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Experimental Investigations on Single Input Dual Output Quasi Z DC-DC Converter

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ABSTRACT

This paper presents a new Single input dual output (SIDO) Quasi Z DC-DC converter for interfacing with renewable energy systems. The dual output is obtained by employing mutually coupled device in LC network and unlike other DC-DC converters, the proposed configuration features added boost capability. The coupled devices are connected in series aiding fashion and dual output is tapped across the primary and secondary windings in the scheme. Mutual energy is effectively harnessed in the circuit by controlling the switching device. Theoretical analysis along with simulation and validation with experimentation on a prototype model is presented. The static and dynamic performance of the proposed system is compared with conventional Z DC – DC converter to claim its advantages. The dual output from the converter could be used as a distributed source for multilevel inverters.

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NOMENCLATURE:

L_1, L_2	Primary winding inductance of transformer 1,2
C_1,C_2	Capacitance of impedance network
V_{L1}, V_{L2}	Voltage across primary winding of transformer 1 and 2
V_{ML1}, V_{ML2}	Voltage across secondary winding of transformer1 and 2
M_{12}	Mutual Inductance
L_{S1},L_{s2}	Inductance of the secondary winding of Transformer 1,2
VDC	Supply voltage
TON	On period of the switch
TOFF	Off period of the switch
B	Boost Value
V_{c1},V_{c2}	Voltage across the capacitor

INTRODUCTION

Pulse width modulated (PWM) DC-DC converters are voltage translators that generate controlled variable DC from fixed DC voltage. The DC input shall be regulated or unregulated voltage from battery, rectified AC source or voltage output from renewable energy sources. The output from the PWM DC –DC converters are step up or step down voltage depending on the circuit configuration adopted by the system. Various classifications of the converters were devised based on the operation [RW. Erickson 1988; N. Mohan *et al* 1995]. The primitive converters yield only single output and for applications with multiple source, the circuit becomes bulky. Hence Single Inductor multiple output DC-DC converters were proposed in literature to obtain multiple output from a single circuit for various electronic applications [Ki-Soo 2014; M. Belloni 2008; D. Lu 2014; C.-S. Chae 2009]. This shares the inductor current to the loads by different switching techniques. The charging and discharging of the inductor current are controlled by non-overlapped phases of the switching cycles to obtain buck, boost and buck boost operation. This necessitates the introduction of additional switches. This circuitry generally holds good for low power applications.

High power DC-DC converters are used as power conditioners for renewable energy sources and are applied for DC drive applications [Karteek Gummi, Mehdi Ferdowsi 2010; Dawidziuk J 2011]. Few special type of DC-DC converters used for high power applications are Cuk, fly back, sepic and Quasi Z source DC-DC converter [Tseng KC, Liang TI 2005; Mohammed H.Rashid 2011]. All these converters are designed to give single output with the aid of energy

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storage elements.

An attempt is made to convert the aforesaid converter to produce dual output with a simple modification in the circuitry. The converter of interest is Quasi Z source DC-DC converter [Vinnikov D, Roasto I 2011]. The advantage of this converter includes high boost value with reduced stress on the components. The new single input dual output (SIDO) Z DC-DC converter replaces the inductors with mutually coupled devices like transformer. Unlike Trans Z source topology where the primary and secondary of the transformer forms the inductive device in the circuit, here two transformers are used with their secondary connected in series aiding fashion in turn feeds the load. This forms one output. The other output is tapped from the load connected to primary of the transformer. The output is controlled by the switching device. Hence dual output is obtained from the circuit with a reasonable boost. To validate the theoretical findings, experimentation is carried in simulation and hardware and the results are presented.

I. Z Source Dc-Dc Converter:

Z-Source DC-DC converter and inverters are gaining importance in the field of renewable energy systems as they could buck/boost the input with the assistance of impedance network. Circuit diagram of Conventional Z source DC-DC converter is given in Fig. 1. Quasi Z structure is used because of its advantage of additional boost value and less stress on the capacitor. Control of the switching devices enables the energy storage operation in the impedance network and is delivered to the load.

The switching response of the converter during ON and OFF of the MOSFET switching device S1 is depicted in Fig. 2.

