Design of Single Input Multiple Output DC-DC Converter

S. Karthik¹, C. Jegan², R. Ilango³
¹PG Student [PED], Department of EEE, M.A.M. School of Engineering, Siruganur, Tiruchirappalli, Tamilnadu, INDIA
²Assistant Professor, Department of EEE, M.A.M. School of Engineering, Siruganur, Tiruchirappalli, Tamilnadu, INDIA
³Professor, Department of EEE, M.A.M. School of Engineering, Siruganur, Tiruchirappalli, Tamilnadu, INDIA

ABSTRACT
This paper proposes a design of single input multiple output (SIMO) dc–dc converter. The proposed converter can generate the voltage of a low voltage input to controllable levels of boosted output voltage and it can also produce the inverted output voltage. This dc–dc converter utilizes the properties of voltage clamping and soft switching based on a coupled inductor. In this paper, the design of SIMO dc–dc converter along with modes of operation has been presented using MATLAB / SIMULINK. Simulation results thus obtained show that, the objectives of high-efficiency, high step up ratio and various levels of output voltages.

Keywords— Coupled inductor, single-input multiple-output (SIMO) converter, soft switching, voltage clamping.

I. INTRODUCTION

Multiple output converters are widely used in the industrial applications. Designing multi-output converters presents a remarkable challenge for the power supply designer. Converters utilizing a single primary power stage and generating more than one isolated output voltage are called multi-output converters. The basic requirements are small size and high efficiency. High switching frequency is necessary for achievement of small size. If the switching frequency is increased then the switching loss will increase. This decreases the efficiency of the power supplies. To solve this problem, some kinds of soft switching techniques need to be used to operate under high switching frequency. Zero Voltage Switched (ZVS) technique and Zero Current Switched (ZCS) technique are two commonly used soft switching methods. By using these techniques, either voltage or current is zero during switching transition, which largely reduce the switching loss and also increase the reliability for the power supplies.

Applications may require step-up, or at times even a bipolar supply from the same battery supply. Bipolar supplies also find a wide range of application in organic light emitting diodes. As a result, the design of a power management IC typically comprises boost to step-up, buck-boost to generate negative supply, and linear regulators to meet different supplies for various circuit applications. Several methods have been proposed to regulate the multiple outputs, to reduce the conduction loss, the MOSFET switch with low turn-on resistance is used; dc–dc converters are widely used in low and high-power applications.

Patra et al. [1] presented a SIMO dc–dc converter capable of simultaneously generating buck, boost, and inverted outputs. However, over three switches for one output were required. This scheme is only suitable for the low output voltage and power application, and its power conversion is degenerated due to the operation of hard switching. Nami et al. [2] proposed a new dc–dc multi-output boost converter, which can share its total output between different series of output voltages for low and high power applications. In this scheme, over two switches for one output were required, and its control scheme was complicated. Besides, the corresponding output power cannot supply for individual loads independently. Chen et al. [3] investigated a multiple-output dc–dc converter with shared zero-current switching (ZCS) lagging leg. Although this converter with the soft-switching property can reduce the switching losses, this combination scheme with three full-bridge converters is more complicated, so that the achievement of high conversion efficiency is difficult and its cost is also increased.

A new generation of single input multiple output (SIMO) dc–dc converters has been developed based on boost and inverted topologies. However, in these configurations, loads are independently constructed except the negative output [4]. In the proposed SIMO converter, the techniques of soft switching and voltage clamping are adopted to reduce the switching and conduction losses via the utilization of a low voltage rated power switch with a small Rds(on). This project presents a newly designed SIMO dc–dc converter based on boost and inverted derived topologies with a coupled inductor. The motivation of this project is to design a single input multiple output converter for increasing the conversion efficiency, voltage gain [5], reducing the complex control and saving the cost of manufacturing.
II. TOPOLOGY OVERVIEW AND ANALYSES

A. Block Diagram

The Fig. 1 shows the block diagram of Proposed Single Input Multiple Output dc-dc converter. The DC Source block consists of the dc input power source and a capacitor. The value of input is in the range of 12V. Switch Integrated with Coupled Inductor block consisting of a coupled inductor, a MOSFET switch and a diode. The coupled inductor primary has a series connected leakage inductor and a parallel connected magnetizing inductor. Output Voltage 1 Circuit consists of an auxiliary inductor, a diode and a filter capacitor. The value of output voltage 1 is 28V. Output Voltage 2 Circuit consists of a capacitor connected in series with the coupled inductor secondary and a diode connected in parallel with the above combination. In addition, the series connected diode and a filter capacitor is used. The value of output voltage 2 is 200V. Output Voltage 3 circuit consists of two MOSFET switches, two diodes and two capacitors. The value of output voltage 3 is -200V.

