

## Digital Simulation Of Current Fed Quasi - Z Source Inverter

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### ABSTRACT

Quasi-Z Source Inverters (qZSIs) are an improvement to traditional Z Source inverters (ZSIs). The advantages of qZSIs include different combinations of: lower component ratings, reduced source stress, reduced component count and simplified control strategies. The conventional current-source inverter (CSI) has two major problems: unidirectional power flow and voltage boost operation, which make it impossible to be used in many applications such as hybrid electric vehicles and general-purpose variable-speed motor drives. ZSIs can solve above problems with a limitation of boosting up the output current levels. This can be overcome with the proposed Current-fed quasi-impedance source inverter. This paper presents a comprehensive study on the new features of current-fed qZSI, which include the advantageous like boost function, improved reliability and reduced passive component ratings.

**Keywords** — Current-source inverter (CSI), voltage-source inverter (VSI), Z - Source inverter (ZSI), Current fed quasi Z Source inverter (qZSI).

### 1.INTRODUCTION:

The traditional general-purpose motor drive (or adjustable speed drive—ASD) system is based on the voltage-source inverter (V-source inverter), which consists of a diode rectifier front end, dc link capacitor, and inverter bridge, as shown in Fig. 1. In order to improve power factor, either an ac inductor or dc inductor is normally used. The dc link voltage is roughly equal to 1.35 times the line voltage, and the V-source inverter is a buck (or step-down) converter that can only produce an ac voltage limited by the dc link voltage.

The traditional three-phase current-source inverter is shown in Fig. 2. A dc current source feeds the main converter circuit, a three-phase bridge. The dc current source can be a relatively large dc inductor fed by a voltage source such as a battery, fuel-cell stack, diode rectifier, or thyristor converter. Six switches are used in the main circuit each is traditionally composed of a semiconductor switching device with reverse block capability such as a gate-

turn-off thyristor (GTO) and SCR or a power transistor with a series diode to provide unidirectional current flow and bidirectional voltage blocking. The main switches of the I-source inverter have to block reverse voltage that requires a series diode to be used in combination with high-speed and high-performance transistors such as insulated gate bipolar transistors (IGBTs). This prevents the direct use of low-cost and high-performance IGBT modules and intelligent power modules (IPMs).

In addition, both the V-source converter and the I-source converter have the following common problems:

1. They are either a boost or a buck converter and cannot be a buck-boost converter. That is, their obtainable output voltage range is limited to either greater or smaller than the input voltage.
2. Their main circuits cannot be interchangeable. In other words, neither the V-source converter main circuit can be used for the I-source converter, or vice versa.
3. They are vulnerable to EMI noise in terms of reliability.

Z-Source inverters have been proposed as an alternative power conversion concept for adjustable speed AC drives (ASD) with voltage buck and boost capabilities as they allow inverters to be operated in the shoot through state. It utilizes an exclusive z-source network (LC component) to link the main inverter circuit to the power source (rectifier). By controlling the shoot-through duty cycle, the inverter system using IGBTs, provide ride-through capability during voltage sags, reduces the line harmonics, improves power factor, increases reliability and extends output voltage range.

