Implimentation of EV Charge and Drive System Using GaN Device

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***Abstract*—This project focuses on voltage regulation of a Gallium Nitride (GaN)-based buck converter tailored for electric vehicle (EV) applications. GaN devices, due to their superior switching capabilities and lower conduction losses, have emerged as an ideal solution to improve the efficiency and power density in EV converters. The current system for EVs, mainly based on Silicon (Si) technology, suffers from lower switching frequencies and larger passive components, reducing efficiency. This project aims to address these limitations using a GaN-based buck converter, with a particular emphasis on maintaining stable voltage output under various load conditions.**

Keywords—Analysis, investigation, research, GaN, Electric Vehicle, Buck Converter

I. INTRODUCTION

The world transitions to cleaner and more sustainable energy systems, electric vehicles (EVs) have taken center stage as a viable solution for curbing greenhouse gas emissions and reducing dependence on fossil fuels. Despite their increasing popularity, EVs still face several technological challenges, particularly in the domain of power electronics and charging systems. Efficient, compact, and scalable charging architectures are essential to meet the growing demand for high-performance EVs, and the role of power semiconductor technology is critical in this context.

Traditional EV power systems rely heavily on silicon (Si) devices for power conversion and control. While silicon-based electronics have served the power industry for decades, they face significant limitations in modern high-power, high- frequency applications. These include increased conduction and switching losses, larger heat sinks, limited switching frequencies, and substantial system volume and weight. As a result, they fall short of fulfilling the requirements of next- generation EV infrastructure, which demands higher energy efficiency, faster charging speeds, and compactness without compromising thermal and operational stability.

A. Problem Statement

The core challenge addressed in this project is the inefficiency and bulkiness of traditional silicon-based EV chargers. These systems are often plagued by high switching losses, large passive components, and inadequate thermal management. Additionally, their limited switching frequency restricts the scalability and compactness required for modern onboard and fast-charging systems. Another critical issue is the need for intelligent control strategies that ensure accurate battery management, prevent overcharging or deep discharging, and extend battery lifespan. Existing charging systems often lack dynamic control, resulting in energy inefficiencies and reduced battery performance over time.

B. OBJECTIVES

The design a GaN-based buck converter for EV charging systems.

I. To simulate and validate the proposed system using MATLAB Simulink.
II. To evaluate the efficiency, thermal performance, and size reduction achieved through GaN devices.
III. To implement a PID-based control mechanism for monitoring SOC, voltage, and current in real time.
IV. To explore the scalability and feasibility of GaN technology in large-scale EV infrastructure deployment.

II. LITERATURE REVIEW

A. OVERVIEW

The evolution of electric vehicles (EVs) has been intrinsically tied to advances in power electronics, particularly in the development of efficient and compact charging systems. Traditional silicon (Si)-

based semiconductors, while long- standing in power applications, are rapidly being replaced or supplemented by wide-bandgap (WBG) materials such as Gallium Nitride (GaN). GaN technology offers numerous advantages, including higher breakdown voltage, better thermal conductivity, and faster switching capabilities, making it well-suited for EV charging systems that demand high power density and energy efficiency. This chapter reviews existing literature focusing on GaN-based power converters, specifically within the domain of EV charging. The review spans system-level design considerations, efficiency optimization, control strategies, and thermal management improvements brought by GaN devices.

B. TRENDS IN EV CHARGING TECHNOLOGY

Recent advancements in high-power onboard chargers (OBCs) emphasize the growing trend toward integrating GaN devices in EV systems. Khaligh and D'Antonio (2019) analyzed global trends in EV charging, identifying the shift towards high-frequency, high-efficiency converters to meet the fast-charging needs of modern EVs. The study highlighted how GaN devices could surpass traditional Si in enabling compact, high-power density designs while maintaining thermal reliability. Another significant contribution by Mei et al. (2021) demonstrated a two-stage OBC entirely built on GaN components, with superior efficiency and reduced size. Their work showed a marked decrease in passive component requirements and better heat dissipation due to GaN’s low switching losses and high thermal limits.

C. GaN IN GRID-INTEGRATED APPLICATIONS

The integration of EV chargers into smart grid infrastructure necessitates bidirectional power flow and communication capabilities. Kong and Li (2019) explored the use of GaN-based converters in vehicle-to-grid (V2G) applications. They developed a GaN bidirectional converter capable of handling grid interactions without compromising efficiency. Their work highlighted the role of GaN in enabling flexible, grid-responsive charging systems that could support renewable energy integration and demand-side management. Meng and Wang (2018) extended this analysis to wireless charging systems. They demonstrated how GaN’s high- frequency operation makes it particularly suited for resonant converters used in inductive wireless charging platforms.

III. SYSTEM ANALYSIS AND DESIGN

A well-designed power conversion system is critical to the success of any electric vehicle (EV) charging infrastructure. In this project, the system is centered around a GaN-based buck converter, chosen for its ability to deliver high switching frequencies, compact form factor, and superior energy efficiency. The system design considers electrical, thermal, and control perspectives, ensuring optimal performance for EV battery charging applications. The architecture is built around core components including a DC-DC converter, real- time control unit, gate driver, and a battery management system (BMS), all integrated within a feedback-controlled loop.

