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SINGLE-INPUT MULTI-OUTPUT BOOST CONVERTER WITH POWER FACTOR CORRECTION

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Abstract— A single input, multi-output AC-DC boost converters with power factor correction is proposed. Conventional transformer-based multi-output DC-DC converters have the drawbacks of high cost and large volume. Therefore, the single-input multi-output configuration with power factor correction is developed in order to reduce the component count and cost for multi-output DC-DC converters. Mathematical model of the proposed converter with PFC is developed and dynamic simulation model is developed in MATLAB/Simulink platform. Simulation study is carried out and results show that this topology promises improved performance compared to earlier systems.
Keywords— Multiple output DC-DC converter, Boost Converters, AC-DC converters, DC link, H bridge converter, Input power factor, Passive power factor correction.

INTRODUCTION

This work mainly focuses on single input multiple output DC-DC boost converters used in low voltage applications. Its application comes in the area of portable and hand held consumer devices MP3 players, digital camera etc. Nowadays there are lots of portable devices that work with DC input which is taken from AC sources, so there is a concern of input power factor. Conventionally, the transformer-based multi-output DC-DC converters are widely employed to provide multiple output voltages. However, the drawbacks of these transformer-type converters include the amount and cost of electronic components and circuit volume. The single-input multi-output AC-DC converters were developed to effectively reduce the amount of electronic components for providing multiple output voltages. Number of switches is minimum in this circuit. The boost-type single-inductor multi-output DC-DC converter is the main part of the circuit, which needs only a single inductor for any number of outputs. The problems faced due to transformer usage in DC-DC converters is explained in [1] and also why Power MOSFET is superior over Power transistor. Basic idea of single input multiple output converters [3] and also the idea of coupled inductor in DC-DC converters are derived from [2]. The proposed converter employs transformer less operation [5]. In this proposed system single boosting inductor [4] is enough for any number of outputs. The single inductor multiple output DC-DC boost converter derived from [1]-[5]. Input power factor correction with H bridge converter [7] and inductor [6] is adopted here. Various types of input power factor correction methods [8]-[9] are analyzed and passive power factor correction method is the one used here.

PRINCIPLE AND WORKING

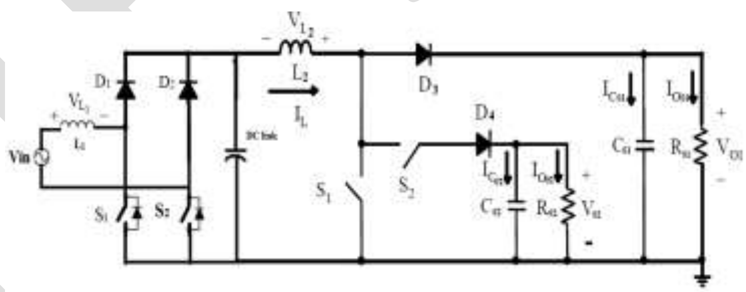

Figure 1: Circuit diagram of Single-Input Multiple-Output Boost Converter

The circuit can be divided into two sections, first is an AC-DC converter which focuses on the Power Factor Correction and the second is a single inductor DC-DC boost converter which provides multiple outputs. A DC link connects both the sections. First section contains an H bridge converter with two switches and two diodes and an inductor in the input side for power factor correction. The two diodes are placed in the upper leg and two switches placed in lower leg of H bridge converter. Input inductor L_1 works as a low pass filter and filtered out harmonics, which improves power factor. Here AC is converted to DC and stored in the DC link which acts as the input of second section. Second section consists of one inductor for boosting purpose, two switches, two diodes, two outputs. One output is with resistor R_{01} and filter capacitor C_{01} and second one is auxiliary output with resistor R_{02} wand filter capacitor C_{02}. This topology uses the least number of switches among multiple output converters. Number of switches should be one less than number of outputs. Switch S_1 controls the amount of boosting along with value of inductor L_2. Working of first section consists of 4 stages and that of second stage consists of 3 stages.

