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Integrated Current - Fed Quasi - Z - Source Solar Inverter with Power Buck - Boost Capability

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Abstract: ***Solar integrated current - fed quasi - Z - source inverter (qZSI) have been proposed to overcome the limitations of current - source inverter (CSI) and current - fed Z (impedance) source inverter (ZSI). The problems with CSI are unidirectional power flow and can perform only voltage boost operation. On the other hand ZSI is bidirectional with an additional diode and have voltage buck - boost capability. The techniques of ZSI and qZSI are more or less the same but qZSIs are considered to be more efficient and reliable. The drawback of ZSI is that the inductors must sustain high currents. Space vector pulse - width modulation is analyzed in this paper; here the power buck - boost capability is attained by changing the values of input inductance. Simulation results are shown.***

Keywords: Current - fed quasi - Z - source inverter (qZSI), current - source inverter (CSI), buck - boost, space vector pulse - width modulation (SVPWM).

1. Introduction

Traditional inverters namely Voltage - source inverter (VSI) and CSI and current fed ZSIs in [1] are normally used. The dc voltage sources to these inverters are battery, solar module, fuel - cell stack or rectifier. Each inverter has six switches (MOSFET) in the main circuit. These switches are power switches with anti parallel diodes. The diodes will provide bidirectional power flow and reverse voltage blocking capability.

a) Solar Module

Photovoltaic (PV) [2] is emerging as a major power resource, steadily becoming more affordable and proving to be more reliable than utilities. The photovoltaic effect is the basic principal process by which a PV cell converts sunlight into electricity. In this paper solar module provides the dc input source to the inverter. Fig.1 shows the solar module.

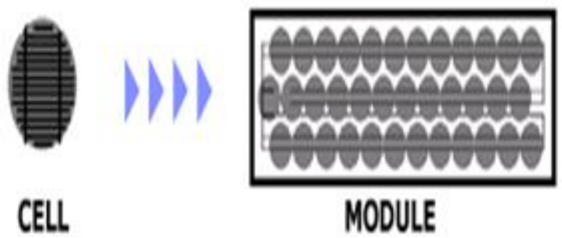

Figure 1: Solar Module

b) Voltage - Source Inverter and Current - Source inverter

VSI has stiff dc source voltage. VSI is voltage buck inverter. Fig.2. a shows the VSI.

CSI has constant current source, high source impedance; unidirectional power flow and voltage boost capability. Fig.2. b shows the CSI.

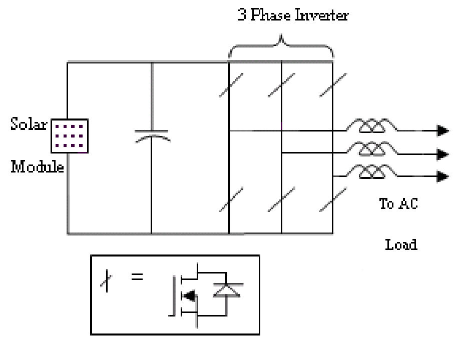

Figure 2 (a): Voltage - source inverter

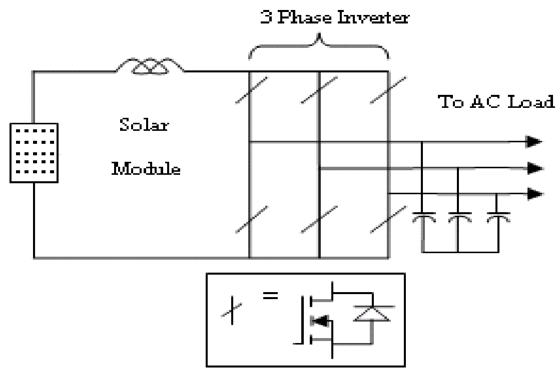

Figure 2 (b): Current - source inverter

c) Limitations of VSI and CSI

They can operate as buck or boost inverter but not as buck - boost inverter, main circuit cannot be interchanged as proposed in [3], vulnerable to electromagnetic interference (EMI). Adds up cost for installing power conversion stage and has low efficiency.

d) Current - Fed Z - Source Inverter

Current - fed ZSI in [3] has evolved to overcome the limitation of VSI and CSI. The inverter main circuit, dc current source and ac load can be coupled through impedance network. The impedance network is X shaped which consist of split - inductors (L_1, L_2) and capacitors (C_1, C_2). ZSI provides power buck - boost capability, bidirectional power flow through diode, reduced cost, high efficiency. As the impedance network provides buck - boost capability additional power conversion stage is not needed. The diode is present before the impedance network. Fig.3 shows the ZSI.

