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Analysis and Control of a Coupled Inductor Based Multi-Level DC-DC Converter for Multiple DC Output Applications

M. Harsha Vardhan Reddy[1], D. Rohini[2], G. Kishor[3]

[1]Associate Professor, Department of EEE, G.Pulla Reddy Engineering College, Kurnool
[2]Assistant Professor, Department of ECE, G.Pulla Reddy Engineering College, Kurnool
[3]Professor, Department of EEE, G.Pulla Reddy Engineering College, Kurnool

Abstract

This paper presents the performance analysis of a Coupled Inductor Single-Input Dual-Output (SI-DO) Multi-Level DC-DC Converter for high-efficiency power conversion applications. The proposed converter integrates a coupled inductor and multi-level voltage boosting technique to achieve high voltage gain with reduced switching stress and improved output regulation. The converter provides two independent DC outputs from a single input source, making it suitable for renewable energy systems and electric vehicle applications. The operating principles, voltage gain characteristics, and steady-state performance are analyzed. Simulation results demonstrate improved voltage conversion capability, reduced ripple, and better dynamic response under varying load conditions. The proposed topology offers an effective solution for compact and reliable multi-output DC power conversion systems.

Keywords: Coupled Inductor, Multi-Level DC-DC Converter, Dual Output, High Voltage Gain, Power Electronics.

1. Introduction

In power electronics field now a day's an engineer is facing a number of challenges, his everyday job needs expert skills in three fundamental areas of electrical engineering such as: power conversion methods, magnetic circuits, control system techniques. Fundamental conversion techniques such as BUCK (step-down), BOOST (step-up), and BUCK-BOOST are used. These DC/DC converters have only one switch for controlling output voltage which is done by controlling the duty ratio of the switch. High voltage battery pack with high energy density to store energy is used in PLUG-IN hybrid vehicle. These battery packs are charged form AC outlets by converting AC to DC. This typically includes, a power factor corrector come next to an isolated DC/DC converter. PFC improves the quality of i/p current and regulates DC bus voltage. DC converter isolates utility mains and battery pack.

The buck converter is operated between the duty ratio ranging 0 to 0.5, the I/P voltage V_{in} is chopped by the switch which results in a pulsed waveform. After Low-Pass filtering of this Voltage gives average DC output Voltage $V_o=DV_{in}$, Where 'D' is the Duty cycle of the switch, which is the ratio of status ON period to the total switching period 'T_s'. It is also called as step-down DC-DC converter. Buck converters provide efficient operation of more than 90%, so these are useful in computer mother board. When the switch is turned on then the output inductor is charged linearly, and the diode gets reverse biased. When the switch is open then the diode gets forward biased and the output inductor current is discharged linearly.

The output voltage obtained from this converter is always greater than input voltage so it is also called as step-up DC-DC converter. This converter is operated between the duty ratio ranging 0.5 to 1.

When the switch is turned-on then the inductor is charged and the path of current will be source to inductor to switch and to the negative terminal of switch. When the switch is turned-off then the only path to the inductor current is through the diode and the inductor current is supplied to the load applied. The ripples in the output are reduced by introducing filters at the output side.

2. Multiple-Input Multiple-Output DC-DC Converter

Sustainable energy sources and the power electronic systems for utilizing such energy sources have attracted much attention recently. The ability of multiport converters to mitigate the intermittency issues associated with these energy sources has made them attractive candidates for renewable energy conversion systems. Multiport converters can be synthesized by connecting several single-input single-output (SISO) converters to a common dc bus, as shown in Fig.1. Although prevalent in conventional hybrid power systems, such configuration results in a complex structure and high cost. Moreover, the control and stability issues associated with the multi-SISO converter systems further degrade their popularity and make single-stage multiport converters more attractive alternatives. Single stage multiport converters can be categorized into multiple-input single-output (MISO), single-input multiple-output (SIMO), and multiple-input multiple-output (MIMO) topologies.

