Wind-PV Hybrid Energy Source Fed Three Level NPC with Quasi Z Source Network

Palanisamy R, Vijayakumar K
Department of EEE, SRM University, Tamilnadu, India

Article Info

Article history:

Received Mar 3, 2017
Revised Jun 6, 2017
Accepted Jul 1, 2017

Keyword:

Coupled inductor Z source NPC
Grid connected system
Quasi Z source inverter
Wind –PV Hybrid system

ABSTRACT

Multilevel inverters find use in industrial drive applications and grid based power generation. Owing to the increasing power demand and rising conventional generation costs a new alternative in renewable energy source is gaining popularity and acceptance. A Wind-PV hybrid renewable energy source is proposed which increases power reliability and improves standalone generation efficiency. A Quasi Z source network allows inverter shoot through possibility while boosting the dc voltage fed to the Neutral Point Clamped MLI. Simulation results were obtained for two levels VSI and further simulations for 3 level quasi NPC-TLI verified using Matlab Simulink and hardware implementation results verified by using DSP controller.

Corresponding Author:

R. Palanisamy,
Department of EEE, SRM University, Tamilnadu, India.
Email: krspalani@gmail.com

1. INTRODUCTION

Renewable sources are gaining increasing acceptance and implementation in energy sector mainly for solar, wind and fuel cells. A wind PV Hybrid energy source improves their standalone efficiency and reliability besides increasing the output power capacity [1], [2]. DPGS (Distributed power Generation Systems) have the additional advantage of supplying grid as well as capability of acting as standalone energy provider [3]. But a dc-dc boost converter is necessary in such converter circuits to meet the output voltage requirements. A ZSI (Z-Source Inverter) [4] eliminates the need for a boost converter thereby reducing the circuit complexity, size, providing necessary dc boost, improving inverter efficiency and allowing shoot through states. In a traditional inverter shoot through is forbidden for it causes short circuiting of the dc input components and carries a risk of damaging inverter switches. This is made possible by a ZSI. A Quazi-Z source inverter [5] besides having all the fore mentioned ZSI advantages, provides simpler control with lesser components and reduces voltage stresses during operation. Maximum Boost Control, being easy and effective [5] is used to control the inverter switches.

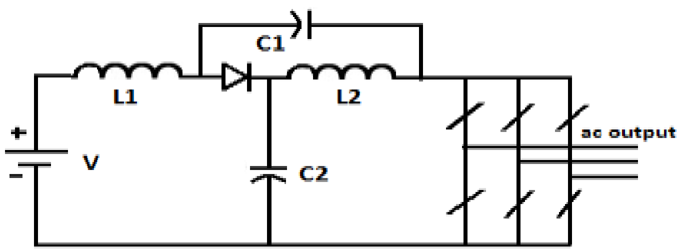


Figure 1. Q-ZSI circuit topology

2. PV-WIND HYBRID SOURCE

2.1. PV Source

Photovoltaic effect takes place when the barrier potential is overcome by electrons absorbing solar radiation. PV cell utilizes this to get dc current when irradiated with sunlight. Series or parallel connections of PV cells and arrays are used to increase power output [6]. The equations governing the PV array current are given as,

$$\mathrm{I} = \mathrm{I_{st}} - \mathrm{I_{d1}} \tag{1}$$

$$I_{d1} = I_1\left(exp\left(\frac{qV1}{kT}\right) - 1\right) \tag{2}$$

Where, I_1 is reverse saturation current of diode, p is the electron charge, V_1 is the voltage across diode, k is Boltzmann constant, T is junction temperature, I_{st} - short circuit current, I_{d1} - diode current.

2.2. MPPT (Maximum Power Point Tracking)

MPPT is the technique to get maximum power out of the PV arrays. P&O (Perturb and Observe) is one technique of MPPT in which the controller adjusts the array voltage every time it detects a change in it. If the calculated change in power is positive, then it keeps on shifting the voltage in that direction till the change in power becomes negative [7]. When the incremental power increases, then a pulse is sent by the MPPT controller to the switch to deliver power to the load. If there is a decrement in power for this voltage change, then no pulse is given and the switch remains in the off state. The load is fed with the present maximum value reached earlier. Since the P-V characteristics of a PV cell approach a peak, or maximum power point, this method is also called as hill climbing method. It is a common method with easy implementation [8].

