Non Isolated Charger Design for Electric Vehicles

M.Tech Thesis

by

Abhishek Kumar

CENTRE FOR ELECTRIC VEHICLE AND INTELLIGENT TRANSPORT SYSTEMS

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Non Isolated Charger Design for Electric Vehicles

A THESIS

Submitted in partial fulfillment of the

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Abhishek Kumar

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **Non Isolated Charger Design for Electric Vehicles** in the partial fulfillment of the requirements for the award of the degree of **Master of Technology** and submitted in the **Center for Electric Vehicle and Intelligent Transport System, Indian Institute of Technology Indore,** is an authentic record of my own work carried out during the period from July 2024 to May 2025 under the supervision of Asst.Prof. Prathap Reddy B, Indian Institute of Technology Indore, India.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute.

Abhishek Kumar

Signature of the Student

(Abhishek Kumar)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

B. prathep Reddy 01/06/2025

Signature of Thesis Supervisor with Date

(Asst.Prof. Prathap Reddy B)

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Abhishek Kumar

Dedicated to My Family

ABSTRACT

This thesis presents the design, simulation, and partial hardware implementation of a non-isolated buck converter-based charger for electric vehicle (EV) battery applications. The proposed system is engineered to perform high-efficiency step-down DC-DC conversion from a high-voltage source to a lower battery voltage, ensuring safe and optimized charging.

The initial phase of the project includes the simulation of a dead-band circuit to avoid cross-conduction of switches and a MOSFET gate driver circuit, both verified using LTspice. Following this, an open-loop buck converter was designed using the TL494 PWM controller, with switching frequency analytically derived and passive components such as inductors and capacitors calculated based on ripple constraints. Hardware realization of the converter was also carried out, and results were captured using a digital storage oscilloscope.

Further, a Constant Current Constant Voltage (CCCV) charging strategy was implemented in MATLAB Simulink. This closed-loop system uses PI controllers to regulate both output current and voltage dynamically. The system successfully delivered a regulated current of 90A in CC mode and transitioned seamlessly to CV mode as the battery voltage approached its rated threshold, while monitoring the battery's state-of-charge (SOC).

Simulation and hardware results confirm that the designed system ensures minimal ripple, stable operation, accurate switching transitions, and safe charging behavior, making it suitable for real-world EV charging applications. The overall system provides a strong foundation for further enhancements involving digital control, battery management system integration, and AI-driven predictive charging strategies.

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Acronyms

BMS	Battery Management System
CCCV	Constant Current Constant Voltage
SOC	State Of Charge
EV	Electric Vehicle
IGBT	Insulated Gate Bipolar Transistor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PWM	Pulse Width Modulation
DSO	Digital Storage Oscilloscope
PI	Proportional Integral
Rt	Timing Resistor
Ct	Timing Capacitor
DSP	Digital Signal Processor

Chapter 1

Introduction

1.1 Background

Electric vehicles (EVs) are becoming increasingly popular due to the growing concern over environmental pollution, rising fuel costs, and the push towards sustainable energy solutions. One of the most critical components of an EV ecosystem is the battery charger, which ensures efficient and safe charging of the vehicle's battery. As the demand for faster and more reliable charging increases, charger design must evolve to balance performance, size, cost, and safety.

Chargers can broadly be classified into isolated and non-isolated types. Non-isolated chargers are gaining attention for applications where electrical isolation is not mandatory, especially in low-voltage systems. These chargers are typically more compact, efficient, and cost-effective compared to isolated counterparts. Among non-isolated topologies, the buck converter stands out due to its simplicity and suitability for step-down voltage conversion, which is common in EV battery charging systems.

1.2 Motivation

While many EV charger designs focus on full-fledged digital control systems and complex feedback loops, there is a practical need to explore simple analog and pulse-width modulation (PWM) controller-based designs. In particular, the TL494 PWM controller IC offers an effective and economical solution for implementing controlled power converters such as buck converters.

Additionally, ensuring safe and reliable switching of power MOSFETs is crucial in these circuits. This requires proper design of dead band circuits to avoid short-circuit conditions (shoot-through) and effective gate driver circuits to control the switching elements.

Finally, implementing the Constant Current-Constant Voltage (CCCV) charging method, a widely accepted standard for battery charging, adds another layer of control and efficiency in charger design.

1.3 Objective of the Work

This project focuses on the design, simulation, and evaluation of a non-isolated buck converter-based charger for electric vehicles (EVs), aimed at safe, efficient, and cost-effective charging of lithium-ion batteries. The charger follows a Constant Current–Constant Voltage (CC-CV) profile to enhance battery safety, lifespan, and performance.

An analog control scheme using the TL494 PWM controller is implemented, leveraging its features like dual error amplifiers, internal oscillator, and PWM generation. Theoretical calculations determine parameters such as duty cycle, inductor/capacitor sizing, and switching frequency. Simulations in LTspice validate circuit behavior under various conditions.

Key performance aspects such as current ripple, voltage regulation, dynamic response, and thermal behavior under full load are analyzed. The design ensures stability during the CC–CV transition and robust performance despite changes in supply voltage or battery state-of-charge.

The main objective of this thesis is to design, simulate, and analyze a non-isolated EV charger based on a buck converter topology using the TL494 PWM controller. All circuit designs and simulations are carried out using **LTspice**, a powerful and widely-used circuit simulation tool. The key tasks involved in this project are:

- To design and simulate a **dead band circuit** to prevent simultaneous conduction of power switches.
- To develop a **MOSFET gate driver circuit** and analyze its timing characteristics.
- To design and simulate an **open-loop buck converter** using the **TL494 PWM controller**.
- To implement and simulate a **CCCV-based charging scheme** for better battery protection and charging performance.

1.4 Thesis Organization

This thesis is structured into six chapters:

- **Chapter 1** provides a brief background, motivation, objectives, and the structure of the thesis.

- **Chapter 2** presents a review of the literature related to EV charging technologies, non-isolated converters, TL494 controller applications, and CCCV charging strategies.
- **Chapter 3** discusses the design and simulation of the dead band circuit and MOSFET gate driver using LTspice.
- **Chapter 4** focuses on the implementation of the buck converter with TL494 in open-loop configuration and includes both simulation and practical considerations.
- **Chapter 5** explains the CCCV mode of charging and its simulation using the buck converter setup.
- **Chapter 6** summarizes the results, discusses the conclusions drawn, and suggests possible future work in the area of EV charger design.

Chapter 2

Literature survey

Electric vehicles (EVs) have emerged as a sustainable alternative to traditional internal combustion engine vehicles due to their energy efficiency and environmental benefits. At the core of EV performance lies the battery management and charging system, which dictates operational efficiency, safety, and battery longevity. This chapter provides a comprehensive review of the key components and control strategies in EV chargers, with a particular emphasis on non-isolated charger design using analog control and the TL494 PWM controller. The literature is presented with suggested images that can be incorporated to enhance understanding.