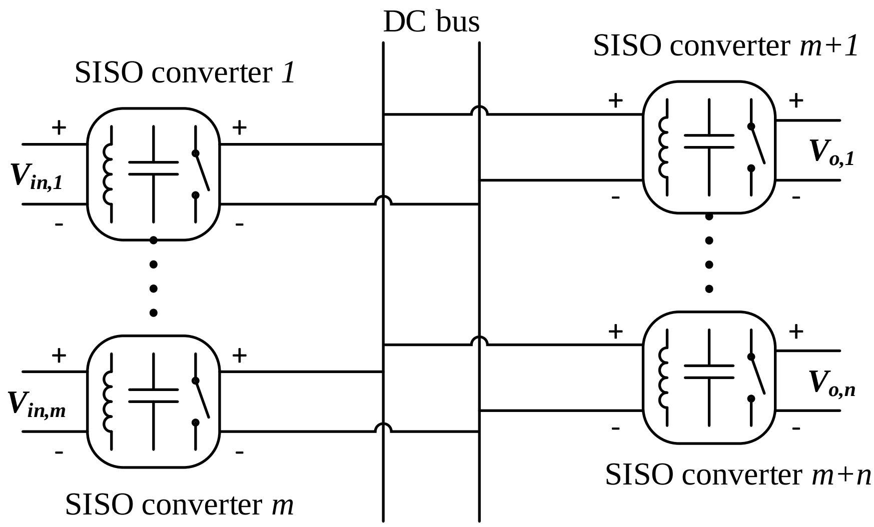

Fig.1 Conventional Hybrid Power System

SIMO converters can be categorized into isolated and non-isolated configurations. In isolated topologies, a transformer with multiple secondary windings interfaces between the input and output ports. Only one output voltage (usually the one with the heaviest load) is regulated while the others are determined by the turn ratios of the secondary windings. Hence, independent output voltage regulation is not straight forward. The non-isolated SIMO topologies can be further categorized into independent- and series-output configurations. In the independent-output configuration, all output ports chare the same ground, where as in the series-output configuration, different outputs are constructed in a series fashion. Series-output SIMO converters are suggested as efficient solutions to balance the dc-link voltages of diode-clamped multilevel inverters. To date, MIMO converters have not receives as much attention as MISO or SIMO converters. They are potentially able to combine the advantages of both MISO and SIMO topologies and provide a more cost-effective solution.

MIMO buck-boost converter

A MIMO converter has multiple dc inputs of different voltages and incorporates other MISO circuits to give the multiple outputs. The sole purpose of this type of converter is to run the diversified loads. As in DC systems, there are such types of loads (DC fans (12V), charger (5V), and LED (3.7V)), which require different voltages and currents to run, so by obtaining different outputs from a single converter, they can be ran successfully.

The MIMO system mainly depends upon the MISO technology. The design is pretty simple, just there is a need to select an output and find its duty cycle of switch and distribute it accordingly. The greater voltage, then lesser the duty cycle. All the design will be done like it's a combination of three MISO converters.

3. Single-Input Dual-Output Multi-Level DC-DC Converter

The simulation of Single-Input Dual-Output Multi-Level DC-DC Converter is dome in Matlab platform. The results are as shown in the figures below.

