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# Control of Single Inductor Multi Output DC-DC Converter in Continuous Conduction Mode

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## ABSTRACT
This paper presents the technique for the analysis and design of a new DC-DC multi output boost converter using which the output can be shared between different loads. The proposed converter can generate the voltage of a low voltage input to levels of boosted output voltage. Several single output power supplies can be replaced by this configuration. This deals with the single inductor multi output (SIMO) DC-DC converter. The drawback of conventional transformer based multi output DC-DC converters such as high cost and large volume is avoided using a single inductor boost type dual output DC-DC converter using wireless control. The design of SIMO dc-dc converter along with modes of operation has been presented using MATLAB / SIMULINK. And the application of wireless control of DC-DC converter is given.

**Keywords :** Boost converter, Continuous conduction mode (CCM), Conventional transformer, Multi output DC-DC converters, Single-inductor multiple-output (SIMO).

## I. INTRODUCTION

DC-DC converters are widely used in low and high power applications. Multiple outputs DC-DC converters are efficient and economical devices which are used instead of several separate single output converters to make up a multiple output power supply. In recent years, Multi output DC-DC converters because of its reduced size and less weight is used in various applications. The conventional transformer based multi-output DC-DC converters are extensively utilized to provide multiple output voltages. In addition to conventional DC-DC devices like boost, buck, buck-boost, and flyback, there is an increasing need of DC-DC converters capable to generate many outputs while using a single inductor. The reason is that when on the same system it is required to generate multiple supply voltages, the increased PCB area, the number of components, and the reduced reliability for the many inductors used, becomes complex. The SIMO DC-DC converters are extensively used in low- and high power applications. The number of required inductors will also be increased as the number of output voltage required which leads to an increase in the cost and size of the system. Depending on buck, boost and buck-boost topologies a new generation of single-inductor multiple-output (SIMO) DC-DC converters have been addressed in [1]. This proposed topology reduces the number of external and complicated components such as inductors and as well as power switches, leading to reduced cost and losses in the converters. For SIMO converters to improve the dynamic performance several voltage and current control techniques have been applied in continuous conduction mode (CCM). However, loads are independently constructed in these configurations.

## II. PROPOSED TOPOLOGY

A circuit diagram of the N-output boost converter is shown in Fig.1[1] This circuit consists of a boost switch, N-1 sharing switches $S_1$ to $S_{N-1}$ , N diodes ($D_1$ to $D_{N-1}$), an inductor and N capacitors ($C_1$ to $C_N$) with different loads ($R_1$ to $R_N$) which is addressed in [6]. In the subinterval zero, $S_0$ is turned 'ON' and the inductor can be charged by the current flowing through it. In the next N subintervals, $S_0$ remains 'OFF' and the $S_1$ to $S_{N-1}$ are switched to charge N-I capacitors into the desired value. When $S_1$ to $S_{N-1}$ are 'OFF', the diode (ON) directs the inductor current to charge all $C_1$ to $C_N$ to generate $V_1$ to $V_N$, respectively. $D_1$ to $D_{N-1}$ are used to block the negative voltage and provide two quadrant operation of $S_1$ to $S_{N-1}$.

