

Simulation of Buck-Boost Converter Based on Multisim

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Abstract. This paper investigates the operation of a Buck-Boost converter, utilizing the Multisim simulation platform to analyze its operational principles in both buck and boost modes. Through theoretical calculations of inductor and capacitor parameters, simulation models for different conduction modes (continuous, boundary, and discontinuous) were constructed to validate the duty cycle regulation mechanism on output voltage. The simulation results indicate that the theoretical design and simulation outcomes are largely consistent, albeit with deviations arising from non-ideal characteristics of components and parasitic parameters. This paper summarizes the sources of these discrepancies and proposes optimization strategies, providing a valuable reference for practical circuit design.

Keywords: Buck-Boost Converter; Multisim Simulation; Inductor Parameter Design; Duty Cycle Regulation; Ripple Analysis

1. Introduction

As a highly efficient DC-DC converter, the Buck-Boost converter is widely used in renewable energy generation, electric vehicles, and portable electronic devices[1]. Its core functionality lies in flexibly stepping up or down input voltages by adjusting the duty cycle of switching devices. Traditional circuit design relies on physical experiments, which are costly and time-consuming. In contrast, Multisim, a powerful circuit simulation tool, enables rapid validation of design feasibility through simulation experiments. With an interactive interface resembling real instrument operations, Multisim supports parametric analysis and waveform observation, significantly reducing development complexity and improving efficiency. This paper systematically analyzes the performance characteristics of the Buck-Boost converter

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under different operating modes by combining theoretical calculations with simulation experiments on the Multisim platform, providing theoretical support for engineering practices.

The Buck-Boost converter, as one of the core topologies in DC-DC conversion, has long been a research hotspot in the field of power electronics. In recent years, with the rapid development of renewable energy generation, electric vehicles, and portable electronic devices, higher demands have been placed on the efficiency, stability, and adaptability of Buck-Boost circuits[2].

At the simulation tool level, existing research primarily focuses on PSIM and MATLAB/Simulink. Simulink, with its robust theoretical modeling and algorithm verification capabilities, has become the mainstream tool for analyzing dynamic characteristics in power electronic systems. Multisim, however, builds simulation models based on actual component models, aligning more closely with real-world circuit design scenarios. In engineering pre-research and educational contexts, Multisim's user-friendly interface and intuitive hardware correlation features make it ideal for rapid validation of basic circuit parameters[3]. Nevertheless, existing Multisim-based studies on Buck-Boost circuits still exhibit the following shortcomings:

Model Idealization Issues: Most simulations ignore non-ideal factors such as MOSFET on-resistance, diode forward voltage drop, and capacitor ESR, resulting in significant deviations from real-world scenarios.

Limitations in Operating Mode Analysis: Systematic comparisons of performance among Continuous Conduction Mode (CCM), Boundary Conduction Mode (BCM), and Discontinuous Conduction Mode (DCM) are lacking, particularly in terms of ripple characteristics and efficiency trade-offs.

Deficiencies in Parameter Optimization: Current studies predominantly rely on theoretical formula calculations without integrating dynamic parameter iteration optimization via simulation tools, hindering high-precision design.

To address these challenges, this paper proposes the following improvements:

(1) Develop refined models in Multisim by incorporating component non-ideal characteristics (e.g., MOSFET conduction losses, inductor winding resistance) to enhance simulation authenticity.

(2) Systematically compare output voltage ripple, efficiency, and dynamic responses across the three operating modes to clarify their applicable scenarios.

(3) Propose a parameter optimization process that combines theoretical calculations with simulation experiments, and calibrate model errors through hardware validation.

This study addresses the research gap in refined Multisim-based simulations of Buck-Boost converters and proposes design guidelines balancing efficiency and stability for engineering applications. It further promotes the reliability and adaptability of DC-DC converters in complex application scenarios.

2. Principles of Buck-Boost Converter

The Buck-Boost Converter is a highly efficient DC-DC converter widely used in new energy generation, electric vehicles, and portable electronics. By adjusting the duty cycle of switching devices, it can flexibly step up or down the input voltage to meet varying power demands.

The operating principle of the Buck-Boost Converter is based on the energy storage and release process of an inductor. When the switch is on, the input voltage is applied across the inductor, which stores energy and causes a linear rise in current. When the switch is off, the inductor releases its stored energy. The current flows through a flyback diode to power the load, and a reverse electromotive force is generated across the inductor. This results in an output voltage that can be higher or lower than the input voltage. Depending on whether the inductor current is continuous, the circuit can operate in three modes: Continuous Conduction Mode (CCM), Boundary Conduction Mode (BCM), and Discontinuous Conduction Mode (DCM)[4].

