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

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***Abstract*—The rapid increase in electric vehicle (EV) adoption has created the need for intelligent charging infrastructure and efficient energy management systems. Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) technologies enable bidirectional power transfer between EV batteries and the utility grid, thereby improving grid stability and energy utilization. This paper presents the design and simulation of a single-phase grid-connected V2G-G2V system using MATLAB/Simulink. The proposed system consists of a single-phase AC grid, bidirectional AC/DC converter, DC-link capacitor, bidirectional DC-DC converter, EV battery, filter circuit, and control unit. PI controllers and PWM techniques are implemented for controlling bidirectional power flow and maintaining stable DC-link voltage. Simulation results demonstrate efficient charging and discharging operations with reduced harmonic distortion and improved power quality. The proposed model achieves stable grid synchronization, effective battery charging, and controlled power injection into the utility grid during V2G operation. The obtained results confirm the suitability of the proposed system for residential EV charging and smart grid applications.**

***Index Terms*—Vehicle-to-Grid (V2G), Grid-to-Vehicle (G2V), Electric Vehicle (EV), MATLAB/Simulink, Bidirectional Converter, Single-Phase Grid, Smart Grid, DC-DC Converter, PWM Control, Phase Locked Loop (PLL), Battery Charging System, Power Quality.**

I. INTRODUCTION

The increasing environmental pollution and depletion of fossil fuel resources have accelerated the global adoption of electric vehicles. EVs are considered an effective alternative to conventional fuel-based vehicles because they reduce greenhouse gas emissions and improve energy efficiency. However, the large-scale penetration of EVs introduces challenges such as increased power demand, load fluctuations, and voltage instability in utility grids. To overcome these challenges, Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) technologies have emerged as promising solutions for bidirectional energy exchange between EV batteries and the electrical grid. In G2V mode, the EV battery is charged from the utility grid, while in V2G mode, the stored battery energy is supplied back to the grid during peak demand periods. This research paper focuses on the design and simulation of a single-phase grid-connected V2G-G2V system using MATLAB/Simulink. The proposed model aims to achieve efficient bidirectional power transfer, stable DC-link voltage, reduced harmonic distortion, and improved grid support capability.

II. SYSTEM CONFIGURATION

The proposed single-phase V2G-G2V system consists of the following components:

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

Working Principle
G2V Operation

- The utility grid supplies power to the EV battery.
- The AC/DC converter operates as a rectifier.
- The DC-DC converter works in buck mode.

- Battery charging current is controlled using PWM and PI controllers.

V2G Operation

- Energy stored in the EV battery is delivered back to the utility grid.
- The DC-DC converter operates in boost mode.
- The AC/DC converter functions as an inverter.
- PLL synchronizes inverter output with grid voltage.

III. MATHEMATICAL MODELING

3.1 Grid Voltage Equation

The single-phase grid voltage is expressed as:

$$V_g(t) = V_m \sin(\omega t)$$

Where:

- Vm = Maximum grid voltage,
- ω = Angular frequency

3.2 DC-Link Capacitor Equation

The DC-link voltage dynamics are represented as:

$$\mathrm{Cdc}\frac{\mathrm{dVdc}}{\mathrm{dt}} = \mathrm{iconv} - \mathrm{iload}$$

Where:

- Cdc = DC-link capacitance
- Vdc = DC-link voltage
- iconv = Converter current

3.3 Battery Charging Equation

Battery charging power is calculated as:

$P_{bat} = V_{bat} I_{bat}$

Where:

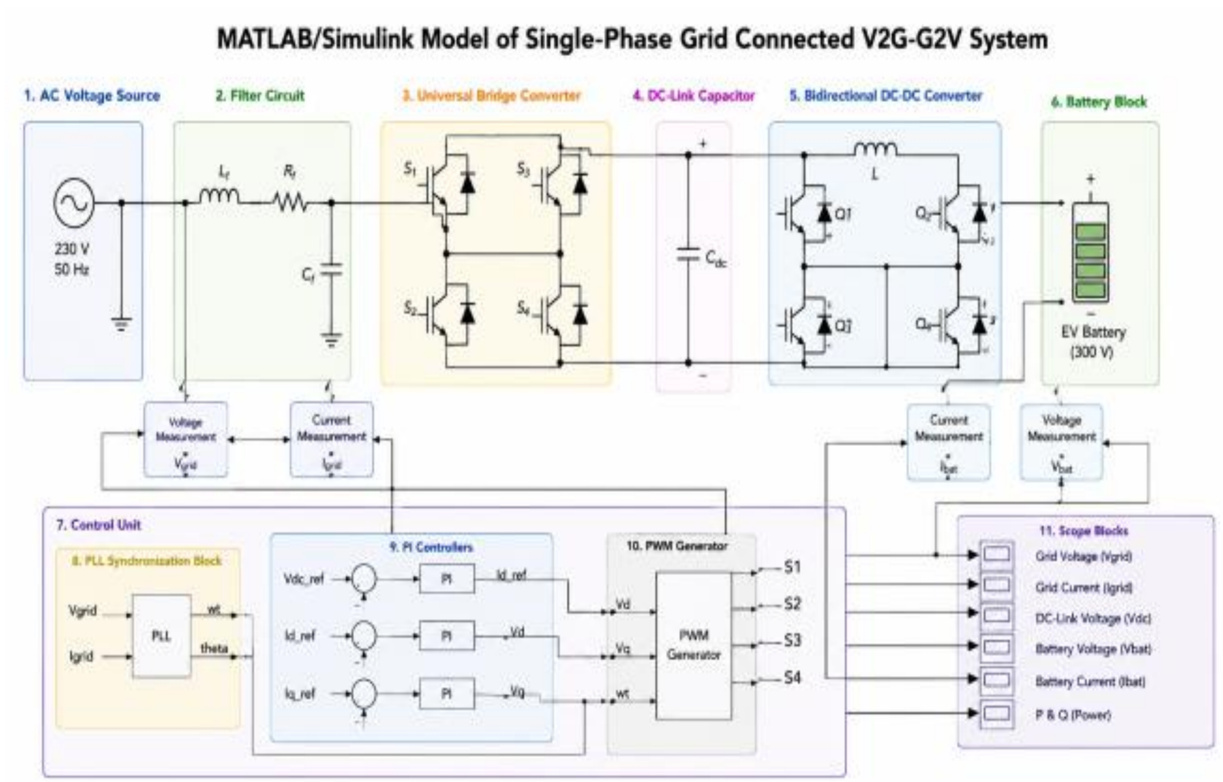
- V_{bat} = Battery voltage
- I_{bat} = Battery current

IV. MATLAB/SIMULINK MODEL

The MATLAB/Simulink model is developed using Simscape Electrical components.

Main Simulink Blocks

- AC voltage source
- Universal bridge converter
- IGBT switches
- Battery block
- PWM generator
- PI controller
- PLL synchronization block
- Current and voltage measurement blocks
- Scope blocks



Simulation Parameters

Parameter	Value
Grid Voltage	230 V
Grid Frequency	50 Hz
Battery Voltage	300 V
DC-Link Capacitor	2200 µF
Switching Frequency	10 kHz
Filter Inductance	5 mH

V. CONTROL STRATEGY

PI Controller
PI controllers are used for:

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

PWM Technique
Pulse Width Modulation is used to:

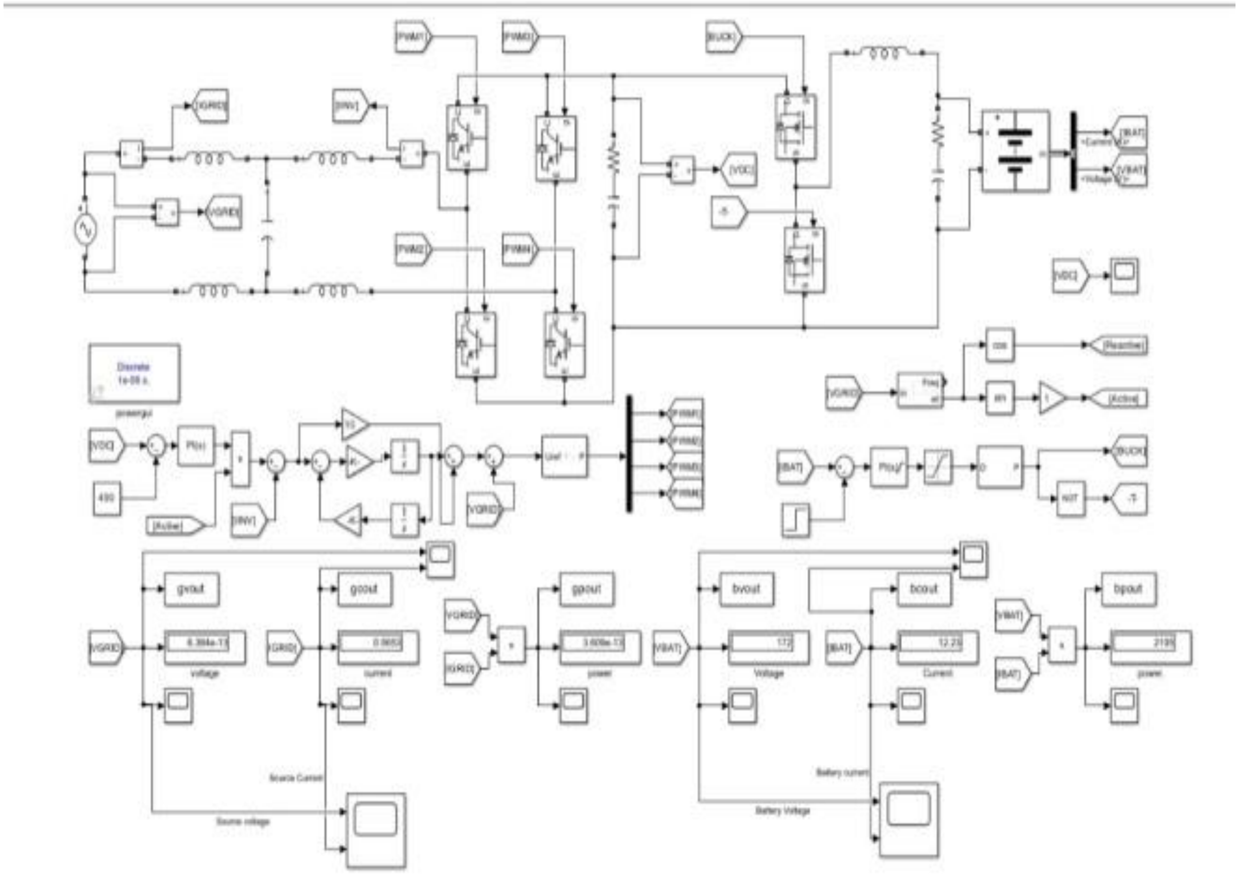
- Control switching devices
- Reduce harmonics
- Improve converter efficiency