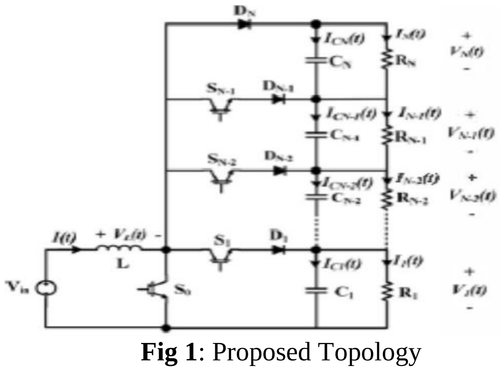

**Fig 1**: Proposed Topology

**Circuit Diagram**

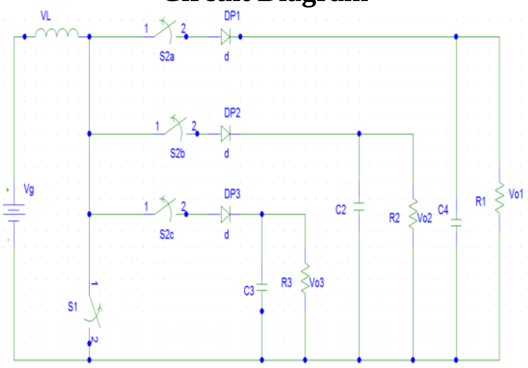


**Fig 2:** Circuit diagram of proposed topology

The proposed topology discussed here is a single inductor boost output dc-dc converter. Here a single input ($V_g$) and three boost outputs ($V_{o1}$), ($V_{o2}$), and ($V_{o3}$). Capacitors $C_4$, $C_2$, and $C_3$ are the output capacitors at the outputs $V_{o1}$, $V_{o2}$, and $V_{o3}$ respectively. $R_1$, $R_2$ and $R_3$ are the loads at the corresponding output nodes. The circuit diagram with three outputs is shown in figure 2. This topology can be extended to generate "n" outputs. In the proposed configuration, the voltage levels of three outputs can be adjusted by varying the duty cycles of switches $S_1$, $S_{2a}$, $S_{2b}$ and $S_{2c}$.

The timing diagram describes the operation of the converter to generate the desired outputs. The inductor is charged through switch $S_1$ duration $D_1T$. Once $S_1$ is turned OFF, $S_{2a}$ turns ON for the time $D_2$ T to supply the mandatory boost output. $S_{2b}$ turns ON for the time $D_2T$ and $S_{2c}$ for next time [1-($D_1$+D-$_2$+$D_3$)] to drive the boost output. The inductor current waveform $I_L$ is plotted. It should be noted that a different timing sequence or a different switching sequence will result in a different output configuration. Table 1 denotes the switching configuration.

| Switching states | $S_1$ $S_{2a}$ $S_{2b}$ $S_{2c}$ | $C_4$ $C_2$ $C_3$ |
|---|---|---|
| 1 0 0 0 | ON OFF<br>OFF OFF | Discharge<br>Discharge<br>Discharge |
| 0 1 0 0 | OFF ON<br>OFF OFF | Charge<br>Discharge<br>Discharge |
| 0 0 1 0 | OFF OFF<br>ON OFF | Discharg<br>Charge<br>Discharge |
| 0 0 0 1 | OFF OFF<br>OFF ON | Discharge<br>Discharge<br>Charge |

**Table 1:** Switching Modes

## III. Modes Of Operation

### 3.1 Mode I

The switch $S_1$ is turned on at time $D_1T$ and the equivalent circuit is shown in figure 1. The input voltage source and the inductor current increases as the inductor are charged. The Kirchhoff's voltage law around the path containing the source, inductor and closed switch $S_1$ is given in equation (a). It's assumed that capacitors $C_4$ and $C_2$ is precharged and supply the load voltages at this interval.

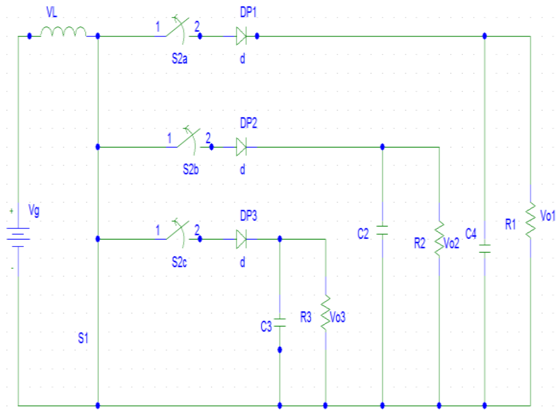


**Fig 3:** Mode I

As shown in the above figure at mode I, the incremental inductor current $\Delta I_1$ can be obtained as shown below,

$$V_g - V_L = 0 \qquad \text{(a)}$$

$$L\frac{di_L}{dt} = V_g$$

The rate of change of current is constant, so the current increases linearly while switch $S_1$ is closed as in figure 8.

$$\Delta i_L = \frac{V_g}{L}\,\Delta t$$

$$\Delta I_1 = \frac{V_g}{L}\,(D_1T) \qquad (1)$$

a.Mode II

At mode II, the switch $S_1$ is turned OFF at time $D_1T$ and switch $S_{2a}$ is turned ON until $D_2T$ to supply the boost output. The equivalent circuit when switch $S_{2a}$ is closed as shown in Figure 4. In the intervening period of time, the inductor discharges to the output capacitor $C_4$ and load resistor $R_1$ through diode $D_{p1}$. So the inductor current decreases linearly as shown in figure 8. During this interval also the capacitor $C_2$ delivers the load voltage to $V_{o2}$.

