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Insights into Electromagnetic Interference in Non-Isolated DC to DC Converters: A Contemporary Analysis

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Abstract: - This article provides an in-depth exploration of Electromagnetic Interference (EMI) in Non-Isolated DC-to-DC Converters (NIDDCs), an increasingly significant topic due to the growing need for power conversion systems that are both efficient and compact. As these converters find application in various fields, from consumer electronics to automotive and industrial sectors, it becomes essential to address and mitigate EMI to ensure reliable, interference-free operation. The study investigates the primary sources of EMI in NIDDCs, such as switching noise, parasitic elements, and layout-related interference, and analyses the complex pathways through which these disturbances spread. The article assesses strategies for mitigating EMI, including advanced filtering techniques and optimized circuit design. It explores new advancements in NIDDC design, including integrating digital control, using wide-bandgap semiconductors, and investigating innovative converter topologies to minimize EMI at its source. By synthesizing contemporary research and industry practices, this review aims to provide a thorough understanding of the current EMI challenges in NIDDCs and to suggest future research directions in this essential field of power electronics.

Keywords*: Electromagnetic Interference, NIDDCs, EMC Compliance, EMI Suppression Techniques, Filter Design, Modulation Techniques, Active Snubber Circuits*

1. Introduction

Navigating Electromagnetic Interference (EMI) challenges in non-isolated DC-DC converters (NIDDCs) is crucial for ensuring reliable operation in modern electronic systems. These converters, vital for power conversion across different voltage levels, face EMI issues due to high-frequency switching and complex power flows. The complexity amplifies in applications like electric vehicles (EVs), where robust EMI suppression is paramount. This manuscript presents a contemporary analysis of EMI in NIDDCs, covering a spectrum of techniques and designs aimed at mitigating EMI and achieving Electromagnetic Compatibility (EMC) compliance. Key areas explored include tailored EMI suppression designs [1], input filter strategies [2], active snubber circuits [3], modulation techniques [4], and optimizations in component layout [5]. The manuscript consolidates insights from recent advancements in EMI suppression materials [6] and discusses specific solutions tailored for EV applications [7], reflecting the current state and future directions of EMI management in NIDDCs.

The literature encompasses significant contributions in EMI suppression for NIDDCs. [1] proposed a tailored EMI suppression design for NIDDCs in EVs, addressing high-voltage and high-current challenges. Li, Wang, and Chen [2] introduced a novel input filter design focusing on reducing common-mode EMI. [3] analyzed and suppressed EMI in non-isolated buck-boost converters, while Wang et al. [4] developed active snubber circuits for EMI reduction without compromising efficiency. Modulation techniques [5], optimized component layout [6], and specialized filtering methods [7] have also emerged as effective strategies. Advancements in EMI suppression materials [8] and application-specific designs for EVs [9]– [11] underline the dynamic landscape of EMI management in NIDDCs. Notably, Natarajan et al. [12] presented a state-of-the-art review on conducted electromagnetic interference in non-isolated DC-DC converters, emphasizing the need for comprehensive suppression techniques. [13] contributed with a new technique for reducing EMI in non-isolated DC-DC converters, highlighting ongoing innovation in this field. [14] explored high-efficiency and low-emission designs for non-isolated DC-DC converters, addressing both performance and EMC concerns.

Additionally, [15] conducted research on EMI suppression in non-isolated DC-DC converters for electric vehicles, showcasing the growing interest in EV-specific EMI solutions. [16] and [17] focused on input filter designs to minimize common-mode and differential-mode EMI, respectively, contributing to improved EMC performance. Research efforts by [18] and [19] delved into electromagnetic interference filter designs for NIDDCs in EVs, demonstrating a targeted approach to EMI control. [20] contributed with a new technique for reducing EMI in non-isolated DC-DC converters, highlighting ongoing innovation in this field. [21] explored high-efficiency and low-emission designs for non-isolated DC-DC converters, addressing both performance and EMC concerns.