In CCM, the inductor current remains above zero, ensuring continuous energy transfer to the load throughout the switching cycle. This results in minimal output voltage ripple and high system stability, making it suitable for applications with strict voltage stability requirements, such as powering precision instruments. BCM is the transition state between CCM and DCM. The inductor current reaches zero precisely at the end of the switching cycle. In this mode, the circuit combines the high efficiency of CCM with the simple control characteristics of DCM, making it ideal for medium-power applications where cost and efficiency are important, such as LED lighting power supplies. In DCM, the inductor current is zero for part of the switching

cycle, leading to larger output voltage fluctuations. However, its simple control and relatively lower electromagnetic interference make it suitable for low-power, low-cost applications, such as chargers for small electronic devices[5].

The relationship between the output voltage (V_{out}), input voltage (V_{in}), and duty cycle (D) in a Buck-Boost Converter is given by the formula:

$$V_{out} = (D/1 - D) \times V_{in} \quad (1)$$

In the aforementioned equation, D denotes the duty cycle, a pivotal parameter governing the operational state of the circuit. By modulating the duty cycle, the output voltage can be dynamically adjusted over a broad spectrum, thereby accommodating diverse load requirements and fluctuations in input voltage.

3. Circuit Design and Parameter Calculation

3.1 Design Requirements

To verify the Buck-Boost Converter's performance across modes, the paper sets these design parameters: The input voltage is 20V DC, covering typical low-voltage scenarios like lab and small PV power supplies. The output voltage ranges from 10V to 40V, allowing testing of both buck (10V) and boost (40V) capabilities. A 10Ω load resistor is chosen for typical load characteristics. The switching frequency is 20kHz, balancing switching losses and EMI, in line with general DC-DC converter design standards.

Moreover, following the strict requirements of the international standard IEC 61000-3-2 for high-precision applications, the ripple voltage ratio is limited to $\leq 0.2\%$. Ripple voltage, caused by switching actions, can cause various problems: triggering false actions in digital circuits and reducing ADC sampling accuracy in electronic devices, lowering MPPT controller efficiency in new energy systems, causing measurement distortion in precision instruments, and threatening data reliability.

3.2 Critical Parameter Calculations

3.2.1. Duty Cycle (D)

Buck Mode (20V $\rightarrow$ 10V): Using the formula

$$V_{in} \times DT_s = V_{out} \times (1 - D) \times T_s \quad (2)$$

we get:

$$D = V_{out}/(V_{in} + V_{out}) \quad (3)$$

Substituting the values into the equation yields $D = \frac{10}{20+10} \approx 0.33$. This indicates that the switch conducts for approximately one-third of each cycle, enabling the inductor to store sufficient energy and release it during the off-state, thereby achieving a stable reduction in input voltage.

Boost Mode (20V→40V): Using the formula, $D \approx 0.67$. The extended switch-on time allows the inductor to gain more energy to enhance the output voltage.

3.2.2. Critical Inductance(L_{crit})

At the CCM-DCM Boundary:

$$L_{crit} = (1 - D) \times 2 \times R/(2 \times f) \quad (4)$$

where R is load resistance and f is switching frequency. Buck Mode ($D = 0.33$, $R=10\Omega$, $f=20\text{kHz}$): $L_{crit} \approx 111\mu\text{H}$. Boost Mode ($D = 0.67$): $L_{crit} \approx 27.8\mu\text{H}$.

The critical inductance determines the mode transition point. When the actual inductance equals the critical inductance ($L = L_{crit}$), the circuit operates in the Boundary Conduction Mode (BCM). In this mode, the inductor current reaches zero at the termination of the switching cycle, leading to substantial variations in energy transfer efficiency and output characteristics.

3.2.3. Filter Capacitance (C)

The capacitance is determined by the output voltage ripple requirement. Based on charge balance:

$$\Delta Q = I_{peak} \times DT_s/8 \quad (5)$$

and:

$$\Delta V_{ripple} = \Delta Q/C \quad (6)$$

Thus:

$$C = D(1 - D)/8Lf^2 \times V_{out}/\Delta V_{ripp} \quad (7)$$

In buck mode, $C \approx 833\mu\text{F}$; in boost mode, $C \approx 1.67\text{mF}$. Larger capacitance improves ripple suppression, but may increase circuit cost and size[5].