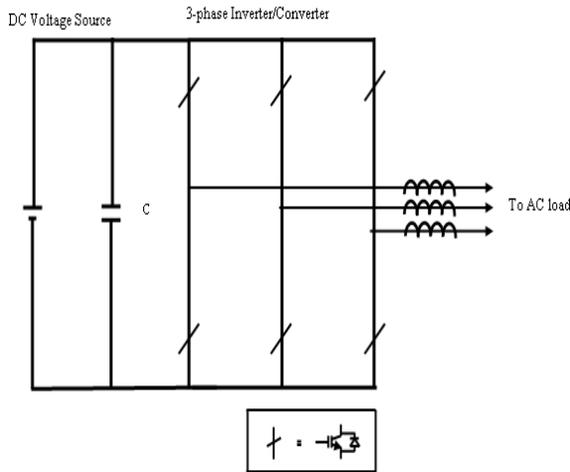


Fig.1. Voltage Source Inverter

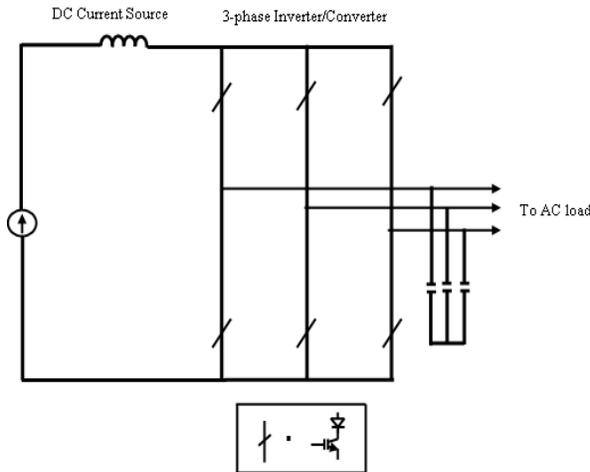


Fig.2. Current Source Inverter

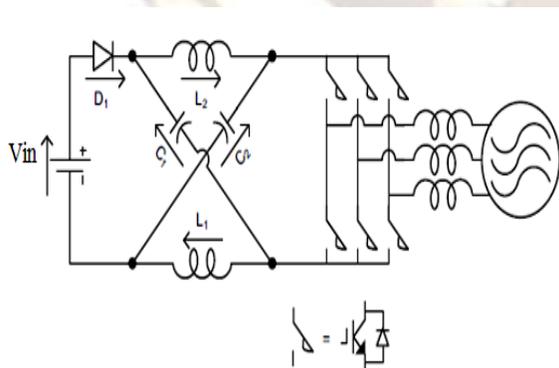


Fig.3. Z-Source inverter

The z-source Network is a combination of two inductors and two capacitors. This combined

circuit, the z-source Network is the energy storage or filtering element for the z-Source inverter. This z-source network provides a second order filter. This is more effective to suppress voltage and current ripples. The ZSI topology features the inverter coupled with a symmetrical lattice network consisting of two inductors and two capacitors connected in X-shape.

The Z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac and dc-to-dc power conversion. The inductor and capacitor requirement should be smaller compare than the traditional inverters. When the two inductors ( $L_1$  and  $L_2$ ) are small and approach zero, the Impedance source network reduces to two capacitors ( $C_1$  and  $C_2$ ) in parallel and becomes traditional voltage source. Therefore, a traditional voltage inverter's capacitor requirements and physical size is the worst case requirement for the Impedance source inverter but with the newly developed reverse blocking insulated gate bipolar transistor (RB-IGBT), the CSI is becoming more efficient and thereby more attractive.

The ZSI has inherent voltage boost and buck capability using the shoot through switching states in each phase leg of the PWM inverter. This enables the proposed wind generation system to achieve the demanded variable-speed operation. The utilization of quasi-Z-source (qZS) network in the interface converter, in addition to the benefits of the Z-source based converter offers continuous input current of the qZS-network as well as reduced DC voltage of the capacitor  $C_2$ .

To improve on the traditional ZSIs, four new quasi-Z source inverters, qZSIs, have been developed which feature several improvements and no disadvantages when compared to the traditional ZSIs. They are Voltage Fed qZSI with Continuous and Discontinuous Input Current and current Fed qZSI with Discontinuous Input Current. The current fed qZSI in a manner consistent with the current fed ZSI, are bidirectional with the diode, D. The qZSI shown in Fig. 6, features reduced current in inductor  $L_2$ , as well as reduced passive component count and features lower current in inductors  $L_1$  and  $L_2$ . Again, due to the input inductor,  $L_3$ , the ZSI as shown in Fig. 3 and qZSI in Fig. 6 do not require input capacitance. All four qZSI topologies also feature a common dc rail between the source and inverter, unlike the traditional ZSI circuits [2]. Furthermore, these qZSI circuits have no disadvantages when compared to the traditional ZSI topologies. These qZSI topologies therefore can be used in any application in which the ZSI would traditionally be used.

## II. CONVENTIONAL CURRENT SOURCE INVERTER:

The CSIs are less investigated and applied, compared to VSIs, partly because the switches of the CSIs have to be reverse blocking. It has the advantages of directly supporting regeneration back to the AC supply when supplied from an SCR rectifier, implicit output, and short circuit protection, and significant reduction in load harmonics because of the voltage filtering that occurs at the output capacitors of the inverter.