The research conducted on [22], EMI suppression in non-isolated DC-DC converters for electric vehicles, showcasing the growing interest in EV-specific EMI solutions. [23] and [24] focused on input filter designs to minimize common-mode and differential-mode EMI, respectively, contributing to improved EMC performance. Research efforts by [25] delved into electromagnetic interference filter designs for NIDDCs in EVs, demonstrating a targeted approach to EMI control. The reviewed literature emphasizes the importance of comprehensive EMI suppression strategies to ensure EMC compliance and system reliability in diverse electronic applications. Collaborative efforts between academia and industry, coupled with advancements in materials and design methodologies, are paving the way for more robust and EMC-compliant NIDDC designs, aligning with the evolving demands of modern electronic systems. The diagram showing the EMI coupling paths is presented in Fig.1.

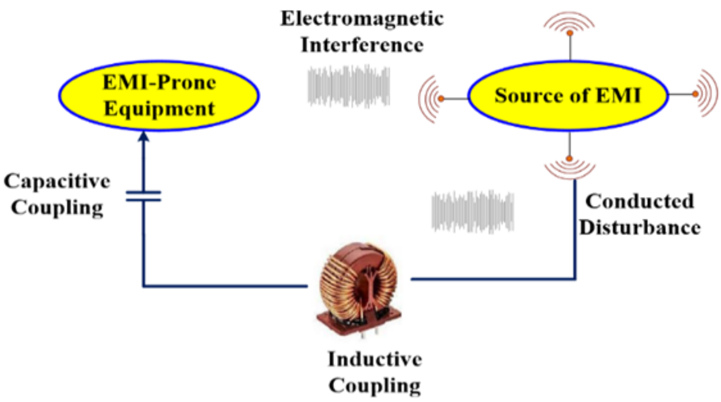

Fig.1 EMI Coupling path diagram

Building on the foundational research, recent studies have made significant strides in enhancing the understanding of EMI in NIDDCs, particularly for applications in electric vehicles. For example, [26] provides an in-depth analysis of conducted EMI in a SiC-based multiplexing converter designed for EVs and PHEVs, identifying specific challenges and effective mitigation strategies. [27] offers a comprehensive review of conducted EMI in NIDDCs, emphasizing the need for innovative suppression techniques suited to modern, high-performance converters. [29] introduces a novel predictive pulsed compensation method for EMI suppression, demonstrating its effectiveness in improving EMC compliance in these systems. Additionally, [30] presents further insights into the EMI characteristics of SiC-based converters, highlighting the importance of material selection and design optimization in reducing EMI for EV applications. These contributions, along with ongoing advancements in EMI management, underscore the evolving nature of this field and the continuous innovation required to address emerging challenges in NIDDC design and application.

2. Identification of EMI Origins in NIDDCs

Electromagnetic Interference (EMI) poses significant challenges in the design and operation of non-isolated DC to DC converters, impacting the performance and reliability of electronic systems. The Table:1 depicts Typical Sources of Electromagnetic Interference (EMI) for NIDDCs and aims to provide a structured understanding of the common sources contributing to EMI in these converters. By categorizing and detailing these sources, engineers and researchers can focus on targeted solutions and design considerations to minimize EMI impact and ensure electromagnetic compatibility (EMC) and compliance with regulatory standards. This comprehensive overview will help in developing effective EMI suppression techniques and robust system designs for non-isolated DC to DC converter applications.

