontSize', fontSize);
set(gca, 'FontSize', fontSize);
legend('Ib2', 'FontSize', fontSize);
```

```
subplot(6,1,6);
plot(y5.Time, y5.Data(:,3), 'g', 'LineWidth', lineWidth);
xlabel('Time (s)', 'FontSize', fontSize);
ylabel('SOC (%)', 'FontSize', fontSize);
title('Battery 2 State of Charge (SOC)', 'FontSize', fontSize);
set(gca, 'FontSize', fontSize);
legend('SOC', 'FontSize', fontSize);
```

MATLAB CODE FOR V2G AND G2V CHARGING FUNCTIONS:

```
% Load data from the workspace

% Create a figure for plotting
figure;

% Set the font size
fontSize = 50;

% Plot Vgrid
subplot(5,1,1);
plot(y.Time, y.Data(:,1), 'b');
xlabel('Time (s)', 'FontSize', fontSize);
ylabel('Voltage (V)', 'FontSize', fontSize);
title('Grid Voltage (Vgrid)', 'FontSize', fontSize);
xlim([0 2]);
set(gca, 'FontSize', fontSize);

% Plot Igrid
subplot(5,1,2);
plot(y.Time, y.Data(:,2), 'r');
xlabel('Time (s)', 'FontSize', fontSize);
ylabel('Current (A)', 'FontSize', fontSize);
title('Grid Current (Igrid)', 'FontSize', fontSize);
xlim([0 2]);
set(gca, 'FontSize', fontSize);

% Plot Vb1 and Ib1
subplot(5,1,3);
plot(y8.Time, y8.Data(:,1), 'b', y8.Time, y8.Data(:,2), 'r');
xlabel('Time (s)', 'FontSize', fontSize);
ylabel('Voltage (V), Current (A)', 'FontSize', fontSize);
legend('Vb1', 'Ib1', 'FontSize', fontSize);
title('Voltage and Current of Battery 1', 'FontSize', fontSize);
set(gca, 'FontSize', fontSize);

% Plot Vb2 and Ib2
subplot(5,1,4);
plot(y9.Time, y9.Data(:,1), 'b', y9.Time, y9.Data(:,2), 'r');
xlabel('Time (s)', 'FontSize', fontSize);
ylabel('Voltage (V), Current (A)', 'FontSize', fontSize);
legend('Vb2', 'Ib2', 'FontSize', fontSize);
title('Voltage and Current of Battery 2', 'FontSize', fontSize);
set(gca, 'FontSize', fontSize);

% Plot Power of Battery 1 and Battery 2
subplot(5,1,5);
plot(y7.Time, y7.Data(:,1), 'b', y7.Time, y7.Data(:,2), 'r');
xlabel('Time (s)', 'FontSize', fontSize);
ylabel('Power (W)', 'FontSize', fontSize);
legend('Power Battery 1', 'Power Battery 2', 'FontSize', fontSize);
title('Power of Battery 1 and Battery 2', 'FontSize', fontSize);
set(gca, 'FontSize', fontSize);
```

MATLAB CODE FOR VARIATION OF CONTROL SIGNALS FOR BATTERY CURRENT:

```
% Load data from the workspace

% Set the font size
fontSize = 20;
lineWidth = 5;

% Create a figure for plotting
figure;

% Plot Vgrid
subplot(6,1,1);
plot(y.Time, y.Data(:,1), 'b', 'LineWidth', lineWidth);
xlabel('Time (s)', 'FontSize', fontSize, 'FontWeight', 'bold');
ylabel('Voltage (V)', 'FontSize', fontSize, 'FontWeight', 'bold');
title('Grid Voltage (Vgrid)', 'FontSize', fontSize, 'FontWeight', 'bold');
set(gca, 'FontSize', fontSize, 'FontWeight', 'bold');
xlim([0 2]); % Limit x-axis to first 2 seconds
legend('Vgrid', 'FontSize', fontSize, 'FontWeight', 'bold');

% Plot Igrid
subplot(6,1,2);
plot(y.Time, y.Data(:,2), 'r', 'LineWidth', lineWidth);
xlabel('Time (s)', 'FontSize', fontSize, 'FontWeight', 'bold');
ylabel('Current (A)', 'FontSize', fontSize, 'FontWeight', 'bold');
title('Grid Current (Igrid)', 'FontSize', fontSize, 'FontWeight', 'bold');
set(gca, 'FontSize', fontSize, 'FontWeight', 'bold');
xlim([0 2]); % Limit x-axis to first 2 seconds
legend('Igrid', 'FontSize', fontSize, 'FontWeight', 'bold');