2.1 Overview of Electric Vehicle Charging Systems

Electric vehicles (EVs) represent the future of sustainable transportation. Their widespread adoption requires a supporting infrastructure, one of the most critical components being the battery charging system. The charger directly influences charging time, energy efficiency, and battery life. Depending on factors such as cost, safety, size, and application requirements, different types of chargers are used.

EV chargers are broadly classified into two categories based on electrical isolation:

1. **Isolated Chargers**
2. **Non-Isolated Chargers**

Isolated chargers include galvanic isolation between the input source and the battery using a high-frequency transformer. They offer high safety and are preferred in high-voltage, high-power applications.

On the other hand, non-isolated chargers are structurally simpler, more compact, and cost-effective. However, due to the absence of isolation, additional safety design considerations are needed. These are typically used for onboard charging in low-voltage systems such as electric two-wheelers or bicycles.

2.2 Isolated vs. Non-Isolated Chargers

Both isolated and non-isolated chargers serve different purposes. Table 2.1 presents a comparative analysis.

Table 2.1: Comparison between Isolated and Non-Isolated Chargers

Feature	**Isolated Charger**	**Non-Isolated Charger**
Electrical Isolation	Present (via transformer)	Absent
Safety	High	Lower (requires precautions)
Size and Weight	Large and heavy	Compact and lightweight
Cost	High	Low
Efficiency	Lower (due to transformer losses)	Higher
Applications	Commercial EVs, fast DC chargers	Two/three-wheelers, on-board chargers

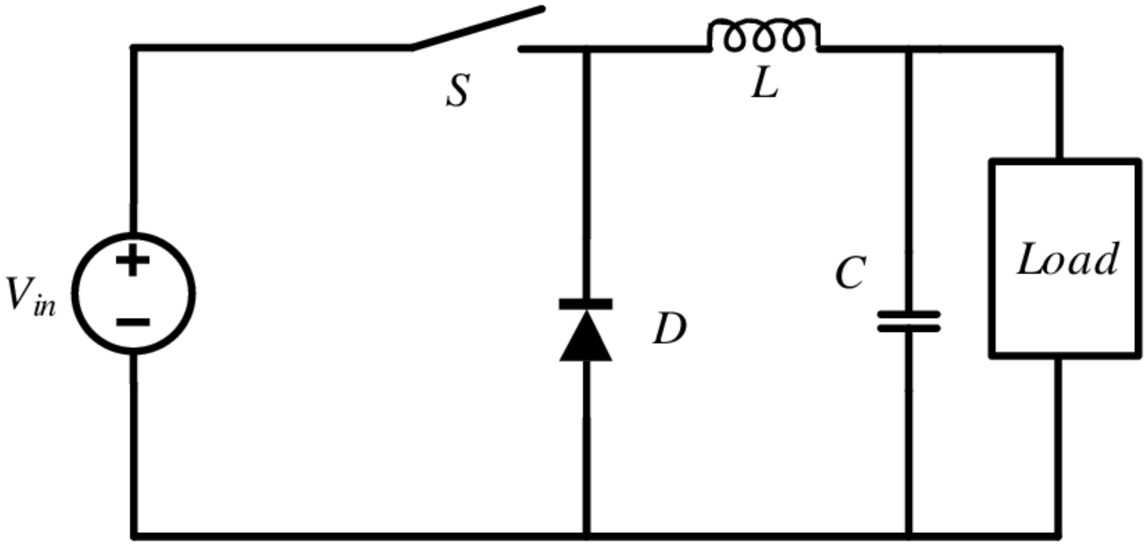

Figure 2.1: DC-DC topology converter [1]

2.3 Buck Converter Topology for EV Charging

A buck converter is a step-down DC-DC converter that reduces a higher DC input voltage to a lower output voltage suitable for battery charging. It consists of a switch (MOSFET), a diode, an inductor, and an output capacitor. The switching operation alternates between energy storage in the inductor and energy transfer to the output load.

The operation is controlled using a pulse-width modulation (PWM) signal to regulate the duty cycle. The buck converter is known for:

- High efficiency
- Simple structure
- Low component count
- Easy integration with analog or digital controllers

In this project, the buck converter topology is selected as it aligns well with the requirements of non-isolated, compact, and efficient EV charging systems.

2.4 TL494 PWM Controller in Power Electronics

The TL494 is a popular analog PWM controller IC used extensively in power electronics. It integrates key functions such as error amplification, dead-time control, oscillation generation, and PWM signal output in one package.

Key Features:

- Dual error amplifiers
- Adjustable dead-time control
- On-chip oscillator (frequency set via external RC)
- PWM comparator
- Dual/single-ended output options

The TL494 works by generating a PWM signal based on the comparison between an internal ramp waveform and the output of the error amplifier. It is capable of maintaining voltage or current regulation based on external feedback. In this work, TL494 is used in open-loop mode to generate a fixed PWM signal.

2.5 Dead Band and Gate Driver Circuit Design

Dead Band Circuit:

High-speed switching circuits must avoid shoot-through conditions, where both high-side and low-side MOSFETs conduct simultaneously. A dead band circuit introduces a small delay (dead time) between turning OFF one device and turning ON the next. This is critical in half-bridge or push-pull configurations.

Gate Driver Circuit:

MOSFETs need precise voltage and current signals at their gate terminals to switch efficiently. Gate driver circuits act as intermediaries between the low-voltage control signals (e.g., from TL494) and the MOSFET gate. They:

- Boost signal voltage to 10–15V
- Supply current to charge/discharge the gate capacitance quickly
- Prevent noise and false triggering

In this work, discrete gate driver circuits are simulated to verify their timing and effectiveness.

2.6 Constant Current-Constant Voltage (CCCV) Charging Technique

The CCCV method is widely used for charging lithium-ion batteries, balancing fast charging with safety and battery life.

- **Constant Current (CC):** The charger supplies a fixed current. Battery voltage gradually increases.
- **Constant Voltage (CV):** Once the voltage limit is reached, the charger maintains constant voltage, and the current gradually tapers off.

This technique ensures:

- Fast charging in the initial stage
- Safe charging and full capacity utilization in the final stage
- Reduced risk of overcharging and thermal runaway

In this thesis, CCCV logic is implemented using control circuits in LTspice.

2.7 Simulation Tool: LTspice

LTspice is a SPICE-based simulation platform developed by Analog Devices. It is widely used in industry and academia for analyzing analog and power electronic circuits.

Advantages:

- Free and lightweight
- Easy to draw and simulate circuits
- Ideal for switching converter simulations
- Offers waveform viewing, transient analysis, and parameter sweeps

All simulations in this project—dead band, gate driver, buck converter with TL494, and CCCV mode—are performed using LTspice.

2.8 Summary

This chapter provided a comprehensive review of the theoretical background necessary for non-isolated charger design. Key topics discussed include:

- EV charger classifications
- Buck converter topology
- PWM control using TL494
- Dead band and gate driver circuits
- CCCV charging methodology
- LTspice as the primary simulation tool

The insights gained from this literature form the basis for the circuit design and simulations presented in the next chapter.

