ANALYSIS AND IMPLEMENTATION OF SEMI Z SOURCE INVERTER FOR PV SYSTEMS

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Abstract: *This paper presents non isolated semi-Z source inverters for a single phase photovoltaic (PV) system. These semi-Z-source inverters employ the Z-source/quasi-Z-source network with two active switches controlled complementarily to achieve the sinusoidal output voltage, what the traditional voltage-fed full-bridge inverter does. The input dc source and the output ac voltage of the semi-Z-source inverter share the same ground; that means doubly grounded leads to less leakage ground current. A modified sinusoidal pulse width modulation method is used to obtain the output sinusoidal voltage.*

Key words: *Inverter, Photovoltaic (PV), Quasi-Z source, Semi-Z-source.*

1. Introduction

In recent years renewable sources such as solar, wave, and wind are used for the generation of electricity. Photovoltaic (PV) source has achieved global attention as an alternative power source due to the environmental concerns. As the energy from the sun is free, the major cost for photovoltaic generation is the installation cost, which is mainly composed of the solar modules and the interface converter system (PCS). These inverters can be divided into two categories: isolated inverters and non-isolated inverters based on galvanic isolation.

Isolated inverters have two approaches, a single-stage isolated buck–boost inverter [1] and the second approach of isolated dc-dc converter and a full bridge inverter. Isolated inverters usually utilize a line frequency or high frequency Transformer for electrical isolation. They require costlier switches. But it has higher voltage gain and safety advantages. Galvanic isolation is not a requirement in the low-voltage grid or power levels below 20 kW [2].This leads to the development of low-cost transformer-less inverter topologies. In order to solve this problem, extra switches have to be added to the existing topology which will inevitably increase the cost [5]. To simplify the system complexity and to reduce the cost, single-stage inverter topologies are investigated. The single-stage inverter consists of two relatively independent dc–dc converters with possible shared passive components and each converter produces a half-cycle sinusoid waveform 180◦ out of phase [3].

However, for the transformer less inverter topologies, if the input dc-source and the grid do not share the same ground, the input dc source, especially for PV cell, may have large leakage current, which will cause safety and electromagnetic interference problems [4].

To reduce the cost and to increase the system reliability, Z-source and quasi-Z-source inverter as a single- stage transformer-less inverter topology is proposed [6], [7]. utilizing the unique LC network, a shoot-through zero state can be added to replace the traditional zero state of the inverter and to achieve the output voltage boost function.[8] Many different PWM strategies have been proposed to control the Z-source inverter or multilevel Z-source inverter based on different methods of placing the shoot-through zero state [8], [9], [10]. Traditionally, Z-source and quasi-Z-source inverters are applied to the three-phase PV or wind power grid-connected generation systems, or three-phase motor drive for hybrid electric vehicle (HEV) application [11], [12], [13] .

Recently, many Z-source/modified Z-source single-phase inverters have been proposed for PV, motor drive or UPS applications [14], [15]. Compared with the traditional single-phase Z-source inverters, the proposed semi-Z-source inverters share the same form of Z-source network. But the Z-source network used in semi-Z-source inverter is in ac side, which is smaller in size than the traditional Z-source network used in dc side. The modulation strategy of the proposed circuit is also different.

The traditional Z-source inverters use sinusoidal reference with extra shoot-through reference to output sinusoid voltage and achieve the voltage boost function. However, in accordance with output sinusoid voltage, the semi-Z-source inverter has to utilize its nonlinear voltage gain curve to generate a modified voltage reference [16]. These differences are the reasons for why the term semi-Z-source inverter to represent the proposed topologies and to distinguish it from the traditional single-phase Z-source inverter[17].

Fig.1 shows the Block Diagram, explains how the DC source from the PV panel is converted to AC by semi Z-Source inverter using modified SPWM for an application.

The circuit operation and the modulation strategy of the proposed topology are analysed in detail and verified by the experimental results.

