

Mitigation of Ripple in Single Phase Z - Source Inverter for Photovoltaic Home Applications

Khalid Salem Aboualajrass, Abobkr Saleh Nasr, and Ibrahim Mahariq

Electrical and Electronic Department, University of Turkish Aeronautical Association, Ankara, Turkey

Email: {khaled_can, Abobkrsalehnaser}@yahoo.com, ibmahariq@gmail.com

Abstract—The Z-source providing unique LC impedance network features that cannot be obtained in the traditional Voltage-Source (VSI) and Current-Source (CSI) inverters where a capacitor and inductor are used. This paper focuses on the effect of capacitance and inductance of z-source inverter, on the voltage ripple, current ripple allows the use of the shoot-through switching state, which eliminates the need for a dead time that used in the traditional inverters to avoid the risk of damaging the inverter circuit. Moreover, it provides a ride-through capability that reduces harmonics, hence; improving the power factor, high reliability, and extends output voltage range. National Instrument Software (Multisim) utilized to simulate the circuit.

Index Terms—photovoltaic, Z-source inverter, traditional inverter, NI Multisim™ power pro. edition 14.0

I. INTRODUCTION

PV power system designs concentrate on converting as much irradiant power as possible into real power. Solar cells, which are the establishment of PV systems, convert the energy in sunlight directly into electricity. A number of solar cells electrically connected to each other and mounted on a support structure or frame, called a photovoltaic module. The current produced is straightforwardly depending on how much light strikes the module. The structure of the solar cell, module and array as shown in Fig. 1 [1].

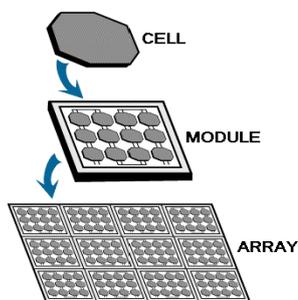


Figure 1. Solar cell structure

The solar inverter is a critical component in a solar energy system. It converts the variable DC yield of the solar panel module(s) into a clean sinusoidal 50- or 60 Hz AC current that is connected directly to a local electrical network [2].

If the photovoltaic route is chosen, non-consumed electricity, more often is stored in storage batteries, thereby extending the operating time of the system. The (typical 12 V) storage batteries are ordinarily used in the home solar conversion system to satisfy its operation and maximize power tracking purposes. The aim is to collect the maximum possible power from solar panels at all times, regardless of the load [2].

A DC-AC inverter requires its own small amount of electricity to operate. Electricity, which is converted by the inverter, must be available in order for the system to work.

Utility switches are connected to either an inverter's input or output and frequently include over current protection.

There are two traditional inverters: Voltage Source (VSI) and Current Source (CSI). Different types of power converters used for different applications. Fig. 2 shows the traditional single phase voltage source converter (abbreviated as V source converter) [3], [4].

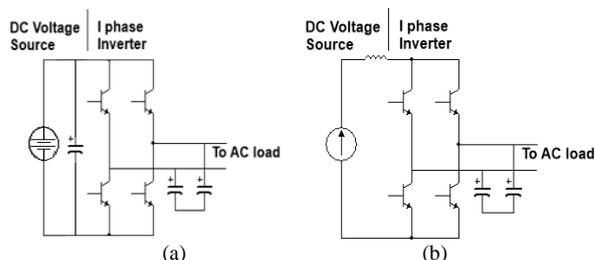


Figure 2. (a) Traditional single-phase voltage source inverter structure (b) Traditional single-phase current source inverter structure

The V- source and I - source converters are broadly utilized, but they have the following common problems:

- 1) The voltage source and the current source inverters are either a boost or a buck converter and cannot be a buck–boost converter.
- 2) Neither the V-source converter main circuit can be used for the I-source converter, nor vice versa. On the other hand, their main circuits cannot be interchangeable.
- 3) Their reliability is affected due to EMI noise.

