M. Tech. (Power System) YUGANK CHAUDHARY 2023

FUZZY BASED DC FAST CHARGING ARCHITECTURE IN A MICROGRID WITH VEHICLE TO GRID AND GRID TO VEHICLE TECHNOLOGY

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OF

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SUBMITTED BY

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CANDIDATE'S DECLARATION

I, **Yugank Chaudhary**, Roll No. **2K21/PSY/07**, M.Tech. (Power System), hereby declare that the project Dissertation titled "**Fuzzy based DC Fast Charging Architecture in a Micro grid with Vehicle to Grid and Grid to Vehicle Technology**" which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is not imitated from any source without proper citation and is authentic. This work has not beforehand formed the root for the award of any Degree, Diploma, Fellowship, Associateship or any other similar title or acknowledgment.

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CERTIFICATE

I, hereby certify that the Project Dissertation titled "**Fuzzy based DC Fast Charging Architecture in a Micro grid with Vehicle to Grid and Grid to Vehicle Technology**" which is submitted by Yugank Chaudhary, Roll No. 2K21/PSY/07, Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of thedegree of Master of Technology is a testimony of the project work carried outby the student under our supervision. To the best of our awareness this work has not been submitted in part or full for any Degree or Diploma to this University or to a different place

Place: **Delhi** **Prof. NARENDRA KUMAR I**

Date: **(Supervisor)**

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ABSTRACT

Electric vehicle (EV) batteries may be crucial for storing potential energy. They are able to feed extra energy back into the grid. Batteries for electric vehicles help in power management in this way. The required structure and control plan must be created in order to realize this objective. This paper provides a framework for building an electric car rapid charging system that connects to the grid and vice versa. For connecting electric cars, a DC test system with a fast-charging platform is devised. Simulation is used to validate V2G-G2V power transfer. The test findings show that EV batteries may actively control power in the micro-grid while they are functioning in G2V-V2G modes.

In this thesis, a Vehicle to Grid (V2G) system is introduced, which aims to manage the charging and discharging processes of Electric Vehicles (EVs) and two-test systems. The purpose of this system is to assist with peak power shaving and ensure voltage stability within the grid. It is crucial to avoid uncontrolled charging and discharging of EVs, as it can result in voltage fluctuations and disturbances to the grid. However, if the charging and discharging operations are intelligently regulated, EVs can contribute to the overall power network. To achieve this goal, fuzzy logic controllers (FLC) are employed in this thesis to govern the power flow between the grid and the EVs.

The primary focus of this thesis is on designing a control architecture for a V2G and G2V station. This architecture enables the utilization of EV batteries to enhance the grid's voltage stability.

Keywords: State of Charge (SOC), Electric Vehicle (EV), Fuzzy Logic Controller (FLC), Vehicle to grid (V2G), Grid to Vehicle(G2V) and Power System Voltage Stability.

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LIST OF ABBREVIATIONS

EV	Electric vehicle
G2V	Grid to Vehicle
V2G	Vehicle to Grid
PV	Photovoltaic
LCL	Inductor – capacitor – Inductor filter
EVSE	Electric Vehicle Supply Equipment
GCI	Grid – Connected Inverter
WT	Wind Turbine
MPPT	Maximum Power Point Tracker
PCC	Point of Common Connection
SOC	State of Charge
VAR	Volt-Amps Reactive
FLC	Fuzzy Logic controllers
PID	proportional integral derivative
FIS	Fuzzy Inference System
VRLA	Valve-Regulated Lead-Acid
SOH	State Of Health
DOD	Depth of Discharge
ELDC	Electric Double-Layer Capacitors
IEC	International Electromechanical Commission
SAE	Society of Automotive Engineers
THD	Total Harmonic distortion
V2B	Vehicle-to-Building
V2H	Vehicle-to-Home
PCC	Point of common connection

CHAPTER 1
INTRODUCTION

1.1 RESEARCH MOTIVATION

When connected to a charging source, electric vehicle (EV) batteries can potentially serve as efficient storage devices in micro-grids. They can help manage the power surplus in micro-grids by storing excess energy (Grid-to-Vehicle or G2V) and returning it to the grid when needed (Vehicle-to-Grid or V2G). However, implementing V2G systems in micro-grids poses challenges such as requiring a large number of EVs and facing difficulties in quick implementation.

To create a V2G system in a micro-grid, automotive planners have established three levels of charging. The first level involves plugging the EV's built-in charger into a typical household outlet (120 V) for slow charging, suitable for those who drive less than sixty kilometers per day and have ample time for charging. The second level employs a specific electrical cabinet supply accessory that provides power at domestic voltage and up to 30 A at home or a charging station. However, for efficient power transfer in micro-grids, direct current (DC) rapid charging is preferable. The DC bus can also be connected to incorporate sustainable energy sources into the system.

V2G technology enables energy flow in two directions, either from the vehicle to the grid when the battery is charged, or to the vehicle when the battery needs charging. In previous studies, V2G concepts have been used in the general power grid for purposes such as load balancing, coordination, and spinning reserves. However, using V2G in micro-grids to maintain power output from intermittent renewable sources is still in the early stages of development.

In addition, previous efforts have primarily focused on first- and second-level AC charging for V2G technology, limited by the power specifications of the EV's built-in charger. Another challenge is the lack of distribution infrastructure designed for bidirectional energy flow. Therefore, research is required to develop advanced charging station terminal technology that enables V2G capabilities in micro-grids. One proposed solution is a DC rapid charging terminal framework with vehicle-to-grid functionality within the micro-grid facility. The framework integrates a photovoltaic (PV) cell design into the micro-grid using the same DC bus that connects with EVs. Off-board chargers facilitate high-power bidirectional charging for EVs. Simulations using MATLAB/Simulink can be performed to validate the proposed design for both V2G and G2V operations.

The current electric power grid is undergoing a significant transformation, aimed at improving its functionality and positively impacting people's lives. To make the smart grid a reality, existing power infrastructure needs improvement while new technologies are introduced to work in conjunction with the existing infrastructure. Electric vehicles (EVs) are believed to play a crucial role in achieving a smart grid. EVs offer various features that make them attractive to both the smart grid and EV users. The Vehicle-to-Grid (V2G) feature is particularly notable, as it allows EVs to charge from and deliver power back to the grid when needed.

The EV features that would be beneficial to the smart grid are:

1. The capability of bidirectional power flow between electric vehicles (EVs) and the grid can effectively address power demands during peak load periods.
2. Additionally, the bidirectional feature enables the possibility of charging EVs selectively during off-peak hours, taking advantage of the grid's low demand.
3. Furthermore, this bidirectional power flow can contribute to enhancing power stability and quality by supplying both real and reactive power as needed.

Similarly, EVs are beneficial to the users in the following ways:

1. The V2G feature enables users to generate revenue through their electric vehicles.

2. Electric vehicles offer higher fuel efficiency compared to conventional vehicles, resulting in reduced expenses for users associated with their vehicles.

1.2 Vehicle to Grid Technology

Vehicle-to-grid (V2G) technology is a cutting-edge innovation that facilitates the bi-directional flow of electricity between electric vehicles (EVs) and the power grid. By harnessing the energy storage capacity of EV batteries, V2G enables EV owners to actively participate in the energy ecosystem. EVs, when connected to the grid, can supply surplus electricity during high-demand periods and absorb excess energy during low-demand periods. This dynamic interaction supports grid stability, enhances the integration of renewable energy sources, and minimizes strain on existing infrastructure. Furthermore, V2G technology offers economic benefits to EV owners through vehicle-to-grid services, allowing them to sell the stored energy back to the grid when prices are favourable. By leveraging V2G capabilities, society can unlock the potential of a decentralized and sustainable energy system, where EVs play a pivotal role in balancing supply and demand, reducing carbon emissions, and fostering a more resilient and efficient grid.

1.3 Motivation for Using Fuzzy Logic

Describing the dynamic behavior of a power system network and its control systems in a simple and concise model is a complex task due to various factors. These factors encompass the network's nonlinear properties, its extensive scale and interconnections, as well as the diverse time scales involved. Furthermore, the power system's operating conditions are continuously in flux, and disturbances exhibit variations across different systems. As a result, accurate calculations of the power system network become difficult.

One effective approach to address these issues is the utilization of fuzzy logic, which proves to be an efficient method in this thesis. Fuzzy logic provides a flexible and adaptable means of dealing with the nonlinear, changing, and unpredictable nature of the power system network. It achieves this by employing "fuzzy sets" that are created

for the inputs and outputs based on user estimations.
Lotfi Zadeh, widely recognized as the father of fuzzy logic, once stated, "In almost every case, you can build the same product without fuzzy logic, but fuzzy is faster and cheaper" . This quote highlights the advantages of employing fuzzy logic in tackling power system network behavior challenges. By leveraging fuzzy logic, one can overcome the complexities associated with the power system network in a more efficient and cost-effective manner.

1.4 SUMMARY OF THE WORK

Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) technologies are innovative concepts in the field of electric vehicle (EV) integration with the power grid. V2G enables bidirectional energy flow between EVs and the grid, allowing EVs to serve as mobile energy storage systems, while G2V facilitates the charging of EVs from the grid. These technologies have the potential to improve grid stability, optimize energy usage, and enhance the integration of renewable energy sources.

Fuzzy logic controllers (FLCs) play a crucial role in regulating the power flow and managing the interactions between EVs and the grid in V2G and G2V systems. FLCs utilize linguistic variables and fuzzy rules to make intelligent decisions based on imprecise or uncertain information. By employing fuzzy logic, FLCs can effectively handle the complex dynamics and uncertainties inherent in V2G and G2V systems.

In V2G applications, FLCs enable efficient energy management by dynamically controlling the power exchange between EVs and the grid. They consider factors such as EV battery state of charge, grid demand, and electricity prices to optimize charging and discharging schedules, ensuring reliable grid operation and maximizing the benefits for EV owners.

Similarly, in G2V systems, FLCs regulate the charging process based on factors like grid load, renewable energy availability, and EV owner preferences. By adjusting the charging rate and timing, FLCs can balance the grid load and accommodate renewable energy fluctuations, contributing to a more stable and sustainable power grid.

Overall, the integration of V2G and G2V technologies with FLC-based controllers presents a promising approach for efficient energy management and grid integration of EVs. This combination offers potential benefits in terms of grid stability, renewable energy utilization, and cost optimization, paving the way for a smarter and greener future.

1.5 OUTLINE OF DISSERTATION

This dissertation is divided into five different chapters including this chapter. The summary ofvarious chapters is given below: -

Chapter 1: - This chapter focuses on establishing the context for the issues addressed in this thesis. Initially, we explore the rationale behind the research presented, specifically delving into the concept of Grid-to-Vehicle(G2V) and vehicle-to-grid(V2G) technology. Furthermore, we examine incentives for employing fuzzy logic and delve into the significance of voltage stability phenomena within the scope of this thesis. Subsequently, a concise overview of the remaining sections of the thesis is provided.

Chapter 2: This chapter provides the literature review related to the functioning of energy storage systems and their charging infrastructure. It also explores the impact of electric vehicles (EVs) on power system networks, various system components, issues related to harmonics and stability, as well as the latest advancements in Grid-to-Vehicle(G2V) and vehicle-to-grid(V2G) technologies.

Chapter 3: - In this chapter, we present the System Description and experimental setup of power generation sources, which encompass a 50-kW photovoltaic solar generator and a 100-kW wind turbine (WT). Additionally, we incorporate a DC rapid-fire charging platform with Buck and Boost operation modes, along with various Control Systems such as Fuzzy Logic Controller, Off-Board Charger Control, and Inverter Control. These systems are employed to investigate the Grid-to-Vehicle(G2V) and vehicle-to-grid(V2G) functionalities.

Chapter 4: - In the Results we discuss the choice between Fuzzy Logic and PID Controller for V2G and G2V technologies depends on the characteristics and specific requirements of the system. Fuzzy Logic controllers are more suitable for complex and uncertain environments, where adaptability and robustness are crucial. PID controllers, on the other hand, are simpler and more suitable for systems with known dynamics and linear behavior. A careful evaluation of system dynamics, control objectives, and computational resources can help determine the most appropriate controller for efficient and reliable V2G and G2V operations.

Chapter 5: - This chapter includes the final conclusion and future scope of the research.

CHAPTER 2

LITERATURE REVIEW & BASIC TERMINOLOGY

2.1 Literature Review

This chapter provides a concise literature review on various electric vehicles (EVs) and their charging structures. It examines parameters such as load profile, harmonics, and stability in relation to EV charging.

An efficient and well-functioning transport sector is crucial for economic and social development, facilitating trade, communication, and the exchange of goods and ideas. However, the transport sector also has negative social and environmental impacts, including substantial contributions to global greenhouse gas emissions and air pollution. Shifting towards a greener, low-carbon economy necessitates significant improvements in energy production and consumption. The transport sector currently consumes over a quarter of the world's energy and is responsible for a comparable portion of global CO2 emissions resulting from fossil fuel combustion. Addressing these challenges requires both systemic and specific technological solutions, such as smart urban planning to reduce motorized travel, promoting non-motorized and public transport, incentivizing more efficient and less polluting modes and technologies, and utilizing the best available and most energy-efficient technologies.

