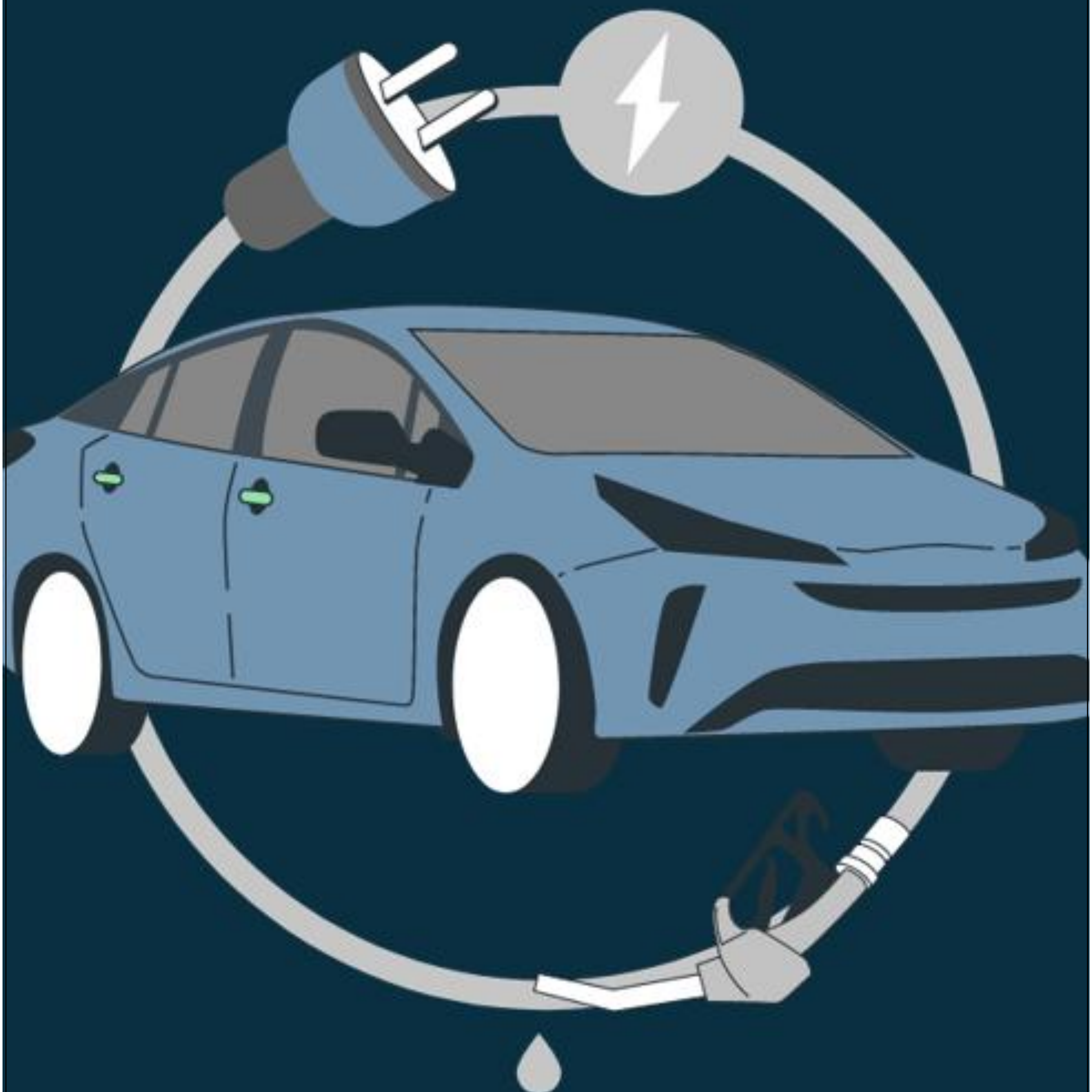


SOC-Battery based charger with V2G Capability

Omar Mohamed Ashmawy

Contents

1. Abstract

This project presents the modeling and simulation of an advanced electric vehicle charging system using MATLAB/Simulink. The system features a bidirectional charger with a Buck-Boost converter acting as the load, enabling both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operation. A Constant Current–Constant Voltage (CC–CV) charging strategy is implemented, with dynamic control logic that transitions to constant voltage mode when the State of Charge (SOC) exceeds 80%. The model incorporates a dq-axis control system, phase-locked loop (PLL) synchronization, and pulse width modulation (PWM) signal generation. Compared to a previous unidirectional charger model, this design provides enhanced grid interaction, control accuracy, and realistic energy flow behavior. Simulation results confirm the system's effectiveness in regulating power, supporting bidirectional energy transfer, and ensuring safe battery charging.

