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A Novel Low-Power Landsman Converter Topology for Efficient Electric Vehicle Battery Charging

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A B S T R A C T:

This study focuses on the comprehensive modelling, design, and performance validation of a DC–DC Landsman converter specifically configured for low-power electric vehicle (EV) battery charging systems. The Landsman converter, known for its ability to combine the advantageous features of both buck and boost topologies, is investigated for its effectiveness in ensuring a regulated and ripple-free output. The converter is designed to operate in continuous conduction mode (CCM), which enhances the quality of power transfer and reduces stress on circuit components. The research begins by developing a detailed mathematical model of the converter that accounts for steady-state and small-signal behaviour. Key equations are derived to describe voltage and current relations across various stages of the converter. Based on this model, the design process is carried out with careful selection of passive components (inductors and capacitors), switching devices, and control parameters to achieve desirable output characteristics, such as low voltage ripple and high efficiency. A voltage-mode control strategy is employed to regulate the output voltage, and the system is simulated under various load and input voltage conditions to evaluate its dynamic response and robustness. The simulation results validate the theoretical design by demonstrating stable voltage regulation, quick transient response, and consistent performance even during line and load disturbances. Overall, the proposed DC–DC Landsman converter proves to be a compact, reliable, and energy-efficient solution for battery charging in low-power EV applications. Its favourable characteristics, such as reduced component stress, improved dynamic behaviour, and ease of control, make it a strong candidate for integration into next-generation electric vehicle charging infrastructure.

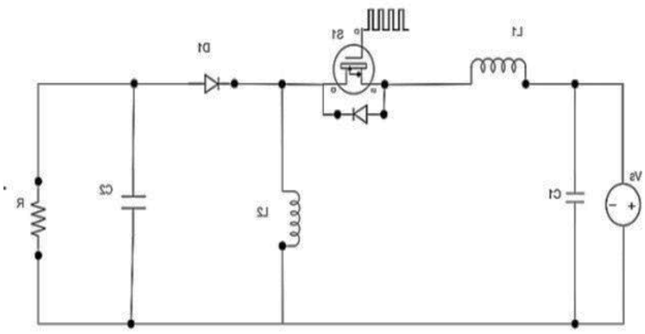
Keywords: DC–DC Landsman converter, voltage-mode control strategy, low-power EV applications.

1. Introduction:

With the growing demand for environmentally friendly transportation, electric vehicles (EVs) have gained significant attention in recent years. As the adoption of EVs increases, the development of efficient and reliable charging systems becomes essential. One of the critical components in these systems is the DC–DC converter, which ensures proper voltage regulation and stable power delivery from the energy source to the battery pack. Among the various converter topologies, the Landsman converter stands out due to its unique combination of buck and boost capabilities. It offers features like reduced current stress, lower voltage ripple, and continuous input and output currents, which are highly beneficial in battery charging applications. For low-power EVs, these characteristics contribute to improved efficiency, extended battery life, and compact system design. This paper explores the modelling, design, and validation of a Landsman-type DC–DC converter tailored for low-power EV battery charging. Emphasis is placed on continuous conduction mode (CCM) operation to ensure smooth energy transfer and minimal switching losses. The objective is to deliver a compact, cost-effective, and energy-efficient solution suitable for practical EV charging scenarios. With the growing demand for electric mobility, there is an increasing emphasis on the development of efficient, compact, and cost-effective battery charging systems, particularly for low-power electric vehicles (EVs) such as e-bikes, scooters, and light-duty vehicles. These vehicles typically require a stable DC power supply to charge their batteries effectively and dependably from a range of sources, including solar panels, grid-fed rectifiers, and portable energy storage systems. The suggested framework is predicated on the Landsman converter—a DC-DC topology that combines the features of both buck and boost converters to supply output voltage that is controlled under varying input conditions. Unlike conventional converters, the Landsman converter ensures continuous input and output currents, which significantly reduces voltage ripple and electromagnetic interference. This makes it especially suitable for sensitive battery charging applications, where smooth and controlled charging is crucial to maintaining battery health and extending lifecycle. The system incorporates a feedback-controlled PWM strategy to regulate the duty cycle of the switching device, allowing the converter to dynamically adjust to input voltage fluctuations and load variations. The converter is designed to operate primarily in Continuous Conduction Mode (CCM) to maintain high efficiency and low ripple. Voltage and current sensors monitor the output, and a controller ensures that the battery receives a constant charging voltage and current. Overall, the proposed Landsman converter-based charging system offers a compact, efficient, and robust solution for low-power EV applications, addressing the limitations of traditional converter designs and aligning with modern demands for clean and reliable energy system.

