3.3 Kw Level2-On Board Charger Simulink Model

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Contents

1. Abstract

This report presents the design and simulation of a two-level On-Board Charger (OBC) for electric vehicles using MATLAB/Simulink. The model includes three main power stages: an AC-DC conversion stage, a boost converter, and a buck converter, followed by a lithium-ion battery model. In addition, the simulation incorporates a voltage control loop and a Constant Current–Constant Voltage (CC-CV) charging strategy to manage battery charging. Efficiency measurements and state-of-charge (SOC) tracking are implemented to evaluate the system's performance. This work aims to provide a practical understanding of the components and control mechanisms involved in OBC systems for EVs.

2. Introduction

The increasing adoption of electric vehicles (EVs) has created a strong demand for reliable, efficient, and cost-effective charging solutions. Among the key components of an EV's power system is the **On-Board Charger (OBC)**, which enables the vehicle to be charged from a standard AC power outlet by converting AC power to regulated DC power suitable for battery charging. OBCs are essential for user convenience, especially when dedicated DC fast-charging infrastructure is not available.

This report focuses on the modeling and simulation of a **two-level on-board charger system** using MATLAB/Simulink. The two-level converter topology is widely used due to its relative simplicity, effectiveness in low to medium power applications, and ease of control. The OBC model developed in this work consists of three major power conversion stages:

- **AC-DC Conversion**: To rectify and filter the input AC power.
- **Boost Converter**: To step up and stabilize the intermediate DC voltage.
- **Buck Converter**: To manage the charging current and voltage applied to the battery.

To ensure safe and efficient battery charging, the system includes a **Voltage Control Loop** and a **Constant Current–Constant Voltage (CC-CV)** charging method. These strategies regulate the charging process according to the battery's state of charge (SOC) and voltage limits.

The objective of this project is to simulate and analyze the behavior of each subsystem under different operating conditions and evaluate the overall efficiency and effectiveness of the charging process.

3. System Overview

This simulation project models a two-level on-board charger (OBC) for electric vehicles, consisting of a complete power conversion path from an AC wall supply to a regulated DC output for battery charging. The system is divided into functional blocks representing the physical stages of the OBC, allowing modular analysis of each part.

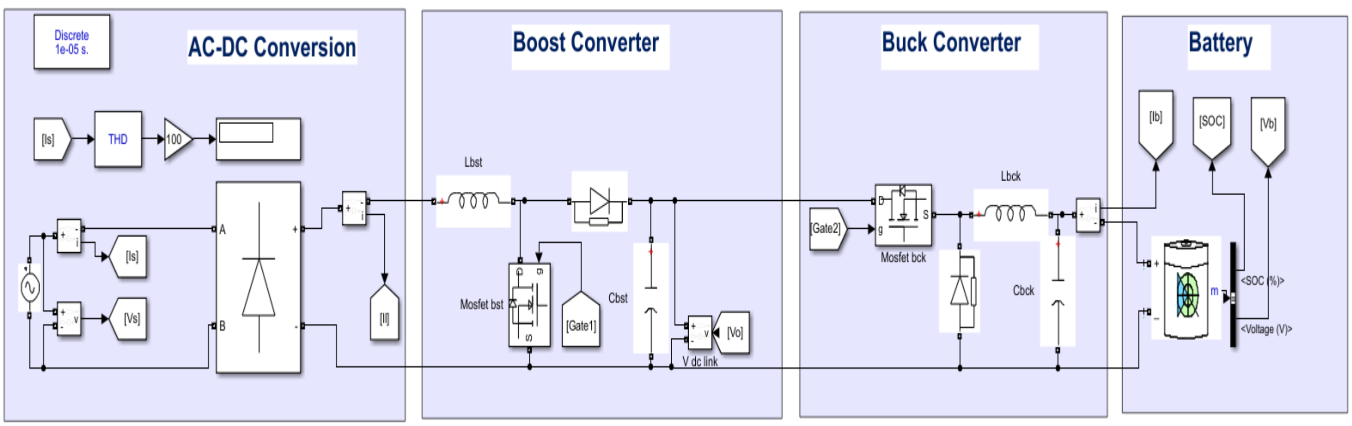

Figure 1(Power circuit)

3.1 AC-DC Conversion

The first stage in the system is the **AC-DC conversion**, which rectifies the input single-phase AC voltage into an unregulated DC voltage. This block includes a diode bridge rectifier and a low-pass LC filter to reduce voltage ripple and harmonics. The output of this stage serves as the input for the boost converter.