A. AC-DC Converter

1) *Stage 1:* In stage 1, during the positive half cycle with switch S_1 turned ON, input inductor L_1 charges through S_1 and body diode of S_2. L_1 works as a low pass filter and filters out harmonics, which improves power factor. Fig 2(a) shows positions of switches and diodes and corresponding current directions.
2) *Stage 2:* In stage 2, during the positive half cycle with switch S_1 turned OFF, input inductor L_1 discharges through Diode D_1 and body diode of S_2. Fig 2(b) shows positions of switches and diodes and corresponding current directions.
3) *Stage 3:* In stage 3, during the negative half cycle, with switch S_2 turned ON, input inductor L_1 charges through S_2 and body diode of S_1. Fig 2(c) shows positions of switches and diodes and corresponding current directions.
4) *Stage 4:* In stage 4, input voltage belongs to negative half cycle and switch S_1 is in OFF position. Input inductor L_1 discharges through Diode D_2 and body diode of S_1. Fig 2(d) shows positions of switches and diodes and corresponding current directions.

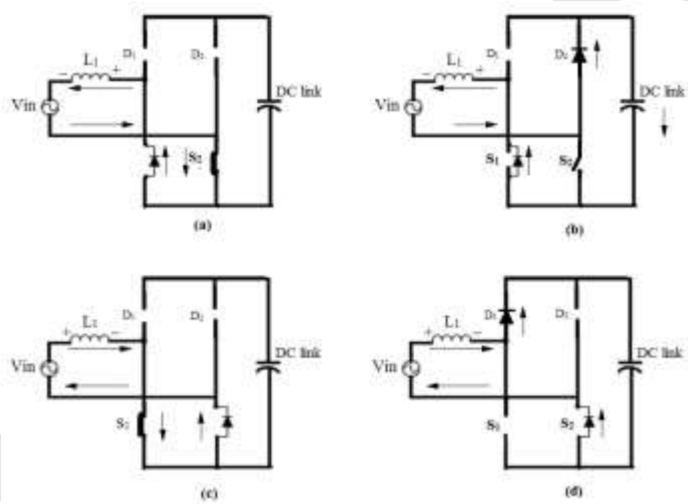

Figure 2: Current directions of the ac-dc converter during (a) Stage 1, (b) Stage 2, (c) Stage 3, (d)Stage 4.

B. DC-DC Boost Converter

1. *Stage 1:* In stage 1, both switches, S_3 and S_4 are turned ON at t_0. The inductor L_2 stores energy and inductor current I_{L2} increases in this stage. Current directions and voltage polarities are shown in Figure 3(a).
2. *Stage 2:* In stage 2, at $t = t_1$ switch S_3 is turned OFF and S_4 remains in ON position. The inductor L_2 discharges energy to auxiliary output and inductor current I_{L2} decreases. Current directions and voltage polarities are also shown in Figure 3(b).
3. *:* In stage 3, at $t=t_2$, switch S_4 is turned OFF and both switches are in OFF position. The inductor L discharges energy to main output R_{01} and inductor current I_{L2} decreases. Current directions and voltage polarities are also shown in Figure 3(c)

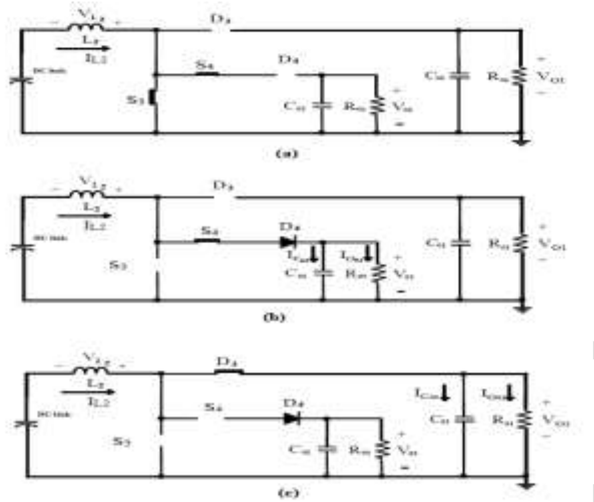

Figure 3: Current directions of the dc-dc converter during (a) Stage 1, (b) Stage 2, (c) Stage 3

DESIGN OF COMPONENTS

A. AC-DC Converter

Input Inductor,	L_1	= 33 μH
DC link capacitor,	C_{DC}	= 1 F
Duty Ratio,		
For S_1,	D_1	= 40%
For S_2,	D_2	= 40%