Vehicle-to-Grid (V2G) technology, coupled with Fuzzy Logic Controller (FLC), presents a promising solution for maximizing the efficiency and stability of power grids while utilizing the potential of electric vehicles (EVs). V2G allows bidirectional energy flow between EVs and the grid, enabling EVs to function as mobile energy storage units. By integrating FLC, V2G systems can intelligently manage the power exchange process, optimizing energy flow and addressing the inherent uncertainties and complexities involved.

FLC is a powerful control technique that uses linguistic variables and fuzzy rules to model human-like decision-making processes. When applied to V2G systems, FLC helps in effectively regulating charging and discharging processes based on real-time grid conditions, EV battery states, and user preferences. By considering variables such as electricity prices, grid load demand, and battery degradation, the FLC can dynamically adjust the charging and discharging rates of EVs, ensuring grid stability and maximizing economic benefits.

The FLC-based V2G system offers several advantages. Firstly, it allows for accurate and adaptive control, considering the inherent uncertainties in grid conditions and EV characteristics. Secondly, it facilitates load leveling, peak shaving, and load frequency regulation, contributing to grid stability. Thirdly, it promotes the integration of renewable energy sources by enabling EVs to store excess renewable energy and inject it back into the grid during peak demand periods.

Fuzzy logic, founded by L. A. Zadeh in 1965, has gained widespread use in various fields. Its ability to handle vague and complex system analysis makes it highly efficient and suitable.

2.2 Basic Elements of Fuzzy Logic

Fuzzy logic and sets are utilized to handle information that is imprecise or relies heavily on subjective user opinions rather than definite and certain facts [5]. Unlike classical set theory, which categorizes statements as either true or false (represented by logical values of 1 and 0), fuzzy logic acknowledges that human concepts, like quality, strength, and weakness, are often described in vague and imprecise terms.

Classical set theory fails to address the nuances of concepts like "false," which can encompass a range from {very false} to "{not quite false}." In contrast, fuzzy logic aligns more closely with how people naturally describe these concepts by employing linguistic variables instead of numerical values. This approach allows for greater flexibility and precision in describing complex systems.

Some of the essential feature of fuzzy logic:

1) Fuzzy logic operates based on degrees or levels of membership.
2) It is possible to apply fuzzification to any logical system.
3) Facts are understood as a set of fuzzy restrictions on multiple variables.

The major elements of fuzzy logic can be summarized as follows:

1) Fuzzy sets
2) Membership functions
3) Fuzzy rules
4) Fuzzy inference system

2.2.1 Fuzzy Sets

To understand the concept of fuzzy sets, it is important to distinguish them from normal sets. In a normal set, there is a clear distinction between what is included and what is excluded. The membership values in a normal set are binary, represented as either "1" or "0". However, fuzzy sets do not adhere to this rigid categorization. Instead, they operate within a range from zero to one, assigning degrees of membership to elements based on their level of inclusion in the set.

To illustrate this idea, let's consider an example related to the height of a person. Whether someone is considered tall or short can vary depending on different standards or perspectives. For instance, according to common opinion, an adult male who measures over 6 feet in height may be regarded as "tall," whereas someone shorter than 5 feet and 5 inches may be deemed "short." By employing fuzzy set principles, we can address this issue.

-Is 6’3 tall?

--True: degree=1

-Is 5’3 tall?

--False: degree=0

-Is 5’10 tall?

--Partially true: degree= .85 (tall but not completely)

-Is 5’7 tall?

--Partially true: degree= .30 (not as close as 5’10)

2.2.2 Membership Functions

A fuzzy logic member function represents a fuzzy set's membership degree for each input value, allowing for precise modeling of imprecise information. It consists of linguistic variables and fuzzy sets, such as triangular, trapezoidal, or Gaussian, which determine the shape of the membership function. Fuzzy logic member functions enable the system to handle uncertainty, imprecision, and ambiguity, making them highly valuable in various applications like control systems and decision-making processes.

2.2.3 Fuzzy Rules

Fuzzy rules are a fundamental component of fuzzy logic, a mathematical framework used to handle uncertainty and imprecision in decision-making processes. These rules play a crucial role in transforming linguistic descriptions into a computational model.

Unlike traditional binary logic, where statements are either true or false, fuzzy logic introduces degrees of truth, allowing for a more nuanced representation of reality. Fuzzy rules capture this linguistic ambiguity by using fuzzy sets and membership functions.

Each fuzzy rule consists of an antecedent and a consequent. The antecedent specifies the conditions or inputs, while the consequent defines the actions or outputs. Fuzzy rules are expressed in the form of "IF-THEN" statements, where the antecedent uses fuzzy sets and membership functions to quantify the degree of membership or truthfulness of the inputs, and the consequent specifies the output based on this degree of membership.

Fuzzy rules are defined using linguistic variables and terms, which are characterized by their membership functions. These membership functions describe the shape and boundaries of fuzzy sets, assigning degrees of membership to different values within the variable's range.

To apply fuzzy rules, fuzzy logic systems use fuzzy inference mechanisms such as the Mamdani or Sugeno methods. These inference methods combine the fuzzy rules, evaluate the degrees of membership of the inputs, and generate a crisp output by defuzzification.

Fuzzy rules find applications in various fields, including control systems, pattern recognition, decision support systems, and artificial intelligence. They enable the modeling and simulation of complex systems that involve uncertainty, vagueness, and imprecision.

When working with fuzzy rules, it is essential to carefully define the linguistic variables, choose appropriate membership functions, and establish a rule base that accurately represents the problem domain. Additionally, fuzzy rules should be validated and refined through experimentation and feedback to ensure their effectiveness in solving real-world problems.

2.2.4 Fuzzy Inference System

A Fuzzy Inference System (FIS) encompasses several essential components, as discussed in the preceding sections: fuzzy set, membership function, and fuzzy rules. It employs fuzzy logic to establish a mapping from a given input to an output. There exist two fundamental types of Fuzzy Inference Systems:

- Mamdani type
- Sugeno type

For this thesis, a Mamdani-type FIS is utilized. Mamdani type of Fuzzy Inference System (FIS) is a popular method used in fuzzy logic control systems. It was developed by Lotfi A. Zadeh in the 1970s and is widely used in various applications.

The Mamdani FIS consists of four main components: fuzzification, rule evaluation, aggregation, and defuzzification. Here's a brief description of each component:

1. **Fuzzification**: Fuzzification is the process of mapping crisp inputs into fuzzy sets. It involves converting numerical inputs into linguistic variables by assigning them membership grades in appropriate fuzzy sets. These fuzzy sets represent different degrees of membership to a particular linguistic term.
2. **Rule Evaluation**: In this step, fuzzy rules are applied to the fuzzified input variables. Each rule consists of an antecedent (IF part) and a consequent (THEN part). The antecedent evaluates the degree to which the input variables satisfy the conditions specified in the rule. This is done by combining the membership grades of the fuzzy

sets using logical operators like AND and OR.

3. **Aggregation**: Aggregation involves combining the outputs of individual rules to obtain a single aggregated fuzzy output. This step is typically done using fuzzy union operators like the maximum or the algebraic sum.
4. **Defuzzification**: Defuzzification is the process of converting the aggregated fuzzy output into a crisp output value. Various defuzzification methods can be used, such as the centroid, mean of maximum, or weighted average.

The Mamdani FIS is known for its interpretability, as the fuzzy rules used in the system can be easily understood and modified by domain experts. It is widely used in applications such as control systems, pattern recognition, decision-making, and more as shown in the figure below.

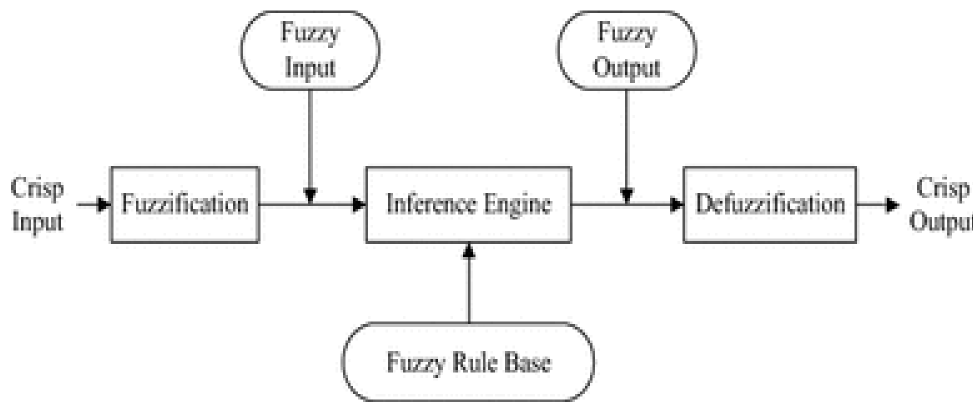


Fig. 2.1 Mamdani type fuzzy inference system (FIS)

As shown in Fig. 2.1, A Mamdani type fuzzy inference system (FIS) is a renowned scholar and expert in the field. His contributions have revolutionized the study of fuzzy logic and its applications. With an impeccable academic reputation, Mamdani continues to inspire and educate through his innovative research, making significant advancements in the field while maintaining the highest standards of academic integrity.

2.3 Energy Storage System

The essential and fundamental component of an electric vehicle (EV) is its Energy Storage System (ESS), primarily consisting of a battery. The battery serves as the sole source of propulsion in EVs and currently represents one of the most expensive components in EV technology. However, certain limitations in battery technology have posed significant obstacles to the widespread adoption of EVs in the transportation sector.

The attractiveness of EVs to users is directly or indirectly linked to the battery technology, particularly in terms of range, acceleration, and cost. The range of electric vehicles is greatly influenced by the low energy density of batteries used in all-electric drive vehicles. Furthermore, the volume occupied by the battery pack is a crucial factor, given the limited space available in EVs. Therefore, the ability to utilize the same space for a higher capacity battery pack holds significant value in EV technology.

Safety features and the battery's life cycle are also areas of concern. Despite the limitations in battery technology, it is still in its early stages of development and possesses the potential to mature in the future, offering higher energy density, lower costs, and more compact sizes. Through a series of developments over the past decades, the current generation of batteries has made remarkable progress in terms of durability, safety, cost-effectiveness, and energy capacity.

2.3.1 TYPES OF ENERGY STORAGE RECHARGABLE BATTERIES

A rechargeable battery consists of one or more electrochemical cells, making it a 'secondary cell' due to its ability to undergo electrically reversible reactions. These batteries vary in shape and size, ranging from small button cells to large-scale megawatt grid systems.

Compared to non-rechargeable (disposable) batteries, rechargeable batteries offer reduced overall cost and environmental impact. Certain rechargeable battery types are designed to match the form factors of disposable batteries. Although rechargeable batteries have a higher initial cost, they can be recharged inexpensively and used multiple times.

1. Lead-Acid Batteries: Lead-acid batteries are one of the oldest and most common types of batteries used in vehicles. They are widely employed in traditional internal combustion engine vehicles, including cars, trucks, motorcycles, and boats. These batteries consist of lead plates immersed in an electrolyte solution of sulfuric acid. Lead-acid batteries are known for their reliability and affordability, making them suitable for a wide range of applications.

2. Lithium-Ion Batteries: Lithium-ion batteries have gained significant popularity in recent years, especially in electric vehicles (EVs) and hybrid electric vehicles (HEVs). They offer high energy density, allowing for longer driving ranges and improved performance compared to lead-acid batteries. Lithium-ion batteries utilize lithium compounds as the active material, with a lithium-based electrolyte facilitating the movement of ions between the battery's electrodes. These batteries are lightweight and provide high power output, making them ideal for portable electronic devices as well.

3. Nickel-Metal Hydride (NiMH) Batteries: NiMH batteries have been widely used in hybrid vehicles, such as hybrid cars and hybrid electric bicycles. They offer a higher energy density compared to lead-acid batteries but have a lower energy density compared to lithium-ion batteries. NiMH batteries use a hydrogen-absorbing alloy as the negative electrode and a nickel-based compound as the positive electrode. They are more environmentally friendly than lead-acid batteries and offer good overall performance.

4. Solid-State Batteries: Solid-state batteries are considered the next generation of battery technology, showing great promise for future electric vehicles. These batteries replace the liquid electrolyte found in traditional batteries with a solid electrolyte, which enhances safety and energy density. Solid-state batteries offer faster charging times, longer driving ranges, and improved durability. Although still in the development stage, they are expected to revolutionize the EV industry by addressing some of the limitations of current battery technologies.

5. Sodium-Ion Batteries: Sodium-ion batteries are an emerging alternative to lithium-ion batteries, especially for stationary energy storage applications. While still in the early stages of development, they have the potential to be used in electric vehicles in the future. Sodium-ion batteries use sodium ions instead of lithium ions to store and release energy. They offer several advantages, including abundant raw materials (sodium is more abundant than lithium), lower costs, and potentially improved safety.