Although modulation and control strategies for a CSI are much less developed than for a VSI, some advances have been made in applying pulse width modulation (PWM) theory to the control of these inverters [3], [4]. If IGBTs are used for the CSI, then the reverse blocking capability can only be achieved with diodes connected in series to the IGBTs, as shown in Fig. 4. This yields relatively high semiconductor conduction loss. The newly developed RB-IGBT has a symmetrical voltage blocking characteristics. That is, it can block both forward and reverse voltages in its off state. The improvement of the semiconductor switches has made CSIs more attractive in several applications, as in uninterrupted power supplies, ac drives, and reactive power compensators due to its intrinsic output short-circuit protection, ruggedness, and direct current control ability [3], [4].

In CSI for every 60 degree only two switches will be conducting. The square wave inverter does not provide for the magnitude control of the output current within the inverter, hence the rectifier supplying the inverter controls the current. Fourier analysis of these waveforms yields a simple square-wave type of geometric progression of the harmonics [10]. The disadvantage is that the output current stepped waveform introduces high distortion in the waveform quality. The conventional CSI has nine possible switch states, of which three are zero states (vectors) and six are active states. Three zero states can be assumed by turning on an upper switch ( $S_{ap}$ ,  $S_{bp}$ , or  $S_{cp}$ ) and a lower switch ( $S_{an}$ ,  $S_{bn}$ , or  $S_{cn}$ ) from the same phase leg.

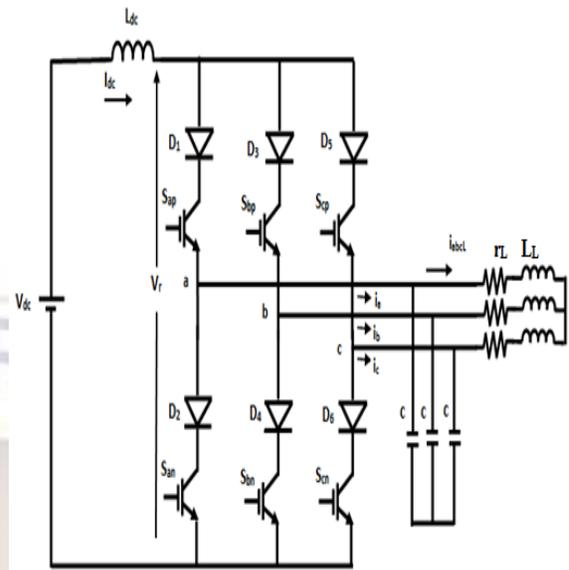


Fig.4. Current Source Inverter

The waveforms for the 120 degree mode of conduction for the current source inverter are shown in figure 5.

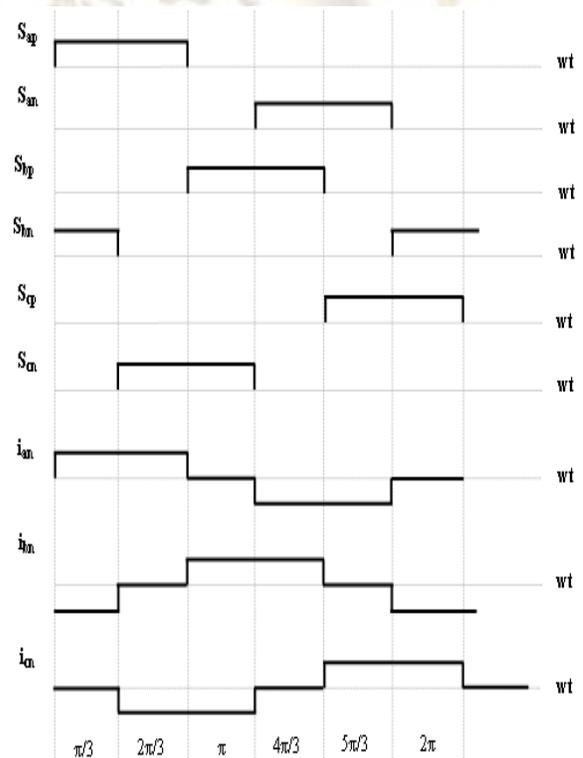


Fig.5. Gating signals and output currents of three phase current source inverter in square wave mode

(HEVs) and general-purpose variable-speed motor drives.

