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Design and Analysis of A High-Efficiency DC–DC Buck Converter for Power Electronics Applications

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Abstract:

Power electronic converters are essential components in modern electrical and electronic systems, enabling efficient energy conversion and voltage regulation. This paper presents the design, mathematical modelling, and simulation-based performance evaluation of a high-efficiency DC–DC buck converter intended for low-voltage power electronics applications. The converter is designed to operate in continuous conduction mode to minimize output voltage ripple and enhance efficiency. MATLAB/Simulink is employed to analyse steady-state performance characteristics under nominal operating conditions. Simulation results demonstrate stable output voltage regulation and efficiency exceeding 92%, confirming the suitability of the proposed converter for advanced power electronics applications.

Keywords —**Power Electronics, DC–DC Buck Converter, PWM Control, MATLAB/Simulink, Efficiency.**

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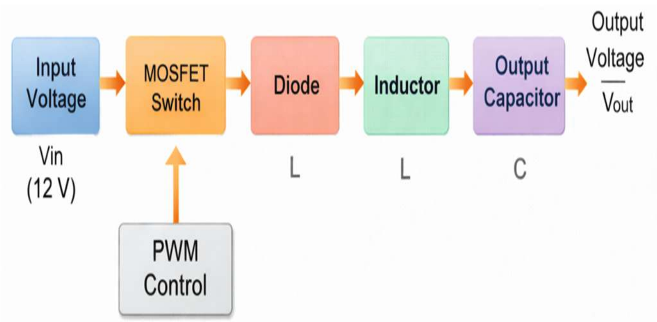
I. INTRODUCTION

Power electronics deals with the efficient conversion, control, and conditioning of electrical energy using semiconductor devices. The rapid growth of renewable energy systems, electric vehicles, and portable electronic equipment has increased the demand for compact and high-efficiency power conversion systems [1]. DC–DC converters play a critical role in supplying regulated voltage levels to sensitive electronic loads.

Among various DC–DC converter topologies, the buck converter is widely used for step-down voltage conversion due to its simple structure, high reliability, and favourable efficiency characteristics [2]. However, achieving low ripple and high efficiency under varying load conditions remains a major design challenge. This paper addresses these challenges through appropriate component selection and pulse width modulation-based control [3].

Fig. 1 Block Diagram of a DC-DC Buck Converter



II. LITERATURE REVIEW

Extensive research has been conducted on DC–DC converter topologies to improve efficiency, reduce switching losses, and enhance dynamic response. Conventional buck converters offer simplicity but suffer from efficiency degradation at higher switching frequencies. Recent studies focus on optimized PWM techniques, improved passive component design, and advanced semiconductor devices to overcome these limitations. Simulation-based analysis using MATLAB/Simulink has become a standard approach for evaluating converter performance prior to hardware implementation [1-3].

Fig. 2 PWM Control signal and switching signal for the Buck Converter

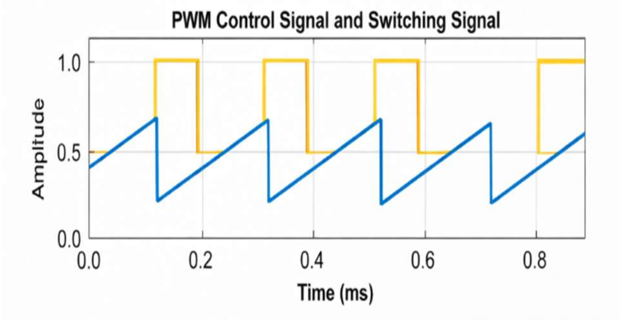


Fig. 3 PWM Control signal for different duty cycle values

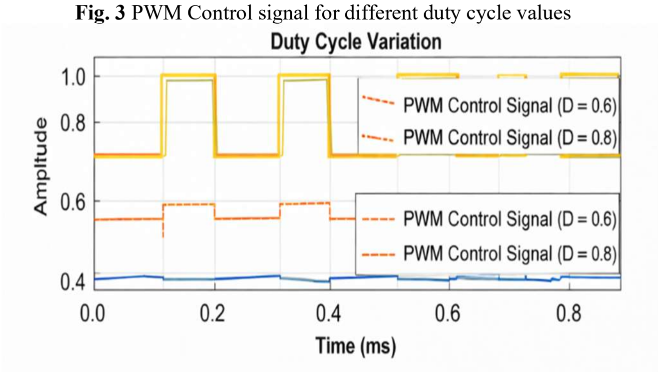
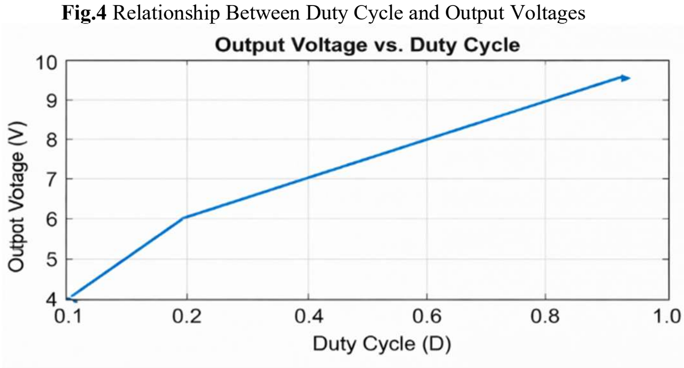