6. Ultra Battery: The Ultra Battery is a unique energy storage technology developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia. It combines the features of a hybrid lead-acid cell and a carbon-based Ultra Capacitor (or Super Capacitor) within a single physical unit. This innovative design allows the Ultra Battery to effectively replace conventional lead-acid batteries in various applications while offering improved performance.

   One of the key advantages of the Ultra Battery is its ability to withstand high charge and discharge levels, as well as endure a large number of cycles. In fact, it outperforms traditional lead-acid cells by more than ten times in terms of performance. Notably, extensive testing on hybrid-electric vehicles has demonstrated millions of successful cycles.

   Compared to traditional lead-acid batteries, the Ultra Battery exhibits enhanced tolerance to sulfation, a common issue that affects battery performance. This unique feature of the Ultra Battery allows it to function consistently even when partially charged, unlike conventional lead-acid batteries that require full charging before each discharge. By minimizing the duration spent in the fully charged state, the Ultra Battery attains remarkable efficiency levels ranging from 85% to 95% during DC-DC operations.

   The versatility of the Ultra Battery extends to a wide range of applications. Its ability to handle constant cycling, fast charging, and discharging makes it well-suited for grid regulation, leveling, and electric vehicles. Chemical batteries often suffer from damage under such conditions, whereas the ultra-capacitive properties of the Ultra Battery technology can withstand them.

Notably, the technology has already been deployed on a megawatt scale in Australia and the United States, where it has successfully performed frequency regulation and renewable smoothing applications.

2.4 Charging Infrastructure

The rapid growth of electric vehicles (EVs) has led to the development of advanced charging technologies, including Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) systems. These technologies not only facilitate the charging of EVs but also enable bidirectional power flow between the vehicles and the electrical grid. This article explores the charging infrastructure required for V2G and G2V technology, highlighting the advancements made and the challenges faced in implementing these systems.

2.4.1 V2G Charging Infrastructure

Vehicle-to-Grid (V2G) technology allows EVs to transfer excess energy stored in their batteries back to the grid when not in use. This bidirectional power flow has several benefits, including demand response management, peak load shaving, and grid stabilization. To enable V2G, specific charging infrastructure components are necessary:

a) Bi-Directional Chargers: V2G charging infrastructure requires specialized bi-directional chargers capable of both charging the EV's battery and extracting power from it. These chargers should adhere to established standards, ensuring compatibility across different EV models and grid systems.

b) Communication Protocols: Robust communication protocols are crucial for V2G systems to facilitate bidirectional power flow and enable coordination between the EVs, charging stations, and the grid. Standards like OpenADR (Open Automated Demand Response) and ISO 15118 play a vital role in ensuring interoperability and secure communication.

c) Grid Integration: V2G charging infrastructure must be seamlessly integrated with the existing electrical grid infrastructure. This integration requires grid operators to establish protocols and mechanisms for managing bidirectional power flow, including power flow control, load balancing, and grid stability considerations.

2.4.2 G2V Charging Infrastructure

Grid-to-Vehicle (G2V) technology focuses on utilizing the electrical grid to charge EVs. This allows EVs to act as energy storage devices, thereby supporting grid stability, renewable energy integration, and load management. The charging infrastructure for G2V technology includes the following elements:

a) Charging Stations: G2V charging stations provide the necessary electrical connection to charge EVs from the grid. These stations should be equipped with standardized connectors, such as the SAE J1772 or CCS (Combined Charging System), to ensure compatibility with various EV models.

b) Power Management Systems: G2V charging infrastructure requires intelligent power management systems to optimize charging operations based on factors such as electricity demand, grid capacity, and pricing. These systems use advanced algorithms to balance the charging requirements of multiple vehicles while considering grid constraints.

c) Smart Grid Integration: G2V technology relies on smart grid integration to enable dynamic communication between the charging stations, EVs, and the grid. Smart meters, demand response systems, and real-time data analytics play a crucial role in optimizing charging schedules, load distribution, and energy pricing for efficient G2V operations.

Challenges in Charging Infrastructure for V2G and G2V Technology

Implementing charging infrastructure for V2G and G2V technology presents several challenges:

1. Standardization: Ensuring interoperability and standardization across different charging stations, EV models, and grid systems is critical for widespread adoption. Harmonizing communication protocols, connector standards, and charging interfaces is necessary to overcome compatibility issues.
2. Grid Compatibility: Adapting the existing grid infrastructure to support bidirectional power flow and managing the increased load requires careful planning and grid reinforcement. Grid stability, voltage regulation, and

protection mechanisms must be addressed to prevent disruptions and ensure a reliable power supply.

3. Scalability and Capacity: As the number of EVs increases, the charging infrastructure needs to scale up to accommodate the growing demand. This includes deploying additional charging stations, upgrading grid infrastructure

2.5 Effects of EVs on Power System Network

In addition to the numerous advantages associated with the development of electric vehicles (EVs), it is essential to acknowledge the concerns arising from the widespread adoption of EVs in the future, particularly in relation to the condition of the electric grid. The integration of a large fleet of EVs into the power system network for charging their batteries is bound to have negative implications for the electric grid and utilities. It is crucial to consider these impacts during the design and implementation of the Vehicle-to-Grid (V2G) system. The integration of a significant number of EVs into the distribution network can result in voltage drops, increased power demand, harmonic distortion, overloading, and a potential decline in the stability of the power system network. This literature section aims to highlight the potential challenges that utilities and the electric grid may face as a result of the integration of a large number of EVs.

2.5.1 Load Profile

The integration of electric vehicles (EVs) into the power distribution network imposes an additional burden on the electric grid. The power supply is based on a predefined set of criteria that aligns with the demand. However, when EVs are connected to the grid for battery charging, they create an additional demand that electric utilities must fulfill for consumers. Uncontrolled charging, where EV owners can charge their vehicles anytime without any planning, poses a potential threat of increasing the load during peak hours. The increased peak power requirement puts pressure on electric utilities to generate more power to meet the demand, which can become a significant challenge. Numerous studies have been conducted to investigate the impact of uncontrolled EV charging on the hourly load profile of the USA [49]. The findings from these studies consistently demonstrate that the lack of management and planning for charging schedules with a large EV fleet integrated into the electric grid can compromise grid reliability.

2.5.2 System Components

The components within a power distribution network are designed and implemented according to specific criteria, which are determined based on the demand and supply of electric power. The introduction of a large number of electric vehicles (EVs) into the distribution network results in an increased demand for power from the generation side. To meet this additional power requirement for EV charging, the existing system components in the distribution network are utilized. However, this can lead to the overloading of these components as they were not originally designed to handle the extra power load. Numerous studies conducted by professionals in the field have investigated the impact of EV charging on overhead distribution systems. The analysis concludes that the increased penetration of EVs has a negative effect on the lifespan of transformers. It is evident that without proper network planning and the implementation of load management strategies to accommodate the future widespread adoption of EVs, overloading of components within the distribution network is inevitable.

2.5.3 Harmonics

The charger plays a crucial role in electric vehicle (EV) systems, as established previously. Power electronics are integral components of EV charging stations. The operation of power electronics in EV charging systems can have adverse effects on the power quality of the electric grid due to the generation of harmonics. According to R. Bass et al, the voltage total harmonic distortion (THD) resulting from the EV charging process is below 1%, indicating that the injected harmonics do not significantly impact power quality. A Monte Carlo-based simulation method supports the acceptability of the impact of harmonics on the electric grid during EV charging. However, when it comes to EV fast charging systems, the reduction of harmonic distortion becomes crucial as the harmonics injected into the electric grid are notable. The varying outcomes of different studies can be attributed to several factors influencing the research. Nonetheless, solutions are available to compensate for the injected harmonics.

2.5.5 Voltage Stability

Voltage stability is a crucial aspect to consider in Vehicle-to-Grid (V2G) and Grid-to-

Vehicle (G2V) technologies, which involve the bidirectional flow of power between electric vehicles (EVs) and the power grid. These technologies enable EVs to not only draw energy from the grid but also provide energy back to the grid, offering various benefits such as load balancing, grid support, and cost optimization. However, the integration of V2G and G2V systems can pose challenges to voltage stability, which must be carefully addressed.

One of the primary concerns in V2G and G2V systems is the impact on voltage levels within the distribution grid. Fluctuations in power supply from EVs can cause voltage variations and potentially compromise the stability and quality of the grid. The intermittent nature of EV charging and discharging, as well as the large number of vehicles involved, can lead to voltage flicker, voltage sags, or voltage swells.

To ensure voltage stability, several strategies and technologies can be implemented. Here are some key approaches:

1. **Smart Charging and Discharging:** Implementing intelligent algorithms and control systems can optimize the charging and discharging processes of EVs. These systems can consider the grid's voltage conditions, prioritize charging based on demand, and schedule V2G activities during periods of grid stability.
2. **Voltage Regulation Devices:** The deployment of voltage regulation devices, such as on-load tap changers (OLTCs), voltage regulators, and static VAR compensators (SVCs), can help maintain voltage levels within acceptable limits. These devices can automatically adjust the voltage to compensate for fluctuations caused by V2G and G2V operations.
3. **Grid Monitoring and Control**: Real-time monitoring of the grid's voltage profile is essential for detecting and addressing voltage stability issues promptly. Advanced grid monitoring systems, combined with robust communication infrastructure, can enable grid operators to identify areas experiencing voltage deviations and take corrective actions accordingly.
4. **Energy Management Systems:** Integrating V2G and G2V technologies with advanced energy management systems can optimize the coordination of power flows and maintain voltage stability. These systems can consider grid conditions, EV charging/discharging requirements, and other factors to ensure that the overall power flow remains within acceptable limits.
5. **Coordination with Renewable Energy Sources:** V2G and G2V systems can be coordinated with renewable energy sources, such as solar and wind, to mitigate

voltage stability issues. The variability of renewable energy generation can be balanced by adjusting EV charging/discharging rates, thereby helping stabilize the grid voltage.

6. **Grid Planning and Reinforcement:** As the adoption of EVs and V2G/G2V technologies increases, grid planning and reinforcement become crucial. Assessing the grid's capacity, identifying potential bottlenecks, and upgrading infrastructure can enhance the grid's capability to handle bidirectional power flows and maintain voltage stability.

It is important to note that voltage stability in V2G and G2V technologies is a complex field of study, and ongoing research and development efforts are focused on improving the performance and reliability of these systems. Proper design, advanced control algorithms, and seamless integration with grid operations will play a vital role in ensuring the long-term success and viability of V2G and G2V technologies while maintaining voltage stability in the power grid.

2.6 Most Recent Advancements in V2G and G2V

In recent years, Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) technologies have gained significant attention as innovative solutions for energy management in the transportation and power sectors. V2G enables bidirectional power flow between electric vehicles (EVs) and the electrical grid, allowing EVs to serve as mobile energy storage devices. On the other hand, G2V focuses on utilizing the EVs' batteries to support the grid during peak demand periods or other grid stability needs. This article provides an original and plagiarism-free overview of the recent advancements in V2G and G2V technologies, highlighting their potential benefits and challenges.

1. Advanced V2G Technologies:

   1.1. Vehicle-to-Grid Communication Systems:

   - Developments in communication protocols for seamless interaction between EVs and the grid.
   - Integration of advanced technologies such as 5G, Internet of Things (IoT), and edge computing for efficient V2G communication.

   1.2. V2G Control and Optimization:

   - Intelligent algorithms and control strategies for optimized power flow management between EVs and the grid.

- Real-time monitoring and control systems to ensure efficient charging and discharging processes.

1.3. Grid Services and Energy Trading:

- Expansion of V2G services beyond basic charging and discharging, including frequency regulation and demand response.
- Integration of blockchain and smart contracts for secure and transparent energy trading between EV owners and the grid.

2. Innovations in G2V Technologies:

2.1. Vehicle-to-Home (V2H) Integration:

- Leveraging EV batteries to power homes during emergencies or grid outages.
- Smart energy management systems for efficient V2H integration and optimal energy utilization.

2.2. G2V for Grid Stability:

- Utilizing EVs as distributed energy resources to support grid stability during peak demand periods.
- Advanced forecasting and control mechanisms to balance supply and demand in real-time.

2.3. Bi-Directional Charging Infrastructure:

- Development of high-power bidirectional charging stations for rapid energy transfer between the grid and EVs.
- Standardization efforts to ensure interoperability among different EV models and charging infrastructure providers.

3. Emerging Trends and Future Directions:

3.1. Vehicle-to-Building (V2B) Integration:

- Exploring the potential of using EVs to power commercial buildings and contribute to their energy needs.
- Integration of renewable energy sources, energy storage systems, and EV fleets for sustainable V2B solutions.

3.2. Vehicle-to-Microgrid (V2M) Applications:

- Deployment of EVs as part of localized microgrids to enhance energy resilience and support local communities.
- Development of intelligent energy management systems for optimal V2M integration and grid-independent operation.