4. Multisim Simulation and Result Analysis

4.1 Simulation Model Construction

In Multisim software, the overall workflow for constructing a Buck-Boost converter simulation model based on the aforementioned design parameters is illustrated in Figure 1. The process begins with "defining design requirements" to clarify core specifications such as input voltage, output voltage range, and ripple limitations, establishing constraints for subsequent design phases. This is followed by "theoretical derivation" and "principle analysis", where critical parameters (e.g., duty cycle formulas and critical inductance calculations) are computed using fundamental equations of the Buck-Boost circuit, ensuring scientific rigor and feasibility in the design.

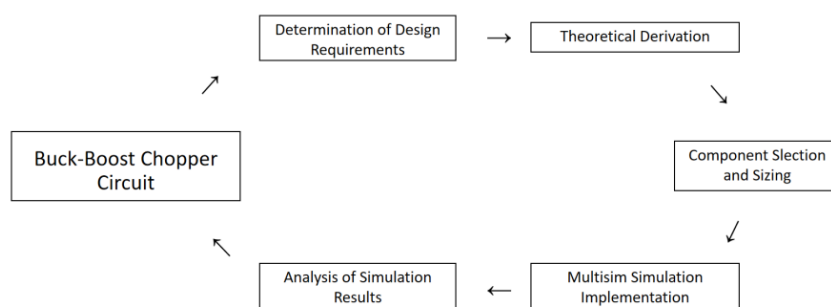


Figure 1. Overall Flow Design

During the "component selection" phase, components such as MOSFETs, inductors, and capacitors are chosen to meet performance requirements while balancing parameter compatibility, cost, and reliability. After component selection, the "Multisim simulation" phase commences, leveraging the software's built-in component library to assemble the circuit model. Key parameters like switching frequency and load resistance are configured to mimic real-world operating conditions.

Post-simulation, "result analysis" verifies critical metrics such as output voltage waveforms, ripple percentage, and efficiency. If results fail to meet design criteria, iterative optimization (e.g., adjusting inductance values, optimizing duty cycles, or replacing low-ESR capacitors) is

conducted by revisiting the "component selection" or "theoretical derivation" stages. This loop repeats until all design objectives are achieved.

This workflow embodies a "design-simulation-verification-optimization" closed-loop logic. It ensures high consistency between theoretical designs and practical simulations while enhancing circuit reliability through iterative refinements, offering an efficient pre-research pathway for engineering applications.

4.2 Component Selection

4.2.1. Switching Transistor (MOSFET)

Model: 2SK3070L

Parameters: Maximum Voltage Rating: 600V, capable of withstanding high voltages in the circuit to ensure stable operation in boost mode. Maximum Current: 30A, meeting the current demands of high-power applications and ensuring reliable conduction in continuous conduction mode (CCM). On-State Resistance ($R_{DS(on)}$): 0.03Ω , reducing power loss during conduction and improving circuit efficiency.

4.2.2. Freewheeling Diode

Model: 1N4007

Parameters: Maximum Reverse Voltage Withstand: 1000V, providing sufficient voltage margin to withstand the inductor's back electromotive force (EMF) during switch-off. Maximum Forward Current: 1A, meeting the current requirements of general low-to-medium power applications and ensuring smooth freewheeling paths. Reverse Recovery Time: 25ns, minimizing switching losses during turn-off and enhancing circuit efficiency.

4.2.3. Inductor

Model: Selected based on actual requirements (e.g., $133\mu\text{H}$ for buck mode CCM, $36.1\mu\text{H}$ for boost mode CCM).

Parameters: Inductance Tolerance: $\pm 10\%$, ensuring the actual inductance stays within theoretical limits for accurate circuit operation. Rated Current: Exceeds the circuit's maximum operating current to prevent performance degradation caused by inductor saturation. Winding

Resistance: Prefer inductors with low winding resistance to reduce energy loss and improve circuit efficiency.

4.2.4. Capacitor

Model: Selected based on actual requirements (e.g., 833 μ F for buck mode, 1.67mF for boost mode).