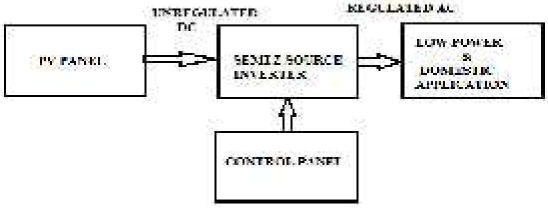


Fig.1. Block Diagram

2. Semi Z- source inverter and topology derivations

Fig. 2 shows the proposed single-phase semi-quasi-Z-source inverter. This paper will concentrate on semi -Z-source inverter and the modified SPWM control strategy. For the proposed semi-Z-source inverter, only two switches (MOSFET) are needed for the operation.

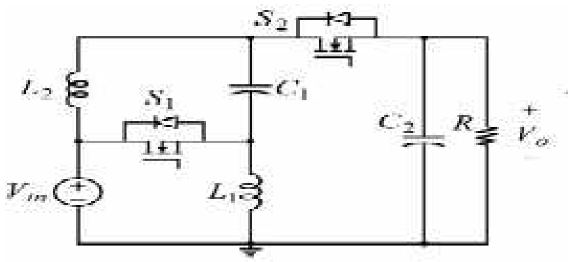
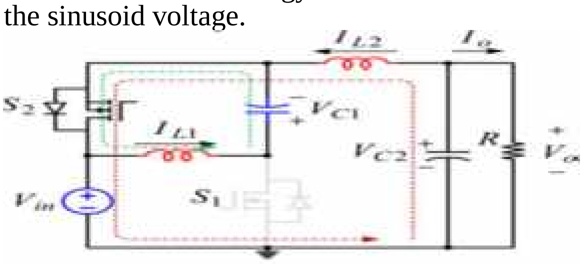
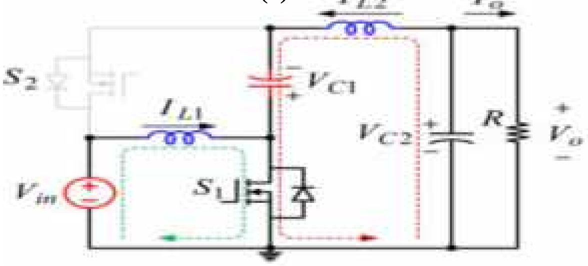


Fig. 2. Proposed single phase semi-quasi Z-source inverters control

The voltage gain of the proposed semi-Z-source in not a straight line as the full-bridge inverter, a modified SPWM strategy has to be used to obtain the sinusoid voltage.



(a)



(b)

Fig.3. Semi quasi Z-source operation modes in one switching period. (a) State I S1 is ON (b) State II S2 is ON

3. Operating Principles of Semi-Z Source Inverter

In one switching period, semi-quasi-Z-source inverter Duty cycle D changing from 0 to 2/3, that time the proposed inverters will get the output voltage range (+Vin to−Vin) same as the full-bridge inverter does. When the duty cycle of S1 changes from (0–0.5), inverter will give the positive output voltage; when the duty cycle of S1 changes from (0.5–2/3), the inverter will give the negative output voltage. When the duty cycle is equal to 0.5, the semi-Z-source inverters will give the zero output voltage. Fig. 3 shows the two states of the semi-quasi-Z-source inverter. Fig. 3(a) shows state I (switch S1 conduction). During this period, capacitor C1 and the input voltage source will charge the two inductors, and the inductor current is increased. Fig. 3(b) shows state II (switch S2 is conduction). During this period, the two inductors become the source and the inductor current is decreased.

According to the inductor voltage balance and the capacitor charge balance equations, we can have the following steady-state equations:

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

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

$V_{c1}$is the voltage across capacitor C1

Current thorough the Inductor L2 will be,

$$IL_2 = I_0 \quad (3)$$

Current flowing thorough the inductor L_1

$$IL_1 = \frac{-D}{1-DI_0} \quad (4)$$

The output voltage and the input voltage of the semi-Z-source inverter are no longer in a linear relationship with the switch duty cycle.

