INVESTIGATION OF SLIDING MODE CONTROL FOR PV BASED GRID CONNECTED SYSTEM

Ekta Ashok Mohitkar[1]
1.Yeshwantrao Chavan College of Engineering, Nagpur, India

ABSTRACT

PV based systems are increasingly use in most of the part in all over world. PV base system are being controlled with various type of converters along with maximum power point tracking that are used. Among the Sliding mode control is the one of the robust ways of controlling the DC-DC converter however, the sliding mode control are being investigated in PV base system with its different issues like increasing current and voltage repulse. Therefore, in this proposed work the sliding mode control of PV base grid connected system is to be investigated. The simulations results are to be carried out in MATLAB software and the system will be investigated for various type of loads and disturbances from input and load side / grid side.

Keyword: Quasi-Z-source inverter, sliding mode control (SMC), grid connected system.

INTRODUCTION

PV based systems are increasingly use in most of the part in all over world. PV base system are being controlled with various type of converters along with maximum power point tracking that are used. Among the Sliding mode control is the one of the robust ways of controlling the DC-DC converter however, the sliding mode control are being investigated in PV base system with its different issues like increasing current and voltage repulse. Therefore, in this proposed work the sliding mode control of PV base grid connected system is to be investigated. The simulations results are to be carried out in MATLAB software and the system will be investigated for various type of loads and disturbances from input and load side / grid side

A PV cell's voltage varies widely with temperature and irradiation, but the normal voltage source inverter (VSI) cannot affect this wide selection without over-rating of the inverter, because the VSI may be a buck converter whose input dc voltage must be greater than the height ac output voltage. Because of this, a transformer and/or a dc/dc converter is typically utilized in PV applications, so as to deal with the range of the PV voltage, reduce inverter ratings, and produce a desired voltage for the load or connection to the utility. This results in a better component count and low efficiency, which opposes the goal of cost reduction **[1]-[3]**.

The q-Z-source inverter (qZSI) employs a unique impedance network to couple the inverter main circuit to the power source, which provides a novel power conversion concept. By controlling the shoot-through duty ratio and modulation index, the Z-source inverter can intensify and down the input voltage using passive components with improved reliability and reduced cost, thus providing unique features, such as ride-through capability during voltage sags, reduced line harmonics, improved power factor and reliability, and extended output voltage range **[4]-[5]**. The recent proposed quasi-Z-source inverter (qZSI) inherits all the advantages of the traditional ZSI and has several more advantages, including reduced passive component stress and continuous input current features. Due to the above-mentioned features, the qZSI topology is very attractive for renewable energy sources interface application, such as photovoltaic panel, wind turbine and fuel cell. It contains impedance network connected to the single-phase H-bridge inverter. The impedance network of qZSI consists of inductors L1, L2, capacitors C1, C2 and diode D. Also, the battery is connected across capacitor C1 [6].

The system is designed in such a way that the voltage VC1 can be boosted to suitable level. Also, the capacitor voltage is regulated with shoot-through based control. The operation of the quasi-Z-Source converter is as follows. For the defined range of input voltage Vin the qZSI always operates in two states; one is non-shoot-through state and therefore the other is that the shoot-through state. During the shoot-through state, the two switches in a single leg conducts simultaneously so that the diode get reverse biased and the output of the impedance network get short-circuited **[7]**.

This network will effectively protect the circuit from damage when the shoot-through occurs and by using the shoot-though state, the quasi- Z-source network boosts the dc-link voltage. The major differences between the ZSI and qZSI are (1) the qZSI draws endless constant dc current from the source while the ZSI draws a discontinuous current and (2) the voltage on capacitor C2 is greatly reduced. The Continuous and constant dc current drawn from the source with this qZSI make this technique especially well-suited for PV power conditioning systems. This leads to the stepping-up of the input voltage which is controlled by the shoot-through duty ratio (D) **[8]-[9]**. During non-shoot-through state, the inverter operates normally as a traditional voltage source inverter (VSI) where the two switches of one inverter leg do not operate simultaneously. Therefore, from this, total time period (T) will be the sum of both shoot-through state time (T0) and non-shoot-through state time (T-T0).

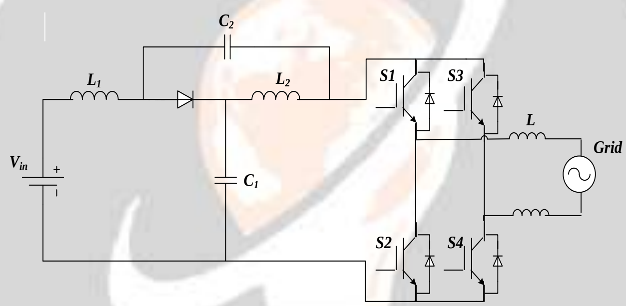


Fig. 1 Grid connected quasi-Z-Source-Inverter.

