Single Switch Dual Output High Step up Boost Converter

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Abstract- In this work, a novel single switch dual output high step up DC-DC converter. It is designed especially for regulating the DC interface between various micro sources. The converter is a quadratic boost converter with the coupled inductor is the second boost converter. It applicable to demand single-input dual output (SIDO). This can be accomplished using techniques of coupled inductor. The first boost stage is also benefited the input current ripple reduction and in second boost converter the leakage inductor energy of the coupled inductor can be recycled, it reduces the voltage stress on the main switch, and also improved conversion efficiency is significantly. The converter achieves high step-up voltage gain. Simulation study of this converter is carried out in MATLAB/Simulink. To verify the performance of the proposed converter, a 20W prototype sample is implemented with an input voltage range of 12 V and dual output voltages of up to 43V and 67V using PIC16F877A controller and the driver circuit is implemented. The switch is driven along with its driver TLP250. A 12 V input voltage, 67 V and 43 V dual output voltage and 20 W output power prototype circuit is implemented and verified the performance.
Keywords – boost converter, coupled inductor, voltage stress, single-input dual output (SISO)

I. INTRODUCTION

Multiport converters are widely demanded in applications such as photo voltaic systems, hybrid electric/fuel cell vehicles, personal computers, and so on, to provide energy flow and voltage regulation among different inputs and outputs. Although employing multiple single-input single output (SISO) converters is a simple scheme to satisfy the requirement, the component number significantly increases and thus undesirable high cost is incurred [1]. In order to achieve lower cost, a variety of integrated multiport converters with reduced components has been proposed, including multiple output converters with multiple windings or transformers, multiple output converters with secondary side post regulators (SSPR), single-inductor multiport converters and multiport converters with reduced semiconductor devices[2]. A conventional Boost converter can increase the output voltage, but with limited duty ratio. Further, the switching stress is also close to output voltage. Thus cascaded Boost converter is actually two boost converters connected in series. Although this converter increases the output voltage, it requires two switches to be included with a conduction loss on both the switches with reduced efficiency [3]. To improve efficiency, a new converter has been proposed in which contain a single switch to attain the same output voltage of cascaded converter. Thus losses in the switch are being reduced by this technique with a reduced the number of switches. But duty ratio is not low which again increases conduction loss[4]. Coupled inductor based boosting technique has emerged as it has two degree of freedom introduced by assigning turns ratio in addition to duty cycle to attain high voltage gain. Thus for any specific voltage gain, duty cycle can be considered with a lesser value and the converter becomes more efficient.

The above mentioned methods have been combined with the conventional Boost converters, few of the topologies like integrated boost and fly back converter integrated boost and switched capacitors, Cascaded boost with fly back integration and buck boost integration with fly back are presented. However, several other high boost techniques and design concepts based on coupled inductor technique are used [5]. The reviewed converters with coupled inductor technology, increases the voltage gain and also increases the current stress of the switch. The efficiency and voltage gain of DC-DC boost converter are restrained by either the parasitic effect of power switches or the reverse-recovery issue of diodes [6]. In addition, to that overall efficiency is also affecting by equivalent series resistance (ESR) of capacitor and the parasitic resistances of inductor. There are several methods available for reduction of switch voltage stress in the DC-DC converters as proposed. But the switch current stress reduction technique is not considered in a larger scale in the field of DC-DC converters. However, this technique is very much used in Power factor correction.

Working principle of converter is presented in section II. Experimental results are presented in section III. Concluding remarks are given in section IV.

II. SINGLE SWITCH DUAL OUTPUT CONVERTER

2.1 single switch boost-flyback integrated dc-dc converter –

This converter construction is same as the conventional converter, except parallel combination of L-D, is connected in series with the main switch. This converter becomes more advantageous over the conventional one by reducing the switch current stress with the use of L-D. The current conduction path with respect to different modes of operation are in figure 3(a-f). A single switch boost-fly-back high step up DC-DC converter consists of one switch S, five diodes D1, D2, D3, D4 and DS, five inductors L1, Llk1, Llk2, Lm and LS, one coupled inductor, three capacitors Cl , C2 and C3, and one load resistor R. Shown in figure 1 (a).

