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Dual Switch Boost DC-DC Converter in Fuel Cell Powered Vehicle

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Abstract— **The development of a dual-switch boost DC-DC converter topology tailored for fuel-cell-powered vehicles, aiming to facilitate precise voltage matching between fuel-cell stacks and power batteries. This converter design is motivated by the need for efficient voltage regulation in electric automotive applications, where fuel cell voltage characteristics are highly variable. The proposed dual-switch boost converter offers a compelling solution to meet the demanding requirements of fuel-cell converters, including high efficiency, substantial voltage boosting, minimal current ripple, and stable operation. It simplifies the control mechanism with just two switches operating in sync, reduces component count, minimizes power-device stress, and delivers superior efficiency compared to traditional boost circuits, particularly at varying output voltage and current levels. In summary, this converter topology demonstrates its effectiveness in enhancing voltage matching and overall performance in fuel-cell-powered vehicles**.

*Index Terms—***Boost converter, bridge rectifier, driver circuit, PICIC, fuel cell.**

1. Introduction

DC-DC converters play a vital role in electric automotive applications, particularly in matching voltage between fuel cells and auxiliary power supplies while enhancing the fuel cell's output voltage characteristics. These converters regulate power output by controlling the switching operation of power switches, aiming for efficient fuel cell operation by accurately matching output voltage with the DC bus and suppressing output current ripples to extend the fuel cell's lifespan.

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Fuel cells pose unique challenges compared to lithium-ion batteries due to significant voltage fluctuations, weak output characteristics, and fluctuating power output, especially in applications like lift vehicles. Consequently, designing DC-DC converters for fuel cells requires considerations for stable operation over a wider range and faster response speeds compared to those used with lithium-ion batteries. Achieving this necessitates high operating efficiency, a high boost ratio, high power density, minimal input-current ripple, and stable operation over extended periods.

Monitoring the condition of transformers manually in large electric systems distributed over a wide area is challenging. Hence, a distribution transformer system is proposed to monitor essential parameters and send data to a monitoring system in real time. This IoT-embedded system uses sensors and a single-chip Node MCU microcontroller to measure load currents, overvoltage, transformer oil level, and oil temperature. The system records sensor output values and detects abnormalities based on predefined instructions, updating details automatically via serial communication. This IoT-enabled monitoring system optimizes transformer utilization, identifies issues preemptively, and enhances reliability, leading to significant cost savings.

In fuel-powered vehicles, a dual-switch boost DC-DC converter is commonly employed to convert low battery voltage into higher voltage necessary for various systems, including fuel injection and ignition. This converter utilizes two MOSFET switches to regulate voltage conversion, offering advantages such as high efficiency, reduced switching losses, and improved overall efficiency. It provides enhanced control over output voltage and current, ensuring a steady power supply to vehicle systems, and incorporates protection features against overcurrent and overvoltage to safeguard components from damage.

2. Comparison With Other Converters

Single-Switch Boost Converter: The dual-switch boost converter utilizes two switches, while the single-switch boost converter uses only one switch. This difference in the number of switches affects the efficiency and output voltage ripple. The dual-switch converter typically offers higher efficiency and lower output voltage ripple compared to the single-switch converter. Dual-switch converters are commonly used in high-power applications, while single-switch converters are more suitable for lower-power scenarios. Buck Converter: The buck converter moves down the input voltage, whereas the dual-switch boost converter accelerates the voltage. Buck converters are known for their high efficiency when the output voltage is lower than the input voltage. They are commonly used in battery-operated devices and applications that require voltage reduction. Buck-Boost Converter: Buck-boost converters can step up and step-down voltage, while dual-switch boost converters only step up the voltage. The efficiency of a buck-boost converter depends on the specific input and output voltage requirements. Buck-boost converters are versatile and find applications in various systems that require voltage regulation. Flyback Converter: Flyback converters are designed for voltage conversion and isolation, whereas dual-switch boost converters focus primarily on voltage boosting. Flyback converters provide isolation between the input and output, which is not typically offered by dual-switch boost converters. They are commonly used in power supplies and battery chargers.

