

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

Design of Battery Assisted Quasi Z Source Inverter Using Space Vector Modulation for Hybrid Power System

S.P.Sathya¹, S.Palanikumar²

P.G. Student, Department of EEE, Shreenivasa Engineering College, Dharmapuri, Tamilnadu, India¹

Professor & Vice Principal, Shreenivasa Engineering College, Dharmapuri, Tamilnadu, India²

ABSTRACT: Higher targets for renewable energy and current trend in wind and solar power suggest that future power systems will include large amounts of renewable and variable power generation. Using these two renewable energy sources, a battery-assisted Quasi Z Source Inverter (QZSI) using Space Vector Modulation (SVM) is designed for a hybrid wind/Photo voltaic (PV) power system. Quasi Z source Inverter is a new topology derived from the traditional Z Source Inverter (ZSI) which inherits all the advantages of ZSI, which can realize buck/boost, inversion and power conditioning in a single stage with improved reliability. In addition, it has the unique advantages of lower component rating, reduced source stress, reduced component count and constant dc current from the source. A battery along with QZSI plays a significant role in wind/PV power systems since it reduces the power fluctuations. And a modified space vector modulation technique for the QZSI is applied to achieve low harmonics, high voltage utilization and high efficiency.

KEYWORDS: Hybrid system, Wind power, Photovoltaic, Quasi Z Source Inverter, Space Vector Modulation.

I. INTRODUCTION

The ever increasing energy consumption, the exhaustible nature of fossil fuel and the worsening global environment have created booming interest in renewable energy source power generation systems [1,2]. Wind and solar power generation are two of the most promising renewable power generation technologies. The wind and photovoltaic sources of energy are inexhaustible, the conversion processes are pollution-free, and their availability is free. The growth of wind and photovoltaic (PV) power generation systems has exceeded the most optimistic estimation. Nevertheless, because different renewable energy sources can complement each other, multi-source hybrid alternative energy systems have great potential to provide higher quality and more reliable power to customers than a system based on a single resource. Because of this, hybrid energy systems have caught worldwide research attention [2]. Quasi Z Source Inverter (QZSI) is very well suited for renewable energy systems. QZSI derived from the Z-Source Inverter topology offers two important characteristics, the capability of dc-dc boost and dc-ac inversion in a single circuit module. Hence, the step up dc-dc converter is no longer required. With less switching devices the system becomes less complex and more reliable.

The energy storage technique presents a significant role in PV power systems since it not only assists the PV panel to store redundant energy or supplement inadequate energy, but also reduces the PV power fluctuations [3]. A traditional energy storage system usually requires an extra bidirectional dc-dc converter [4], which increases the system cost, volume, and control complication. Hence, an energy storage battery paralleled to the capacitor of quasi-Z-source network is presented, where the battery is directly connected to the quasi-Z-source capacitor, without any additional circuit, greatly simplifying the entire system.

Pulse width modulation (PWM) methods are essential to properly operate the ZSI/qZSI. The sinusoidal PWM (SPWM)-based techniques of qZSI can be divided into simple boost control [5], maximum boost control [6], and maximum constant boost control [7]. They are simple to implement, but have defects of high switching frequency and addi-

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

tional switching operations, resulting in the incremental losses. Therefore, the traditional space vector modulation (SVM) has been modified and applied to the ZSI/QZSI [8-10]. The SVM-based ZSI/qZSI system presents advantages of i) high dc-link voltage utilization and low harmonics; ii) low switching losses through distributing shoot-through zero states into the transition moment of the zero vectors and active vectors; iii) easy implementation via commonly used digital processors without extra comparators.

II. CIRCUIT OF THE QUASI-Z-SOURCE INVERTER

Figs. 1a and 1b show the traditional voltage fed ZSource Inverter (ZSI) and the proposed voltage fed quasi ZSource Inverter (QZSI), respectively. In the same manner as the traditional ZSI, the QZSI has two types of operational states at the dc side: the non-shoot through state (i.e. the six active states and two conventional zero states of the traditional VSI) and the shoot-through state (i.e. both switches in at least one phase conduct simultaneously). In the non-shoot-through state, the inverter bridge viewed from the dc side is equivalent to a current source. The equivalent circuits of the two states are as shown in Figs. 2a and 2b. The shoot-through state is forbidden in the traditional VSI, because it will cause a short circuit of the voltage source and damage the devices.

