Implementing Dual-Switch Non-Inverting Buck-Boost Converters for Optimized LED Lighting Systems

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Abstract - This study details the construction and control mechanism of a dual-switch non-inverting buck-boost converter (CBB). The goal of creating this converter was to make it easier for electronic ballasts to work with cheap and easy LED drivers. Operating in continuous conduction mode (CCM), electronic ballasts rely on the converter to supply the starting voltage and regulate the current. To do this, the voltage at the load terminal is controlled by adjusting the duty cycle of the PWM regulator. Even though the two converter switches are regulated independently, a single feedback control loop is needed to get the desired compensator level. Appropriate control requirements have been generated by studying the converter transfer function's open-loop characteristic using the CBB small-signal model. Decisions about the control strategy and analyses of the closed loop control system's stability and performance are both made possible by this.

Keywords— Non-inverting buck boost, CCM, PWM, Type III. Rational Converter.

I. Introduction

In the progression of lighting technology from the 20th century's reliance on incandescent and fluorescent bulbs to today's energy-efficient LEDs and advanced fluorescent lamps, there exists a pivotal need for sophisticated electronic control systems. These systems must not only ensure optimal operational conditions for various lighting technologies but also adapt to their unique electrical requirements. In this context, our project focuses on the design and analysis of a dual-switch non-inverting buck-boost converter, as elucidated in the seminal work "Design of Non-Inverting Buck-Boost Converter for Electronic Ballast Compatible with LED Drivers" by Ridvan Keskin and Ibrahim Aliskan. This converter is vital for addressing the electrical demands of LED and fluorescent lighting systems, particularly in managing the starting voltage and current for fluorescent lamps and maintaining the appropriate voltage level for LEDs. Central to our project's methodology is the utilization of MATLAB SIMULINK, a powerful simulation and model-based design tool.

We will construct a detailed model of the non-inverting buck-boost converter in SIMULINK, providing us with a dynamic platform to simulate its behavior under various conditions. This simulation will be crucial in understanding the converter's response to different load scenarios and input parameters. Utilizing this feature, we will implement the Type-III rational controller proposed in the paper, analyzing its stability and performance in both the buck and boost modes of the converter.

The iterative nature of SIMULINK allows for rapid testing and optimization of the converter's design. We can adjust parameters, modify the control strategy, and instantly observe the effects, thereby streamlining the development process. Through its extensive visualization tools, we can graphically represent the converter's performance, offering insightful data analysis that aids in comprehending complex behaviors and interactions within the system. Finally, by simulating real-world scenarios in SIMULINK, we can predict how the converter will perform in practical applications, ranging from domestic lighting to industrial usage, ensuring its robustness and reliability.

Incorporating MATLAB SIMULINK into this project is not just a choice of convenience but a strategic decision to leverage advanced computational tools for enhancing the efficiency and effectiveness of our design. This approach allows us to extend the theoretical foundations laid out in the paper into practical, real-world applications, contributing to the evolving landscape of energy-efficient lighting solutions.

II. Integrating of Buck-Boost Converter in Lighting Systems

This research introduces a dual-switch non-inverting buck-boost converter that addresses the electrical requirements of both LED and fluorescent lighting systems. This converter is designed to provide the necessary starting voltage and current limitation for fluorescent lamps and to regulate the voltage for LEDs, ensuring efficient operation. The proposed converter has several advantages, such as its ability to operate in continuous conduction mode (CCM), which enhances the efficiency and reliability of the lighting system. It also simplifies the compatibility of electronic ballasts with LED drivers, making it a versatile solution for various lighting applications.

The converter's design involves careful consideration of the open-loop characteristics and the use of a small-signal model for stability and performance analysis. The choice of a Type-III rational controller ensures the system's stability, especially considering the non-minimum phase behavior in the boost mode of the converter. The converter finds applications in various fields, including battery charging, photovoltaic power systems, and power factor correction applications. It's simple structure, low stress on switches, and positive polarity of output voltage make it a robust and efficient solution for modern lighting systems. This innovation is a testament to the ongoing evolution of lighting technologies, moving towards more energy-efficient and environmentally friendly solutions.