B. Boost Converter

ΔI_{L_1}	= change in inductor Current
V_g	= Input Voltage
D_3, D_4	= Duty Ratios of S_3 and S_4

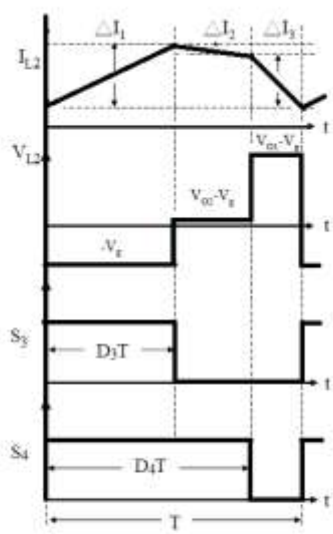

Figure 4: Waveform of Inductor Current and Voltage

Assume,

Main output,	V_{01} = 12 V
Auxiliary output,	V_{02} = 5 V
Duty ratio for $S_{3,}$	D_3 = 50 %

Duty ratio for S_4,	D_4	= 80 %
Switching Frequency,	F	= 100 kHz
Switching period,	T	$= 1 \times 10^{-5}$ sec
Output resistances,	R_{01}	= 82 Ω
	R_{02}	= 22 Ω

By using volt-second balance

Stage 1,

$$\Delta I_{L2} = \frac{V_g \times D_3 \times T}{L_2} = 0.35\ A \qquad (1)$$

Stage 2,

$$\Delta I_{L2} = \frac{(V_{02} - V_g) \times (D_2 - D_1) \times T}{L_2} = 0.06A \qquad (2)$$

Stage 3,

$$\Delta I_{L2} = \frac{(V_{01} - V_g) \times (1 - D_1) \times T}{L_2} = 0.29 \text{ A} \qquad (3)$$

Increase in I_L in stage1 is equal to the sum of decrease in I_L in stage 2 and stage 3

So, voltage ratio relationship in between V_g, V_{01} and V_{02} is

$$V_g = V_{01} \times (1 - D_2) + V_{02} \times (D_2 - D_1) \qquad (4)$$

By substituting values of D_1 and D_2 in Equation (4) we get DC link voltage as V_{DC} = 3.9 V for output voltages 12 V and 5 V.

Based on principle of energy conservation and minimum value of inductor current,

Minimum value of inductance,

$$L_{min} \geq \frac{[V_{01} D_2 (1 - D_2) + V_{02}({D_2}^2 - {D_1}^2 - D_2 - D_1)] \times [V_{01} (1 - D_2) + V_{02}(D_2 - D_1)]\, T\, R_{01} R_{02}}{2[R_{02} V_{01}^2 + R_{01} V_{02}^2]} \qquad (5)$$

$$\geq 17.6\ \mu H$$

C_1 and C_2 can be found using amp-sec balance principle

$$\Delta V_{01} = \frac{(V_{01} \times (1 - D_1) \times T)}{C_{01} \times R_{01}} = 10\ \mu F \qquad (6)$$

$$\Delta V_{02} = \frac{V_{02} \times (1 - (D_2 - D_1) \times T}{C_{02} \times R_{02}} = 33\ \mu F \qquad (7)$$

SIMULINK MODEL AND RESULTS

SIMULINK MODEL

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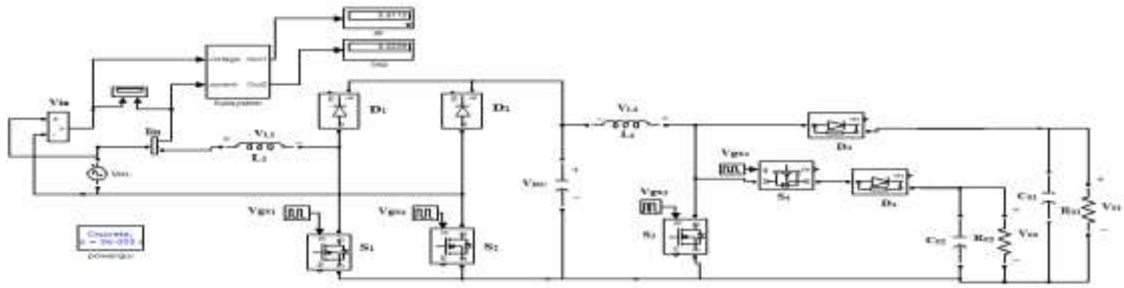