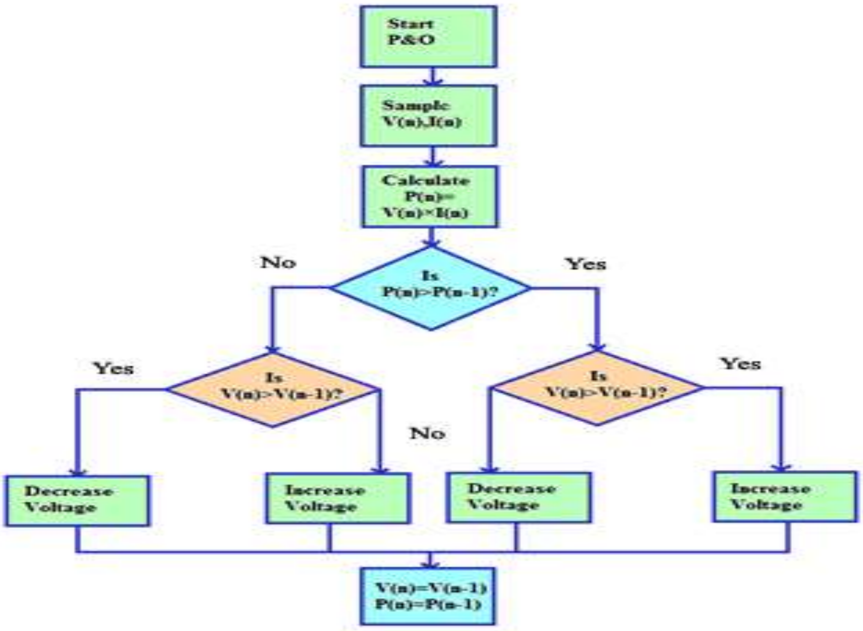


Figure 2. MPPT algorithm flow chart

2.3. Wind Energy Conversion System

Wind enegy is another naturally available source which can be converted into electical energy by a Wind Energy Conversion System. It consists of a wind turbine which acts as a prime mover for a generator. They share a common shaft through which mechanical power is transferred to the generator. A Permanent Magnet Synchronous Genertor does not need an excitation field which consideraly reduces energy wastage [9], [10]. It facilitates the wind turbine operation without a gearbox so the operatingcost is reduced.

Permanent magnets which have been made easily available in the recent years contribute towards cost reduction [11].

A Wind-Pv hybrid source is realised by feeding the ac voltage from PMSG into a three phase diode rectifier and coupling this dc voltage with the PV array output [12]. A renewable hybrid energy source is realised prvoding sufficient dc voltage for inverter operation.Improved reliabitily during overcast conditions or insufficient wind speed can be expected from it [13].

3. REVIEW OF A QUASI Z-SOURCE INVERTER

A quazi-Z source inverter is a modified version of a Z-source inverter with reduced switching stresses and continuous inverter current [14]. Two inductors and capacitors are arranged as shown in Figure 3. A quazi Z- source inverter has two modes of operation: shoot through mode and active (non-shoot through) mode. All the inverter switches of at least one leg should be on for a full shoot through to occur. Figure 3 shows QZSI during active mode. Applying KVL to loops 1, 2 and 3, we get,

$$V_{in} = V_{L1} \tag{3}$$

$$V_{in} = V_{L1} + V_{C2} \tag{4}$$

$$V_{out} = V_{C2} - V_{L2} \tag{5}$$

$$V_{C1} = -V_{L2} \tag{6}$$

From 2 & 3, we get

$$V_{out} = V_{C1} + V_{C2} \tag{7}$$

During shoot through state, diode is open circuited and we get two loops. In the next figure its equivalent circuit is shown. Applying KVL we get two Equations,

$$V_{in} = V_{L1} + V_{C1} \tag{8}$$

$$V_{L2} = V_{C2} \tag{9}$$

Since during shoot through, inverter leg output is zero, Vout is zero.