Shoot-through duty ratio D can be given as $D = T_0/T$. For symmetrical qZS network, assuming identical values of inductances L_1, L_2 and identical values of capacitances C_1, C_2 **[10]**.

For the non-shoot-through state as shown in Fig. 2, the system equations can be written as

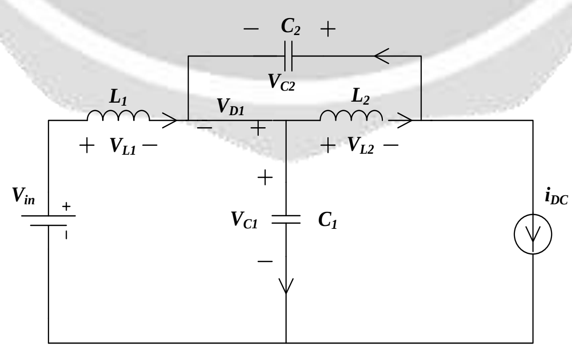


Fig. 2. quasi-Z-Source Inverter during non- shoot- through state.

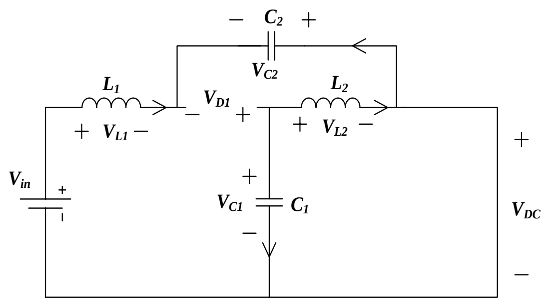


Fig. 3. quasi-Z-Source Inverter during shoot-through state.

$$\left.\begin{aligned} V_{L1} &= V_{in} - V_{C1} \\ V_{L2} &= - V_{C2} \end{aligned}\right\} \quad (1)$$

$$V_{DC} = V_{C1} - V_{L2} = V_{C1} + V_{C2} \text{ , } V_D = 0 \quad (2)$$

For the shoot-through state as shown in Fig. 3, the system equations can be written as

$$\left.\begin{aligned} V_{L1} &= V_{C2} - V_{in} \\ V_{L2} &= V_{C1} \end{aligned}\right\} \quad (3)$$

$$V_{DC} = 0 \text{ , } V_D = V_{C1} + V_{C2} \quad (4)$$

At steady state the average voltage across the both inductors over one switching cycle is zero.
From (1) and (3),

$$V_{L1} = \frac{T_0\ (V_{C2} + V_{in}) + T_1\ (V_{in} - V_{C1})}{T} = 0 \quad (5)$$

$$V_{L2} = \frac{T_0\ (V_{C1}) + T_1\ (- V_{C2})}{T} = 0 \quad (6)$$

Solving (5) and (6),

$$V_{C1} = \frac{T - T_0}{T - 2T_0} V_{in} \quad (7)$$

$$V_{C2} = \frac{T_0}{T - 2T_0} V_{in} \quad (8)$$

The DC-link voltage can be given as,

$$V_{DC} = V_{C1} + V_{C2} = \frac{T}{T - 2T_0} V_{in} \quad (9)$$

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

$$V_{DC} = B.V_{in} \quad (11)$$

B is the boost-factor of qZSI.

Equations (1) to (11) demonstrate the mathematical interpretation of the proposed system [11]-[13].

PROPOSE SCHEME

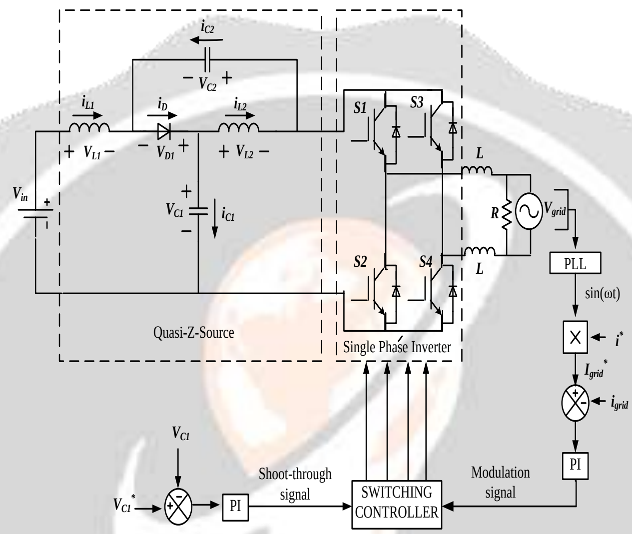


Fig.4 Block Diagram of q-Z-Source Based Single-Phase Inverter Grid Connected System with PI**.**