2. Introduction

The evolution of electric vehicle (EV) infrastructure is closely tied to the development of intelligent, efficient, and flexible charging systems. Traditional unidirectional chargers, while suitable for basic vehicle charging needs, limit the potential for energy management and grid interaction. With growing interest in renewable energy integration and smart grid applications, **bidirectional chargers** are becoming increasingly important.

This project builds upon a previously developed two-level on-board charger model by introducing significant functional enhancements. The earlier system focused on unidirectional charging with passive filtering, a simple CC–CV charging strategy, and basic power conversion stages. While effective for demonstrating standard EV charging concepts, it lacked dynamic adaptability, realistic load control, and grid support functionality.

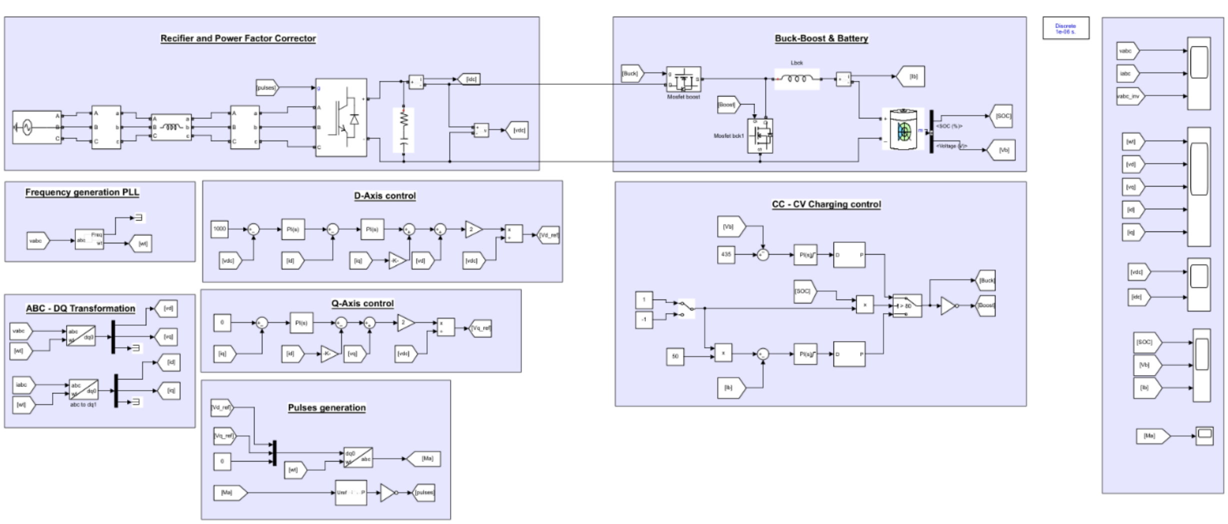
The model presented in this report addresses those limitations by implementing:

- A **Buck-Boost converter** in place of the resistive load, enabling active control of power flow.
- A **bidirectional charging scheme**, allowing both charging (G2V) and discharging (V2G) of the battery.
- **SOC-based logic**, which automatically switches from constant current to constant voltage mode as the battery approaches full charge.
- Advanced control elements, including **dq-axis transformation**, **PLL synchronization**, and **PWM pulse generation** for precise switching control.

These upgrades align the simulation more closely with real-world applications and open the door for future integration of battery management systems (BMS), balancing strategies, and grid coordination protocols.

3. System Overview

This simulation project models an advanced bidirectional EV charger using a Buck-Boost converter and full dq-axis control. The system enables both Grid-to-Vehicle (G2V) and Vehicle-



to-Grid (V2G) power flow, while implementing smart battery charging through CC–CV control and SOC-based switching. The model is organized into functional blocks representing key power and control stages, including rectification, PLL synchronization, dq transformation, and PWM-based switching, allowing modular testing and analysis of each component.