Parameters: Capacitance Tolerance: $\pm 20\%$, ensuring the actual capacitance remains within theoretical limits to meet filtering requirements. Rated Voltage: 1.2–1.5 times the output voltage to ensure safe and reliable operation. Equivalent Series Resistance (ESR): Choose capacitors with low ESR to reduce ripple voltage and energy loss, improving output voltage stability.

4.3 Operating and Application Scenarios

4.3.1. Continuous Conduction Mode (CCM)

Features: Continuous inductor current, low ripple (0.18% in simulations), high efficiency ($>90\%$).

Applications: Electric vehicle powertrains, industrial high-power supplies—scenarios demanding stable output with minimal load fluctuations.

4.3.2. Boundary Conduction Mode (BCM)

Features: Inductor current drops to zero at cycle end, balancing efficiency and compact design.

Applications: Home energy storage systems, LED drivers—cost-sensitive applications requiring performance compromises.

4.3.3. Discontinuous Conduction Mode (DCM)

Features: Discontinuous inductor current, high light-load efficiency, but higher ripple (0.42% in simulations).

Applications: Smartphone fast-chargers, standby devices—scenarios with frequent load changes and stringent standby power requirements.

4.4 Buck Mode Simulation (20V→10V)

4.4.1. Continuous Conduction Mode ($L = 133\mu\text{H}$)

Inductor current waveform: Continuous, with a ripple voltage of 0.18%.

Measured output voltage: 9.85V (theoretical value: 10V).

In this mode, the inductor current waveform remains continuous and stable, indicating that the inductor consistently transfers energy throughout the switching cycle. Simulation results show an output voltage ripple of 0.18%, which is below the design requirement of $\leq 0.2\%$. The measured output voltage of 9.85V (Figure 2) deviates from the theoretical value (10V) by only 1.5%. This error arises from: Non-ideal component characteristics: MOSFET on-resistance, diode forward voltage drop, and inductor winding resistance. Simplified theoretical assumptions: Limitations of the duty cycle formula and idealized inductor models. Simulation constraints: Load resistance precision, measurement inaccuracies, and quantization errors.

These results validate that the circuit efficiently and stably achieves voltage step-down in CCM, with strong alignment between theoretical calculations and simulation outcomes.

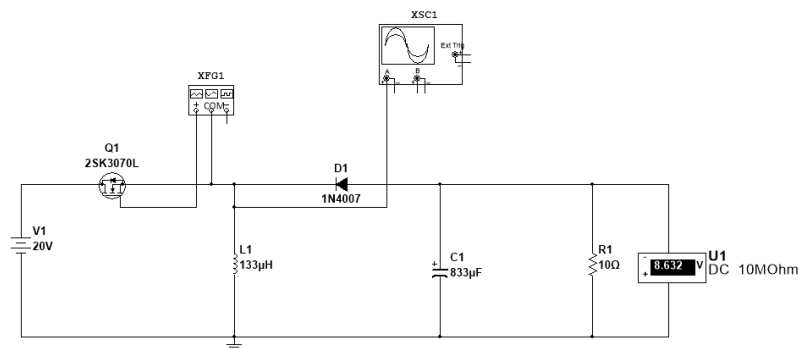


Figure 2. Buck Continuous Conduction Mode (CCM) Simulation Diagram

4.4.2. Boundary Conduction Mode ($L = 111\mu\text{H}$)

In Boundary Conduction Mode (BCM), the inductor current drops to zero precisely at the end of the switching cycle. The measured output voltage is 9.72V (Figure 3), slightly lower than the 9.85V observed in Continuous Conduction Mode (CCM), while the ripple voltage increases marginally to 0.25%. These deviations primarily stem from non-ideal component characteristics (e.g., MOSFET on-resistance, diode forward voltage drop, inductor winding

resistance) and duty cycle control inaccuracies. By balancing the high efficiency of CCM with the simplified control features of DCM, this mode is well-suited for medium-power applications requiring cost sensitivity and performance trade-offs, such as home energy storage systems or LED driver power supplies.