q-Z-SOURCE INVERTER

Block diagram of qZSI based Single-Phase Inverter grid connected system is shown in Fig.1. In this model the PV array is connected as DC input to the system and it is connected to the qZSI network which is used as buck/boost converter. And this impedance network is connected to the single-phase inverter and before inverter is connected to the grid it is given output filter, here inductors are used as filtering devices. PLL is connected to the output of the grid which gives the phase angle of voltage or current and also synchronization is done between the grid frequency and the inverter frequency.

There are two controls those are AC and DC side controllers. AC side is current control method which is shown in figure. And the next is DC side control, i.e, regulating capacitor voltage V_{C1}, for that the sliding mode concept is introduced and the equivalent control is designed and then given to the PWM generator. The sliding mode control is designed **[14]-[15]**.

In Z source network values of inductor and capacitor play a very important role. The voltage boost require is depend on shoot through time period but it is also depending on rating of capacitor and inductor if values of q-Z source network is not calculated properly then require amount of boost is not gain at output side and causes adverse effects in terms of ripples.

A. Inductor Design

During traditional operation mode the input voltage appears across the capacitor and no voltage appears across the inductor (just a pure DC current flow through the inductors). During shoot-through time, the inductor voltage is same as capacitor voltage and inductor current increases linearly. The job of the inductor is to limit the current ripple during shoot-through state. Inductor value can be calculated as

$$L = \frac{VT_{sh}}{\Delta I} \qquad (12)$$

Where, V is the average voltage of capacitor during both shoot-through and non-shoot-through time and ΔI is the assumed current ripple of the inductor.

B. **Capacitor Design**

The capacitor absorbs the current ripple and achieves quite a stable voltage. The inductor is charged by the capacitor during shoot-through time. The capacitor value can be calculated as,

$$C = \frac{I_L T_{sh}}{\Delta V_c} \qquad (13)$$

Where I_L is the average current of the inductor and ΔV_C is the assumed voltage ripple of the capacitor [16].

SLIDING MODE:

The sliding mode control is well known for stability and robustness towards system input, output variation and parameters uncertainties. SMC cannot be applied ideally, due to the limited switching frequency of power converters so all of them act as quasi-sliding mode controllers. There are many papers proposed and discussed several sliding surfaces to control output voltage of dc-dc converters such as buck, boost and cuk converters. This basically concerns with the selection of sliding coefficients on the desired dynamic properties. In renewable applications where dc input voltage of the converter varies in different circumstances or dc voltage which is needed for inverter varies due to the load, qZSI seems to be suitable because of capability of controlling the dc voltage and SMC is an appropriate control approach because of robustness towards system input, output variation. In this paper SMC is employed to control and regulate the dc output voltage of grid connected qZSI impedance network **[17]**.

A. STATE-SPACE MODEL:

$$\dot{X} = Ax + Bu + D \qquad (14)$$

$$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \qquad (15)$$

B. SLIDING SURFACE:

The proposed sliding-mode controller contains the capacitor voltage and the input inductor current as controlled state variables. Therefore, to reduce these errors we take errors of both capacitor voltage and the inductor current is introduced which is given as,

$$x_1 = V_{ref} - V_{C1} \qquad (17)$$

$$x_2 = i_{ref} - i_{L1} \qquad (18)$$

Therefore state-space equation in the standard form can be given as

$$\dot{X} = Ax + Bu + D$$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & \frac{1}{C} \\ \frac{1}{L} & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} \frac{2i_L - i_{DC}}{C} \\ \frac{V_{C1} - V_{C2}}{L} \end{bmatrix} u + \begin{bmatrix} \frac{i_{DC} - i_{ref}}{C} \\ \frac{V_{in} - V_{ref}}{L} \end{bmatrix} \qquad (18)$$

Were,

$$A=\begin{bmatrix}0 & \frac{1}{C}\\ \frac{1}{L} & 0\end{bmatrix}, B=\begin{bmatrix}\frac{2i_L - i_{DC}}{C}\\ \frac{V_{C1}-V_{C2}}{L}\end{bmatrix}, D=\begin{bmatrix}\frac{i_{DC}-i_{ref}}{C}\\ \frac{V_{in}-V_{ref}}{L}\end{bmatrix} \quad (19)$$

