Design and Implementation of High Power Buck-Boost Converter Circuit with TL494 IC

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Abstract— **The objective of this project is to design, calculate, and implement a high-power Boost Converter using the TL494 Pulse Width Modulation (PWM) IC. The boost converter steps up a low input voltage (4.27V) to a higher output voltage (60V), making it highly suitable for applications where the output voltage must be greater than the input. This project aims to demonstrate the design and operation of the circuit while maintaining efficiency and reliability under varying load conditions.**

Keywords— Boost converter, TL494, PWM controller, DC-DC converter, power electronics

I. INTRODUCTION

The inverting buck-boost converter is a versatile power conversion topology that provides an output voltage either higher or lower than the input voltage, while also reversing the polarity of the output. This configuration is particularly useful in applications where a negative voltage rail is required. The TL494 integrated circuit (IC), commonly used for pulse-width modulation (PWM) control, serves as the core component in regulating the output of the inverting buck-boost converter. By utilizing its flexible PWM control, the TL494 ensures efficient energy transfer and stable operation, making it an ideal choice for various low-to-medium power DC-DC conversion applications. This IC allows precise control over the switching frequency and duty cycle, providing designers with the ability to fine-tune the converter's performance to meet specific requirements.

The goal of this project was to design, implement, and test a high-power buck-boost converter capable of stepping up a 12V input to 60V using the TL494 PWM controller. This report details the working principles, component selection, design process, testing, and efficiency calculations of the boost converter.

II. METHODOLOGY

The design and implementation of an inverting buck-boost converter using the TL494 IC involves several key steps. First, the input voltage range and desired negative output voltage are defined, followed by selecting the TL494 IC for its pulse-width modulation (PWM) control capabilities. This IC regulates the switching frequency and duty cycle, ensuring efficient power conversion. Critical components, such as the inductor, diode, and switching transistor (MOSFET or BJT), are selected based on the power and voltage requirements of the converter. In configuring the circuit, the TL494 is set up in PWM mode, with the switching frequency defined by external timing components. A feedback loop is then implemented using a voltage divider to maintain stable output voltage by comparing the actual output to a reference signal. Finally, the TL494 drives the switching transistor, controlling energy transfer to the load according to the feedback signal. This design methodology ensures the converter efficiently handles input variations while maintaining a stable and regulated negative output voltage.

A. Working Principle of basic Buck-Boost Converter

The buck-boost converter is a type of DC-DC converter and it has a different magnitude of the output voltage. The output voltage can be more than less than, or equal to the input voltage depending upon the PWM pulse and load condition. Buck-boost converters are very much similar to a flyback converter but the buck-boost converter uses a single inductor instead of a transformer. They have two different topologies: Inverting Buck-Boost converter and the non-inverting Buck-Boost converter. In this project, we will talk about the non-inverting buck-boost converter only. A basic schematic of the non-inverting buck-boost converter is shown below.

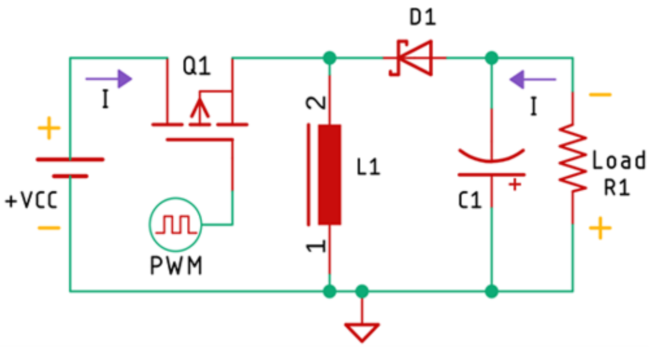

Figure 2.1: A basic non-inverting buck-boost converter.

As we can see in the above image, the output of the inverting covert is exactly opposite to that of the input. Instead of VCC, we get Ground, and instead of Ground, we get VCC, so how does the voltage get inverted? To answer this question, we need to know the working principle of this circuit.

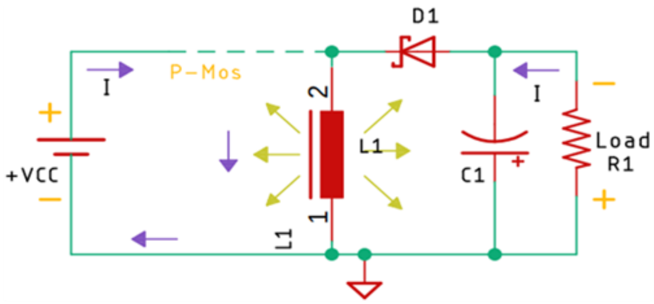

Figure 2.2: RLC model circuit -I.

As we can see in the above diagram, the circuit consists of an inductor, a diode, a MOSFET as a switch, and a capacitor. We are operating this circuit with a switching signal. As the used MOSFET is a P-channel MOSFET, it's on when the pulse is low, and it's off when the pulse is high. Now when the MOSFET is on, the inductor charges and builds up its energy; while that is happening, the diode prevents the capacitor from charging.