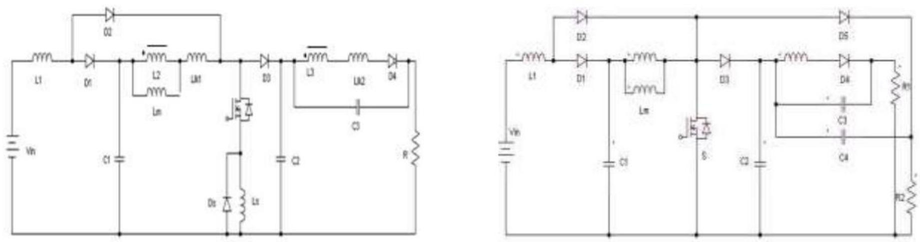

Figure 1. (a) Power circuit of Quadratic Fly back converter (b) single switch dual output boost converter

A single switch dual output boost DC-DC converter is the modification of the quadratic fly back converter. It consists of one switch S, five diodes D1, D2, D3, D4 and D5, two inductors L1, Lm, one coupled inductor, four capacitors pumping capacitor C1, C2 and output capacitor C3, C4 with two load resistor R1, R2. Figure 1 (b) shows a circuit of typical arrangement of single switch dual output boost converter.

The first boost stage is like a boost converter that includes an input inductor Lin, two diodes D1 and D2, and a pumping capacitor C1 output capacitor C 4. The second boost stage is a boost flyback converter that includes a dual winding coupled inductor, two diodes D3 and D4, and two output capacitors C3 and C4. In particular, these two stages are driven by a single switch S

2.2. Operation principle–

The working of the circuit can be explained by six modes of operation.

Mode 1 (t0 - t1) - During this mode, switch S and diode D2, D4, are conducting. The leakage inductor Ilk2 releases its energy through D4 and C3 in the secondary winding of the coupled inductor. The current through C2 is passes through capacitor C4 and to load. The current through the leakage inductor Ilk1 is increasing as capacitor C1 discharges though the primary winding of coupled inductor. The diode D1 becomes reverse biased by the capacitor C1. Capacitor C2 discharges through the secondary winding of the coupled inductor and load. Mode ends with the extinction of secondary winding leakage current. Figure 3(a) shows the equivalent circuit diagram of the converter and current paths for this mode is also shown. The theoretical waveform of all modes is shown in figure 2.

Mode 2 (t1 - t2) - In this mode, switch S and diode D2 conducts, whereas diodes D1, D3, D4, D5 become turned OFF. This mode ends with the complete release of the energy stored in this inductor with secondary winding open circuited. The capacitor C2, C3 discharges through the load. The capacitor C4 is again charges through C2 Ilk1 still rises with the discharging of capacitor C1. Figure 3(b) shows the equivalent circuit diagram of the converter and current paths for this mode is also shown.

Mode 3 (t2 – t3) -In this mode, all other conditions remain same as in mode 2 and mode ends when the switch is turned OFF.

Figure 3(c) shows the equivalent circuit diagram of the converter and current paths for this mode is also shown.

Mode 4 (t3 - t4) - In this mode, the switch S turned off, diodes D1, D3, D4 , D5 are turned ON whereas D2 remains OFF. Inductor L1 will now release the energy through D1 and charging the capacitor C 1. The capacitor D4 will now discharge through load. The current through leakage inductor Ilk1 reduces through D3 and charges capacitor C2. Diode D 4 becomes forward biased and starts to conduct. The capacitor C3 still discharges through the load until Ilk2 greater than Ilk1 to maintain the load current constant throughout. This mode finishes when C3 again starts its charging process. Switch voltage VDS appears in this mode. Figure 3(d) shows the equivalent circuit diagram of the converter and current paths for this mode is also shown.

Mode 5 (t4 - t5) - In this mode, the condition of each element remains same as mode 4 except the capacitor C3. To maintain a constant load current, a portion of Ilk2 circulates through C3 thus by making it charged. The voltage in the capacitor C4 is zero. This mode ends when Ilk1 fully extinct to zero and the diode D 3 will become reverse biased. Figure 3 (e) shows the equivalent circuit diagram of the converter and current paths for this mode are also shown.