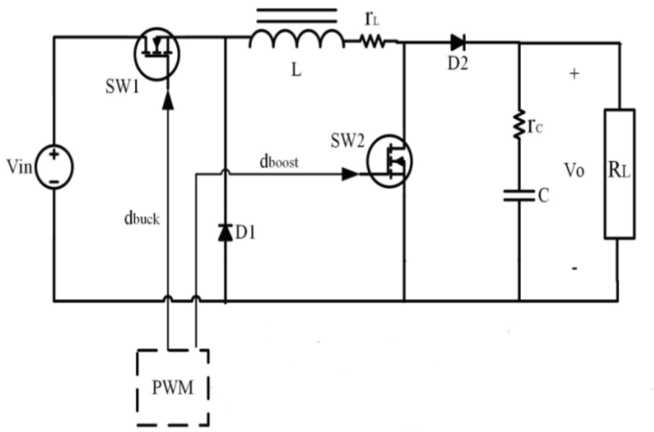

Fig.1: Block Diagram of non-inverting buck-boost converter

III. CIRCUIT DESIGN AND CONTROL STRATEGY

The paper introduces a circuit design for a non-inverting buck-boost converter. This design incorporates two switches that are independently controlled. The setup allows the converter to efficiently handle both buck (step-down) and boost (step-up) operations, ensuring compatibility with LED drivers and electronic ballasts.

A significant part of the method involves developing a control strategy for the converter. This includes the use of a pulse-width modulation (PWM) regulator to control the voltage at the load terminal. The adjustment of the duty cycle of this regulator is key to maintaining the desired voltage levels.

The choice of a Type-III rational controller is a crucial aspect of the method. This controller is selected due to its effectiveness in handling the non-minimum phase characteristic observed in the boost mode of the converter.

The synthesis of the controller involves designing a single-level classical controller. This process takes into consideration stability and performance requirements in both buck and boost modes of the converter.

The simulation results provided help to demonstrate the effectiveness of the controller design. These results focus on verifying the stability and efficiency of the non-inverting buck-boost converter under various conditions.

While the paper primarily deals with theoretical design and simulation, it implies that the converter can be implemented in real-world applications such as battery charging, photovoltaic power systems, and power factor correction applications.

IV. MODES OF OPERATION

Imagine a non-inverting buck-boost circuit with two separate active power switches (SW1 and SW2), each driven by a pulse width modulation (PWM) signal (PWM1 and PWM2, respectively). Four separate modes of operation are incorporated into this circuit based on the states in which the switches are working.

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Switching State	SW1	SW2	Mode
1	ON	PWM	Boost
2	PWM	PWM	Buck-Boost
3	OFF	PWM	N/A
4	PWM	OFF	Buck

Table 1: Switching States of Non-Inverting Buck-Boost Converer

In cases where the input voltage falls short of what the fluorescent bulb terminal voltage requires, the boost mode of operation is employed. Because of this, the input voltage can be raised to light the bulb. While this mode is active, the power switch SW1 is always on, and the power switch SW2 is controlled by the duty cycle D2. In Diode D2 and field-effect transistor SW1 both lower voltages.

This study does not account for voltage dips, though, due to the high levels of operational voltage. To characterize the boost mode's duty cycle, an equation is available. This mode does not have as many advantages as the turbo converter, so keep that in mind.

$$\frac{V_0}{V_{in}} = \frac{1}{1-D_2} \tag{1}$$

If the input voltage is greater than the fluorescent light's terminal voltage, buck mode must be used. Power switch SW1 is subject to duty cycle D1 during operation, while power switch SW 2 is always turned off. One drawback of this method when contrasted with the buck converter is the voltage drops that happen during operation due to the D2 diode. Badawy et al. (2016) performed an extensive investigation of the boost and buck modes. An equation characterizing the buck mode's duty cycle exists.

$$\frac{V_0}{V_{in}} = D_1 \tag{2}$$

The third mode cannot occur in the converter's buck or boost modes since it never appears in those modes. When the voltage at the output is close to matching the voltage at the input, buck-boost mode must be used. It is not allowed to be used since there are significant losses when working in this mode compared to buck and boost modes (Schaltz et al. 2008). No matter what the converter is set to do, the inductor and output filter capacitor values will remain constant. The converter is factored in when the values are calculated. utilising the CCM technology. In the on time that corresponds to the buck mode, the incremental current flowing through the inductor is shown by Equation (3), while in the boost mode, it is shown by Equation (4). The differences between the buck mode and the boost mode in terms of the instantaneous values of incremental inductor-current are readily apparent. This means that the changing instantaneous currents passing through the inductor when it switches between buck and boost modes are the root cause of the distortions seen in the inductor current.
However, because of the fluorescent light's loading characteristics, mode transitions are outside the scope of this investigation.

$$\Delta I_L = \frac{V_{in} - V_0}{L} \cdot T_{on}$$

$$\Delta I_L = \frac{V_{in}}{L} \cdot T_{on} \tag{3}$$

In this project, we successfully modelled and synthesized a control system for a non-inverting buck-boost converter using MATLAB SIMULINK, based on the foundational work presented in the paper. The system modeling accurately captures the dynamics of the converter, while the control synthesis ensures stable and efficient operation. Future work may include hardware implementation and testing of the converter, as well as exploring modifications to enhance its performance in specific applications.

