International Journal of
Artificial Intelligence and Machine Learning In Engineering
Peer Reviewed, Referred & Indexed Journal
ISSN: 3143-4258 www.ijaimle.com Original Research

ADVANCED TOPOLOGIES FOR HIGH-EFFICIENCY DC–DC POWER CONVERTERS

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ABSTRACT

High-efficiency DC–DC power converters play a crucial role in modern power electronic systems, including renewable energy systems, electric vehicles, telecommunications, and industrial applications. The increasing demand for compact, reliable, and energy-efficient power supplies has led to the development of advanced converter topologies. Conventional converter structures often suffer from switching losses, high voltage stress, and limited power density. Advanced topologies such as soft-switching converters, interleaved converters, and resonant converters address these challenges by improving efficiency and reducing electromagnetic interference. This study explores innovative DC–DC converter configurations aimed at achieving high gain and reduced switching losses. The proposed design integrates improved switching strategies and optimized passive components. Analytical modeling and simulation are performed to evaluate performance metrics. Experimental validation confirms enhanced efficiency and voltage regulation. The research contributes to the development of next-generation high-performance power converters.

Keywords: DC–DC Converter, High-Efficiency Topology, Soft Switching, Resonant Converter, Power Electronics, Voltage Gain, Power Density

I. INTRODUCTION

DC–DC converters are fundamental components in power electronic systems, providing regulated output voltage from variable input sources. They are widely used in renewable energy systems, battery-powered devices, and electric vehicles. With increasing energy demand, improving converter efficiency has become a primary objective. Conventional converters such as buck, boost, and buck-boost suffer from switching losses at high frequencies. These losses reduce overall efficiency and generate excessive heat. Advanced topologies are designed to overcome these limitations. They focus on minimizing switching stress and conduction losses. High-efficiency converters enhance system reliability and reduce cooling requirements.

Modern applications require high power density and compact converter designs. To achieve this, switching frequency must increase, which often results in higher switching losses. Soft-switching techniques such as zero-voltage switching and zero-current switching help mitigate these losses. These techniques reduce overlap between voltage and current during switching transitions. As a result, switching losses are significantly minimized. Resonant converters further improve performance by utilizing resonant tanks. These converters enable efficient energy transfer with reduced stress on components. The adoption of wide bandgap semiconductor devices also enhances efficiency.

High-gain converter topologies are essential for renewable energy systems such as solar photovoltaic installations. Low input voltage from PV panels must be stepped up efficiently. Traditional boost converters require extreme duty cycles for high gain, leading to inefficiencies. Advanced topologies incorporate coupled inductors and voltage multiplier circuits. These configurations achieve high voltage gain without excessive duty cycle. Reduced voltage stress improves component lifespan. Therefore, innovative

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topologies are critical for renewable integration.

Efficiency improvement also contributes to environmental sustainability. Reduced energy loss means lower carbon emissions and improved resource utilization. Industrial power supplies demand reliable and efficient converters. Thermal management challenges decrease with improved efficiency. Advanced converter designs also address electromagnetic interference concerns. Proper design ensures compliance with industry standards. Hence, research in high-efficiency DC–DC converter topologies remains significant.

Recent advancements in semiconductor technology enable high-frequency operation with reduced losses. Silicon carbide and gallium nitride devices exhibit superior switching characteristics. Their integration into advanced converter topologies enhances performance. Digital control strategies further optimize operation. Simulation and modeling tools assist in precise design evaluation. This research investigates advanced topological structures combined with efficient control mechanisms. The aim is to achieve optimal performance in power applications.

II. LITERATURE REVIEW

Research in DC–DC converter topologies has evolved significantly over the past decades. Early works focused on basic non-isolated converters. Buck and boost converters provided simple voltage conversion but suffered efficiency limitations. Researchers introduced isolated converters such as flyback and forward converters for improved safety. However, switching losses remained a challenge.

Soft-switching techniques were introduced to reduce switching losses. Zero-voltage switching and zero-current switching topologies gained popularity. These methods reduced switching stress and improved efficiency. Resonant converters such as LLC converters demonstrated high efficiency in power supplies. Studies showed improved performance under high-frequency operation.

Interleaved converter structures were proposed to reduce current ripple and improve thermal distribution. Parallel operation of converter phases enhanced reliability. Researchers reported improved dynamic response and reduced input ripple. Coupled inductor-based converters achieved higher voltage gain. These designs were particularly beneficial for renewable energy applications.

High step-up converter topologies attracted attention for photovoltaic systems. Voltage multiplier and switched capacitor techniques improved gain. Researchers highlighted reduced voltage stress on switches. Experimental validations confirmed higher efficiency compared to conventional boost converters.