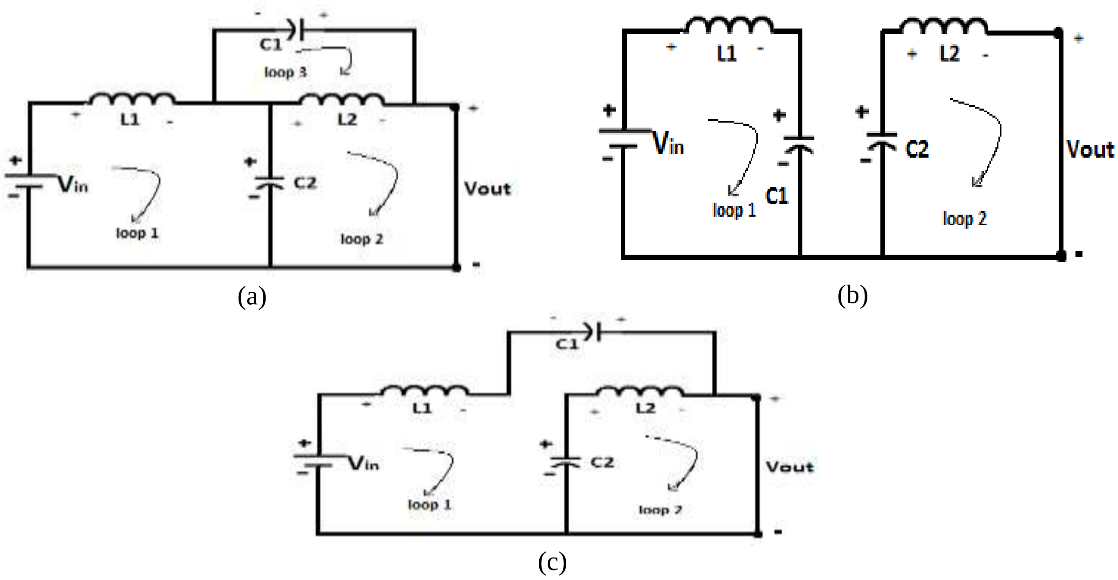


Figure 3. (a)-(c) Q-ZSI modes of operation

From Equations (1), (2), (5), (6) we get two equations each for L1 and L2. Tsh and Tnon are the shoot through and non-shoot through times respectively, their sum being the total switching time [15]. Calculating inductor voltage for the whole switching instant, the capacitor voltages can be rearranged and determined. Using Equation (4) the output voltage equation in terms of input can be found and the duty cycle of the inverter varied to get the desired boost [16].

$$V_{L1}(T) = (V_{in} - V_{C2})T_{non} + (V_{L1} + V_{C1})T_{sh} \quad (10)$$

$$V_{L2}(T) = (-V_{C1})T_{non} + (V_{C2})T_{sh} \quad (11)$$

4. CONTROL STRATEGY

Out of various Sinusoidal PWM techniques available, maximum boost control is applied for the inverter. It is simple to implement and produces a significant voltage boost [4], [7-8]. The zero inverter switching states are converted to shoot through and the active states are retained as such in MCB is shown in Figure 4.

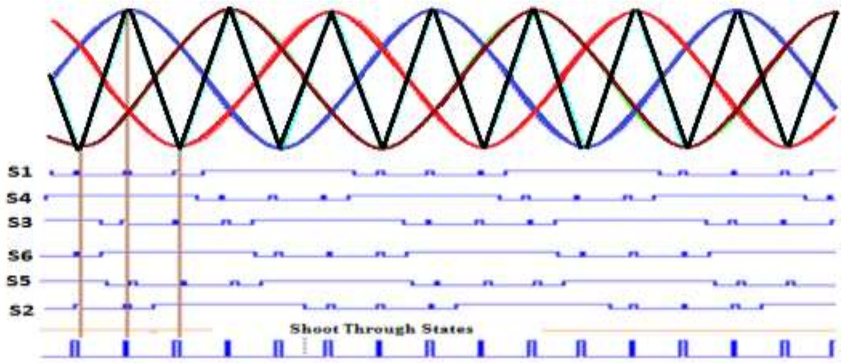


Figure 4. Maximum Boost Control

A triangle carrier is compared with a three phase reference, each phase for a positive switch .Shoot through occurs whenever the triangle peak overshoots the sinusoid peak magnitude so twice for each phase in one cycle. At other instants when the sinusoid magnitude is greater, the inverter exhibits active switching states. As said earlier, active inverter operation is achieved by comparing sinusoid with the carrier waveform when the former's magnitude is greater. Using min/max function for the three phase sinusoid its upper and lower envelope waveforms are compared against the same carrier to generate shoot through pulses for the positive and negative carrier peaks respectively, which are then OR function (logic gate) together to obtain the shoot through pulse for three phases [13-14]. This waveform is combined with the active state waveforms using OR gate and given to the switches.

5. QUASI Z SOURCE NPC-TLI

A Neutral point clamped Three Level Inverter produces three level stepped ac voltage. Each inverter leg consists of four switches and two clamping diodes for the dc neutral point connection. Half the dc voltage is shared by two capacitors thus split it into three levels +Vdc/2, 0, and –Vdc/2 which would have otherwise required two dc sources is shown in Figure 5. Top two or middle two or bottom two switches in each leg switch on together who produce 3×3×3=27 switching states; this is during normal NPC-TLI operation, which is shown in Figure 6.