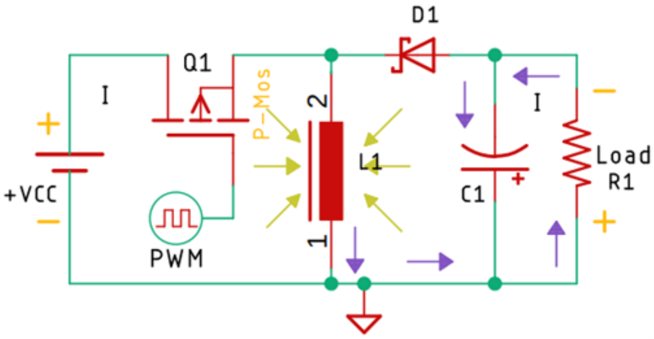

Figure 2.3: RLC model circuit -II.

Now, when the MOSFET gets turned off, the energy of the coil is transferred into the capacitor, and from the capacitor, it flows to the load but because the diode is connected in the reverse direction, the polarity of the voltage is now opposing to the input that is why it's known as the inverting buck-boost converter.

B. Components Required to Build TL494 Based Buck-Boost Converter

Components required for building the TL494 Based Buck-Boost Converter are listed below.

SL.No.	Component Name	Quantity
01	IC TL494 PWM Controller	1
02	IRFZ44N MOSFET	1
03	220 uH Inductor	1
04	LM358 Op-amp	1
05	MBR20100CT Diode	1
06	1000uF,25V Capacitor	2
07	2.2nF Capacitor	1
08	560-ohm Resistor	2
09	2.2K Resistor	2
10	4.7K Resistor	1
11	10K Resistor	6
12	50K Resistor	1
13	10K POT	1
14	Bread-Board	1
15	5.08mm Screw Terminal	1

C. Working Principle of TL494 Based Buck-Boost Converter

The complete circuit diagram for TL494 Based Inverting Buck-Boost Converter is shown below.

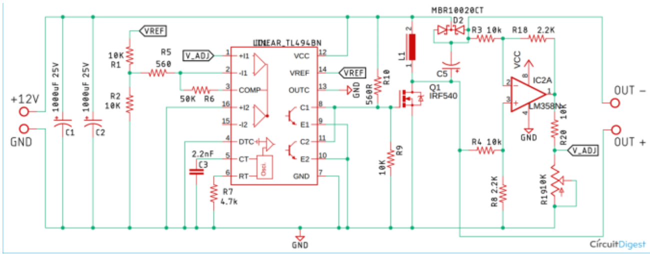

Figure 2.4: Schematic diagram of TL494 based buck-boost converter.

The working principle of this circuit is very simple. The circuit is divided into three parts, the first one being the TL494 PWM controller. We are using the TL494 PWM controller to drive the MOSFET. This IC is configured to switch at 100KHz switching frequency which is suitable for this type of application.

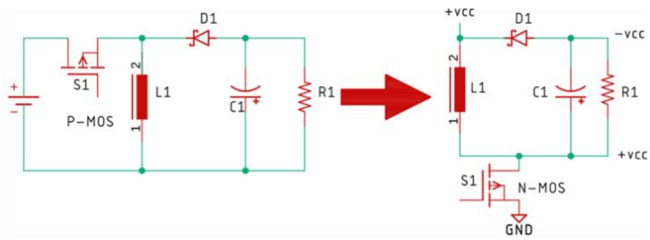

Figure 2.5: circuit modification

As we can see in the above schematic on the left side, we have our inverting buck-boost converter that uses P-Channel MOSFET as a switch, but one big disadvantage of a P-channel MOSFET is its internal resistance. If we consider a generic IRF9540 P-Channel MOSFET, the internal resistance of it is 0.22R or 220ms but if we consider its complementary N-Channel one that is the IRF540, its internal resistance is 0.077R or 77ms that is 3 times less than the P-Channel one. This is the reason why we have decided to modify the circuit. We have done this so that we can use an N-channel MOSFET to drive the circuit and the above-simplified circuit on the left-hand side shows exactly that. It uses an N-Channel MOSFET instead of a P-Channel One.

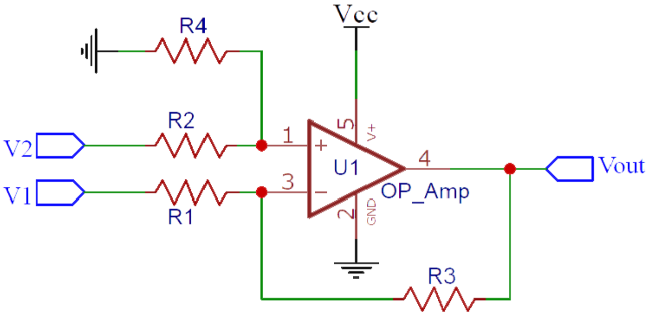

Figure 3.1: Differential amplifier.

The final part of the circuit is a differential amplifier. A differential amplifier takes in two voltage values, finds the difference between these two values, and amplifies it. The resulting voltage can be obtained from the output pin.

