Double Carrier Pulse width Modulation Control for a Quasi Impedance Source Inverter

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Abstract – **The quasi-Z-source inverter (QZSI) is similar to the ZSI. The QZSI has been developed which feature several improvements and no disadvantages when compared to the ZSI. Also Double carrier pulse width modulation control is a new control method for controlling the ZSI and it has a lot of benefit if to compare with other traditional control methods. This paper improved properties of the QZSI by using the double carrier pulse width modulation control. Simulation results will be presented to demonstrate the new features.**

Keywords – **Distributed generation, Double carrier PWM, Impedance source inverter, quasi impedance source inverter**

I. INTRODUCTION

With the increasing in energy consumption and increasing costs associated with it, tendency toward generating power with smaller generators that may be dispersed in a wide area, and most of them are renewable, as they have greater advantages due to their environmentally friendly nature. This concept is commonly known as distributed generation (DG) [1]–[3].

Most of these DG systems are connected to the grid through the power electronic Inverter. Traditionally, there are two types of inverters that are being used, namely as voltage-source inverter (VSI) and current-source inverter (CSI). Both of these inverters have a limited operating range, even though both are widely used in DG applications [1]–[3].

Generally, in DGs, this limitation overcomes by using a dc–dc converter at the front end of the VSI or CSI [4], [5]. This enables them to operate in both buck and boost modes. This topology is commonly known as a two stage inverter. Small-scale two-stage inverters have been developed for domestic DG applications with fuel cells [4], [5]. However, two-stage inverters are expensive; furthermore, controlling them is difficult.

Recently, a *Z*-source inverter (ZSI) was proposed [6]. The ZSI is including two capacitors and two inductors and an inverter bridge and provides unique buck boost characteristics. Moreover, unlike traditional inverter, it does not need dead time. Due to these unique features, the *Z*-source inverter has found applications in numerous industrial processes including DG system [7].

The ZSI topology provides a modern approach to the boost voltage conversion techniques. The main feature of the ZSI is that it can boost the input voltage by creating a shoot-through operation mode, which is forbidden in traditional inverters [6]. Although the control principle of the ZSI is more complicated than the traditional inverter, it provides a possibly cheaper, more powerful, reliable and efficient approach to be used for DG systems [6], [7]. A voltage fed ZSI is shown in Fig. 1.

The quasi-Z-source inverter (QZSI) is alike to the ZSI described above, However has several profit including, in various combinations; lower component ratings, decreased source stress, decreased component count and made easier control strategies [8].

In this paper, at first, all methods of control of QZSI which before this to control it has been used will be introduced. Then while introducing method of controlling double carrier pulse width modulation, from that, to control QZSI will be used.
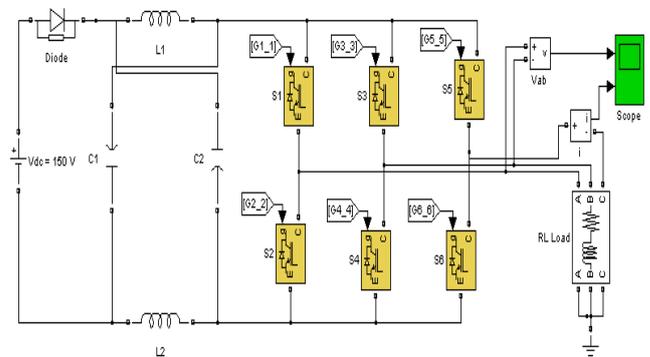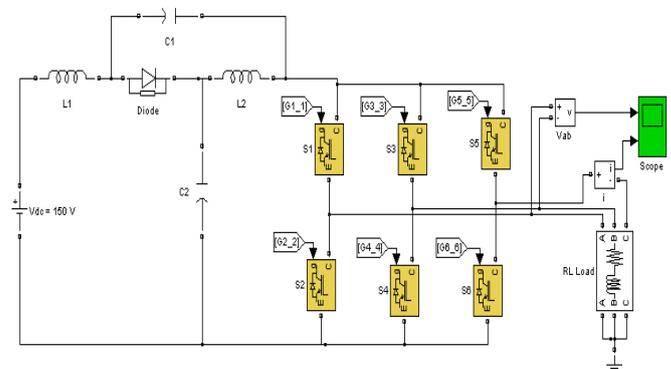

Fig. 1. Voltage Fed ZSI

Fig. 2. Voltage Fed QZSI

II. QUASI IMPEDANCE SOURCE INVERTER

For improve properties the ZSI, a QZSI in [8] proposed. QZSI has been developed which feature several improvements and no disadvantages when compared to the ZSI.