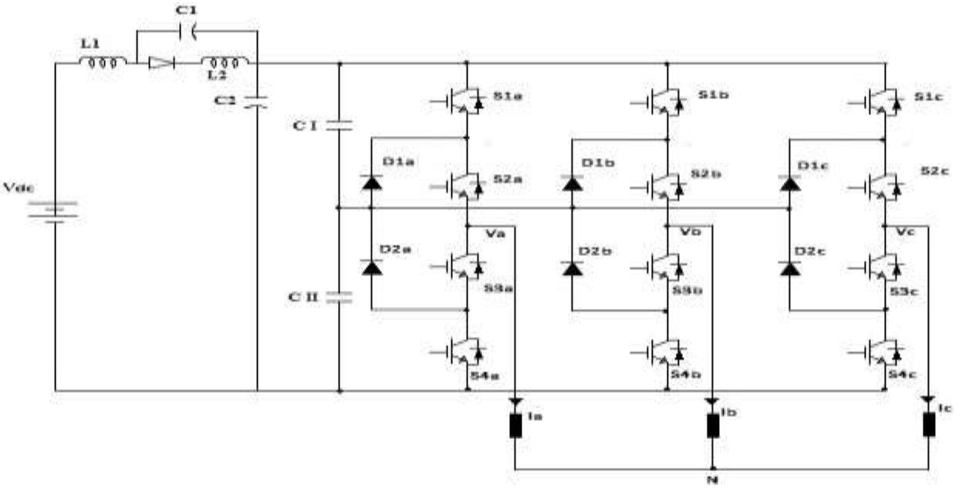


Figure 5. Quasi Z source NPC-TLI

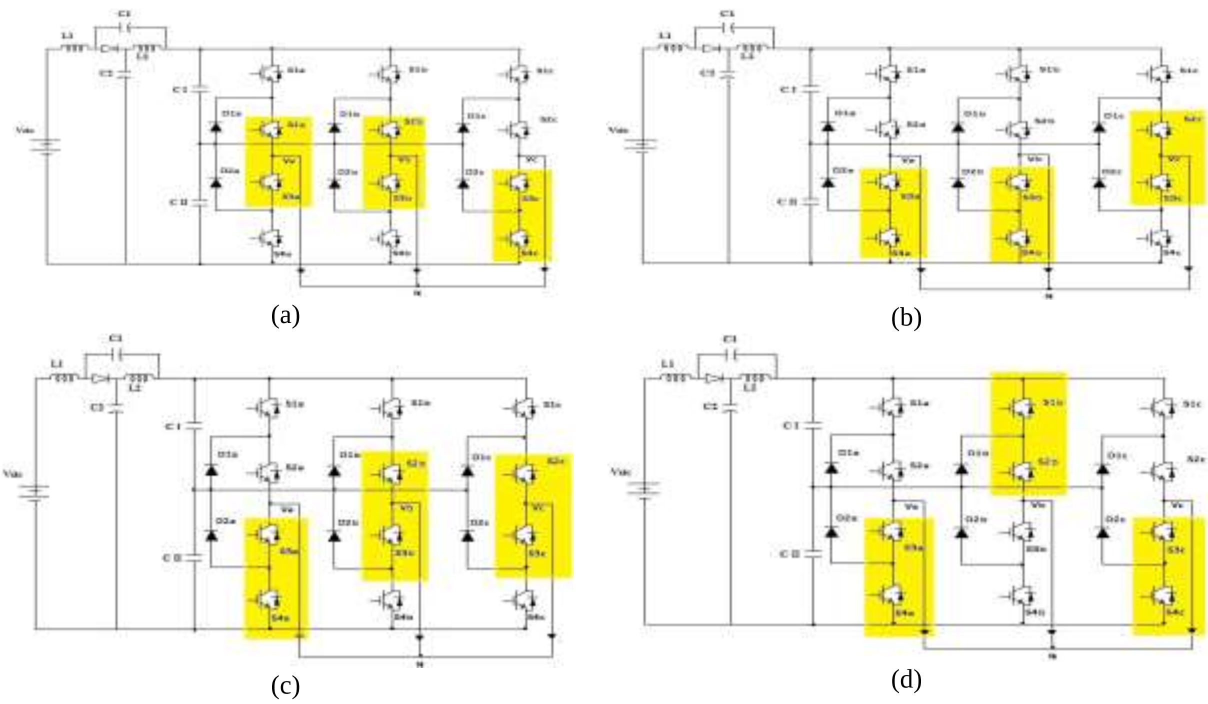


Figure 6. Non-shoot through Modes of Operation (a) Mode1 (b) Mode2 (c) Mode3 (d) Mode4

