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Design and operation of closed-loop triple-deck buck-boost converter with high gain soft switching

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ABSTRACT

This paper presents the design and operation of three-stage buck-boost converter with high gain soft switching using closed loop proportional integral (PI) controller. The proposed converter is designed by arranging three identical buck-boost converters working in parallel. The converter units are connected to each other by an inductor as a bridge. This inductor plays a vital role in soft switching operation of converter by maintaining the voltage applied to switches at zero voltage at switching intervals, i.e., the zero-voltage switching (ZVS). The closed-loop system is designed by PI controller, and it maintains the output constant irrespective of changes in input, and the system becomes stable. The proposed converter is efficient in reducing switching losses, leading to improved converter efficiency. Due to parallel operation of three identical converters, the output voltage and input current contain fewer ripples than those of a single converter with same specifications. Proposed converter is more economical and reliable with simpler structure as it utilizes only two inductors as extra elements. The design and analysis of proposed circuit has been carried out in MATLAB Simulink by operating the circuit in various modes.

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1. INTRODUCTION

Nowadays, DC/DC converters are utilized for various reasons when the conversion between two dc voltage levels, such as electrical vehicles, dynamic filters, power factor correction circuits, appropriated ages, dc/dc regulated power supplies, etc. is required. A buck-boost converter is an exchanged mode power supply that consolidates the standards of buck converter, and the boost converter in a solitary circuit. Recently, interleaved converters are used in various applications and give many focal points, such as expanding efficiency, decreasing the voltage and current ripples, and providing high load power. The efficiency of dc/dc converters is an important issue. Therefore, different control methodologies and converter topologies are proposed for the delicate switching operation of converters to accomplish least switching losses, improved efficiency and effective operations [1].

A new two-stage buck-boost converter with a soft switching operation with two identical buck-boost converters working in parallel is proposed in reference [2]. In reference [3], a double-deck buck-boost converter with soft switching capability by parasitic capacitors is constructed with two identical buck-boost converters working in parallel. Reference [4] proposes a new structure-stage buck-boost converter with a soft level switching operation with feedback proportional integral (PI) loop control. A double-deck converter with a PI controller is proposed in [5], which provides a decent efficiency under both buck and boost modes. A two-stage buck-boost converter with two identical buck-boost converters working in parallel and soft switching operation for renewable energy applications is proposed in reference [6]. A new M-SEPIC dc-dc converter fed brushless-DC motor drive is controlled by voltage source inverter and powered by single-phase grid system with improved power-quality features is proposed in reference [7].

A double-stage buck-boost converter with zero-voltage switching (ZVS) capability is proposed in reference [8]. A transformerless buck-boost dc-dc converter has been proposed in reference [9]. A voltage regulated two stage buck-boost converter with a soft switching operation is proposed in [10]. Reference [11] proposes an active-clamp ZVS buck-boost converter to improve the performance of converter during light loading condition. Comparison of various dc-dc converters for solar photovoltaic (PV) systems has been presented in reference [12]. Design and implementation of buck-boost converter for its application to stabilize voltage has been proposed in reference [13]. Reference [14] proposes two quasi-Z-source dc-dc converters (q-ZSCs) with buck-boost converter gain.

The design and operation of three-stage buck-boost converter with soft switching using closed loop PI controllers has been proposed in the present paper. The proposed converter is constructed by arranging three identical buck-boost converters working in parallel. The converter units are connected to each other by an inductor as a bridge. This inductor plays a vital role in soft switching operation of converter by maintaining the voltage applied to switches is zero at switching intervals, i.e., zero-voltage switching (ZVS). The system is made closed loop by PI controller which maintains the output constant irrespective of changes in the input, i.e., system is stable. The proposed converter is efficient in reducing the switching losses and leading to improved converter efficiency.

The rest of this paper is organized as follows. Section 2 presents the description of proposed triple-deck buck-boost converter. Section 3 describes the implementation of closed-loop triple-deck buck-boost converter. Section 4 presents the discussion of numerical results. Finally, Section 5 of the article depicts the contributions with concluding remarks.

2. TRIPLE-DECK BUCK-BOOST CONVERTER

Figure 1 depicts the schematic diagram of buck-boost converter. A control unit is incorporated in it and it is used to detect the level of information voltage, and that point is chosen for fitting circuit activity [15]. MOSFETs are utilized as a part of high recurrence power converters, and the diodes appeared as Schottky sorts. These diodes have a low forward intersection voltage when leading, and can switch at high speeds. This converter is useful in self regulating power supplies and in battery control frameworks. They have less voltage ripples, low voltage on MOSFETs, and high efficiency [16].