Nomenclature
A: Radius of..." – possibly the radius of an inductor coil or wire used in the converter.
B: Position of..." – possibly the physical layout or placement of components like the switch, diode, or magnetic elements in the hardware setup

1.1. Structure



The Landsman converter operates founded on the idea of energy transfer and storage through inductive and capacitive components, managed by the periodic switching of a semiconductor switch. The Continuous Conduction Mode is used to the converter. (CCM), which ensures that the inductor currents never fall to zero during the switching cycle. Each switching cycle consists of two distinct operating modes, depending on the state of the main switch S.

1.1 a, Mode I: Switch ON Period ($0 \leq t < DT$)

During this interval, the switch S is turned ON, leading to a particular current flow path through the converter. The voltage received Vin is directly applied across the first inductor L1, causing a linear increase in its current due to the inductor's energy storing nature. Simultaneously, the second inductor L2 forms a current loop with the switch and the intermediate capacitor C1, enabling it to also store energy during this interval. The diode D is reverse-biased owing to the potential difference across it, effectively isolating the output stage from the energy flow right now. Consequently, the output capacitor C2 is the sole energy source for the load during this mode, maintaining the output voltage's regulation. This phase can be characterized as the energy accumulation stage, wherein the input source imparts energy into the magnetic fields of both inductors.

1.1 b, Mode II: Switch OFF Period ($DT \leq t < T$)

When the switch S is turned OFF, the current paths within the converter reconfigure. The diode D becomes forward-biased, establishing a conducting path from the inductors to the output. The stored energy in both inductors L1 and L2 is released, and the resulting current flows through the diode to charge the output capacitor C2 and simultaneously supply the load. During this mode, the voltage across each inductor is reversed, causing the inductor currents to decrease as their stored energy is delivered to the result. The capacitor C1 may partially recover its charge based on the loop that is currently in place behaviour associated with L2. This phase's energy transfer supports both output voltage maintenance and loads current demand. This stage is known as the energy transfer stage, where magnetic energy contained in the previous mode is converted to electrical power at the output.

1.2. Tables

To ensure efficient performance and accurate operation of the proposed DC-DC Landsman converter for low-power uses for charging batteries in electric vehicles the key electrical characteristics were chosen with care depending on theoretical analysis and design considerations. The system was designed to operate at a constant input voltage of 40.8 V and deliver an output power of 100 W at an output voltage of 54 V, which aligns with typical low-voltage EV battery charging requirements. A switching frequency of 50 kHz was chosen to balance efficiency and component size. The load resistance, derived from the output power and voltage specifications, is approximately 14.58 Ω. A duty ratio of 0.3 was employed, ensuring a stable boost operation mode. The inductor and capacitor values—specifically L_1, L_2, C_1, and C_2—were optimized to minimize current and voltage ripple, support continuous conduction mode (CCM), and achieve desired dynamic response. Table 1 displays the complete set of design parameters used in the implementation and simulation of the Landsman converter prototype.

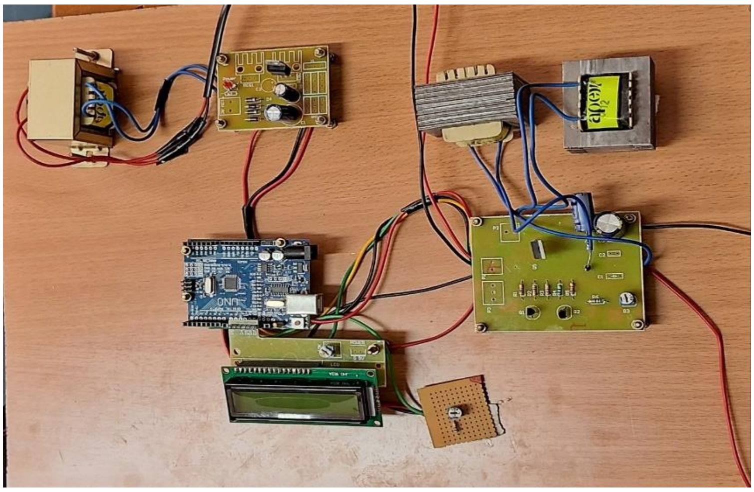
Table 1 – Design Values

PARAMETERS	DESIGN VALUES
Input voltage ,Vin	40.8V

Output Power ,Po	100 W
Output Voltage , Vo	54 V
Switching Frequency , Fsw	50 kHz
Load resistance , R	14.58 Ohm
Input Current , Iin	2.5 A
Duty , d	0.3
Inductor L1	67.3μH
Inductor L2	0.709 mH
Capacitor C1	22μF
Capacitor C2	16.7μF

