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Topology and Control of Current-Fed Quasi Z-Source Inverter

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ABSTRACT
Quasi Z-source inverter is improvement to traditional Z-source inverter. Current-fed quasi Z-source inverter (CF-QZSI) is an enhancement to Z-source inverter (ZSIs), it owns lower component rating, decreased source stress, decreased component compute and prosaic control synthesis. With its distinct structure, the CF-QZSI can operate the traditional zero states to buck the output voltage, which improves the inverter dependability greatly, and provides a tantalizing single stage dc-ac conversion that is able to buck and boost the voltage. For dedications with a variable input voltage, this inverter is a very competitive topology. The paper presents a comprehensive study on the new features of CF-QZSI which include the advantageous buck-boost function, improved reliability and reduced passive component rating, its characteristics is verified by the simulation results .
Keywords- Current-source inverter, Voltage source inverter, Current-fed quasi Z-source inverter, buck-boost.

I. INTRODUCTION

The voltage source inverter and current source inverter provide an attractive single-stage dc-ac conversion that is able to buck or boost voltage, increase efficiency and reduce cost. However, traditional inverters have drawbacks, i.e. behave in a boost or buck operation only, and thus the obtainable output voltage range is limited, either lower or higher than the input voltage. The main switching device of VSI and CSI are not interchangeable, and the capacitor passes through high voltage. Z-source inverter can overcome the inherent drawbacks of the traditional inverters. The quasi Z-source inverter (qZSI) is the improvement to traditional Z-source inverter, voltage-fed qZSI have more attention than the current-fed qZSI. The main drawback of current-fed Z-source inverter is that the inductor passes through high current.

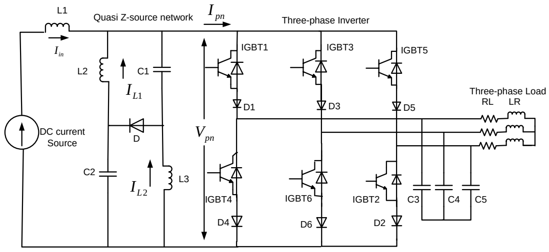
The traditional current-fed quasi Z-source inverter uses dc current source as the input. The dc current source can be created by using uncontrollable diode rectifier, battery and fuel-cell series an inductor. Six switches are used in the traditional three-phase inverter. Semiconductor devices are used as the switches.SCR or power transistor with a series diode can be used to provide unidirectional current flow and bidirectional blocking. Newly developed switches the reverse blocking IGBT (RB-IGBT) also promotes the research on CSI [9], [10].

If we compare to current source inverter (CSI), the standard voltage source inverter have 8 switching states, including 6 active states and two zero states. When the upper three or lower three switches are gated on, shorting the load terminals. Current source inverter have 9 nine valid states, 6 active and three zero state. The three zero states produce zero ac line currents. In this case, the dc-link current free wheels through either the switches pole. The remaining states produce non-zero ac output line currents.

This paper mainly focuses on the new feature of current-fed quasi Z-source inverter, especially the switching technique.

II. CURRENT-FED QZSI CIRCUIT ANALYSIS

To improve the traditional ZSIs, four new quasi-Z-source inverters, have been developed which feature several improvements when compared to the traditional ZSIs. They are voltage-fed qZSI with continuous and discontinuous input current, current-fed qZSI with continuous and 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. 1, features reduced current in inductor L_2 and L_3, as well as reduced passive component count. Again, due to the input inductor, L_1, the qZSI in Fig. 1 do not require input capacitance. All four qZSI topologies also feature a common dc rail between the source and the inverter bridge, unlike the traditional ZSI circuits. 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.



. Fig 1 current-fed qZSI with continuous input current

A. Active state

In active mode only one upper device and one lower device which lies not same phase are conducted simultaneously. In the active mode the inverter works as traditional CSI.