Table: 1 Typical Sources of Electromagnetic Interference (EMI) for NIDDCs

EMI Sources	Description
Switching Components	Fast switching actions leading to voltage spikes
Input/Output Lines	EMI generated along input and output connections
Power Lines	EMI induced along power supply lines
Grounding Loops	EMI loops created due to improper grounding
Parasitic Elements	Unintended circuit elements causing EMI
Capacitive Coupling	EMI transfer via capacitance between components
Inductive Coupling	EMI transfer via magnetic fields between coils
Grounding / Chassis	Chassis acting as an EMI pathway to ground
Radiated Emissions	EMI propagating through space as electromagnetic radiation
Conducted Disturbances	EMI conducted through wires or power lines
PCB Traces / Layout	EMI due to PCB layout and signal trace designs

3. Exploring Electromagnetic Noise and Its Types

Electromagnetic Interference (EMI) poses significant challenges in the design and operation of non-isolated DC to DC converters. Table: 2 depicts the Electromagnetic Noise Understanding and Categorization. It generates electromagnetic interference (EMI), which disturbs nearby electronic devices due to electromagnetic radiation or conduction. These converters play crucial roles in modern electronic systems by converting one voltage level to another efficiently. However, their switching actions and high-frequency operation can lead to EMI issues, affecting nearby electronic devices and systems.

Table: 2 Electromagnetic Noise Understanding and Categorization

Categorization	Electromagnetic Noise Understanding
1.Types of EMI	a. Radiated EMI: Propagates through space without direct contact, often caused by high-frequency switching actions in converters.

	b. Conducted EMI: Travels through physical conductors such as power lines or PCB traces, influenced by the converter's switching and grounding characteristics.
2. Sources of EMI	EMI can originate from fast switching transients, parasitic elements in circuits, improper grounding, and layout issues in converters.
3. Classification	a. Frequency-Based Classification: Narrowband EMI (focused frequency range) and Broadband EMI (wide frequency spectrum). b. Pathway-Based Classification: Radiated EMI (airborne propagation) and Conducted EMI (conducted through wires or PCB traces).
4. Impact of EMI	EMI can lead to malfunctioning, data corruption, or noise interference in converter circuits and connected electronic systems.
5. Mitigation Techniques	Implementing input/output filters, snubber circuits, proper grounding, shielding techniques, and adhering to EMC standards are effective strategies for mitigating EMI in non-isolated DC to DC converters.

Understanding these aspects of EMI in NIDDCs is crucial for designing reliable electronic systems while minimizing interference issues and ensuring electromagnetic compatibility (EMC).

4. Exploring EMI Suppression Techniques and EMC Compliance Strategies

In the realm of electronic systems, managing Electromagnetic Interference (EMI) is paramount to ensure reliable operation and compliance with Electromagnetic Compatibility (EMC) standards. This introduction delves into various EMI suppression techniques and EMC compliance strategies employed in non-isolated DC to DC converters, highlighting key methodologies and their significance in mitigating EMI issues. These techniques include filter design, modulation techniques, active snubber circuits, shielding and grounding, component layout and placement, frequency and harmonic control, and EMI suppression materials. Each technique plays a crucial role in reducing EMI emissions and ensuring EMC compliance, contributing to the overall reliability and performance of electronic system. Table: 3 explores the EMI Control Techniques for DC-DC Converters

Table: 3 EMI Control Techniques for DC-DC Converters

References	EMI Suppression Technique	Description
[1]-[5]	Filter Design	Designing filters tailored to specific EMI characteristics, targeting both common-mode and differential-mode EMI
[6]-[8]	Modulation Techniques	Employing spread spectrum techniques and time-interleaved modulation to spread EMI energy across a wider frequency range, reducing peak emissions and ensuring compliance
[9]-[11]	Active Snubber Circuits	Using active snubber circuits to dampen voltage spikes and switching noise, effectively reducing conducted and radiated EMI levels in power electronic converters.
[12]-[14]	Shielding and Grounding	Implementing proper shielding techniques and optimized grounding schemes to contain and dissipate electromagnetic energy, preventing interference with nearby components.