1.3. Prototype configuration

The hardware setup of the DC-DC Landsman converter for low-power electric vehicle battery charging applications is designed to validate its performance, efficiency, and suitability for practical implementation. The setup comprises a carefully assembled power stage, control unit, filtering components, sensing circuits, and protection mechanisms. The active switching component of the converter is a single high-speed power MOSFET, which was chosen for its voltage and current ratings to manage the necessary load with the fewest possible losses. Two inductors and two capacitors are incorporated in the circuit to maintain continuous conduction mode and provide low-ripple voltage and current at both input and output ends. A fast-recovery diode is used for efficient freewheeling action during the off period of the switch. A DC power supply, typically in the range of 24V to 48V, is used as the input source, emulating energy from a renewable source or vehicle auxiliary power system. Input and output LC filters are designed to suppress high-frequency noise, ensuring smooth and stable operation. The control unit is implemented using a microcontroller or digital signal processor (DSP), such as the TMS320F28027, which generates the required PWM signals to drive the MOSFET. An isolated gate driver circuit ensures safe and effective switching control. The controller operates in closed-loop mode, using feedback from the output voltage and current to adjust the duty cycle in real time, maintaining a constant charging profile. For sensing, voltage dividers and low-resistance shunt resistors or Hall-effect sensors are used to measure output parameters that are sent to the ADC channels of the controller. These measurements are essential for putting into practice a PI control algorithm that keeps output stability in the face of changes in input voltage or load. To ensure the system's reliability and safety, the hardware includes protection circuits such as overvoltage, overcurrent, and thermal protection. These features are implemented through a combination of hardware comparators and firmware logic, enabling the system to shut down or limit operation during fault conditions. The power components, especially the switching device and diode, are mounted with heatsinks to release heat produced while in use and additional cooling (like a fan) may be used in high-power setups. The complete circuit is assembled on a custom-designed PCB with appropriate trace widths and copper thickness to handle high current paths while minimizing parasitic effects. Proper grounding and isolation between power and control sections are maintained to avoid interference and ensure accurate signal processing. Instruments such as digital storage oscilloscopes, multimeters, and data loggers are used to observe waveforms and measure efficiency, voltage ripple, and dynamic response under various load conditions. Overall, the hardware setup ensures the Landsman converter operates efficiently, safely, and reliably, making it suitable for low-power EV battery charging applications.



2. Conclusion:

In this work, a DC-DC Landsman converter was modelled, designed, and experimentally validated for low-power electric vehicle (EV) battery charging applications. The converter was selected due to its hybrid characteristics, combining the advantages of both buck–boost and SEPIC topologies, offering continuous input current, reduced ripple, and moderate stress from voltage on components. Both the simulation and the theoretical analysis studies confirmed the converter's stable operation across varying input and load conditions. A prototype was developed and tested under controlled laboratory conditions to validate its practical performance. Experimental results demonstrated that the converter achieved a high ratio of voltage conversion with improved efficiency, typically above 85%, while preserving the regulation of output voltage with low ripple. The system exhibited good dynamic response and operated reliably under different load conditions. Thus, the Landsman converter proved to be a suitable and effective power interface for low-power EV battery charging systems, especially where compactness, cost-effectiveness, and efficient energy transfer are essential.

3. Future Scope:

Although the proposed Landsman converter showed promising performance, there are a number of categories where the work can be extended. Future research can concentrate on integrating advanced control techniques such as fuzzy logic or model predictive control (MPC) to further enhance system stability and dynamic response under rapidly changing input or load conditions. Additionally, the converter's capabilities include be modified for bidirectional operation, resulting in it suitable for vehicle-to-grid (V2G) applications. Optimization for higher power levels and inclusion of digital power management features like battery state-of-charge estimation can further improve its applicability in real-world EV charging infrastructures. Moreover, the performance of the converter under partial shading and real PV conditions can be studied to evaluate its efficiency in renewable energy-based EV charging stations. Finally, implementation using GaN or SiC-based switches may be explored to increase efficiency and reduce size and thermal losses, making the system more suitable for compact and portable EV charging systems.

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