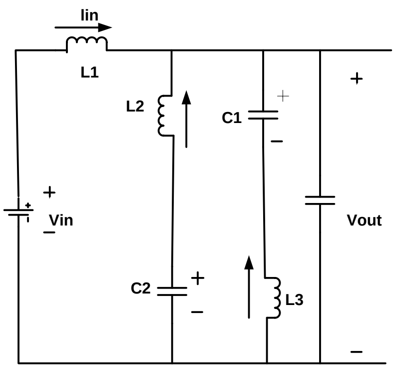
The inverter bridge, viewed from the DC side is equivalent to a current source, the input dc voltage is available as dc-link voltage input to the inverter, which makes the current-fed qZSI behave similar to a VSI. In active state based on type of switch states the dc-link voltage is equal to ac line voltage. So $V_{pn}=V_{ae}$. Fig 2(a) shows the active state equivalent circuit.

B. Traditional zero state

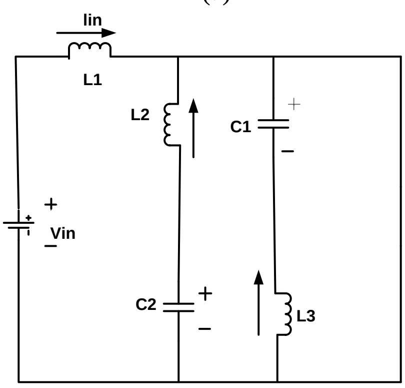
In traditional zero state, the dc-link voltage is zero ($V_{pn}=0$), the diode is OFF and the switches block the ac output voltage. Fig. 2(b) shows the short-zero state equivalent circuit.

C. Open zero state

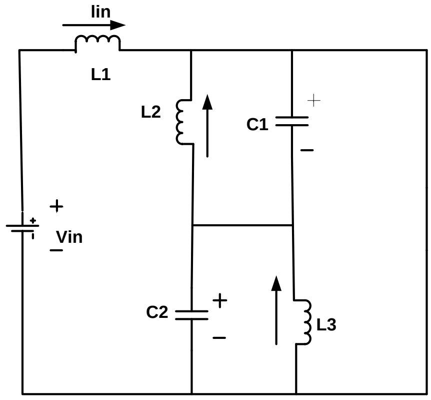
Fig. 2(c) shows the equivalent circuit of the open-zero state, the inverter bridge is equivalent to an open circuit, the diode is ON and charges the capacitors (C_1, C_2). The dc-link voltage is equal to sum of Capacitors ($V= V_{Cl}+V_{C2}$).



(a)



(b)



(c)

Fig 2(a) Active State, (b) Traditional zero state, (c) open zero state

III. SPACE VECTOR PULSE WIDTH MODULATION

IGBT is a gate controlled device; SVPWM give path and control to AC Voltage. It technique use for 3-phase inverter; ac output is sinusoidal and has high adaptability. Any three functions of time that gratify use space transformation.

$$u_a(t)+u_b(t)+u_c(t)=0 \quad (1)$$

Represented two dimensional space

$$u(t) = \frac{2}{\sqrt{3}}\left(u_a + u_b^{\,ej\left(\frac{2}{\sqrt{3}}\right)\pi} + u_c^{\,e-j\left(\frac{2}{\sqrt{3}}\right)\pi} \right) \quad (2)$$

$\frac{2}{\sqrt{3}}$ is a scaling factor. if V_a ,V_b and V_c are phase voltage of a fair supply with a peak value of V_m

$$u_a = V_m.\sin(\omega t) \quad (3)$$

$$u_b = V_m \sin(\omega t - 2\pi / 3) \quad (4)$$

$$u_c = V_m \sin(\omega t + 2\pi / 3) \quad (5)$$

In the space vector illustration is

$$u(t) = V_m e^{j\omega t} \quad (6)$$

A. Switching technique

The current-fed QZSI has ten possible switching states, of which three are traditional zero state and six are active states and one of open zero state. In open zero state all the switches of the inverter bridge is turned off. Traditional zero state can be incept by turning on an upper switch (S1, S3, and S5) and a lower switch (S4, S6, and S2) from the same phase leg. Active state can be incepting by turning on the switches from different phase legs.