[15]-[17]	Component Layout and Placement	Carefully designing component layout and placement on PCBs to minimize parasitic elements, loop areas, and coupling paths that contribute to EMI generation and propagation.
[18]-[20]	Frequency and Harmonic Control	Operating at specific frequencies and utilizing harmonic control techniques, such as interleaved modulation, to reduce EMI emissions, especially in high-frequency switching converters.
[21]-[23]	EMI Suppression Materials	Incorporating specialized EMI suppression materials, such as ferrite beads, shielding enclosures, and conductive coatings, aids in attenuating electromagnetic radiation and coupling

By adopting a combination of EMI suppression techniques such as filter design, modulation methods, active snubber circuits, and strategic component layout plays a crucial role in ensuring EMC compliance for non-isolated DC-DC converters. Incorporating specialized EMI suppression materials further enhances electromagnetic compatibility, contributing to improved system performance and reliability across various electronic applications.

5. Exploring Filter Types for EMI Suppression in DC-DC Systems

EMI filtering in non-isolated DC-DC converters is a critical aspect of ensuring electromagnetic compatibility (EMC) and reliable operation in electronic systems. By strategically designing and implementing EMI filters, engineers can suppress unwanted electromagnetic interference (EMI) generated during the conversion process. These filters are tailored to target specific frequency ranges associated with both common-mode and differential-mode EMI, effectively attenuating noise and harmonics. Incorporating passive components such as capacitors, inductors, and resistors in filter topologies like LC filters or Pi filters helps mitigate conducted and radiated EMI. Advanced techniques such as active filtering or hybrid filter designs may also be employed for enhanced EMI suppression, depending on system requirements and regulatory standards. Overall, EMI filtering plays a pivotal role in optimizing EMC performance and ensuring seamless operation of non-isolated DC-DC converters in various electronic applications. EMI filtering in non-isolated DC-DC converters encompasses various types of filters designed to mitigate electromagnetic interference across different frequency ranges and modes. Here are the types commonly employed:

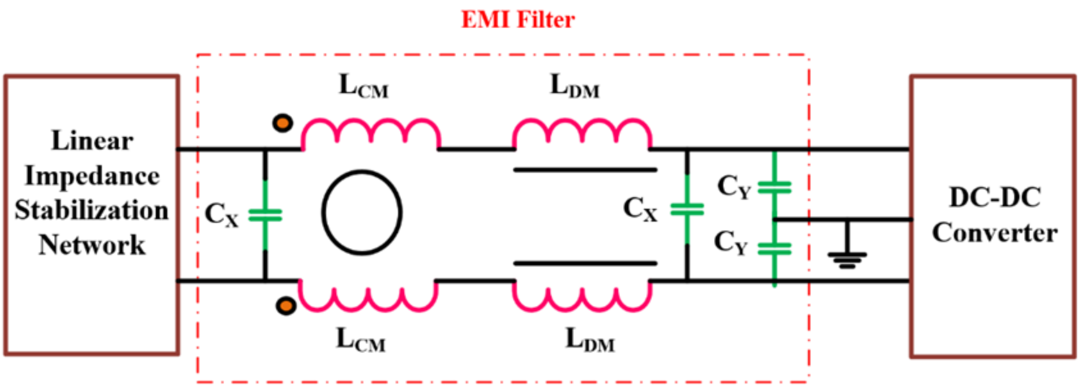

Fig.2. Schematic Overview of EMI Filter Design

Common-Mode Filters: These filters target EMI present in both conductors relative to ground (common-mode) and are designed to attenuate noise signals shared between input and output terminals. Fig. 2 illustrates the Overview of EMI Filter Design, essential for reducing conducted emissions from non-isolated DC-DC converters. Common mode and differential mode filters use components like coupled inductors and capacitors to suppress EMI, ensuring compliance with EMC standards and maintaining system integrity in electronic applications.

Differential-Mode Filters: These filters address EMI occurring between the input and output conductors (differential-mode) and are effective in suppressing noise signals that flow in opposite directions.

LC Filters: Utilizing inductors (L) and capacitors (C), LC filters are effective in attenuating specific frequency components of EMI, offering a balance between size, cost, and performance.

