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Design of V2g And G2v Systems For Microgrids with Harmonic Disturbance Reduction Using A Dc Fast Charging Architecture

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ABSTRACT

Nowadays, awareness about carbon emissions has increased. Therefore, with the goal of reducing pollution globally, the development of electric vehicles (EVs) has begun to flourish, as their batteries can be used as potential energy storage devices in microgrids. A large number of EVs connected to the power grid and high energy demand will create uncertainty between generation and demand. A DC fast charging station with external chargers (i.e., using buck and boost converters) and grid-connected inverters has been designed to connect EVs to the microgrid. In this project, a high-power bidirectional charging architecture for EVs is presented, and scheduling strategies for grid-to-vehicle (G2V), vehicle-to-grid (V2G), and battery energy storage systems (BESS) are proposed. The effectiveness of these systems is evaluated in MATLAB/SIMULINK. This DC fast charging station design ensures minimal grid distortion.

I. INTRODUCTION

Energy storage systems are important components of a microgrid, enabling the integration of intermittent renewable energy sources. Electric vehicle (EV) batteries can be used as effective storage devices in microgrids when connected for charging. Most personal transportation vehicles remain parked for approximately 22 hours per day, during which time they represent an idle asset. EVs could contribute to microgrid energy management by storing energy when there is a surplus (Grid-To-Vehicle, G2V) and returning it to the grid when there is demand (Vehicle-To-Grid). V2G applied to the general electricity grid faces some challenges, such as its control complexity, the need for a large number of EVs, and its difficulty in short-term implementation [1]. In this scenario, it is easy to implement a V2G system in a microgrid. The Society of Automotive Engineers defines three charging levels for EVs. Level 1 charging uses a plug to connect the vehicle's on-board charger to a standard household outlet (120 V). It is the slowest form of charging and works for those who travel less than 60 kilometers per day and have an entire night to charge. Level 2 charging uses dedicated electric vehicle supply equipment (EVSE) at home or a public station to provide power at 220 V or 240 V and up to 30 A. Level 3 charging is also known as DC fast charging. DC fast charging stations provide charging power of up to 90 kW at 200/450 V, reducing charging time to 20–30 minutes. DC fast charging is preferred for implementing a

V2G architecture in microgrids due to the rapid energy transfer required when EVs are used for energy storage. Additionally, the DC bus can be used to integrate renewable generation sources into the system.

II. WHAT IS SIMULATION IN MATLAB?

A simulation in MATLAB refers to the process of creating a virtual representation of a real system or process within the MATLAB environment and subsequently running experiments on that model to observe its behavior over time or under different conditions.

MATLAB, along with its complementary environment Simulink, provides powerful tools and an intuitive interface for building, simulating, and analyzing dynamic systems.

The following details what simulation entails in MATLAB:

- **Modeling:**
  - Mathematical representation: The first step is to develop a mathematical model of the system to be simulated. This involves defining the system's components, their relationships, and the governing equations that describe their behavior.
  - MATLAB code: These models can be implemented directly in MATLAB using its programming language. This is typically done for systems described by mathematical equations, algorithms, or data-driven models. Simulink Block Diagrams: For more complex and interconnected systems, Simulink offers a graphical environment where models can be built using block diagrams. These blocks represent various mathematical operations, system components, and physical elements. These blocks are connected to define the signal flow and interactions within the system.
- **Simulation:**
  - Defining Simulation Parameters: Once the model is built, simulation parameters must be defined, such as simulation time, input signals or stimuli, and system initial conditions.
  - Running the Simulation: MATLAB or Simulink uses numerical methods (solvers) to calculate the behavior of the model over the specified time period. It essentially runs through time, calculating the state of each component based on the model equations and the inputs it receives.
  - Observing the System Response: During and after the simulation, you can observe how the system responds to inputs and how its internal variables change over time.
- **Analysis and Visualization:**
  - Data Collection: MATLAB and Simulink automatically collect simulation data.
  - Visualization Tools: MATLAB offers extensive graphing and visualization tools to display simulation results in a variety of formats (graphs, tables, animations). Simulink also provides oscilloscopes and displays for real-time signal monitoring during simulation.
  - Analysis: You can use MATLAB's analytical capabilities to process simulation data, calculate performance metrics, perform statistical analysis, and gain insight into system behavior.
- Key Applications of Simulation with MATLAB:
- Simulation with MATLAB is used in a wide range of disciplines, including:
  - Control Systems: Design and testing of controllers for various systems (e.g., aircraft autopilots, industrial robots).
  - Signal Processing: Signal simulation and analysis, and filter design.
  - Communications Systems: Modeling and evaluation of communication channels and protocols.
  - Electrical Engineering: Simulation of power circuits and systems. Mechanical Engineering:

Modeling and simulation of mechanical systems, vibrations, and dynamics. Anywhere, with anything, and anyone, with optimal use on any route/network and service.

III. HISTORY OF MATLAB

Cleve Barry Moler, head of the computer science department at the University of New Mexico, is a mathematician and programmer specializing in numerical analysis. He began developing MATLAB in the late 1970s. He designed it to give his students access to LINPACK and EISPACK without having to learn Fortran. It soon expanded to other universities and found a large audience in the applied mathematics community. Jack Little, an engineer, learned about it during Moler's visit to Stanford University in 1983. Recognizing its commercial potential, he joined Moler and Steve Bangert. They rewrote MATLAB in C and founded MathWorks in 1984 to continue its development. These rewritten libraries became known as JACKPAC. In 2000, MATLAB was rewritten to use a newer set of libraries for matrix manipulation: LAPACK. IV. LITERATURE REVIEW

In the article "Modeling an EV Charging Station for DC Fast Charging," A. Arancibia and K. Strunz explain that the EV charging station model is suitable for DC fast charging of multiple EVs. The station consists of a single grid-connected inverter with a DC bus to which the EVs connect. Control of each EV charging process is decentralized, while a separate central control manages the transfer of power from the AC grid to the DC bus. The electrical power exchange does not depend on communication links between the station and the vehicles and also allows for a seamless transition to vehicle-to-grid mode. The design guidelines and modeling are explained in an educational manner to facilitate implementation in MATLAB/Simulink. MATLAB/Simulink simulations are performed to illustrate the station's behavior. The results demonstrate the feasibility of the proposed model and the capability of the control system for DC fast charging and also for vehicle-to-grid charging.

In the article “Bidirectional Battery Charger for Electric Vehicles,” K. M. Tan, V. K. Ramachandara murthy, and J. Y. Yong propose that transportation electrification is a promising approach to mitigate climate change. The market adoption of electric vehicles has had a significant impact in various areas, especially the power grid. Various policies have been implemented to encourage their implementation, and the growing trend in recent years has been satisfactory. The continuous development of powertrain, battery, and charger technologies for electric vehicles has further improved EV technologies for greater adoption. Despite the environmental and economic benefits, electric vehicle charging has a negative impact on the operation of the existing grid. Appropriate charging management strategies can be implemented to address this problem. In the article “Analysis of dynamic stability of a hybrid wave-photovoltaic power generation system integrated in a distribution power grid”, L. Wang, Q. S. Vo, A. V. Prokhorov evaluate the dynamic stability of a hybrid wave-photovoltaic (PV) power generation system integrated in a distribution power grid. The wave power generation system (WPGS) is simulated using a permanent magnet linear generator driven by an Archimedean wave oscillation (AWS). The outputs of the WPGS and the PV system are connected to a common DC link through a voltage source converter (VSC) and a DC/DC boost converter, respectively. The common DC link is connected to the distribution power grid through a voltage source inverter (VSI). A supercapacitor (SC) is used to smooth the generated power delivered to the distribution power grid. This paper proposes a control scheme to maintain stable operation of the studied system, while achieving maximum power extraction for both the wave and PV systems. Both the root locus analysis of the system's eigenvalues under various operating conditions and the time-domain simulation results of the studied system under perturbation conditions are presented to demonstrate and verify the effectiveness of the SC combined with the proposed control scheme in improving the performance of the studied hybrid wave and PV system.