Therefore, equivalent control signal can be obtained by,

C. EQUIVALENT CONTROL:

$$u_{eq} = -(GB)^{-1}(GAx + GD)$$

$$u_{eq} = \frac{\left[k\frac{(i_{ref}-i_{L1})}{C} - \frac{(V_{ref}-V_{C1})}{L}\right] + \left[k\frac{(i_{DC}-i_{ref})}{C} + \frac{(V_{in}-V_{ref})}{L}\right]}{\left[k\frac{(2i_L - i_{DC})}{C} - \frac{(V_{C1}-V_{C2})}{L}\right]} \quad (20)$$

[18]

SIMULATION PARAMETERS:

PARAMETERS	VALUE
Input Voltage	250V
Load	40 Ω
Inductor(L_1=L_2=L)	160µH
Capacitor(C_1=C_2=C)	1000µF
Filter Capacitance	10Mh
C supply frequency	50Hz
Switching frequency	10kHz
Calculated resister	3250ohm

SIMULATION RESULT:

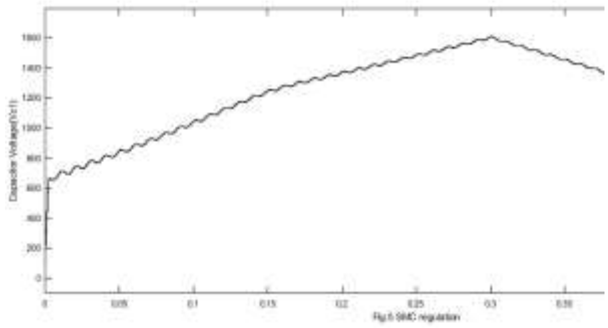


Fig.5 SMC regulation

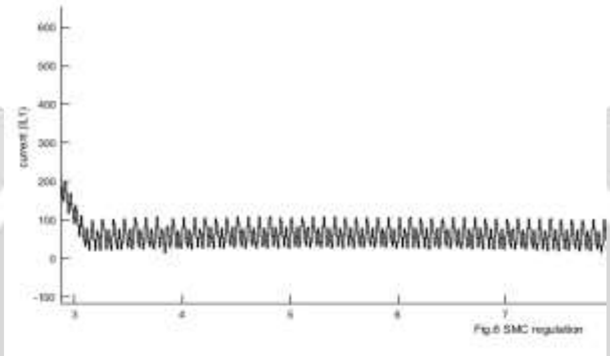


Fig.6 SMC regulation

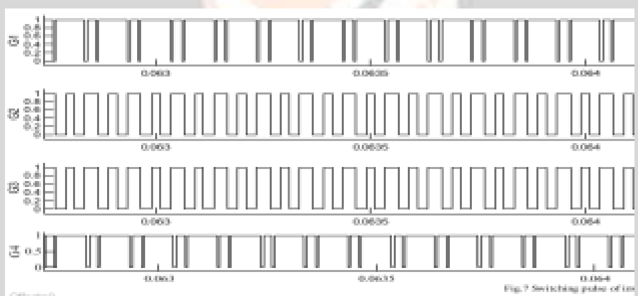
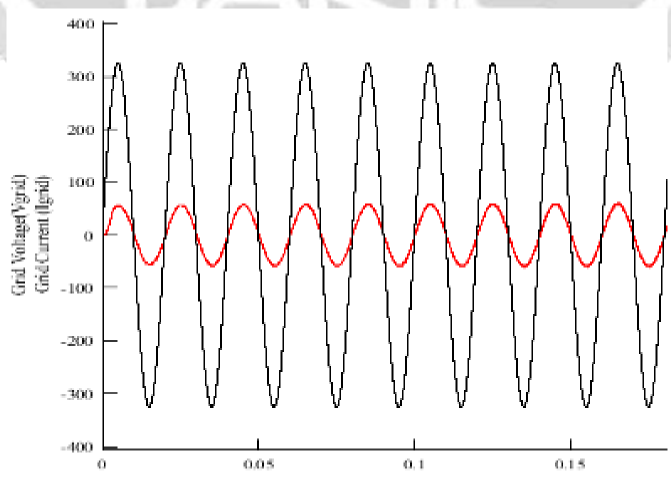


Fig.7 Switching pulse of in



Conclusion

In this paper, SMC is used for supervisory the dynamic response of the grid connected qZSI system. The detailed mathematical study of the SMC is done. Various aspects of the controller, are discussed in the paper, which include the selection method of the sliding surface, and the existence condition. The simulation result shows that the capacitor voltage controller gives a very fast response to a step change in reference value. Also, the controller is stable and robust for wide variations in input and output. A comparison of the proposed controller, with the PI controller, also clearly, proves the advantage, of the SMC based.