3.1 Rectification and power factor correction

This stage converts the 3-phase AC input into DC voltage and reduces harmonic distortion. It forms the interface between the grid and the DC link, improving power quality and ensuring stable voltage for downstream components.

3.2 Buck-Boost converter with battery

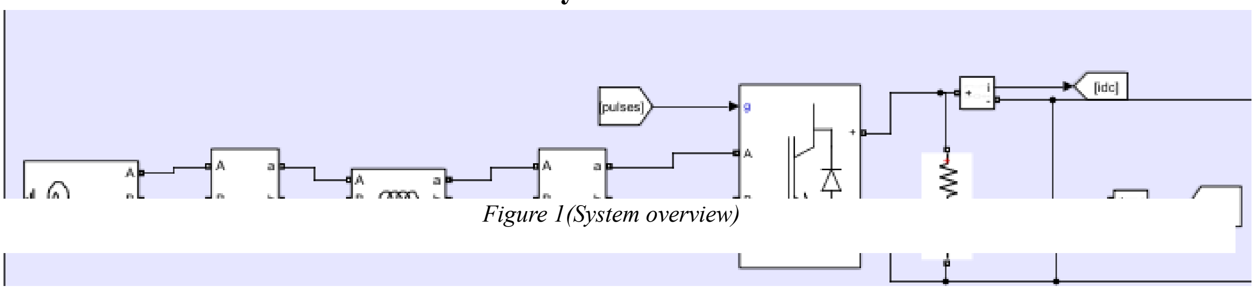


Figure 1(System overview)

Figure 2(Rectifier and PFC)

This bidirectional converter serves as the core charging unit. It steps up or steps down the DC link voltage depending on whether the system is in G2V or V2G mode. It interfaces directly with a lithium-ion battery model, enabling dynamic charging and discharging.

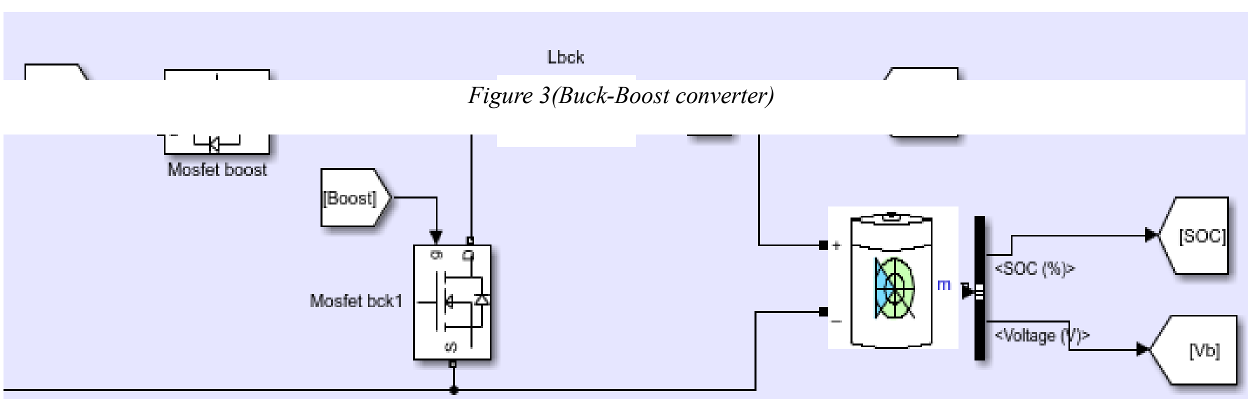


Figure 3(Buck-Boost converter)

4. Control Strategy

The control system in this bidirectional EV charger plays a critical role in managing safe and efficient energy transfer between the grid and the battery. It ensures stability during both charging and discharging operations and enables intelligent switching based on the battery's State of Charge (SOC). Two key control mechanisms are implemented in this model:

- A **dq-axis control system** for active power regulation and synchronization with the grid
- A **battery charging control strategy** using Constant Current–Constant Voltage (CC–CV) with SOC-based mode switching

These control subsystems are realized through **feedback loops**, **PI controllers**, and **PWM signal generation** in Simulink.

4.1 DQ-Axis Control System

This part of the control strategy regulates power flow by transforming three-phase AC quantities into a rotating reference frame (d–q axis), simplifying control of active (real) and reactive power.