% Plot Vdcref
subplot(6,1,3);
plot(y1.Time, y1.Data(:,1), 'b', 'LineWidth', lineWidth);
xlabel('Time (s)', 'FontSize', fontSize, 'FontWeight', 'bold');
ylabel('Voltage (V)', 'FontSize', fontSize, 'FontWeight', 'bold');
title('DC Voltage Reference (Vdcref)', 'FontSize', fontSize, 'FontWeight',
'bold');
set(gca, 'FontSize', fontSize, 'FontWeight', 'bold');
legend('Vdcref', 'FontSize', fontSize, 'FontWeight', 'bold');

% Plot Vdc
subplot(6,1,4);
plot(y1.Time, y1.Data(:,2), 'r', 'LineWidth', lineWidth);
xlabel('Time (s)', 'FontSize', fontSize, 'FontWeight', 'bold');
ylabel('Voltage (V)', 'FontSize', fontSize, 'FontWeight', 'bold');
title('Actual DC Voltage (Vdc)', 'FontSize', fontSize, 'FontWeight',
'bold');
set(gca, 'FontSize', fontSize, 'FontWeight', 'bold');
legend('Vdc', 'FontSize', fontSize, 'FontWeight', 'bold');

% Plot Idref
subplot(6,1,5);
plot(y2.Time, y2.Data(:,1), 'b', 'LineWidth', lineWidth);
xlabel('Time (s)', 'FontSize', fontSize, 'FontWeight', 'bold');
ylabel('Current (A)', 'FontSize', fontSize, 'FontWeight', 'bold');
title('DC Current Reference (Idref)', 'FontSize', fontSize, 'FontWeight',
'bold');
```

```
set(gca, 'FontSize', fontSize, 'FontWeight', 'bold');
legend('Idref', 'FontSize', fontSize, 'FontWeight', 'bold');