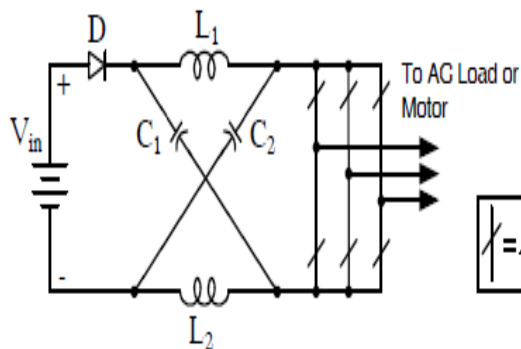


Fig. 1a Voltage fed Z-source inverter

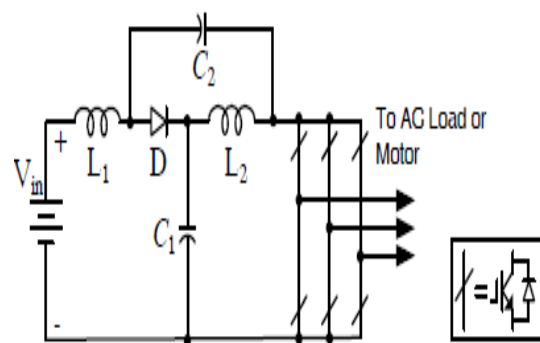


Fig. 1b Voltage fed quasi-Z-source inverter

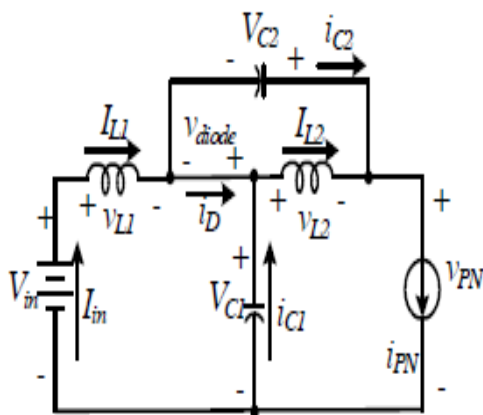


Fig.2 (a)

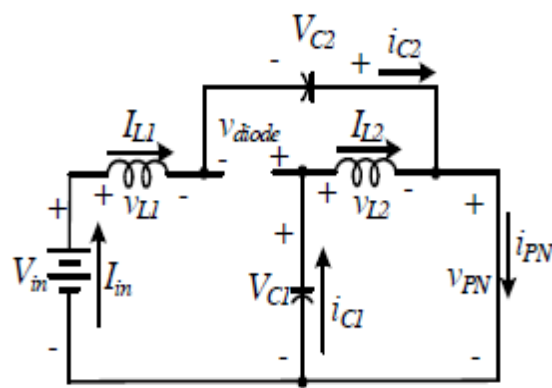


Fig. 2(b)

Fig 2. Equivalent circuit of the QZSI in (a) non-shoot-through state (b) shoot-through state

With the QZSI and ZSI, the unique LC and diode network connected to the inverter bridge modify the operation of the circuit, allowing the shoot-through state. This network will effectively protect the circuit from damage when the shoot-

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

$$C1 \frac{dv_{C1}}{dt} = i_B - i_{L2} \quad (1)$$

$$C2 \frac{dv_{C2}}{dt} = -i_{L1} \quad (2)$$

$$L1 \frac{di_{L1}}{dt} = V_{in} + V_{C2} \quad (3)$$

$$L2 \frac{di_{L2}}{dt} = V_{C1} \quad (4)$$

Where i_{L1} and i_{L2} denote the currents of inductors L_1 and L_2 , respectively; V_{C1} , V_{C2} and V_{in} denote the voltages of capacitors C_1 , C_2 and hybrid wind/PV panel, respectively.