Working Principle:

- Grid voltages and currents are transformed using **ABC–DQ transformation**.
- A **Phase-Locked Loop (PLL)** block ensures the transformation is synchronized with the grid frequency and phase.
- Two separate PI controllers manage the **d-axis** (real power/current flow) and **q-axis** (reactive power compensation).
- The output of the controllers is used to generate **PWM signals** that control the switching elements in the Buck-Boost converter.

Controller Features:

- Enables precise control of bidirectional power flow
- Supports both charging (G2V) and discharging (V2G) modes
- Improves power factor and dynamic system response

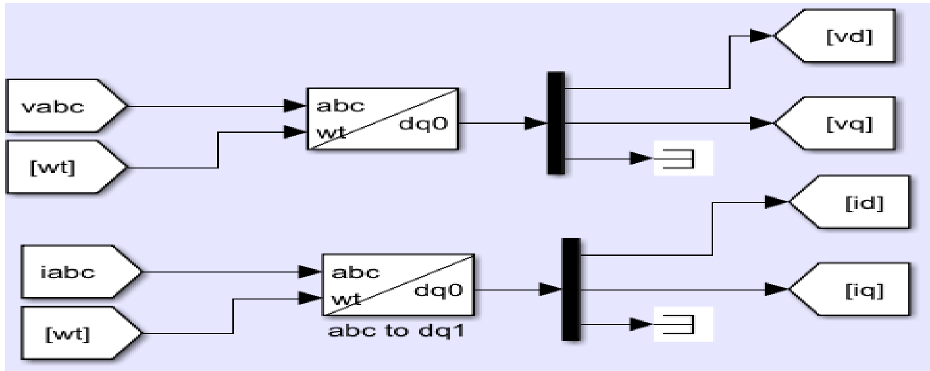


Figure 4 (Phase locked loop)

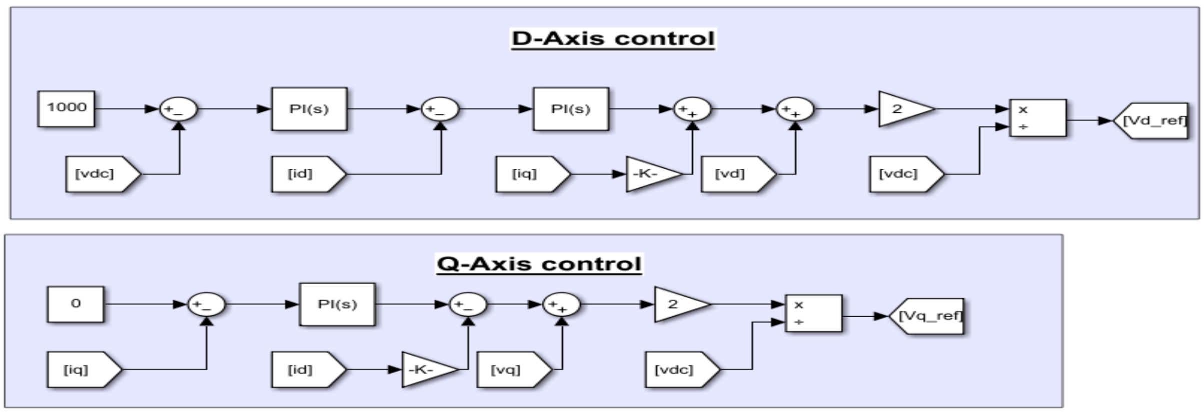


Figure 5(DQ Axis)

4.2 Battery Charging Control (CC–CV Strategy with SOC Switching)

To ensure efficient and safe battery charging, the system uses a **Constant Current–Constant Voltage (CC–CV)** algorithm with an automatic transition based on the battery's State of Charge (SOC).

Charging Phases:

- **Constant Current (CC) Mode**: When SOC is below 80%, the system operates in CC mode. The current reference is set (e.g., 50 A), and a PI controller adjusts the power converter to maintain this charging current. The current is compared with the measured battery current (Ib), and the error is minimized by the PI controller.