Chapter 3

Dead Band and Gate Driver Circuit Design

3.1 Introduction

Efficient and reliable operation of power electronic converters, such as buck converters used in electric vehicle (EV) chargers, requires precise control of the switching devices—typically MOSFETs. This chapter focuses on the simulation and design of two important sub-circuits: the **dead band circuit** and the **MOSFET gate driver circuit**. These sub-circuits ensure the correct operation of the converter by avoiding simultaneous conduction (shoot-through) and by driving the MOSFET with sufficient voltage and current.

All simulations in this chapter are performed using **LTspice**, a reliable and industry-standard circuit simulation software. The designs are evaluated based on waveform analysis and timing behavior.

3.2 Dead Band Circuit

3.2.1 Purpose of Dead Band

In power electronic circuits that use complementary switches (e.g., push-pull, full-bridge), it is essential to avoid simultaneous conduction. This phenomenon, known as **shoot-through**, can lead to catastrophic failure due to shorting the supply voltage through both MOSFETs. To prevent this, a small delay known as **dead time** or **dead band** is introduced between the OFF time of one switch and the ON time of the other.

3.2.2 Circuit Implementation in LTspice

A dead band circuit was implemented and simulated in LTspice using inverters, resistors, capacitors, and diodes to create two PWM signals with a defined delay between them.

Key Parameters Used:

- Duty Cycle, $D = 0.5$
- Switching Frequency, $f_s = 250\,\text{kHz}$
- Desired Dead Time, $t_d = 15\,\text{ns}$

Component Values:

- $R_1 = R_2 = 1\,\text{k}\Omega$
- $C_1 = C_2 = \frac{t_d}{693} \approx 21.6\,\text{pF}$
- Diodes: 1N4148 (fast switching)
- Inverters: Set with $V_{\text{high}} = 5\,\text{V}$

3.2.3 Dead Time Calculation

The delay is based on the RC charging circuit, given by:

$$t_d = 0.693 \cdot R \cdot C \tag{3.1}$$

Solving for C:

$$C = \frac{t_d}{0.693 \cdot R} \tag{3.2}$$

For $R = 1\,\text{k}\Omega$ and $t_d = 15\,\text{ns}$:

$$C = \frac{15 \times 10^{-9}}{0.693 \cdot 1000} \approx 21.6\,\text{pF} \tag{3.3}$$

This capacitor introduces the required dead band delay.

3.2.4 LTspice Circuit Diagram

Figure 3.1 shows the simulated dead band circuit using LTspice.

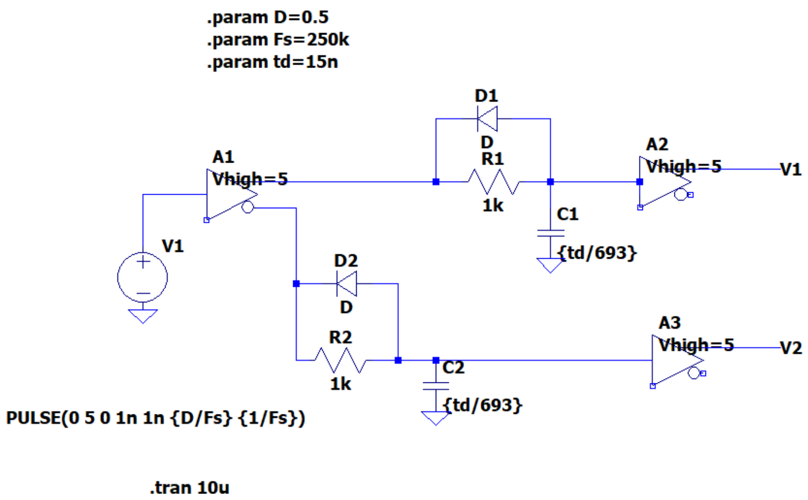

Figure 3.1: Dead Band Circuit Simulated in LTspice

3.2.5 Simulation Results

Figure 3.2 shows the PWM outputs at nodes n003 and n007. The signals alternate with a visible delay (dead time), demonstrating successful dead band generation.

Figure 3.2: LTspice Simulation Waveform Showing Dead Band Delay

3.2.6 Observations

- The dead time introduced is approximately 15 ns as calculated.
- PWM signals are clean and non-overlapping.
- The output signals are safe for driving complementary power MOSFETs.

3.3 MOSFET Gate Driver Circuit

3.3.1 Purpose of Gate Driver

MOSFETs are high-speed switching devices that require proper gate voltage (typically 10–15 V) and adequate gate current to switch ON and OFF efficiently. A logic-level PWM signal (e.g., 0–5 V) is not enough to fully enhance a power MOSFET. A gate driver circuit performs level shifting and supplies the necessary current to overcome the gate capacitance quickly.

Benefits of using a gate driver:

- Faster switching speed (low rise/fall time)

- Reduced switching losses
- Prevention of incomplete or false switching

3.3.2 Circuit Design in LTspice

The gate driver was implemented using a push-pull BJT configuration and simulated in LTspice. The BJT pair acts as a voltage buffer and provides the necessary gate voltage swing (0 V to 15 V) for the power MOSFET.

Circuit Components:

- Q_1: BC547C (NPN), logic level buffer
- Q_2: BC547C (NPN), Q_3: BC557C (PNP), push-pull driver
- M_1: FDMC8462 (N-channel Power MOSFET)
- V_{CC}: 15 V
- $R_1 = 1\,k\Omega$, $R_2 = 12\,k\Omega$
- $R_4 = 0.01\,\Omega$, $R_5 = 20\,\Omega$
- $L_2 = 20\,nH$, D_1: 1N4148

3.3.3 Gate Drive Timing Calculation

Turn-on time is estimated using the formula:

$$t_r = R_g \cdot \frac{Q_g}{V_{GS}} \tag{3.4}$$

Assume:

- $Q_g = 15\,\text{nC}$ (from datasheet)

- $V_{GS} = 15\,\text{V}$
- $R_g = 20\,\Omega$

$$t_r = 20 \cdot \frac{15 \times 10^{-9}}{15} = 20 \times 10^{-9} = 20\,\text{ns} \tag{3.5}$$

This confirms a fast gate transition.