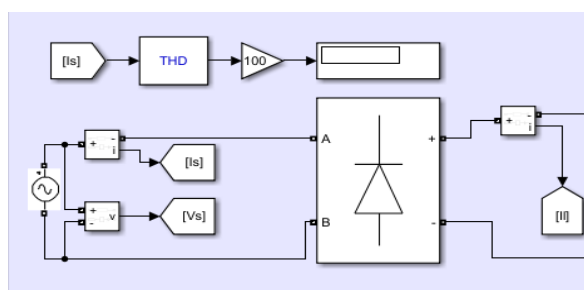

Figure 2(AC-DC Conversion)

Key components:

- Diode bridge
- Series inductor and parallel capacitor (filter)
- THD (Total Harmonic Distortion) monitoring for grid compliance

3.2 Boost Converter

The **Boost Converter** is used to raise the rectified DC voltage to a higher intermediate voltage level, suitable for stable and efficient charging. It consists of a MOSFET switch, boost inductor, and a fast diode. The switching operation is controlled via a PWM signal generated by the voltage control loop.

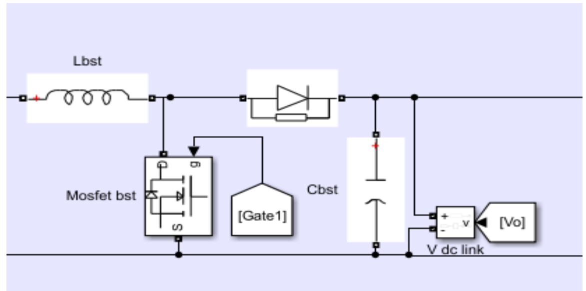

Figure 3(Boost Converter)

Main parameters:

- Boost inductor (L_boost)
- Output capacitor (C_boost)
- PWM-controlled MOSFET gate

This stage stabilizes the intermediate DC voltage and enhances power quality before it is delivered to the next stage.

3.3 Buck Converter

Following the boost converter, the **Buck Converter** steps down the voltage to a level suitable for charging the EV battery. It enables current regulation, particularly during the constant current (CC) phase of charging. The converter consists of another MOSFET switch, a buck inductor, and output filtering.

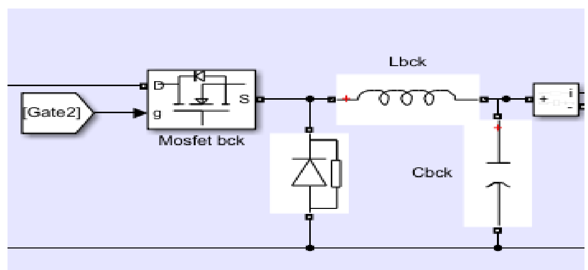

Figure 4(Buck Converter)

Functional highlights:

- Provides fine control over the battery charging current
- Coordinates with the CC-CV charging control strategy
- Controlled via switching signals generated by the control loop

3.4 Battery Model

The battery block simulates the electrical behavior of a lithium-ion battery pack. It includes:

- State of Charge (SOC) monitoring
- Terminal voltage output
- Limits for charging voltage and current

The battery model is dynamic, reacting to charging power and control inputs, and serves as the endpoint of the charger system.

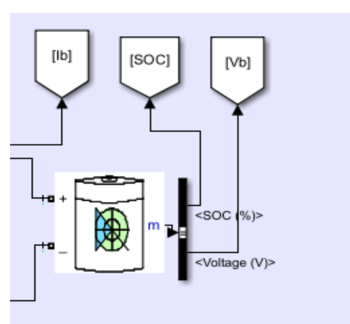

Figure 5(Battery)

4. Control Strategy

The control system of the on-board charger plays a critical role in ensuring stable and efficient power conversion as well as safe battery charging. In this model, two control mechanisms are implemented:

- A **voltage control loop** for regulating the output of the boost converter.
- A **battery charging control strategy** using a Constant Current–Constant Voltage (CC–CV) method to safely charge the lithium-ion battery.

These controllers are implemented using feedback loops and Pulse Width Modulation (PWM) blocks in Simulink.

4.1 Voltage Control Loop

The voltage control loop is used to regulate the output voltage of the boost converter, which serves as the intermediate DC link between the AC supply and the buck converter.