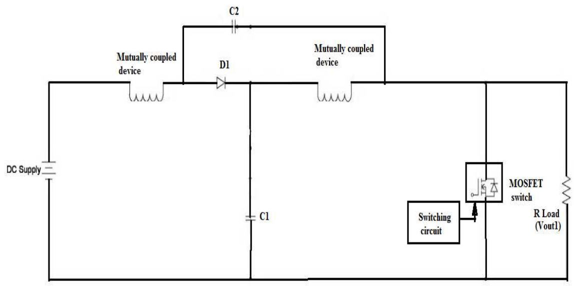

Fig. 1: Circuit diagram of Z Source DC-DC converter.

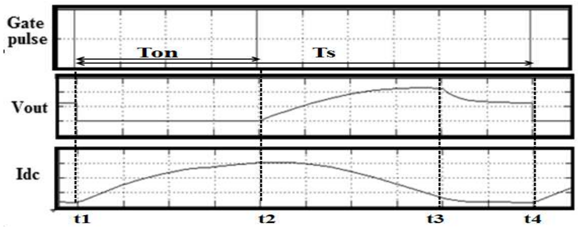

Fig. 2: Switching response of Z Source DC-DC converter.

The interval between t1 to t2 specifies the 'on' condition of s1. The device conducts and the source is shorted by the impedance network. Input current (Inductor current I_{L1}) rises and energy is stored in magnetic field. When device is turned off at t2, the source is connected to the load. The inductor current falls and energy stored in the inductor is delivered to load along with source. The voltage builds up in the load. The interval between t3 to t4 shows drooping characteristics in the load voltage, this is due the total energy discharge of the inductor and the current attains a minimum value. Continuous current is present at the source and this is greatly dependent on the inductance parameter.

II. Proposed Quasi Z Dc-Dc Converter:

The proposed converter is a new version of Z-source DC-DC converter which produces dual output voltage from a single circuit. This is obtained by replacing the inductor by mutually coupled device in the impedance network. In the present study transformer is employed for the purpose. Dual output is characterized by the switching of the MOSFET switching device.

The voltage induced in the inductive elements is given by [1],

$$e_{p1} = L_1 \frac{di_1}{dt} \quad \text{and} \quad V_{ML1} = M_{12} \frac{di_1}{dt} \tag{1}$$

Where e_{p1} and e_{s1} are the voltage induced in primary and secondary of the transformer1. M_{12} is the mutual inductance between the two windings and i_1 is the current in the primary circuit. The same relation exists for transformer2. Fig. 3. gives the circuit layout of SIDO Quasi Z DC-DC converter.

The operation is similar to that of the conventional circuit with the additional secondary voltage tapped across the mutually coupled device. The secondary connections are so given to get additive sum of two secondary voltages. Voltage tappings are taken at the main circuit and across the secondary of the transformer. Hence dual output is produced. The capacitor assist in the energy storage operation of the inductor by charging and discharging during the off and on of the switch. The switching response of the SIDO Quasi Z DC-DC converter shown in Fig . 4. that explains the operation of the circuit.

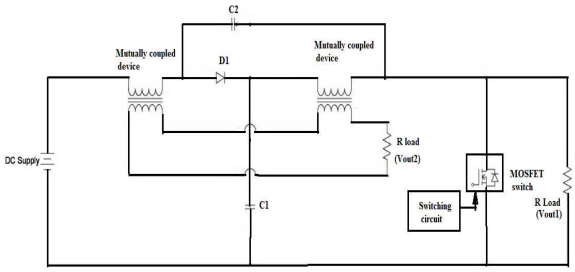

Fig. 3: Schematic of proposed SIDO Quasi Z DC-DC converter.

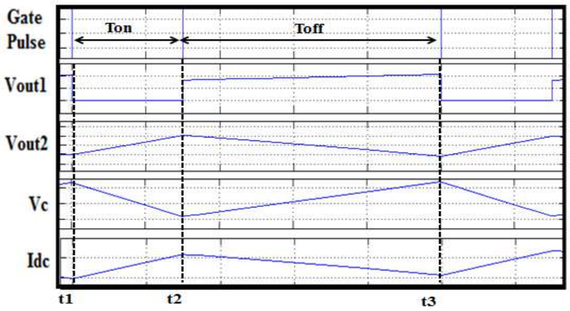

Fig. 4: Switching response of Proposed SIDO Quasi Z DC-DC converter.

