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A novel topology for single-inductor single input triple output DC-DC power converter

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ABSTRACT

A single input triple output (SITO) DC-DC power converter circuit derived from a single inductor boost converter is proposed in this paper. Like multi-level inverters, many electronic circuit applications need multiple DC output voltages. Using different power supply circuits increases the system cost, size, and weight. The multiple-input, multiple-output power conversion system integrates multiple sources and outputs and uses a single controller. The integrated operation results in simple structure, low cost, and size, making it suitable for different power conversions, including renewable sources. In this series, the proposed single-inductor single-input triple-output (SI-SITO) DC-DC power converter is designed to produce three independent DC output voltages and two dependent output voltages. The proposed circuit is derived from a conventional boost converter made up of a single inductor. The advantage of this proposed circuit is the use of minimum components and simple control strategies. The design and performance analysis is done using Mat Lab simulation. The experimental results show the benefits of the proposed circuit.

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1. INTRODUCTION

Many industrial applications need regulated DC power output. To avail of this regulated DC output, there is a need for power conversion and control. Based on the nature of the available power supply, either AC or DC, the power conversion is done at either two-stage or single stage. The DC-DC conversion is achieved by using typical buck [1], [2] boost [3] and buck-boost [4] converter topologies. Few industrial applications [5]-[12] like photovoltaic, electric vehicles, and data processing centers require more than one regulated DC output voltage. The multiple regulated DC voltage requirements are fulfilled by multiple independent sing-input single-output (SISO) converter topologies utilizing conventional DC-DC converters.

The multiple units of SISO converters are the simplest solution to fulfill the multiple regulated DC output voltage requirements. But at the same time, it has the following disadvantages: individual or separate controller circuits, no coordination among the controllers, duplication of gate driver circuits and filters components, etc.; these drawbacks are overcome by multiple-input and multiple-output (MIMO) power converter topologies. The integrated control techniques help to utilize the multiple input sources and coordinate among the multiple loads connected at different voltage and power levels.

Many MIMO converter topologies are proposed, and their performances were analyzed [13]-[32]. This paper is derived from the basic boost converter utilizing a single inductor. The power density [33] and device utilization are improved in the SI-SITO topology. This non-isolated converter topology provides different output voltages at different magnitudes and different voltage levels. This makes the circuit more suitable for applications like multilevel inverters [34], [35]. In this paper, section 2 explains the construction and working principle of the proposed topology and the performance analysis presented in section 3. Section 4 describes the detailed analysis of its MATLAB/Simulink model and hardware part. Section 5 describes the conclusion of this paper.

2. PROPOSED CONVERTER STRUCTURE AND ITS OPERATING MODES

The proposed topology is derived from the basic boost converter topology, built with inductor L1, power semiconductor S1 and diode D1as shown in Figure 1. To produce two different voltages, the unidirectional controllable switches S2 and S3 with the diodes D2 and D3 are used as the buck converter, as shown in Figure 1. These three power semiconductors are enabled with PWM signals at desired duty cycle to avail the required output voltages. The working principle of the proposed converter topology is explained in two different modes. One is boost converter mode and the other one is buck converter mode.

2.1. Boost mode operation

In boost converter operating mode, power semiconductor switch S1 is controlled by PWM signal at desired duty cycle to produce the output voltage. In this mode, the supply voltage is stepped up to the output side and achieved by energy storage inductor L1. The inductor stores energy when the power semiconductor switch S1 is turned on, as shown in Figure 2. Then it discharges towards the load with an input voltage of V_{IN}, as shown in Figure 3. It results in greater output voltage when compared with input voltage. This method can increase the output voltage from input voltage magnitude to above its value. However, the maximum duty cycle value is restricted, thus limiting the maximum output voltage.

2.2. Buck mode operation

After the boost operation, the step-up voltage is again stepped down by buck operation to produce the different output voltages. It is achieved by the power semiconductor switches S2 and S3, as shown in Figure 4. The power semiconductor switches S2 and S3 are operated with a PWM signal, and their duty ratio is adjusted to get the desired output voltages.