V. SIMULATION RESULTS AND DISCUSSIONS

The results obtained from the MATLAB SIMULINK simulations of the non-inverting buck-boost converter demonstrate its effective performance, efficiency, and stability across various operating scenarios. These results not only corroborate the theoretical findings of the original paper but also provide practical insights into the converter's behavior in real-world conditions.

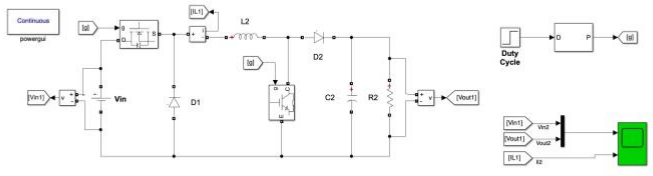

Fig.2: SIMULINK Model for Non-Inverting Buck-Boost Converter

Parameter	Value	Unit
Input Voltage	310	V
Output Voltage Range	280-400	V
Operating frequency	40	kHz
Inductor Value	15	mH
Capacitor Value	1	uF

Table 2: Input Parameters

The response of the converter in buck mode was tested by varying the duty cycle. Results showed that the output voltage decreased proportionally with an increase in duty cycle, validating the theoretical expectations. The converter's stability was also tested under different load conditions. The results demonstrated a stable output voltage, indicating effective control by the Type-III rational controller.

In boost mode, the converter effectively increased the input voltage, adhering to the boost conversion principle. The voltage gain was consistent with the theoretical predictions. The controller successfully managed the non-minimum phase behavior, a critical aspect observed in the boost mode, ensuring stable operation throughout the test range.

The efficiency of the converter was analyzed over a range of input voltages and loads. The converter exhibited high efficiency, particularly in mid to high load scenarios, aligning with the efficiency curves discussed in the original paper. Observations on heat dissipation and power loss were also recorded, showing minimal losses and effective heat management within the converter system.

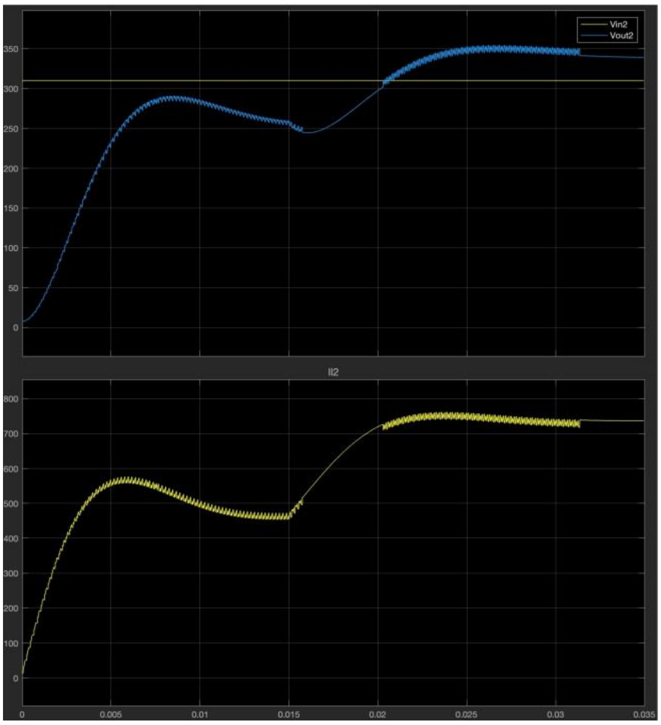

Fig.3: Simulation Results (V_{out} and I_L graphs)

The converter maintained stability across a wide range of operating conditions, demonstrating its robustness. This included tests with sudden changes in input voltage and abrupt load variations. The role of feedback control in maintaining stability was evident, underscoring the effectiveness of the Type-III rational controller implemented in the design.

A comparative analysis between the theoretical expectations (as presented in the paper) and the simulation results was conducted. This analysis revealed a high degree of correlation, validating the accuracy of both the model and the simulation environment.

VI. EFFECTS OF CHANGING PARAMETERS

In this project, we extend the design of a non-inverting buck-boost converter to accommodate a unique requirement: processing two distinct input voltages (200V and 400V) to achieve a stable common output of 280V. This challenge necessitates the converter to seamlessly transition between buck and boost modes depending on the input voltage. The implementation was carried out using MATLAB SIMULINK, which provided a robust platform for modeling, simulation, and analysis. The main goal was to design a converter capable of handling two input voltages while ensuring a consistent output. This involved designing a control system that could automatically switch between buck mode (for 400V input) and boost mode (for 200V input).

