Circuit for clamping bridge overvoltages in voltage-fed quasi-Z-source converter

J. Kitson and N. McNeill✉

Unlike the voltage source converter, the *Z*-source converter can boost as well as buck the input voltage. However, the presence of physically large components in the impedance network introduces large parasitic inductances into power device commutation paths. This leads to consequent overvoltages at power device turn-off. A simple circuit for addressing this is presented. Practical results are given for a voltage-fed quasi-*Z*-source inverter with discontinuous input current.

Introduction: Unlike the traditional voltage source converter, the *Z*-source converter [1] can boost, as well as buck, the input voltage. This can be useful in automotive [2] and renewable energy [3] applications. Fig. 1 shows a voltage-fed quasi-*Z*-source inverter with discontinuous input current (or ‘Series’ *Z*-source inverter) [4].

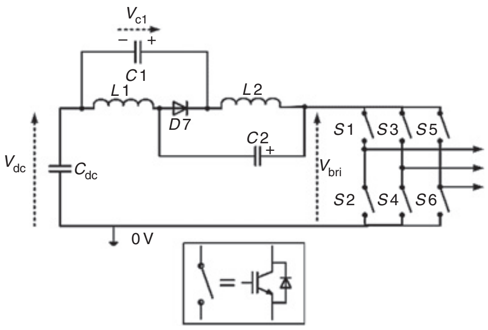

Fig. 1 *Voltage-fed quasi-Z-source inverter with discontinuous input current*

Device turn-off: At device turn-off, it is desirable that the self-inductance of the loop highlighted in Fig. 2 is minimised. If it is not, a high turn-off voltage occurs at point ‘X’ at the bridge voltage potential, v_{bri}, as the current flowing into that node is commutated. However, because of the likely large volume of the passive components, minimising stray inductances is difficult. Although stray inductance in series with L1 and L2 is not in itself problematic, the physical size of these components causes the loop area to be large.

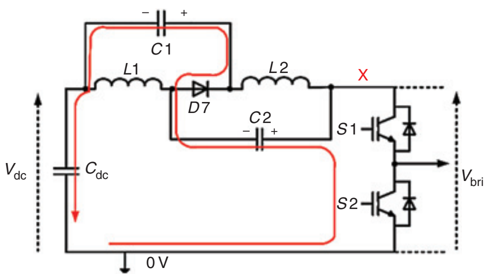

Fig. 2 *Critical path with loop inductance in quasi-Z-source network*

The power switch turn-off action may be made slower to reduce the voltage overshoot, but this increases turn-off losses. Alternatively, snubbers may be used [5]. Fig. 3 shows two variants. A disadvantage of the resistor capacitor diode (RCD) snubber is that its capacitance is charged and discharged once per cycle with losses. The soft clamp snubber does not discharge its capacitance to zero volts and also allows some recovery of energy. However, a difficulty with it in the *Z*-source converter is that the bridge voltage, v_{bri}, fluctuates continuously between zero and its peak value and as such is not suitable as a soft clamp for DC voltages. Snubber applications in related topologies such as the voltage-fed DC–AC *Z*-source inverter are addressed in [6, 7], and in a quasi-*Z*-source DC–DC converter in [8]. This Letter investigates an alternative approach for the *Z*-source inverter in Fig. 1.

Proposed arrangement: The components in the critical loop are replicated as shown in Fig. 4; referred to as a ‘*local replicated network*’ (‘LRN’) in this Letter. Auxiliary capacitances $C1_{aux}$ and $C2_{aux}$ are lower than $C1$ and $C2$ by a factor of 50,000 and $C_{dc_{aux}}$ lower than C_{dc} by 30,000; their consequent small physical sizes means the loop is physically smaller. This provides a low-inductance route for current to divert into. Three low-current connections are made to nodes A–C. The absorption of overvoltage peaks charges the auxiliary capacitors. They then discharge directly into their larger equivalent capacitor: $C1_{aux}$ discharges into $C1$, and similarly with $C2_{aux}/C2$ and $C_{dc_{aux}}/C_{dc}$, respectively. Two or three diodes ($D1_{aux}$–$D3_{aux}$) are connected in series to present a higher aggregate voltage drop across them than $D7$, the main *Z*-source network diode. Consequently, steady-state current preferentially flows through $D7$ to avoid excess losses in the LRN circuit.