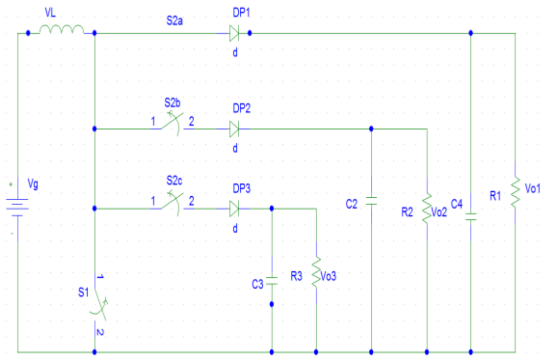


**Fig 4**: Mode II

At mode II, the decrease in inductor current $\Delta I_2$ can be obtained as shown below,

$$V_g - V_L - V_{o1} = 0$$

$$L\frac{di_L}{dt} = V_g - V_{o1}$$

$$\Delta i_L = \frac{V_g - V_{o1}}{L}\ \Delta t$$

$$\Delta I_2 = \frac{V_g - V_{o1}}{L}\ (D_2T) \qquad (2)$$

**Mode III**

At mode III, switch $S_{2b}$ is turned ON and the switches $S_1$ and $S_{2a}$ is turned OFF. The equivalent circuit is shown in figure 5. It is ON for a time $D_3T$ to supply the mandatory boost output. Within the time, the inductor discharges through load resistor $R_2$ and the output capacitor $C_2$ through diode $D_{p2}$. So the inductor current decreases linearly as in figure 8. The capacitor $C_4$ discharges through load $V_{o1}$.

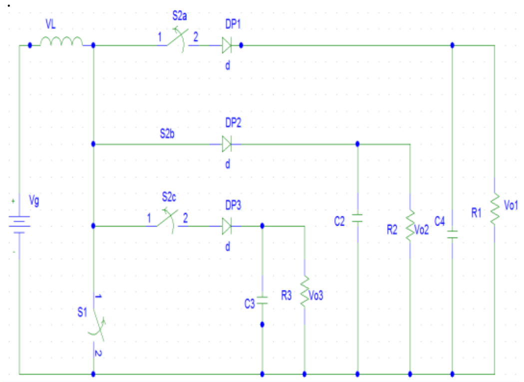


**Fig 5:** Mode III

During mode III, the decrease in the inductor current $\Delta I_3$ can be obtained as shown below,

$$V_g - V_L - V_{o2} = 0$$

$$L\frac{di_L}{dt} = V_g - V_{o2}$$

$$\Delta i_L = \frac{V_g - V_{o2}}{L}\ \Delta t$$

$$\Delta I_3 = \frac{V_g - V_{o2}}{L}\ [1-(D_1+D_2)]T \qquad (3)$$

**Mode IV**

At mode IV, switch $S_{2c}$ is turned ON and the switches $S_1$, $S_{2a}$, and $S_{2b}$ is turned OFF. The equivalent circuit is shown in figure 5. It is ON for a time $[1-(D_1+D_2+D_3)]T$ to supply the boost output. Within the time, the inductor discharges through load resistor $R_3$ and the output capacitor $C_3$ through diode $D_{p3}$. So the inductor current decreases linearly as in figure 8. The capacitor $C_4$ and $C_2$ discharges through load $V_{o1}$, $V_{02}$ respectively.