During the non-shoot through state $T1$, we have

$$C1 \frac{dv_{C1}}{dt} = i_B + i_{L1} - i_d \quad (5)$$

$$C2 \frac{dv_{C2}}{dt} = i_{L2} - i_d \quad (6)$$

$$L1 \frac{di_{L1}}{dt} = V_{in} - V_{C1} \quad (7)$$

$$L2 \frac{di_{L2}}{dt} = -V_{C2} \quad (8)$$

Where i_d is the load current going to the inverter.

Using the state space average method, from (1) to (8), the inverter's state space equation is

$$\begin{bmatrix} C & 0 & 0 & 0 \\ 0 & C & 0 & 0 \\ 0 & 0 & L & 0 \\ 0 & 0 & 0 & L \end{bmatrix} \dot{X} = \begin{bmatrix} 0 & 0 & 1-D & -D \\ 0 & 0 & -D & 1-D \\ D-1 & D & 0 & 0 \\ D & D-1 & 0 & 0 \end{bmatrix} X + \begin{bmatrix} i_B + (D-1)i_d \\ (D-1)i_d \\ V_{in} \\ 0 \end{bmatrix} \quad (9)$$

where x is the state variables, $x=[x_1, x_2, x_3, x_4]^T = [V_{C1}, V_{C2}, i_{L1}, i_{L2}]^T$.

Average voltages and currents have the relationships as

$$V_{C1} = \frac{1-D}{1-2D} V_{in} \quad (10)$$

$$V_{C1} = V_{C2} + V_{in} \quad (11)$$

$$V_{C2} = \frac{D}{1-2D} V_{in} \quad (12)$$

$$i_{L2} - i_{L1} = i_B \quad (13)$$

and the power relationship in the system can be derived as

$$P_{in} - P_{out} + P_B = 0 \quad (14)$$

where P_{in} , P_{out} and P_B are the input power, the inverter output power, and the battery power, respectively. The input power is unidirectional; P_B is bidirectional, and positive when discharging and negative when charging; P_{out} is positive when the inverter delivers power to the grid.

IV. PROPOSED CONTROL SCHEME

A. Battery Current Closed-Loop Control

Using the battery current as a state variable to replace the variable x_1 (voltage V_{C1} of capacitor $C1$), due to $i_B = (V_{B,OP} - X_1)/R_b$, from (9)–(12), we obtain

$$\begin{aligned} CR_b \dot{i}_B &= (D-1)i_B + (2D-1)x_3 + (1-D)i_d \\ L \dot{x}_3 &= R_b(1-2D)i_B + (2D-1)V_{B,OP} + (1-D)V_{in}. \end{aligned}$$

Its small signal model is

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

$$\begin{aligned}
 CR_b \dot{\tilde{i}}_B &= (\bar{D} - 1)\tilde{i}_B + (2\bar{D} - 1)\tilde{x}_3 - (\bar{i}_d - \bar{i}_B - 2\bar{x}_3)\bar{D} \\
 &\quad + (1 - \bar{D})\tilde{i}_d \\
 L\dot{\tilde{x}}_3 &= R_b(1 - 2\bar{D})\tilde{i}_B - R(1 - \bar{D})\tilde{x}_3 \\
 &\quad + (2\bar{V}_B - 2R_b\bar{i}_B - \bar{V}_{in})\bar{D}
 \end{aligned}$$

where small variations of all variables around their equilibrium state are

$$\begin{aligned}
 x_3 &= \bar{x}_3 + \tilde{x}_3, D = \bar{D} + \tilde{D}, i_B = \bar{i}_B + \tilde{i}_B, i_d = \bar{i}_d + \tilde{i}_d, \\
 V_{in} &= \bar{V}_{in} + \tilde{V}_{in}, \tilde{V}_{in} = -R \cdot \tilde{x}_3
 \end{aligned}$$