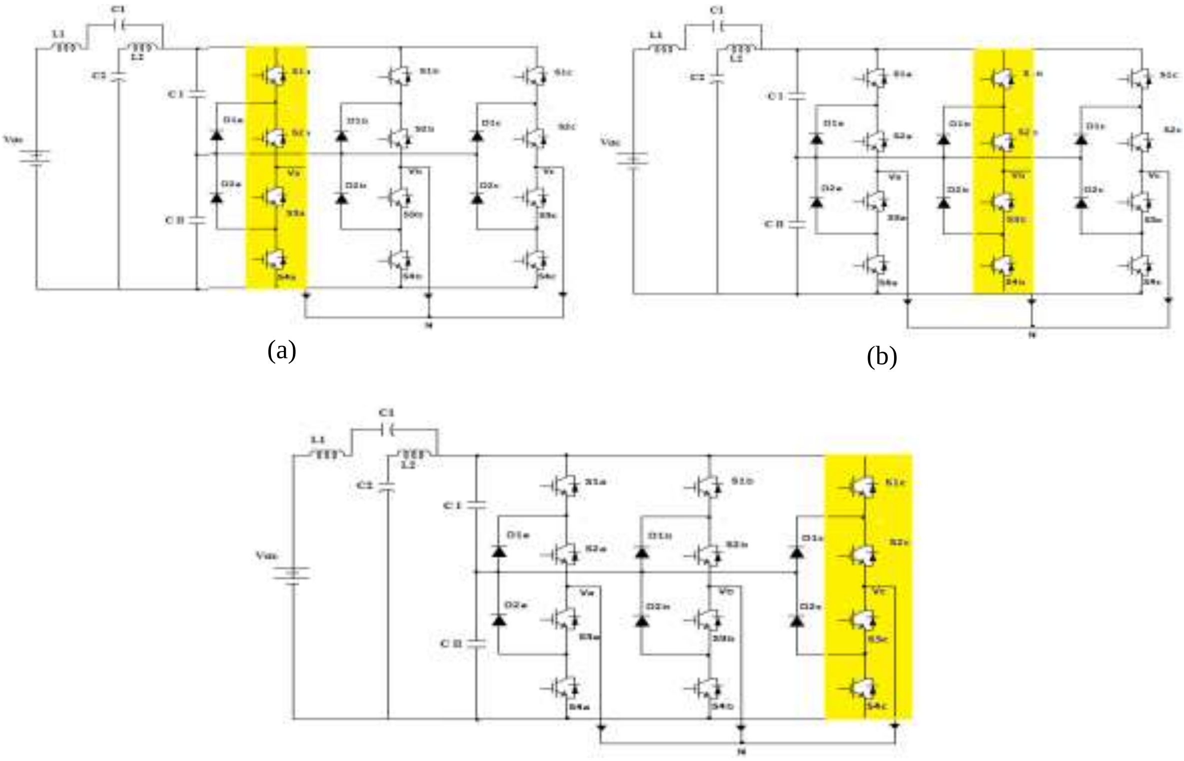
$$\breve{G}_n = \begin{bmatrix} 0 & 0 & -1 & T_n \\ 1 & 0 & \frac{T_n}{L} & \frac{T_{n-1}}{L} \\ \frac{T_{n-1}}{L} & -\frac{T_n}{L} & -1 & 0 \\ 0 & \frac{1-T_n}{L} & 0 & 1 \end{bmatrix} G_n + \begin{bmatrix} \frac{1}{L} & 0 & 1 & -1 \\ 0 & L & 0 & 0 \\ 0 & \frac{1}{L} & -1 & T_n \\ 0 & \frac{T_n}{L} & \frac{1}{L} & -1 \end{bmatrix} + T_n \tag{11}$$

$$G_P(s) = \frac{K_t s^2 + K_1 s + K_0}{s^2 + w_0^2} \tag{12}$$

This is made possible due to the inductor and capacitor arrangement in the QZSI [9]. The output of that inverter leg is zero for this state [9], [10]. During shoot through mode all the switches of any leg, individually or in any combination switch on at the same instant giving rise to seven additional shoot through states.

$$P_{sw} = \frac{1}{2E}\int_0^t F_s(E_0 + E_1 + E_2)dwt \quad (13)$$

Three of them are shown in Figure 7 which is either interms of upper shoot through states or lower shoot through states or full shoot through states Equation (13) shows power across each power switches placed in proposed circuit.



(a) (b)

(c)

Figure 7. Shoot through states (a) State1 (b) State2 (c) State3

At shoot through conditions the generated output voltage is zero, which is short circuited by clamped diodes. Then during the next states of operation the output voltage depends upon the capacitor voltage and applied input voltage, which is twice of input voltage. The table 1 and 2 shows the NPC-MLI operation modes in non-shoot through and shoot through conditions respectively.the voltage across the shoot through state Vpn shows in Equation (14) & (15).

Table 1. NPC-MLI operation modes in active state

Modes	Leg 1	Leg 2	Leg 3	Output Voltage
Mode 1	S2a,S3a	S2b,S3b	S3c,S4c	-Vdc/2
Mode 2	S3a,S4a	S3c,S4c	S2c,S3c	-Vdc/2
Mode 3	S3a,S4a	S3b,S4b	S2c,S3c	-Vdc
Mode 4	S3a,S4a	S1b,S2b	S3c,S4c	-Vdc/2

Table 2. NPC-MLI operation modes in shoot through condition

Modes	Leg 1	Leg 2	Leg 3	Shoot through state
Mode 1	S1a,S2a S3a,S4a	-	-	Full Shoot through
Mode 2	-	S1b,S2b, S3b,S4b	-	Full Shoot through
Mode 3	-	-	S1c,S2c, S3c,S4c	Full Shoot through

$$Vp_n = V_{c1} + V_{c2} \quad (14)$$

$$Vp_n = \frac{1}{1-2T} Vpn \quad (15)$$

The amount voltage stored in capacitors C1 & C2 at shoot through condition is,

$$V_{c1} = \frac{1-T}{1-2T} Vpn \quad (16)$$

$$V_{c2} = \frac{T}{1-2T} Vpn \quad (17)$$

The boosting voltage level due to shoot through state condition is,

$$B = \frac{1}{1-2D} \quad (18)$$

6. SIMULATION RESULTS AND DISCUSSION

The Simulation results were verified in Matlab R2013a. Figure 8 shows the matlab simulation model of the same. For PMSG ac output of 120 V is shown in Figure 9 and PV array dc Output of 80 V is shown in Figure 10. The Cumulative dc input to the QZSI-NPCMLI was 204 V. PV array was operated under varying irradiation from 400-500 W/m^2.Using Q-ZSI, the voltage was boosted to 391 V as shown in Figure 11. The rectifier output and QZSI boosted voltage is as shown in Figure 12 & 13. Normal operation of NPC bucks the voltage level to a little less than 200 V as shown in Figure 14. The inverter output current is obtained with 4.2 A as shown in Figure 15.