Finally, the resistors, R19 and R20 form a voltage divider that feeds back the voltage to pin 1 of the TL494 IC that regulates the PWM pulse depending upon the load condition.

D. Hardware Setup

The hardware setup for the boost converter was built on a breadboard for testing and validation. Below are the images of the actual setup:

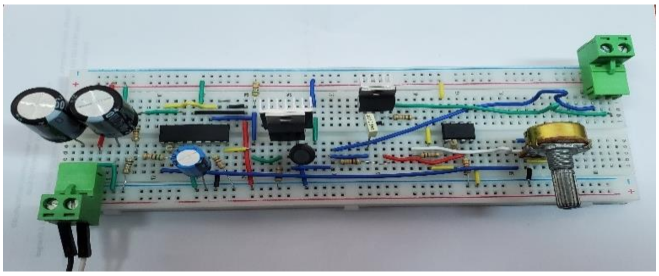

Figure 3.2: Front view of the Boost Converter circuit on the breadboard

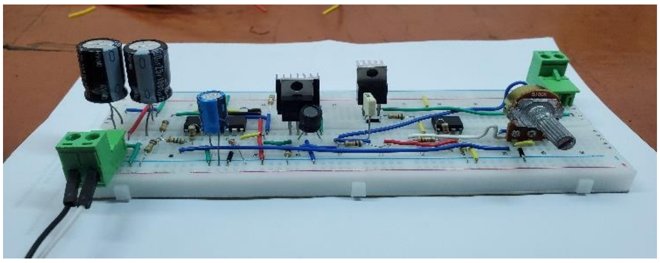

Figure 3.3: Side view of the Boost Converter circuit with components including capacitors, MOSFET, and TL494 IC clearly visible

E. Testing the Buck-Boost Converter Circuit

While powering this circuit for the first time, we used a Constant Current Power Supply to limit the current or we can use a bunch of power resistors to limit the current. If the output of the PWM controller is high, the MOSFET is in ON condition and all the current will flow through the inductor and it will be grounded through the MOSFET and the MOSFET will burn down.

As our input voltage was 12V and we got maximum output from the circuit is 60.1V for boost converter and got 9.04V for buck converter. In our testing the circuit did not perform better for buck converter.

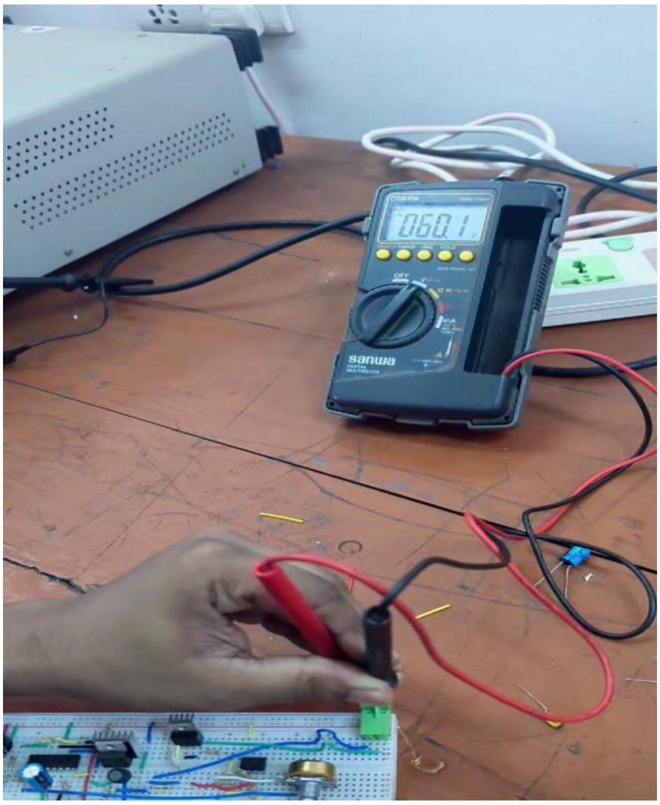

Figure 3.3: The output voltage of 60.1V as displayed on the multimeter, demonstrating the successful voltage step-up by the boost converter

III. Further Enhancements

This TL494 buck-boost converter circuit is for demonstration purposes only hence no protection circuit is added in the output section of the circuit.

- ✓ An output protection circuit must be added to protect the load circuit.
- ✓ The inductor needs to be dipped into varnish otherwise it will generate audible noise.
- ✓ A good quality PCB with a proper design is mandatory
- ✓ The switching transistor can be modified to increase the load current

IV. Conclusion

In conclusion, the buck-boost converter effectively provides a versatile solution for regulating output voltage by either stepping up or stepping down the input voltage, making it ideal for applications requiring flexible voltage conversion. However, in our project, while the boost converter successfully converted 12V to 60.1V, the buck converter did not perform as expected. This could be due to design limitations or issues with the hardware setup because some component was not available in electronics shop. Further investigation and refinement of the circuitry, especially with regard to component selection and layout, are necessary to achieve optimal performance in buck mode.

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