3.3.4 LTspice Gate Driver Circuit

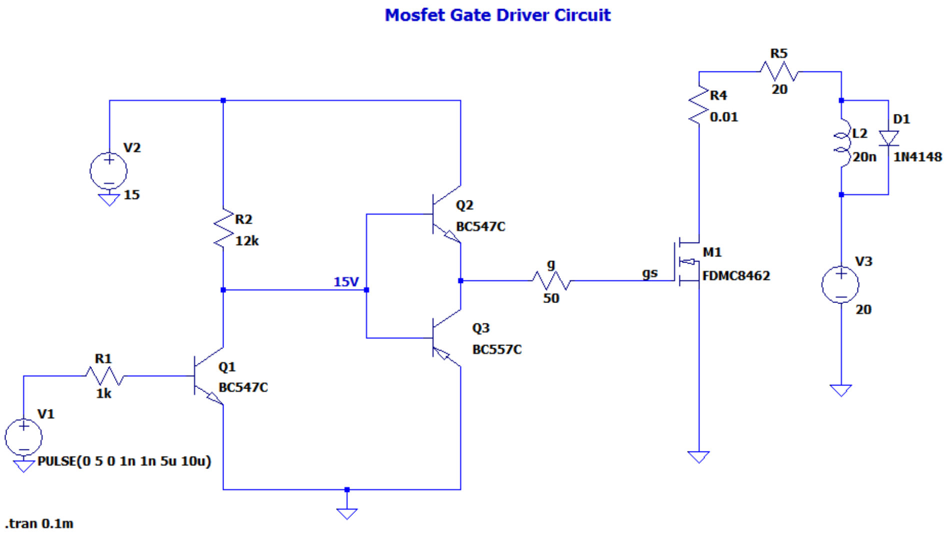

Figure 3.3: MOSFET Gate Driver Circuit Simulated in LTspice

3.3.5 Simulation Result

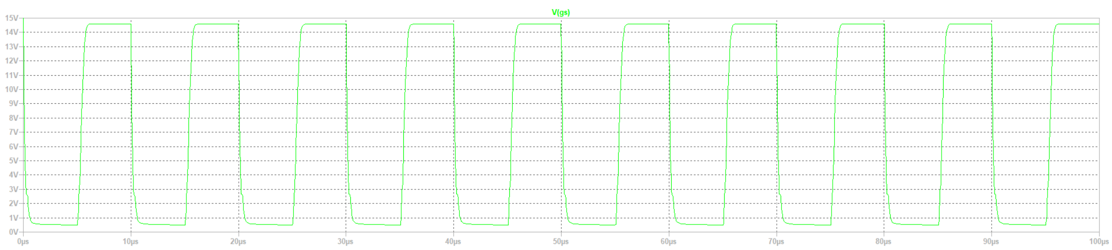

Figure 3.4: Simulation Output Showing V_{GS} of MOSFET

Observations:

- Gate voltage cleanly swings between 0 V and 15 V.
- Rise and fall times are within 20–30 ns.
- No significant overshoot or ringing observed.

3.4 Summary

In this chapter, we designed and validated:

- A dead band circuit using calculated RC delays to prevent shoot-through in switching circuits.
- A gate driver circuit to provide sufficient voltage and current to switch MOSFETs efficiently.

Both circuits were tested in LTspice and confirmed to meet the functional requirements of an EV charger switching system. The next chapter will focus on the design and simulation of the buck converter using the TL494 PWM controller.

Chapter 4

TL494-Based Buck Converter Design, Simulation, and Hardware Implementation

4.1 Introduction

Electric vehicle (EV) battery chargers require efficient, compact, and cost-effective DC-DC converters. One of the most widely used topologies for stepping down voltage is the **buck converter**, known for its simplicity and high efficiency. In this chapter, we design a buck converter in open-loop mode using the **TL494 PWM controller**, simulate it in **LTspice**, and implement it in hardware using discrete components.

4.2 Design Specifications

The buck converter is designed using the parameters in Table 4.1.

Table 4.1: Design Specifications

Parameter	**Value**
Input Voltage (V_{in})	20 V
Output Voltage (V_o)	10 V
Output Power (P_o)	50 W
Load Resistance (R_L)	30 Ω
Output Current (I_o)	5 A (max)
Voltage Ripple (ΔV_o)	0.1 V (1% of V_o)
Inductor Ripple Current (ΔI_L)	0.5 A (10% of I_o)
Switching Frequency (f_s)	100 kHz
Duty Cycle (D)	50%

4.3 TL494 PWM Controller

4.3.1 Overview

The TL494 is a fixed-frequency PWM control IC that integrates all the necessary functions required in a switching regulator. It includes an internal oscillator, two error amplifiers, a dead-time control comparator, output control logic, and an on-chip 5V reference.

4.3.2 Internal Architecture and Features

- Two internal error amplifiers
- A sawtooth oscillator
- PWM comparator
- Dead-time control comparator

- 5V precision reference voltage
- Dual or single-ended output drive

4.3.3 Pin Configuration of TL494

Table 4.2: TL494 Pin Description

Pin No.	Pin Name	Function
1, 2	1IN+, 1IN–	Error amplifier inputs1
3	FEEDBACK	Error amplifier output
4	DTC	Dead-time control
5	CT	Timing capacitor
6	RT	Timing resistor
7	GND	Ground
8	C1	Output PWM signal
9	E1	Emitter output 1
10	E2	Emitter output 2
11	C2	Output PWM signal
12	VCC	Supply Voltage
13	OUTPUT CTRL	Output control
14	REF	5V Reference output
15, 16	2IN-,2IN+	Error amplifier inputs2

4.4 TL494 Switching Frequency Calculation

The switching frequency of the TL494 is determined using the timing resistor (R_t) and capacitor (C_t) as follows:

$$f_s = \frac{1}{R_t \cdot C_t} \tag{4.1}$$

Given:

- $R_t = 100\,k\Omega$
- $C_t = 0.001\,\mu F = 1 \times 10^{-9}\,F$

$$f_s = \frac{1}{100 \times 10^3 \cdot 1 \times 10^{-9}} = 100\,\text{kHz}$$

The calculated switching frequency matches the required value of 100 kHz.

4.5 Inductor Design

$$L = \frac{(V_{\text{in}} - V_o) \cdot D}{\Delta I_L \cdot f_s} = \frac{10 \cdot 0.5}{0.5 \cdot 100000} = 100\,\mu H \tag{4.2}$$

A hand-wound EE core inductor was fabricated with approximately 158.3µH. The value was verified using an LCR meter.

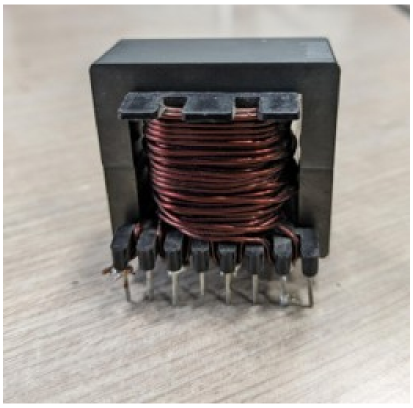

Figure 4.1: Handmade EE Core Inductor

4.5.1 Inductor hardware design calculation

4.6 Output Capacitor Design

$$C = \frac{\Delta I_L}{8 \cdot f_s \cdot \Delta V_o} = \frac{0.5}{8 \cdot 100000 \cdot 0.1} = 6.25\,\mu F \tag{4.3}$$

A 100µF capacitor was used in practice for improved ripple suppression.