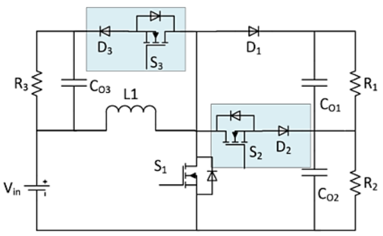

Figure 1. SI-SITO converter circuit

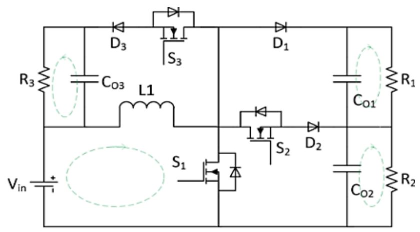

Figure 2. Boost operation: switch S_1 in on the state

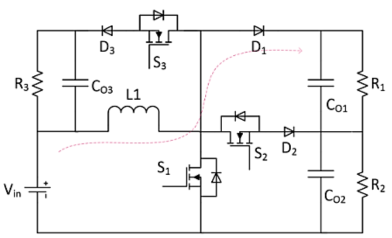

Figure 3. Boost operation: switch S1 in the off state

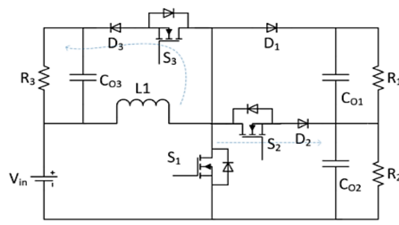

Figure 4. Buck operation

2.3. Performance analysis

The proposed circuit produces three independent output voltages and two dependent output voltages, as shown in Figure 5. The duty cycle of power semiconductor switches S1, S2 and S3 are considered k1, k2 and k3, respectively. The average output voltage of the proposed converter is mathematically represented below.
Boost output voltage:

$$V_4 = \frac{V_{in}}{(1-k_1)} \quad (1)$$

The buck output voltages,

$$V_2 = V_4 * k_2 \quad (2)$$

$$V_3 = V_4 * k_3 \quad (3)$$

and other voltages,

$$V_1 = V_4 - V_2 \quad (4)$$

$$V_5 = V_3 + V_{in} \quad (5)$$

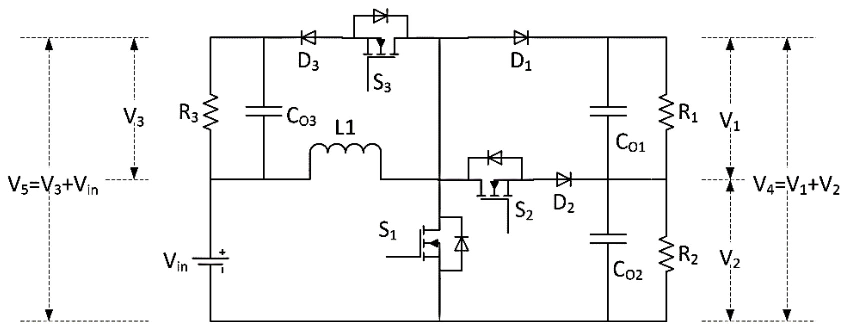

Figure 5. Multiple output voltages of the proposed circuit

3. RESULTS AND DISCUSSION

3.1. MATLAB/Simulation

The proposed converter topology is verified with MATLAB/simulation initially. Followed by, the prototype experiment. The hardware experimentation details are explained after the simulation. The simulation parameters used in the simulation are listed in Table 1. The Ode23tb solver is set with a maximum step size of 5e-6 seconds in MATLAB settings to analyze the circuit functioning.

Table 1. Simulation parameters

Parameter	Value
Input supply voltage	36 V
Output voltage V_1	18 V
Output voltage V_2	60 V
Output voltage V_3	24 V
Output voltage V_4	78 V
Duty cycle k_1	50%
Duty cycle k_2	70%
Duty cycle k_3	70%
Load circuit resistance (all loads)	25 Ω
Device Switching frequency	10 kHz
Inductors	10 µH
Capacitors	500 µF

The output voltage V1 and current I1 are shown in Figures 6(a) and 6(b). V1 is the difference in voltage between the boost output voltage V4 and buck output voltage V2. The current waveform belongs to a 25Ω resistive load. The output voltage V2 and current I2 are shown in Figures 6(c) and 6(d). The voltage V2 is the step-down voltage of V4. The current waveform belongs to a 25Ω resistive load. The output voltage V3 and current I3 is shown in Figures 6(e) and 6(f) The voltage V3 is the step-down voltage of V4. The current waveform belongs to a 25Ω resistive load.