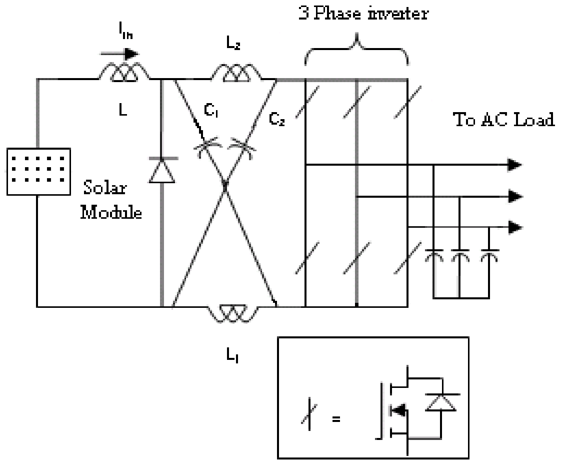

Figure 3: Impedance Source inverter

e) Limitation of ZSI

The inductors in current - fed ZSI must with stand high currents. It has high passive components rating as in [4]. ZSIs are less efficient than current - fed qZSI.

Limitations from VSI, CSI and current - fed ZSI are overcome by current - fed qZSI.

2. Current - FED QUASI ZSI

In qZSI the diode is present within the impedance network there by it avoids high passive components rating. A current - fed qZSI has bidirectional power flow, voltage buck - boost capability and high reliability. Fig.4 shows the qZSI.

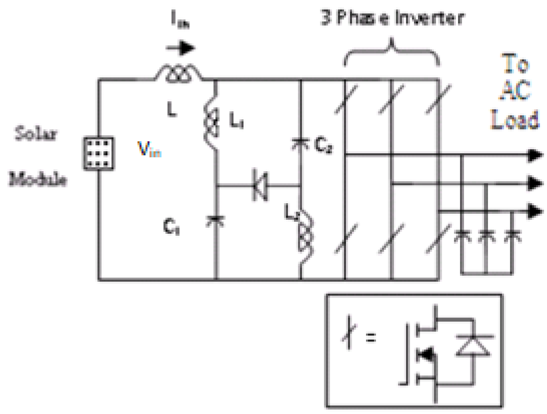

Figure 4: Quasi impedance source inverter

a) Modes of Conduction of qZSI

There exist two (180°, 120°) modes of conduction of switches (MOSFET) in qZSI [5]. Device utilization factor is high for 180° so this paper involves three - phase bridge circuit with 180° conduction mode. In 180° mode three switches conduct in one interval. Period of conduction of each switches are 180°.

b) Switch States of qZSI

The qZSI has eleven switch states, of which six are active states, three are short - zero state and remaining two are open - zero state [6]. Table I shows the switching pattern of switch states.

Table I: Switch States of QUASI ZSI

Switch State Type	Switching Pattern
active state	s_6, s_1, s_2 are on and s_3, s_4, s_5 are off
	s_1, s_2, s_3 are on and s_4, s_5, s_6 are off
	s_2, s_3, s_4 are on and s_5, s_6, s_1 are off
	s_3, s_4, s_5 are on and s_6, s_1, s_2 are off
	s_4, s_5, s_6 are on and s_1, s_2, s_3 are off s_5, s_6, s_1 are on and s_2, s_3, s_4 are off
short-zero state	s_2, s_5 are on
	s_3, s_6 are on
	s_1, s_4 are on
open-zero state	s_1, s_3, s_5 are on and s_4, s_6, s_2 are off
	s_4, s_6, s_2 are on and s_1, s_3, s_5 are off

1) Equivalent Circuit of Active State: In active state based on type of switch states the dc - link voltage is equal to ac line voltage. So $V_{pn}=V_{ac}$. Fig.5. a shows the active state equivalent circuit.