4.7 LTspice Simulation and Results

4.7.1 Schematic

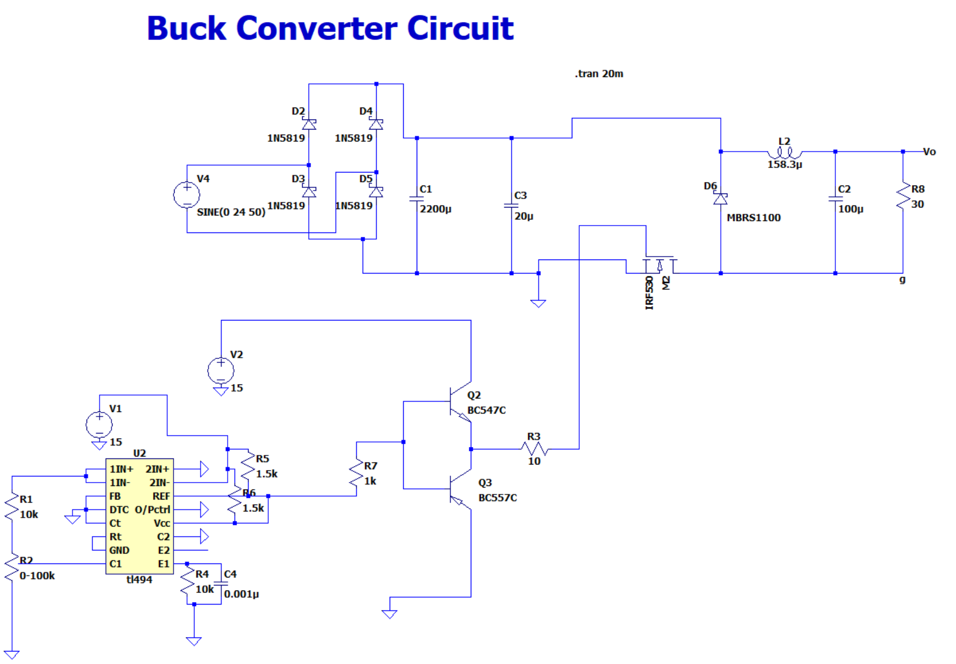

Figure 4.2: LTspice Schematic: Open-Loop Buck Converter with TL494

4.7.2 Simulation Results

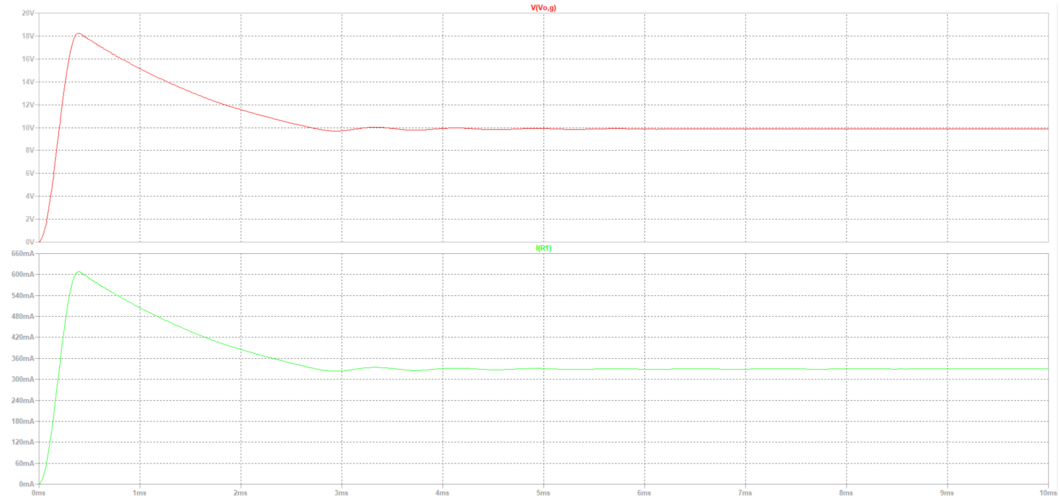

Figure 4.3: Simulated Output Voltage and Load Current

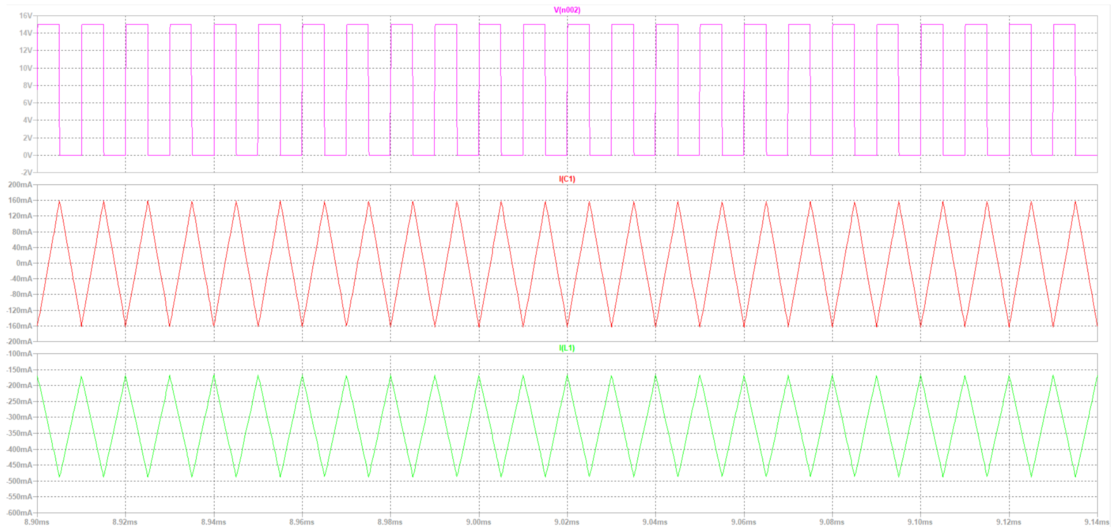

Figure 4.4: PWM, Inductor Current and Capacitor Ripple

Observation: The output voltage stabilizes at 10V with ripple and current within expected limits.

4.8 Hardware Implementation

The buck converter was built on a general-purpose PCB. The TL494 generated the PWM, which was passed to a gate driver and then to the switching MOSFET.