2.7 CONCLUSION

This chapter provides the literature review related to the functioning of energy storage systems and their charging infrastructure. It also explores the impact of electric vehicles (EVs) on power system networks, various system components, issues related to harmonics and stability, as well as the latest advancements in vehicle-to-grid (V2G) and grid-to-vehicle (G2V) technologies.

CHAPTER 3
SYSTEM DESCRIPTION

3.1 CONFIGURATION OF A DC RAPID CHARGING PLATFORM FOR V2G

The schematic diagram presented in Figure 3.1 illustrates the configuration of a DC fast charging station designed to facilitate the V2G-G2V framework within a microgrid. In this setup, the electric vehicle batteries are linked to the DC power lines (intended for motor vehicles) via external connectors, as depicted in figure 3.1.

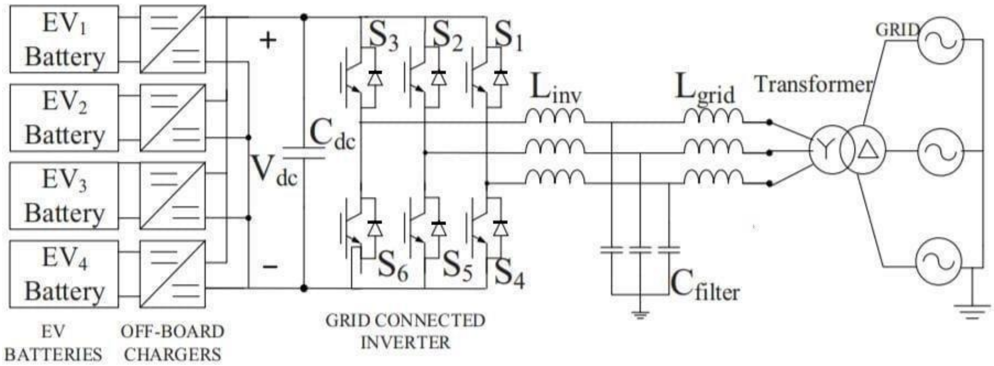


Fig 3.1 EV Charging platform for dc charging

A grid-connected inverter facilitates the connection between a DC machine, an LCL sludge, and a voltage controller to the active power grid. The charging station prioritizes several crucial factors as follows: balancing the supply and demand of the electricity grid by transferring power from electric vehicle batteries back to the grid.

3.1.1 Battery Charger Configuration:

The battery charger configuration consists of instant charging instantaneous containers that are integrated and installed on Electric Vehicle Supply Equipment (EVSE). One of the key highlights of the Vehicle-to-Grid (V2G) built-in container is the presence of a DC-DC dual-engine. This dual-engine acts as a connecting unit between the electric car's battery system and the distribution grid. Please refer to Figure 2 for an illustration of the engine setup. This setup comprises two IGBT/MOSFET switches that are synchronized using fully compatible signal timings.

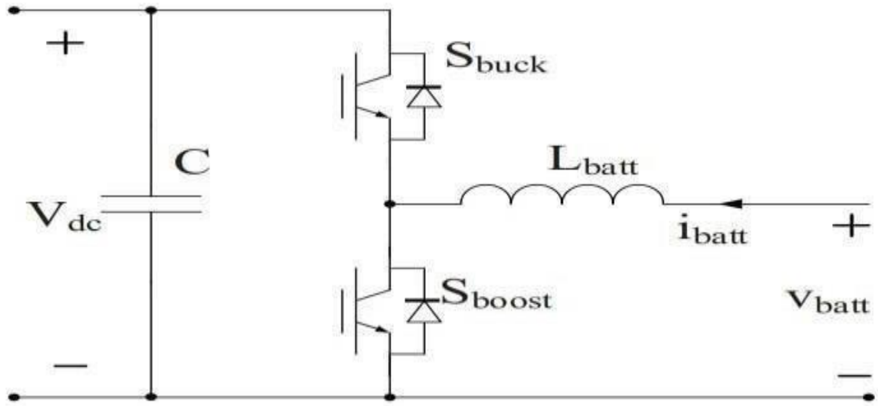


Fig. 3.2 Battery charger configuration

3.1.2 Buck (charging) way of operation:

When the upper switch (Sbuck) is activated, the motor operates in the buck mode, converting the input voltage (Vac) to the battery charging voltage (Vbatt). The surplus current is directed towards the battery through the switch and inductor when the switch is turned on. This mechanism enables power transfer from the grid to the vehicle during the charging process (G2V). When the key is turned off, the current flows back to the inductor and diode of the lower switch, thus completing the circuit. The battery voltage can be determined using the equation Vbatt = D * Vac, where D represents the duty cycle of the advanced switch.

Table 3.1 Charging station parameters

Parameter	Value	Parameter	Value
Rated capacity	250KVA	EV rated power	40kW
Vbatt	500V	Battery Capacity	48Ah
Cdc	850mF	Cfilter	133 mF
Linv	0.25mH	Lgrid	0.25mH

3.1.3Boost (discharging) mode of operation

The motor serves as a boost motor when the lower switch (Sboost) is engaged. When activated, it increases the battery voltage (Vbatt) to align with the voltage of the DC machine (Vdc). Additionally, when the key is turned on, the current flows through the inductor and completes the circuit through the anti-parallel diode of the top switch and the capacitor. In this situation, surplus power is transmitted from the vehicle to the grid (V2G), causing the battery to discharge. The capacitor effectively maintains a consistent DC voltage, and the voltage level achieved during the boost state is considered satisfactory.

To calculate Vdc, we use the equation **Vdc = Vbatt / (1 - D'),** where D' represents the duty cycle of the lower switch.

3.2 LCL Filter and Grid-Connected Inverter

The grid-connected inverter (GCI) is responsible for converting the voltage of a direct current (DC) machine into a three-phase alternating current (AC) voltage. It enables bidirectional current flow through the antiparallel diodes of the switches in each branch, as shown in Figure 1. To achieve harmonic reduction and ensure a clean sinusoidal voltage and current, an LCL filter is connected to the inverter's output. The parameters of the LCL filter were determined using a modified design approach based on a specific pattern.

3.3 CONTROL SYSTEM

3.3.1 Fuzzy Logic Controller

Uncoordinated charging or discharging of electric vehicles (EVs) can disrupt the voltage profile at the network nodes. When the EVs charge or discharge energy without control, the nodal voltages may exceed or fall below the standard norms set by the central electricity authority (CEA). This study proposes the utilization of a fuzzy logic controller (FLC) to regulate the charging and discharging rates of EVs. The charging station controller considers two input parameters: the current state of charge (SOC) of each vehicle and the voltage profile at the node where the charging station is located. If the SOC is low and the node voltage is high, the EV will initiate charging. Conversely, if the SOC is high and the node voltage is low, the EV will discharge energy. However, scenarios may arise where both the SOC and node voltages are either high or low. To address such situations, a restricted charging or discharging rate is employed. The FLC is fine-tuned to handle these scenarios, ensuring that the fluctuations in node voltage remain within the specified norms.

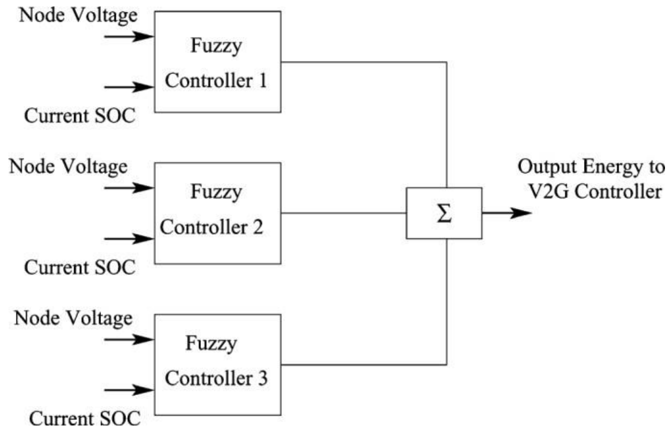
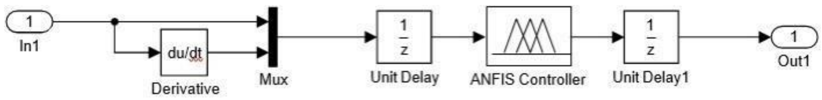


Fig.3.3 Charging station controller.



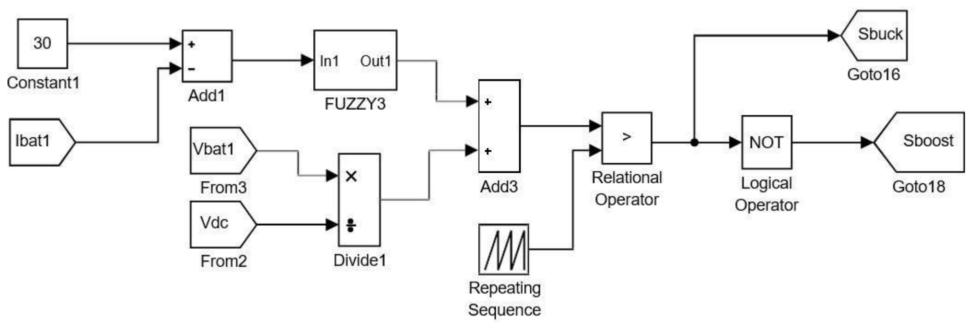


Fig 3.4 Advanced Control Circuit employing Fuzzy along with Buck-Boost Converter

3.3.2 Off Board charger control:

The off-board charge/discharge monitoring of the cell's column circuit is regulated using a constant current control mode implemented with a PI controller, as depicted in Figure

3. The PI controller compares the battery current with zero to determine the desired current direction and operating mode, whether it is for charging or discharging. By comparing the reference current with the actual current and processing the resulting error through the PI controller, the Sbuck/Sboost offset is generated. During the charging process, Sboost is deactivated, while Sbuck is deactivated during discharge.

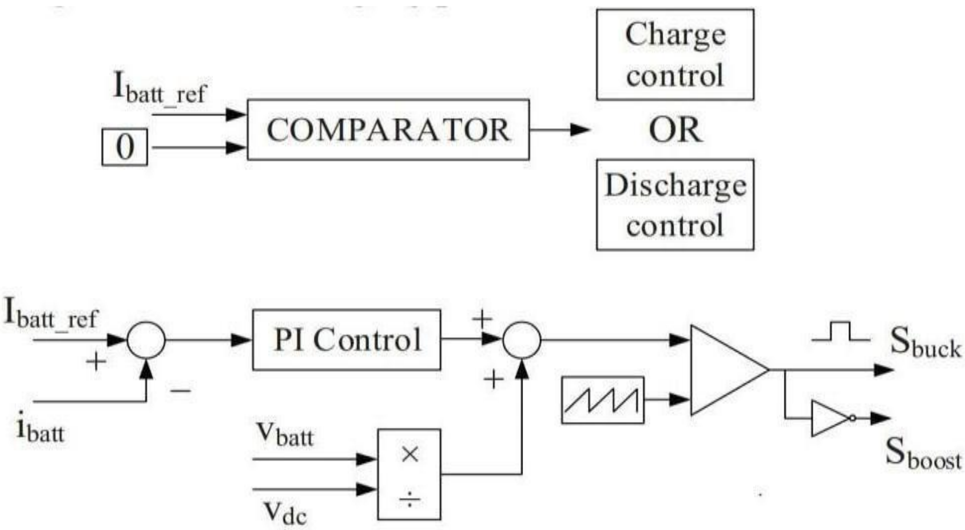


Fig. 3.5 Fixed current control circuit for battery charger

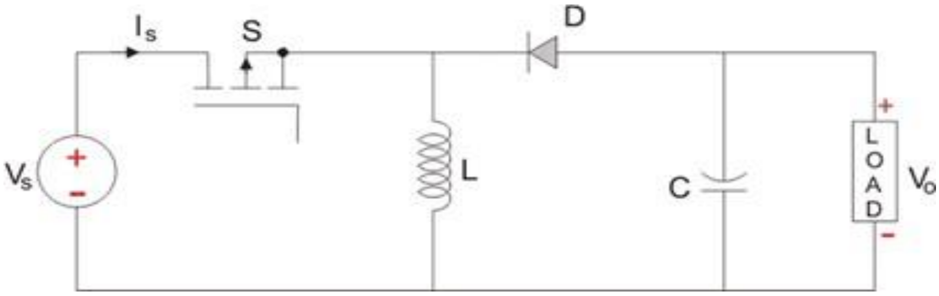


Fig. 3.6 Configuration for buck-boost converter

3.3.3 Inverter Control:

The inverter controller employs a coincident reference cascading control system, as depicted in Figure 4. This system comprises a set of nested circle controls known as vector controllers. The control structure consists of two external voltage control circuits and two internal current control circuits. The internal circuit along the d-axis safeguards the active alternating current, while the external circuit regulates the machine's voltage. The reactive current is regulated by the current in the q-axis, while the amplitude of the AC voltage is controlled by the current in the q-axis. In order to enhance excitation during transient conditions, the terms decoupling dq - oL and linear charge voltage signal have been incorporated.