Table 1 shows the switching states of qZSI

State No	Switch state Type	S1	S4	S3	S6	S5	S2
1	Active State	On	Off	Off	On	Off	On
2		On	Off	On	Off	Off	On
3		Off	On	On	Off	Off	On
4		Off	On	On	Off	On	Off
5		Off	On	Off	On	On	Off
6		On	Off	Off	On	On	Off
7	Traditional zero state	On	On				
8				On	On		
9						On	On
10	Open zero state	Off	Off	Off	Off	Off	Off

Duty ratio are represented as active state ($T_1/T=D_A$), short-zero state ($T_0/T=D_{sh}$) and open zero state ($T_2/T=D_{op}$) [3].The switch states and inductor voltage are illustrated as follows

$$D_A + D_{sh} + D_{op} = 1 \quad (7)$$

$$v_L = D_A(V_{in} - V_o) + D_{sh}V_{in} - D_{op}V_{in} = 0 \quad (8)$$

$$V_o = \frac{1 - 2u_{op}}{D_A} V_{in} \quad (9)$$

Fig.3 shows the SVPWM of quasi z-source inverter. Maximum value of modulation index is $\sqrt{2}/3$, for 0<M<1 the inverter operates as normal SVPWM, when M< $\sqrt{2}/3$ the inverter operates as over modulation. The space vector pulse width modulation diagram is the hexagon. The output power is given as

$$P_o = \frac{3\sqrt{3}}{2\sqrt{2}} M L_{dc} V_o \cos\phi \quad (10)$$

Where V_0 is the rms value of the output phase voltage and Φ is phase angle between the output phase voltage and the corresponding current. Thus by selecting M value and switch states the buck-boost expertise is realized.

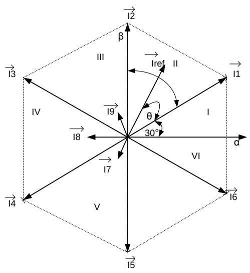


Fig 3 six possible current vectors

Assuming that $\vec{I}_{ref}$ is in sector 1 as shown in Fig.3, the duration's t_1, t_2, and t_0 can be obtained from the following current-time integral:

$$\int_0^{T_s} \vec{I}_{ref}\,dt = \int_0^{t_1} \vec{I}_1\,dt + \int_{t_1}^{t_1+t_2} \vec{I}_2\,dt + \int_{t_1+t_2}^{T_s} \vec{I}_0\,dt$$

On the other hand the duration t_0 = **[$Ts - (t_1 + t_2)$]**

For high switching frequency $\vec{I}_{ref}$ can be assumed constant during each T_s time. I_1, I_2 are also considered constant during each cell time while I_0 =0

$$\sqrt{3}\, I_{dc}\left[t_1\begin{pmatrix}Sin\,30^0\\ Cos\,30^0\end{pmatrix} + t_2\begin{pmatrix}Sin\,90^0\\ Cos\,90^0\end{pmatrix}\right] = \vec{I}_{ref}T_s\begin{pmatrix}Sin\,\theta\\ Cos\,\theta\end{pmatrix}$$

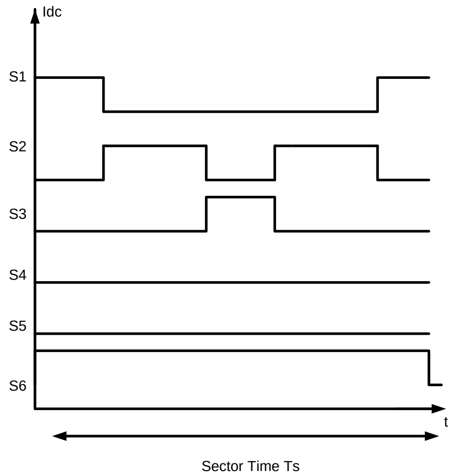


Fig.4 Tsector time switching Strategies

First sector switching sequence and duration

$$\underbrace{\vec{I}_1, \vec{I}_2, \vec{I}_0, \vec{I}_2 \text{ and } \vec{I}_1}_{First\ sector} \text{ and } \underbrace{\vec{I}_1, \vec{I}_2, \vec{I}_0, \vec{I}_2 \text{ and } \vec{I}_1}_{Second\ sector}$$

$$\underbrace{\frac{t_1}{2}, \frac{t_2}{2}, t_0, \frac{t_2}{2} \text{ and } \frac{t_1}{2}}_{First\ sector} \text{ and } \underbrace{\frac{t_1}{2}, \frac{t_2}{2}, t_0, \frac{t_2}{2} \text{ and } \frac{t_1}{2}}_{Second\ sector}$$