Where the symbols “-” and “~” above the variables denote their equilibrium states and small variations, respectively; R is a nonlinear resistance. Then the small signal-based transfer function from the shoot through duty ratio to the battery current is

$$G_B(s) = \frac{\tilde{i}_B}{\tilde{D}} = \frac{F_1(s)}{H_1(s)}$$

$$\begin{aligned}
 F_1(s) &= L(\bar{i}_d - \bar{i}_B - 2\bar{x}_3)s + R(1 - \bar{D})(\bar{i}_d - \bar{i}_B - 2\bar{x}_3) \\
 &\quad + (1 - 2\bar{D})(2\bar{V}_B - 2R_b\bar{i}_B - \bar{V}_{in})
 \end{aligned}$$

$$\begin{aligned}
 H_1(s) &= -LCR_b s^2 - (1 - \bar{D})(CRR_b + L)s \\
 &\quad - R(1 - \bar{D})^2 - R_b(1 - 2\bar{D})^2.
 \end{aligned}$$

The proportional and integral (PI) regulator is employed in battery current closed-loop control to find the desired small variation of the shoot-through duty ratio by

$$\tilde{D} = k_p (\tilde{i}_B^* - \tilde{i}_B) + k_i \int_0^t (\tilde{i}_B^* - \tilde{i}_B) dt$$

where k_p and k_i are the proportional and integral constants, respectively. Defining

$$\tilde{E}_B = \tilde{i}_B^* - \tilde{i}_B$$

the transfer function of the PI regulator is

$$G_{PI,B}(s) = \frac{\tilde{D}}{\tilde{E}_B} = \frac{k_p s + k_i}{s}$$

A feed-forward control will speed up the response by a steady state shoot-through duty ratio value

$$\bar{D} = \frac{V_B - V_{in}}{2V_B - V_{in}}$$

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

B.Space Vector Modulation Applied to QZSI

Traditional SVM: The well-known traditional SVM is defined as

$$\begin{cases} T_1 = T_s M \sin(60^\circ - \theta + 60^\circ(i-1)) \\ T_2 = T_s M \sin(\theta - 60^\circ(i-1)) \\ T_0 = T_s - T_1 - T_2 \\ U_{ref} = U_1 \frac{T_1}{T_s} + U_2 \frac{T_2}{T_s} \end{cases}$$

Where $i = 1, 2, \dots, 6$ is the segment number to calculate the duration of the two involved active states; T_s is the switching period; T_0 is the switching time of traditional zero vector U_0 ; T_1 and T_2 are the switching times of active state vectors U_1 and U_2 ; θ is the inclined angle of U_1 and reference voltage V_{ref} ; the modulation index M is $\sqrt{(3U_{ref}/V_{dc})}$, in which V_{dc} is the dc bus voltage.

The SVM's switching moment is generated by the following steps:

- i) Determine the sector N of voltage vector reference U_{ref} .
- ii) Calculate the switching times T_1 and T_2 of the two adjacent voltage vectors. In different sectors T_1 , is the action time of a vector that immediately follows the starting zero-vector, then is carried out.
- iii) Calculate the switching times T_{max} , T_{mid} and T_{min} of three phases, respectively, they are the maximum, medium, and minimum switching times in three phases.

Modified SVM for the QZSI: As the introduction of shoot through zero states for the QZSI, the voltage reference becomes

$$U_{ref} = U_1 \frac{T_1}{T_s} + U_2 \frac{T_2}{T_s} + U_0 \frac{T_0}{T_s} + V_{sh} \frac{T_{sh}}{T_s}$$

Where V_{sh} is the shoot-through voltage vector, and T_{sh} is the shoot-through time interval. The shoot-through states are in the action time of zero vectors, i.e., $U_0(T_0/T_s) + V_{sh}(T_{sh}/T_s) = 0$, then the shoot-through states will not affect the action of active vectors. T_{max} , T_{mid} and T_{min} are the maximum, medium, and minimum switching times corresponded to the traditional SVM; those with subscripts "+" and "-" denote the modified switching times of the upper and lower switches in one bridge leg, respectively. The entire shoot-through time interval in each switching period is equally divided into six parts. Each part is combined into the transition moment between the traditional zero vector and active vector.