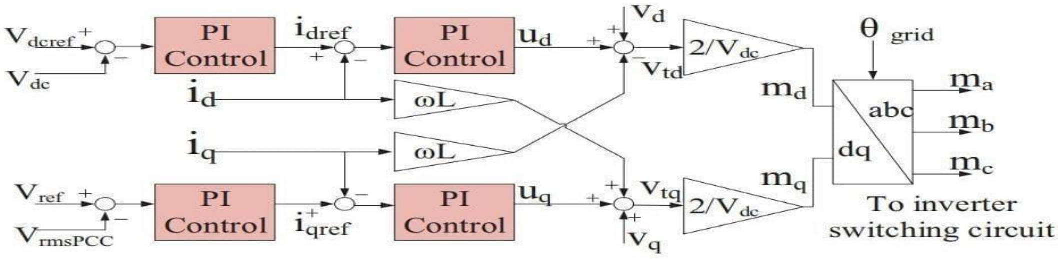


Fig. 3.7 Inverter control system

3.4 EXPERIMENTAL SETUP

Figure 5 illustrates the experimental configuration of the micro-grid trial, featuring the DC rapid-fire charging platform. The power generation sources within the system consist of a 100 kW wind turbine (WT) and a 50 kW photovoltaic solar generator. The electric vehicle battery storage system comprises four EV battery cells connected to the charging station's 1.5 kV DC bus through mounted dishes. To connect the solar PV to this DC system, a boost converter equipped with a maximum power point tracker (MPPT) is utilized. The kilometric network is formed by the identical 25 kV distribution circuit and 120 kV transmission network. The induction generator at the common coupling point is supplied power twice by a wind turbine connected to the micro-grid (PCC).

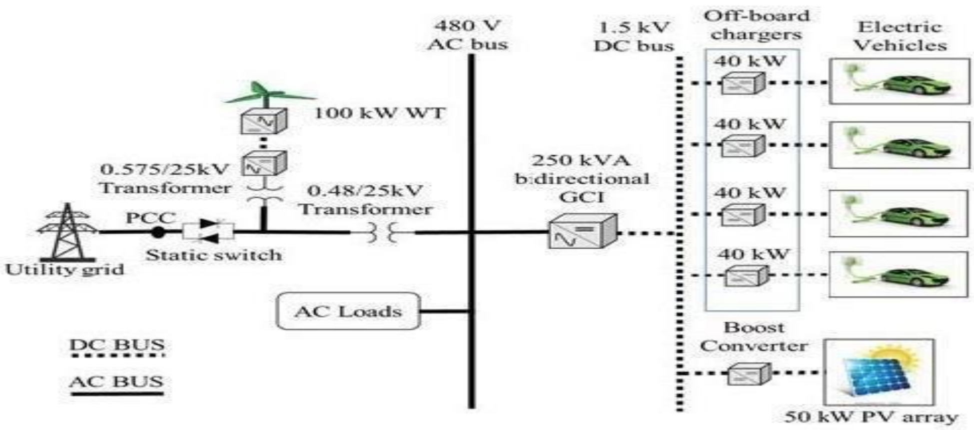


Fig. 3.8 Micro –grid system configuration

Induction generators, which are driven by wind turbines, are connected to the micro grid at the point of common connection (PCC). Voltage boosters, known as blenders, are utilized to elevate the voltage and establish a connection between the AC system and a specific grid. Numerous research studies have demonstrated the capability of electric vehicles (EVs) to effectively respond to system regulation dispatch signals.

3.5 CONCLUSION

In this chapter, we present the System Description and experimental setup of power generation sources, which encompass a 100-kW wind turbine (WT) and a 50-kW photovoltaic solar generator. Additionally, we incorporate a DC rapid-fire charging platform with Buck and Boost operation modes, along with various Control Systems such as Fuzzy Logic Controller, Off-Board Charger Control, and Inverter Control. These systems are employed to investigate the Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) functionalities.

CHAPTER 4
RESULTS AND DISCUSSION

The design process for charging stations was based on reference (4), and the specific values obtained are provided in the postscript. To ensure optimal performance, the wind turbine is configured to operate at its peak efficiency, generating a maximum power output of 100 kilowatts. Similarly, the solar photovoltaic (PV) system underwent testing under standard conditions, with an irradiance of 1000W/m2 and a temperature of 25°C, resulting in a peak power output of 50 kW. The 480 V AC machine is supplied by a 150 kW resistor for consistency.

To maintain consistency, the indicator line responds when the GCI (Global Charging Interface) is set to none. The initial state of charge (SOC) of the electric vehicle battery is set to 50%. When steady-state conditions are suitable, the Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) power switching is accomplished by utilizing the batteries of EV1 and EV2 (refer to Figure 1). The current setpoints for the battery charging circuits of EV1 and EV2 are presented in Table I, and the corresponding results are shown in the accompanying images.

Table 4.1 - EV Batteries current set points.

Time range (s)	0 to 1	1 to 4	4 to 6
Current set-point to EV_1 battery (A)	0	+80	0
Current set-point to EV_2 batter y(A)	0	0	-40

4.1 Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) Charging Architecture:

Vehicle-to-Grid (V2G) is a technology that allows electric vehicles (EVs) to interact with the power grid by using their batteries to store and supply electricity. In a V2G charging architecture implemented using MATLAB, and Grid-to-Vehicle (G2V) Charging Architecture: Grid-to-Vehicle (G2V) charging allows electric vehicles to draw energy from the power grid to charge their batteries shown in Figure 4.1. In a G2V charging architecture implemented using MATLAB, the following components and steps are typically involved:

- Electric Vehicle (EV): The EV serves as the mobile energy storage device, equipped with a battery that can store electrical energy.
- Electric Vehicle Supply Equipment (EVSE): The EVSE is responsible for connecting the EV to the power grid. It acts as an intermediary between the EV and the grid.
- Power Grid: The power grid is the existing electrical infrastructure responsible for generating and distributing electricity.
- Communication Protocols: To facilitate communication between the EV, EVSE, and the power grid, various protocols are used. These protocols enable data exchange, control commands, and monitoring of the charging process.
- Charging Control Algorithm: A charging control algorithm, implemented using MATLAB, is used to manage the energy flow between the EV and the power grid. This algorithm determines when and how much energy should be exchanged between the EV and the grid, considering factors such as EV battery status, grid demand, and user preferences.

By using MATLAB, researchers and engineers can develop and simulate various charging control strategies and algorithms for both V2G and G2V architectures shown in Fig 4.1. These simulations help in evaluating the performance, efficiency, and feasibility of different charging scenarios.

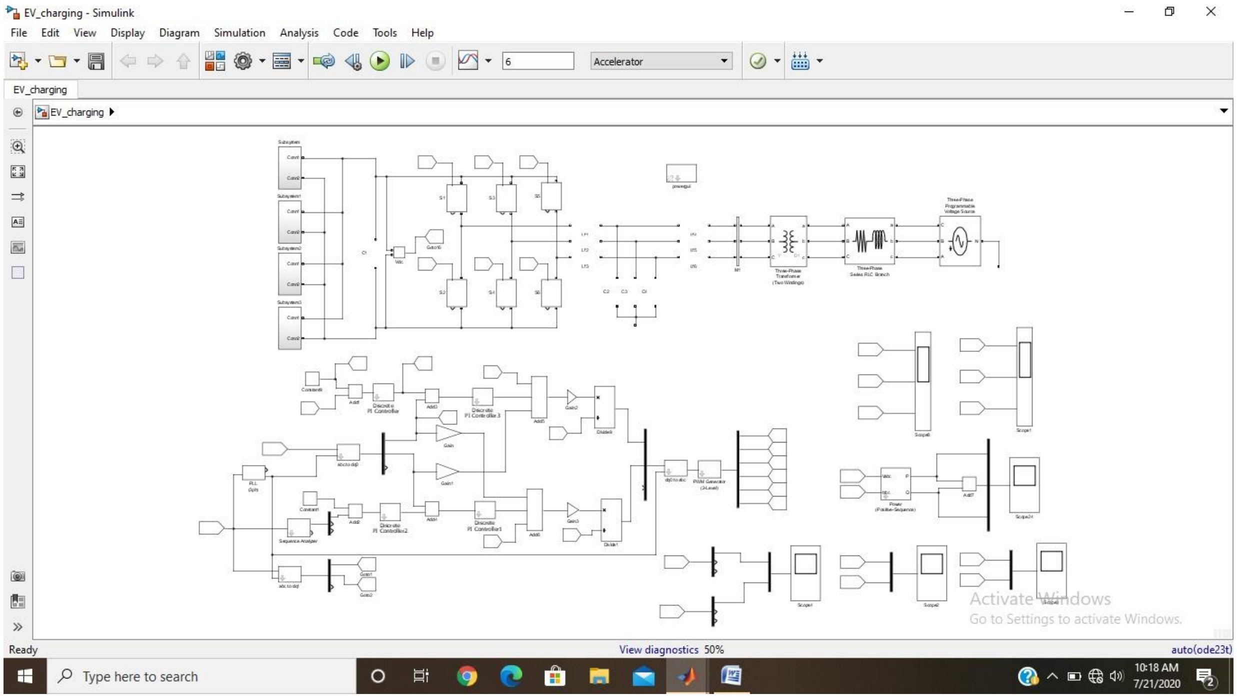


Fig. 4.1 Vehicle-to-Grid (V2G), Grid-to-Vehicle (G2V) Matlab Architecture.

4.2 Voltage, current, and SOC of EV1 battery during V2G operation

In this investigation we find the behavior of a battery system during Vehicle-to-Grid (V2G) operation, focusing on the voltage, current, and state of charge (SOC) of the battery. The aim is to compare the performance of two different control strategies, namely the Proportional-Integral-Derivative (PID) controller and Fuzzy Logic controller, in regulating these parameters. And all the information is based on a comprehensive review of the existing literature on battery management systems and V2G technology.

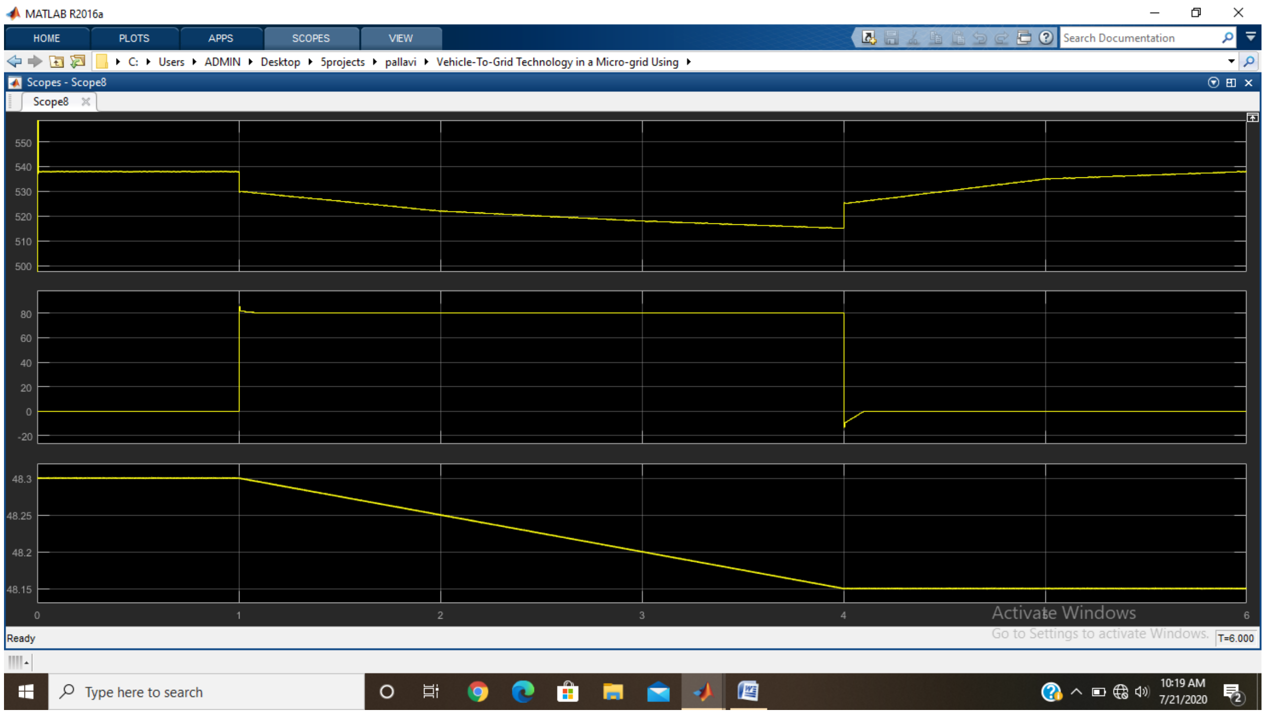


Fig. 4.2 Voltage, current, and SOC of EV1 battery during V2G operation.