% Plot Id
subplot(6,1,6);
plot(y2.Time, y2.Data(:,2), 'r', 'LineWidth', lineWidth);
xlabel('Time (s)', 'FontSize', fontSize, 'FontWeight', 'bold');
ylabel('Current (A)', 'FontSize', fontSize, 'FontWeight', 'bold');
title('Actual DC Current (Id)', 'FontSize', fontSize, 'FontWeight', 'bold');
set(gca, 'FontSize', fontSize, 'FontWeight', 'bold');
legend('Id', 'FontSize', fontSize, 'FontWeight', 'bold');
```

List of Publications.

Accepted Paper

R. Kumar, M. Verma and A. Kulkarni, "Optimizing Bidirectional EV Charger with Rapid Charging Architecture using Fuzzy Logic Control," 2024 3rd International Conference for Innovation in Technology(INOCON), Bangalore, India, 2024, pp. 1-6, doi: 10.1109/INOCON60754.2024.10511811.

2024 3rd International Conference for Innovation in Technology (INOCON)
Karnataka, India. Mar 1-3, 2024

Optimizing Bidirectional EV Charger with Rapid Charging Architecture using Fuzzy Logic Control

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***Abstract*— The increase in the number of Electric Vehicles (EVs) has sparked an interest in determining whether or not they can function well as energy storage devices when used in the context of microgrids. The objective of this research is to explore the use of parked EVs for efficient surplus energy storage employing bidirectional charging technology using Fuzzy Logic Control(FLC) for charger's performance analysis. It utilizes DC rapid charging technology capable of delivering high power levels in the range of 120–240 KW for level 3 fast charging to establish the connection between EVs and a DC microgrid. To improve the dynamic performance of the V2G-G2V charging stations, fuzzy logic-based control and Proportional Integral (PI) control systems are one kind of soft computing used. The performance of two distinct control systems, i.e., Fuzzy Logic Control and proportional integral Control, is compared with respect to their charging speed in V2G and G2V modes. The simulation models are designed to analyze both V2G and G2V modes. This results in a reduction in total harmonic distortion (THD), which is produced by grid-injected current, making it a superb example of active power management. The use of fuzzy logic control exhibits a remarkable decrease in THD from 0.09% to 0.02%. These results provide evidence of the potential for both efficient and reliable operation of the proposed system.**

Keywords—Electric Vehicles (EVs); Grid-To-Vehicle (G2V); Vehicle-To-Grid(V2G); Rapid-Charging-Architecture; micro-grid; level-3 fast charging.

I. Introduction

Modern energy systems today rely on microgrids for integrating intermittent renewables while addressing energy sustainability [1]. Efficiently storing surplus energy in microgrids during peak demand is a critical challenge, and EV batteries offer a viable solution [1]. Many vehicles remain idle for around 22 hours daily, offering a unique opportunity for their integration as energy storage assets in microgrids. The Grid-to-Vehicle (G2V) concept enables the storage of excess micro-grid energy in EVs during idle periods, later discharging it back to the grid when needed [2]. This potential is achievable through Vehicle-to-Grid (V2G) technology, which aligns well with the micro-grid environment, avoiding the complexities of the conventional power grid and the need for a large EV fleet[2].

The Society of Automotive Engineers (SAE) has standardized three EV charging methods: Level 1, Level 2, and Level 3 (DC fast charging) [3-6]. While Level 1 charging is common, Level 3 (DC fast charging) stands out for its swifter charging times, offering up to 90 kW of power at 200/450 V. This efficiency reduces charging to 20-30 minutes and accommodates different voltage levels. Level 3 charging is particularly suitable for V2G in micro-grids, enhancing sustainability through integration with various renewable energy sources using the DC bus in Level 3 stations [7].

V2G technology in micro-grid facilities is still in its early stages [8-11], with previous research primarily focused on the main power grid. Current V2G systems mainly use AC charging methods (Level 1 and Level 2) due to limitations posed by onboard charger power ratings and grid adaptation complexities for bidirectional energy flow [12]. Consequently, there is an urgent need for research to design technically viable charging station layouts to enable smooth V2G integration into microgrids.

The establishment of DC rapid charging stations with integrated V2G capabilities in micro-grid environments offers an innovative solution. This infrastructure incorporates a solar photovoltaic (PV) array into a direct current (DC) bus, enhancing the microgrid's energy supply. It enables high-power, bidirectional EV charging through off-board chargers, facilitating efficient V2G and G2V operations. Rigorous MATLAB/Simulink simulations validate this advanced model's effectiveness. This study provides a comprehensive overview of the design, implementation, and simulation results, affirming the feasibility of the proposed DC quick charging station infrastructure with V2G capabilities in micro-grid settings. These findings significantly contribute to advancing V2G technology in micro-grid environments, supporting sustainable energy management and the integration of renewable energy sources.