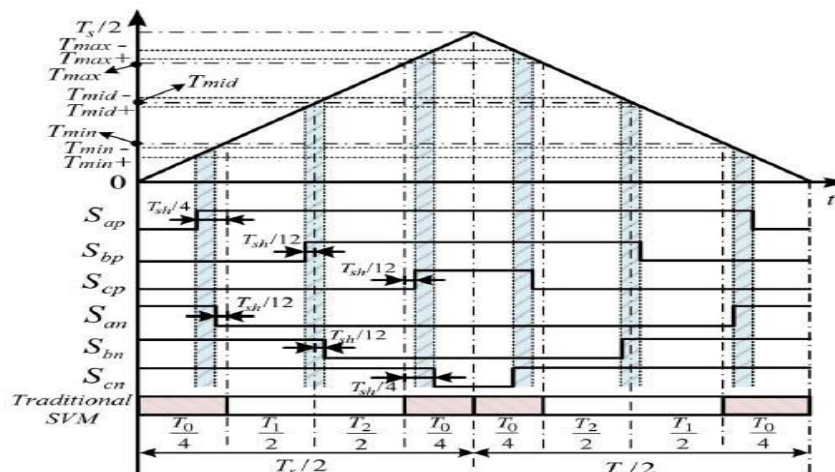


Fig.5 switching sequence of QZSI-SVM

The switching times of traditional SVM are shifted, as a result that the switching signals of the same bridge leg are no longer complementary. The T_{mid} applies a $T_{sh}/12$ time leading and lagging for the upper and lower switches to distribute the $T_{sh}/6$ shoot-through time interval. The T_{min} performs a $T_{sh}/4$ and $T_{sh}/12$ time leading for the upper and lower switches, respectively, to remain the invariable time interval of active states, i.e., T_1 and T_2 ; as well as a $T_{sh}/12$ and $T_{sh}/4$, time lagging for the upper and lower switches are carried out for $T_{sh}/4$. In such a way, each of three bridge legs fulfills the $T_{sh}/6$ shoot-through time interval in each switching and there are six shoot-through actions in one switching period.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

C. Control Strategy

In the same way as the conventional voltage source inverter, the output power of the QZSI can be controlled on the basis of the d-q model. Three-phase grid currents and voltages are measured and transformed to get the d- and q-axis components, i.e., from three-phase a-b-c frame, to two-phase stationary coordinate α - β frame, and finally to two-phase rotation coordinate d-q frame.

The state-space model for the ac side of QZSI in the static coordinate system is

$$L_f \frac{di_{oj}}{dt} = u_{oj} - u_{gj} - r_f i_{oj}$$

$$C_f \frac{du_{gj}}{dt} = i_{oj} - i_{gj}$$

where u_{oj} and i_{oj} represent the inverter output voltage and current, respectively; u_{gj} and i_{gj} represent the grid-connected voltage and current at the point of common coupling (PCC); $j \in \{a,b,c\}$, denotes the phase j .

In the dq synchronous reference frame, the above equations can be expressed as

$$L_f \frac{di_{od}}{dt} = u_{od} - u_{gd} - r_f i_{od} + \omega L_f i_{oq}$$

$$L_f \frac{di_{oq}}{dt} = u_{oq} - u_{gq} - r_f i_{oq} - \omega L_f i_{od}$$

$$C_f \frac{du_{gd}}{dt} = i_{od} - i_{gd} + \omega C_f u_{gq}$$

$$C_f \frac{du_{gq}}{dt} = i_{oq} - i_{gq} - \omega C_f u_{gd}$$

where u_{od} and u_{oq} are the inverter output voltages in the dq coordinate; u_{gd} and u_{gq} are the grid voltages in the dq coordinate; similarly, i_{od} and i_{oq} , i_{gd} and i_{gq} are the inverter output currents and the grid-injected currents in the dq coordinate, respectively. By using the state feedback decoupling control, the inverter outputs will be

$$u_{od}^* = (i_{gd}^* - i_{gd}) \left(k_p + \frac{k_I}{s} \right) - \omega L_f i_{oq} - \omega C_f (L_f s + r_f) u_{gq}$$

$$u_{oq}^* = (i_{gq}^* - i_{gq}) \left(k_p + \frac{k_I}{s} \right) - \omega L_f i_{od} - \omega C_f (L_f s + r_f) u_{gd}$$