Fig 5: Simulink diagram of the proposed Single-Input Multiple-Output Boost Converter with PFC

The steady state analysis of Single-Input Multi-Output Boost Converter with Power Factor Correction was done using MATLAB 2010a. Simulation results of open loop system are obtained. From those results it is understood that this topology provides improvement in the performance of Multiple Output Boost Converters with AC Source. Power Factor also improved when compared with existing systems

The parameter values used in simulation are

L1 = 33 µH
L2 = 56 µH
D1 = D2 = 40%
D3 = 50%
D4 = 80%
CDC = 1 F.
R01 = 82 Ω
C01 = 10 µF
R02 = 22 Ω
C02 = 33 µF

SIMULATION RESULTS

Simulated waveforms obtained are shown below:

1) Switching pulses

Figure 6 and 7 show the switching pulses of switches S_1, S_2, S_3 and S_4. The duty ratio of S_1 and S_2 is 40% and that of S_3 and S_4 is 50% and 80% respectively.

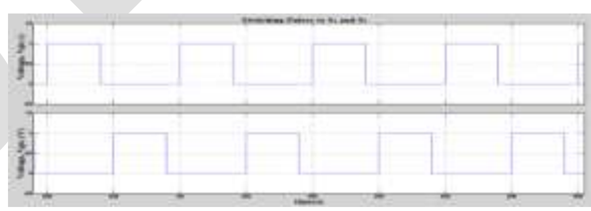

Figure 6: Switching pulses for S_1 and S_2

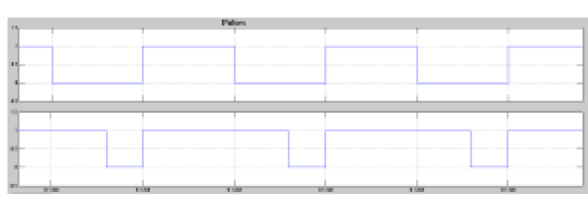

Figure 7: Switching pulses for S_3 and S_4

2) DC Link Voltage

A capacitor acts as a link between AC-DC converter and Boost converter. Figure (8) shows the voltage across the DC link capacitor.

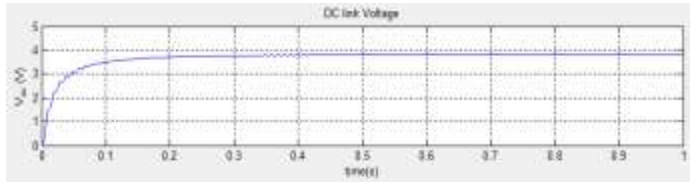

Figure 8: DC link voltage, V_{DC}

3) Inductor Voltage and Current (V_{L2} and I_{L2})

Figure 9 shows the inductor current. In stage 1 I_{L2} increases and L_2 stores energy. In stage 2 inductor L_2 discharges energy to auxiliary output and inductor current decreases gradually. In stage 3 inductor L_2 discharges to main output and inductor current decreases rapidly. Figure 9 shows the current through inductor L and voltage across it. In stage 1 both switches are ON, $V_L = V_g$. At the end of stage 1, S_1 turns OFF. In stage 2, S_2 continues in ON position, inductor discharges energy to auxiliary output and $V_L = V_{02} – V_g$. At the end of stage 2 S_2 also goes to OFF position, inductor discharges energy to main output and $V_L = V_{01} - V_g$ in stage 3.