Mode 6 (t5 - t6) - In this mode, the primary winding leakage current Ilk1 deceases to zero, so inductor L1 is completely released through C1. The secondary winding must release energy due to this, D3 will also become reverse biased and the capacitor C2 is forced to be discharged through the secondary winding and load circuit. Here in this mode the charging current of capacitor C3 will be decreasing gradually to maintain a constant current across the load circuit as Ilk2 is also getting reduced due to energy release. The capacitor C4 is again charging from zero through C2. This mode ends with the end of turning OFF time of the switch S. Figure 3(f) shows the equivalent circuit diagram of the converter and current paths for this mode is also shown.

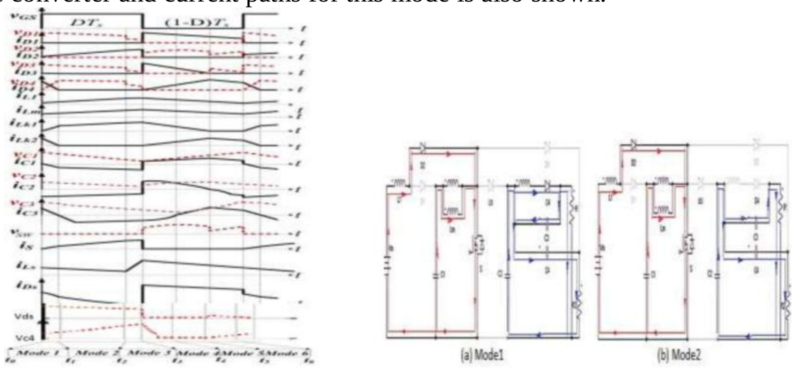

Figure 2 . Theoretical Waveform

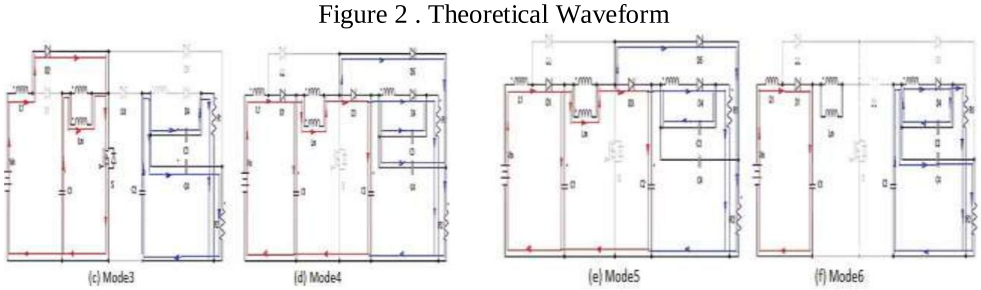

Figure 3.Operating circuits over one switching period

Figure 2 shows the theoretical waveform of the converter and the voltage across inductors, capacitors and diodes, also it gives the knowledge about the current through inductor for the given duty cycle.

2.3. design considerations–

The input voltage is taken as 12V. The pulses are switched at the rate of 10 kHz with a duty ratio of 0.5. Rated Power is 40W. The turns ratio n=1 and design is done so as to reduce input current ripple to 3 % of input current of the boost converter and obtained voltage gain of 0.06. Taking Po as 40 W and output voltage as 72 V, Load resistance is calculated.

$$R_1 = R_2 = \frac{V_o^2}{P_o} = \frac{72^2}{40} = 100\Omega \qquad (1)$$

For design of input and magnetizing inductor

$$I_{L1} = \frac{(1+nD)}{R*(1-D)^4}v_{in} = \frac{(1+1*0.5)}{220*(1-0.5)^4}12 = 1.3090A \qquad (2)$$

$$L_1 = \frac{D*(1-D)^2*R}{n*(2+nD)*f_s\Delta i_{L1}} = \frac{0.5*(1-0.5)^2*100}{1*(2+1*.5)*10000*0.25} = 2.1mH \qquad (3)$$

The value of input inductor is set at 2.1 mH.

$$I_{Lm} = \frac{V_o}{R*(1-D)} = \frac{72}{100*(1-0.5)} = 1.44A \qquad (4)$$

$$L_m = \frac{D*T_s*V_{c1}}{I_m} = \frac{0.5*10000*24}{1.44} = 1mH \qquad (5)$$

The value of magnetizing inductor is set at 1 mH.

