

# Non-isolated resonant quasi-Z-source network DC–DC converter

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A novel non-isolated resonant quasi-Z-source network DC–DC converter is proposed. The resonant impedance source network is derived from the quasi-Z-source network by including the autotransformer-based resonant cell instead of the second inductor of the quasi-Z-network. The leakage inductance of the autotransformer and two resonant capacitors connected in series with the autotransformer windings constitute a high-frequency resonant tank. At the same time, the resonant capacitors block the DC-bias current of the autotransformer. The resonant operation with a sinusoidal current of the main switch and diodes enables electromagnetic interference mitigation and improves the efficiency of the converter. Experimental results of a 100 W, 30 V/200 V prototype are presented to verify the analysis results of the proposed converter.

**Introduction:** A quasi-impedance source (quasi-Z-source) network converter presents an interesting alternative to the conventional boost converter offering wide voltage conversion with continuous input current and load short-circuit protection. The quasi-Z-source DC–DC converter, shown in Fig. 1a includes quasi-Z-network with the input diode and four energy storage elements: two inductors and two capacitors. Although the quasi-Z-source converter can have theoretically infinite voltage gain, its boost factor is affected by series resistances of the inductors and the forward voltage drop of the input diode. Various techniques have been applied to the quasi-Z-source converter to improve its voltage gain. In [1], a step-up DC–DC converter has been proposed which combines voltage multiplier cells to the secondary winding of the coupled inductor which was included in the second inductor of the quasi-Z-source network. In [2], the A-source network has been proposed, in which the secondary inductor of the quasi-Z-source network is replaced with an autotransformer for realising a very high DC voltage gain. Unfortunately, a high turns ratio of the autotransformer increases the  $di/dt$  of the main switch, which may cause several electromagnetic interference problems. Moreover, at higher power, the DC flowing through the A-source autotransformer windings tends to saturate the core.

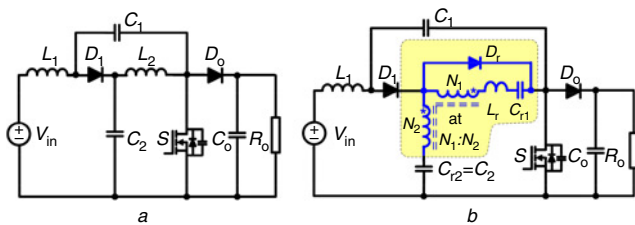


Fig. 1 Quasi-Z-source network DC–DC converter

a Basic topology  
b Conceptual converter with autotransformer-based resonant cell

The conceptual non-isolated resonant quasi-Z-source network DC–DC converter proposed in the present Letter is shown in Fig. 1b. The high-DC voltage gain with the resonant operation and sinusoidal current of the main switch is achieved by replacing the second inductor ( $L_2$ ) of the quasi-Z-network with  $L_r C_{r1} D_r$  resonant cell and including  $N_1:N_2$  autotransformer to couple the  $L_r C_{r1} D_r$  cell with the second capacitor ( $C_2$ ) of the quasi-Z-network. The capacitor  $C_2$  in the same way plays the role of the second resonant capacitor  $C_{r2}$ . Theoretical analysis and experimental results are provided to verify the validity of the proposed converter.

**System configuration:** Fig. 2 shows the proposed converter and its key waveforms. The high-frequency autotransformer is modelled as a magnetising inductor  $L_m$ , an ideal transformer with turns ratio  $1:n$  and a primary leakage inductor  $L_{Lk}$ . The zero current switching (ZCS) of the input diode  $D_1$  and the resonant diode  $D_r$  is realised by resonance between the resonant capacitors  $C_{rp}$  and  $C_{rs}$ , connected in parallel, and the autotransformer leakage inductance  $L_{Lk}$ . The resonant capacitors  $C_{rp}$  and  $C_{rs}$  at the same time block the DC-bias current of the autotransformer.