$$V_g = V_L + V_{o3}$$

$$L\frac{d_{iL}}{dt} = V_g - V_{o3}$$

$$\Delta I_4 = \frac{V_g - V_{o3}}{L}[1-(D_1+D_2+D_3)]T \qquad (4)$$

## IV. RELATION BETWEEN INPUT AND OUTPUT VOLTAGE RATIO

At steady state, increase in the inductor current $\Delta I_1$ is equal to the summation of decreases, $(\Delta I_2+\Delta I_3+\Delta I_3)$, in the inductor current. So the relationship between $V_g$, $V_{o1}$, $V_{o2}$, and $V_{o3}$ can be obtained as in equation (5).

$$\Delta I_1 = \Delta I_2 + \Delta I_3 + \Delta I_4$$

$$V_g = \frac{V_{o1}D_2+V_{o2}D_3+V_{o3}[1-(D_1+D_2+D_3)]}{1-2D_1} \qquad (5)$$

## V. DERIVATION OF MINIMUM INDUCTANCE IN CCM

To make certain that the operation of CCM condition is maintained, the inductance must be greater than a threshold value, as shown in Figure 8, which can be derived by employing the principles of energy conservation, as shown in equation (6)

$$P_{in} = V_g I_L = P_o = \frac{V_{o1}^2}{R_1} + \frac{V_{o2}^2}{R_2} + \frac{V_{o3}^2}{R_3} \qquad (6)$$

Where Pin is the input power and Po is the output power. The threshold level of inductor current $I_{Lmin}$ in Figure 8, the threshold inductance Lmin can be obtained, as shown in Equation (8).

$$Lmin \ge \frac{V_g D_1\left[V_{01}D_2+V_{02}D_3+V_{03}\left(1-(D_1+D_2+D_3)\right)\right]}{2f(V_{01}^2R_2R_3+V_{02}^2R_1R_3+V_{03}^2R_1R_2)(1-2D_1)} \qquad (8)$$

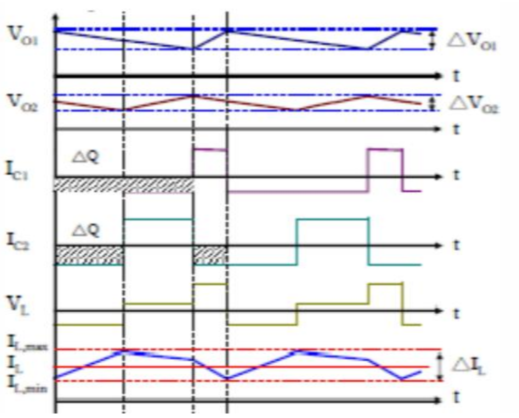


**Fig 8:** (a)Output voltage $V_{o1}$, (b) Output voltage $V_{o2}$, (c) Capacitor currents $I_{c1}$ and $I_{c2}$, (d) Inductor voltage, (e) Inductor current.

## VI. SIMULATION RESULTS

The simulation of single input multi output dc-dc converter is done using MATLAB/SIMULINK software and the results are as follows. The simulation results are discussed and compared with the output voltage results. Single input multi output dc-dc converter is simulated and the results are also shown below.

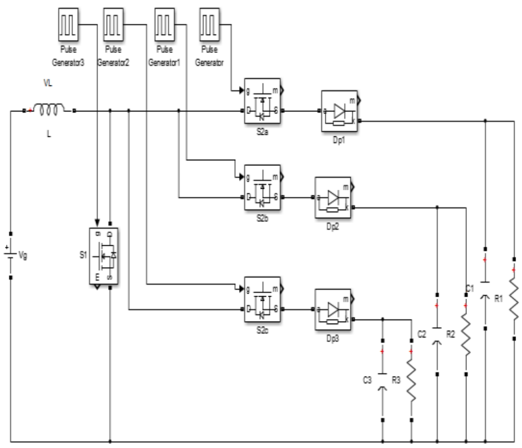

**Fig 9:** Open loop circuit simulation model

Simulation Parameters

| | |
|---|---|
| $V_g$ | 72 V |
| $L_1$ | 1mH |
| $C_4$ | 200µF |
| $C_2$ | 200µF |
| $R_1$ | 100Ω |
| $R_2$ | 100Ω |
| $f_s$ | 3.6kHz |

