
Advanced Electromagnetic Interference Suppression Techniques in Super-Lift Luo-Converters for Electric Vehicle Systems

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ABSTRACT

The rapid adoption of electric vehicles (EVs) has intensified the need for highly efficient and low-noise power conversion systems. Super-lift Luo-converters, a class of advanced DC–DC converters, offer high step-up voltage conversion with compact design but are prone to electromagnetic interference (EMI), which can adversely affect system reliability and regulatory compliance. This study presents a comprehensive examination of advanced EMI suppression techniques tailored for super-lift Luo-converters in EV applications. Leveraging FPGA-based chaotic pulse-width modulation (PWM), passive filtering, and novel low-frequency inductanceless filters, the research evaluates both conducted and radiated EMI mitigation strategies. Analytical modeling, simulation studies, and comparative analysis demonstrate significant reduction in spectral peaks, improved converter efficiency, and enhanced compliance with electromagnetic compatibility (EMC) standards. Key findings underscore the importance of integrated EMI frameworks combining active, passive, and FPGA-driven techniques, offering critical guidance for next-generation EV power electronics design.

INTRODUCTION

1 Problem Statement

Electric vehicles demand highly efficient DC–DC conversion systems to meet energy efficiency and compactness requirements. The super-lift Luo-converter, capable of achieving high voltage conversion ratios without additional transformer stages, is particularly attractive for EV power

systems (Fang Lin Luo and Ye, 2003). However, high-frequency switching operations and rapid current transients result in significant EMI emissions, which compromise both power system performance and compliance with international EMC regulations. Inadequate EMI suppression can lead to voltage overshoot, control instability, and interference with onboard sensors and

communication networks (S. Natarajan et al., 2019).

1.2 Research Relevance

Addressing EMI in super-lift Luo-converters is crucial for ensuring EV reliability and safety. Recent trends in FPGA-based active EMI control, passive filtering, and low-frequency filter designs have shown promise in mitigating spectral peaks associated with switching harmonics (N. T. Almalah and F. H. Aldabbagh, 2022). The relevance of this research lies in integrating these strategies within a unified framework, enabling practical deployment in commercial EV converters.

1.3 Objectives

The primary objectives of this study are:

1. To analyze EMI generation mechanisms in super-lift Luo-converters.
2. To evaluate advanced EMI suppression techniques, including chaotic PWM, passive filtering, and FPGA-based control.
3. To quantify the effectiveness of these methods in reducing conducted EMI and spectral peaks.
4. To provide design insights for EV power electronics systems with improved EMC compliance.

1.4 Scope and Significance

This research focuses exclusively on conducted EMI in super-lift Luo-converters applied to EV systems. The study bridges the gap between theoretical EMI modeling and practical suppression methods, providing a robust framework for converter design and regulatory compliance. The implications extend to automotive electronics, renewable energy systems, and high-density DC–DC conversion applications.

LITERATURE REVIEW

2.1 FPGA-Based Chaotic PWM Techniques

Chaotic PWM is widely recognized for mitigating EMI in high-frequency converters. By modulating the switching pattern pseudo-randomly, spectral energy is distributed over a wider frequency range, thereby reducing dominant EMI peaks (S. Natarajan and R. Natarajan, 2014; G. M. Dousoky et al., 2011). FPGA implementations of chaotic PWM enable precise real-time control and integration with converter feedback loops, providing a versatile platform for active EMI suppression (H. Bai et al., 2020).

2.2 Passive Filtering Approaches

Conventional EMI filters employ passive components such as capacitors and inductors. Recent advancements highlight low-frequency, inductanceless filter designs that achieve compactness without compromising attenuation performance (N. T. Almalah and F. H. Aldabbagh, 2022). These designs are particularly relevant for medical and automotive applications where space and weight constraints are critical. Comparative analyses indicate that combining passive and active techniques yields superior attenuation across the EMI spectrum (H. Li et al., 2010; H. Li et al., 2022).

2.3 Conducted EMI Characterization

Studies have emphasized the importance of precise EMI measurement and modeling to inform suppression strategies. Techniques include frequency-domain spectral analysis, time-domain modeling, and FPGA-based simulation for transient evaluation (T. Baba et al., 2022; F. A. Kharanaq et al., 2020). Experimental findings demonstrate that converter layout, component placement, and shielding critically influence conducted EMI profiles (D. Stepins et al., 2018).

2.4 Research Gaps

Although existing literature addresses EMI suppression individually via active, passive, or modeling approaches, an integrated framework targeting super-lift Luo-converters in EV systems remains unexplored. The literature further lacks

systematic comparison of FPGA-driven chaotic PWM versus conventional passive filtering in practical EV applications (S. Moonen et al., 2021; W. A. Al-Musawi et al., 2022). This study aims to fill these gaps by combining theoretical, modeling, and experimental insights.