For design of coupling inductor we take n=1

$$n = \frac{N_2}{N_1} = 1 \qquad (6)$$

Assume the leakage inductors

$$L_{k1}, L_{k2} = 36\mu H \quad (7)$$

$$L_{11} = L_{k1} + L_m = (36 * 10^{-6}) + (1 * 10^{-3}) = 1.036mH \quad (8)$$

$$L_{22} = L_{k2} + L_m * (\frac{N_2}{N_1})^2 = (36 * 10^{-6}) + (1 * 1 * 10^{-3}) = 1.036mH \quad (9)$$

$$L_{12} = L_m * (\frac{N_2}{N_1})^2 = (1 * 1 * 10^{-3}) = 1mH \quad (10)$$

The value of self-inductance is set at 1.036 mH. The value of mutual inductance is set at 1 mH.
For design of capacitors

$$V_{c1} = \frac{V_{in}}{(1-D)} = \frac{12}{(1-0.5)} = 24V \quad (11)$$

$$V_{c2} = \frac{V_{in}}{(1-D)^2} = \frac{12}{(1-0.5)^2} = 48V \quad (12)$$

$$V_{c3} = \frac{n * V_{in}}{(1-D)^2} = \frac{1 * 12}{(1-0.5)^2} = 48V \quad (13)$$

$$C_1 = \frac{V_{in} * D}{(1-D)^2 * \Delta V_{C1} * R * F_s} = \frac{12 * 0.5}{(1-0.5)^2 * 0.55 * 10 * 10^3 * 100} = 22\mu F \quad (14)$$

$$C_2 = \frac{D * (2 + 1 * D)}{2 * R * f_s * \Delta V_{C2}} = \frac{0.5 * (1 + 1 * 0.5)}{2 * 100 * 10 * 10^3 * 0.06} = 10\mu F \quad (15)$$

$$C_3 = C_4 = \frac{(2 + 1 * D)}{n * R * f_s * \Delta V_{C3}} = \frac{(2 + 1 * 0.5)}{1 * 100 * 10 * 10^3 * 0.3} = 10\mu F \quad (16)$$

III. EXPERIMENT AND RESULT

3.1. Simulink model –

Simulation of single switch boost fly back integrated high step up DC-DC converter is carried based on simulation parameter given in Table 1. An input voltage Vin of 12V gives an output voltage, Vo of 72 V for an output power Po of 40W. The switches are with constant switching frequency of 10 kHz. The duty cycle of switches is taken as D = 0.5. Table

Table I. Simulation Parameters

Parameters		Specification
Input voltage Vin		12 V
Output voltage Vout		72 V
Switching frequency fs		10 kHz
Duty ratio		0.5
Rated power		40 W
Load resistor		220 Ω
Inductors	L1	2.1 mH
	Lm	1 mH
	LS	0.2 mH
	Llk1, Llk2	36 µH
Capacitors	C1	22 µF
	C2,C3	10 µF

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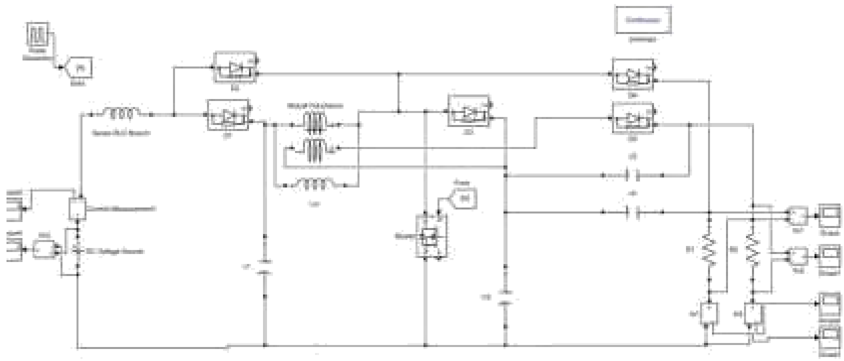

Figure 4. Simulink model of the converter

Shows the simulink model of the converter using this model the entair system is analysed.