In Fig. 2 the QZSI topology is shown . The QZSI, shown in Fig. 2, when compared to the ZSI shown in Fig. 1, has below features:

- lower dc voltage of capacitor C_1
- continuous input current
- does not require input capacitance
- common dc rail between the source and inverter

Additionally, the QZSI topology has no disadvantages when compared to the ZSI topology. The QZSI topology therefore can be used in any application in which the ZSI would customarily be used [8].

As mention in [9] the operation of a QZSI can be broken down into below two states:

- active state
- shoot through state

In a situation that the QZSI is in the active state for the interval T_1, during the switching cycle T, the following voltage equations can be delineated from Fig. 2 as:

$$V_{L2} = V_{C2} - \bar{V}_{out} = -V_{C1} \tag{1}$$

$$V_{L1} = V_{in} - V_{C2} = V_{in} - \bar{V}_{out} + V_{C1} \tag{2}$$

$$\bar{V}_{out} = V_{C1} + V_{C2} \tag{3}$$

When the QZSI is in the shoot-through state for an interval T_0 during a switching cycle T, voltage equations is:

$$V_{C2} = V_{L2}, V_{C1} + V_{in} = V_{L1}, \bar{V}_{out} = 0 \tag{4}$$

During the active state, the inverter is operated in the same behavior as a traditional inverter. But the shoot through state is forbidden in a traditional inverter. The average voltage of the inductor V_{L1}, should be zero during one switching period T and in steady state.

$$V_{L2} = \bar{V}_{L2} = \frac{T_0.V_{C2} + T_1.(-V_{C1})}{T} = 0 \tag{5}$$

$$V_{L2} = \bar{V}_{L2} = \frac{T_0.V_{C2} + T_1.(V_{C1} - \bar{V}_{out})}{T} = 0 \tag{6}$$

$$T_0.V_{C2} = T_1.V_{C1}, V_{C2} = \frac{T_1}{T}.\bar{V}_{out} \tag{7}$$

Also, the average voltage of the inductor, V_{L2} during one switching period T should be zero in the steady state. From (3), (4) and (7), we also have:

$$V_{L1} = \bar{V}_{L1} = \frac{T_0.(V_{C1} + V_{in}) + T_1.(V_{in} - V_{C2})}{T} = 0 \tag{9}$$

$$V_{L1} = \bar{V}_{L1} = \frac{T_0.(V_{C1} + V_{in}) + T_1.(V_{in} - \bar{V}_{out} + V_{C1})}{T} = 0 \tag{10}$$

$$\bar{V}_{out} = \frac{T}{T_1 - T_0}.V_{in} \tag{11}$$

$$V_{in} = V_{C1} - V_{C2} \tag{12}$$

$$\bar{V}_{out} = V_{C2} = \frac{T_1}{T_1 - T_0}.V_{in} \tag{13}$$

In like manner, the average dc-link voltage across the inverter bridge can be founded as follows:

$$V_{out} = \bar{V}_{out} = \frac{T_1.0 + T_1.(V_{C1} - V_{L2})}{T} \tag{14}$$

$$V_{out} = \bar{V}_{out} = \frac{T_1.(V_{C1} + V_{C2})}{T} = V_{C2} \tag{15}$$

And, from (7), (12) and (15), we have:

$$V_{out} = V_{C2} = \frac{T_1}{T_1 - T_0}.V_{in} \tag{16}$$

Then the input voltage of a QZSI is well explaining and can be boosted applying the shoot-through ratio.

III. DOUBLE CARRIER CONTROL

Generally, traditional inverter has eight permissible states: six active and two zero states. The QZSI has an additional zero state the so-called shoot through state which will be inserted in the switching pattern.
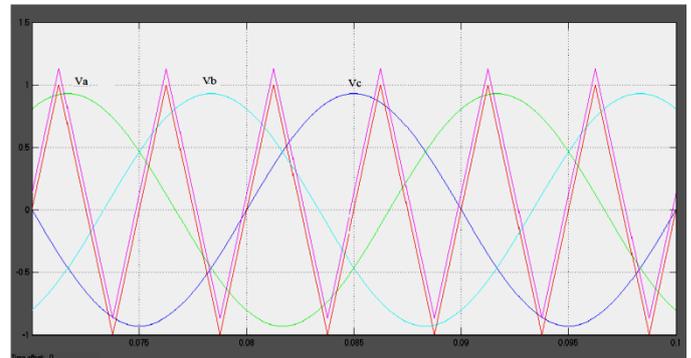

Fig.3. Double carrier control waveform

In order to an output voltage boost to be obtained, a shoot-through state should always be followed by an active state, i.e., shoot through states should be combined with no influence on the active states. Therefore, minor modifications in the traditional three phase sinusoidal PWM technique will

yield various PWM control strategies for the QZSI. There are three available PWM control strategies for QZSI. Traditionally, they are three control methods.