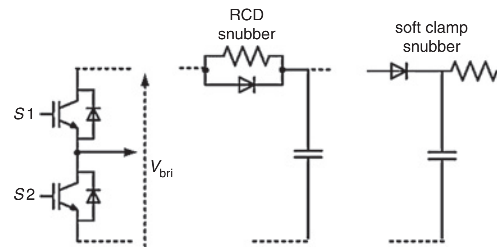

Fig. 3 *Conventional snubber networks [5]*

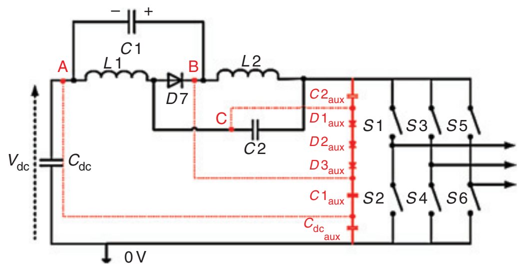

Fig. 4 *Quasi-Z-source inverter with proposed snubber*

Experimental setup: The rig in Fig. 5 is a Z-source inverter (ZSI) corresponding to the circuit in Fig. 1. $S1$–6 are IKW20N60T co-packaged insulated gate bipolar transistors (IGBTs) and antiparallel diodes. $D7$ is a SCS220AEC silicon carbide Schottky diode. $L1 = L2 = 460$ µH. $C1 = C2 = 235$ µF and each was formed with film capacitors in parallel. $C_{dc} = 140$ µF, also being formed with film capacitors in parallel. $D7$ is at a physical distance of ∼166 mm from the main bridge components, $S1$–6. Normally, this is problematic due to a corollary being the introduction of a high parasitic inductance into the loop highlighted in Fig. 2.

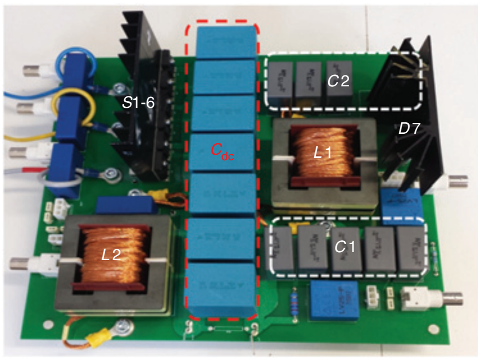

Fig. 5 *Experimental quasi-Z-source converter. (Two of capacitors forming C2 are mounted on underside of PCB.)*

The proposed LRN snubber, Fig. 4, was compared with an RCD snubber, Fig. 3. In each case, the converter was operated with a continuous output power of ∼1.5 kW, an input voltage, V_{dc}, of 200 V and at a constant shoot-through duty cycle (Ds) command of 0.1. The bridge IGBTs and diodes (and thereby indirectly the snubbers) were force air cooled. The relevant snubber was fitted physically close to the bridge on the underside of the printed circuit board (PCB). Fig. 6 shows the LRN and RCD snubber components. Details for the LRN snubber are: $C1_{aux} = C2_{aux} = C_{dc_{aux}} = 4.7$ nF, 1 kV, ceramic; $D1_{aux} = D2_{aux} = D3_{aux}$

= IXYSDSE130-06A. Details for the RCD snubber are: $R = 203.5\ \Omega$, $C = 4.7$ nF, 1 kV, ceramic; D = IXYSDSE130-06A. The overshoot on turn-off with both snubbers is shown in Fig. 7. It is measured at 18 and 15% with the LRN and RCD types, respectively. Fig. 8 shows snubber thermal operation. The root mean square (RMS) voltage measured across the resistance in the RCD snubber at 1.565 kW input power was 51.51 V, which gives a loss of 13 W in it. For a similar overshoot voltage, the RCD snubber circuit is highly dissipative in comparison with the proposed snubber. It will also be noted that the RCD snubber gives a higher bridge input voltage than the LRN snubber for the same shoot-through and output power, consistent with the findings in [6]. This also makes the RCD circuit less desirable as it increases the maximum voltage stress on the bridge devices.

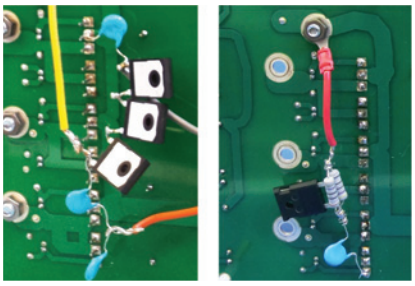

Fig. 6 *Views of snubber components on underside of converter PCB: left: LRN snubber, right: RCD snubber*