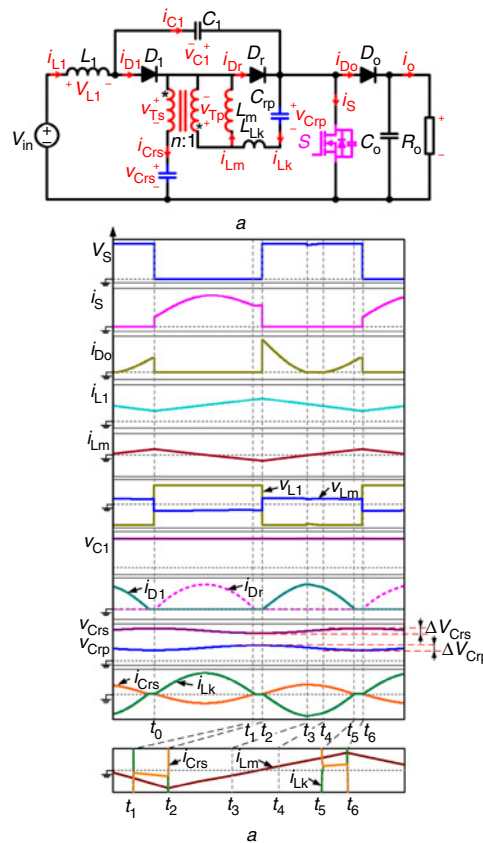


Fig. 2 Proposed converter and its key waveforms

**Basic operating principles:** For the sake of simplicity all components of the analysed converter are assumed ideal. The output voltage equals the voltage of the main switch during turn off which is the sum of the input voltage  $V_{in}$  and voltages of capacitor  $C_1$  and inductor  $L_1$

$$v_S(t) = V_{in} - v_{L1}(t) + v_{C1}(t), \quad (1)$$

where

$$-v_{L1}(t) = (n+1)v_{Lm}(t) + L_{Lk} \frac{di_{Lk}(t)}{dt}. \quad (2)$$

The operating modes of the proposed converter are essentially divided into five modes shown in Fig. 3.

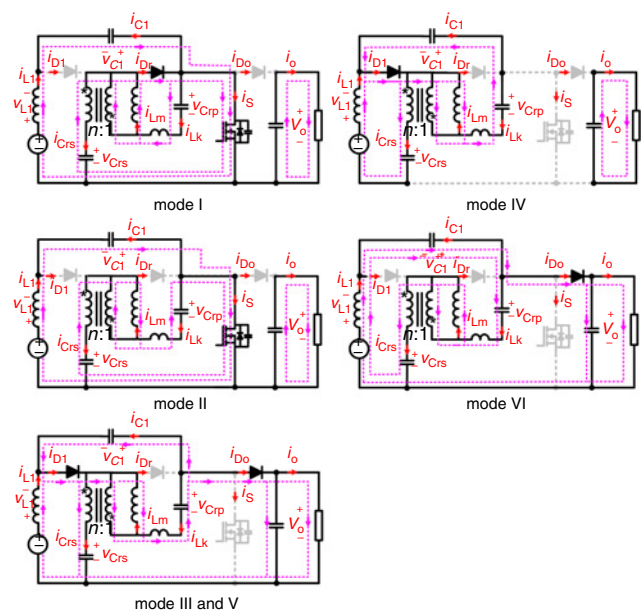


Fig. 3 Operational mode diagrams

**Mode 1** [ $t_0 \sim t_1$ ]: At time  $t_0$ , the main switch  $S$  is turned on. The input diode  $D_1$  is reverse biased and the energy previously stored in  $C_1$  is transferred to the inductor  $L_1$ . The output diode  $D_o$  is reverse biased and the load  $R_o$  is supplied by the capacitor  $C_o$ . The resonant diode  $D_r$  is forward biased and two resonance capacitors  $C_{rp}$  and  $C_{rs}$  and the leakage inductor  $L_{Lk}$  begin to resonant

$$i_{Lk}(t) = \left( \frac{v_{CrS}(t_0)}{nL_{Lk}} - \frac{v_{CrP}(t_0)}{L_{Lk}} \right) \frac{1}{\omega} \sin \omega(t - t_0), \quad (3)$$

where  $\omega = 1/\sqrt{L_{Lk}C_r}$  and  $C_r = \sqrt{C_{rp}n^2C_{rs}/(C_{rp} + n^2C_{rs})}$ .