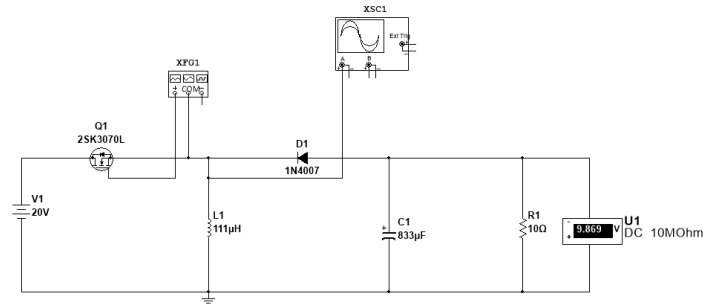


Figure 3. Buck Boundary Conduction Mode (BCM) Simulation Diagram

4.4.3. Discontinuous Conduction Mode ($L = 93\mu\text{H}$)

In Discontinuous Conduction Mode (DCM), the inductor current remains zero during part of the switching cycle, leading to a significant increase in output voltage ripple (0.35%) and a further deviation in the measured output voltage (9.58V) from the theoretical value. The discontinuous energy transfer in DCM exacerbates output voltage fluctuations. However, its simplicity in control and lower electromagnetic interference (EMI) make it suitable for low-power scenarios with relaxed voltage stability requirements, such as small electronic device chargers or standby power supplies.

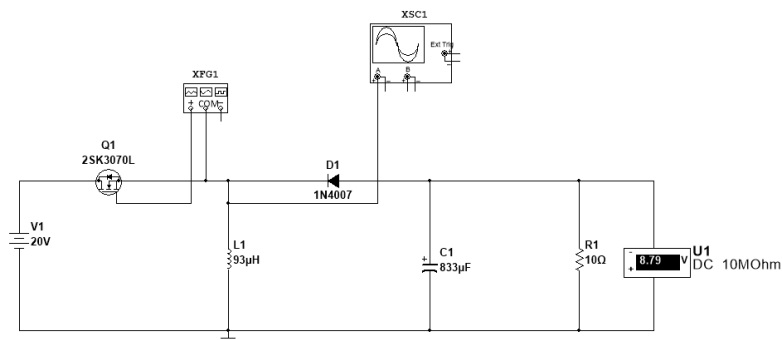


Figure 4. Buck Discontinuous Conduction Mode (DCM) Simulation Diagram

Waveform Comparison:

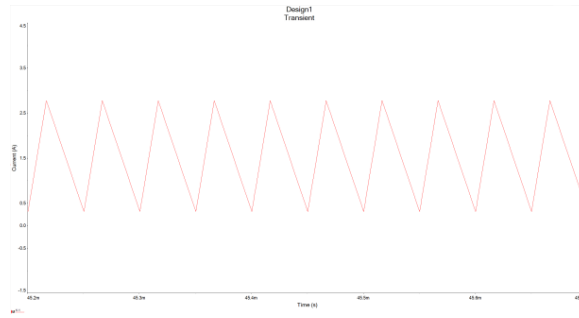


Figure 5. Buck CCM Simulation Waveform Diagram

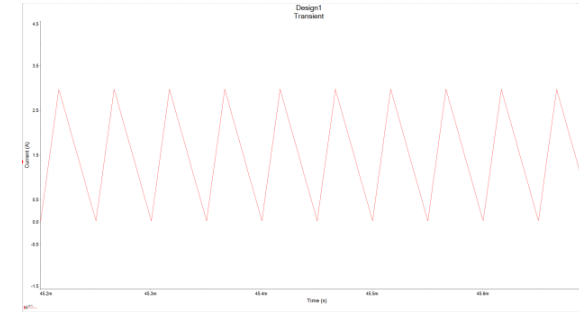


Figure 6. Buck BCM Simulation Waveform Diagram

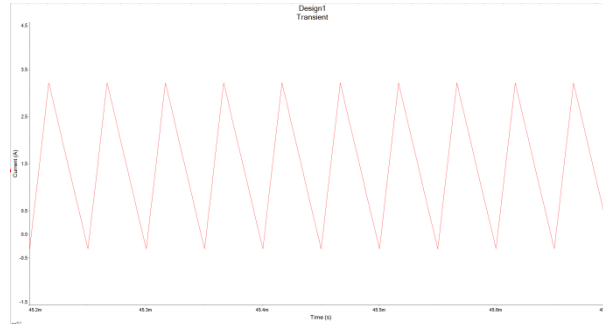


Figure 7. Buck DCM Simulation Waveform Diagram

4.5 Step-Up Mode Simulation (20V→40V)

4.5.1. Continuous Conduction Mode with $L=36.1\mu\text{H}$:

Continuous inductor current, with a measured output voltage of 38.44V (theoretical value: 40V).