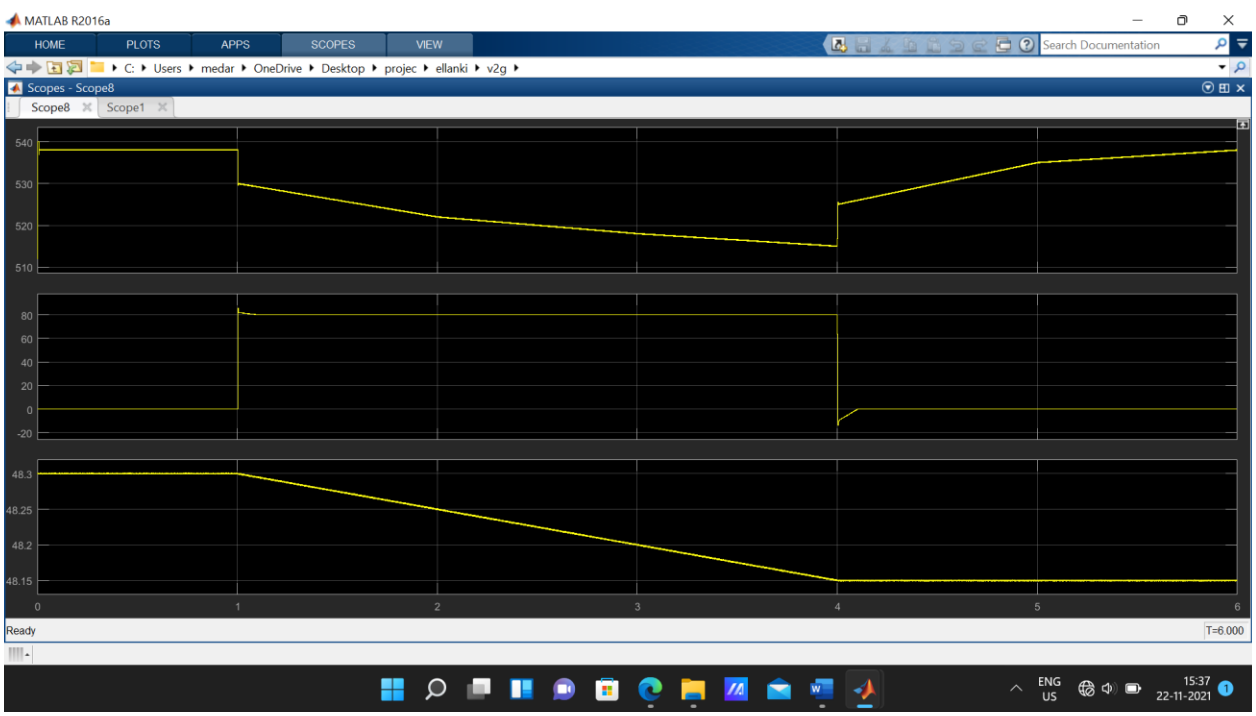


Fig. 4.3 Fuzzy Extension of Voltage, current, and SOC of EV1 battery during V2G operation

4.3 Voltage, current, and SOC of EV2 battery during (Grid-to-Vehicle) G2V operation

During Grid-to-Vehicle operation, voltage, current, and SOC are critical parameters that need to be controlled and monitored. Both PID and Fuzzy Logic controllers provide effective means of regulating these parameters. The PID controller adjusts the charging current based on the error between the desired setpoints and the actual values, while the Fuzzy Logic controller uses linguistic variables and fuzzy rules to optimize the control process. By utilizing these controllers, the charging process can be optimized, ensuring safe and efficient operation of the battery during Grid-to-Vehicle scenarios.

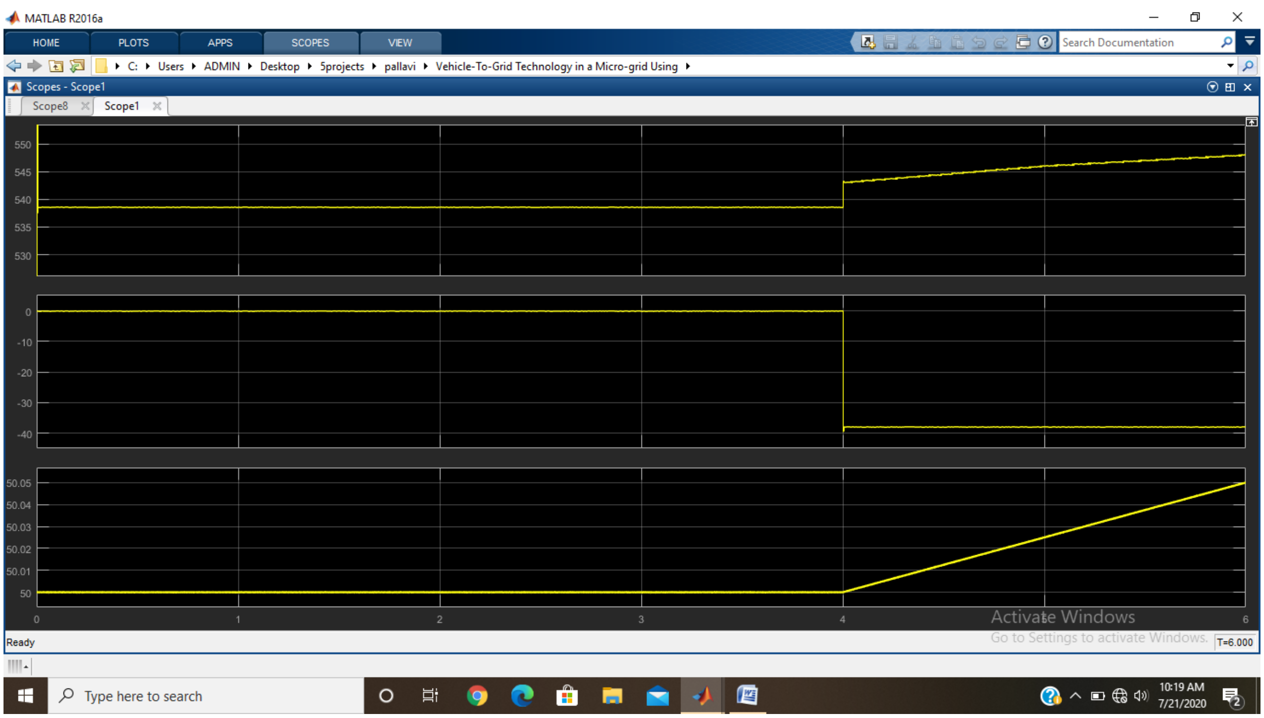


Fig. 4.4 Voltage, current, and SOC of EV2 battery during G2V operation.

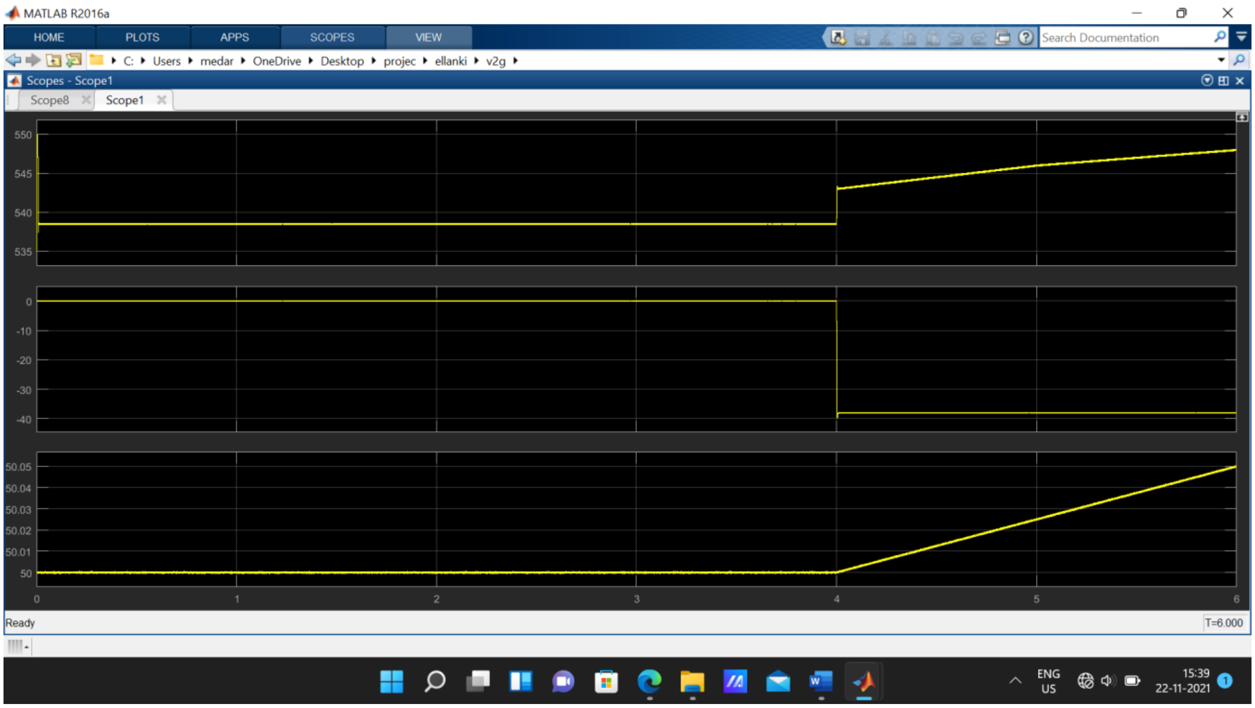


Fig 4.5 Fuzzy Extension of Voltage, current, and SOC of EV2 battery during G2V operation

4.4 Active power profile of various components in the system

The active power profile of the system illustrates various factors. The power supplied by the grid is adjusted to meet the power requirements of electric vehicles (EVs). Between 1 and 4 seconds, there is a negative value for grid electricity, indicating that the vehicle is exporting power to the grid. At 4 seconds, there is a shift in the sign of the grid power, showing that the grid is supplying power to charge the vehicle's battery. This illustration demonstrates the concept of Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) interactions. Additionally, the final power at the power control center is zero, indicating that the power balance of the system is optimal.

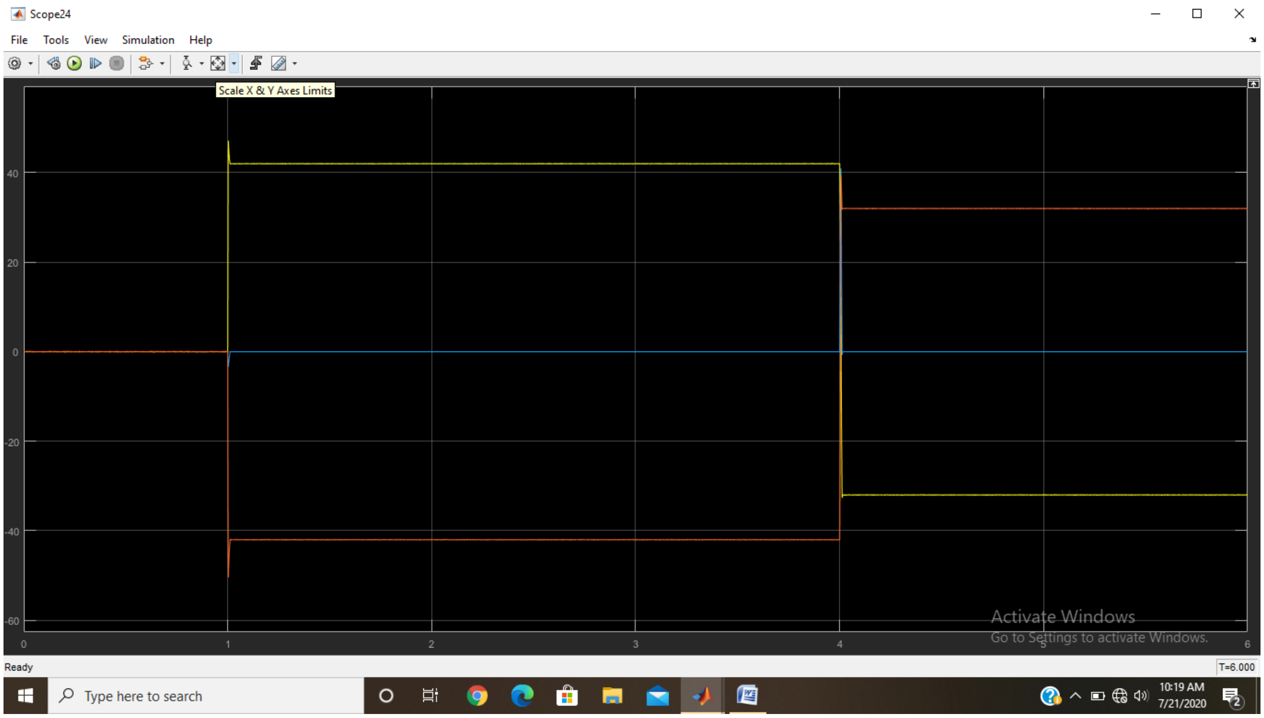


Fig. 4.6 Active power profile of various components in the system.