The phase current is

$$i_{as}(t) = I_{dc} \frac{4}{\pi} \left[ \frac{\pi}{4} + \sin \omega_0 t + \frac{1}{3} \sin 3\omega_0 t + \frac{1}{5} \sin 5\omega_0 t + \frac{1}{7} \sin 7\omega_0 t + \dots \right] \quad (1)$$

The line current is

$$i_{ab}(t) = I_{dc} \frac{4\sqrt{3}}{\pi} \left[ \sin(\omega_0 t + \frac{\pi}{6}) + \frac{1}{5} \sin(5\omega_0 t - \frac{\pi}{6}) + \frac{1}{7} \sin(7\omega_0 t + \frac{\pi}{6}) + \dots \right] \quad (2)$$

For a balanced three-phase linear load, the output phase voltage can be represented as

$$V_a = \sqrt{2}V_0 [\sin(\omega_0 t + \phi)] \quad (3)$$

$$V_b = \sqrt{2}V_0 [\sin(\omega_0 t + \phi - \frac{2\pi}{3})] \quad (4)$$

$$V_c = \sqrt{2}V_0 [\sin(\omega_0 t + \phi + \frac{2\pi}{3})] \quad (5)$$

where  $I_{dc}$  is the input dc current,  $V_0$  is the rms value of the output phase voltage, and  $\phi$  is the phase angle between the output ac voltages and the corresponding currents. The instantaneous output power can be derived as

$$P_{out} = \frac{3\sqrt{3}}{2\sqrt{2}} I_{dc} V_0 \cos\phi \quad (6)$$

$P_{out}$  is also equal to the instantaneous input power  $P_{in}$  drawn from the input dc source  $V_{in}$  thus, one can get

$$P_{out} = P_{in} = V_{in} I_{dc} \quad (7)$$

From (6) and (7), a relationship between the rms value of the output phase voltage ( $V_0$ ), power factor ( $\cos \phi$ ), input dc voltage ( $V_{in}$ ), and modulation index ( $m$ ) can be determined as

$$V_0 = \frac{2\sqrt{2}V_{in}}{3\sqrt{3}\cos\phi} \quad (8)$$

Equation (8) indicates that the CSI can only boost voltage. Since the input voltage source, such as battery, cannot change the polarity in practice, the CSI is effectively unidirectional. In conclusion, the conventional CSI has two major problems: unidirectional power flow and voltage boost operation, which makes it impossible to be used in many applications, such as hybrid electric vehicles

### III. CURRENT FED qZSI:

For the current fed ZSI and qZSIs, the operation can be divided into modes. In the active mode one and only one upper device, and one and only one lower device conduct. During the active mode, the inverter is controlled in the same manner as a standard CSI [2]. During the shoot through mode, the entire upper and/or all of the lower switches are gated off. In general, during the discontinuous mode, the switches are gated as if in an active state, but one line-to-line voltage is greater than or equal to the sum of the capacitor voltages. When this occurs, the diode  $D_c$  conducts and the inverter behaves as if it is an open circuit. Again for the analysis of the current fed ZSI and qZSIs, these modes will be ignored. As described above, Kirchhoff's voltage and current laws, and state-space averaging on the inductors and capacitors for each circuit, the governing equations for current fed inverters, where all voltages and currents are positive in the sense of the arrows shown in Figs. 4 and 6.

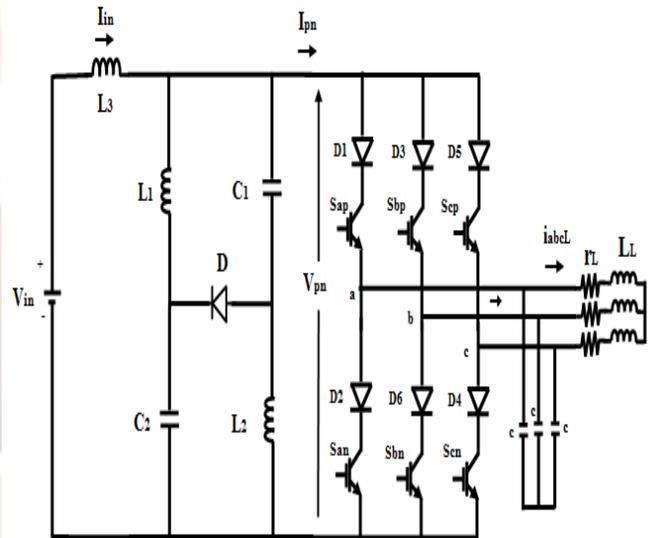


Fig.6. Current-fed qZSI with continuous input current

The maximum shoot through duty cycle,  $D$ , is 0.5 for these topologies with a positive input voltage,  $V_{in}$ . Therefore, by the gain equations for the capacitor voltages, it can be seen that with the qZSI circuits, the capacitor voltages are reduced when compared with the traditional ZSI. If the input voltage is negative, it is also possible to operate the voltage fed topologies with a shoot through duty cycle,  $D$ ,

