Review Paper on Design and Simulation of Single-Phase Grid Connected V2G-G2V System in MATLAB

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***Abstract*—The rapid growth of electric vehicles (EVs) has increased the demand for efficient charging infrastructure and intelligent energy management systems. Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) technologies enable bidirectional power flow between electric vehicles and the utility grid, improving grid stability, renewable energy integration, and energy efficiency. This review paper presents a comprehensive study of the design, modeling, and simulation of a single-phase grid-connected V2G-G2V system using MATLAB/Simulink. The paper discusses converter topologies, control strategies, synchronization methods, battery management systems, and power quality issues associated with bidirectional EV charging. Different control approaches such as PI control, predictive control, and PWM techniques are analyzed. The review also highlights recent developments in bidirectional chargers, grid synchronization methods, harmonic mitigation, and smart charging algorithms. MATLAB/Simulink-based implementation techniques for single-phase V2G-G2V systems are explained with emphasis on system architecture, inverter control, DC-link regulation, and battery charging/discharging operation. Finally, challenges, future trends, and research opportunities in bidirectional EV-grid integration are discussed.**

***Index Terms*—Vehicle-to-Grid (V2G), Grid-to-Vehicle (G2V), Electric Vehicle (EV), Bidirectional Charger, Single-Phase Grid Connected System, Bidirectional DC-DC Converter, DC-Link Control, Energy Management System (EMS).**

I. INTRODUCTION

Growing environmental pollution and the rapid exhaustion of conventional fossil fuel resources have significantly increased the global demand for electric vehicles (EVs). EVs are widely recognized as an effective alternative to traditional fuel-based transportation systems because they help reduce carbon emissions and enhance overall energy efficiency. Nevertheless, the large-scale integration of EVs into the power grid introduces several challenges, including higher electricity consumption, peak load variations, and grid instability. To address these challenges, Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) technologies have been developed to enable intelligent bidirectional energy transfer between electric vehicles and the utility grid. In G2V mode, energy is transferred from the electrical grid to charge the EV battery, while in V2G mode, the energy stored in the vehicle battery can be delivered back to the grid during periods of high-power demand. For residential charging applications, single-phase grid-connected bidirectional chargers are widely preferred because of their simple structure, economical design, and suitability for household electrical systems. MATLAB/Simulink is extensively used for the modeling and simulation of these systems due to its user-friendly interface and comprehensive power electronics simulation tools. Current research efforts mainly concentrate on enhancing converter performance, minimizing harmonic distortion, maintaining stable DC-link voltage, and implementing smart charging control methods. Modern bidirectional converters along with advanced control strategies are increasingly being adopted to achieve efficient energy exchange and reliable grid support operations.

II. OVERVIEW OF V2G AND G2V TECHNOLOGY

Vehicle-to-Grid technology allows EV batteries to act as distributed energy storage units connected to the power grid. During low electricity demand, EV batteries are charged from the grid. During peak load periods, the stored battery energy can be injected back into the grid.

Advantages of V2G-G2V Systems

- Improved grid stability
- Peak load shaving
- Renewable energy support
- Reduction in electricity cost
- Better utilization of battery storage
- Frequency and voltage regulation
- Reduced carbon emissions

Applications

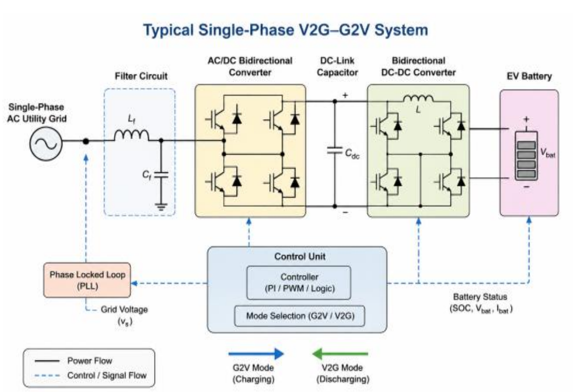
- Smart grids
- Residential charging stations
- Renewable energy integration
- Micro grids
- Emergency backup systems
- Ancillary grid services

Modern bidirectional EV charging systems are designed to provide active and reactive power support while maintaining high power quality standards.

III. SYSTEM ARCHITECTURE OF SINGLE-PHASE GRID CONNECTED V2G-G2V SYSTEM

The typical single-phase V2G-G2V system consists of:

1. Single-phase AC utility grid
2. AC/DC bidirectional converter
3. DC-link capacitor
4. Bidirectional DC-DC converter
5. EV battery
6. Filter circuit
7. Control unit
8. Phase Locked Loop (PLL)



IV. WORKING PRINCIPLE

G2V Mode

In Grid-to-Vehicle mode:

- AC power from the grid is converted into DC power.
- The DC-DC converter regulates charging current.
- Battery SOC increases.

V2G Mode

In Vehicle-to-Grid mode:

- Battery energy is converted into AC power.
- The inverter synchronizes with the grid using PLL.
- Power is injected into the utility grid.