B. Circuit Diagram & Description

The system configuration of the proposed SIMO converter topology to generate three different voltage levels from a single-input power source is depicted in Fig. 2. This SIMO converter contains six parts including an input side circuit (ISC), a clamped circuit, a coupled inductor secondary circuit, output voltage 1 circuit, output voltage 2 circuit and output voltage 3 circuit. The major symbol representations are summarized as follows. $V_{dc}$ ($i_{dc}$) and $V_{01}$ ($i_{01}$) denote the voltages (currents) of the input power source and the output load at the input side voltage circuit and the output voltage 1 circuit, respectively; $V_{02}$ and $i_{02}$ are the output voltage and current in the output voltage 2 circuit. $V_{03}$ and $i_{03}$ are the output voltage and current in the output voltage 3 circuit. $C_{01}$, $C_{02}$ and $C_{03}$ are the filter capacitors at the ISC, a output voltage 1 circuit, a output voltage 2 circuit and a output voltage 3 circuit, respectively; $C_1$, $C_2$ and $C_3$ are the clamped and coupled inductor secondary circuit capacitors in the clamped and coupled inductor secondary circuits respectively. $L_p$ and $L_s$ represent individual inductors in the primary and secondary sides of the coupled inductor respectively, where the primary side is connected to the input power source; $L_{aux}$ is the auxiliary inductor. The main switch is expressed as $S_1$ in the ISC, $S_2$ and $S_3$ are the switches used in the output voltage circuit 3. The equivalent load in the output voltage circuit 1 is represented as $R_{01}$, the output load is represented as $R_{02}$ in the output voltage circuit 2 and the output load is represented as $R_{03}$ in the output voltage circuit 3. The circuit diagram has the six diodes namely $D_1$, $D_2$, $D_3$, $D_4$, $D_5$ and $D_6$ respectively. The coupled inductor in Fig. 2 can be modeled as an ideal transformer including the magnetizing inductor $L_{mp}$ and the leakage inductor $L_{kp}$.

The turn’s ratio $N$ and coupling coefficient $k$ of this ideal transformer are defined in equations 1 & 2 as,

$$N = \frac{N_2}{N_1}$$

$$k = \frac{L_{mp}}{(L_{mp} + L_{kp})} = \frac{L_{mp}}{L_{kp}}$$

where $N_1$ and $N_2$ are the winding turns in the primary and secondary sides of the coupled inductor. Because the voltage gain is less sensitive to the coupling coefficient
and the clamped capacitor $C_1$ is appropriately selected to completely absorb the leakage inductor energy [6], the coupling coefficient could be simply set at unity to obtain $L_{\text{mp}} = L_p$.

C. Modes of Operation

The proposed converter has the six modes of operation, which will be discussed in the following sections.

1) Mode 1: The main switch $S_1$ was turned ON and the diode $D_4$ turned OFF. Because the polarity of the windings of the coupled inductor is positive, the diode $D_3$ turns ON. The secondary current reverses and charges the capacitor $C_2$. When the auxiliary inductor $L_{\text{aux}}$ releases its stored energy completely, and the diode $D_2$ turns OFF. Here $S_2$ is turned ON and $S_3$ is turned OFF, $D_6$ is forward biased and $D_5$ is reverse biased. $V_{02}$ is connected in series with $C_3$, $S_2$ and $D_6$ forms a closed loop and charges $C_3$, this mode ends. The Fig.3(a) shows the mode 1 of operation.

2) Mode 2: As depicted in Fig.3(b) the main switch $S_1$ is turned ON, because the primary inductor $L_p$ is charged by the input power source and the magnetizing current $I_{L_{\text{mp}}}$ increases gradually in an approximately linear way. At the same time, the secondary voltage of coupled inductor charges the capacitor $C_2$ through the diode $D_3$. Because the auxiliary inductor $L_{\text{aux}}$ releases its stored energy completely and the diode $D_2$ turns OFF at the end of mode 1, it results in the reduction of $\frac{\text{d}I_{L_{\text{mp}}}}{\text{d}t}$ at mode 2. Here $S_3$ is turned OFF and $S_2$ is turned ON, $D_6$ is forward biased and $D_5$ is reverse biased. $V_{02}$ is connected in series with $C_3$, $S_2$ and $D_6$ forms a closed loop and charges $C_3$, this mode ends.

3) Mode 3: The main switch $S_1$ is turned OFF. When the leakage energy still released from the secondary side of the coupled inductor, the diode $D_3$ conducts and releases the leakage energy to the capacitor $C_2$. When the voltage across the main switch is higher than the clamped capacitor, the diode $D_1$ conducts to transmit the energy into the clamped capacitor $C_1$. Thus, the current passes through the diode $D_2$ to supply the power for the output load in the output voltage 1 circuit. When the secondary side of the coupled inductor releases its leakage energy completely and the diode $D_3$ turns OFF. The closed loop of $S_3$, $C_3$ and $D_6$ has been continued until the $C_{02}$ completely discharged, this mode ends. The Fig.3(c) shows the operation of mode 3.