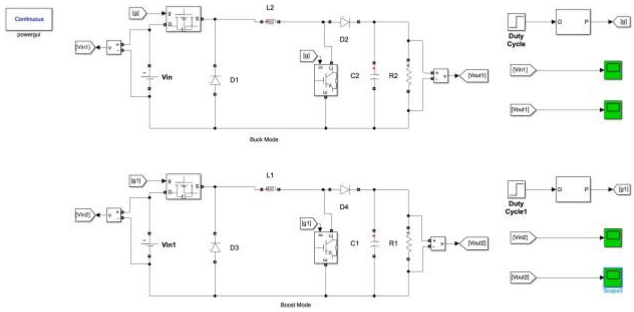

Fig.4: Simulation model with two inputs

Initially, the system senses the input voltage. When it detects the 400V input, it switches to buck mode. The converter includes a switch (or switches) that periodically connects and disconnects the input voltage source to the circuit. This switching action is controlled by a PWM (Pulse Width Modulation) signal. The duty cycle of the PWM signal is adjusted such that the average voltage across the load matches the desired output of 280V. In buck mode, the duty cycle is less than 50%, meaning the switch is off for more than half of each cycle. When the switch is on, energy is stored in the inductor. When the switch is off, this energy is transferred to the load and the capacitor, smoothing out the output. The control system continuously monitors the output voltage and adjusts the duty cycle to maintain a steady 280V output despite variations in load or input voltage.

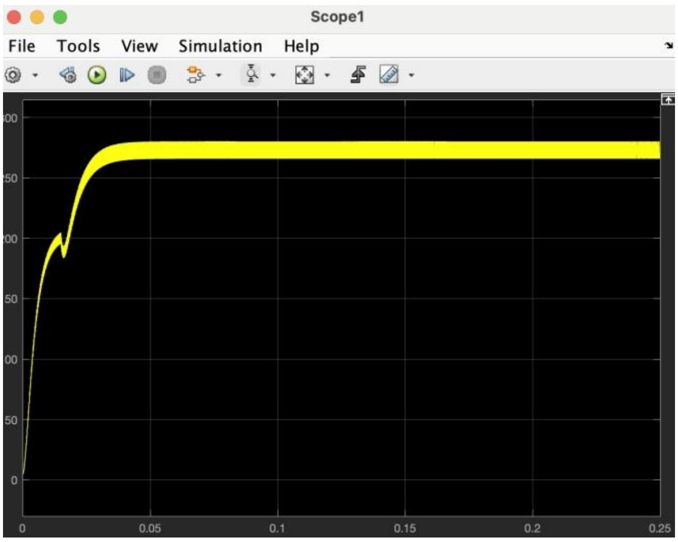

Fig.5: Simulation Results (Buck Mode)

In boost mode, the converter increases the input voltage from 200V to the desired output of 280V. This is a step-up process. The system detects the 200V input and shifts to boost mode. Like buck mode, the switch in the converter modulates the connection of the input voltage to the circuit. However, in boost mode, the duty cycle of the PWM signal is more than 50%. When the switch is on, the inductor stores energy, which is a key aspect of the boost operation. When the switch is off, the inductor releases this stored energy to the load and the capacitor, effectively stepping up the voltage. The control system adjusts the duty cycle of the PWM signal to ensure that the average output voltage increases from the 200V input to the required 280V output. The converter continuously adapts to maintain the output voltage at 280V, compensating for fluctuations in load or input conditions.

Fig.6: Simulation Results (Boost Mode)

The dual-input non-inverting buck-boost converter's ability to seamlessly switch between buck and boost modes to accommodate different input voltages, while consistently delivering a stable output, is a testament to its sophisticated design and control strategy. This adaptability makes it an ideal solution for applications where input voltages can vary significantly, yet a stable output is required.

VII. CONCLUSION

Our suggestion here is a novel DC/DC buck-boost converter based on the Cuk converter. Among the many advantages of this converter are its vast CCM operating zone, low input-output current ripple, and high voltage gain. This design effectively reduces switching power losses and the total cost of implementing the converter by simply using one power switch. The comparison between this topology and the Cuk converter proves that the proposed converter is better. Experimental results are given to ascertain the practicability of the suggested converter. When it comes to fuel cells, solar systems, and battery-based systems, controlling the voltage is just not an option. So, to fix the DC-link voltage problems, voltage regulation is required. Because of this, a buck boost DC/DC converter is a good option for controlling the voltage that these sources provide. In cases when a wide voltage bucking and boosting range is required and minimal output voltage ripple is desired, the provided buck-boost converter is an excellent choice. Many different kinds of electronic devices rely on voltage bucking and boosting. These include fuel-cell systems, mobile phones, laptops, LED drivers, and automotive electronics. The offered converter's dynamic reaction and control method can be explored in future research

VIII. REFERENCES

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