3.1.1. simulation results –

The simulation results of the single switch dual output boost converter are shown in the following figures. Based on the design considerations. The gain factors are 6 and 4. Simulation of input voltage, input current, output voltage, output current, switching pulses, voltage across and current through the switch, voltage across the capacitors and current through the inductors are shown.

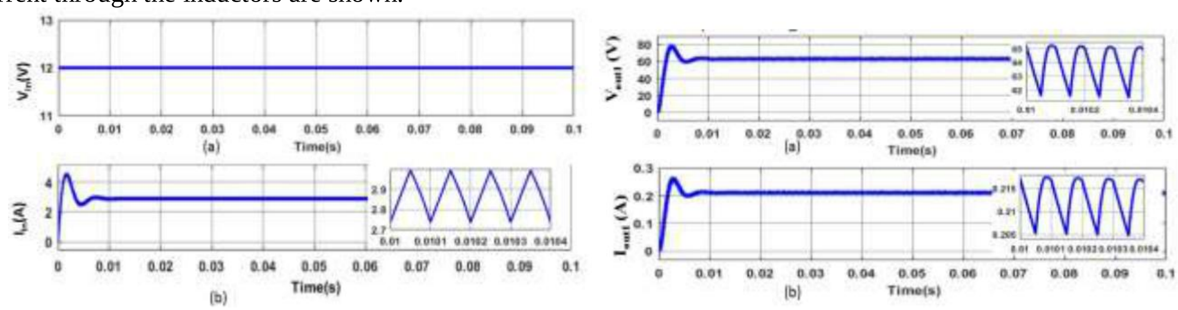

Figure 5 . (a) a) Input Voltage of the converter b) Input Current of the converter (b) a) Output Voltage of the converterb) Output current of the converter

Figure 5(a) shows the input voltage and current waveform. It can be seen that the input voltage Vin is 12 V and input current Iin is 2.67A. Figure 5(b) shows the two output voltage and current. Here the Vout is 67V and 43V. It verifies that the high step up voltage gain.

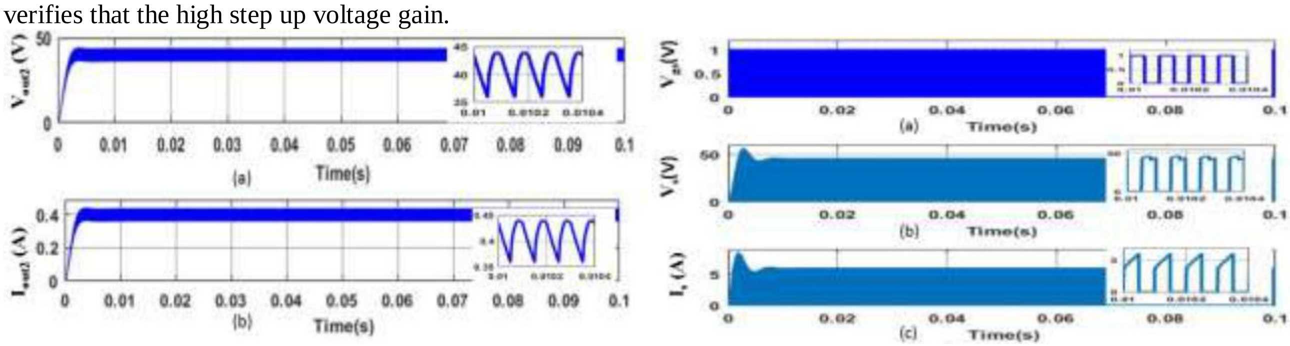

Figure6 (a) a) Output Voltage b) Output current of the converter a) Gate pulse to the switch b) Voltage across switch c) Current through Switch

With the increase in input inductor, switch current stress also reduced in marginal value. But for fixed value of Lm, decrement in L1 value leads to increase in switch current stress rapidly.