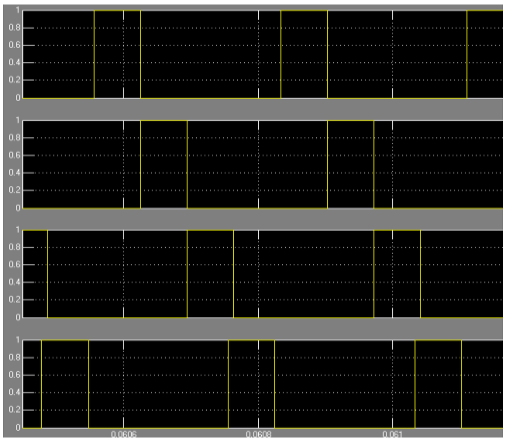

**Fig 10:** Gate pulse

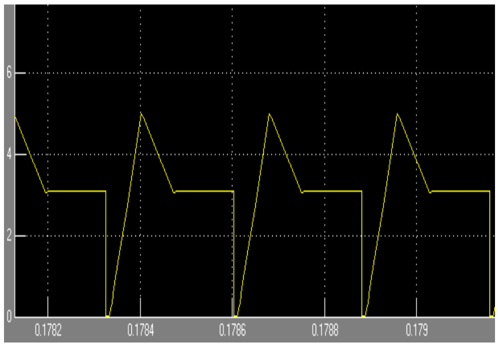

**Fig 11**: Inductor current

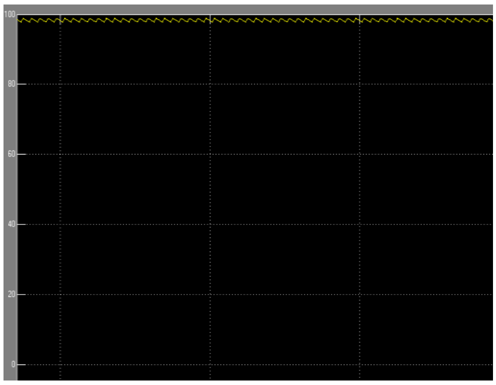

**Fig 12**: Output voltage $V_{o1}$

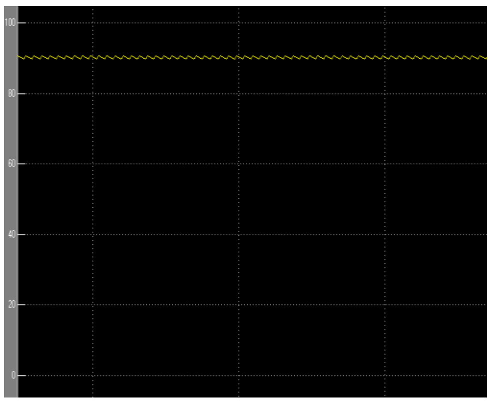

**Fig 13:** Output voltage $V_{o2}$

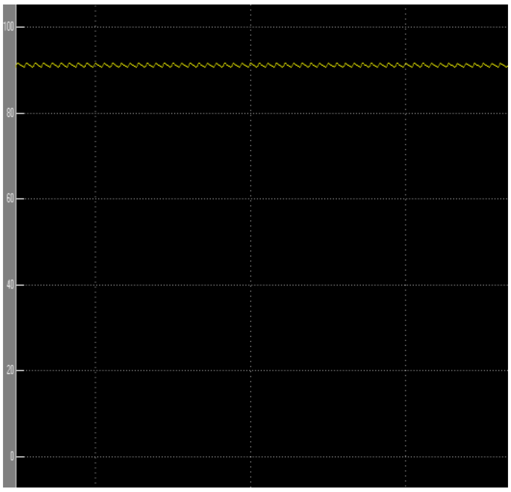

**Fig 14:** Output voltage $V_o$

## VII. CONCLUSION

This study has successfully developed a SIMO dc–dc converter, and this coupled-inductor-based converter was applied well to a single-input power source plus two output terminals. The open loop simulation of the proposed multi output boost converter using MATLAB SIMULINK. The output voltage can be shared between different loads for many applications. The SIMO converter replaces the use of conventional transformer and reduces the size and cost of the system. When frequency of the pulses is 3.6 kHz the proposed topology is working properly.

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