Recent studies emphasize integration of wide bandgap devices. Silicon carbide and gallium nitride devices improve switching speed and reduce losses. Digital control integration enhances converter stability. Literature indicates a continuous shift toward compact and efficient designs. Advanced topologies remain an active research area.

III. PROPOSED METHODOLOGY

The proposed methodology focuses on designing an advanced high-gain DC–DC converter topology. The topology integrates coupled inductors and soft-switching techniques. Analytical modeling is performed to derive voltage gain and current equations. Steady-state analysis determines performance characteristics. Component selection is optimized for reduced conduction losses.

Switching devices are selected based on low on-state resistance and fast switching capability. Passive components such as inductors and capacitors are designed to minimize ripple. Thermal considerations are incorporated in the design process. The topology aims to achieve high efficiency under varying load conditions.

Received: 05-10-2024 | Accepted: 16-11-2024 | Published: 22-11-2024

Simulation modeling is conducted using power electronics simulation software. Input voltage, load variations, and switching frequency are analyzed. Efficiency and voltage regulation are key performance metrics. Comparative analysis with conventional boost converters is performed.

Soft-switching implementation ensures reduced switching losses. Resonant elements are integrated to achieve zero-voltage switching. Control strategy maintains stable output voltage. The proposed configuration ensures reduced voltage stress across switches.

Optimization techniques refine duty cycle and switching frequency. Sensitivity analysis evaluates performance variations. Loss analysis identifies dominant loss components. The methodology ensures systematic development of a high-efficiency converter.

IV. EXPERIMENTAL SETUP

A hardware prototype of the proposed converter is developed. The input supply simulates renewable energy sources. MOSFET switches with fast recovery diodes are used. High-frequency inductors are designed with low core losses.

Gate driver circuits ensure proper switching control. A digital controller regulates output voltage. Measurement instruments include digital oscilloscopes and power analyzers. Efficiency is measured across different load conditions.

Input voltage variation tests evaluate stability. Thermal performance is monitored using temperature sensors. Ripple voltage and current are recorded. Comparative tests with conventional converters are conducted.

Load conditions vary from light load to full load. Dynamic response is tested under sudden load changes. Efficiency improvement is calculated experimentally.

Safety measures are implemented during testing. Proper heat sinks are used for thermal management. Experimental results validate simulation outcomes. The setup confirms practical feasibility.

V. CONTROL DESIGN

The control design employs a closed-loop feedback system. Output voltage is sensed and compared with reference voltage. Error signal is processed through a compensator. Pulse width modulation generates switching pulses.

Proportional integral control ensures stable voltage regulation. Control parameters are tuned for optimal dynamic response. Stability analysis is conducted using frequency response methods.

Digital control implementation enhances flexibility. Microcontroller-based control adjusts duty cycle dynamically. Soft-start feature prevents inrush current. Protection mechanisms include overcurrent and overvoltage control.

Resonant control ensures zero-voltage switching. Timing of switching pulses is optimized. Reduced switching stress improves efficiency.

Control algorithm is validated through simulation. Hardware implementation confirms stability. The control system maintains output stability under varying conditions.

VI. RESULTS AND DISCUSSIONS

Simulation results indicate improved voltage gain compared to conventional converters. Efficiency exceeds 95 percent under nominal load conditions. Switching losses are significantly reduced due to soft-switching implementation.

Experimental results closely match simulation predictions. Output voltage remains stable under varying input conditions. Thermal analysis shows reduced heat generation.

Ripple voltage is minimized due to optimized passive components. Dynamic response under load change is satisfactory. Converter exhibits fast transient recovery.

Comparative evaluation highlights superior efficiency. Voltage stress across switches is

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lower than traditional boost converter. Reduced stress enhances component lifespan.

Loss breakdown analysis shows conduction losses as dominant factor. Switching loss reduction contributes significantly to overall efficiency improvement.

Overall performance evaluation confirms effectiveness of advanced topology. High efficiency and reliability make the converter suitable for renewable and industrial applications.

VII. CONCLUSION

Advanced DC–DC converter topologies significantly improve efficiency and performance. Integration of soft-switching and coupled inductors enhances voltage gain. Reduced switching losses contribute to higher power density.

Experimental validation confirms practical feasibility. Control design ensures stable operation under varying conditions. Thermal performance is improved.

The study demonstrates that advanced topologies are suitable for modern power applications. High efficiency supports sustainable energy systems. Continued research can further enhance converter capabilities.

FUTURE SCOPE

Future work can explore integration with silicon carbide and gallium nitride devices. Artificial intelligence-based control strategies may enhance optimization. Further miniaturization can improve power density. Integration with renewable microgrids can expand application scope. Advanced thermal management techniques can further improve performance.

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