V. EXISTING SYSTEM

The integration of Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) systems within a microgrid, particularly through DC fast charging architecture, presents a promising approach to improving energy management. Existing systems focus on leveraging electric vehicle (EV) batteries as distributed energy storage. These systems employ bidirectional DC-DC converters within external chargers to enable power flow between EVs and the microgrid. This architecture aims to facilitate:
* *G2V:* EV charging during periods of excess grid power.
* *V2G:* EV battery discharge to support the microgrid during peak demand or grid instability.
However, a challenge within these systems is mitigating harmonic disturbances that can arise from DC fast charging processes. Current research focuses on control strategies and filter designs to minimize these harmonics, ensuring grid stability and power quality.

VI. PROPOSED SYSTEM

The proposed V2G/G2V system for a microgrid, designed to mitigate harmonic disturbances from DC fast charging, employs a sophisticated architecture. It integrates bidirectional power converters, advanced control algorithms, and energy storage systems to manage the power flow between electric vehicles (EVs) and the microgrid. By leveraging EV batteries, the system can inject or absorb energy to stabilize the microgrid voltage and frequency, effectively counteracting harmonic distortions introduced by fast charging stations. Intelligent control strategies, such as adaptive filtering and predictive control, are implemented to dynamically adjust the system's response to load fluctuations and harmonic content, ensuring optimal power quality and microgrid stability.

VII. METHODOLOGY

Design a robust V2G to G2V system for microgrid applications, focusing on mitigating harmonic disturbances introduced by DC fast charging. First, a detailed model of the DC fast charging station, including its rectifier and DC-DC converter stages, is developed to accurately simulate harmonic current injection. A microgrid model incorporating distributed generation, energy storage, and critical loads is then established. To integrate V2G capabilities, bidirectional DC-DC converters are designed and controlled using advanced control strategies such as model predictive control (MPC) or adaptive droop control, enabling seamless power exchange between electric vehicle (EV) batteries and the microgrid. Harmonic mitigation techniques, such as active power filters (APFs) or passive filters tuned to the dominant harmonic frequencies, are integrated into the system. Simulation studies are performed using software such as MATLAB/Simulink or PLECS to evaluate system performance under various operating conditions, including different EV penetration levels and load profiles. Finally, experimental validation is performed using a small-scale prototype to verify the simulation results and assess the practical feasibility of the proposed V2G to G2V system, focusing on its ability to maintain power quality and stability in the presence of harmonic disturbances.

VIII. PROBLEM FORMULATION

Electric vehicle (EV) batteries can be used as potential energy storage devices in microgrids. They can contribute to microgrid energy management by storing energy when there is a surplus (Grid-To-Vehicle, G2V) and returning it to the grid (Vehicle-To-Grid, V2G) when there is demand. To implement this concept, appropriate infrastructure and control systems need to be developed. This article presents the architecture for implementing a V2G-G2V system in a microgrid using Level 3 fast charging for EVs. A microgrid test system is modeled, featuring a DC fast charging station for the EV interface. Simulation studies are performed to demonstrate V2GG2V power transfer. Test results show active power regulation in the microgrid using EV batteries using G2V-V2G operating modes. The charging station design ensures minimal harmonic distortion of the current injected into the grid, and the controller offers good dynamic performance in terms of DC bus voltage stability.

IX. BLOCK DIAGRAM

The configuration of a DC fast charging station for implementing the V2G-G2V infrastructure in a microgrid is shown in Fig. 1 [4]. EV batteries are connected to the DC bus via external chargers. A grid-tied inverter connects the DC bus to the power grid via an LCL filter and a step-up transformer. The main components of the charging station are described below.