Figure 2 depicts the schematic diagram of triple-deck buck-boost converter which consists of three identical buck boost converters which are connected in parallel through interleaved inductors [17]. Here, the load is connected across capacitor [18].

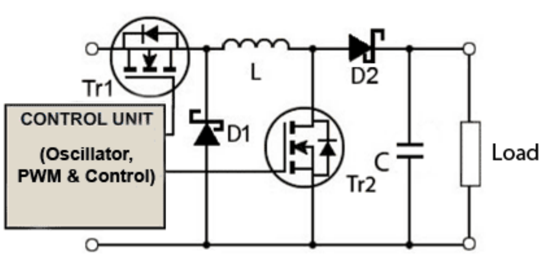

Figure 1. Schematic diagram of buck-boost converter

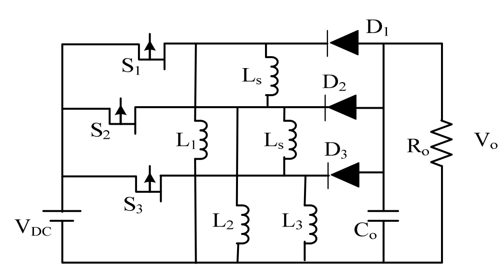

Figure 2. Schematic diagram of triple-deck buck-boost converter

2.1. Closed loop triple-deck buck-boost converter

Figure 3 depicts the schematic diagram of closed loop triple-deck buck-boost converter, in which the output voltage (V_o) is fed back to PI controller to detect the error and make the necessary correction as per the required or desired output by adding or subtracting the gain as per the error detected [19].

Various types of controllers include proportional controller, integral controller, differential controller, proportional integral controller [20], and proportional derivative controller [21]. Proportional controller is used to improve the transient response [22]. Integral controller is used to improve the steady state error by adding a pole at origin which increases the order of the system. Differential controller is used to improve the stability of the system rather than steady state error. Proportional integral (PI) controller improves the steady state stability by increasing the type of the system. Figure 4 depicts the block diagram of closed loop PI controller [23].

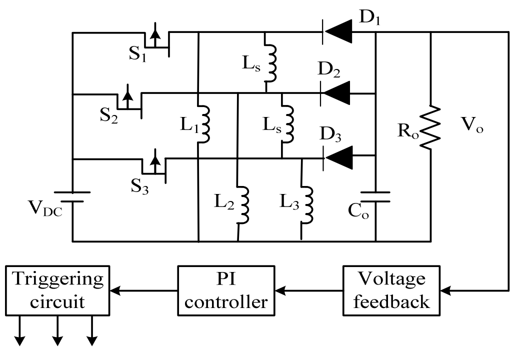

Figure 3. Closed loop triple-deck buck-boost converter

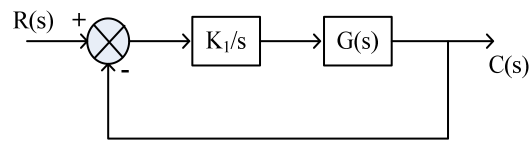

Figure 4. Closed loop Proportional Integral (PI) controller

In the proposed closed loop triple-deck buck-boost converter, the PI controller detects the error which in turn produces the required gain, and then it is fed to the forward path to get the required output [24].

3. IMPLEMENTATION OF CLOSED-LOOP TRIPLE-DECK BUCK-BOOST CONVERTER

Figure 5 depicts the implementation of a closed triple-deck buck-boost converter in MATLAB simulink software. In this circuit, an extra switch is attached and duty ratio of each switch is selected as 0.35, to maitain the effective duty ratio as 0.7. By using this duty ratio, higher voltage can be obtained in comparission to that of double-deck buck-boost converter. This significantly increases the gain and efficiency of the system [25]-[26].