Second sector switching sequence

$$\underbrace{\vec{I}_1, \vec{I}_0, \vec{I}_0, \vec{I}_2 \text{ and } \vec{I}_1}_{First\ sector} \text{ and } \underbrace{\vec{I}_1, \vec{I}_0, \vec{I}_2, \vec{I}_0 \text{ and } \vec{I}_1}_{Second\ sector}$$

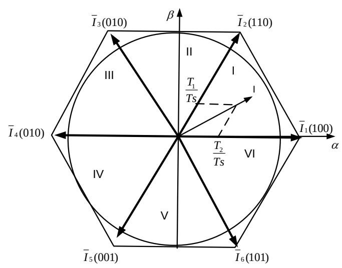


Fig.5 Space vector of Qzsi

IV. SIMULATION RESULTS

The CF-QZSI can be operated in both boost and buck operations depending on inductor value. If $L_1=L_2=20mH$ the current is high, output dc voltage is low and voltage buck expertise is realized. Fig.6 shows the simulation implementation of current-fed qZSI bust capability. When the input inductance value L_1=L_2=150mH the input current is low, output dc voltage is high and voltage boost expertise is realized. The voltage and current blocks are amalgamated to effect power buck capability.

Fig.5 or 6 shows the simulated power buck-boost capability. Directly above, the theoretical calculations are given as:

$$V_o = N V_{in} \quad (11)$$

V_{in} is input dc voltage source of qZSI, V_0 is dc output voltage measured after the impedance network and N is duty ratio of switch states where

$$N = \frac{1 - 2D_{op}}{D_A} \quad (12)$$

If we suppose the ac output voltage is V_{ac}. Modulation index is M, and thus we have

$$I_{ac} = m \cdot \frac{I_{dc}}{0.866} \quad (13)$$

The ac voltage and current blocks are multiplexed to get power buck-boost aptitude. Impedance network parameter are L_1=L_2=L_3=20mh C_1=C_2=200uF and dc input voltage 300V.

Boost operation results

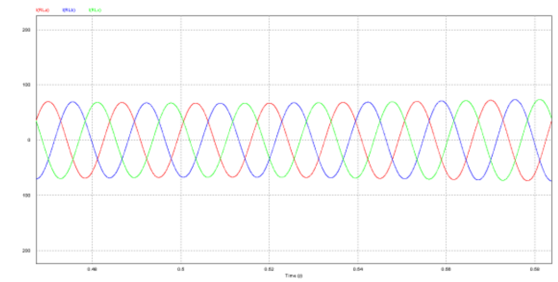


Fig.6 Simulated boost capability of current-fed qZSI

Buck operation results

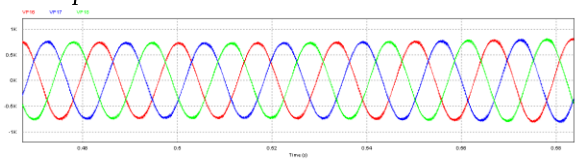


Fig.7 Simulation buck capability of current-fed qZSI

V. CONCLUSION

This paper deals with simple technique to achieve power buck-boost capability. The advantages of this technique are simple, efficient, and reduce complexity. The current-fed integrated qZSI is specially suited for hybrid vehicles and variable speed motor drives. Unique features like single stage power conversion, improved reliability, low EMI are obtained. The current-fed qZSI concept can be easily applied to adjustable-speed drive system. The buck-boost operation is attained in simple procedure. Better results are obtained through qZSI with 120-degree and space vector technique. The effects due misfiring are overcome. Gating pulses for IGBTs are contributing in merited procedure through SVPWM. Two on-line PWM gating pattern generators for three-phase current source converters have been proposed. These are techniques best suited for analog control schemes, which uses carrier signal and one best suited for digital control schemes based on space vector.

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