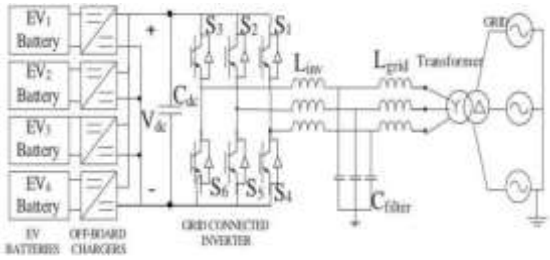


Fig.1 EV Charging station for fast DC charging

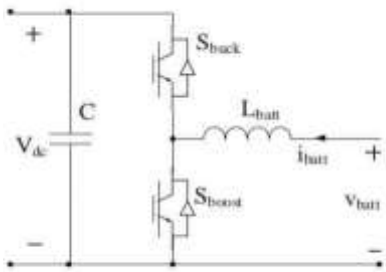


Fig.2 Battery Charger Configuration

A. Battery Charger Configuration

For DC fast charging, chargers are located off-board and integrated into an EVSE. A bidirectional DC-DC converter constitutes the basic component of a V2G-capable external charger. It forms the interface between the EV battery system and the DC distribution grid. The converter configuration is shown in Fig. 2. It consists of two IGBT/MOSFET switches that are always activated by complementary control signals.

1. Buck mode (Charge mode): When the upper switch (k) is operating, the converter acts as a buck, reducing the input voltage (k) to the battery charging voltage (k). During the on state, current flows

through the switch and the inductor to the battery. This is the charging operation, where the energy flow goes from the grid to the vehicle (G2V). When the switch is off, current returns through the inductor and diode of the lower switch, completing the circuit. If D is the duty cycle of the upper switch, the battery voltage is given by:

$Vbatt = Vdc * D$

2. Boost mode (discharge mode): When the lower switch ($Sbooct$) is operating, the converter acts as a boost converter, raising the battery voltage ($Vbatt$) to the DC bus voltage (V). When the switch is on, current continues to flow through the inductor and completes its circuit via the antiparallel diode of the upper switch and the capacitor. In this case, the net power flow is from the vehicle to the grid (V2G), and the battery operates in discharge mode. If the capacitor is large enough to provide a constant DC voltage, the output voltage during boost mode is given by:

$Vbatt$

$V = 1 - D'$

dc

Where D' is the duty cycle of the lower switch.

B. Grid-Tie Inverter and LCL Filter

The grid-tie inverter (GCI) converts the DC bus voltage into a three-phase AC voltage and allows reverse current flow through the antiparallel diodes of the switches in each branch (Fig. 1). An LCL filter is connected to the inverter output terminals to reduce harmonics and obtain a pure sinusoidal voltage and current. The design procedure for determining the LCL filter parameters for this work was adapted from [4].

X. CONTROL SYSTEM

A. External Charger Control

A constant current control strategy [5] is implemented using PI controllers for charge/discharge control of the battery charger circuit, shown in Fig. 3. The controller first compares the battery reference current with zero to determine the polarity of the current signal and decide between charge and discharge operating modes. Once the mode is selected, the reference current is compared to the measured current and the error is passed through a PI controller to generate the switching pulses for $Sbuck/Sbooct$. $Sbooct$ will be turned off throughout the charging process and $Sbuck$ will be turned off throughout the discharging process.

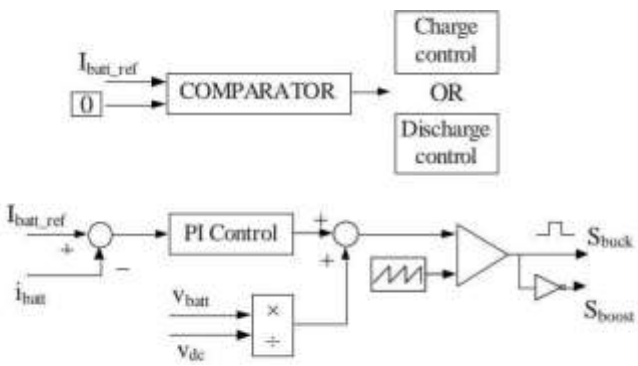


Fig.3 Constant current control charger for battery charger

B. Inverter Control

Cascade control in a synchronous reference system is proposed for the inverter controller. The conventional standard vector control, which uses four PI controllers in a nested loop, is shown in Fig. 4 [4]. The control structure consists of two outer voltage control loops and two inner current control loops. The outer loop controls the DC bus voltage, and the inner loop controls the active AC current. Similarly, the q-axis outer loop regulates the AC voltage magnitude by adjusting the reactive current, which is controlled by the q-axis inner current loop. In addition, dq decoupling terms ωL and forward voltage signals are added to improve transient performance.