greater than 0.5. In this case, the ZSI has lower capacitor voltage than the qZSIs. When the shoot through duty cycle,  $D$ , is greater than 0.5 for the current fed ZSI or the qZSIs, the power flow is negative, and the current through the inductors is lower for the ZSI than the qZSIs. If the diode  $D$  is replaced with a bidirectional blocking, unidirectional conducting switch in any of the current fed topologies, it is possible to feed the system with a positive or negative voltage, and several new operating regions are allowed. Therefore, besides the aforementioned nine possible states in the conventional CSI, the current-fed ZSI/qZSI has two extra open-zero states. These two open-zero states can be assumed by turning off all the upper switches ( $S_{ap}$ ,  $S_{bp}$ , and  $S_{cp}$ ) or all the lower switches ( $S_{an}$ ,  $S_{bn}$ , or  $S_{cn}$ ). Without any open-zero state, the current-fed ZSI/qZSI can operate like the conventional CSI.

**IV. DESIGN PARAMETERS:**

- Input Voltage  $V_{in} = 60V$ ,
- Load Resistance  $r_L = 5 \Omega$ ,
- Load Inductance  $L_L = 12mH$  and
- Output Capacitance  $C = 1000uF$

qZSI Parameters are

- Inductors  $L_1, L_2, L_3 = 150mH$
- and Capacitors  $C1, C2 = 200uF$