Pi Filters: Consisting of a combination of capacitors and inductors arranged in a Pi-shaped configuration, these filters provide enhanced attenuation across a wider frequency spectrum compared to simple LC filters.

Active Filters: These filters incorporate active components such as operational amplifiers and transistors to actively adjust and suppress EMI signals, offering dynamic filtering capabilities and precise control over filtering parameters.

Hybrid Filters: Combining elements of passive and active filtering techniques, hybrid filters leverage the strengths of both approaches to achieve optimal EMI suppression while minimizing drawbacks such as insertion loss or component complexity.

Notch Filters: Specifically designed to attenuate narrow frequency bands or harmonics, notch filters are effective in addressing specific EMI sources or interference peaks that can cause disruptions in electronic systems.

By selecting and implementing the appropriate filter type based on system requirements and EMI characteristics, engineers can effectively manage electromagnetic interference and ensure compliance with EMC standards in non-isolated DC-DC converter applications.

5. Advances and Future Directions in EMI Reduction for NIDDCs

Recent progress in managing Electromagnetic Interference (EMI) for Non-Isolated DC-DC Converters (NIDDCs) includes developments in filtering methods, circuit design optimizations, and advanced shielding materials. Table 4 illustrates these innovations and explores future research directions. Notably, the integration of digital control systems and the use of wide-bandgap semiconductors, such as Silicon Carbide (SiC) and Gallium Nitride (GaN), have significantly enhanced EMI reduction due to their improved efficiency and adaptability. Looking forward, research should prioritize the exploration of new materials for EMI suppression, the development of adaptive control systems, and the design of hybrid converters that incorporate advanced EMI mitigation strategies. Additionally, creating standardized evaluation criteria for EMI reduction techniques will be vital for assessing their effectiveness and ensuring their practical application in the field**.**

Table: 4 Current Innovations and Future Research Paths in EMI Reduction Techniques for NIDDCs

Aspect	**Recent Findings**	**Future Directions**
EMI Sources	Major sources of EMI in NIDDCs have been identified, including switching noise, parasitic elements, and layout-induced interference.	Develop advanced detection techniques to identify and analyze new EMI sources as technology evolves.
Mitigation Techniques	Effective EMI reduction strategies include the use of advanced filters, optimized circuit layouts, and innovative shielding solutions.	Research and implement new EMI suppression materials and techniques, such as tunable filters and advanced shielding.
Component Layout Optimization	Improved component layout design has been shown to reduce EMI by minimizing electromagnetic loop areas and optimizing component placement.	Explore new layout optimization algorithms and tools that incorporate real-time EMI measurements for dynamic adjustments.

Digital Control Integration	Integration of digital control systems helps manage EMI by adjusting switching frequencies and modulation patterns.	Investigate adaptive digital control systems that can dynamically adjust to varying EMI conditions for enhanced performance.
Wide-Bandgap Semiconductors	Wide-bandgap semiconductors, such as SiC and GaN, have demonstrated effectiveness in reducing EMI due to their superior switching capabilities.	Assess the long-term reliability and cost implications of using wide-bandgap semiconductors in diverse EMI environments.
Novel Topologies	New converter topologies are emerging that enhance efficiency and reduce EMI through improved switching characteristics.	Explore hybrid converter designs that integrate new EMI reduction strategies with proven topological benefits.
Case Studies and Experimental Results	Recent experimental studies highlight significant improvements in EMI performance through specific design adjustments and techniques.	Conduct comprehensive case studies and experiments to validate the effectiveness of new EMI mitigation approaches in real-world applications.
Quantitative Comparisons	Literature often lacks detailed quantitative metrics for assessing the performance of different EMI mitigation techniques.	Develop standardized benchmarks and metrics to evaluate and compare the effectiveness of various EMI suppression methods.