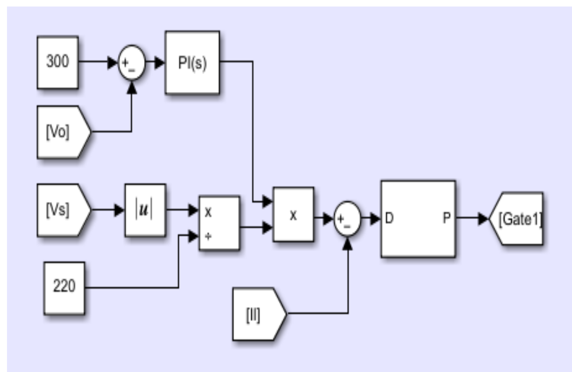

Figure 6(Voltage control loob)

Working Principle:

- The loop measures the output voltage of the boost stage and compares it with a predefined reference voltage (V_ref).
- The error signal is passed through a Proportional-Integral (PI) controller to generate a control signal.
- This control signal adjusts the duty cycle of the PWM that drives the boost converter's MOSFET.

Controller Features:

- Fast response to input voltage fluctuations
- Stabilizes the DC bus voltage under varying load and grid conditions
- Designed to reduce ripple and improve power factor

Set Parameters:

- Boost reference voltage: [Insert value, e.g., 400 V]
- PI controller tuning: [Insert Kp and Ki if known]

3.2 Battery Charging Control (CC–CV Strategy)

To ensure efficient and safe battery charging, the system implements a **Constant Current – Constant Voltage (CC–CV)** charging algorithm through the buck converter stage.

Charging Phases:

- **Constant Current (CC) Phase**:
  When charging begins, the controller maintains a fixed charging current. The voltage across the battery gradually increases.
- **Constant Voltage (CV) Phase**:
  Once the battery voltage reaches its maximum safe threshold, the controller switches to constant voltage mode, reducing the current gradually as the battery approaches full charge.

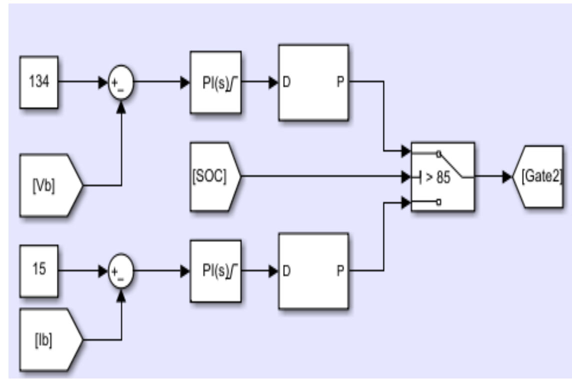

Figure 7(CC-CV Charging)

Implementation in Simulink:

- Battery voltage is continuously monitored and compared with a maximum voltage limit (e.g., 54 V).
- Depending on the battery voltage:
  - If below the limit → current is regulated by a PI loop.
  - If at/above the limit → the voltage is held constant, and current decreases naturally.
- A switch block toggles between CC and CV control logic.

Safety Features:

- Current and voltage limiters prevent overcharging.
- SOC monitoring block is used for logging and future control enhancements.

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.

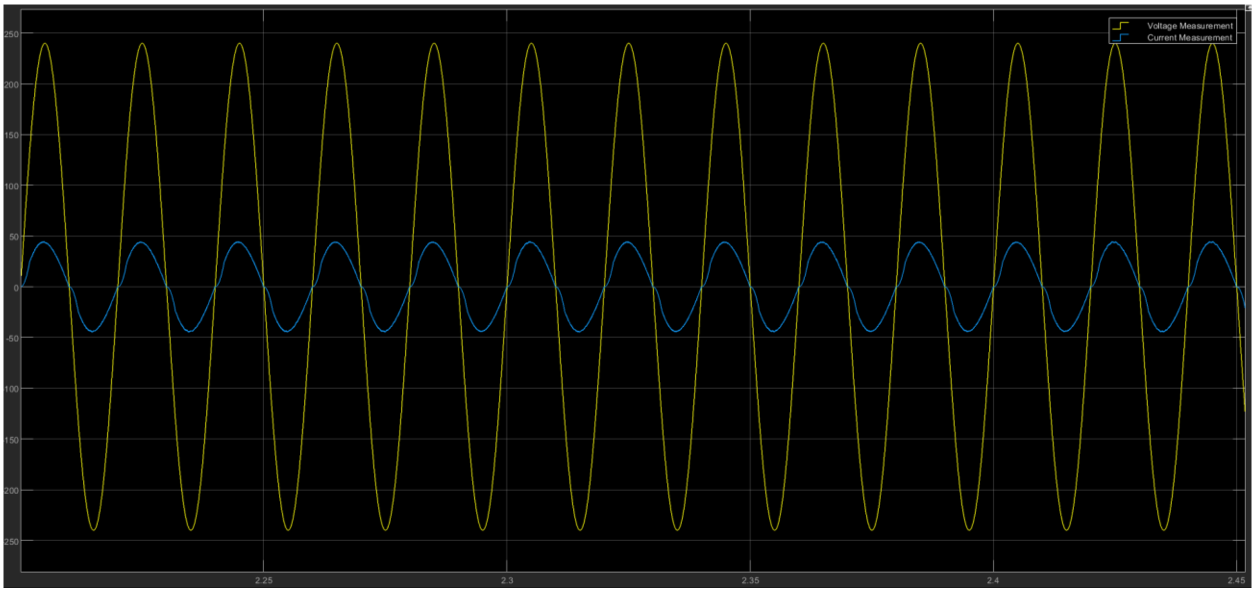

Figure 9(Source Voltage & Current)