**V. SIMULATION RESULT:**

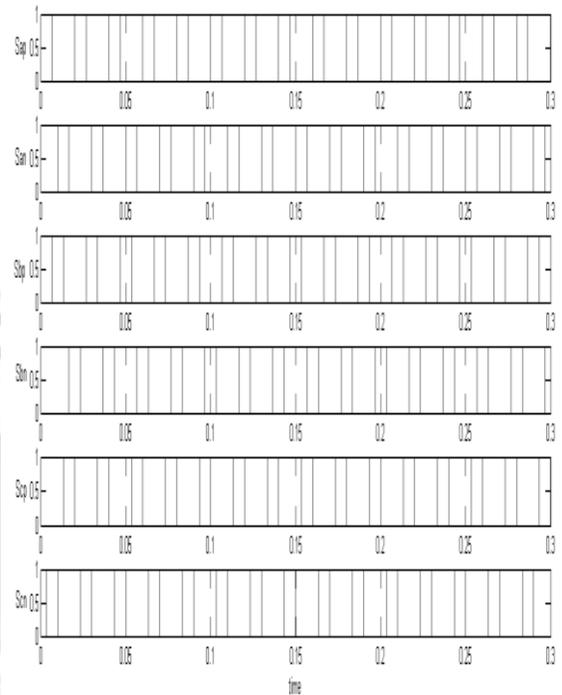


Fig.7. Digital Pulse Generation for the Current fed qZSI

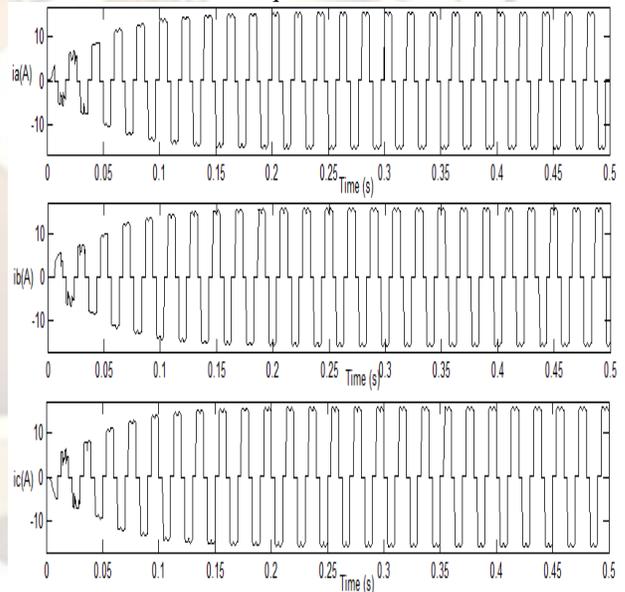


Fig.8. Output currents of the Inverter

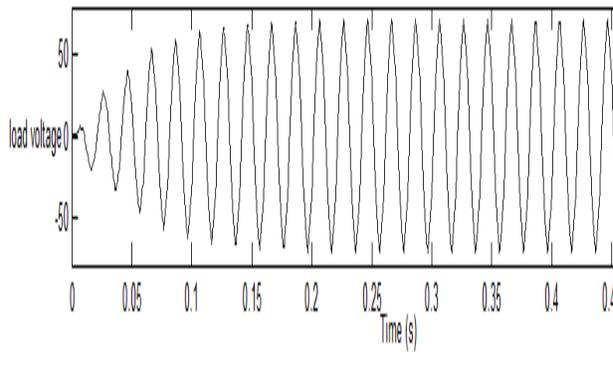


Fig.9. Output voltage of RL load

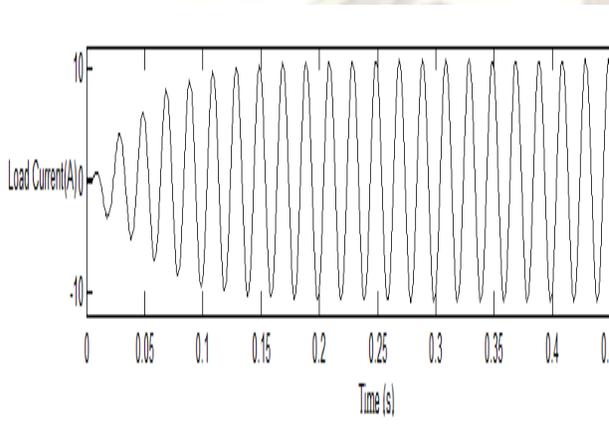


Fig.10. Output Current of RL load

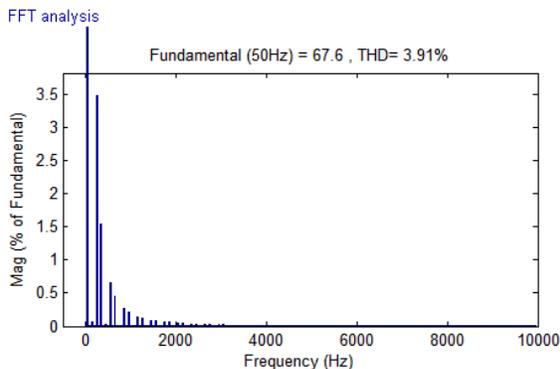


Fig.11. THD of Output Voltage (3.91%)

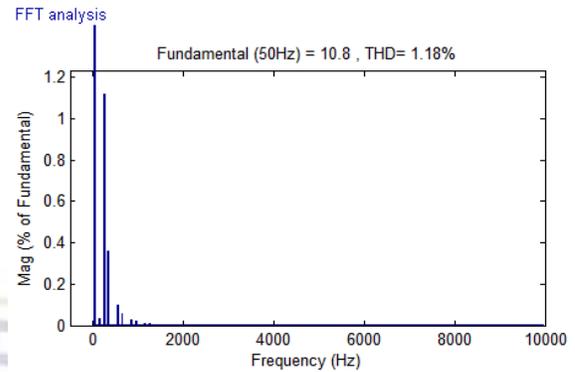


Fig.12. THD of Output current

## VI. CONCLUSION:

The quasi Z-Source inverter system can produce an output voltage greater than the ac input voltage by controlling the boost factor, which is impossible for the traditional ASD systems. Digital gating pattern generators for three-phase current-source converters have been proposed. The current-fed qZSI can buck-boost voltage and achieve bidirectional power flow with a single-stage configuration. Detailed analysis and description of this system with boost operation is shown and further current fed qZSI with different PWM techniques will be presented in future papers. Experimental results are shown with RL load using MATLAB/simulink.

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