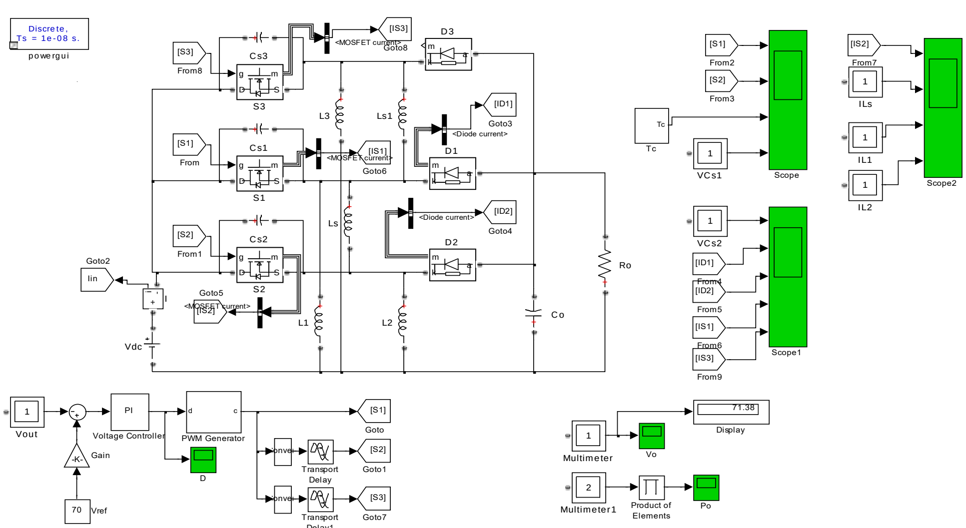

Figure 5. Implementation of closed-loop triple-deck buck-boost converter.

This closed loop PI controller makes the output constant irespective of change in input, and there is an improvement in the stability of closed-loop system [27]-[28].

4. RESULTS AND DISCUSSION

The proposed triple-deck buck-boost converter is designed by selecting the effective duty ratio as 0.55 and the input, output voltages as 20V and 50V, respectively. Output power is 100W and the switching frequency is taken as 133 kHz [29]-[30]. The circuit parameters considered in this work is: inductors (L1 and L2) are 180µh, inductor (Ls) is 30µh, capacitor (Co) is 100µF, type of power MOSFETS is IRF 640, and the type of diode is BYV32. Switching and communication times considered as 7.5µs and 30µs. The output resistance is considered as 25Ω. A 200W power, 70V output voltage, with 20-30 volts input, switching frequency of 133 kHz prototype is analyzed [31], and the results are presented below:

Figure 6 depicts the output voltage obtained in the proposed triple-deck buck-boost converter. Figure 7 depicts the output power of proposed triple-deck buck-boost converter.