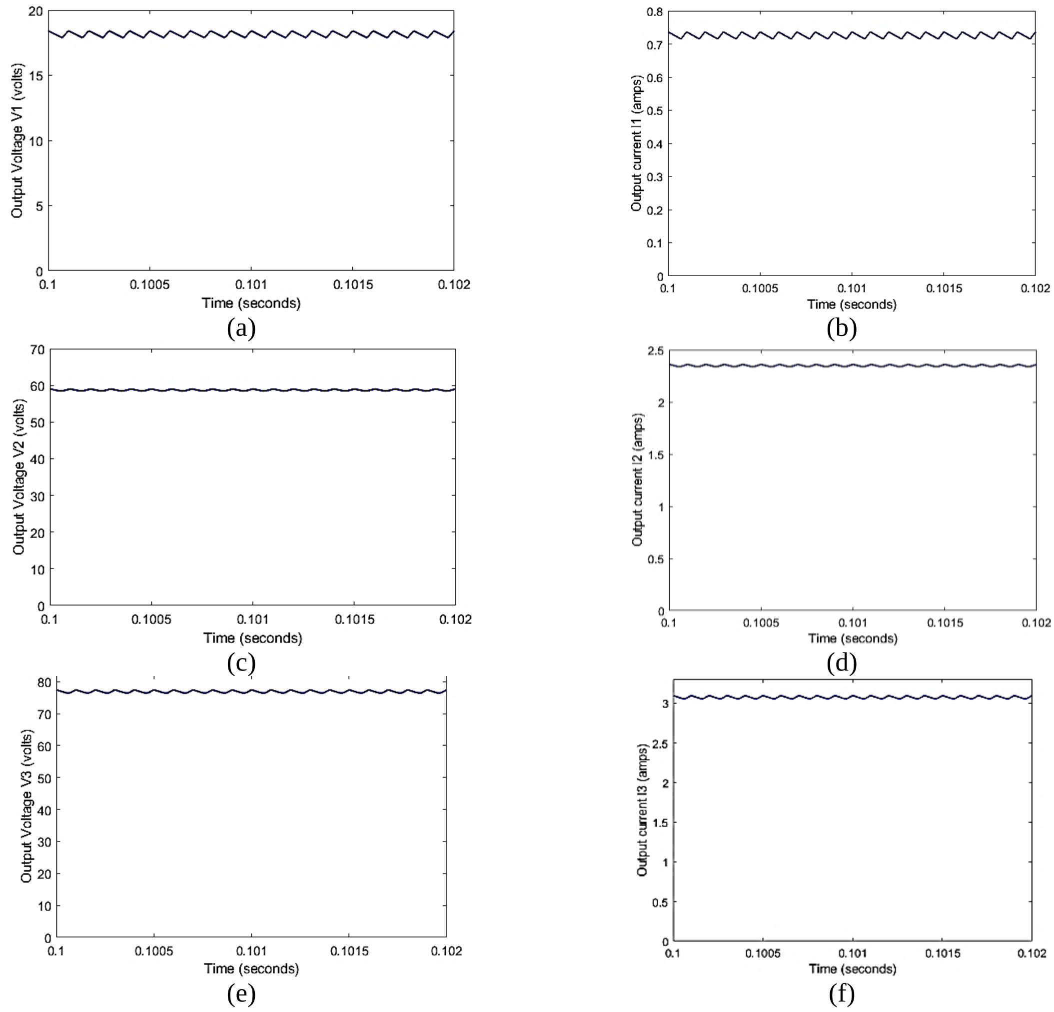

Figure 6. The output: (a) voltage across V1, (b) current I1, (c) voltage across, (d) current I2, (d) voltage across V3, and (f) current I3

4. PROTOTYPE AND RESULTS

The experimental setup is shown in Figure 7. The PIC16F877A microcontroller generates the required PWM signals. The TLP250 driver IC is used in the gate driver circuit. It is used to interface the controller and power circuit. The hardware details are listed in Table 2. The hardware results are shown in Figures 8(a) to 8(d). The components present in the experimental setup are marked in Figure 7 and listed below:

- PIC16F877A Microcontroller
- Microcontroller power supply circuit
- Power and gate driver circuit made up of TLP250respectively
- Isolated gate driver power supply
- Single inductor
- Load

Figures 8(a) and 8(b) shows the output voltage V1 and V2, respectively. It is the step-down voltage of V4. So, it is less than the magnitude of V4. Figures 8(c) and 8(d) show the output voltage V3 and V4, respectively. It is the step-down voltage of V4. So, it is less than the magnitude of V4.