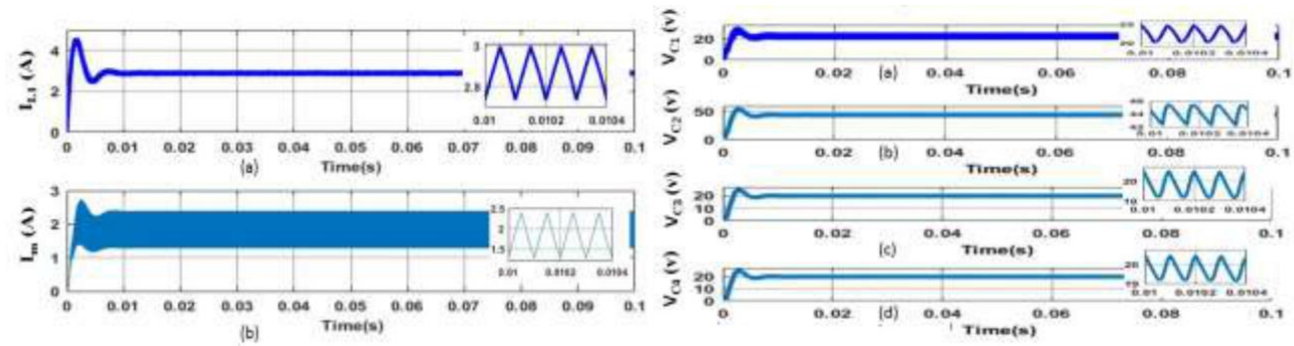

Figure 7 (a) a) Current through inductor L1 b) Current through inductor Lm (b)Voltage across capacitor s a) C1 b) C2 c) C3 d) C4

Figure 7 (a) shows the current through the inductors L1,Lm,of the converter and the current through inductors L1 and Lm is around 4.3A, 2.9A respectively. The figure 7(b) shown the voltage appearing across the load terminal is a combination of the capacitors C2,C3 and C4. The voltage output remains constant over the cycle.

3.2. Analysis -

The analysis of dual output boost converter is carried out by considering parameters like voltage gain, efficiency, voltage stress and duty cycle etc.

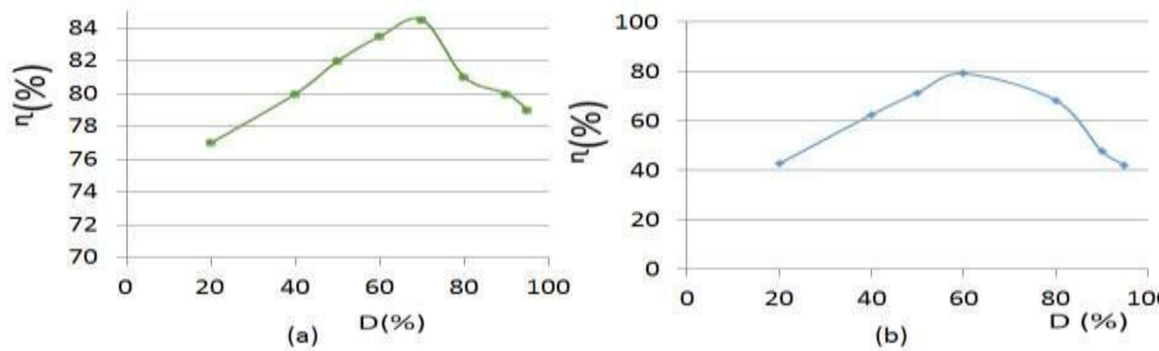

Figure 8 (a) a)η(%) Vs duty ratio with R load b) η (%) Vs duty ratio with RL load

The converter efficiency is around 85% for 40W output power.