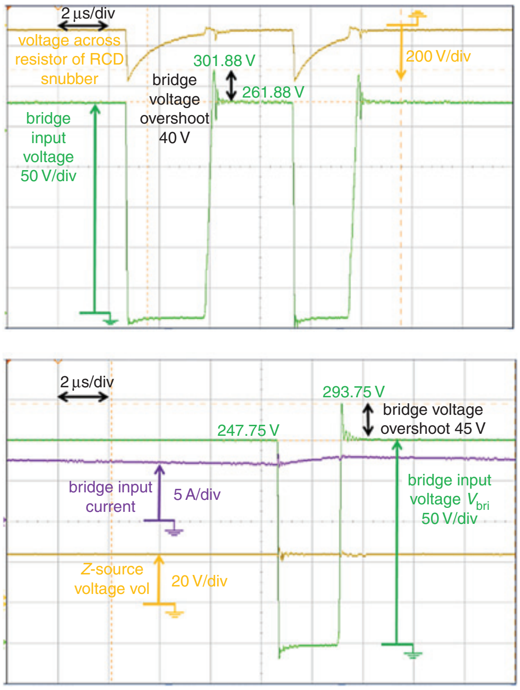

Fig. 7 *Transient v_{bri} at turn-off using: top: RCD snubber, bottom: proposed LRN snubber*

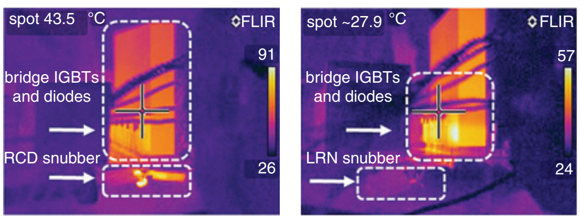

Fig. 8 *Thermal images of bridge devices (top) and snubber components: left: RCD snubber, right: LRN snubber*

Optimisation of the LRN snubber component values has not been attempted, but practical measurements have been presented. Further analysis of the snubber operation including a study of energy stored in the stray inductances in the connections made between the LRN components and the nodes A–C in the main impedance network, Fig. 4, forms future work in this area.

Conclusion: A snubber circuit has been presented for the voltage-fed quasi-*Z*-source inverter with discontinuous input current. The proposed arrangement provides overshoot suppression similar to the conventional RCD snubber, but with the advantages of much lower-power dissipation and without an increase in the peak bridge input voltage associated with RCD snubbers.

Acknowledgment: The authors gratefully acknowledge the financial support of the Engineering and Physical Sciences Research Council (http://www.epsrc.ac.uk grant EP/K035096/1).

Submitted: *27 November 2015* E-first: *3 March 2016*
doi: 10.1049/el.2015.4164
One or more of the Figures in this Letter are available in colour online.

J. Kitson and N. McNeill (*Electrical Energy Management Group, Department of Electrical and Electronic Engineering, University of Bristol, Bristol BS8 1TR, United Kingdom*)

✉ E-mail: n.mcneill@bristol.ac.uk

References

1 Peng, F.Z.: ‘Z-source inverter’, *IEEE Trans. Ind. Appl.*, 2003, **39**, (2), pp. 504–510
2 Peng, F.Z., Shen, M., and Holland, K.: ‘Application of Z-source inverter for traction drive of fuel cell-battery hybrid electric vehicles’, *IEEE Trans. Power Electron.*, 2007, **22**, (3), pp. 1054–1061
3 Huang, Y., Shen, M., Peng, F.Z., and Wang, J.: ‘Z-source inverter for residential photovoltaic systems’, *IEEE Trans. Power Electron.*, 2006, **21**, (6), pp. 1776–1782
4 Tang, Y., Xie, S., Zhang, C., and Xu, Z.: ‘Improved Z-ssource inverter with reduced Z-source capacitor voltage stress and soft-start capability’, *IEEE Trans. Power Electron.*, 2009, **24**, (2), pp. 409–415
5 Williams, B.W.: ‘Power electronics: devices, drivers, applications and passive components’ (McGraw-Hill Higher Education, Columbus, Ohio, USA, 1992, 2nd revised edn.)
6 Dong, S., Zhang, Q., Zhou, C., and Cheng, S.: ‘Analysis and design of snubber circuit for *Z*-source inverter’. 16th European Conf. on Power Electronics and Applications (EPE’14-ECCE Europe), Lappeenranta, Finland, August 2014, pp. 1–10
7 Shen, M., Joseph, A., Huang, Y., Peng, F.Z., and Qian, Z.: ‘Design and development of a 50 kW *Z*-source inverter for fuel cell vehicles’. CES/IEEE Fifth Int. Power Electronics and Motion Control Conf., 2006, Shanghai, China, December 2006, vol. 2, pp. 1–5
8 Zakis, J., Vinnkov, D., Roasto, I., and Jalakas, T.: ‘Practical design guidelines of qZSI based step-up DC/DC converter’, *Power Electr. Eng. Riga Tech. Univ.*, 2010, **27**, pp. 107–114