A. Operating Modes:

The operation of the converter is explained under various modes:

Mode 1(t1-t2): On period of the switching device s1. The source is shorted by the impedance network. Voltage builds up in the primary of the transformer and current rises. The rate of change of current induces voltage in the secondary due to mutual inductance and voltage appears across the load connected to the secondary. The capacitor discharges during this time interval .C_1discharges to the primary winding of TR2 and C2 discharges to the primary winding of TR1.

Mode 2(t2-t3): The switch is turned off during this mode. The transformer primaries are connected to the load during this mode and current flows to the load. The supply voltage and the energy in the inductor are delivered to the load which results in boosted voltage. As the inductor dissipates energy, its current droops out. Hence the voltage induced in the secondary of the transformer V_{out2} decreases. The capacitor charges during this period and the current is maintained in continuous mode.

III. Circuit Analysis:

The analysis of Quasi Z Source Converter with dual output is performed under 'on' state and 'off' state of the MOSFET switch. Basic Kirchhoff's Voltage Law (KVL) equations are used for the analysis.

3.1 On State:

During this state capacitor C_2 will be in parallel to V_{L1} and C_1 will be presented parallel to V_{L2}. The diode is reverse biased and does not conduct. The 'on' state circuit diagram is given in Fig. 5.

The governing equations are given by [2] to [5].

$$V_{dc} - V_{L1} + V_{C2} = 0 \quad (2)$$

$$V_{ML1} = M_1 \frac{d_{i1}}{dt} + L_{s1} \frac{d_{i3}}{dt} \quad (3)$$

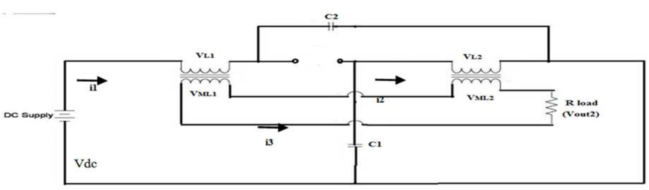

Fig. 5: On State equivalent circuit diagram of the proposed converter.

$$-V_{L2}+V_{C1}=0 \quad (4)$$

$$M_{12}\frac{d_{i1}}{dt}+M_{12}\frac{d_{i2}}{dt}+L_{s1}\frac{d_{i3}}{dt}+L_{s2}\frac{d_{i3}}{dt}=V_{load2} \quad (5)$$

3.2Off State:

During the 'off' state of the switch, the current flows to the load and the governing equations are given by [6] to [8]. Fig. 6. gives the equivalent circuit of the proposed converter during the off state.

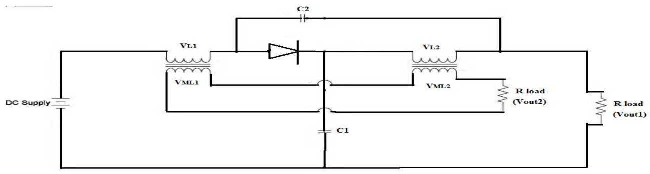

Fig. 6: Off State equivalent circuit diagram of the proposed converter.

Applying KVL in the circuit for the different loops given in Fig. 6. The resultant equations are given by [6] to [9],

$$V_{dc}-V_{L1}-V_{C1}=0 \quad (6)$$

$$-V_{L2}+V_{load1}+V_{C1}=0 \quad (7)$$

$$-V_{L2}+V_{C2}=0 \quad (8)$$

$$V_{ML1}+V_{ML2}+V_{load2}=0 \quad (9)$$

The average voltage across the transformer 2 is given by [10],

$$\frac{T_{on}(V_{C1})+T_{off}(V_{L2})}{T_{on}+T_{off}}=0 \quad (10)$$

On simplification, we get the expression of capacitor voltage given by [11]-[13]

$$V_{C2}=\frac{T_{on}}{T_{off}}V_{C1} \quad (11)$$

$$V_{C1}=\frac{T_{off}}{T_{off}-T_{on}}V_{dc} \quad (12)$$

$$V_{C2}=\frac{T_{on}}{T_{off}-T_{on}}V_{dc} \quad (13)$$

Substituting the above relation in equation [7] and rearranging gives [14]-[16]

$$-\left(\frac{T_{on}}{T_{off}-T_{on}}\right)V_{dc}=-V_{load1}+\left(\frac{T_{off}}{T_{off}-T_{on}}\right)V_{dc} \quad (14)$$

$$V_{load1}=\left(\frac{T}{T_{off}-T_{on}}\right)V_{dc} \quad (15)$$

$$\frac{V_{load1}}{V_{dc}}=\frac{T}{T_{off}-T_{on}}=B \quad (16)$$

B specifies the boost value of the voltage in the primary load.