3. Converter Topology

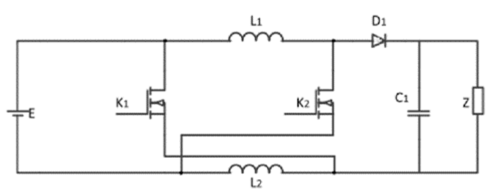

Fig.1. Proposed Dual-Switch Boost DC-DC Converter

The schematic of the proposed dual-switch boost DC-DC converter topology consists of two MOSFET power switches (K1 and K2), two energy-storage inductors (L1 and L2), a diode (D1), and an output filter capacitor (C1). Both power switches can be simultaneously turned on or off. This topology has a simple structure and is capable of generating a relatively high boost voltage, which fulfills the essential requirements of DC-DC converter topologies intended for fuel-cell-powered vehicles.

4. Basic Working Principle

When switches K1 and K2 are turned on, the operation of the proposed converter can be described as shown in Figure 3.2(a). The circuit consists of two current loops. The first loop includes the series connection of K1-L2 and K2-L1, which are connected in parallel across the input power supply E. The second loop consists of the filter capacitor C1 and the load Z. By ignoring the voltage drop across the MOSFETs when they are in the ON state, the equivalent circuit of the converter during this working mode. This can be simplified as shown in Figure 3.2(b). In this simplified circuit, the inductors L1 and L2 are represented as equivalent current sources, with their corresponding voltages being equivalent to the input supply voltage E. The voltage and current directions in the circuit are aligned with the reference directions depicted in the figure, representing the time during which the inductor absorbs energy.

When the power switches are in the OFF state, the input voltage E is connected in series with the inductors L1 and L2. In this state, energy is supplied to the filter capacitor C1 and the load Z through the diode D1, while the capacitor replenishes energy. The working mode of the proposed converter circuit in this state is shown in Figure 3.3(a). In this condition, the converter circuit forms a single loop consisting of inductors L1 and L2, input voltage E, diode D1, filter capacitor C1, and load Z. By ignoring the voltage drop across D1, the equivalent circuit in this case is depicted in Figure 3.3(b). It can be observed that the voltage directions across inductors L1 and L2 are unrelated to the corresponding current directions during the energy release period.

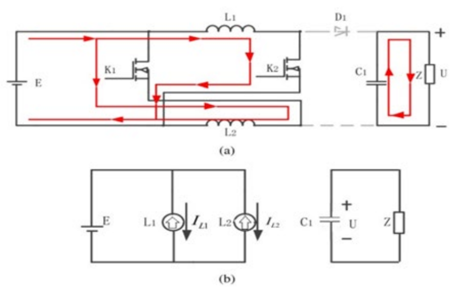

Fig.2. Operation Dual-Switch Boost DC-DC Converter at ON state

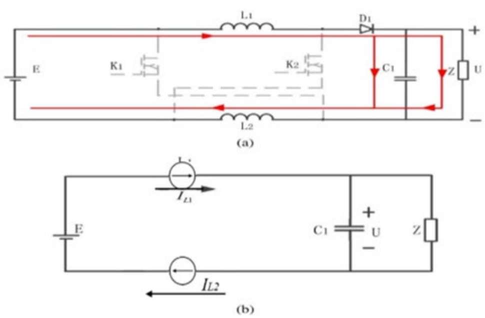

Fig.3. Operation Dual-Switch Boost DC-DC Converter at OFF state

5. Simulation

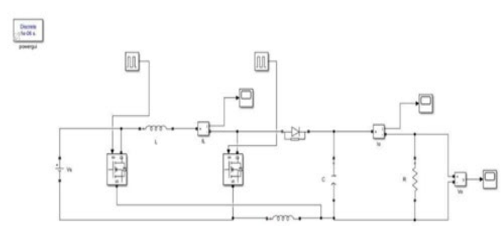

Fig.4. Simulation of Dual Switch Boost dc-dc Converter

Simulation is done in MATLAB Software. The pulse generator provides a square wave pulse to the gate terminal of the two MOSFETS. DC supply is provided as input to the MOSFETS. An inductor of 76.8 microhenry and a capacitance of 35 microfarad is provided. The load provided is resistive. It involves simulating the switching operation of the converter and analyzing its performance parameters such as input and output voltage, current, efficiency, and ripple. By varying the duty cycle and load resistance, the converter's behavior can be studied under different operating conditions. This simulation provides insights into the converter's voltage regulation, power transfer efficiency, and overall performance characteristics.