MATLAB/Simulink models generally employ full-bridge voltage source converters with PWM control for bidirectional operation.

V. POWER ELECTRONIC CONVERTER TOPOLOGIES

5.1 AC-DC Bidirectional Converter

The AC-DC stage performs rectification and inversion operations during G2V and V2G modes respectively.

Common Topologies

- Full bridge converter
- Half bridge converter
- Interleaved converter
- Multilevel converter

Among these, full-bridge voltage source converters are widely used because of:

- Better efficiency
- Lower harmonic distortion
- Bidirectional capability
- Simple control implementation

5.2 Bidirectional DC-DC Converter

The DC-DC converter regulates battery charging and discharging.

Operating Modes

Buck Mode: Used during charging operation.

Boost Mode: Used during discharging operation.

Bidirectional buck-boost converters are commonly used in MATLAB/Simulink implementations due to their simple structure and efficient control.

VI. CONTROL STRATEGIES

Efficient control techniques are essential for stable V2G-G2V operation.

6.1 PI Controller

The Proportional-Integral (PI) controller is widely used for:

- DC-link voltage regulation
- Current control
- Battery charging control

Advantages:

- Simple implementation
- Low computational complexity
- Reliable performance

6.2 PWM Control

Pulse Width Modulation (PWM) controls switching devices in converters.

Benefits:

- Reduced harmonic distortion
- Improved power quality
- Better efficiency

6.3 Phase Locked Loop (PLL)

PLL synchronizes inverter output with grid voltage frequency and phase.

Functions:

- Grid synchronization
- Frequency tracking
- Stable power transfer

6.4 Model Predictive Control (MPC)

MPC is an advanced control method that predicts future converter behavior and optimizes switching states.

Advantages:

- Fast dynamic response
- Reduced THD
- Improved stability

Research shows MPC-based systems significantly improve waveform quality and reduce harmonic distortion in V2G-G2V systems.

VII. MATLAB/SIMULINK MODELING MATLAB

Simulink provides an effective platform for simulation of grid-connected EV systems.

Major Simulink Blocks Used

- Voltage source inverter
- Universal bridge
- Battery model
- PLL block
- PWM generator
- PI controller
- Current measurement blocks
- Scope blocks

Simulation Process

Step 1: Grid Modeling

A single-phase AC voltage source is connected through an L-filter.

Step 2: Converter Design

A bidirectional full-bridge converter is implemented using IGBT switches.

Step 3: Battery Modeling

Battery parameters such as SOC, voltage, and current are defined.

Step 4: Control System Design

PI controllers and PWM generators regulate power flow.

Step 5: Performance Analysis

Waveforms of:

- Grid current
- Grid voltage
- Battery current
- Battery SOC
- Active and reactive power are analyzed.

MATLAB provides several ready-to-use models for bidirectional EV chargers and grid synchronization systems.

VIII. POWER QUALITY ISSUES

Large-scale EV charging can affect grid power quality.

Major Issues

- Harmonic distortion
- Voltage fluctuations
- Reactive power imbalance
- Current ripple

Harmonic Reduction Techniques

- LCL filters

- PWM optimization
- Multilevel inverters
- Advanced control algorithms

Maintaining Total Harmonic Distortion (THD) within IEEE standards is essential for reliable grid integration.

IX. CHALLENGES IN V2G-G2V SYSTEMS

Despite many advantages, several challenges remain:
Technical Challenges

- Battery degradation
- Grid synchronization complexity
- High converter losses
- Bidirectional power management
- Cybersecurity issues

Economic Challenges

- High installation cost
- Infrastructure development
- Smart meter integration

Research Challenges

- Fast charging optimization
- AI-based charging algorithms
- Renewable energy coordination
- Real-time energy management

Recent research also highlights cybersecurity vulnerabilities in V2G systems and the need for secure communication frameworks.

X. FUTURE SCOPE

Future research directions include:

- AI-based smart charging
- IoT-enabled EV charging stations
- Renewable energy integrated charging
- Wireless V2G systems
- Machine learning-based control
- Fast charging infrastructure
- Wide band-gap semiconductor devices

Advanced bidirectional charging algorithms and smart grid coordination are expected to play an important role in future EV energy systems.

XI. CONCLUSION

This review paper presented a detailed study of the design and simulation of a single-phase grid-connected V2G-G2V system using MATLAB/Simulink. Bidirectional EV charging systems improve energy efficiency, enhance grid stability, and support renewable energy integration. Different converter topologies, control strategies, and simulation methods were discussed comprehensively. MATLAB/Simulink offers a flexible and efficient environment for analyzing power flow, converter operation, battery management, and grid synchronization. Although significant progress has been achieved in bidirectional EV charging technology, challenges related to battery aging, cyber security, harmonic mitigation, and smart energy management still require further research. Future developments in intelligent control algorithms, artificial intelligence, and smart grid technologies will further improve the performance and reliability of V2G-G2V systems.

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