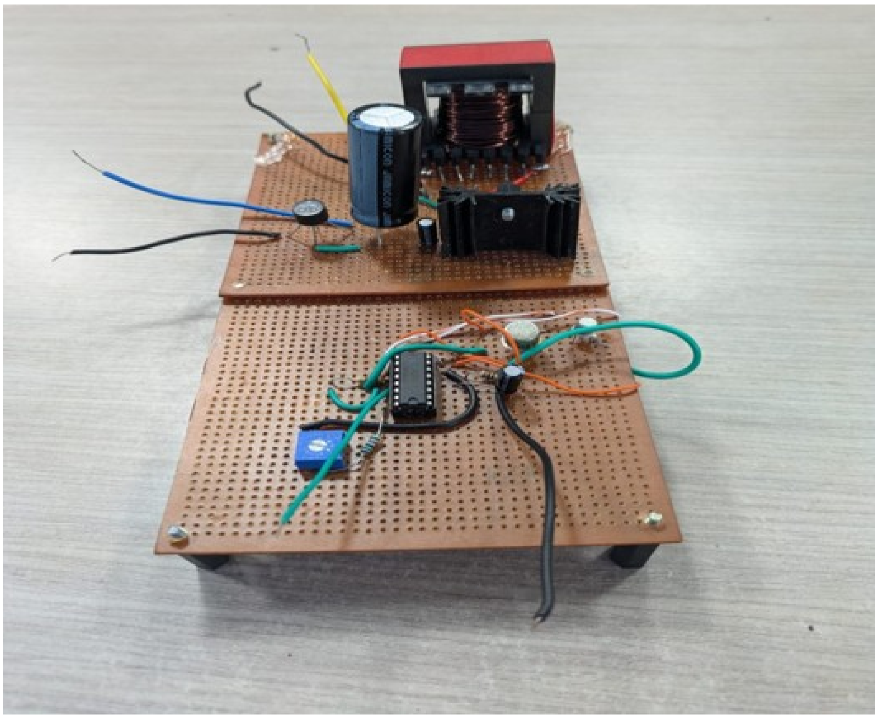

Figure 4.5: Buck Converter Hardware

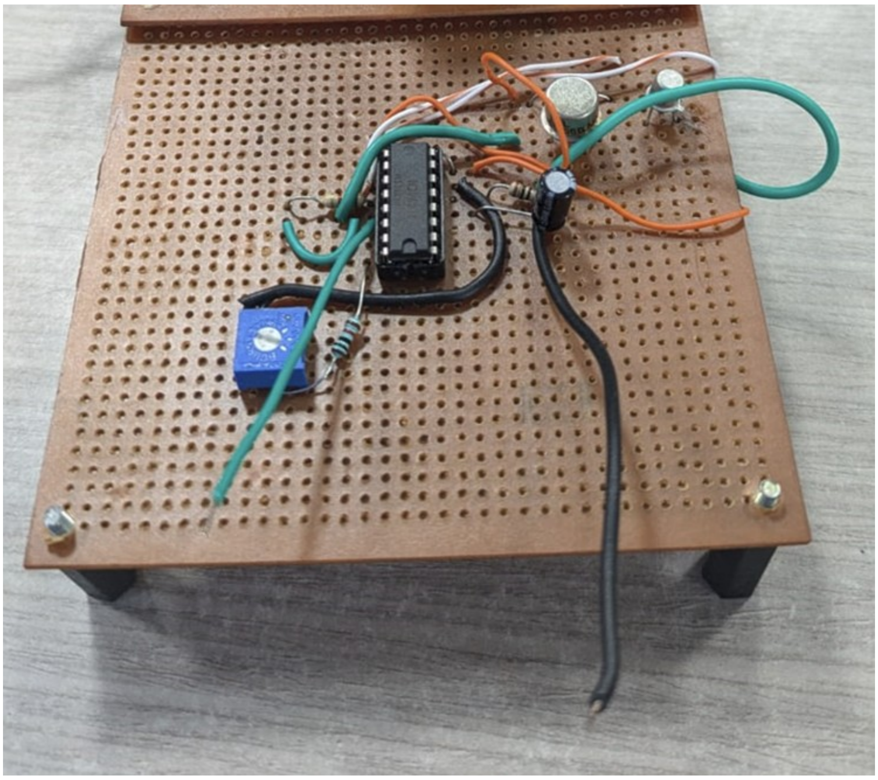

Figure 4.6: Control Circuit Section with TL494

4.9 Working of Open-Loop Buck Converter

- TL494 generates a PWM signal using external R_t and C_t.
- The PWM is fed to a BJT-based push-pull gate driver.
- The MOSFET (IRF530) switches at 100kHz.
- During ON period, energy flows through inductor to load.
- During OFF period, inductor discharges through the freewheeling diode.
- Output capacitor maintains a stable 10V DC at the load.

4.10 Gate Driver Output (DSO)

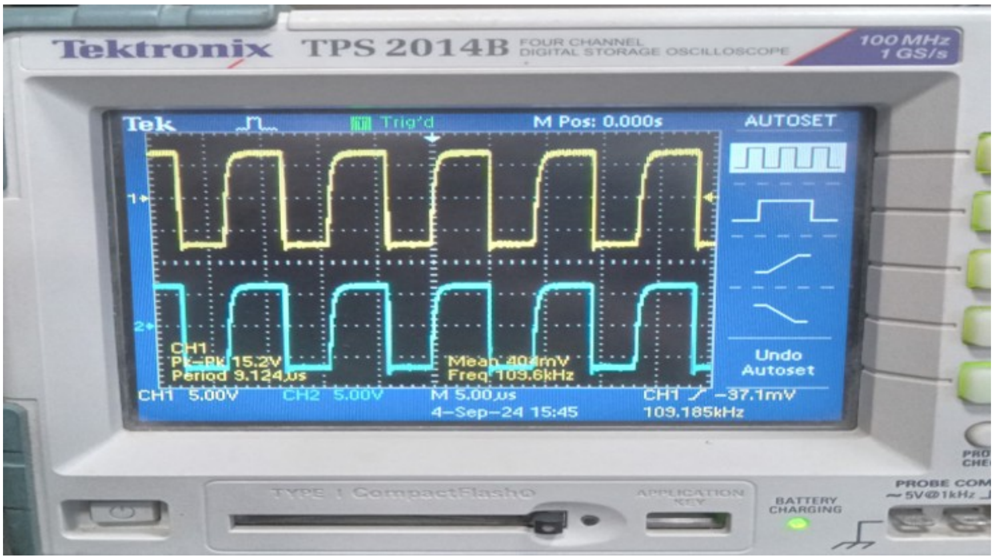

Figure 4.7: Gate Driver Output and PWM from TL494 Captured on DSO

The DSO shows clean switching with a frequency of approximately 109.6 kHz.

4.11 Summary

This chapter presented the complete design and realization of a TL494-based open-loop buck converter. From theoretical design to LTspice simulation and practical hardware testing, every stage was analyzed. The calculated and measured results validate the proper operation of the converter.

Chapter 5

Constant Current Constant Voltage (CCCV) Mode Buck Converter Simulation for EV Battery Charging

Electric vehicle (EV) batteries require an efficient and reliable charging methodology that not only reduces charging time but also enhances battery life and safety. Among the various techniques, the **Constant Current Constant Voltage (CCCV)** charging method is considered one of the most robust and widely used charging strategies for lithium-ion batteries.

The CCCV method operates in two sequential stages:

- **Constant Current (CC) Mode:** The charger supplies a fixed current until the battery terminal voltage reaches the maximum threshold.
- **Constant Voltage (CV) Mode:** Once the voltage threshold is reached, the charger maintains a constant voltage, and the current decreases gradually as the battery reaches full charge.