- **Constant Voltage (CV) Mode**: Once the battery reaches 80% SOC, the system switches to CV mode. A separate control loop maintains the battery voltage at a set point (e.g., 435 V) using another PI controller. This ensures safe charging as the battery nears full capacity.
- **Switching Mechanism**: A logic unit compares the SOC value to the 80% threshold. When exceeded, a switch toggles the control path from current to voltage regulation. The switching signal is then fed into a multiplexer that selects whether the **buck** or **boost** converter should operate based on the direction of power flow.

This block is central to mimicking real-world lithium-ion battery charging behavior and provides a foundation for smart battery management integration in future enhancements.

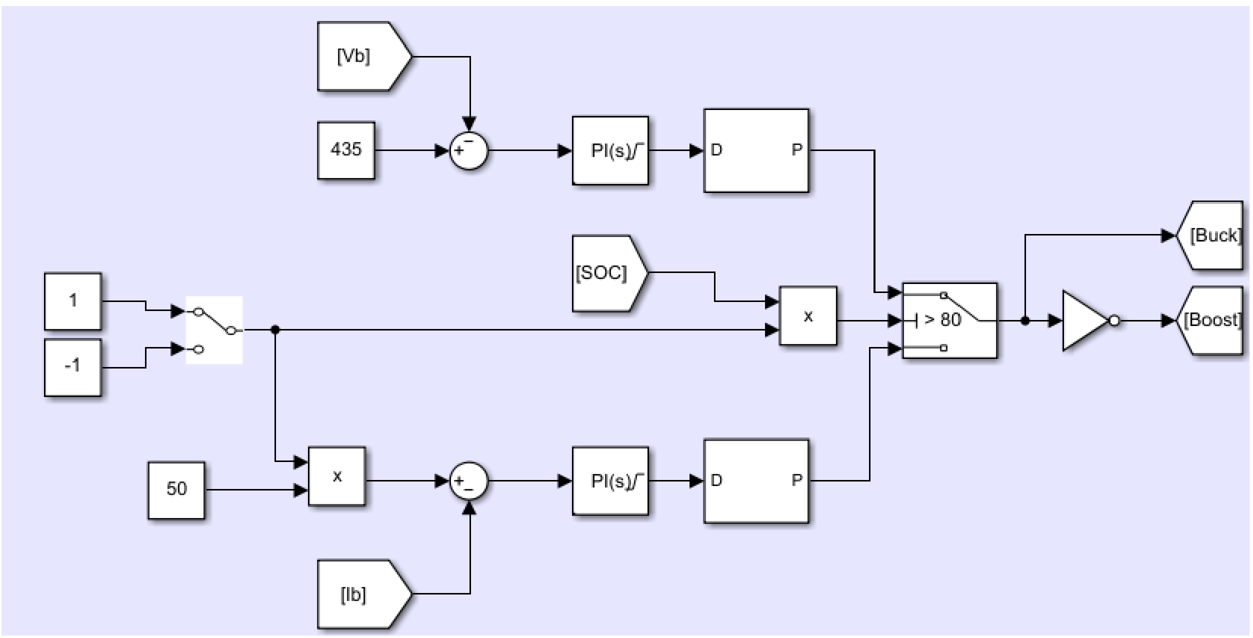


Figure 6 (SOC dependent charging)

5. Simulation Results

This section presents the outcomes of the simulation under nominal conditions and discusses the behavior of each subsystem during the charging process. The simulation was carried out for a total time of 10 seconds with a fixed input AC voltage and an initially partially charged battery.