The inverter output voltage can be represented by

$$V_0 = V sin\omega t \quad (5)$$

The modulation index can be defined as (6)

$$M = \frac{V}{V_{in}} \quad (6)$$

The inverter output voltage can be represented by

Plugging (5) and (6) into (1), we can get (7)

$$D = \frac{1-Msin\omega t}{2-Msin\omega t} \quad (7)$$

D is the duty cycle of the switch S1 and Duty Cycle of the Switch S2 is,

$$D' = \frac{1}{2-Msin\,\omega t} \quad (8)$$

In order to achieve the sinusoid output voltage, the duty cycle cannot be changed in a sinusoid manner. A corresponding nonlinear revised duty cycle has to be used to generate the correct sinusoid output voltage. A new duty cycle reference D', as shown in (7) or (8) has to be used. Voltage stress of the inverter is given by,

$$V_s = V_{in} + V_c \quad (9)$$

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

Current stress of the inverter,

$$Io = I \sin \omega t \quad (11)$$

Current stress will be the summation of current through the Inductor L1 and L2, Normalized Voltage ripple across the Capacitor C1 will be,

$$V_{C1} = \frac{D}{1-D} V_{in} = (1 - Msin\omega t) V_{in} \quad (12)$$

Normalized Current ripple across the Inductor L1 will be,

$$I_{L1} = \frac{D}{D-1} I_0$$

$$= (\sin \omega t - M (\sin \omega t^2))\, I \qquad (13)$$

Minimal changes of the normalized Voltage ripple across the Capacitor C1 will be,

$$\Delta VC_1 = \frac{(1-D)Ts\, IL_I}{C_1} \qquad (14)$$

$$= \frac{(\sin \omega t) + M (\sin \omega t) 2Ts}{2 - M(\sin \omega t) C_1}$$

Minimal changes of the normalized Current ripple across the Inductor L1 will be,

$$\Delta IL_1 \Delta IL_2 = \frac{V_{in} TsD}{C_1} \cdot \frac{V_{in} Ts\,(1 - M \sin \omega t)}{L_1 (2 - M \sin \omega t)} \qquad (15)$$

We have arrived, the configuration parameters as shown in Table 1 of magnetic components L and C of the semi Z-source inverter from these equations.

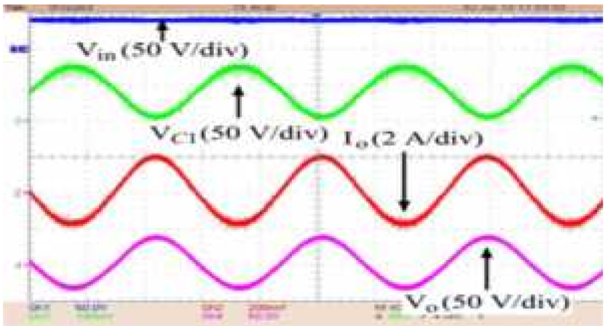


Fig. 4. Input voltage, capacitor *C*1 voltage, output voltage, and output current

Fig. 4 shows the Input voltage, capacitor voltage, output voltage, and output current of the semi-ZSI.

Table 1 Configurations Parameters

Semi Z-Source parameter	L_1,L_2 C_1,C_2	1Mh 50µF
Switching Frequency	f	10KHz
Resistive load(R)	R	1000 Ω
Passive load (RL)	R L	100Ω 30 mH

5. **Modulation of semi z-source inverter**

For the modulation of semi z-source inverter, a modified voltage reference as derived is used as the reference signal for the conduction of switch S2 in order to output the sinusoid voltage. When the reference is greater than the carrier, switch S2 is turned ON; otherwise, S2 is turned OFF. The gate signal of S1 is complementary with switch S2. The modified voltage reference as derived in (7) can be also used directly to generate the gate signal of S1 .The modulation index of the modified SPWM method is also in the range of 0-1.