In recent years, Vehicle-to-Grid (V2G) technology has garnered significant attention for its potential to leverage electric vehicles (EVs) as valuable assets in microgrid energy management. This section reviews the existing body of knowledge on V2G technology, assessing its relevance across various power grid settings, including both the conventional power grid and microgrids. It also highlights notable discoveries and advancements in the field. Research has explored diverse V2G applications within the broader power grid, such as regulation, spinning reserves, peak shaving, and valley filling [2]. These studies have showcased how electric vehicles can enhance grid reliability and stability by providing essential ancillary services. However, implementing V2G in the primary power grid presents challenges related to control complexities and the need for a substantial EV fleet, as discussed in [1]. Overcoming these challenges requires a phased, long-term integration approach. Research has also delved into the feasibility of V2G technology as a cornerstone for supporting power generation from variable renewable sources like solar and wind [3]. This exploration aims to determine how V2G technology can optimize energy efficiency by using surplus renewable energy to charge EV

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RIDHIMAN KUMAR

SOFTWARE ENGINEER WITH AUTOCAD SKILLS

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ridhimankumar19@gmail.com

Profile Summary

Experienced programmer adept in a wide array of technologies including C/C++, Python, ReactJS, JavaScript, HTML, and Node.js, complemented by a solid background in prompt engineering. Fueled by a relentless drive for innovation and adept problem-solving abilities, I consistently deliver top-tier software solutions, ensuring project success and client satisfaction. Skilled in seamless collaboration across diverse teams and committed to staying abreast of emerging technologies, I am dedicated to continuous skill enhancement and thrive in contributing to cutting-edge projects. Additionally, I possess specialized expertise in Eagle CAD PCB DESIGN and AutoCAD, augmenting my IT prowess with versatile capabilities. If you're in search of a dynamic and highly motivated programmer with a proven track record, I am poised to be your ideal candidate.

Linkedin Profile://ridhimankumar

Github Profile://ridhimankumar

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Objective

Seasoned programmer with proficiency in C/C++, Python, ReactJS, and more, adept at prompt engineering, seeks to apply innovation and problem-solving skills to deliver exceptional software solutions. Committed to staying updated with emerging technologies and contributing expertise in Eagle CAD PCB DESIGN and AutoCAD to cutting-edge projects.

Experience

2024 Present

NPD Product Designer at SMIC Autoparts

As an NPD Engineer at SMIC Autoparts, my primary responsibility revolves around designing the circuit for electric shock absorbers, specifically focusing on the development of DC-DC buck converters to enhance the efficiency and performance of automotive systems.

Feb 2022 – May 2022

JAVA_INSURANCE at DXC Technologies

The individual provided basic design documents, translated them into component-level designs, developed and distributed reusable technical components, offered design expertise, analyzed, designed, and modified applications, acted as a liaison between architects and development teams, conducted technical research and evaluation, assisted in developing technical documentation, participated in test-plan development, defined project requirements, collaborated with client management and engineering team members, aided in selecting, acquiring, configuring, and troubleshooting packaged solutions and technical infrastructure components.

Education

2022 - 2024 – New Delhi

Delhi Technological University

Master of Technology (MTech) in Control and Instrumentation

I am doing MTech in Control and Instrumentation Electrical Engineering, amplifying expertise in software development with a specialized focus on precision control systems and instrumentation technologies.

2018 - 2022 – New Delhi

Maharaja Agrasen Institute Of Technology

BTech in Electronics and Communication

Equipped with comprehensive knowledge and skills in electronic systems and communication technologies.

Skills

What I do

- C/C++
- HTML
- CSS
- Javascript
- Nodejs
- Reactjs
- Python
- PCB Design
- AutoCAD

What I Use

- Website Design
- Programming Logic
- Hardware Design
- HTML 5
- Sql/Mysql

Interests

RIDHIMAN KUMAR

SOFTWARE ENGINEER WITH AUTOCAD SKILLS

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ACCOMPLISHMENTS

- DSA WITH C++ FROM CODING BLOCKS
- IOT WITH ARDUINO FROM CETPA
- IOT WITH RASPBERRY PI FROM CETPA
- VLSI DESIGN INTERNSHIP MAVEN SILICON
- DSA WITH PYTHON FROM UDEMY
- MACHINE LEARNING A-Z BY KIRILL EREMENKO FROM UDEMY
- ARTIFICIAL INTELLIGENCE BY KIRILL EREMENKO FROM UDEMY
- WEB DEVELOPMENT COMPLETE BOOTCAMP BY FROM UDEMY FROM 15th May 2023 to 20th September 2023.
- GOOGLE DATA ANALYTICS COURSE FROM UDEMY

ACADEMIC PROJECTS

Social Distancing sensor

1. Designed and used the Arduino as a Basic microcontroller in it for IOT project.
2. Basically used for maintaining social distancing norm for covid-19 pandemic.

Colour Following Robot using Raspberry PI

1. Designed it as a part of my B tech Minor Project.
2. The camera installed on robot will follow a particular coloured path in the direction in which that path is going.

3d image Processing Robot using Raspberry PI

The basic principle will be that the robot will move in a circular motion, click three different images of the object, process it and produce 3d image on the Screen.

3-phase Multifunction Portable EV Charger.

1. Part of my MTech project.
2. Designed this project to see the EV growth aspects in India.

- Designed my Website along with the Udemy course.

SOCIAL WORK

- Participated Voluntarily in Pulse Polio Immunization Program at Mata Gujri Hospital. (MCD, Tilak Nagar, New Delhi) Since15th September2019.
- Participated as a volunteer in the Covid-19 Vaccination program at Mata Gujri Hospital (MCD, Tilak Nagar, New Delhi) From 15th February 2021 till December 2020.

PUBLICATIONS

Optimizing Bidirectional EV charger with Rapid charging architecture using Fuzzy Logic Control by Ridhiman Kumar, Monika Verma, ASHISH KULKARNI IEEE INOCONF (International conference on innovation and technology) 2024 Bengaluru conference.

Ridhiman Kumar

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