XI. MICROGRID SYSTEM CONFIGURATION

The configuration of the microgrid test system with the DC fast charging station is shown in Fig. 5. A 100 kW wind turbine (WT) and a 50 kW solar photovoltaic system serve as generation sources.

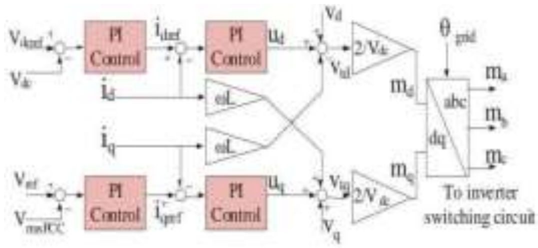
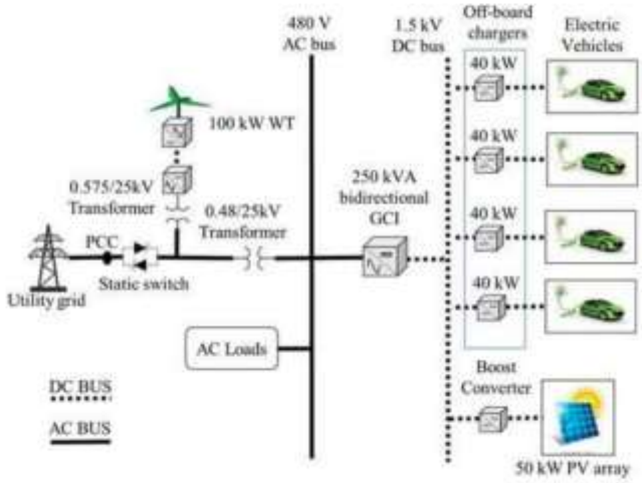


Fig. 4 Inverted controlled system. The electric vehicle's battery storage system consists of four batteries connected to a 1.5 kV DC bus at the charging station via external chargers. The solar PV is also connected to this DC bus via a boost converter with a maximum power point tracking (MPPT) controller. The power grid consists of a 25 kV distribution feeder and a 120 kV equivalent transmission system. The doubly fed induction generator, driven by a wind turbine, is connected to the microgrid at the point of common coupling (PCC). Transformers are used to step up the voltages and connect the respective AC systems to the power grid.



- **ADVANTAGES**
- Greater grid stability:
  - V2G can inject or absorb energy to counteract harmonic distortions and voltage fluctuations.
  - G2V enables controlled charging, avoiding excessive harmonic injection from chargers.
- Higher power quality:

- The active filtering capabilities of DC fast chargers can mitigate harmonics.
- V2G can provide reactive power compensation, reducing voltage distortions.
- Greater microgrid resilience:
- Battery storage (V2G) provides backup power during disturbances.
- Controlled charging (G2V) reduces stress on the microgrid during peak demand.
- Faster response to disturbances:
- DC fast charging systems offer rapid control of power flow.
- This enables rapid compensation of harmonic variations.
- Efficient Energy Management:
- The DC link in the fast charging architecture provides a good place to filter harmonics.
- V2G and G2V allow for optimized power dispatch and load balancing. APPLICATIONS
- **Bidirectional Power Flow Management:***
- The key to V2G/G2V lies in the ability to manage power flow in both directions. Applications should prioritize stable and efficient power transfer between EVs and the microgrid.
- This includes algorithms for:
- Grid synchronization.
- Power regulation.
- Voltage control.
- **Harmonic Mitigation:***
- DC fast charging can introduce significant harmonic distortions into the microgrid. Applications should include robust harmonic mitigation strategies.
- This involves:
- Active filters: Software/hardware that actively cancels harmonic distortion.
- LCL Filters: Passive filters designed to smooth current waveforms.
- Software that runs algorithms to monitor and control the harmonics that occur.
- **Microgrid Stability and Control:***
- The integration of electric vehicles into a microgrid can affect its stability. Applications should focus on maintaining grid stability under varying loads and EV charging/discharging conditions. • This includes:
- Frequency Regulation: Maintaining a stable grid frequency.
- Voltage Stability: Ensuring constant voltage levels.
- Energy management systems that predict and react to load changes.
- **DC Fast Charging Architecture:***
- DC fast charging infrastructure should be designed to support bidirectional power flow and manage high power demands. • Key components include:
- Bidirectional DC-DC converters.
- Grid-tied inverters.
- Advanced control systems.
- **Energy Management Systems (EMS):***
- An EMS is crucial for coordinating V2G/G2V operations within the microgrid.
- Functions include:
- EV charging/discharging scheduling.