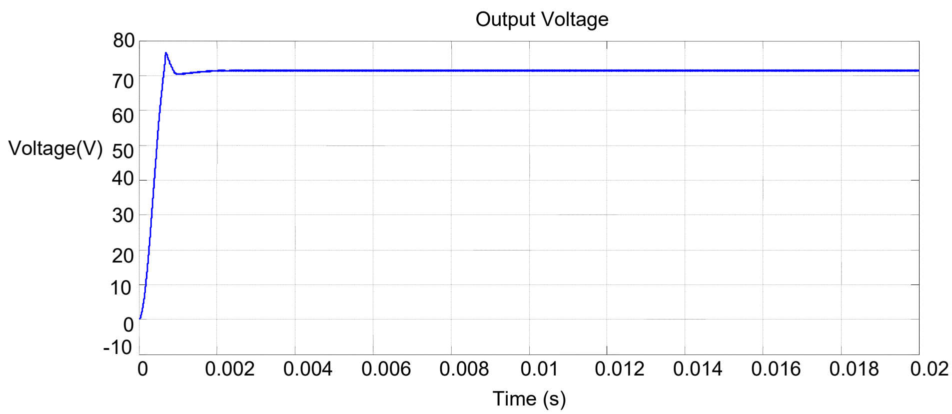

Figure 6. Output voltage of proposed triple-deck buck-boost converter

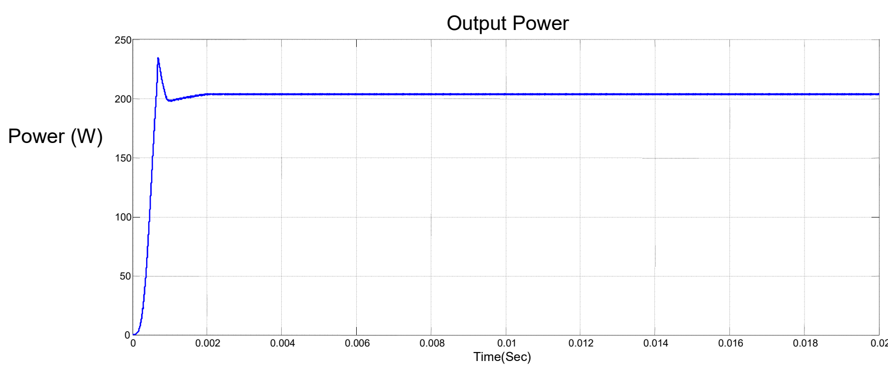

Figure 7. Output power of proposed triple-deck buck-boost converter

The obtained duty ratio of proposed triple-deck buck-boost converter is depicted in Figure 8. Switching waveforms of gate voltages, communication time and intrensic voltage are depicted in Figure 9. Switching waveforms of intrensic voltage, diode currents and switch currents are depicted in Figure 10. Switching waveforms of switch current, interleaved inductor current and inductor currents are depicted in Figure 11.

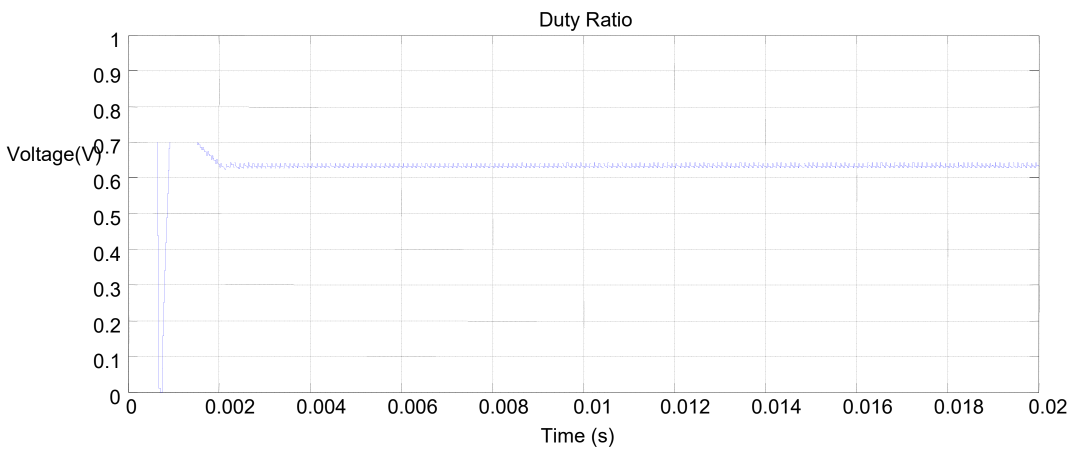

Figure 8. Duty ratio of proposed triple-deck buck-boost converter

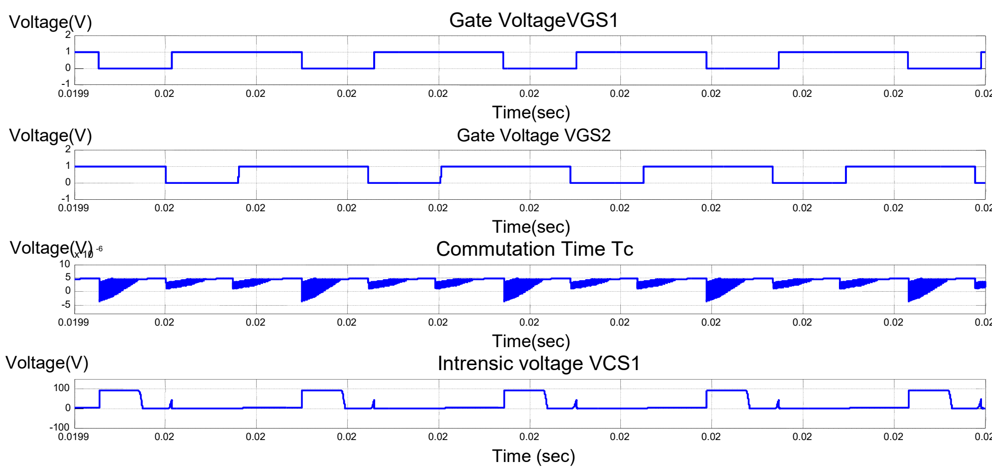

Figure 9. Switching waveforms of gate voltages, communication time and intrensic voltage