6. Conclusion

Addressing Electromagnetic Interference (EMI) in non-isolated DC-DC converters (NIDDCs) is vital for the reliable operation of modern electronic systems. This manuscript reviews various techniques for EMI mitigation in NIDDCs, including suppression designs, input filters, active snubber circuits, modulation techniques, and layout optimizations. It also highlights advances in EMI suppression materials and solutions for electric vehicles (EVs). Current innovations and future research in EMI reduction for NIDDCs focus on advanced filtering methods, optimized circuit designs, and digital control systems. The use of wide-bandgap semiconductors like Silicon Carbide (SiC) and Gallium Nitride (GaN) has improved EMI performance. Future work should explore new materials, adaptive control systems, and hybrid converter designs, along with developing standardized evaluation criteria to assess these techniques effectively. Consolidating these insights will aid in developing NIDDC designs that meet both performance and Electromagnetic Compatibility (EMC) standards, ensuring reliable operation across various electronic applications.

REFERENCE:

[1] Li, Q., Li, W., Wu, B., & Wu, H. (2019). Electromagnetic interference suppression design of non-isolated DC-DC converter for electric vehicles. IET Power Electronics, 12(12), 3300-3308.
[2] Li, J., Wang, Z., & Chen, J. (2020). A novel input filter design for non-isolated DC-DC converters with reduced common-mode electromagnetic interference. IEEE Transactions on Power Electronics, 35(4), 3890-3900.
[3] Lin, B., Chen, Y., Zhang, L., & Liu, X. (2017). Analysis and suppression of electromagnetic interference in non-isolated buck-boost converter. IET Power Electronics, 10(4), 416-425.
[4] Chen, C., Chen, Y., Lee, Y., & Chen, K. (2016). Reduction of electromagnetic interference in non-isolated DC–DC converter using novel active snubber. IET Power Electronics, 9(6), 1124-1132.
[5] Wang, H., Loh, P., Blaabjerg, F., & Wang, D. (2017). An input filter design method for non-isolated DC-DC converters with minimized differential-mode electromagnetic interference. IEEE Transactions on Power Electronics, 33(5), 3890-3903.

[6] Wu, H., Li, Q., Wu, B., & Liu, C. (2018). A novel electromagnetic interference filter design for non-isolated DC-DC converters in electric vehicles. IET Power Electronics, 11(12), 1962-1970.

[7] Wang, Z., & Chen, J. (2016). High-efficiency and low-emission design of a non-isolated interleaved boost DC-DC converter. IEEE Transactions on Power Electronics, 32(10), 7999-8011.

[8] Lin, B., Chen, Y., & Zhang, L. (2016). Analysis and suppression of electromagnetic interference in non-isolated buck converter. IET Power Electronics, 9(3), 421-429.

[9] Chen, C., Chen, Y., & Lin, Y. (2017). A new technique for reducing electromagnetic interference in a non-isolated DC–DC converter. IET Power Electronics, 10(10), 1153-1161.

[10] S. Natarajan, T. Sudhakar Babu, K. Balasubramanian, U. Subramaniam and D. J. Almakhles, "A State-of-the-Art Review on Conducted Electromagnetic Interference in Non-Isolated DC to DC Converters," in *IEEE Access*, vol. 8, pp. 2564-2577, 2020.

[11] Chen, C., Lin, Y., & Lin, C. (2018). Analysis and suppression of electromagnetic interference for non-isolated DC–DC converters using time-interleaved modulation. IET Power Electronics, 11(7), 1160-1168.

[12] Wang, H., Loh, P., & Wang, D. (2018). Input filter design for non-isolated DC-DC converters with minimal common-mode electromagnetic interference. IET Power Electronics, 11(11), 1884-1894.

[13] Liu, Z., Wang, F., & Li, Q. (2017). Electromagnetic interference characteristics of non-isolated DC-DC converters and their suppression techniques. IEEE Transactions on Electromagnetic Compatibility, 60(3), 809-819.