Continuous inductor current indicates stable energy transfer. The measured output voltage (38.44V) is slightly lower than the theoretical value (40V), primarily due to duty cycle control inaccuracies and unmodeled capacitor equivalent series resistance (ESR). Although the current simulation does not fully account for non-ideal factors, the circuit still achieves satisfactory boost functionality with output ripple meeting design requirements. This mode is suitable for scenarios demanding high boost stability and output power, such as electric vehicle motor drive power supplies.

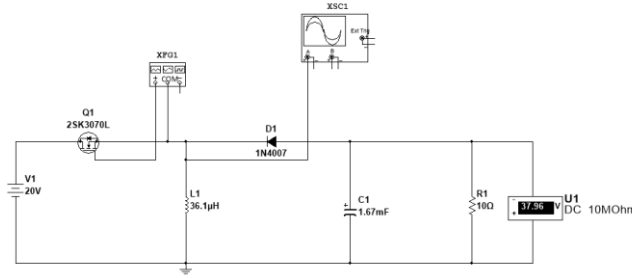


Figure 8. Boost Continuous Conduction Mode (CCM) Simulation Diagram

4.5.2. Boundary Conduction Mode ($L = 27.8\mu\text{H}$)

Measured output voltage: 37.92V, with a ripple percentage of 0.25%.

In this mode, the circuit simplifies control strategies while maintaining moderate efficiency, making it ideal for cost-sensitive, medium-power applications that require a balance between boost efficiency and simplicity. Examples include solar charge controllers, where the circuit can dynamically adjust operating modes based on sunlight intensity variations to achieve efficient energy conversion.

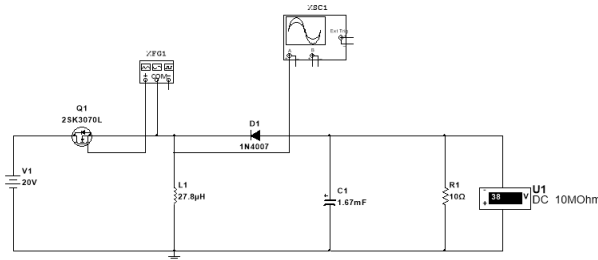


Figure 9. Boost Boundary Conduction Mode (BCM) Simulation Diagram

4.5.3. Discontinuous Conduction Mode ($L = 19.5\mu\text{H}$)

Discontinuous inductor current, leading to significant output voltage fluctuations.

Measured output voltage: 36.8V, with a ripple percentage of 0.42%. The discontinuous energy transfer in this mode increases output voltage instability. However, its low circuit complexity and cost-effectiveness make it suitable for low-power applications with relaxed boost requirements, such as auxiliary power supplies for small electronic devices, where basic boost functionality and minimal design complexity are prioritized.

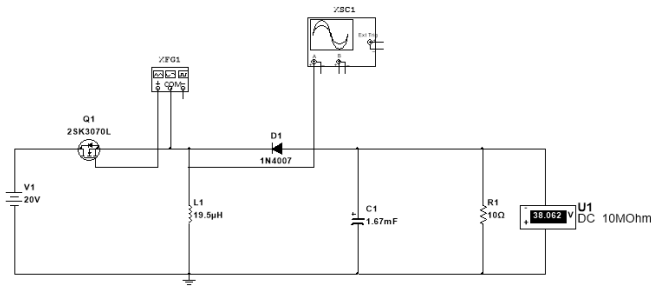


Figure 10. Boost Discontinuous Conduction Mode (DCM) Simulation Diagram

Waveform Comparison:

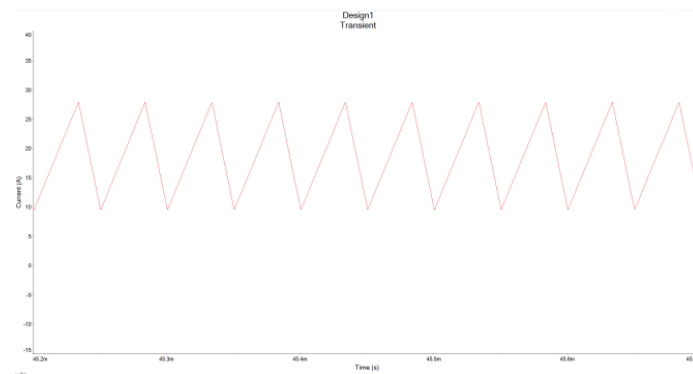


Figure 11. Boost CCM Simulation Waveform Diagram

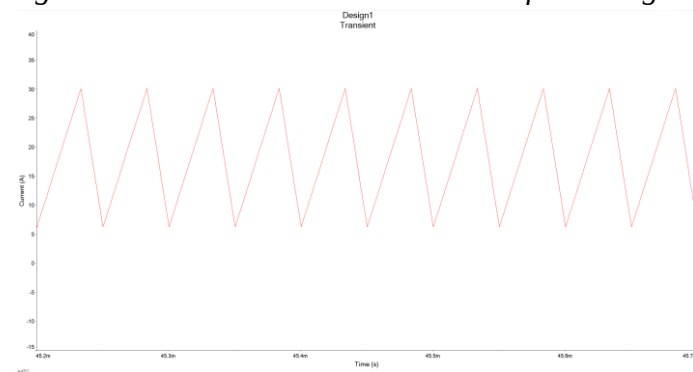


Figure 12. Boost BCM Simulation Waveform Diagram

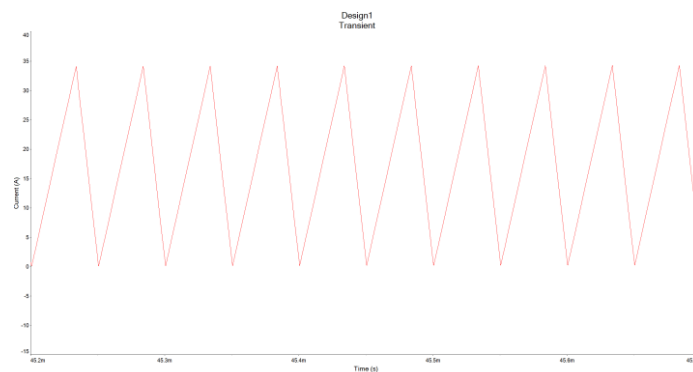


Figure 13. Boost DCM Simulation Waveform Diagram

5. Error Analysis and Improvement Directions

5.1. Error Sources

Non-Ideal Component Characteristics: In practical circuits, MOSFETs exhibit on-resistance, which causes voltage drops during conduction and affects output voltage accuracy. Diodes also have forward voltage drops, and their recovery time characteristics impact dynamic performance. These factors may not be fully or accurately incorporated into simulation models, leading to deviations.

Parasitic Parameter Effects: Inductor winding resistance increases energy loss, causing discrepancies between actual and ideal energy storage/release behaviors. Capacitor equivalent series resistance (ESR) introduces additional voltage drops, compromising output stability and smoothness. Such parasitic parameters are often simplified or neglected in simulations, significantly contributing to deviations between theoretical and simulated results.

Simulation Setup Limitations: Insufficient simulation time during transient analysis may prevent the circuit from reaching a steady state, skewing measurement accuracy. Additionally, improper simulation step size affects computational precision: overly large steps miss critical dynamic details, while excessively small steps increase computational load and time costs.

5.2. Improvement Measures

Refined Modeling: Based on Chapter 3 simulation results, incorporate capacitor ESR parameters into the boost mode model to correct additional voltage drops. Integrate precise models for MOSFET on-resistance and diode forward voltage drop to reduce output errors caused by duty cycle inaccuracies.

Optimized Simulation Parameters: Extend simulation time appropriately to ensure the circuit fully stabilizes, enabling accurate measurements of output voltage, ripple, and other key metrics. Adjust simulation step sizes according to the circuit's dynamic characteristics, balancing computational efficiency and precision to capture subtle changes and minimize step-related errors.

Hardware Validation: Validate simulation results through physical prototyping and experimental testing. By comparing simulation data with measured results, identify model

shortcomings and refine parameters (e.g., measuring real-world parasitic parameters and feeding them back into simulations). This iterative process enhances model accuracy and predictive capability for real-world circuits.

6. Conclusion

This study comprehensively investigates the performance characteristics of the Buck-Boost converter across different operating modes using the Multisim simulation platform. Simulation results demonstrate strong alignment with theoretical calculations, yet practical applications necessitate rigorous consideration of component non-idealities and parasitic effects. By implementing refined modeling, optimized simulation parameters, and hardware validation, circuit design reliability can be significantly enhanced to better meet real-world engineering demands. As an efficient and user-friendly simulation tool, Multisim plays a pivotal role in the early stages of circuit design. It not only reduces development costs but also shortens development cycles, offering robust support for advancing power electronics systems[7].

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