6. Simulation Results

MATLAB is a high performance language for technical computing. It integrates the computation visualizations and programming in an easy-to-use environment where problems and solutions are express ed in familiar mathematical notations. Very important to most uses of MATLAB, has tool boxes allow you to learn and apply specialized technology. Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation and many others. The semi Z-source inverter is simulated using Simpower system tool box, which consists of two inductors and two capacitors connected with the two switches working on complimentarily. The purpose of semi Z-source inverter is to boost or buck the voltage depending on the duty cycle.

The open loop Simulink model of semi Z-source inverter with R load is shown in Fig 5. In the open loop circuit the output voltage is 30 volts decreased with the input voltage of 48 volts in without disturbance. The output voltage is bucked up in semi ZSI in Fig. 6

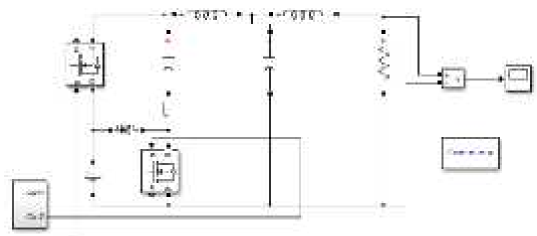


Fig.5. Simulink model of single phase semi ZSI with R load

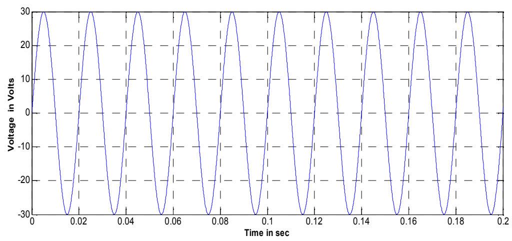


Fig. 6. Simulation result for simple buck control of single-phase semi ZSI

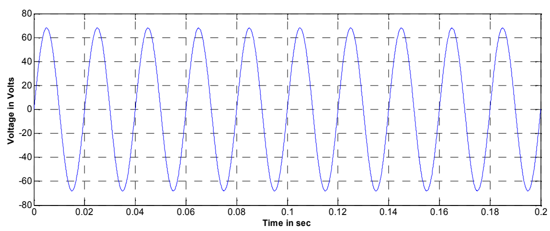


Fig. 7. Simulation result for simple boost control of single-phase semi ZSI

In Fig. 7, the open loop circuit the output voltage 150volts is increased with the input voltage of 120 volts in without disturbance. The output voltage is boosted up in semi ZSI.

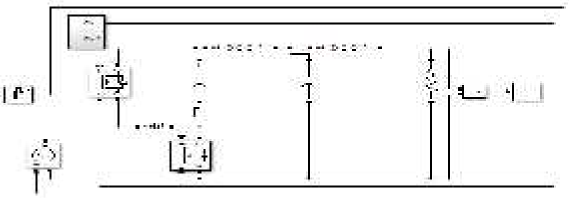


Fig. 8.Simulink model of single phase semi ZSI with R load – with disturbance

Fig 8 shows Simulink model of single phase semi ZSI with a disturbance given at the input side. Fig 9 shows the single phase semi ZSI the bucked output Voltage varies with the disturbance of variations given at the input side.