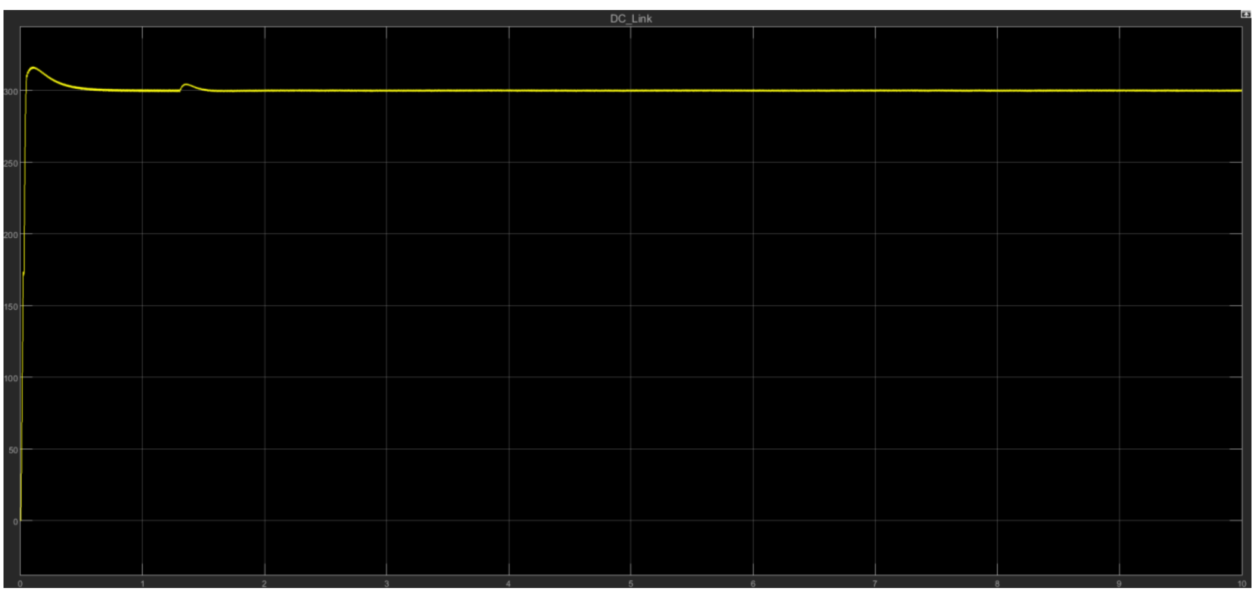

Figure 8(DC Link Voltage)