- Load balancing.
- Energy consumption optimization.
- Grid status monitoring.

- **Control Strategies:***
  - Advanced control strategies are required for a stable and efficient system.
  - Adaptive Neuro-Fuzzy Inference System (ANFIS) controllers.
  - Cascade control. • Constant current control.

XII. SIMULATION RESULTS

The battery parameters when EV1 is operating in V2G mode and EV2 operating in G2V mode are shown in Figs. 6 and 7, respectively.

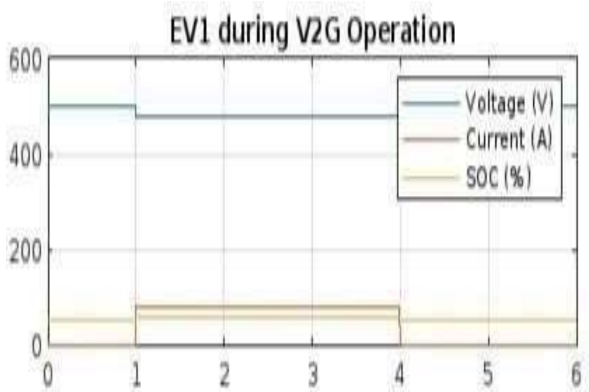


Fig.6. Volt age , cur rent, a nd SO C of E V 1 battery duri ng V 2G

The grid power changes to accommodate the power transferred by the EVs. The negative polarity of the grid power from 1s to 4s shows that the power is being fed tothe grid from the vehicle.

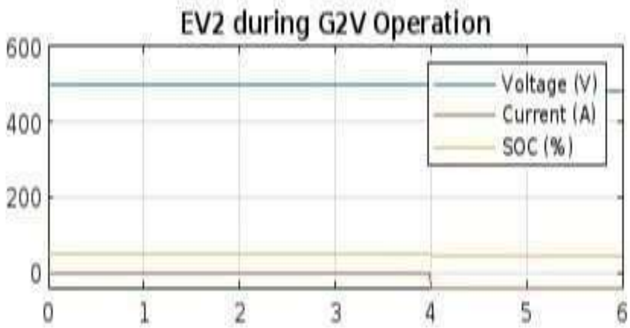


Fig.7. Volt age , curre nt, a nd SOC of E V 2 bat tery duri ng G 2 V operatio

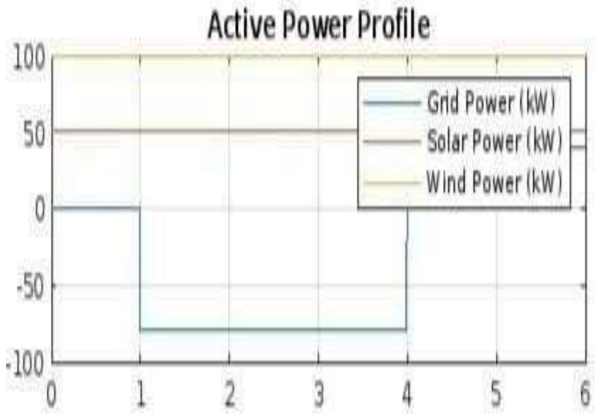


Fig.8.Active power profile of v a r i o u s C o m p o n e n t s i n t h e s y s t e .