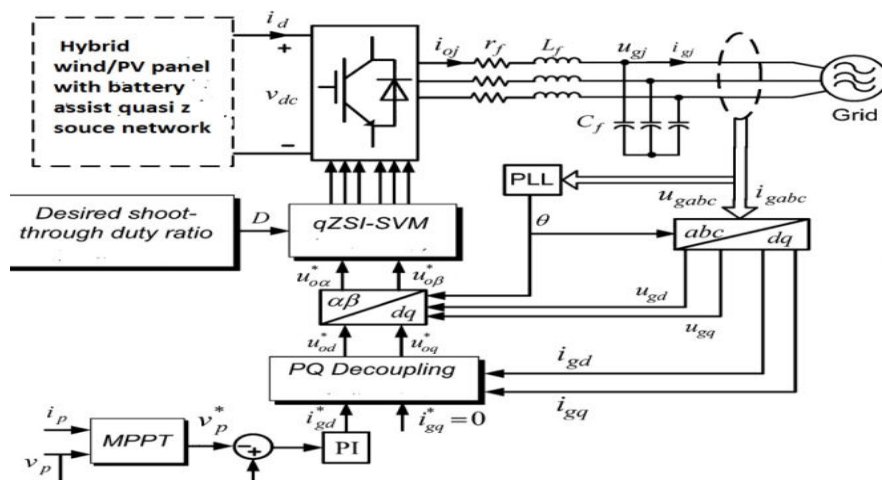


Fig.6 Proposed hybrid power system with battery assisted QZSI

PLL is used to get the phase of grid voltage, which will be used in the d-q transformation. The d-axis and q-axis components of grid currents are regulated with a closed-loop controller in order to deliver constant currents, and thereby,

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

constant active power P and reactive power Q to the grid. The reference currents $i^* d$ and $i^* q$ can be obtained from the active power reference P^* and the reactive power reference Q^* , respectively. P^* is decided by the output of energy management unit and Q^* is kept at zero all the time. The grid-injected currents are controlled in the phase with the grid voltage, and this causes a unity power factor for the generation system. After these calculations, the modulation index M will be derived. Then M and D are combined together to produce the pulse and control the operation of QZSI. The d-axis current reference i^*_{gd} is determined by $i_{gd}^* = (k_p + k_I/s)(v_p - v_p^*)$. The active power injected to the grid increases when the error is positive; the v_p^* is obtained by the maximum power point tracking (MPPT). And $i_{gq}^* = 0$ to get unity power factor