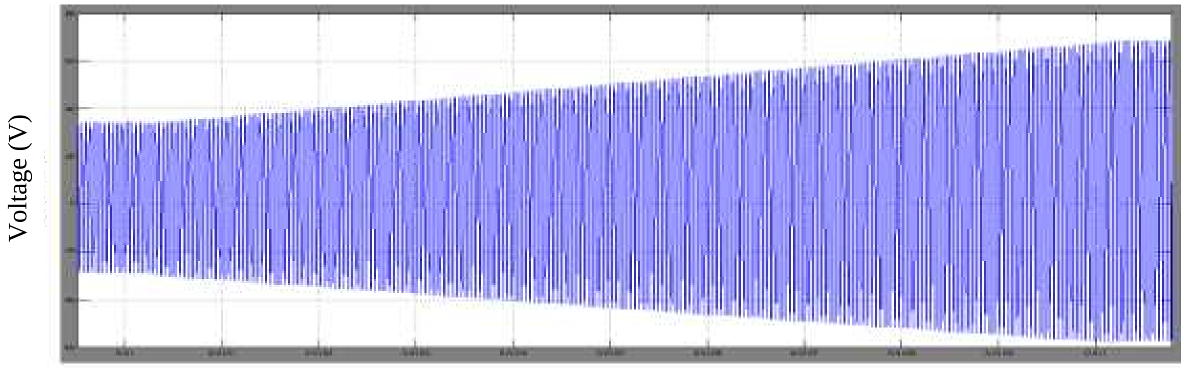


Fig. 9. Simulation result for simple buck control of single phase semi ZSI - with disturbance

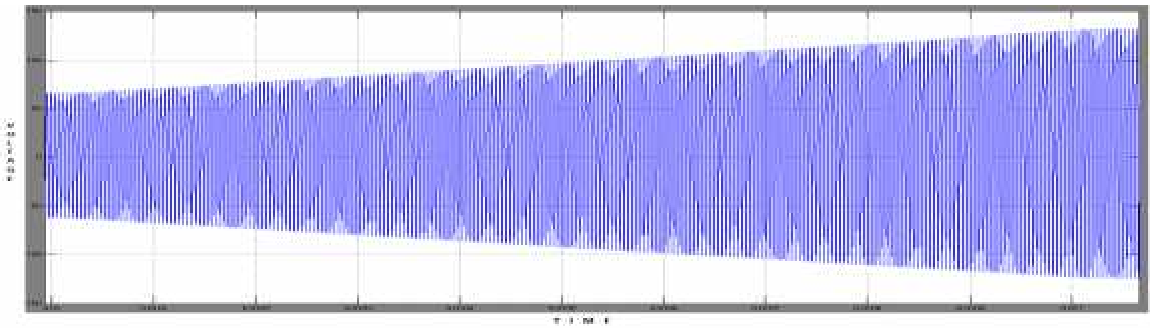


Fig 10 Simulation result for simple boost control of single phase semi ZSI - with disturbance

Fig 10 shows the single phase semi ZSI the boosted output voltage varies with the disturbance of variations given at the input side. In order to achieve the desired voltage regulation, the closed loop circuit is designed with reference value of 230 volts. PI controller is used for regulating the desired value of 230 volts with the input of 120 volts. Fig 11 shows Simulink model of the closed loop single phase semi ZSI.

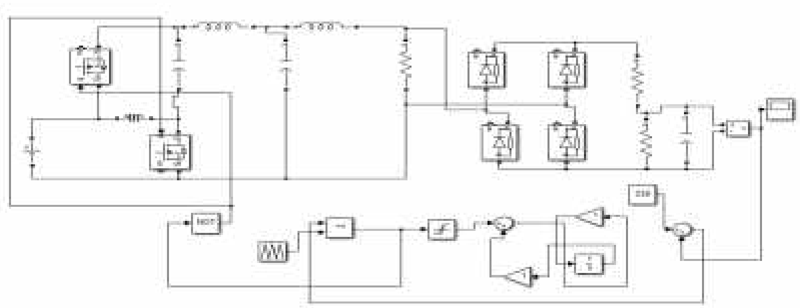


Fig.11. Simulink model for closed loop single phase semi ZSI

Modified SPWM pulses are generated to trigger the switches. Here the output voltage is rectified, compared with the constant and an error signal is obtained which is regulated by the PI controller which will give pulses to the switches. When the reference is greater than the carrier, switch S_2 is turned ON; otherwise, S_2 is turned OFF. And the gate signal of S1 is complementary with switch S_2. The Fig 12 and Fig 13 shows the modified SPWM pulses, applied to the switch S_2 and $S_{1.}$