**Mode 2** [ $t_1 \sim t_2$ ]: At the beginning of this time interval the resonance between  $L_{Lk}$  and resonant capacitors  $C_{rp}$  and  $C_{rs}$  is finished and diode  $D_r$  is turned off at ZCS condition. The voltage  $v_{CrP}$  reaches its maximum value and  $v_{CrS}$  reaches its minimum value. The currents flowing through autotransformer primary and secondary have both negative values, close to zero and are equal which results from the finite permeability of the autotransformer core and non-zero reluctance of the autotransformer magnetic circuit. Switch  $S$  is still turned on and the input inductor current  $i_{L1}$  is further increased due to the charging action of capacitor  $C_1$ .

**Mode 3** [ $t_2 \sim t_3$ ]: At time  $t_2$ , switch  $S$  turns off and, then, the input diode  $D_1$  and the output rectifier  $D_o$  is turned on to deliver the input energy to the output load through the autotransformer. Part of another input inductor energy transfers to impedance source capacitor  $C_1$

**Mode 4** [ $t_3 \sim t_4$ ]: At time  $t_3$  diode  $D_o$  turns off naturally at zero current,  $i_{L1}$  flows through the autotransformer and charges the impedance source capacitor  $C_1$ .

**Mode 5** [ $t_4 \sim t_5$ ]: As diode  $D_o$  conducts, part of the input energy flows through  $D_o$ . In this mode, diode  $D_1$  continues to turn on to provide the current flowing path for  $i_{L1}$  until  $C_1$  is completely charged accordingly to (6), diode  $D_1$  is then turned off with ZCS.

**Mode 6** [ $t_5 \sim t_6$ ]: This time interval begins when diode  $D_1$  is turned off at ZCS condition and  $C_1$  starts to discharge to load. The voltage  $v_{CrS}$  reaches its maximum value and  $v_{CrP}$  reaches its minimum value. The autotransformer primary and secondary currents have positive values close to zero and are equal, which is the effect of the non-zero reluctance of the autotransformer magnetic circuit. This time interval ends when the switch  $S$  is turned on again.

Applying the volt-second law to the input inductor  $L_1$  and the magnetizing inductor  $L_m$

$$\int_{t_0}^{DT+t_0} v_{L1}(t)dt + \int_{DT+t_0}^{T+t_0} v_{L1}(t)dt = 0, \quad (4)$$

$$\int_{t_0}^{DT+t_0} v_{Lm}(t)dt + \int_{DT+t_0}^{T+t_0} v_{Lm}(t)dt = 0, \quad (5)$$

following equations for the input capacitor voltage  $V_{C1}$  and average voltages of the resonant capacitors  $V_{CrP-avg}$  and  $V_{CrS-avg}$  can be written

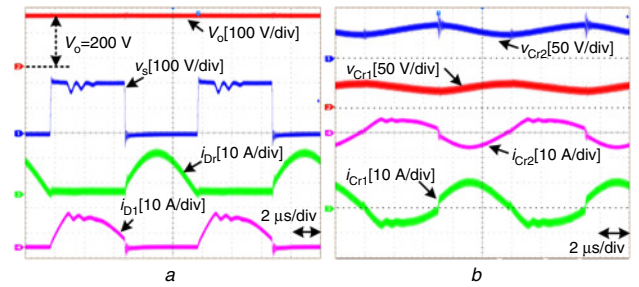
$$V_{C1} = (1/(1-D))V_{CrP-avg} = (1/(n(1-D)))V_{CrS-avg}, \quad (6)$$

where  $D$  represents the duty cycle of main switch  $S$ . Consequently, the voltage gain of the proposed DC-DC converter can be obtained as