Capacitors of 470µF and inductors of 1µH were used for Q-ZSI. Three phase RL load of 100Ω and 1mH was used at the inverter side. The gating pulses for six switches of two level inverter generated using maximum boosting controller. Based on this PWM control for three levels quasi Z source NPC was designed. The two level QZSI output is shown in Figure 16. For a 300 V dc input, ac output of 500 V was obtained.

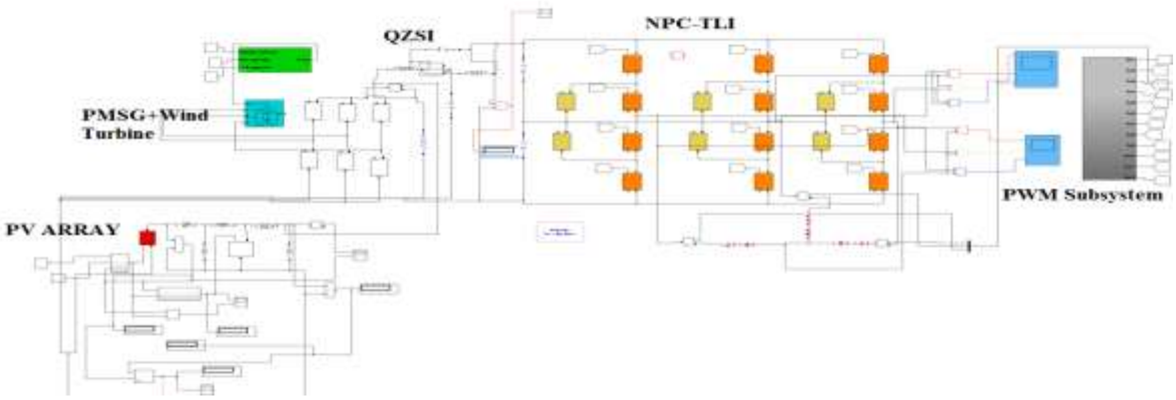


Figure 8. Matlab Simulaton Model

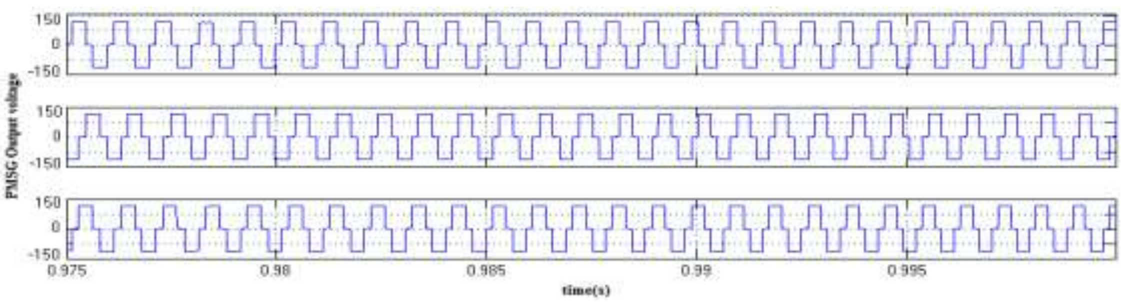


Figure 9. PMSG output voltage

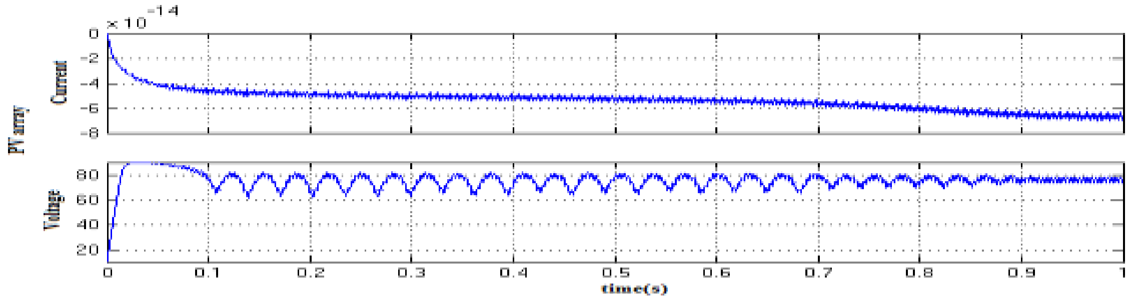


Figure 10. PV array output current and voltage

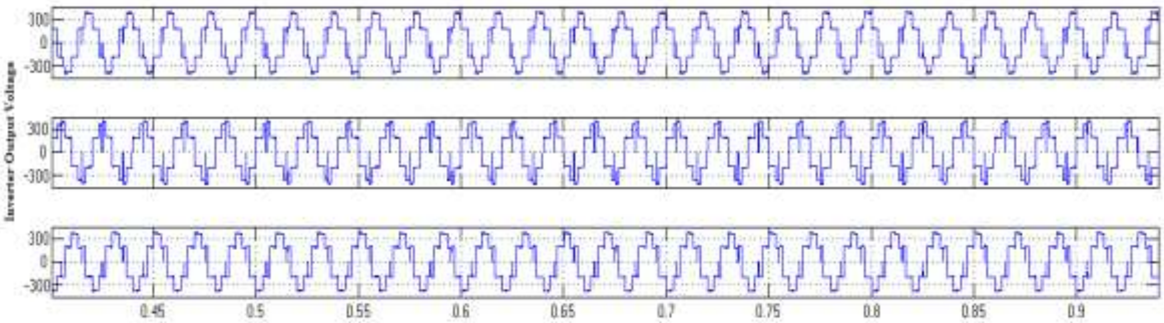


Figure 11. QZSI-Three level Output Voltage

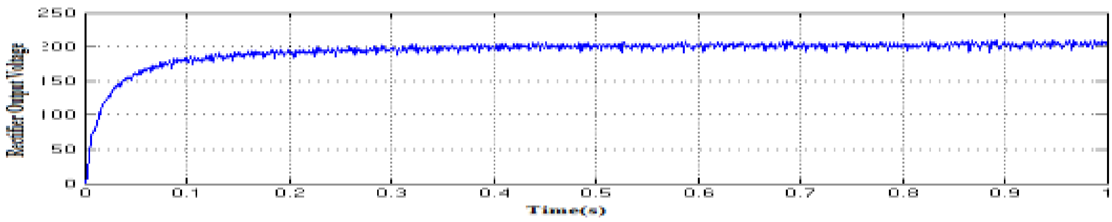


Figure 12. Rectifier Output Voltage