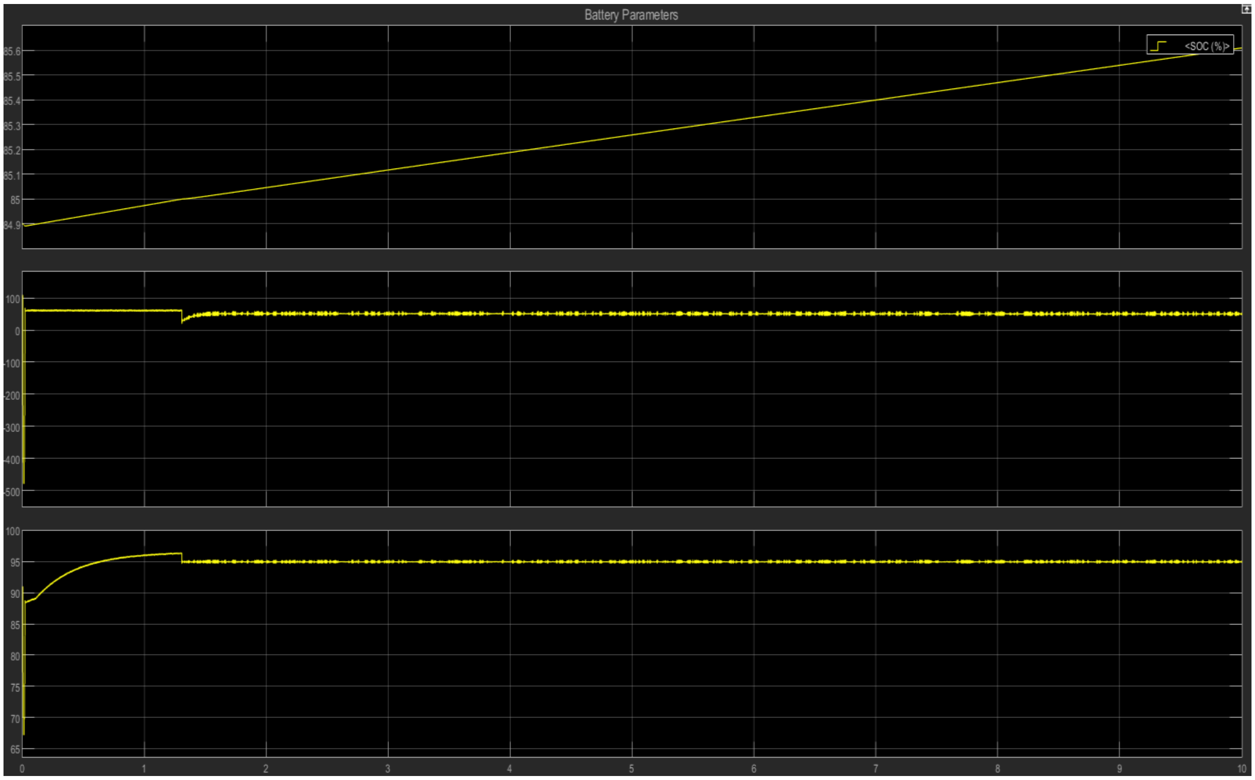

Figure 10(Battey Parameters)

5.1 Parameter Values Used

The following parameters were used in the simulation model:

Component	Value	Notes
AC Input Voltage	240 V (Peak)	Single-phase input
Line Frequency	50 Hz	Standard grid frequency
Boost Inductor (L_boost)	5 mH	Smooths current during voltage step-up
Boost Capacitor (C_boost)	50 mF	Filters high-frequency ripple
Buck Inductor (L_buck)	1 mH	Used for current control during charging
Buck Capacitor (C_buck)	10 mF	Filters output before battery
Battery Rated Voltage	80 V	Lithium-ion pack
Battery Capacity	20 Ah	Simulated using dynamic SOC
Max Charging Voltage	95 V	CV mode threshold
Max Charging Current	60 A	CC mode limit
PI Controller – Voltage loob	Kp = 0.03, Ki = 3	Regulates DC bus voltage
PI Controller – Buck(CC-Mode)	Kp = 5, Ki = 0.01	Regulates battery current during constant current mode
PI Controller – Buck(CV-Mode)	Kp = 10, Ki = 0.095	Regulates battery voltage during constant voltage mode

5.2 Observed Waveforms and Behavior

The simulation results validate the performance of the on-board charger system in regulating power, achieving power factor correction, and safely charging the battery using the CC–CV strategy. The following key behaviors were observed:

a) Supply Voltage and Current (PFC Verification)
The input voltage and current waveforms were monitored to assess the system's power quality and PFC performance:

- The **input current waveform** is nearly sinusoidal and in phase with the **input voltage**, indicating effective power factor correction.
- **Total Harmonic Distortion (THD)** of the input current remains within acceptable limits (typically <5% for good PFC).
- This ensures that the charger draws power from the grid efficiently and with minimal harmonic distortion.

b) DC Link Voltage (Boost Output)
The output of the boost converter, which serves as the intermediate DC voltage, shows:

- A fast rise to the target reference voltage (300 V) after the initial AC-DC rectification.
- Minimal ripple due to effective LC filtering and well-tuned voltage control.
- Stability throughout the charging process, confirming the boost converter's ability to support the buck stage consistently.

c) Battery Charging Behavior and SOC Response

The buck converter regulates the battery charging current and voltage based on the CC–CV control method:

- **Before SOC Limit (CC Mode):**
  - The battery receives a constant charging current (15 A).
  - Battery voltage gradually increases as the SOC rises.
  - This phase continues until the battery SOC reaches the predefined value 85%
- **After SOC Limit (CV Mode):**
  - The system switches to constant voltage mode to maintain the battery terminal voltage at 134.
  - The charging current gradually decreases as the battery reaches full charge.
  - This prevents overcharging and reflects the natural behavior of lithium-ion batteries.

This smooth transition between CC and CV modes ensures battery protection while maintaining charging efficiency.