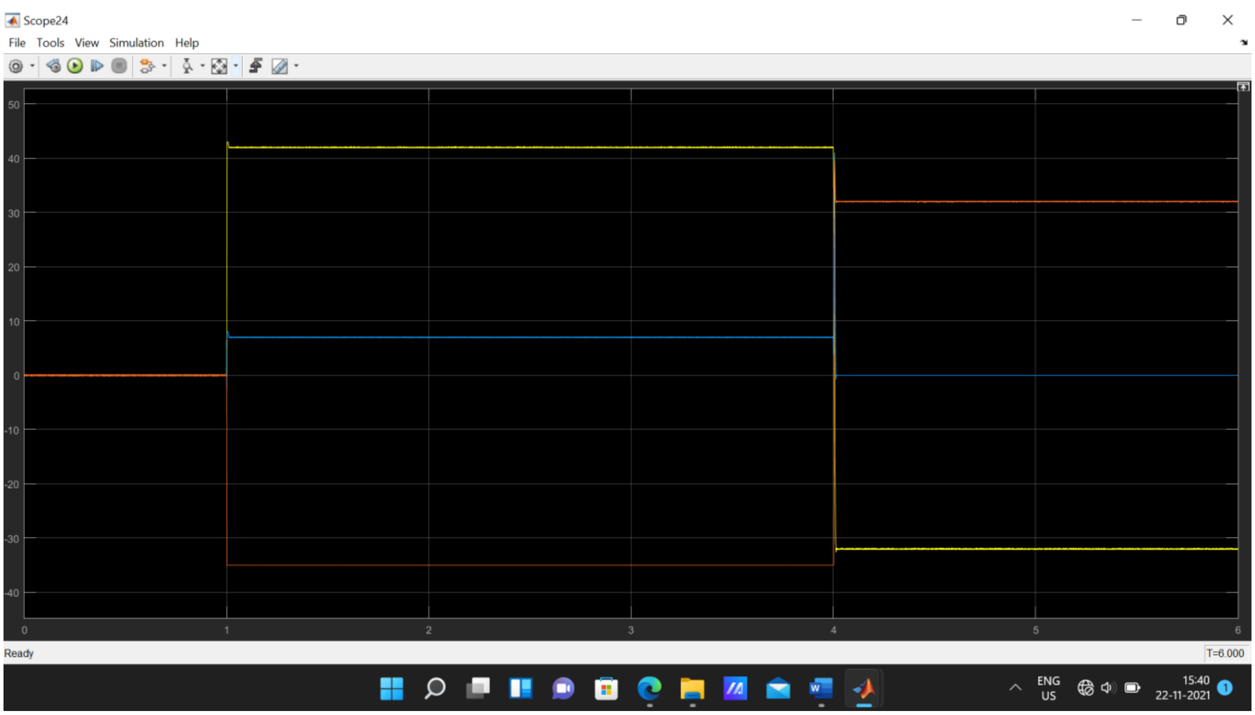


Fig. 4.7 Fuzzy Extension Active power profile of various components in the system.

4.5 Variation in dc bus voltage

The inverter controller's outer potential control loop manages the direct current (DC) bus voltage to regulate it around 1500 V, as depicted in Figure 9.

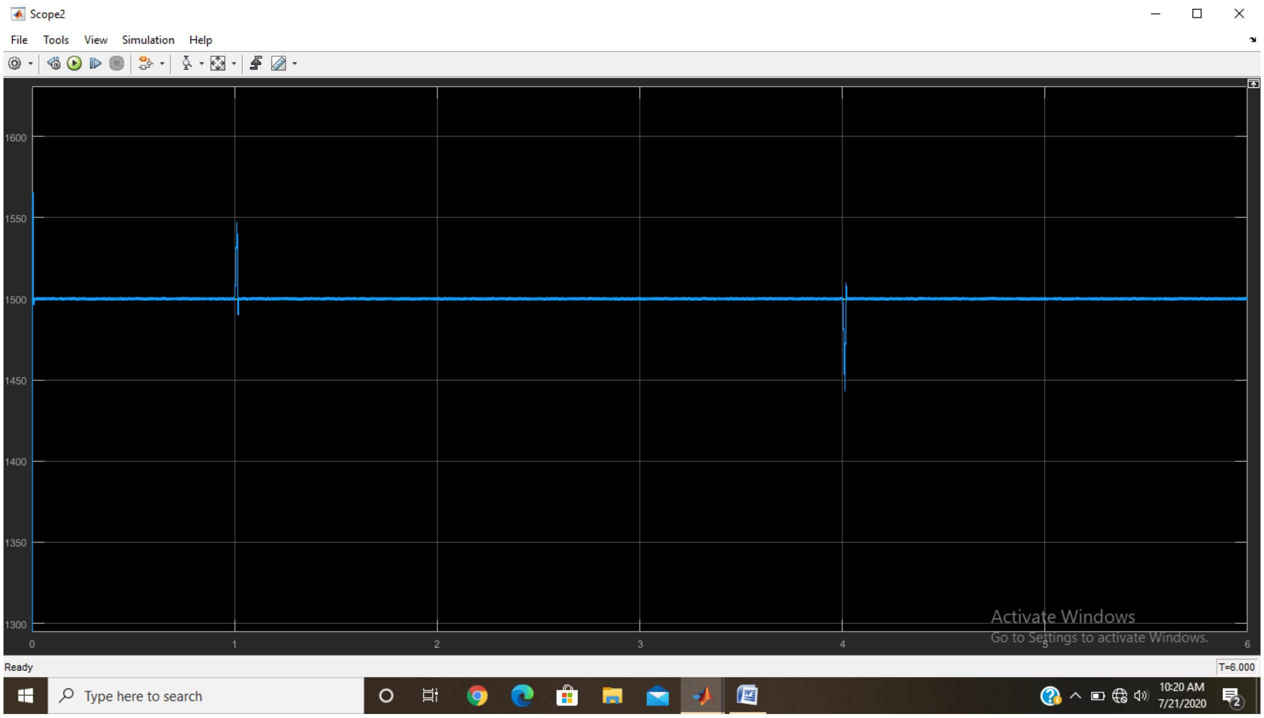


Fig. 4.8 Variation in dc bus voltage.

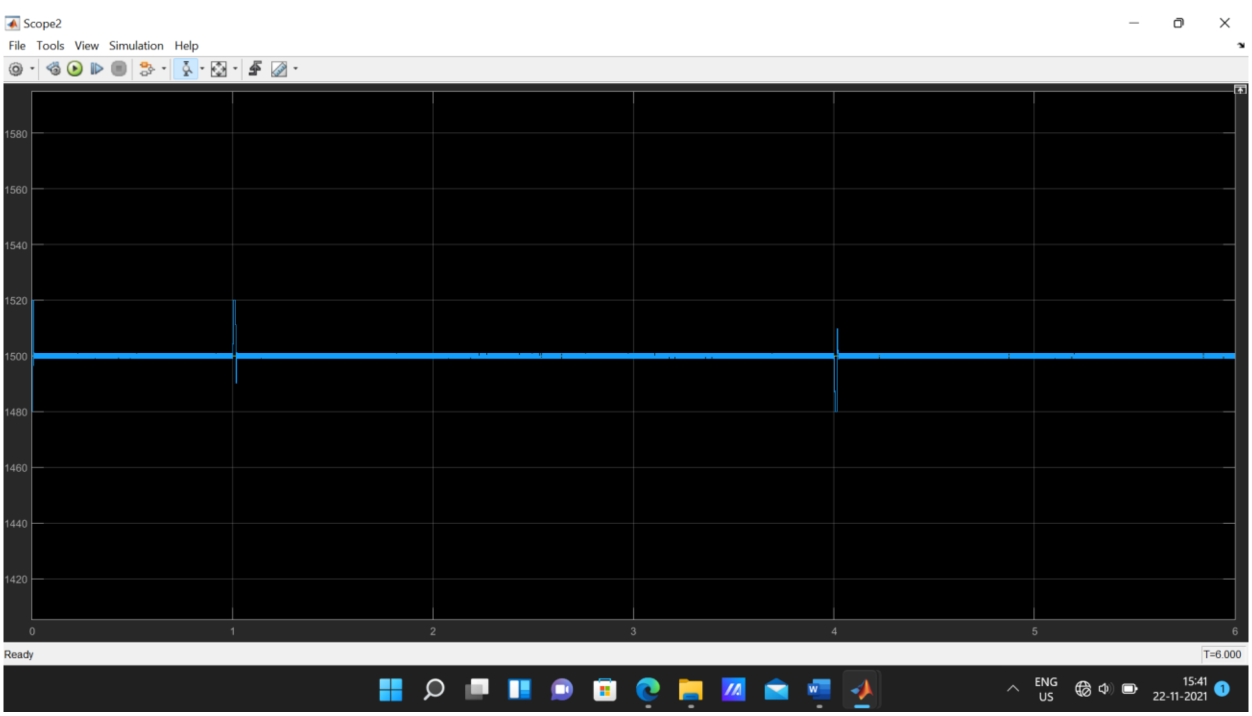


Fig. 4.9 Fuzzy Extension of Variation in dc bus voltage.