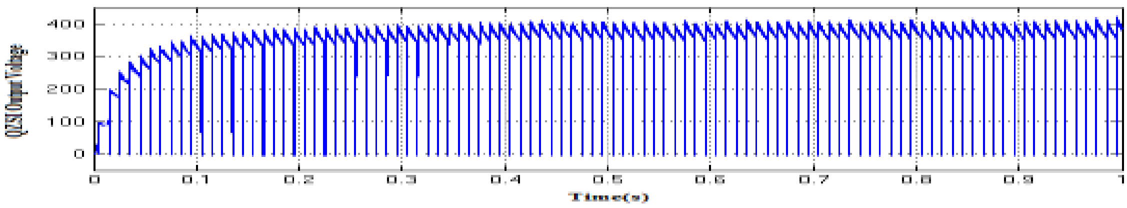


Figure 13. Q-ZSI Boosted voltage

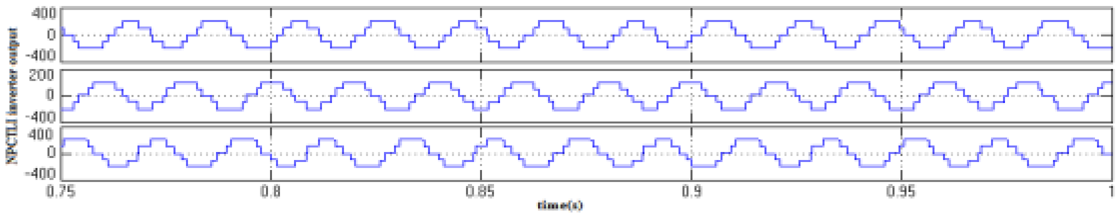


Figure 14. NPC-MLI Output Voltage

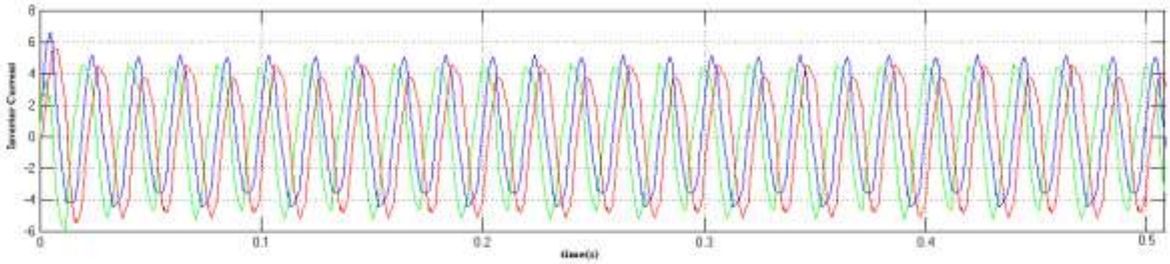


Figure 15. Inverter output current

7. CONCLUSION AND FUTURE WORK

This paper presents a Quasi-Z source network for three level inverter based on two level VSI model. Wind-PV hybrid energy source increases the dc voltage level supplied to the inverter. Using MPPT control optimum available power is obtained from the PV array. Simulation results confirm the voltage boost and shoot through capability of Q-ZSI network.

a. 1.9 times voltage boost was observed compared to NPC-TLI with additional shoot through states.
b. Maximum boost is implemented as a control strategy for TLI switches.