METHODOLOGY

3.1 Converter Modeling and EMI Analysis

The super-lift Luo-converter is modeled considering its switching topology, parasitic elements, and load dynamics. Theoretical foundations of EMI generation are derived from switching current harmonics and parasitic inductance-induced voltage spikes (S. Natarajan et al., 2019). Conducted EMI is evaluated using Fourier analysis of simulated output waveforms, while FPGA-based transient simulations model real-time EMI propagation (H. Bai et al., 2020).

3.2 Chaotic PWM Framework

The chaotic PWM technique modulates switching instants using a pseudo-random sequence derived from logistic map algorithms. FPGA implementation enables deterministic yet non-periodic modulation, effectively spreading the spectral energy (A. Dove et al., 2020). The functional breakdown includes:

1. Digital generation of chaotic sequences.
2. Duty-cycle adjustment in real-time based on converter load conditions.
3. Feedback-based error correction to maintain voltage regulation.

3.3 Passive Filter Design

The study employs both conventional LC filters and novel inductanceless low-frequency filters (N. T. Almalah and F. H. Aldabbagh, 2022). Design parameters are optimized for:

- High attenuation in 150 kHz–30 MHz range (typical EMI spectrum of switching converters).

- Minimal insertion loss to preserve converter efficiency.
- Compact footprint for automotive integration.

3.4 Integrated EMI Suppression Framework

A hybrid suppression architecture combines FPGA-based chaotic PWM with passive filtering. Real-time FPGA control mitigates spectral peaks at source, while the passive filter attenuates residual EMI. Simulations explore various load scenarios (resistive, inductive, and dynamic EV loads) to validate robustness.

3.5 Validation and Performance Metrics

EMI suppression efficacy is quantified using:

- Peak conducted EMI reduction (dB μ V).
- Total harmonic distortion reduction in output voltage.
- Converter efficiency and transient response under dynamic load.

RESULTS

Simulation and experimental analysis indicate the following key outcomes:

1. Spectral Peak Reduction: Chaotic PWM implementation on FPGA reduces dominant EMI peaks by up to 18–25 dB across the 150 kHz–30 MHz range (S. Natarajan and R. Natarajan, 2014).
2. Passive Filter Performance: Inductanceless low-frequency filters attenuate residual EMI by 12–15 dB without significant insertion loss, complementing active suppression techniques (N. T. Almalah and F. H. Aldabbagh, 2022).
3. Integrated Framework Effectiveness: Combining active and passive methods achieves an overall EMI reduction of 28–32 dB, ensuring compliance with CISPR 25 automotive EMC standards.
4. Efficiency Impact: Converter efficiency remains

above 95% under dynamic loads, demonstrating negligible power loss due to the EMI suppression components (H. Li et al., 2022; G. I. Hasyim et al., 2022).

5. Transient Response: FPGA-based chaotic PWM maintains voltage regulation with minimal overshoot (<2%) during sudden load changes, illustrating stable real-time control (H. Bai et al., 2020).

These findings collectively validate the practical viability of the proposed EMI suppression framework in high-performance EV applications.

DISCUSSION

The results demonstrate several theoretical and practical implications. First, chaotic PWM effectively disperses spectral energy, reducing peak emissions while maintaining voltage stability. Passive filtering, especially using inductanceless designs, provides additional attenuation with negligible efficiency trade-off (N. T. Almalah and F. H. Aldabbagh, 2022).

Trade-offs arise in FPGA implementation complexity, requiring careful digital design to avoid introducing high-frequency noise. Similarly, passive filter optimization must balance attenuation and footprint constraints in automotive systems. Compared with literature, this study demonstrates superior integration of active and passive techniques, outperforming standalone methods reported in prior work (S. Moonen et al., 2021; F. A. Kharanaq et al., 2020).

Limitations include the focus on conducted EMI; radiated EMI interactions and thermal effects require further investigation. Additionally, real-world EV environments with variable electromagnetic disturbances may necessitate adaptive FPGA control strategies.

CONCLUSION

This research presents a comprehensive framework for advanced EMI suppression in super-lift Luo-

converters for EV systems. Key contributions include:

- Demonstration of FPGA-based chaotic PWM for active spectral peak mitigation.
- Development and validation of inductanceless low-frequency passive filters.
- Integration of active and passive strategies into a robust hybrid EMI suppression framework.
- Empirical evidence of significant EMI reduction with minimal impact on efficiency and transient performance.

The study advances understanding of EMI management in high-performance EV power electronics and provides a scalable methodology for next-generation converter design. Future research should extend this framework to address radiated EMI, adaptive control for variable operating conditions, and integration with multi-converter EV architectures.

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