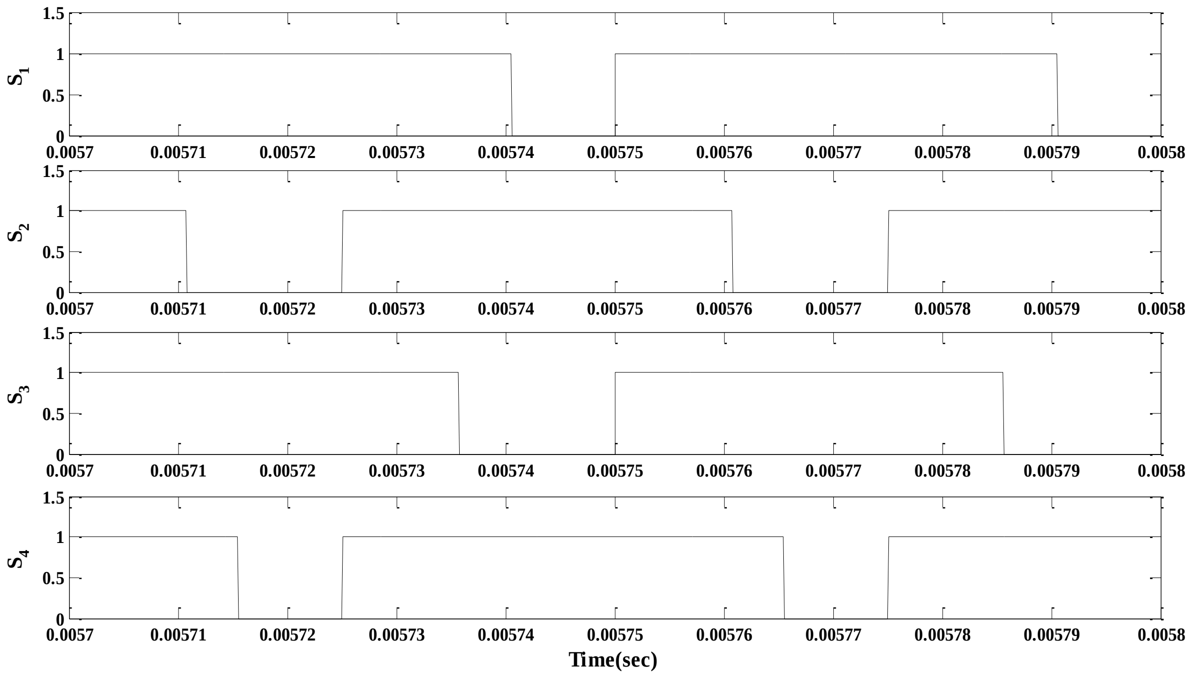

Fig.2: Pulse pattern for the switches of SIDO-TLC converter

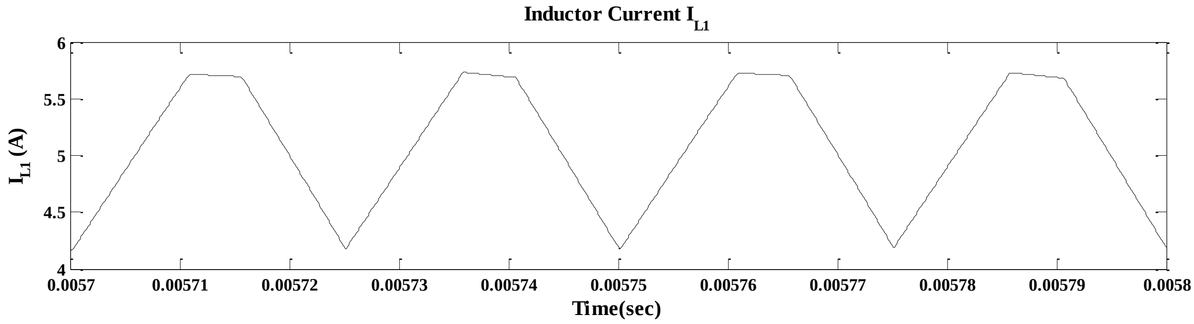

Fig.3 Inductor current I_{L_1}

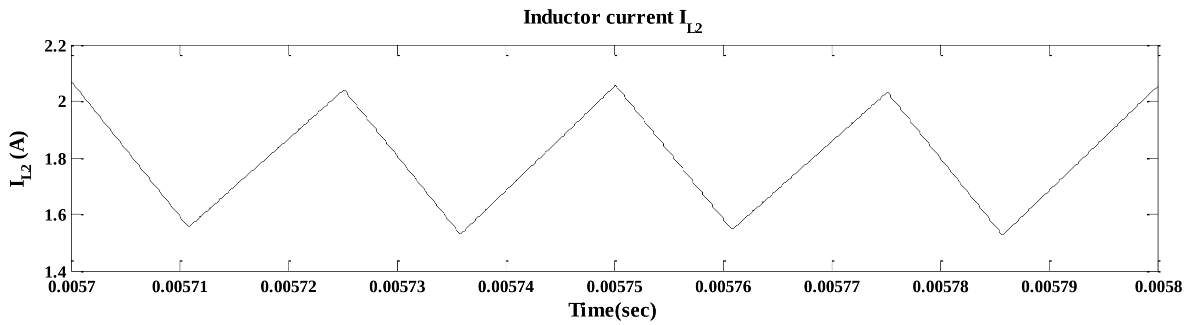

Fig.4 Inductor current I_{L_2}

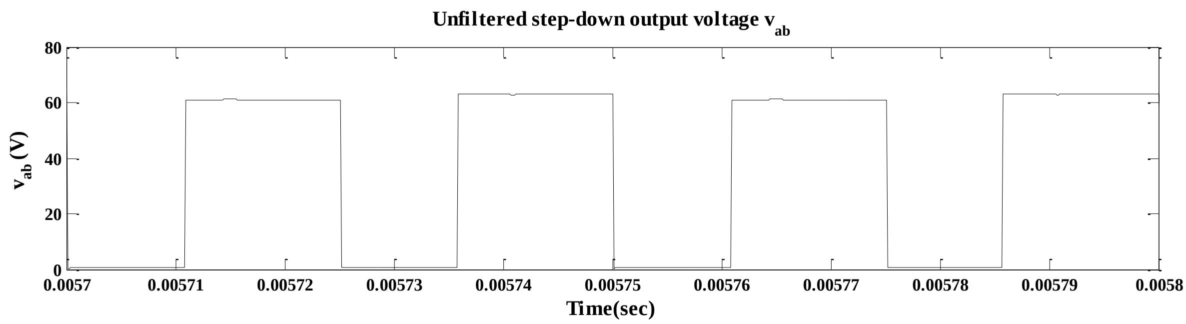

Fig.5 Unfiltered step-down output voltage v_{ab}

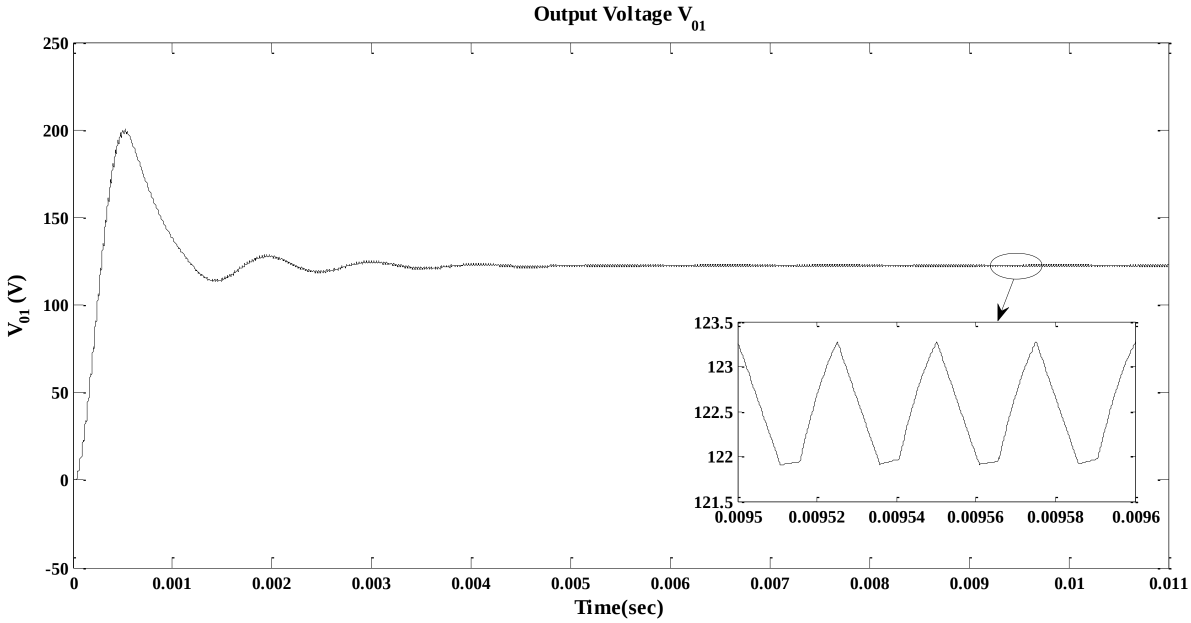

Fig.6 Simulation waveforms of step-up output voltage V_{01}

Conclusion

A high-efficiency non-isolated Single-Input Dual-Output (SIDO) converter is analyzed and simulated to validate its operating principle and performance. The simulation results demonstrate the effective operation of the proposed converter in both buck and boost modes. However, conventional SIDO converters generally require two separate inductors, which increase the converter size, weight, cost, and circuit complexity. To overcome these limitations, a novel coupled inductor-based SIDO multilevel DC-DC converter is proposed. The coupled inductor structure reduces the number of magnetic components while maintaining high voltage conversion capability and improved power density. A detailed small-signal analysis is carried out to evaluate the dynamic behavior and stability characteristics of the proposed converter. The performance analysis confirms that the proposed topology achieves similar output characteristics with reduced component count and enhanced efficiency. Simulation results validate the converter operation in both buck and boost modes, demonstrating its suitability for compact and high-performance power conversion applications.

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