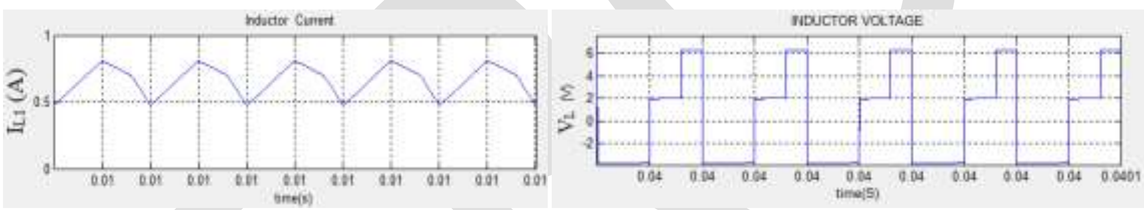

Figure 9: Current through and voltage across inductor L_1

4) Output Currents (I_{01} and I_{02})

Figure 10 shows the main output current. It is obtained when both switches are OFF and diode corresponding to main output is in forward based condition.

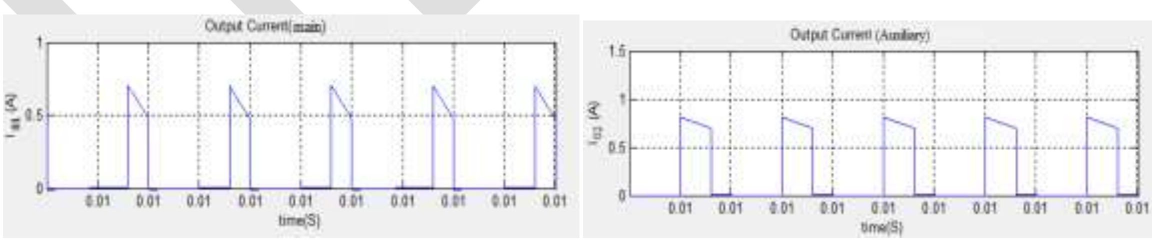

Figure 10: Main output current, I_{01} and Auxiliary output current, I_{02}

5) Output Voltages. (V_{01} and V_{02})

Figure 11 shows the main output voltage. When switches S_3 and S_4 are OFF ,main output voltage increases and rest of the switching cycle it decreases. Figure 12 shows the Auxiliary output voltage. When S_1 is OFF and S_2 is in ON position, Auxiliary output voltage increases (30 % of switching cycle) and rest of the switching cycle it decreases.

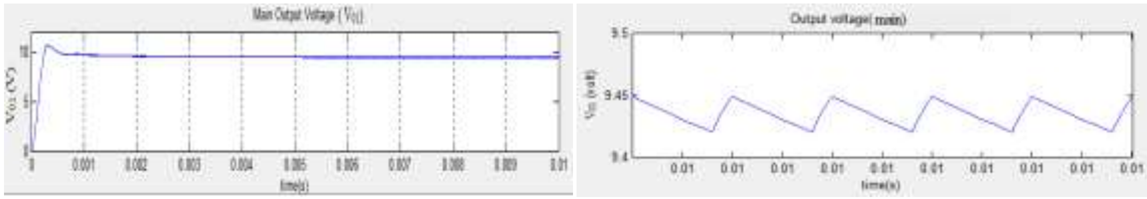

Figure 11: Main output voltage, V_{01}

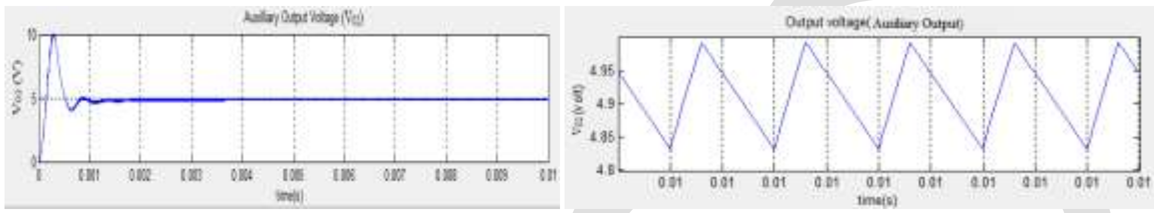

Figure 12: Auxiliary output voltage, V_{02}

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CONCLUSION

Single-Input Multi-Output Boost Converter with Power Factor Correction provides multiple outputs with improved input power factor correction. Input Power factor is improved up to 0.9115 and THD up to 0.22. This was accomplished by a H bridge inverter with input inductor. In DC-DC section only one inductor is needed to attain any number of DC outputs. It works with least number of switches among different topologies in multiple output DC systems.

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