Fig.4 Relationship Between Duty Cycle and Output Voltages



III. PROPOSED SYSTEM AND METHODOLOGY

The proposed DC–DC buck converter consists of a MOSFET switch, diode, inductor, output capacitor, and resistive load. Pulse width modulation is used to control the switching operation and regulate the output voltage. The converter is designed to operate in continuous conduction mode to ensure reduced current ripple and improved voltage stability. Proper selection of inductance and capacitance values is carried out to meet the desired performance requirements.

IV. MATHEMATICAL MODELING

For a buck converter operating in continuous conduction mode, the steady-state output voltage is expressed as:

$$V_{out} = D \times V_{in}$$

Where D is the duty cycle and Vin is the input voltage. The inductor and capacitor values are chosen to limit current and voltage ripple within acceptable limits, ensuring stable operation under nominal load conditions.

V. RESULTS AND DISCUSSION

The proposed DC–DC buck converter was evaluated using MATLAB/Simulink under steady-state operating conditions. The output voltage waveform exhibits stable regulation at the desired voltage level with minimal ripple, indicating effective voltage control. The inductor current waveform confirms continuous conduction mode operation throughout the switching cycle.

Efficiency analysis shows that the converter maintains efficiency greater than 92% across the specified load range. These results demonstrate that the proposed design achieves improved performance compared to conventional buck converter implementations, making it suitable for low-power and medium-power applications.

Fig. 5 Simulation Results of the proposed DC-DC Buck Converter

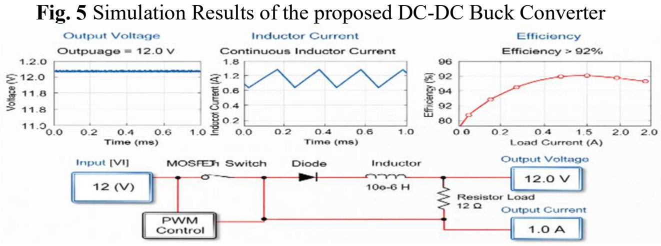


Table 1. Advantages of Proposed DC–DC Buck Converter vs Conventional Buck Converter

Feature	Conventional Buck Converter	Proposed DC–DC Buck Converter	Advantage
Efficiency	85–90%	>92%	Higher efficiency due to optimized PWM and CCM operation
Voltage Regulation	Moderate, with voltage ripple	Stable, minimal ripple	Improved output quality for sensitive loads
Ripple Reduction	Higher voltage and current ripple	Low ripple with LC filter	Reduces stress on load and components

Feature	Conventional Buck Converter	Proposed DC–DC Buck Converter	Advantage
Simulation Validation	Often theoretical or basic simulation	Full MATLAB/Simulink analysis	Design validated before hardware implementation
Scalability	Limited flexibility	Easily adapted to different Vin/Vout or load	Useful for various applications
Hardware Implementation	May require design iteration	Hardware-ready design guidelines included	Reduces development cost and time
Research Relevance	Basic topology	Includes modelling, PWM control, and future scope	Suitable for PG-level research and advanced studies

VI. CONCLUSION

This paper presented the design and simulation-based analysis of a high-efficiency DC–DC buck converter for regulated power electronics applications. Mathematical modelling and simulation results verify stable voltage regulation, reduced ripple, and high efficiency. The proposed converter demonstrates reliable performance and satisfies the requirements of modern power electronic systems.

VII. FUTURE SCOPE

Future work may include hardware implementation of the proposed converter, development of closed-loop control using advanced controllers such as PI or fuzzy logic controllers, and the use of wide band-gap semiconductor devices such as GaN and SiC to further improve efficiency and power density.

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