$$M = \frac{V_o}{V_{in}} = \frac{1 + (1/n)}{1 - \frac{n+1}{n}D}. \quad (7)$$

**Experimental results:** A 100 W prototype with 200 V/0.5 A output and 100 kHz switching frequency was implemented in the laboratory to verify the analysis results of the proposed converter. The input voltage ( $V_{in}$ ) is 35 V. The resonant capacitors  $C_{rp}$  and  $C_{rs}$  are 2 and 1  $\mu$ F, respectively. The 0.2 mH input inductor ( $L_1$ ) is implemented with the T225-26B-type toroid core. The  $n = 1.8$  autotransformer using low-loss F867-type core has magnetising inductance  $L_m = 1.6$  mH and the primary leakage inductance  $L_{Lk} = 1.5$   $\mu$ H. The duty ratio of main switch  $S$  is  $D = 0.5$ . Experimental results for the output voltage ( $V_o$ ), the main switch voltage ( $v_s$ ) and currents of the resonant diode ( $i_{Dr}$ )

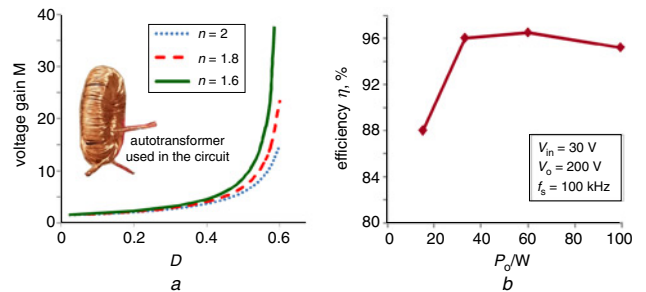
and the input diode ( $i_{D1}$ ) are depicted in Fig. 4a. Owing to the resonance between  $L_{Lk}$  and capacitors  $C_{rp}$  and  $C_{rs}$ , the input diode  $D_1$  is switched at ZCS condition which minimises the diode overall loss. The resonant capacitors currents  $i_{CrP}$  and  $i_{CrS}$  in Fig. 4b correspond to the currents of the primary and secondary winding of the autotransformer.



**Fig. 4** Experimental results

a Output voltage  $V_o$ , voltage of switch  $v_s$  and diode currents  $i_{D1}$  and  $i_{Dr}$   
b Resonant capacitors  $C_{rp}$  and  $C_{rs}$ , voltages  $v_{CrP}$ ,  $v_{CrS}$  and currents  $i_{CrP}$ ,  $i_{CrS}$

Fig. 5 shows the voltage gain with the variation of turns ratio  $n$  and duty cycle  $D$  and the measured efficiency of the proposed converter.



**Fig. 5** Voltage gain and efficiency (experimental results)

**Conclusion:** A novel autotransformer-based non-isolated resonant quasi-Z-source network DC-DC converter is proposed in the Letter. The used autotransformer turns ratio enables the high voltage gain of the converter. Owing to resonance between autotransformer leakage inductance and resonant capacitors connected in series with the transformer windings the ZCS operation of diode  $D_1$  of the quasi-Z-network can be achieved. This feature alleviates the reverse recovery problem of the diode meanwhile reduces turn off loss of the diode. The capacitors connected in series with the autotransformer windings prevent the core from saturation and allow the reduction of size and weight of the autotransformer and the whole converter. Owing to the resonant operation of the main switch the reduction of its di/dt can be also achieved

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One or more of the Figures in this Letter are available in colour online.

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## References

- Andrade, A.M.S.S., and Guisso, R.A.: 'Quasi-Z-source network DC-DC converter with different techniques to achieve a high voltage gain', *Electron. Lett.*, 2018, **54**, (11), pp. 710-712, doi: 10.1049/el.2018.1005
- Ayachit, A., Siwakoti, Y.P., Galigekere, V.P.N., et al.: 'Steady-state and small-signal analysis of A-source converter', *Trans. Power Electron.*, 2018, **33**, (8), pp. 7118-7131, doi: 10.1109/TPEL.2017.2756626