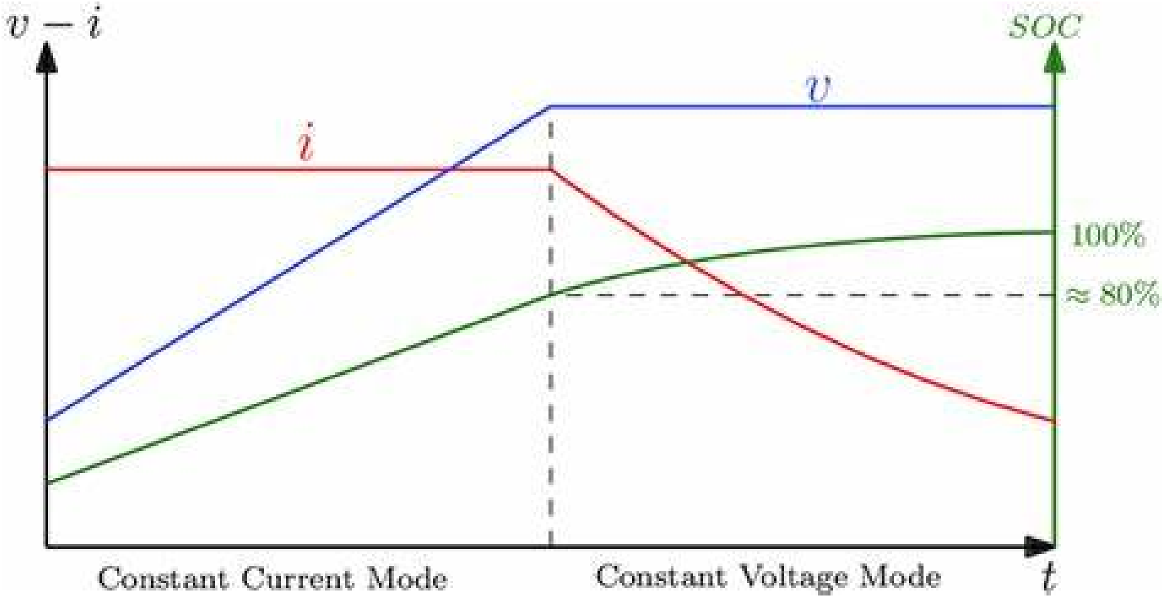

Figure 5.1: CCCV charging profile [2]

This chapter presents the design and simulation of a CCCV-based buck converter using MATLAB Simulink for charging a 72 V, 106 Ah battery from a 400 V DC input. PI controllers regulate both current and voltage while dynamically switching from CC to CV mode based on the battery's State of Charge (SOC).

5.1 Design Specifications

The system is designed using the specifications shown in Table 5.1.

Table 5.1: CCCV Buck Converter Design Specifications

Parameter	**Value**
Input Voltage (V_{dc})	400 V
Output Voltage (V_o)	72 V
Battery Capacity	106 Ah
Charging Current	90 A
Current Ripple (ΔI)	0.2 A
Voltage Ripple (ΔV)	0.01 V
Switching Frequency (f_s)	65 kHz
Inductor (L)	5 mH
Output Capacitor (C)	20 mF

5.2 CCCV Controller Design

5.2.1 Constant Current Mode

During this mode:

- The PI controller maintains the current at 90 A.
- Battery voltage gradually increases.
- The mode continues until the voltage reaches its upper limit (near 79.3 V).

5.2.2 Constant Voltage Mode

Once the terminal voltage reaches the reference:

- The controller maintains a fixed voltage (near 79.3 V).
- The battery charging current decreases gradually.
- This ensures the battery is not overcharged.

5.2.3 Mode Switching Logic

The system continuously monitors the battery SOC. A comparator logic determines the active controller:

- If SOC $< 60\%$, the constant current controller remains active.
- If SOC $\geq 60\%$, the system switches to the constant voltage controller.

5.3 Simulink Model

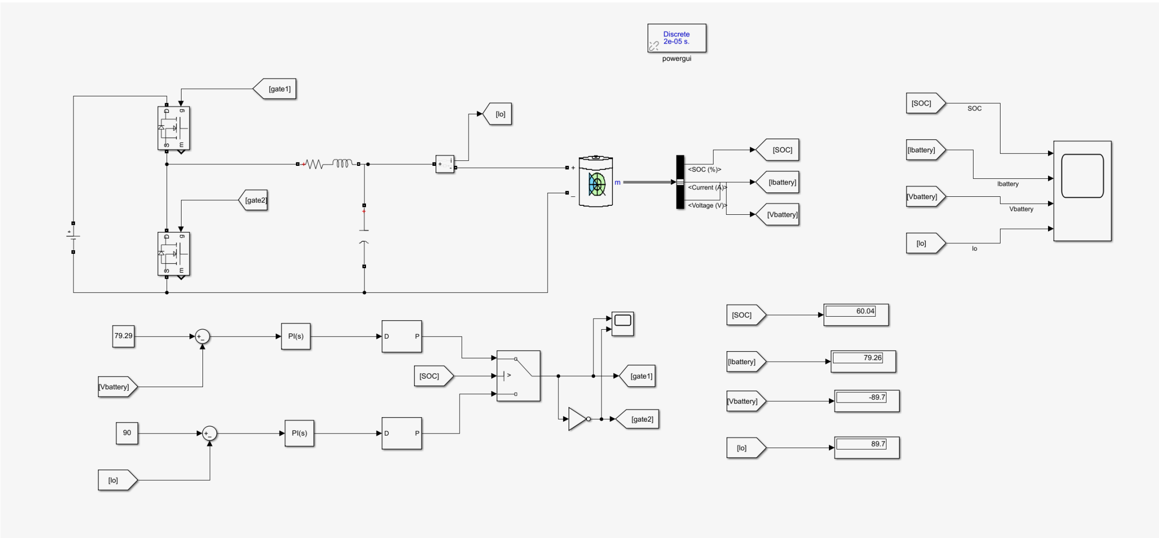

Figure 5.2: Simulink Model of CCCV-Controlled Buck Converter

The model includes:

- Two IGBTs forming a buck converter topology.
- An LC filter (5 mH inductor and 20 mF capacitor).
- Battery block from Simscape providing SOC, voltage, and current outputs.
- Two PI controllers for current and voltage regulation.
- Logic switch to alternate between CC and CV modes.

5.4 Design Calculations

5.4.1 Inductor Calculation

Using the ripple current method:

$$L = \frac{(V_{in} - V_o) \cdot D}{\Delta I \cdot f_s}$$

Where,

- $V_{in} = 400\,V$, $V_o = 72\,V$
- $D = \frac{72}{400} = 0.18$
- $\Delta I = 0.2\,A$, $f_s = 65 \times 10^3$

$$L = \frac{(400 - 72) \cdot 0.18}{0.2 \cdot 65000} \approx 4.54\,\text{mH}$$

Selected: 5 mH

5.4.2 Capacitor Calculation

$$C = \frac{\Delta I}{8 \cdot f_s \cdot \Delta V} = \frac{0.2}{8 \cdot 65000 \cdot 0.01} = 3.84\,\text{mF}$$

Selected: 20 mF for better filtering.