Table 2. Hardware components values

Item	Component	Rating
Input voltage	Vin	36 V
Inductor	L_1	10 μH
Capacitor	C_1-C_3 and C_O	500 μF
MOSFET- IRF540	S_1-S_5	100 V, 33 A
Diode- MBR40250G	D_1-D_{13}	250 V, 40 A

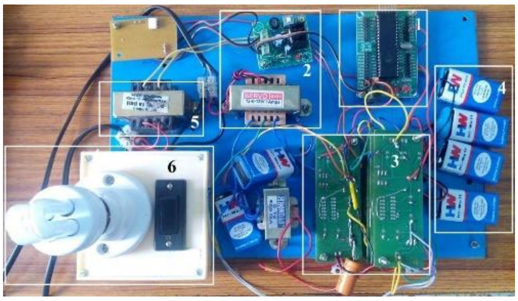

Figure 7. Hardware prototype

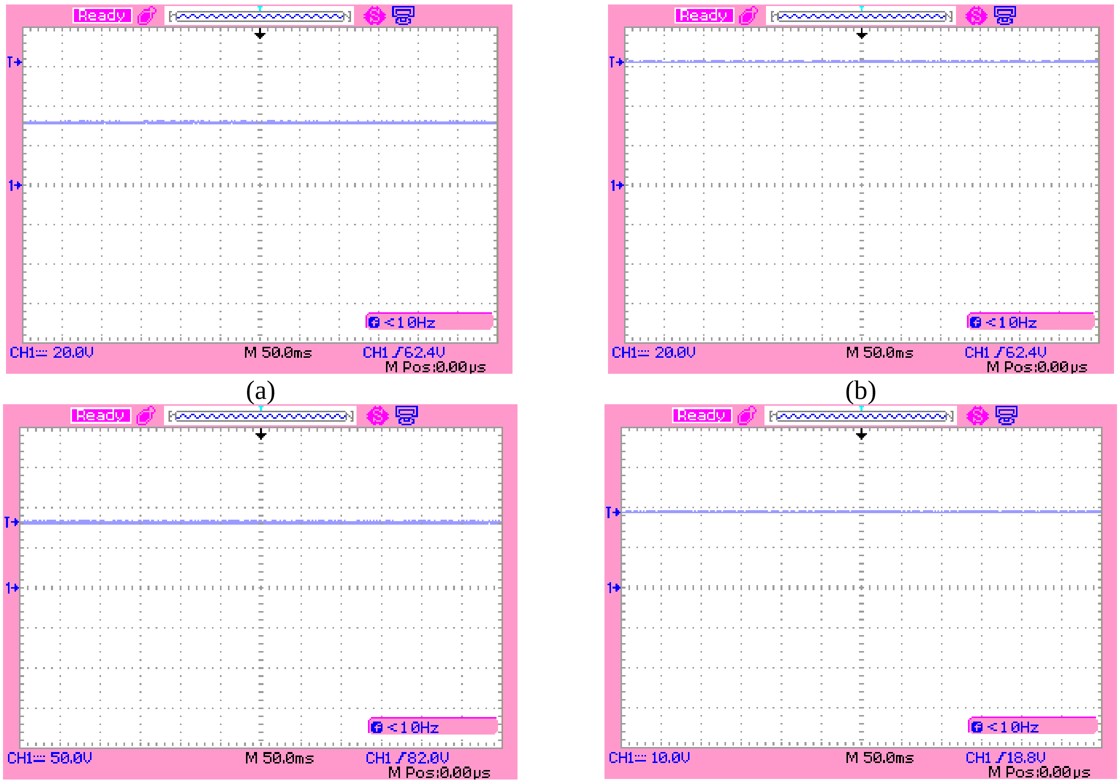

Figure 8. Experimental Results of output voltage: (a) V1, (b) V2, (c) V3, and (d) V4

5. CONCLUSION

The simple control and construction of the proposed circuit are revealed. The simulation and prototype demonstration of the SI-SISO are given in detail. The proposed converter topology is built with a single inductor. The independent triple output and dependent two outputs supply multiple power supply voltage requirement engineering applications like multilevel inverters and electric vehicles. Multilevel inverter circuits are used instead of a conventional inverter. It produces the quality output with less THD and torque ripple in speed control of the induction motor. Also, electric vehicles need a different power supply. The number of output voltages increased by duplicating the buck converter units. As a non-isolated converter, the voltage levels are not possible to add like isolated sources but can be added to the adjacent voltages like V1, V2 and, V3, V5.

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