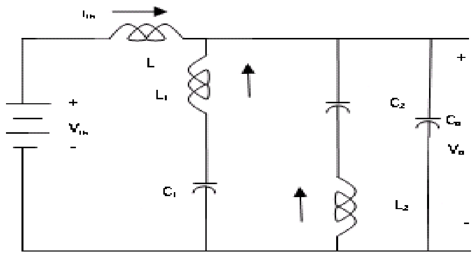

Figure 5: a Active state equivalent circuit

2) Equivalent Circuit of short - Zero State: In short - zero state dc - link voltage is zero ($V_{pn}=0$), the diode is OFF and the switches block the ac output voltage. Fig.5. b shows the short - zero state equivalent circuit.

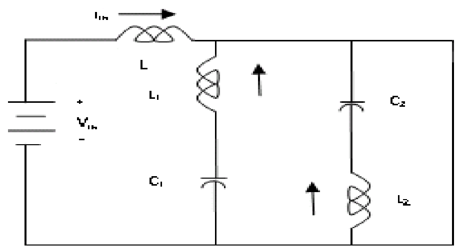

Figure 5: b Short - zero state equivalent circuit

3) Equivalent Circuit of open - Zero State: Fig.5. c shows the open - zero state equivalent circuit, the inverter bridge is equivalent to an open circuit, diode is ON and charges the capacitors (C_1, C_2). The dc - link voltage is equal to sum of capacitors ($V_{pn}= V_{C1}+V_{C2}$).

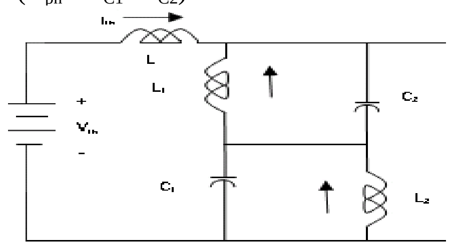

Figure 5: c Open - zero state equivalent circuit

3. Output Voltage Control Techniques

The ac output voltage is fixed at fixed frequency. If the frequency is variable ac output is also variable since the magnitude and frequency are getting varied. A variable ac output is obtained by varying the dc input current and maintaining the gain or modulation index of inverter as constant or by maintaining the input current as constant and varying the modulation index [7].

a) Space Vector Pulse Width Modulation

MOSFET is a gate controlled device; space vector pulse width modulation (SVPWM) provides gating and control of ac output voltage. SVPWM technique is applicable only for three - phase inverters; ac output is sinusoidal, and has high flexibility. It is a digital technique [6]. By varying modulation index (M) around 0 to 1 buck - boost capability is attained.

1) Space Transformation: Any three functions of time that satisfy

$$u_a(t)+u_b(t)+u_c(t)=0 \tag{1}$$

Can be represented in two dimensional spaces [1]

$$u(t)=\frac{2}{3}\left[u_a+u_b e^{j\left(\frac{2}{3}\right)\pi}+u_c e^{-j\left(\frac{2}{3}\right)\pi}\right] \tag{2}$$

2/3 is a scaling factor. u (t) can be written in real and imaginary components in x - y domain

$$u(t)=u_x+ju_y \tag{3}$$

$$\begin{pmatrix} u_x \\ u_y \end{pmatrix}=\frac{2}{3}\begin{pmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{pmatrix}\begin{pmatrix} u_a \\ u_b \\ u_c \end{pmatrix} \tag{4}$$

If u_a, u_b and u_c are three - phase voltages of a balanced supply with a peak value of V_m we denote as

$$u_a=V_m\sin(\omega t) \tag{5}$$

$$u_b=V_m\sin\left(\omega t-\frac{2\pi}{3}\right) \tag{6}$$

$$u_c=V_m\sin\left(\omega t+\frac{2\pi}{3}\right) \tag{7}$$

Space vector representation is

$$u(t)=V_m e^{j\omega t} \tag{8}$$

Normally buck - boost capability is achieved by varying modulation index or selecting appropriate switch states or by changing input voltage values.

b) Switch State Selection

Duty ratios are represented [4] as active state ($T_1/T=D_A$), short - zero state ($T_0/T=D_{sh}$) and open - zero state ($T_2/T=D_{op}$). The switch states are represented as follows

$$D_A+D_{sh}+D_{op}=1 \tag{9}$$

From equivalent circuit we get inductor voltage as

$$v_L=D_A(V_{in}-V_o)+D_{sh}V_{in}-D_{op}V_{in}=0 \tag{10}$$

$$V_o=\frac{1-2D_{op}}{D_A}V_{in} \tag{11}$$

For better results some of short - zero states are made to open - zero state [4]. Fig.6 shows the space vector of qZSI. Maximum value of modulation index (M_{max}) is $\frac{2}{\sqrt{3}}$ for $0<M\leq 1$ the inverter operates as normal SVPWM, $M<\frac{2}{\sqrt{3}}$ the inverter operates as over modulation. The boundary between normal and over modulation range is the hexagon.