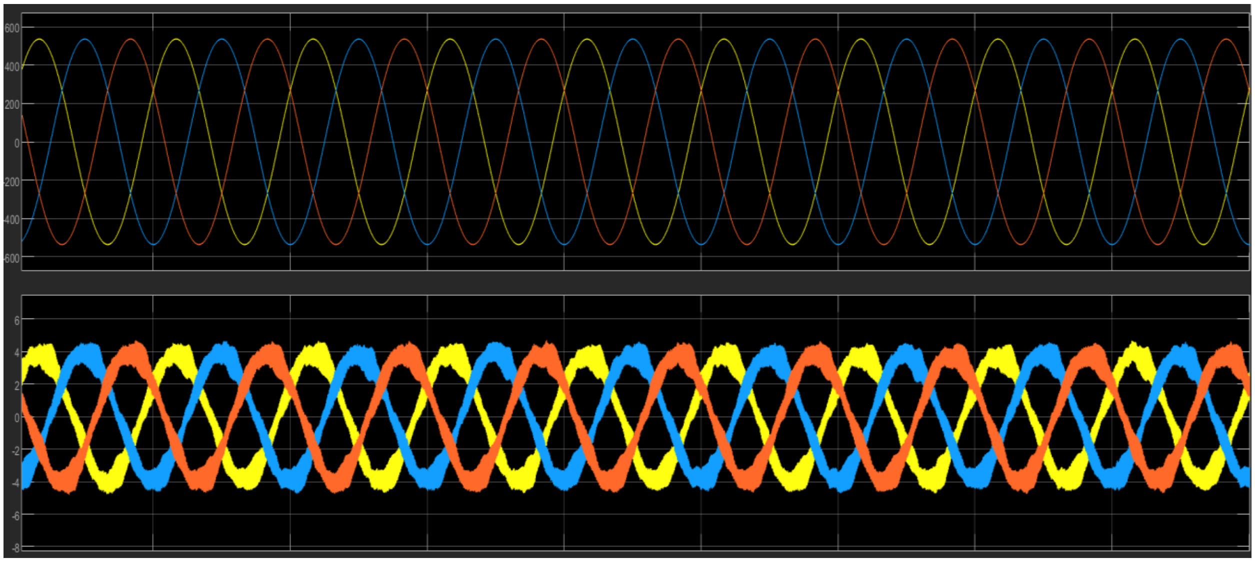


Figure 7(In phase grid voltage & Current)

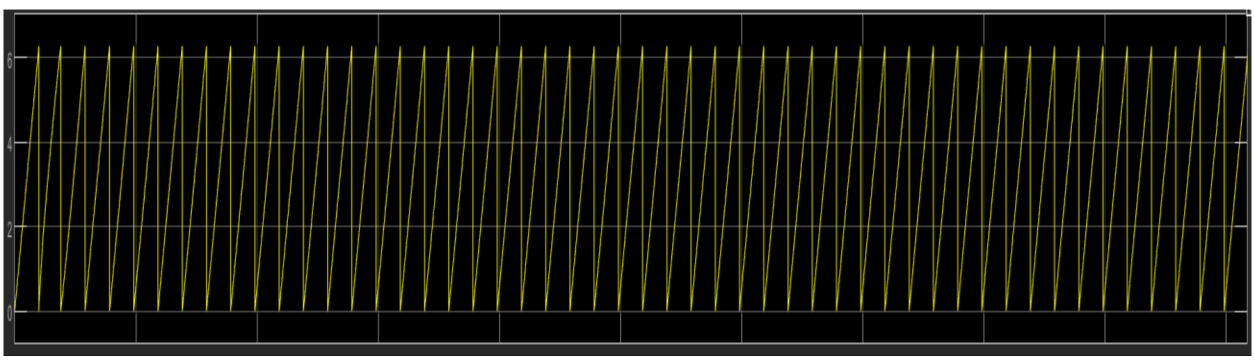


Figure 8(Generated frequency)

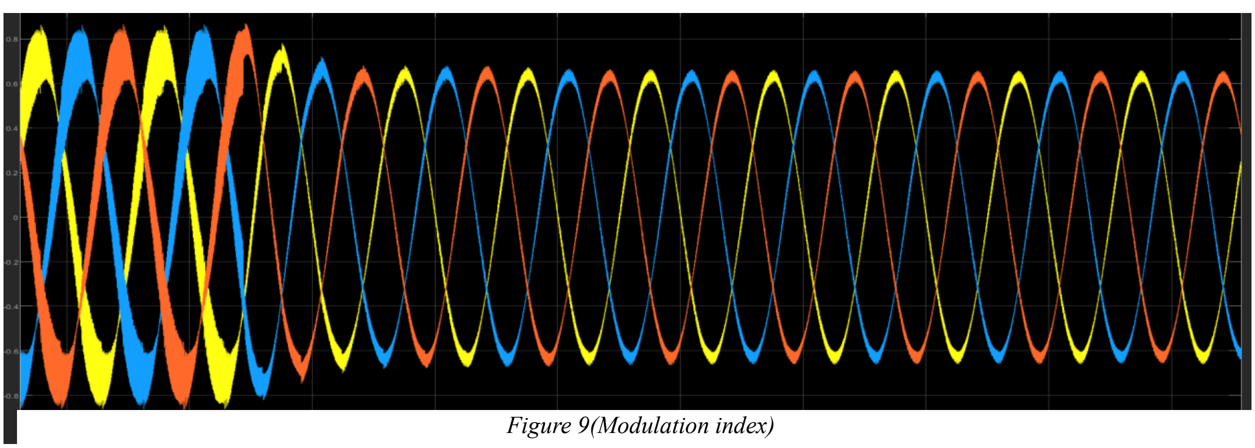


Figure 9(Modulation index)