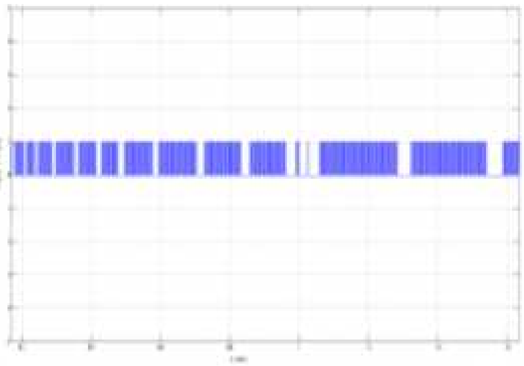


Fig. 12. Modified SPWM Pulses for Switch 2

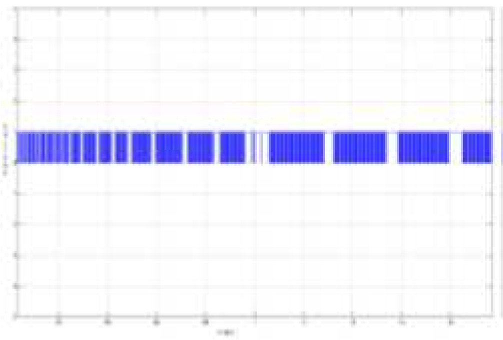


Fig. 13. Modified SPWM Pulses for Switch 1

The Fig. 14 shows the simulation result of semi ZSI load voltage.

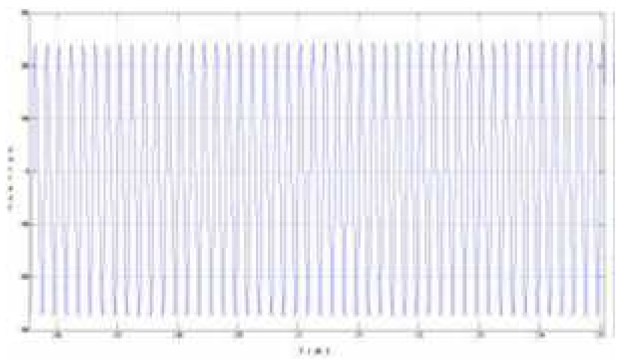


Fig.14. Simulation result for closed loop load voltage

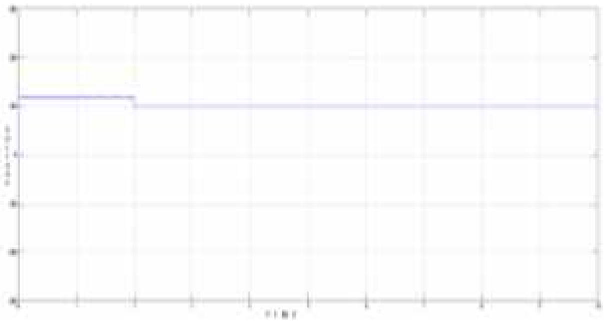


Fig.15. Simulation result for closed loop input voltage with disturbance

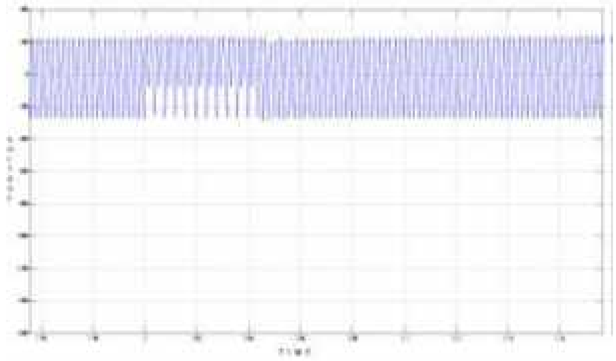


Fig .16.Simulation result for the closed loop load voltage.