An impedance-source power converter (abbreviated as Z-source inverter)overcomes limitations of the traditional voltage source converter and current source converter and provides a novel power conversion concept.

The Z-source converter uses LC impedance network to couple the main converter circuit to the power source,

which provides the boosting of the input voltage that is not possible in traditional Voltage-Source (voltage-fed) Inverter (VSI) and Current-Source (current-fed) Inverter (CSI). The Z-source concept is new electronic circuit recently recognized, because of its application in all DC to AC, AC to DC, AC to AC, and DC to DC power conversion. In this paper an investigation of the impact of z-source capacitance in shoot through mode and non-shoot through mode which will impact on the voltage ripple of the Z-source capacitor, concentrating on the impact of Z-source inductance on the current ripple in the inductor.

II. MODELLING OF PHOTOVOLTAIC ARRAYS

There are two different types of solar energy systems that will convert the solar resource into electricity; one method is by collecting solar energy as heat and converting it into electricity using a typical power plant or engine; the other method is by using photovoltaic PV cells to convert solar energy directly into electricity.

The basic equation from the theory of semiconductors that mathematically describes the I-V characteristics of the ideal photovoltaic cell as shown in Fig. 3.

$$I = I_{ph} - I_r [e((q V + I_{rs}) / akT) - 1] - V + I_{rs} / R_p$$

where, I_{ph} is the current generated by the incident light (it is directly proportional to the Sun irradiation), (I_r) is the reverse saturation or leakage current of the diode is T the temperature of the p-n junction, (a) is the diode ideality constant, (q) is the electron charge [1.60217646 *10⁻¹⁹C], and (k) is the Boltzmann constant [1.3806503 *10⁻²³J/K] [2].

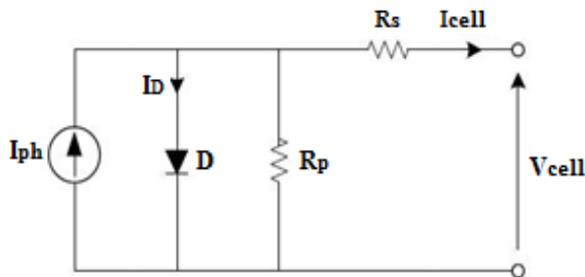


Figure 3. PV equivalent circuit

III. Z-SOURCE INVERTER

Z-source converter is shown in Fig. 4 where an impedance network is put between d.c. link and inverter. Z-Source Inverter (ZSI) provides a greater voltage than the d.c. link voltage. It reduces the inrush current & harmonics in the current because of the existence of two inductors in z source network. It forms a second order filter & handles the undesirable voltage sags of the d.c. voltage source.

A. Switching States

Table I shows, how the shoot through state of a single-phase Z-source inverter controlled [5].

TABLE I. SWITCHING STATES OF SINGLE PHASE ZSI

Switching States	S1	S2	S3	S4	Output Voltage
Active States	1	0	0	1	Finite Voltage
	0	1	1	0	
Zero States	1	0	1	0	Zero
	0	1	0	1	
Shoot Through State	1	1	S3	S4	Zero
	S1	S2	1	1	
	1	1	1	1	