4) Mode 4: As shown in Fig.3(d), here the main switch $S_1$ is turned OFF. When the leakage energy has released from the primary side of the coupled inductor, the secondary current is induced in reverse from the energy of the magnetizing inductor $L_{L_{\text{mp}}}$ through the ideal transformer and flows through the diode $D_2$ to the output voltage 2 circuit. At the same time, partial energy of the primary side leakage inductor $I_{L_{\text{kp}}}$ is still persistently transmitted to the auxiliary inductor $L_{\text{aux}}$ and the diode $D_2$ keeps conducting. Moreover, the current $I_{L_{\text{mp}}}$ passes through the diode $D_5$ to supply the power for the output load in the output voltage 1 circuit. Here $S_1$ is turned OFF and $S_3$ is turned ON, $D_5$ is
forward biased and \( D_6 \) is reverse biased. \( C_3 \) is connected in series with \( S_3, D_5 \) and \( C_{03} \) to form a closed loop and delivers the total voltage to \( C_{03} \), so the output voltage across \( C_{03} \) is inverting voltage.

5) **Mode 5:** As depicted in Fig. 3(e), the main switch \( S_1 \) is turned OFF and the clamped diode \( D_1 \) turns OFF because the primary leakage current equals to the auxiliary inductor current. In this mode, the input power source, the primary winding of the coupled inductor and the auxiliary inductor \( L_{aux} \) connect in series to supply the power for the output load in the auxiliary circuit through the diode \( D_2 \). At the same time, the input power source, the secondary winding of the coupled inductor, the clamped capacitor \( C_1 \) and the capacitor \( C_2 \) connect in series to release the energy into the output voltage 2 circuit through the diode \( D_4 \). Here \( S_3 \) is turned ON and \( S_1 \) is turned OFF, \( D_5 \) is forward biased and \( D_6 \) is reverse biased. \( C_3 \) is connected in series with \( S_3, D_5 \) and \( C_{03} \) to form a closed loop and delivers the total voltage to \( C_{03} \), so the output voltage across \( C_{03} \) is inverting voltage.

6) **Mode 6:** The operation of mode 6 is represented in Fig. 3(f). This mode begins when the main switch \( S_1 \) is triggered. The auxiliary inductor current needs time to decay to zero, the diode \( D_2 \) conducts. The input power source, the clamped capacitor \( C_1 \), the secondary winding of the coupled inductor and the capacitor \( C_2 \) still connect in series to release the energy into the output voltage 2 circuit through the diode \( D_4 \). Moreover, the rising rate of the primary current \( I_{lkp} \) is limited by the primary-side leakage inductor \( L_{kp} \). Here \( S_1 \) & \( S_3 \) is turned ON, \( D_5 \) is forward biased and \( D_6 \) is reverse biased. \( C_3 \) is connected in series with \( S_1, D_5 \) and \( C_{03} \) to form a closed loop and delivers the total voltage to \( C_{03} \), so the output voltage across \( C_{03} \) is inverting voltage. When the secondary current of the coupled inductor decays to zero, this mode ends.

### III. SIMULINK MODEL AND RESULTS

The design of single input multiple output DC-DC converter is modeled using MATLAB/Simulink and the simulation model is shown in Fig. 4.
Fig. 4 Simulink model of proposed converter

A. Simulation model results

Fig. 5(a) to Fig. 5(h) shows the simulation results of the proposed circuit. Fig. 5(a) shows the simulated waveform of input voltage, here the input voltage of circuit is about 12V. Fig. 5(b) shows the simulated waveform of gate pulses for switch S1, S2&S3. Fig. 5(c) shows the simulated waveform of output current 1, here the output current of the circuit 1 is about 1A. Fig. 5(d) shows the simulated waveform of output voltage 1, here the output voltage of circuit 1 is about 28V. Fig. 5(e) shows the simulated waveform of output current 2, here the output current of circuit 2 is about 1A. Fig. 5(f) shows the simulated waveform of output voltage 2, here the output voltage of circuit 2 is about 200V. Fig. 5(g) shows the simulated waveform of output current 3. Fig. 5(h) shows the simulated waveform of output voltage 3, here the output voltage of circuit 3 is about -200V.
Fig. 5(c) Output current at terminal 1 of the proposed circuit

Fig. 5(d) Output voltage at terminal 1 of the proposed circuit

Fig. 5(e) Output current at terminal 2 of the proposed circuit

Fig. 5(f) Output voltage at terminal 2 of the proposed circuit

Fig. 5(g) Output current at terminal 3 of the proposed circuit
IV. CONCLUSION

This paper has presented a SIMO dc–dc converter and this coupled inductor based converter was applied well to a single input power source plus three output terminals composed of two boost and one inverted voltages. The proposed SIMO converter is suitable for the application required one common ground, which is preferred in most applications. As mentioned above the voltage gain can be substantially increased by using a coupled inductor, the stray energy can be recycled by a clamped capacitor into the output terminal 1 or output terminal 2 to ensure the property of voltage clamping and an auxiliary inductor is designed for providing the charge power to the load 1 and assisting the switch turned ON under the condition of ZCS.

Thus the proposed SIMO converter provides designers with an alternative choice for converting a low voltage source to multiple boost outputs with inverted voltage output efficiently.

REFERENCES