Fig.15. shows the closed loop input voltage of semi Z-source inverter with a variation at the input side. Fig 16 shows the closed loop load output voltage of semi Z-source inverter where the input voltage is maintained at 120 Volts with output voltage of 230 Volts even when a disturbance is given at the time period of two seconds.

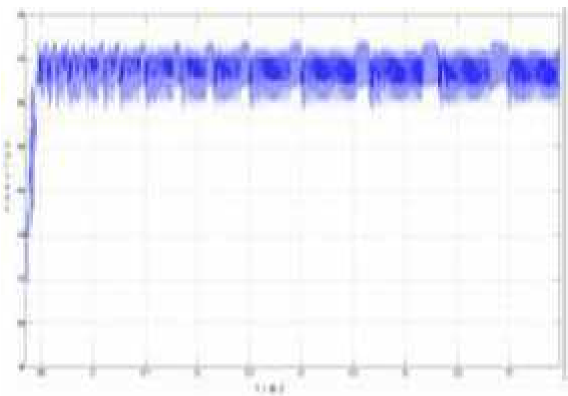


Fig.17. Simulation result for DC output voltage.

Fig. 17 shows the rectified DC output voltage of closed loop semi Z-source inverter where the input voltage is varied with output voltage of 230 Volts.

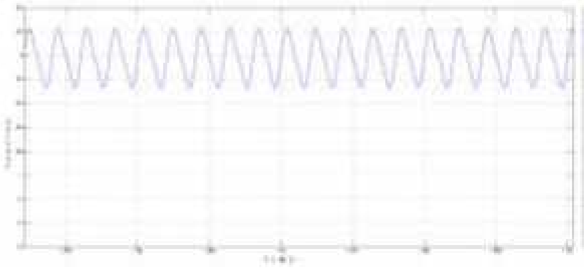


Fig.18. Simulation result for load current.

Fig.18. shows the load current of semi Z-source inverter where the input voltage is varied to obtain the output voltage of 230 Volts.

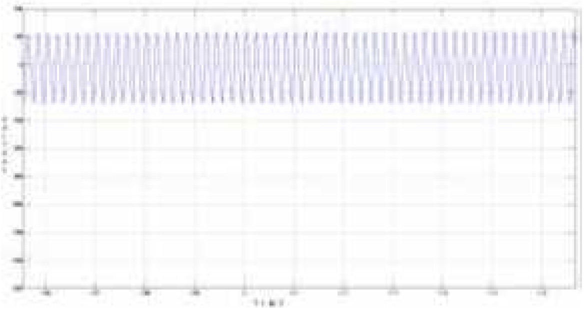


Fig.19. Simulation result for capacitor voltage.

Fig 19 Shows the capacitor voltage of semi Z-source inverter where the input voltage is varied to attain the output voltage of 230 Volts.

7. Topology expansion and discussion

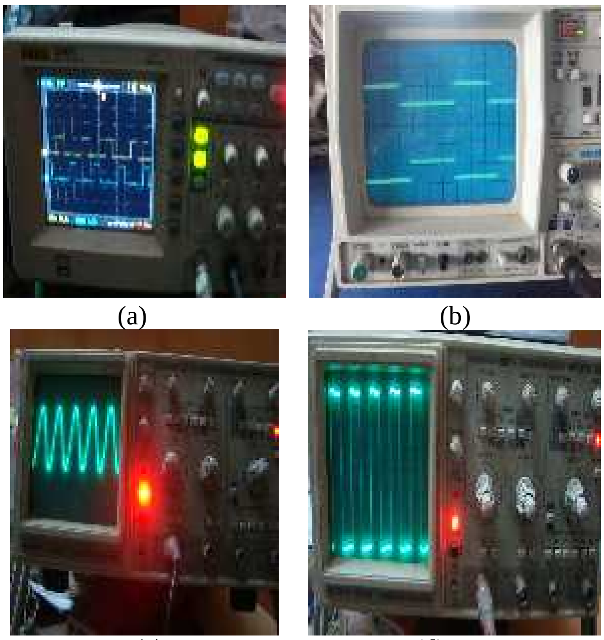
The proposed single-phase semi-Z-source inverter can be expanded to two-phase or three-phase inverter very easily. The voltage gain of two-phase or three-phase semi-Z-source inverter can also be increased, because the operation range of the duty cycle can be increased from (0–0.667) to (0–1).the two-phase semi-quasi-Z-source inverter, which can also be used in the split single-phase application. The output voltage of a two-phase semi-quasi-Z-source inverter is twice bigger than the full-bridge inverter with the same input voltage, if the voltage reference is the same with the single-phase version. By changing the voltage reference, the output voltage of a two-phase semi-quasi-Z-source inverter can be increased more. Single-phase inverter with modified SPWM strategy explained here. The conventional controller can be replaced by intelligent controller. Hardware implementation can be made using embedded controller.