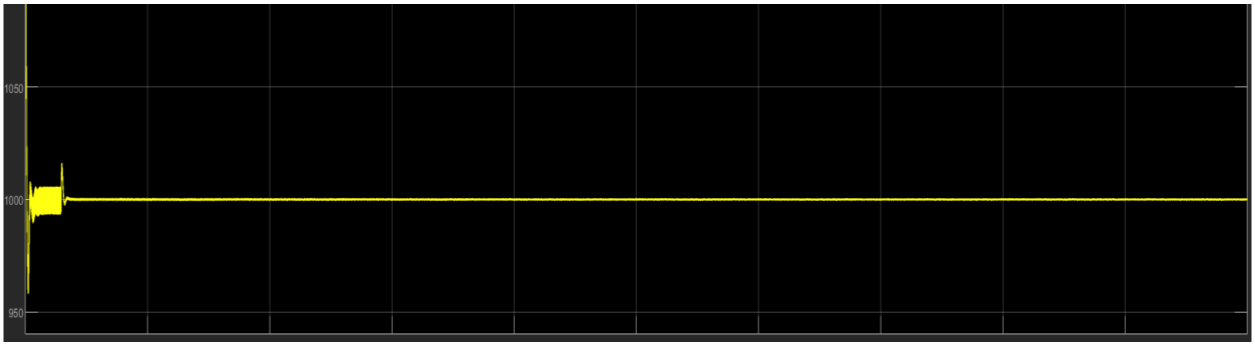


Figure 10(DC-Link Voltage)

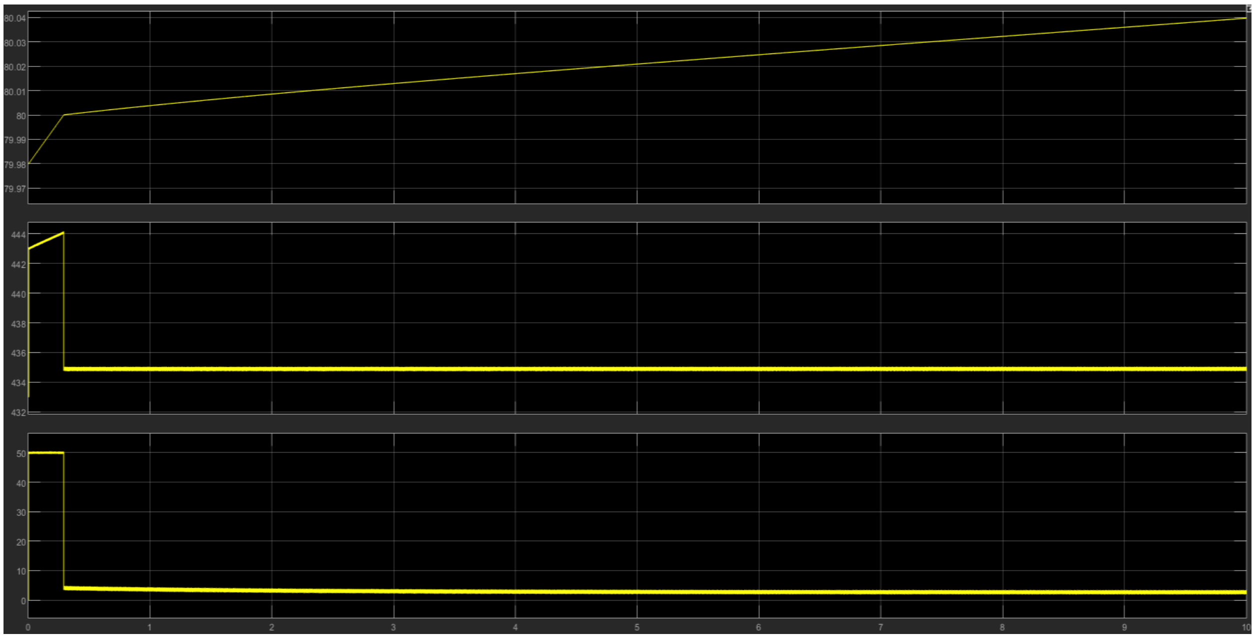


Figure 11(Battery SOC,V & I during charging Modes)