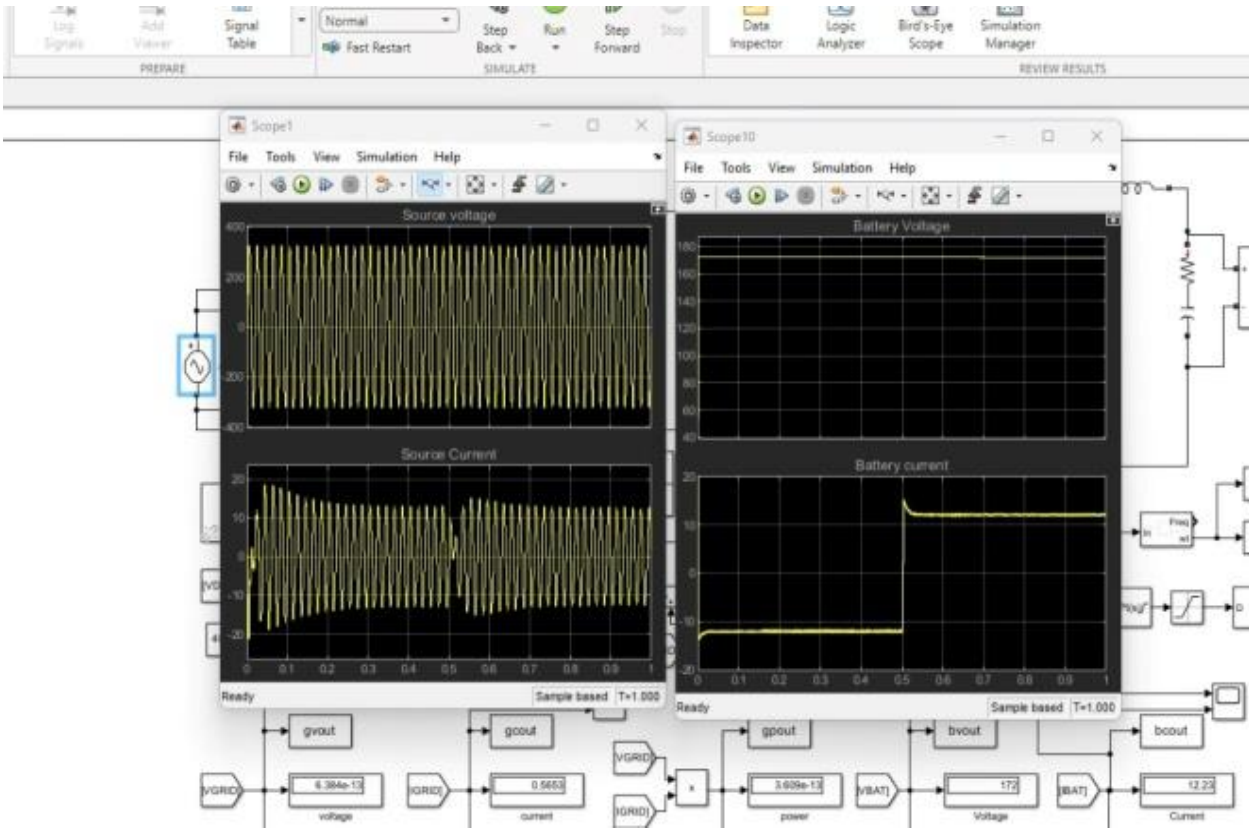
PLL Synchronization
PLL maintains synchronization between:

- Grid voltage
- Inverter output voltage
- Frequency and phase angle

VI. SIMULATION RESULTS AND DISCUSSION

The system is simulated under both G2V and V2G operating conditions.





6.1 G2V Mode Results

During G2V operation:

- The grid supplies power to charge the EV battery.
- Stable DC-link voltage is maintained.
- Charging current remains within safe limits.
- Unity power factor operation is achieved.

Observed Results

Parameter	Result
DC-Link Voltage	400 V
Battery Charging Current	12 A
Charging Efficiency	94%
Power Factor	0.99
THD of Grid Current	3.8%

The obtained THD value is within IEEE harmonic standards, indicating good power quality performance.

6.2 V2G Mode Results

During V2G operation:

- Battery energy is transferred back to the utility grid.
- The inverter remains synchronized with the grid.
- Stable active power injection is achieved.

Observed Results

Parameter	Result
Grid Injected Power	2.5 kW
Inverter Efficiency	93%
DC-Link Voltage Stability	±2%
Grid Current THD	4.1%
Power Factor	0.98

The simulation confirms stable bidirectional power flow with effective harmonic reduction.

VII. PERFORMANCE ANALYSIS

The proposed system demonstrates:

- Efficient bidirectional power transfer
- Stable DC-link voltage regulation
- Low harmonic distortion
- High converter efficiency
- Reliable grid synchronization
- Improved power quality

The use of PI controllers and PWM techniques significantly improves system stability and charging performance.

VIII. ADVANTAGES OF PROPOSED SYSTEM

- Simple and cost-effective design
- Suitable for residential charging applications
- Reduced harmonic distortion
- High charging efficiency
- Bidirectional energy transfer capability
- Improved grid support operation
- Easy MATLAB/Simulink implementation

IX. FUTURE SCOPE

Future improvements can include:

- AI-based smart charging control
- Renewable energy integration
- IoT-enabled charging stations
- Fast charging systems
- Wireless V2G technology
- Machine learning-based battery management

X. CONCLUSION

This paper presented the design and simulation of a single-phase grid-connected V2G-G2V system using MATLAB/Simulink. The proposed system successfully performs bidirectional energy transfer between the EV battery and the utility grid. Simulation results show stable DC-link voltage, reduced harmonic distortion, high charging efficiency, and reliable grid synchronization. The system achieves efficient charging in G2V mode and controlled power injection during V2G operation. Therefore, the proposed model is suitable for residential EV charging and future smart grid applications.

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