- simple boost control
- maximum boost control
- maximum constant boost control

The simple boost control uses two straight lines equal to or greater than the peak value of the three phase references to control the shoot through duty ratio in a traditional SPWM. Simple boost control is very easy and easy to implement. However switch stress in this method is very high. As during shoot through the entire switch are ON, so switching loss is high [10].

Maximum boost control turns all traditional zero state into shoot trough state. The voltage stress across the switching device is greatly reduced by fully utilizing the zero state. However, doing so also causes a shoot trough duty ratio varying in a line cycle, which causes inductor current ripple. This will require a high inductance for low frequency or variable frequency applications [10].

In order to reduce value and cost, it is important always to keep the shoot trough rather constant. At the same time, a greater voltage boost for any given modulation index is desired to reduce the voltage stress across the switch. This method achieves maximum boost while keeping shoot through duty ratio constant all the time, reducing ripple content in inductor current [10].

A new Control strategy is Double Carrier pulse width modulation. First time in [11] used from double carrier pulse width modulation for control a ZSI. As mentioned in [11], this method employs three phase sinusoidal reference signals, V_a, V_b and V_c and two triangular waves of high frequency as carrier signals. One of the carrier wave is with zero dc offset value whereas the other carrier wave is up-shifted to certain dc offset voltage to control shoot through duty ratio. Gating pulses which are achieved by comparing lower triangular wave (with zero dc offset) and reference wave is given to the upper leg devices of inverter circuit, whereas the pulses obtained by comparing upper triangular wave and reference wave is inverted and given to the lower leg devices of inverter circuit. Fig. 3 shows double carrier control waveforms.

Double carrier pulse width control has the following benefit in compare to other traditional control methods [11].

- Boost factor is made independent of the modulation index.
- Number of shoot through states per cycle of carrier wave is increased.
- Switching loss is decreased as only one of the phase legs is gated during shoot through states.
- It involves alternative active state and shoot through state and no zero states. Hence, it reduces the ripple content in inductor current.
- The voltage stress across the switches is reduced as modulation index could be kept high.
- It improves the fundamental voltage by decreasing the total harmonic distortion.

TABLE I

SIMULATION PARAMETERS

Input voltage V_{dc}	150 V
Inductors L1, L2	1μH
Capacitors C1, C2	1000μF
Switching frequency	20000Hz
L_{load}	10mH
R_{load}	50Ω
Modulation index	0.8
dc offset ratio	%15

IV. DOUBLE CARRIER PULSE WIDTH MODULATION CONTROL FOR A QUASI IMPEDANCE SOURCE INVERTER

As it was stated in the previous section QZSI has many advantages and has no disadvantages compared to the ZSI. So it can substitute ZSI. Also double carrier pulse width modulation has many advantages compared to methods of simple boost control, maximum boost control and maximum constant boost control. So it can be also be used instead of these methods. For these reasons in this paper QZSI operated in double carrier pulse width modulation mode has been investigated.

To investigate this purpose in this paper, simulation was conducted. The simulation results are presented in this section and the relevant waveforms are given. The simulation was carried out with parameters that are shown in table 1. Other properties of simulated system (Fig. 2) are as follows: type of switches is IGBT/Diode and three-phase RL circuit is used as the load of QZSI.

The waveform of line-to-line voltage of QZSI is shown in Fig.4. It can be seen the amplitude of output Line voltage has increased to 650V. Waveform of load current is shown in Fig.5. The harmonic profile of the load current of QZSI for double carrier pulse width modulation method is given in Fig.6.
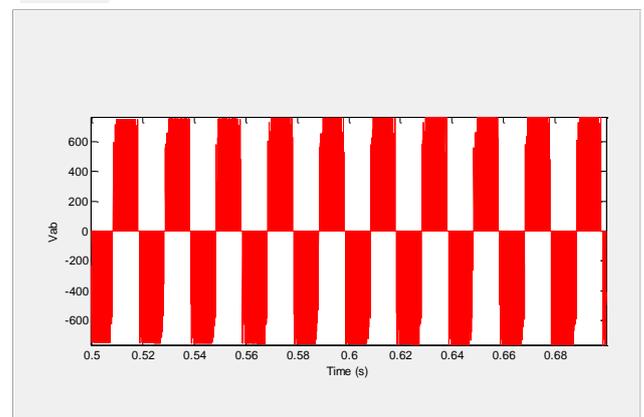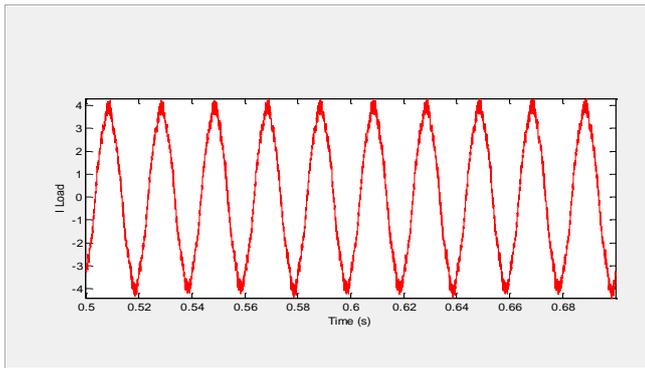