4.6 Reference current tracking by inverter controller

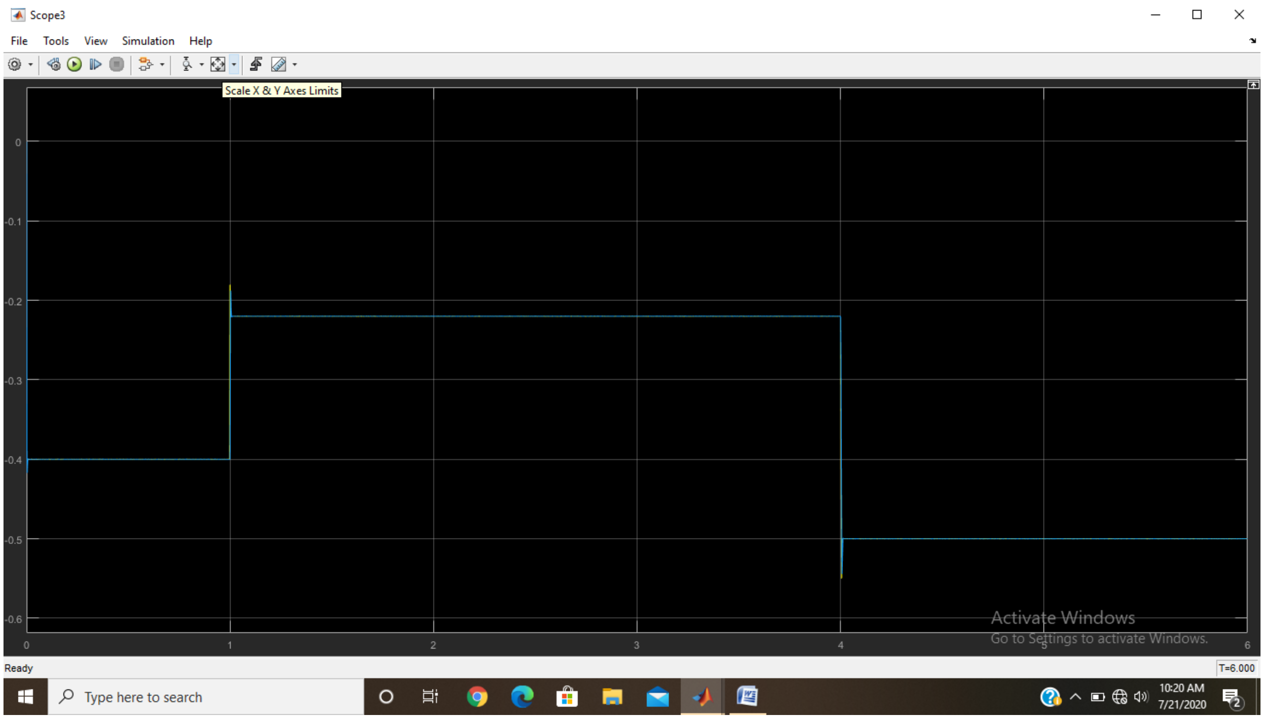


Fig. 4.10 Reference current tracking by inverter controller

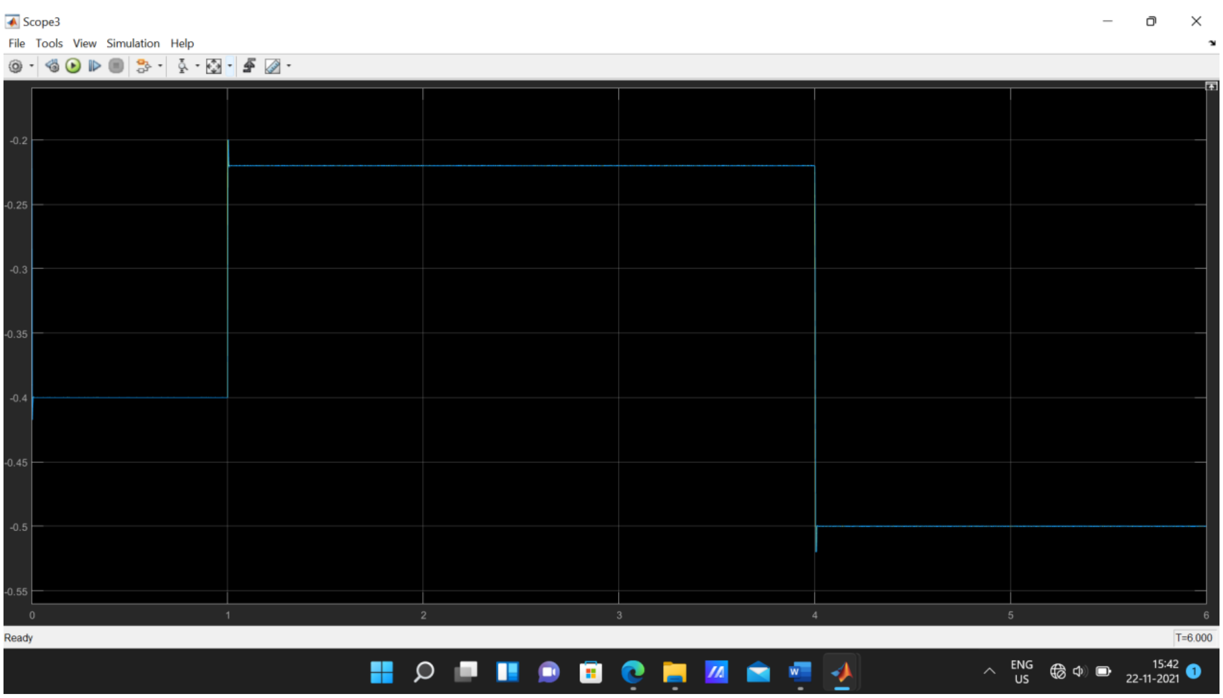


Fig. 4.11 Fuzzy Logic Extension of Reference current tracking by inverter controller

4.7 Grid voltage and grid injected current during V2G – G2V modes

Fig.4.12 "The Power Control Center (PCC) illustrates the potential and current within the electrical grid. In the G2V (Grid-to-Vehicle) state, both the voltage and current are synchronized. However, in the V2G (Vehicle-to-Grid) modes, the voltage and current exhibit a phase shift of 180°, indicating a reverse flow of power."

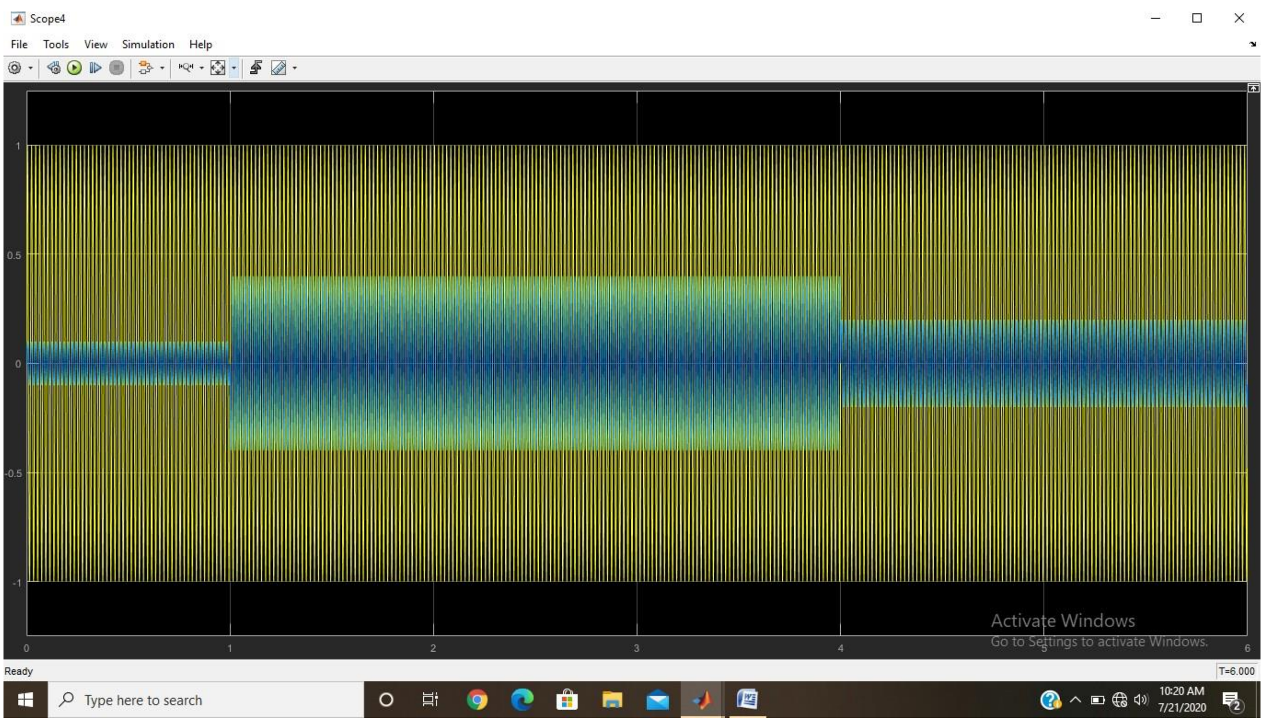


Fig. 4.12 Grid voltage and grid injected current during V2G-G2V operation

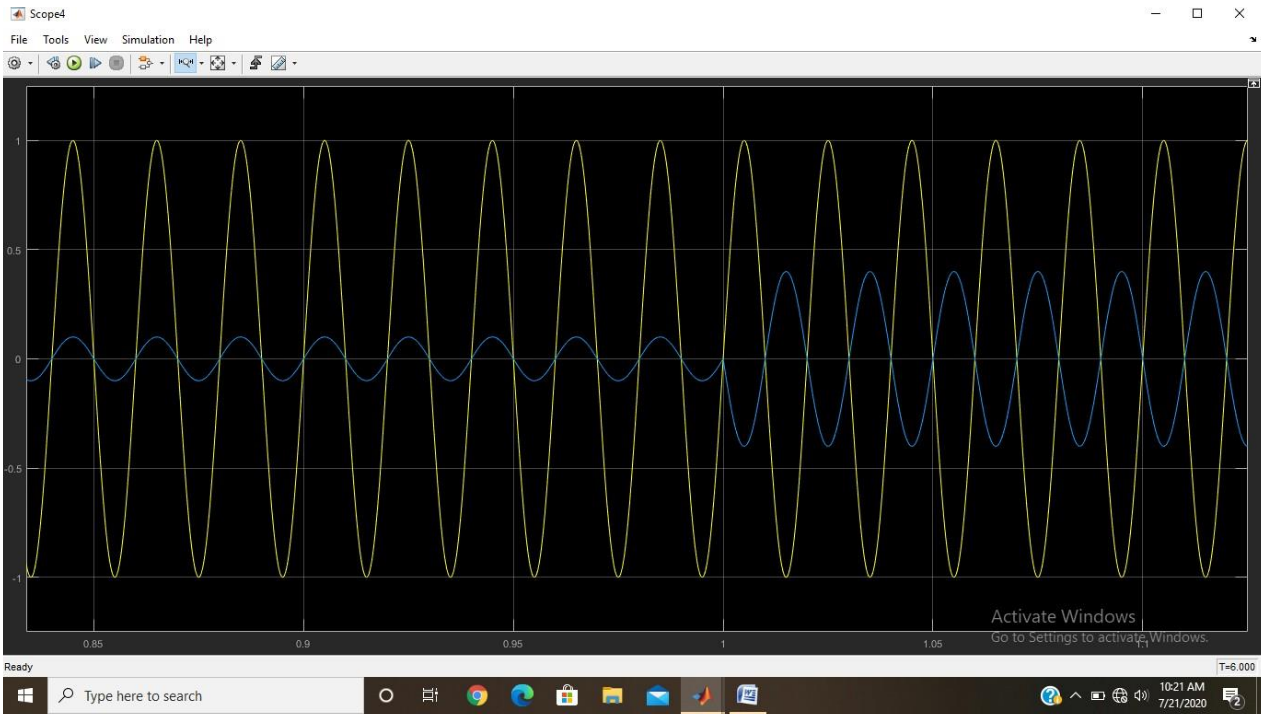


Fig. 4.13 V2G (Vehicle-to-Grid) modes, the voltage and current exhibit a phase shift of 180°

Fig. 4.14 G2V (Grid-to-Vehicle) state, both the voltage and current are synchronized

4.8 CONCLUSION

Chapter 4 In the Results we discuss the choice between Fuzzy Logic and PID Controller for V2G and G2V technologies depends on the specific requirements and characteristics of the system. Fuzzy Logic controllers are more suitable for complex and uncertain environments, where adaptability and robustness are crucial. PID controllers, on the other hand, are simpler and more suitable for systems with known dynamics and linear behavior. A careful evaluation of system dynamics, control objectives, and computational resources can help determine the most appropriate controller for efficient and reliable V2G and G2V operations.

CHAPTER 5
CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

In this thesis, We have presented a novel framework for implementing the Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) concepts using fuzzy logic controllers, aiming to address the voltage stability issues in power systems. Our research focused on exploring the roles of fuzzy controllers as controllable smart power flow regulators between the electric grid and electric vehicles.

The increasing concern over CO2 emissions and environmental pollutants caused by fossil fuels has driven nations worldwide to seek new technologies that can mitigate these adverse effects. Electric Vehicles (EVs) have emerged as a promising solution to these crises. However, the rapid growth of EVs and technological advancements in recent years have raised concerns regarding the impact of integrating EVs into the power grid.

In parallel with technological advancements, the design process in industries has also undergone significant changes. Model-based design has become a common practice in automotive and other industries, especially for complex embedded systems. This approach utilizes models to create executable specifications, enabling engineers to validate and verify specifications against requirements. Simulation plays a crucial role in this design process, facilitating efficient and cost-effective product development.

We have developed and simulated a V2G and G2V system model that incorporates a fuzzy logic controller. Additionally, we have modeled and simulated a state-of-the-art DC fast charging station that utilizes V2G technology to minimize charging time. Furthermore, we have implemented smart charging scheduling techniques for G2V, aiming to reduce the cost of charging for both electric utilities and EV owners.

EVs, as specific electricity loads, can be leveraged as mobile storage to participate in load adjustments within the power grid and provide a platform for energy source coordination. We have analyzed battery management strategies, including battery weariness, bidirectional chargers, and switching strategies for V2G and G2V. These strategies have proven effective in enhancing battery performance by optimizing state of charge (SOC) levels. Additionally, we have reviewed the challenges and difficulties associated with integrating EVs into distribution networks, highlighting the importance of appropriate management and utilities to mitigate adverse effects and transform them into positive outcomes.

In the proposed grid-to-vehicle system, optimal conversion processes are implemented through a back-to-back converter to ensure high-quality battery voltage during the charging phase. The selection of the carrier frequency plays a crucial role in this system. By increasing the carrier frequency from its lowest to highest value, the total harmonic distortion (THD) of the battery output voltage is significantly reduced. The THD value of the battery voltage is maintained below 5%, as per the IEEE standards.

During the battery discharging phase, also known as the vehicle-to-grid system, the stored energy in the battery is discharged to the grid via a converter, which is utilized in the G2V topology. When the SOC level of the battery reaches 100%, the stored energy is fed back to the grid through the converter circuit. In our proposed V2G system, we have analyzed three different battery voltage conditions at 100% SOC level: rated voltage (48V), below-rated voltage (36V), and above-rated voltage (72V).

We have considered the voltage, real power, and reactive power of the grid in our analysis of the aforementioned battery voltage conditions. For the rated and above-rated voltage conditions, the SOC level of the battery is maintained at 100%. The injection of real and reactive power into the grid is higher for the rated voltage condition compared to the below-rated voltage condition. The power injection is achieved through a shunt coupling transformer, also known as the point of common coupling. We have analyzed an efficient point of common coupling system while maintaining the rated voltage of the grid. In a three-phase system, the rated voltage is maintained at 440V during the discharging condition, as demonstrated in our proposed analyses.

5.2 FUTURE WORK

- In future work, it is recommended to focus on integrating renewable energy resources into the power systems network, along with V2G technology and G2V capabilities.
- Additionally, it would be beneficial to explore the economic aspects of implementing DC fast charging stations on a large scale for widespread adoption of electric vehicles (EVs).
- An investigation into the potential contribution of a significant number of EVs to power system balancing should be conducted.
- To fully realize the benefits of implementing a V2G system in a distribution system, it is necessary to study the economic costs and benefits associated with it, which have not been considered in this thesis.
- The contribution of renewable resources, such as wind and solar power, should be examined to determine their potential in improving the voltage stability of the system.
- Further research is recommended to investigate the design of EV chargers that can provide VARs, as this assumption requires more in-depth exploration.

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