8. Hardware implementation of semi Z-source inverter

To verify the concept and simulation results experimentally, a hardware prototype of the semi Z-source inverter is constructed and is shown in Fig. 20.a. In this section, a10-W semi Z-source inverter prototype is built with 48 V input voltage and 30 V output. The switching frequency of this model is 10 kHz. The semi Z-source inverter is constructed using two MOSFETs with200 V voltage rating are selected to act as switching device. The inductors $L1$ and $L2$ are designed using equation (16). According to circuit configuration of semi Z-Source inverter the turn on and turn off time of the two switches are equal. Two switches worked on complementarily. Hence the output is given to the one single driver circuit.

Fig. 20. Hardware implementation of semi ZSI with 1211-SUNSTAR solar Panel.

The triggering pulses from the microcontroller is shown in Fig 21 (a).The driver pulses for two switches are shown in Fig 21 (b). Fig 21 (c) shows the output obtained for semi Z- source inverter with capacitance. The output obtained for semi Z-source inverter without capacitance is given in Fig 21 (d).



(a) (b) (c) (d)

Fig.21. Experimental results of semi ZSI.(a) Triggering pulses from microcontroller (b) Driver pulses for MOSFET (c) Output voltage waveform with capacitance c) Output voltage of semi ZSI without capacitor

9. **Hardware model of PV power generation system**

To verify the concept and simulation results experimentally, complete hardware prototype model of PV power generation system is constructed. It consists of PV panel and digital multi meter. This prototype model is used to test the output voltage of PV panel. The test readings are taken under open circuit condition is listed in Table 2. At each time instant, the data of the actual sun irradiance obtained from the experiment is recorded. In this model, the sun is assumed to travel from 0 degree (sunrise) to 180 degree (sunset). From the table it is observed that at noon time high output power have been obtained.

Table 2 Test readings of solar panel

Time	Voltage (V)	Current (A)	Power (W)
10.30AM	20.5	0.344	7.052
11.00AM	20.2	0.343	6.928
11.30AM	20.0	0.391	7.820
12.00PM	20.1	0.420	8.442
12.30PM	20.2	0.421	8.504
1.00 PM	20.1	0.401	8.060
1.30PM	20.1	0.400	8.040
2.00PM	20.0	0.395	7.900
2.30PM	20.1	0.350	7.035
3.00PM	20.0	0.301	6.020
3.30PM	19.9	0.260	5.172
4.00PM	19.9	0.200	3.980

10. Conclusion

This paper has investigated the simulation results of semi Z source inverter with PV panel. Moreover, extra shoot-through zero state is employed to achieve the boost function or buck operation. To verify the performance of single-phase semi-Z-source inverter, the prototype model has been constructed and tested. It is found that this type of inverter is most suited for a PV based applications and used in low-voltage grid connected applications. From the results, it is observed that as numbers of cells are being increased for different values of solar radiation, the output voltage level and power output has been increased.

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