Reference

1. Boroujeni, Mojtaba Shirvani, et al. "Torque ripple reduction of brushless DC motor with harmonic current injection based on integral terminal sliding mode control." *IET Electric Power Applications* 12.1 (2017): 25-36.
2. Y. Yu, Q. Zhang, X. Liu, S. Cui, "DC-link voltage ripple analysis and impedance network design of single-phase Z-source inverter," *Proceedings of the 2011-14th European Conference on Power Electronics and Applications*, pp.1-10, Aug. 30-Sept. 1, 2011.
3. J. G. Cintron-Rivera et al., "Quasi-Z-Source inverter with energy storage for photovoltaic power generation systems," in Proc. 26th IEEE Anna. Appl. Power Electron. Conf. Expo. (APEC), 2011, pp. 401–406. source Shinde, Umesh K., et al. "Sliding mode control of single-phase grid-connected quasi-Z-source inverter." *IEEE Access* 5 (2017): 10232-10240.

4. Bharatiraja, C., et al. "Analysis, design and investigation on a new single-phase switched quasi-Z-inverter for photovoltaic application." *International Journal of Power Electronics and Drive* Systems 8.2 (2017): 853.

5. Verma, Arjun, A. S. Pandey, and S. K. Sinha. "Quasi-Z-Source Inverter for Photovoltaic Energy Conversion System."

6. Liu, Jianxing, et al. "Extended state observer-based sliding-mode control for three-phase power converters. "*IEEE Transactions on Industrial Electronics*64.1 (2016): 22-31. APA

7. Sebaaly, Fadia, et al. "Sliding mode fixed frequency current controller design for grid-connected NPC inverter." *IEEE Journal of Emerging and Selected Topics in Power Electronics* 4.4 (2016): 1397-1405.

8. Baghaee, Hamid Reza, et al. "Decentralized sliding mode control of WG/PV/FC microgride under unbalanced and nonlinear load condite for on-and off-grid modes." *IEEE System Journal* 12.4 (2017): 3108-3119.

9. Chu, Chen-Chi, and Chieh-Li Chen. "Robust maximum power point tracking method for photovoltaic cells: A sliding mode control approach." *Solar Energy* 83. (2009): 1370-1378.

10. Marouani, Rym, Kamel Echaieb, and Abdelkader Mami. "Sliding mode controller for buck-boost dc-dc converter in pv grid-connected system." *2012 16th IEEE Mediterranean Electrotechnical Conference*. IEEE, 2012.

11. Pan, Meichen, Caixue Chen, and Da Zhang. "Fractional-order Sliding Mode Control Strategy for Quasi-Z

Source Photovoltaic Grid-Connected Inverter." *2019 IEEE 3rd Conference on Energy Internet and Energy System Integration (EI2)*. IEEE, 2019.

12. Y. Liu, B. Ge, H. Abu-Rub, and F. Z. Peng, “An effective control method for quasi-Z-source cascade multilevel inverter base grid-tie single-phase photovoltaic power system,” IEEE Trans. Ind. In format, vol. 10, no. 1, pp. 399–407, Feb. 2014.

13. Y. Liu, B. Ge, H. Abu-Rub, and D. Sun, “Comprehensive modeling of single-phase quasi-Z-source photovoltaic inverter to investigate low frequency voltage and current ripple”, IEEE Trans. Ind. Electron. vol.62, no. 7, pp. 4194–4202, Jul. 2015.

14. Z. J. Zhou, X. Zhang, P. Xu, and W. X. Shen, “Single-phase uninterruptible power supply based on Z-source inverter,” IEEE Trans. Ind. Electron., vol. 55, no. 8, pp. 2997–3004, Aug. 2008.

15. Tariba, N. E., Ikken, N., Haddou, A., Bouknadel, A., El Omari, H., & El Omari, H. (2020). Integral sliding mode controller for maximum power point tracking in the grid-connected photovoltaic systems. *International Journal of Electrical and Computer Engineering*, *10*(4),4400.

16.Mostafa, Mostafa R., Naggar H. Saad, and Ahmed A. El-sattar. "Tracking the maximum power point of PV array by sliding mode control method." *Ain Shams Engineering Journal* 11.1 (2020): 119-131.

17. Ferrara, Antonella, Gian Paolo Incremona, and Michele Cucuzzella. *Advanced and optimization based sliding mode control: Theory and applications*. Society for Industrial and Applied Mathematics, 2019.

18. Perruquetti, Wilfrid, and Jean-Pierre Barbot. *Sliding mode control in engineering*. CRC press, 2002.