A. Simulation Output

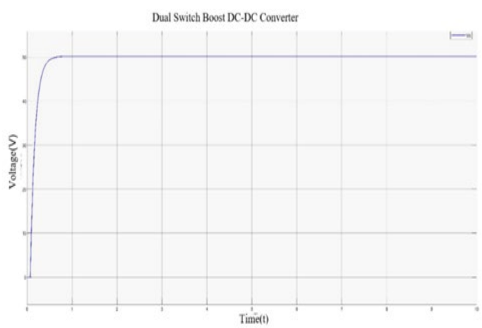

Fig.5. Simulation Output

As we provide an input of 10V and duty ratio of 0.8, the output of the Dual-Switch boost DC-DC Converter gets boosted to 50V providing an efficiency of 97.5 percent. It efficiently increases input voltage to a higher output voltage using two switches. The output result depends on input voltage, duty cycle, switching frequency, and load conditions. To analyze specific outcomes, provide details such as input voltage, duty cycle, and load characteristics.

B. Hardware

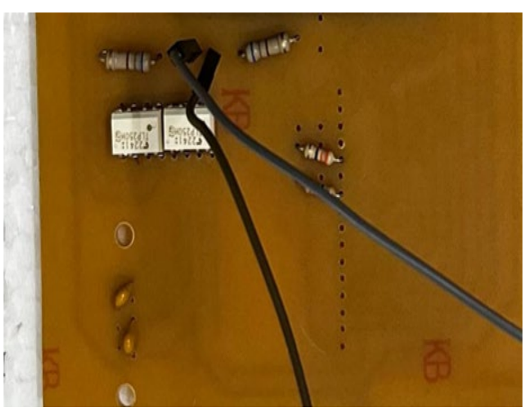

Fig.6. Driver Circuit

The driver circuit of the dual switch boost dc-dc converter is shown above. The driver circuit will help to trigger the MOSFETs.

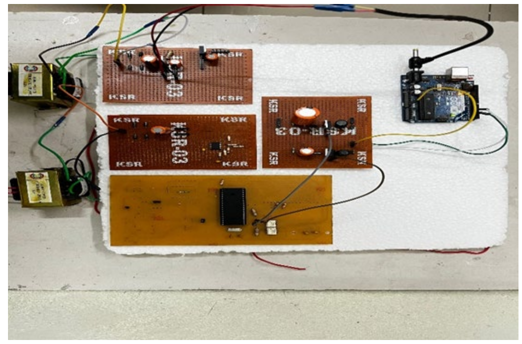

Fig.7. Hardware segments

The final hardware incorporating together all the hardware segments is shown below.

6. Results And Discussion

Fig.8. Hardware input

Fig.9. Hardware Output

The PIC16F677 microcontroller serves as the brain of the system, enabling precise control and monitoring functionalities. It facilitates dynamic adjustment of parameters like duty cycle and switching frequency, ensuring efficient operation under varying load

and environmental conditions. This capability allows for fine-tuning the converter's performance to deliver a consistent and stable power supply while maximizing energy utilization.

The driver circuit complements the microcontroller's functions by ensuring efficient and reliable switching operation of the power switches in the converter. By delivering precise gate drive signals and minimizing switching losses, the driver circuit enhances the overall efficiency and longevity of the converter. This optimized switching operation not only improves the converter's performance but also reduces stress on components, contributing to enhanced reliability over the long term. With the help of a 230/12V transformer, we obtain 12V. This is provided to a full wave bridge rectifier circuit where ac is converted to dc. The voltage regulators provide a constant output voltage of 5V to PIC16F677 and 12V to Arduino and Driver IC. PIC16F677 will produce a pulse width modulation of 30KHz. As a result, we can conclude that the output of the dual switch boost DC-DC converter gets doubled corresponding to the input. This property of the converter will be applicable in high-power applications. This capability is particularly critical in vehicles where voltage fluctuations can adversely impact essential systems such as engine control units, ignition systems, and onboard computers. By ensuring consistent voltage regulation, the converter safeguards the proper functioning of these critical systems, contributing to the overall reliability and performance of the vehicle.

7. Conclusion

The dual switch boost DC-DC converter is an essential component in fuel cell-powered vehicles as it facilitates the efficient conversion of the low voltage output from the fuel cell to a higher voltage suitable for the vehicle's electrical system. Through meticulous circuit design and simulation, we can ensure optimal performance, efficiency and stability. The accuracy of the design is validated through physical prototyping and testing, allowing for necessary adjustments to be made. The utilization of this converter enables fuel cell-powered vehicles to reliably and effectively provide power to their electrical systems, thereby contributing to cleaner and more sustainable transportation solutions.

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