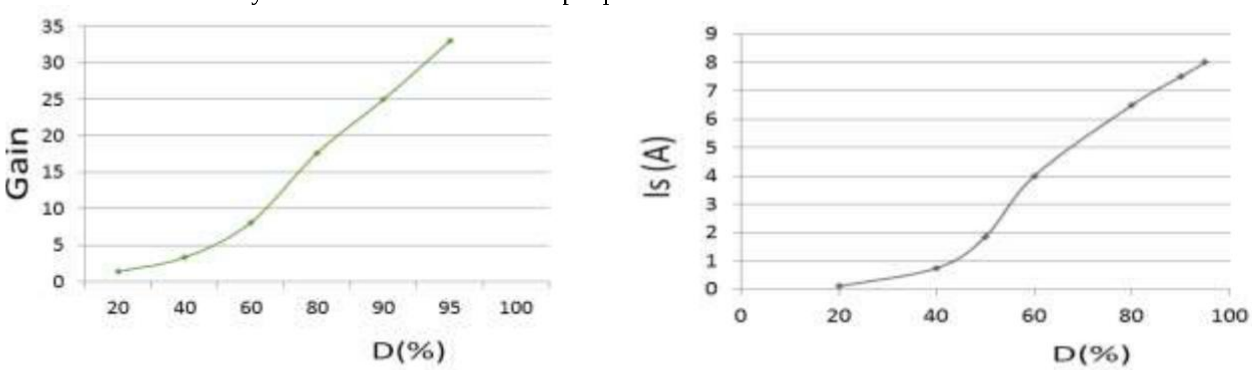

Figure 9(a) Voltage gain Vs duty ratio curve (b)Switch current stress Vs duty ratio curve

The voltage gain is 17 when the duty cycle is equal to 80 %. If the duty cycle is reduced gain also reduced. From this figure, the current stress is less when the duty cycle is low.

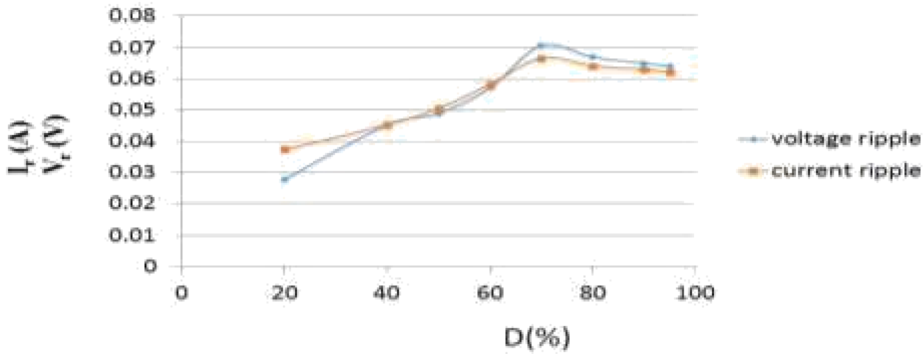

Figure 10 voltage & current ripple Vs duty ratio curve

From this figure, the voltage ripple is 0.05 and the voltage ripple is also 0.05 when the duty cycle is equal to 50%.

Table 2. Comparison

	Conventional converter	Flyback converter	Modified converter
No of coupled inductor	Nill	1	1
No of diodes	2	5	5
Switch used	2	1	1
Capacitor	2	3	4
Inductor	2	3	2
Efficiency	79%	85%	85%
Voltage stress on switch	85	45	48
Switch current stress	9	4.3	4.5
Voltage ripple	21.2%	4.11% of V_{out}	5.22% of V_{out1}
			13.3% of V_{out2}
Current ripple	19.6%	3.64% of I_{out}	0.407% of I_{out1}
			17.7% of I_{out2}

It is observed from the above table the boost converter has improved efficiency and voltage gain and reduces the switching losses of the converter.

3.3. Experimental setup and results–

The experimental setup of dual output converter is done through two stages. First the program is written in micro C for generating gate pulses for switching devices. The program is verified and frequency is checked by simulating it in the Proteus software. The program is burned to the microcontroller (PIC16F877A) using the software micro programming suit for PIC. The switches used are MOSFET IRF540 along with its driver TLP250.The switching pulses for single switch dual output boost converter are shown in figure 9(a).It generated using PIC shown in figure 17. A prototype of the boost converter with input voltage of 12V is implemented. The experimental setup of dual output boost converter is shown in Fig. 16. It consists of control circuit, driver circuit and power circuit. Control circuit is composed of PIC microcontroller and its power supply. The control pulses for MOSFET switches are generated using PIC microcontroller. The pulse from microcontroller is amplified by driver circuit which is composed of TLP250. It also provides isolation between control and power circuit. The output voltage obtained is shown in Fig. 18. For the hardware prototype 220 Ω, 40W load resistors are used.