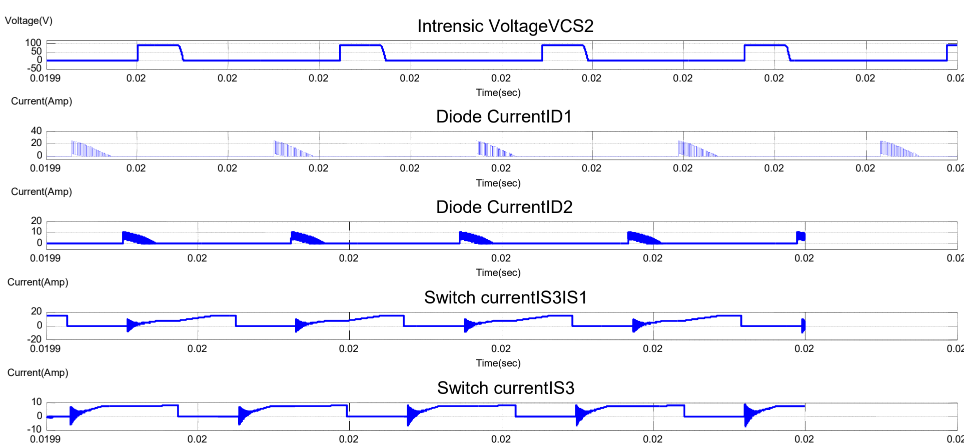

Figure 10. Switching waveforms of intrensic voltage, diode currents and switch currents

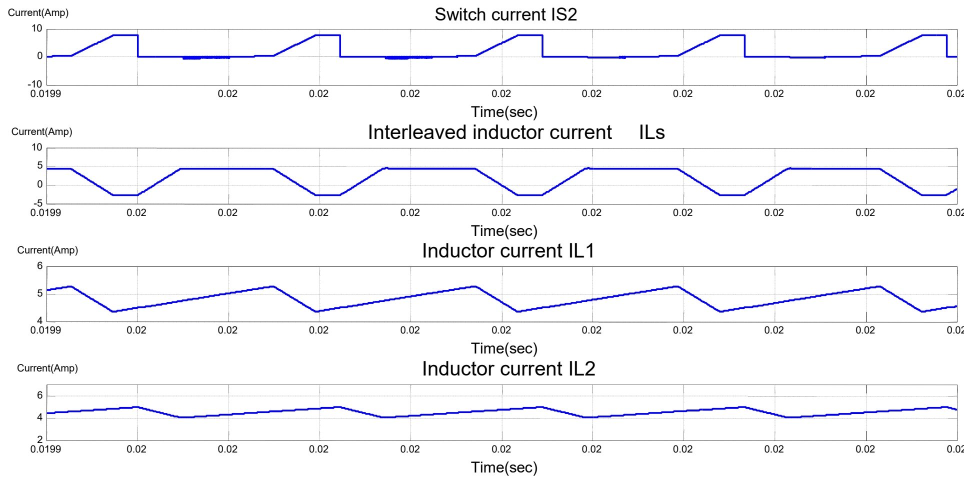

Figure 11. Switching waveforms of switch current, interleaved inductor current and inductor currents

From the above simulation results on closed loop triple-deck buck-boost converter with PI controller, it can be observed that it maintains the output voltage and power at constant magnitude. The main drawback of double-deck buck-boost converter is that it has high switching losses. However, the proposed one utilizes two converters in parallel, which reduces the ripples in the output voltage and also improves the gain of the system. The proposed triple-deck buck-boost converter is suitable for medium voltage and power levels.

5. CONCLUSIONS

A closed loop triple-deck buck-boost converter with high gain soft switching operation has been proposed in this paper. The soft switching operation of proposed closed-loop triple-deck buck-boost converter has been performed by operating the switches at zero switching intervals. This operation reduces the switching losses and ripples, which in turn improves the efficiency. The main control of closed loop controller is provided by proportional integral (PI) controller, which controls the output voltage as per the desired value and it is set by the reference voltage. A 200W, 70V output voltage with (20-30)V input, switching frequency of 133 kHz prototype is analyzed and the simulation results are presented in this paper. Closed loop PI controller of proposed converter maintains the output voltage and power at constant magnitude. The proposed triple-deck buck-boost converter is ideal for medium voltage and power applications.

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