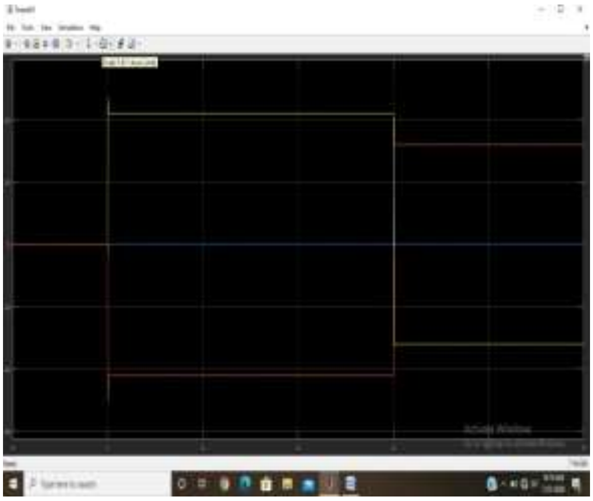


Fig .9 .Variation in dc bus voltage

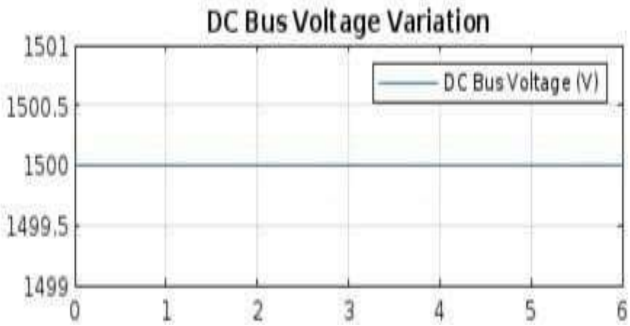


Fig.10.Re ference current trac king by inverter controller

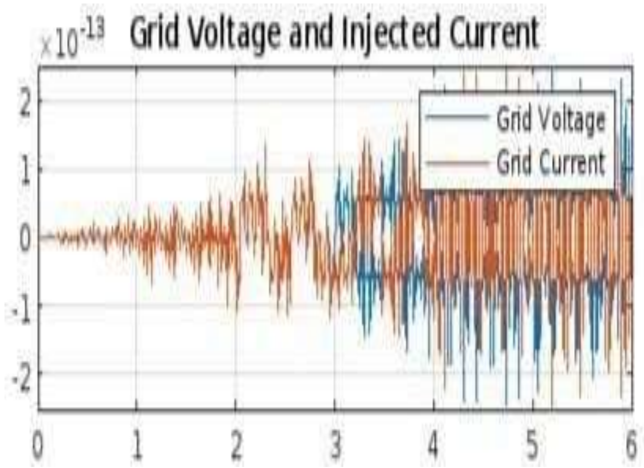


Fig. 11.Grid vol ta ge a nd gri d in je cte d current duri ng V 2 G- G 2V

The grid polarity change at 4 s indicates that the grid is supplying power to charge the vehicle battery. This demonstrates V2G-G operation at 2 V. Furthermore, the net power at the PCC is zero, indicating optimal power balance in the system.
The DC bus voltage is regulated to 1500 V by the external voltage control loop of the inverter controller, as shown in Fig. 1. This, in turn, is achieved by the internal current control loop, which tracks the modified d-axis reference current, as shown in Fig. 9.

XIII. CONCLUSION

This paper presents the modeling and design of a V2G system in a microgrid using a DC fast charging architecture. A DC fast charging station with external chargers and a grid-connected inverter is designed to interconnect EVs with the microgrid. The control system designed for this power electronics interface enables bidirectional power transfer between EVs and the grid. Simulation results show smooth power transfer between EVs and the grid, and the quality of the power injected into the grid from the EVs complies with relevant standards. The designed controller offers good dynamic performance in terms of DC bus voltage stability and tracking of the modified active power reference. This work considers aspects of microgrid active power regulation, and the proposed V2G system can be used for other services, such as reactive power control and frequency regulation. The design of a supervisory controller that provides command signals to individual EV charger controllers is suggested for future research.

XIV. FUTURE SCOPE

The future of microgrid design is increasingly linked to the sophisticated integration of Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) systems, particularly through the use of DC fast charging architectures. This integration seeks to leverage electric vehicle (EV) batteries as distributed energy storage, improving microgrid stability and resilience. However, the prevalence of DC fast charging introduces complexities, particularly harmonic disturbances, which require advanced power electronic control strategies. Future designs will focus on robust control algorithms, innovative filter designs, and intelligent energy management systems to mitigate these harmonics, ensuring smooth bidirectional power flow and optimal microgrid performance. This will be key to the growth of renewable energy integration into local grids.

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