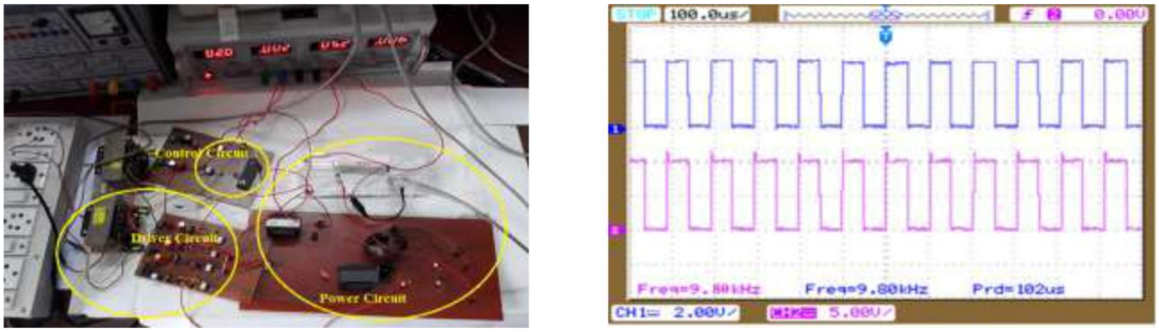

Figure 11 (a) (a) Top view of Hardware Setu (b) Output pulse of PIC and driver circuit

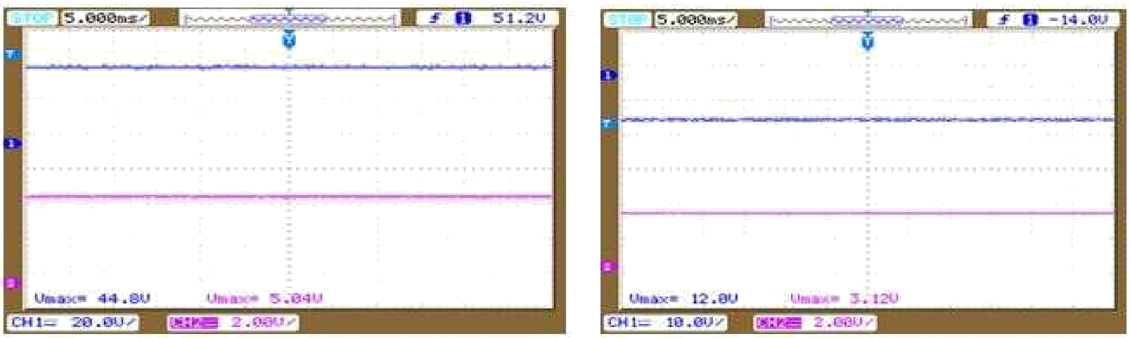

Figure 12 Hardware Output Vout1 and Vout2

It is observed from the experimental result that the output voltage VO1 is slightly greater than the desired value and output voltage VO2 is almost same to desired value. The voltage gain is almost remains constant for all ranges of input voltage. Here for an input voltage of 5.04 V, output of the hardware is obtained as 44.8 V and for input voltage of 3.12 V, output of the hardware is obtained as 12 V. Since ideal switches with no voltage drop and no resistance are considered in simulation, so this slight variation in output voltage is appreciable. This confirms that the output voltage closely matches simulation results.

IV. CONCLUSION

The single switch dual output boost converters is successfully combined as a quadratic boost converter driven by a single switch and achieved high step-up voltage gain. The leakage energy of coupled-inductor can be recycled, which is effectively constrained the voltage stress of the main switch. The prototype of single switch boost converter with input voltage of 12V is built. The output voltage is dual voltage of 72V with ripple factor of 3.5V is verified. It achieves a voltage gain of 8V for duty ratio 0.5 is suitable for this converter so as to keep the voltage stress across the switches and diodes to a safe limit. The converter can be used for applications with low input voltage and high dual output voltage, such as in industrial applications like for driving a motor, in hybrid vehicles etc.

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