RESULTS AND DISCUSSION

The simulation of the proposed SIDO Quasi Z converter is performed in MATLAB Simulink with the following parameters. The input voltage fed to the The transformer primary voltage is averaged for a duty cycle and is system is 18V. The primary and the secondary inductance of the transformer is 105mH, 650mH and mutual inductance is 47mH. Fig. 3. is experimented in laboratory as a prototype model. The hardware requirements are given in Table I.

The input voltage fed to the SIDO Z converter is 18V. Fig. 7. shows the simulated and hardware waveforms of the input voltage. In hardware, constant DC source is generated using regulator ICs and fed to the system.

The hardware setup of the proposed SIDO quasi Z DC-DC converter is given in Fig. 8.

PIC microcontroller is used to produce the high frequency switching pulse to the converter. The pulse produced at a frequency of 1.2 kHz is shown in Fig. 9. The duty ratio of the pulse is 0.65.

On applying the gate pulse to the switching device, the output voltage is obtained across load 1 and load2. The voltage across the load1 is boosted to 42V for a duty ratio of 30%. The boost factor is 3.5 and the results obtained in simulation and hardware is given in Fig. 10.

Table I: Hardware Specifications.

Component	Specification
E cored Transformer	Primary turns-40 Secondary turns- 80 18V, 15A
MOSFET switch	IRF480
PIC microcontroller	16F877A
Switching Frequency	1.2 kHz
Capacitance	47μF
Driver IC	IC7667 IC6N135
Load	100Ω and 5mH

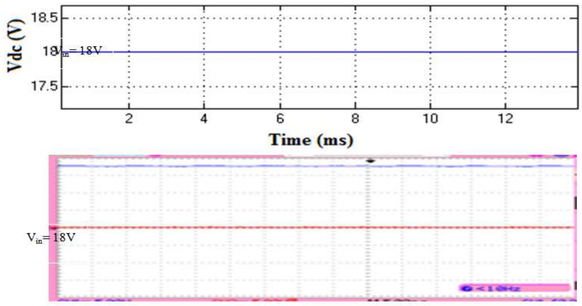

Fig. 7: Input voltage waveform in (a) Simulation (b) Hardware.

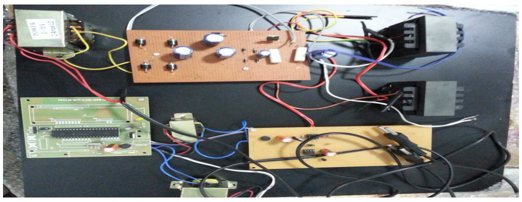

Fig. 8: Hardware setup of the proposed Converter.

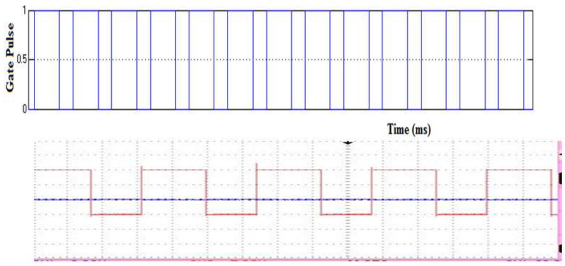

Fig. 9: Gate pulse for the MOSFET switching device (a)Simulation, (b) Hardware.

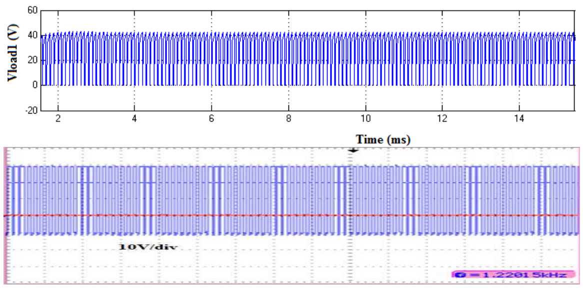

Fig. 10: Output Voltage across load1 (a)Simulation, (b) Hardware.