Current control can be achieved using Space Vector applied for a closed loop system. In future, the control performance of this proposed system can implement using 3D space vector pulse width modulation.

REFERENCES

[1] Li, Yuan, et al. "Modeling and control of quasi-Z-source inverter for distributed generation applications". *Industrial Electronics, IEEE Transactions on* 60.4 (2013): 1532-1541.

[2] J. Dai, D. Xu, B. Wu, and N. R. Zargari, "Unified DC-link current control mfor low-voltage ride-through in current-source-converter-based wind energy conversion systems", *IEEE Trans. Power Electron.*, vol. 26, no. 1, pp. 288–297, Jan. 2012.

[3] Z. Shu, S. Xie, and Q. Li, "Single-phase back-to-back converter for active power balancing, reactive power compensation, and harmonic filtering in traction power system", *IEEE Trans. Power Electron.*, vol. 26, no. 2, pp. 334–343, Feb. 2012.

[4] R. Palanisamy, K. Vijayakumar "Maximum Boost Control for 7-level z-source cascaded h-bridge inverter", International Journal of Power Electronics and Drive Systems, vol 8, Issue 2, June 2017.

[5] M. C. Di Piazza, A. Ragusa, and G. Vitale, "An optimized feedback common mode active filter for vehicular induction motor drives", *IEEE Trans. Power Electron.*, vol. 26, no. 11, pp. 3153–3162, Nov. 2011.

[6] K. Yuen and H. S. H. Chung, "An active low-loss motor terminal filter for overvoltage suppression and common mode current reduction", *IEEE Trans. Power Electron.*, vol. 27, no. 7, pp. 3158–3172, Jul. 2012.

[7] M. C. Di Piazza, A. Ragusa, and G. Vitale, "Power-loss evaluation in CM active EMI filters for bearing current suppression", *IEEE Trans. Ind. Electron.*, vol. 58, no. 11, pp. 5142–5153, Nov. 2011.

[8] J. Rabkowski, "Improvement of Z-source inverter properties using advanced PWM methods", in *Proc. the 13th Eur. Conf. Power Electron.Appl.*, Sep. 8–10, Sep 2013, pp. 1–9.

[9] R. Palanisamy, A.U Mutawakkil, K. Vijayakumar "Hysteresis SVM for coupled inductor z source diode clamped 3-level inverter based grid connected PV system", International Journal of Power Electronics and Drive Systems, vol 7, Issue 4, Dec 2016.

[10] Bharatiraja, C., Raghu, Paliniamy, K.R.S. "Comparative analysis for different PWM techniques to reduce the common mode voltage in three-level neutral-point- clamped inverters for variable speed induction drives", International Journal of Power Electronics and Drive Systems, vol. 3, Issue 1, March 2013, Pages 105-116.

[11] D. Li, P. C. Loh, M. Zhu, F. Gao, and F. Blaabjerg, "Generalized multicellswitched-inductor and switched-capacitor Z-source inverters", *IEEETrans. Power Electron.*, vol. 28, no. 2, pp. 837–848, Feb. 2013.

[12] W. Wu *et al.*, "A robust passive damping method for *LLCL*-filter-based grid-tied inverters to minimize the effect of grid harmonic voltages", *IEEE Trans. Power Electron.*, vol. 29, no. 7, pp. 3279–3289, Jul. 2014.

[13] R. Beres, X. Wang, F. Blaabjerg, C. L. Bak, and M. Liserre, "Comparative analysis of the selective resonant LCL and LCL plus trap filters", in *Proc. Int. Conf. Optim. Elect. Electron. Equip. (OPTIM)*, May 2014, pp. 740–747.

[14] R. N. Beres, X. Wang, F. Blaabjerg, M. Liserre, and C. L. Bak, "Optimal design of high-order passive-damped filters for grid-connected applications", *IEEE Trans. Power Electron.*, vol. 31, no. 4, pp. 2083–2098, Mar. 2016.

[15] S. Vesti, T. Suntio, J. A. Oliver, R. Prieto, and J. A. Cobos, "Impedance based stability and transient-performance assessment applying maximum peak criteria", *IEEE Trans. Power Electron.*, vol. 28, no. 5, pp. 2099–2104, May 2013.

[16] R. Palanisamy, K. Vijayakumar, Shaurya Misra, K. Selvakumar, D. Karthikeyan, "A Closed Loop Current Control of PV-Wind Hybrid Source Fed Grid Connected Transformerless Diode Clamped-Multi Level Inverter", International Review on Modelling and Simulations (I.RE.MO.Svol. 8.), no. 4, August 2015.