Fig.4. Output line voltage waveform
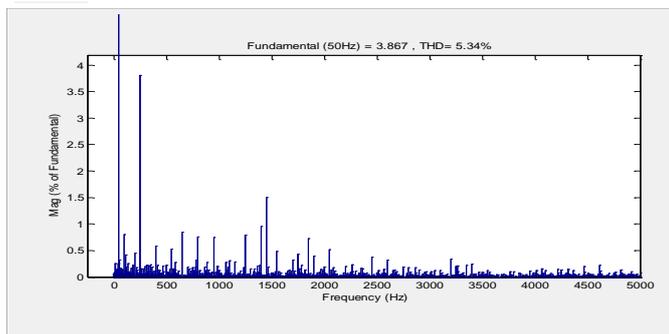
Fig.6. Load current waveform

Fig.7. Harmonic profile of output current waveform

V. CONCLUSION

The quasi-Z-source inverter (QZSI) is alike to the ZSI. Double carrier pulse width control has the following benefit in comparison to other traditional control methods for controlling QZSI. Results of this paper have shown that by using double carrier pulse width modulation for control the QZSI has below benefits.

- The output voltage can be available to increase in vast scope.
- It improves total harmonic distortion in load current.

Also, the use of the proposed topologies has all good properties of the QZSI and double carrier pulse width modulation method that has been described in references.

REFERENCES

[1] M. N. Marwali and A. Keyhani, "Control of distributed generation systems, Part I: Voltages and currents control," *IEEE Trans. Power Electron.*, vol. 19, pp. 1541–1550, Nov. 2004.

[2] M. N. Marwali, J.W. Jung, and A. Keyhani, "Control of distributed generation systems, Part II: Load sharing control," *IEEE Trans. Power Electron.*, vol. 19, pp. 1551–1561, Nov. 2004.

[3] A. A. Chowdhury, S. K. Agarwal, and D. O. Koval, "Reliability modeling of distributed generation in conventional distribution systems planning and analysis," *IEEE Trans. Ind. Appl.*, vol. 39, pp. 1493–1498, Sep.–Oct. 2003.

[4] A. M. Tuckey and J. N. Krase, "A low-cost inverter for domestic fuel cell applications," in Proc. 33rd Annu. IEEE Power Electron. Spec. Conf. *(PESC 2002)*, Darwin, Australia, pp. 339–346.

[5] J. Wang, F. Z. Peng, J. Anderson, A. Joseph, and R. Buffenbarger, "Low cost fuel cell converter system for residential power generation," *IEEE Trans. Power Electron.*, vol. 19, no. 5, pp. 1315–1322, Sep. 2004.

[6] F. Z. Peng, "Z-source inverter," *IEEE Trans. Ind. Appl.*, vol. 39, no. 2, pp. 504–510, Mar./Apr. 2003.

[7] J. W. Jung, M. Dai, and A. Keyhani, "Modeling and control of a fuel cell based Z-source converter," in *Proc. 22th Annu. IEEE Appl. Power Electron. Conf. (APEC), Expo,* Austin, TX, 2005, pp. 1112–1118.

[8] J. Anderson and F.Z. Peng, "Four Quasi-Z-Source Inverters," Power Electronics Specialists Conference 2008 PESC '08 39th IEEE 15-19, June 2008, pp. 2743-2749.

[9] J. H. Park, H. G. Kimy, E. C. Nho, and T. W. Chun, "Power Conditioning System for a Grid Connected PV Power Generation Using a Quasi-Z-Source Inverter," Journal of Power Electronics, Vol. 10, No. 1, January 2010, pp. 79-84.

[10] S. Ott, I. Roasto, D. Vinnikov, "Comparison of pulse width modulation methods for a quasi impedance source inverter", 10th International Symposium Topical Problems in the Field of Electrical and Power Engineering, Pärnu, Estonia, January 10-15, 2011.

[11] U. Shajith Ali, V. Kamaraj, "Double Carrier Pulse Width Modulation Control of Z-Source Inverter," European Journal of Scientific Research Vol.49 No.2 (2011), pp.168-176.

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