5.5 Simulation Results

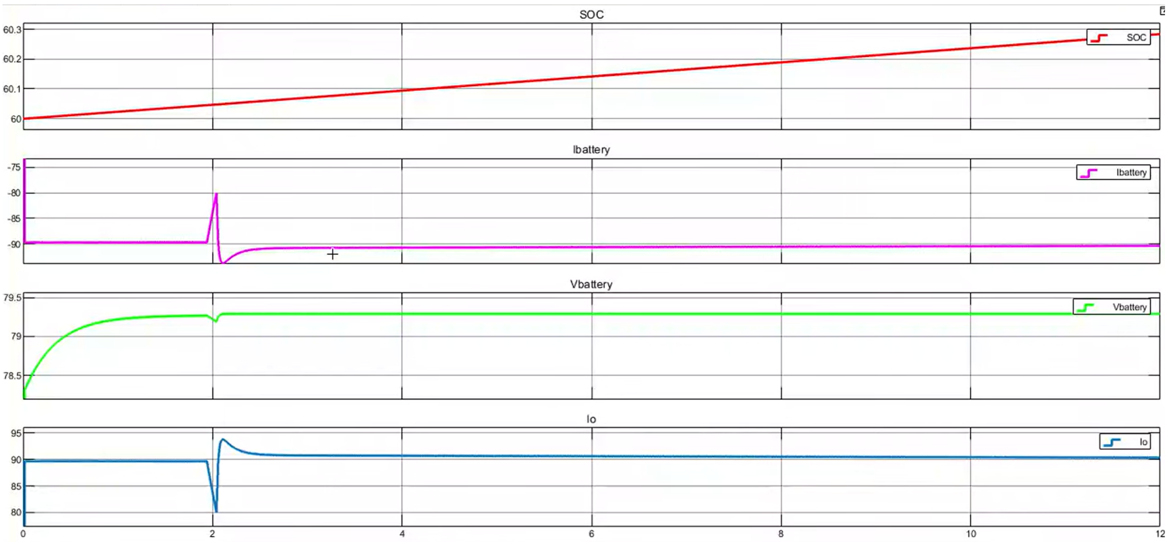

Figure 5.3: Simulation Results: SOC, $I_{battery}$, $V_{battery}$, and Output Current I_o

5.5.1 State of Charge (SOC)

- SOC starts from 60%.
- Gradually increases to 60.04% during simulation.
- The linear rise indicates accurate and constant energy delivery during CC mode.

5.5.2 Battery Current ($I_{battery}$)

- Held constant at 90 A during CC mode.
- Around 2 seconds, a dip appears, indicating mode shift from CC to CV.
- Current then starts reducing gradually.

5.5.3 Battery Voltage ($V_{battery}$)

- Starts at 78.5 V and rises smoothly to 79.3 V.

- Voltage remains constant after transition to CV mode.
- Slight dip during the switch is corrected by the PI controller.

5.5.4 Output Current (I_o)

- Mirrors $I_{battery}$ as load is in series.
- Constant in CC mode, then decreases after CV control becomes active.
- Shows stable, ripple-free response due to filtering.

5.6 Conclusion

This chapter presented a MATLAB Simulink-based design and simulation of a CCCV-controlled buck converter for charging a 72 V, 106 Ah EV battery using a 400 V DC supply. The system incorporates PI controllers and logic-based mode switching using SOC.

- Accurate constant current control is achieved up to the voltage threshold.
- Smooth transition to constant voltage mode ensures battery safety.
- SOC increases as expected, confirming effective charging.
- Voltage and current ripples are minimized using appropriate passive components.

The system demonstrates a reliable and safe CCCV charging approach for electric vehicle batteries.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

The growing demand for electric vehicles (EVs) necessitates the development of compact, efficient, and cost-effective charging solutions. This thesis presented the design, simulation, and partial hardware implementation of a **non-isolated buck converter-based charger** for EV applications, addressing both constant current (CC) and constant voltage (CV) charging requirements.

The project was divided into key milestones, each achieved systematically:

- **Design and Simulation of Supporting Circuits:** A dead-band circuit was simulated to prevent simultaneous conduction of switching devices, enhancing system protection and efficiency. A discrete MOSFET gate driver circuit was also designed and validated through LTspice simulations, demonstrating clean and sharp transitions.

- **TL494-Based Buck Converter:** An open-loop buck converter was developed using the TL494 PWM controller. The switching frequency was analytically determined, and both simulation and hardware were successfully implemented.

Passive component design, including a handmade EE core inductor, confirmed theoretical design expectations.

- **CCCV Mode Simulation in MATLAB Simulink:** A closed-loop CCCV-based buck converter model was developed using Simulink. PI controllers regulated both current and voltage, with logic-based mode switching based on SOC feedback. Simulation results showed that the converter delivered a constant 90 A current during CC mode and smoothly transitioned to CV mode while maintaining a fixed output voltage.

The proposed system demonstrated:

- Efficient down-conversion from 400 V to 72 V
- Stable transitions between CC and CV modes
- Minimal output ripple using appropriately selected filter components
- Accurate PI-based control loop behavior

In conclusion, the proposed charger design is reliable, scalable, and well-suited for EV battery charging applications.

6.2 Future Work

While the developed system successfully meets the primary objectives, several extensions can be pursued to enhance the design's robustness, flexibility, and applicability in practical environments:

1. **Closed-Loop TL494 Control:** Incorporating voltage and current feedback into the TL494-based buck converter would enable real-time duty cycle modulation, improving dynamic performance and load handling.

2. **Hardware Realization of CCCV Controller:** Future work can involve implementing the CCCV model in hardware using microcontrollers or digital signal processors (DSPs), enabling real-time control and validation.

3. **BMS Integration:** Integrating the buck converter with a Battery Management System (BMS) would allow dynamic adjustments based on real-time battery temperature, SOC, and internal resistance, ensuring safer operation.

4. **Digital PWM Implementation:** Replacing the analog TL494 with modern microcontrollers such as STM32, TI C2000, or PIC32 would offer advanced features such as fault tolerance, real-time tuning, and adaptive control algorithms.

5. **Multi-Phase Converter Design:** Interleaved buck converters or dual-stage designs can be considered for higher power levels, reducing component stress and enhancing thermal performance.

6. **AI-Based Predictive Charging:** Future systems may employ machine learning models like LSTM or reinforcement learning to forecast user behavior and battery degradation, enabling optimized charging profiles.

6.3 Final Remarks

This work successfully demonstrates the potential of a non-isolated buck converter-based charging architecture for electric vehicle batteries. The modeling, simulation, and hardware results validate the design's efficacy. With future developments focused on digital control, BMS integration, and intelligent predictive strategies, the proposed system can evolve into a fully functional, real-time EV charger.

Such advancements are vital for promoting sustainable transport solutions and aligning with national and global clean energy goals.

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