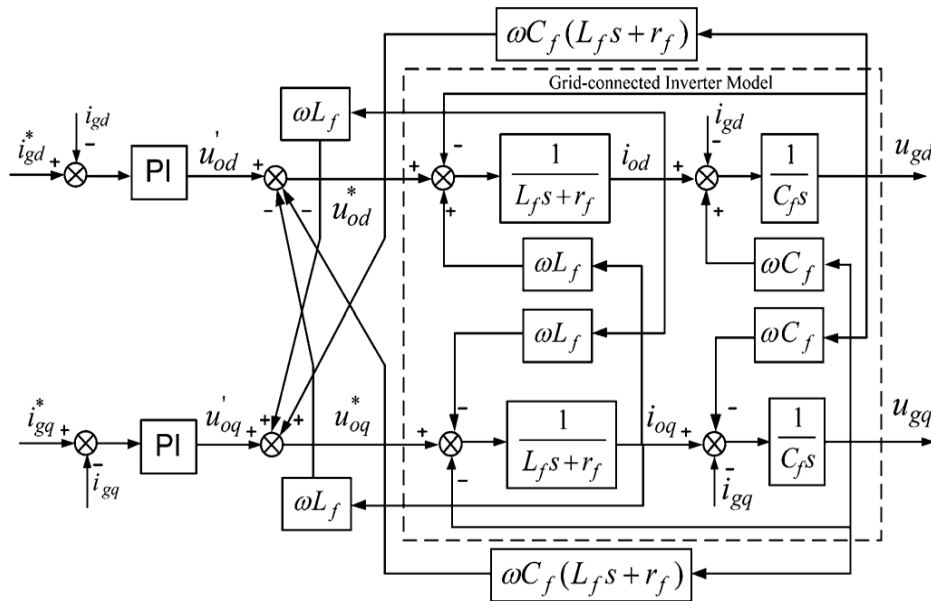


Fig. 7 PQ Decoupling Control

Further, the dq-axis voltage references are then obtained by the inner PI regulators, respectively. Through the $dq- \alpha\beta$ transformation, the obtained voltage references $u_{o\alpha}^*$ and $u_{o\beta}^*$ and the desired shoot-through duty ratio are applied to generate gate drive signals by the addressed QZSI-SVM.

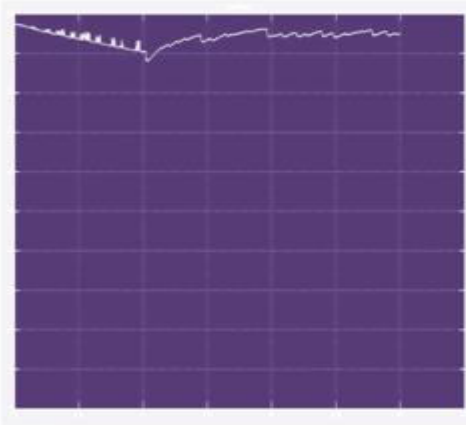


Fig.8 (a)

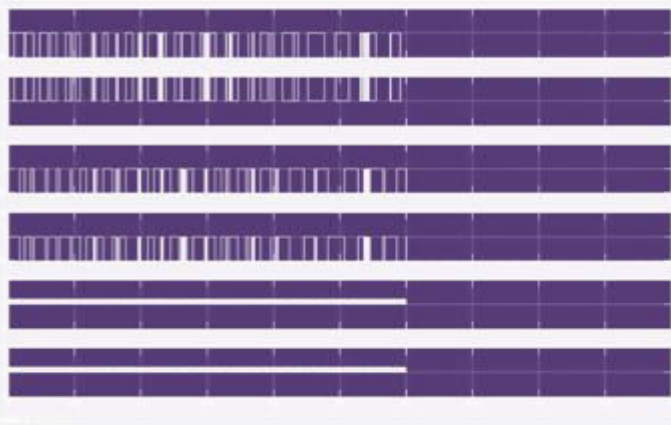


Fig.8 (b)