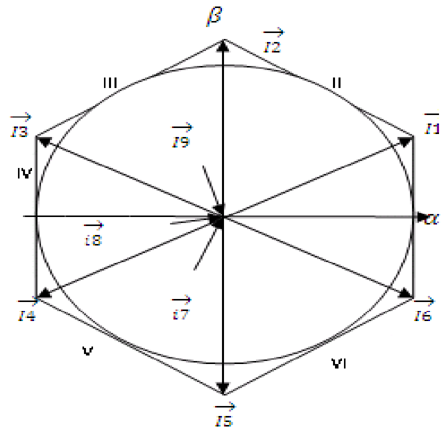

Figure 6: Space vector of qZSI

The output power is given as

$$P_o=\frac{3\sqrt{3}}{2\sqrt{2}}MI_{dc}V_o\cos\Phi \tag{12}$$

Where V_o 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 appropriate M values and switch states buck - boost capability is attained.

c) Variation of Dc Input Current

This paper deals with simple technique to achieve power buck - boost capability, here the input inductance (L) value is changed which results is change of output voltage. By using above power equation power buck - boost capability is attained and is shown in simulation results. The advantages of this technique are simple, efficient, and reduce complexity.

4. Simulation Results

Simulation results have been performed to conform the above analysis. Impedance network parameters are

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$L_1=L_2=2mH$ and $C_1=C_2=200\mu F$ and dc input voltage by solar module is 43V.

When the input inductance value L=2mH the input current is low, output dc voltage is high and voltage boost capability is attained. The voltage and current blocks are multiplexed to get power boost capability. Fig.7 shows the simulated power boost capability

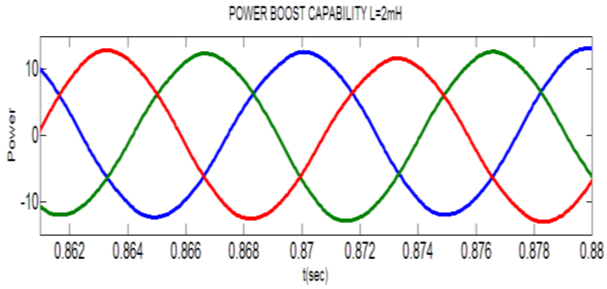

Figure 7: Simulated boost capability of qZSI L=2mH

When the input inductance value L=150mH the input current is high, output dc voltage is low and voltage buck capability is attained. The voltage and current blocks are multiplexed to get power buck capability. Fig.8 shows the simulated power buck capability.

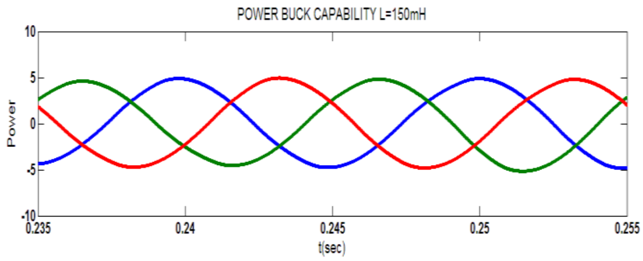

Figure 8: Simulated buck capability of qZSI L=150mH

From the above analysis, the theoretical calculations are given as:

$$V_o = BV_{in} \tag{13}$$

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

$$B = \frac{1-2D_{op}}{D_A} \tag{14}$$

Ac output voltage is $V_{ac.}$ Modulation index is M

$$V_{ac} = M\frac{V_o}{2} \tag{15}$$

Thus by changing the input inductance values the input current and dc output voltage varies which in turn results in buck - boost of ac output voltage $V_{ac.}$ The ac voltage and current blocks are multiplexed to get power buck - boost capability.