A. BUCK CONVERTER DESIGN PARAMETERS

The converter should be designed to meet the following specifications:

- Input Voltage (Vin): 36 V DC
- Output Voltage (Vout): 24 V DC
- Power Output: 100 W
- Switching Frequency: 50 kHz
- Output Current: ~4.16 A
- Duty Cycle (D): ≈ 67.5% Using standard formulas:

Inductor Ripple Current (ΔIL):
$\Delta IL = 0.4 \times Iout = 0.4 \times 4.16 = 1.66$ A
Inductor Value (L):
$L = \Delta IL \times fVin \times (1-D) = 1.66 \times 5000036 \times (1-0.675) \approx 48.6$ μH
Capacitor Values: Series Capacitor (CS):
$CS = Vripple \times fIout \times D \approx 50\mu F$

Output Capacitor (Cout):
$Cout = 0.5 \times Vripple \times fIout \times D \approx 234\mu F$
These values are selected to balance performance and size while minimizing ripple voltage and electromagnetic interference (EMI).

B. CONTROL STRATEGY

The controller plays a crucial role in maintaining system stability and performance. A PID (Proportional-Integral- Derivative) control algorithm is used to adjust the duty cycle of the PWM signal applied to the GaN switch. The control logic is executed in real-time, using battery parameter feedback such as:

- Voltage
- Current

- State-of-Charge (SOC) The PID controller ensures:
- Accurate tracking of reference current and voltage.
- Compensation for transient loads.
- Stable charging current profile, avoiding overcurrent or undervoltage conditions.

C. BLOCK DIAGRAM OVERVIEW

The system block diagram includes the following elements:

- DC Input Source – Supplies power to the converter.
- GaN-Based Buck Converter – Performs voltage conversion using the IGOT60R042D1.
- Controller (Microcontroller or DSP) – Runs PID logic and PWM generation.
- Gate Driver – Interfaces between controller and GaN switch.
- Battery Pack – Final load with integrated SOC and voltage monitoring.
- Feedback Loop – Provides real-time data to the controller for dynamic regulation. Feedback from the battery, particularly SOC and output current, is critical for regulating charging cycles and maintaining battery health.

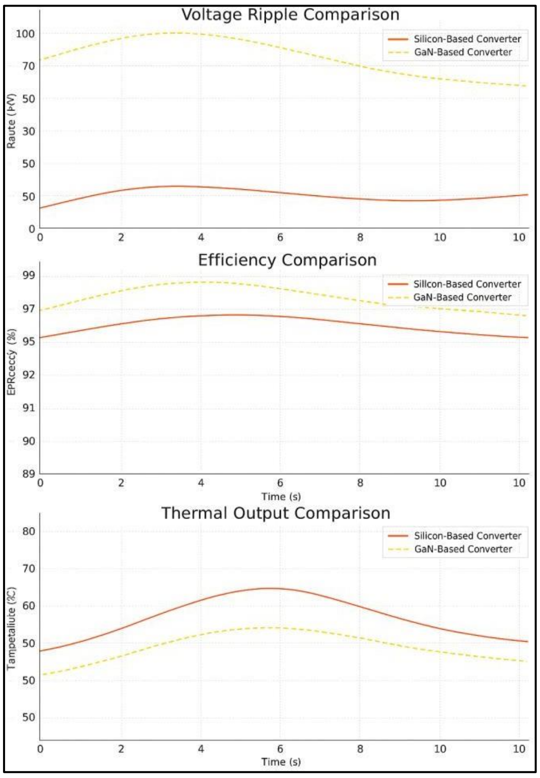

Figure 1 Simulation Result

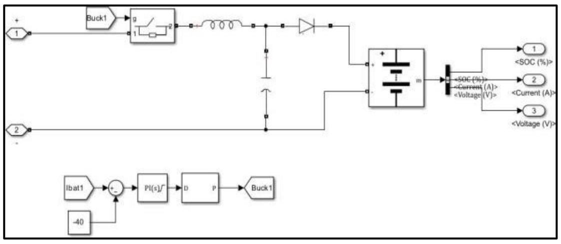

Figure 1 GaN Switch Simulation

The trends in high-power onboard chargers for electric vehicles. It highlights the advantages of using GaN-based devices in EV charging systems, particularly their ability to operate at higher switching frequencies than traditional silicon-based devices. This results in smaller passive components, which are critical for reducing size and weight in EV chargers. The research also explores the potential for GaN technology to achieve higher power densities, contributing to faster and more efficient charging systems.

This paper underscores the shift towards GaN technology in modern EV power electronics [1]
a two-stage onboard charger that employs GaN devices for high-efficiency operation. The study compares traditional silicon-based systems with GaN-based technology, showing how the latter significantly reduces system size while maintaining efficiency. By incorporating GaN devices in both the AC/DC and DC/DC stages of the charger, the researchers demonstrate substantial improvements in thermal management and power density. The results suggest that GaN-based systems are more suitable for the high-power demands of electric vehicles, especially as EV adoption increases globally [2]
variable-switching-frequency and phase-shift control methods tailored for GaN-based converters. Their study found that GaN devices perform better in EV battery chargers by optimizing power control and enhancing efficiency. The paper the dual-phase-shift control mechanism, which allows for reduced current stress in the converter, leading to better power handling and reduced energy losses. Their findings highlight the ability of GaN devices to achieve precise voltage control, which is essential for extending EV battery life [3]
the issue of low-frequency harmonics in EV battery chargers, proposing a technique to compensate for these harmonics using a bidirectional DC-DC converter with GaN devices. The research emphasizes that GaN devices' superior switching characteristics make them ideal for improving

power factor correction (PFC) circuits. Their bidirectional converter design enhances the overall efficiency and reduces the size of the power filter, making it a key technology for next-generation EV charging infrastructure [4]

IV. ACKNOWLEDGMENT

The preferred spelling of the word "acknowledgment" in America is without an "e" after the "g". Avoid the stilted expression "one of us (R. B. G.) thanks ...". Instead, try "R.
B. G. thanks...". Put sponsor acknowledgments in the unnumbered footnote on the first page.

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