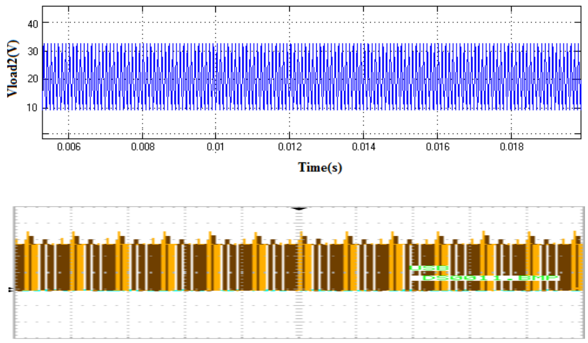

Fig. 11: Output Voltage across load2 (a) Simulation, (b) Hardware.

The voltage across the V_{load2} is obtained as 32V in simulation and 28V in hardware. The turns ratio is 2 and the input voltage of 18V is transformed to 32V (peak). The resulting waveforms are given in Fig. 11.

Sequence of simulation was conducted to study the effect of duty ratio on the output voltage across load1 and load2. The converter exhibits the features of boost converter for increasing duty ratio. The voltage obtained across the load for different duty ratio is given in Fig. 12. It is observed that for increasing duty ratio, the output voltage increases in both the load. The voltage across load1 is comparably higher than voltage across load2. This is because the V_{load2} depends upon the voltage rise and fall of the inductor current.

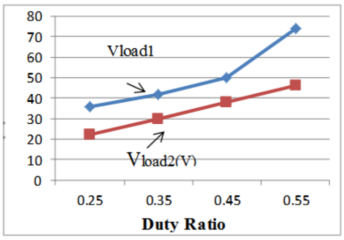

Fig. 12: Effect of duty ratio on output voltage

Comparative evaluation on the steady state analysis is made between the boost converter, conventional Z DC-DC converter and SIDO Quasi Z DC-DC converter to study the voltage variations for different switching intervals. Sequence of simulations is carried and the results are tabulated in Table II . The primitive boost converter produces boosted output voltage but the boost value is less compared to other boost converters. The Z DC-DC converter has high boost value but capable of producing only single output. The proposed SIDO is capable of producing dual output but the boost value is less compared to Z DC-DC converter. It is also noted that voltage is shared in SIDO Quasi Z DC-DC converter by the primary and secondary circuit of the transformers. The Quasi structure reduces the stress on the capacitors which is an added advantage.

Table II: Comparative evaluation of different boost converters.

Duty Ratio	Boost Converter		Z DC-DC converter		SIDO Z DC-DC converter	
	Vload1 (V)	Vload2 (V)	Vload1 (V)	Vload2 (V)	Vload1 (V)	Vload2 (V)
25%	24V	--	38V	--	36V	22V
30%	27V	--	56V	--	42V	30V
35%	32.7V	--	74V	--	50V	38V
40%	40	--	115V	--	74V	46V

On performing simulations for different duty ratios, the stress on the capacitor is recorded and plotted in Fig. 13. to view the effect of duty ratio. It is observed that the stress increases for increasing duty ratio, this is due to the increase in the boost value. As the duty ratio increases, the turn on time of the switch increases. The energy build up in the inductor is more and capacitor is subjected to a high voltage.

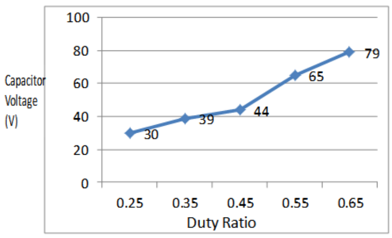

Fig. 13: Effect of duty ratio on capacitor voltage.

Thus the new SIDO Z DC-DC converter has the capability to produce dual voltage from a single voltage source by replacing inductor by mutually coupled device. Voltage is shared between the two coils with considerable boost. Continuous current is maintained on the source side. The effect of mutual inductance and the analysis of the secondary circuit including the current relations are to be studied in detail in the future research.

CONCLUSIONS

The current work ventures to propose the new single input dual output Z DC-DC converter for renewable energy systems. The proposed theoretical analysis of the converter is validated in simulation and experimentation. It is learnt from the study, the input is shared between the coupled devices with a considerable boost. Continuous current is featured by the converter and the ripple in the input current is reduced. Comparative analysis forecast the advantage of the SIDO Z converter over other boost converters met with a small increase in cost of the circuit. Experimentation approximates the simulation results and this converter serves as a distributed source for multilevel inverters.

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