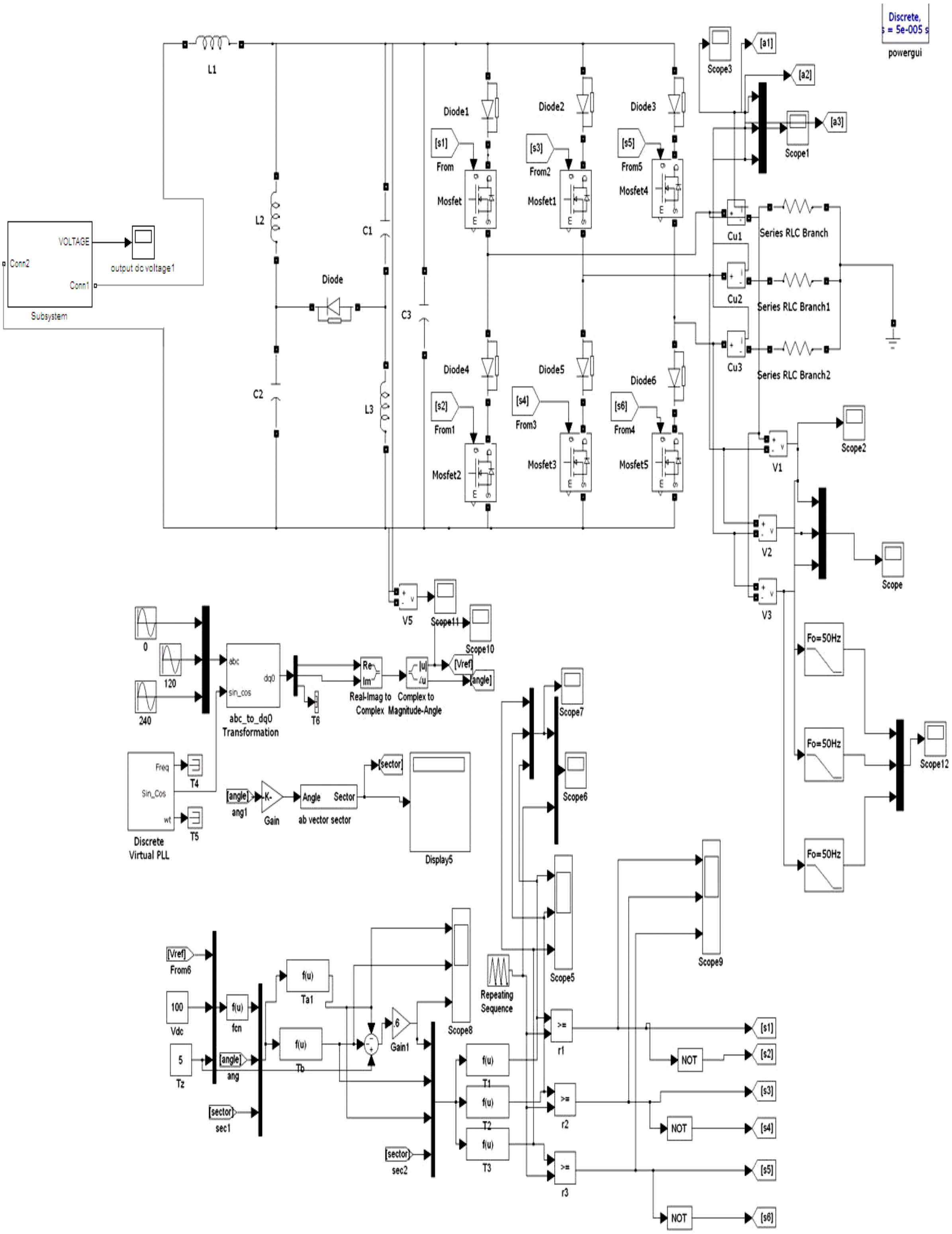

Figure 9: Simulation of solar integrated current - fed qZSI with buck - boost capability

5. Conclusion

This paper has presented a new type of solar integrated current - fed qZSI with power buck - boost capability. The solar 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 achieved. The qZSI concept can be easily applied to adjustable - speed drive system. The buck - boost operation is attained in simple manner. Better results are obtained through qZSI with 180 - degree and space vector technique. The effects due misfiring are overcome. Gating pulses for MOSFET are provided in efficient manner through SVPWM.

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