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

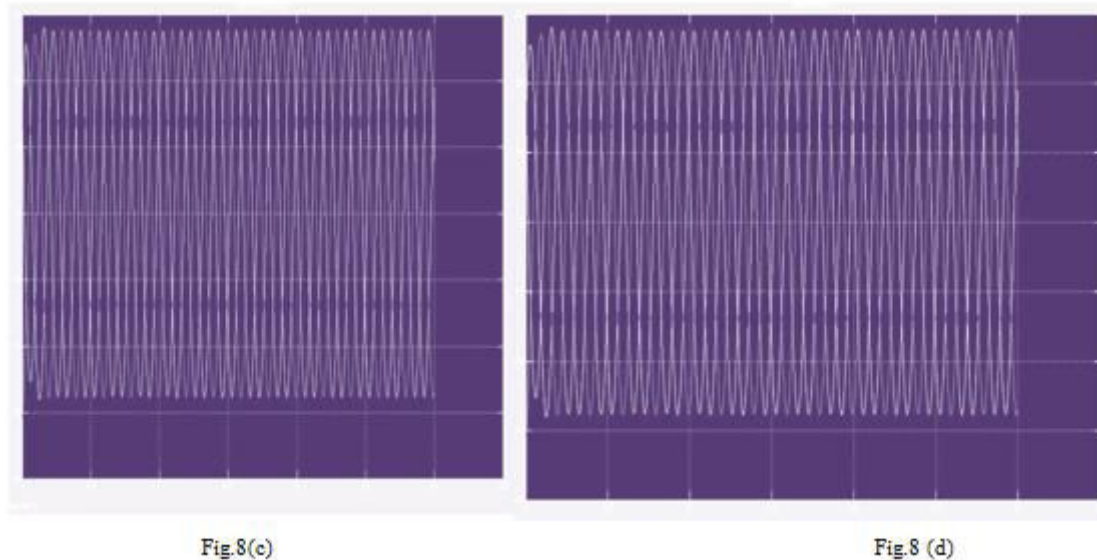


Fig.8 Simulation result of (a) input voltage (b) SVM sequence (c) Load output voltage (d) Grid output voltage

V.CONCLUSION

In this paper, a control scheme for hybrid power generation system based on battery assisted quasi Z source inverter was proposed. Three operating modes of battery - charging, no charging, and discharging prevent the battery from over charging or over discharging, which will prolong the battery lifetime and keep the battery safe. An SVM technique was performed for the QZSI with high dc-link voltage utilization and high efficiency. The whole control scheme is simulated in MATLAB/ SIMULINK to test the correctness of proposed strategy.

REFERENCES

- [1] Ramakumar R, Bzura JJ, Eyer J, Gutierrez-Vera J, Hoff TE, Herig C, et al. Renewable technologies and distribution systems. *IEEE Power Eng Rev*; Nov.1999;5e14.
- [2] Kane M, Larrain D, Favrat D, Allani Y. Small hybrid solar power system. *Energy* 2003;28:1427e43.
- [3] X. Li, D. Hui, and X. Lai, "Battery energy storage station (BESS)-based smoothing control of photovoltaic (PV) and wind power generation fluctuations," *IEEE Trans. Sustain. Energy*, vol. 4, no. 2, pp. 464–473, Apr. 2013.
- [4] H. Zhou, T. Bhattacharya, D. Tran, T. S. T. Siew, and A. M. Khambadkone, "Composite energy storage system involving battery and ultracapacitor with dynamic energy management in microgrid applications," *IEEE Trans. Power Electron.*, vol. 26, no. 3, pp. 923–930, Mar. 2011.
- [5] F. Z. Peng, "Z-source inverter," *IEEE Trans. Ind. Applicat.*, vol. 39, no. 2, pp. 504–510, Mar./Apr. 2003.
- [6] F. Z. Peng, M. Shen, and Z. Qian, "Maximum boost control of the Z-source inverter," *IEEE Trans. Power Electron.*, vol. 20, no. 4, pp. 833–838, Jul. 2005.
- [7] M. Shen, J. Wang, A. Joseph, F.-Z. Peng, L. M. Tolbert, and D. J. Adams, "Constant boost control of the Z-source inverter to minimize current ripple and voltage stress," *IEEE Trans. Ind. Applicat.*, vol. 42, no. 3, pp. 770–778, May/June. 2006.
- [8] P. Loh, D. M. Vilathgamuwa, Y. S. Lai, G. T. Chua, and Y. Li, "Pulsewidth modulation of Z-source inverters," *IEEE Trans. Power Electron.*, vol. 20, no. 6, pp. 1346–1355, Nov. 2005.
- [9] M. Von Zimmermann, M. Lechler, and B. Piepenbreier, "Z-source drive inverter using modified SVPWM for low output voltage and regenerating operation," in *Proc. 13th Eur. Conf. Power Electronics and Applications (EPE'09)*, Sep. 8–10, 2009, pp. 1–10.
- [10] Y. Liu, B. Ge, F. J. T. E. Fernando, A. T. de Almeida, and H. Abu-Rub, "Modeling and SVPWM control of quasi-Z-source inverter," in *Proc. 2011 11th Int. Conf. Electrical Power Quality and Utilisation (EPQU)*, Oct. 17–19, 2011, pp. 1–7.