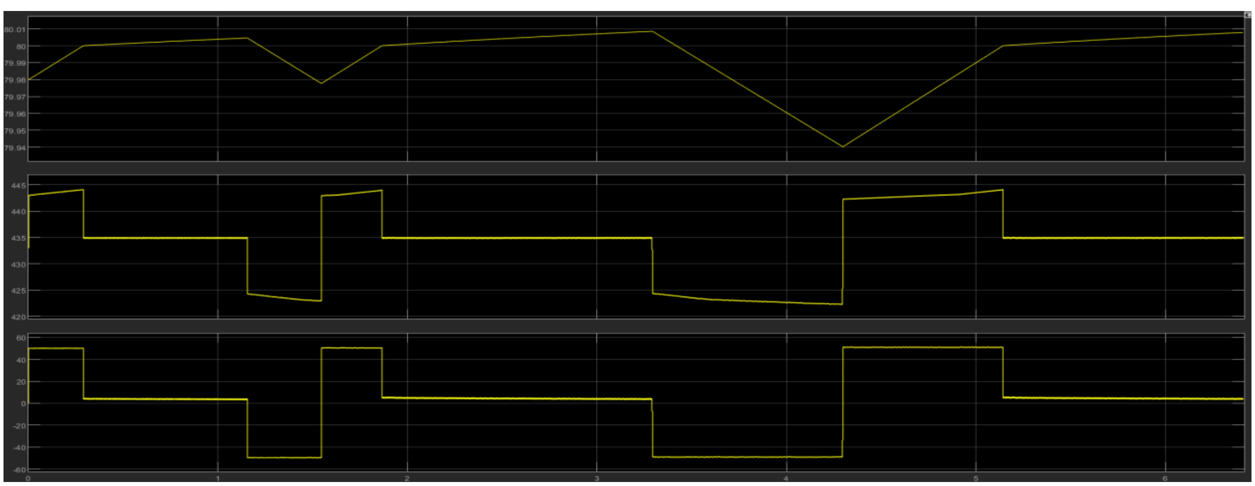


Figure 12(G2V and V2G Switching)

5.1 Parameter Values Used

The simulation model relies on carefully selected electrical parameters and controller gains to ensure accurate behavior of the charging system under both G2V and V2G conditions. The table below summarizes the key component values and PI controller settings used in the system, including inductance, capacitance, voltage/current limits, and tuning constants for each control loop.

Component	Value	Notes
AC Input Voltage	380 V (RMS)	3-phase supply input for grid-connected operation
Line Frequency	50 Hz	Standard frequency for synchronization and PLL tracking
Series Inductor	5 mH	Reduces high-frequency current ripple in the input rectifier stage
DC-Link capacitor	5 mF	Stabilizes DC voltage and filters switching ripple from rectifier output
Buck Inductor (L_buck)	16 mH	Smooths current flow during battery charging and discharging
Battery Nominal Voltage	400 V	Nominal voltage of the simulated lithium-ion battery pack
Battery Capacity	20 Ah	Used for SOC tracking and simulating realistic battery behavior
Max Charging Voltage	435 V	Target terminal voltage during constant voltage (CV) charging
Max Charging Current	50 A	Current limit during constant current (CC) phase
PI Controller – Dc Link	Kp = 2, Ki = 290	Regulates the DC link voltage between the rectifier and Buck-Boost stage
PI Controller – DQ-Axis	Kp = 8, Ki = 405	Controls active and reactive current components in the dq reference frame
PI Controller – Buck(CC-Mode)	Kp = 10, Ki = 0.095	Maintains battery charging current during the CC phase
PI Controller – Buck(CV-Mode)	Kp = 5, Ki = 0.01	Maintains constant terminal voltage during the CV phase