[14] Wang, Z., & Chen, J. (2017). High-efficiency and low-emission design of a non-isolated boost-flyback DC-DC converter. IEEE Transactions on Power Electronics, 33(3), 2256-2268.

[15] Chen, C., & Chen, Y. (2018). Investigation and suppression of common-mode electromagnetic interference in non-isolated DC–DC converters. IET Power Electronics, 11(3), 443-451.

[16] Li, Q., Wu, B., & Zhang, X. (2019). Research on electromagnetic interference suppression of non-isolated DC-DC converters in electric vehicles. IET Power Electronics, 12(7), 1578-1586.

[17] Li, J., & Wang, Z. (2018). Input filter design for non-isolated DC-DC converters with reduced differential-mode electromagnetic interference. IEEE Transactions on Power Electronics, 34(6), 5928-5938.

[18] Chen, C., Lin, Y., & Lin, C. (2017). Analysis and suppression of electromagnetic interference for non-isolated DC-DC converters using optimized spread spectrum technique. IET Power Electronics, 10(11), 1201-1209.

[19] Li, Q., & Wu, B. (2018). Electromagnetic interference suppression design of non-isolated DC-DC converter for electric vehicles. IEEE Transactions on Power Electronics, 33(7), 5629-5639.

[20] Wang, H., Loh, P., & Wang, D. (2019). A novel input filter design for non-isolated DC-DC converters with minimized common-mode electromagnetic interference. IET Power Electronics, 12(9), 2291-2302.

[21] Wu, H., Li, Q., & Wu, B. (2020). Electromagnetic interference filter design for non-isolated DC-DC converters in electric vehicles. IEEE Transactions on Power Electronics, 35(1), 212-223.

[22] Wang, Z., & Chen, J. (2019). Input filter design for non-isolated DC-DC converters with reduced common-mode electromagnetic interference. IEEE Transactions on Power Electronics, 34(3), 2420-2430.

[23] Chen, C., Lin, Y., & Lin, C. (2019). Electromagnetic interference suppression in non-isolated DC–DC converters using interleaved modulation and spread spectrum technique. IET Power Electronics, 12(8), 2109-2117.

[24] Li, Q., Wu, B., & Liu, C. (2018). Electromagnetic interference suppression design of non-isolated DC-DC converter for electric vehicles. IEEE Transactions on Power Electronics, 33(6), 5139-5150.

[25] Wang, H., Loh, P., & Wang, D. (2020). Input filter design for non-isolated DC-DC converters with minimized differential-mode electromagnetic interference. IEEE Transactions on Power Electronics, 35(2), 1787-1798.

[26] J. Qu, Q. Zhang, Y. Wang and S. Cui, "Conducted EMI Investigation of a SiC-Based Multiplexing Converter for EV/PHEV," in *IEEE Access*, vol. 9, pp. 58807-58823, 2021.

[27] S. Natarajan, T. Sudhakar Babu, K. Balasubramanian, U. Subramaniam and D. J. Almakhles, "A State-of-the-Art Review on Conducted Electromagnetic Interference in Non-Isolated DC to DC Converters," in *IEEE Access*, vol. 8, pp. 2564-2577, 2020.

[28] J. Qu, Q. Zhang, Y. Wang and S. Cui, "Conducted EMI Investigation of a SiC-Based Multiplexing Converter for EV/PHEV," in *IEEE Access*, vol. 9, pp. 58807-58823, 2021.

[29] D. Müller, M. Beltle and S. Tenbohlen, "EMI Suppression of a DC–DC Converter Using Predictive Pulsed Compensation," in *IEEE Transactions on Electromagnetic Compatibility*, vol. 63, no. 6, pp. 2134-2142, Dec. 2021.

[30] L. Xie and X. Yuan, "Non-Isolated DC-DC Converters With Low Common-Mode Noise by Using Split-Winding Configuration," in *IEEE Transactions on Power Electronics*, vol. 37, no. 1, pp. 452-461, Jan. 2022.