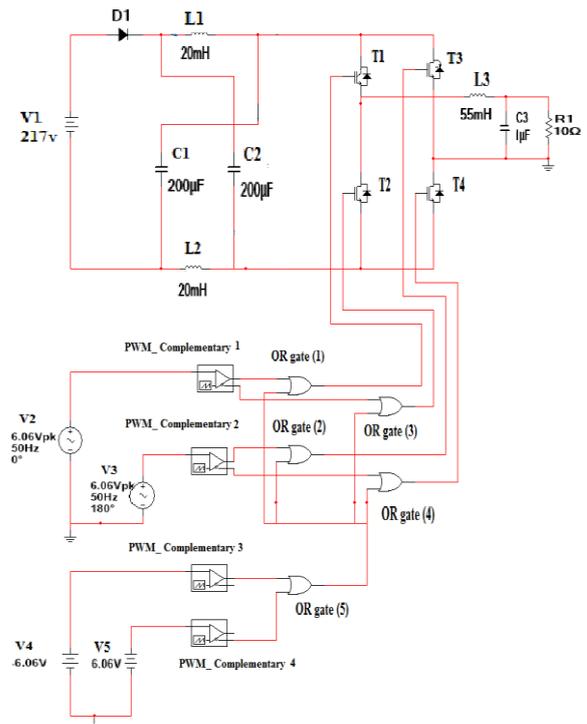


Figure 4. Single phase ZSI inverter

It has five possible switching states:

1) Active state

Two active states when the dc voltage connected across the load.

2) Zero state

Two zero states when the load terminals are shorted through either the lower or the upper two switches.

3) Shoot through state

One shoot through state when the load terminals are shorted through both the upper and the lower switches of any one leg or two legs. [6], [7]

Z-source inverter utilizes the shoot through zero states to boost voltage in addition to traditional active and zero states [8], [9].

B. Operating Modes

1) Mode 1

The circuit is in a shoot-through zero state, the sum of the two capacitors voltage V_{C1} and V_{C2} are greater than the DC source voltage ($V_{C1}+V_{C2}> V_0$), the diode is reverse biased, and the capacitors charge the inductors. The voltages across the inductors are:

$$V_{L1} = V_{C1}, V_{L2} = V_{C2}$$

The inductors current I_{L1} and I_{L2} increase linearly assuming the capacitor voltage is constant during this period. Because of the symmetry ($L1 = L2 = L$ and $C1 = C2 = C$) of the circuit, so

$$V_{L1} = V_{L2} = V_L, I_{L1} = I_{L2} = I_L \text{ and } V_{C1} = V_{C2} = V_C$$

2) Mode 2

The inverter is in a non-shoot through state (one of the six active states and two traditional zero states) and the inductor current meets the following in the equation, $I_L > (1/2)*I_i$, where I_i is the load current.

Again, because of the symmetry of the circuit, the capacitor current I_{C1} and I_{C2} and the inductor current I_{L1} and I_{L2} should be equal to each other respectively. In this mode, the input current I_{in} from the DC source becomes

$$I_{in} = I_{L1} + I_{C1} = I_{L1} + (I_{L2} - I_i) = 2I_L - I_i > 0$$

Therefore, the diode is conducting and the voltage across the inductor is:

$$V_L = V_0 - V_C$$

Which is negative (the capacitor voltage is higher than the input voltage during boost operation when there is shoot through states), thus the inductor current decreases linearly assuming the capacitor voltage is constant. As time goes on, the inductor current keeps decreasing to a level that no longer the condition of (2) can be met. At this point, the input current I_{in} or the diode current is decreased to zero, Mode 2 ends and the inverter enters to a new mode.

3) Mode 3

The inverter is in one of the six active states, and at the end of Mode 2, the inductor current decreases to half of the inverter DC side current, I_i . As a result, the input current becomes zero and the diode becomes reverse-biased. Assuming that the inverter load is inductive and has a much larger inductance than that of the inductor $L1$ and $L2$, the inductance of $L1$ and $L2$ are negligible and the inductor current and inverter voltage V_i are respectively.

$$I_L = (1/2)*I_i \text{ and } V_i = V_C$$

4) Mode 4

The inverter is in one of the two traditional zero states ($I_i = 0$) and at the end of Mode 2, the inductor current decreases to zero, thus a new operation mode appears. In Mode 4, the diode stops conducting and the inverter is an open circuit to the Z-source network because of $I_i = 0$. The inductor current becomes zero and maintains zero until the next switching action. Therefore, in this mode, the Z-source circuit is isolated from both the DC source and the load.

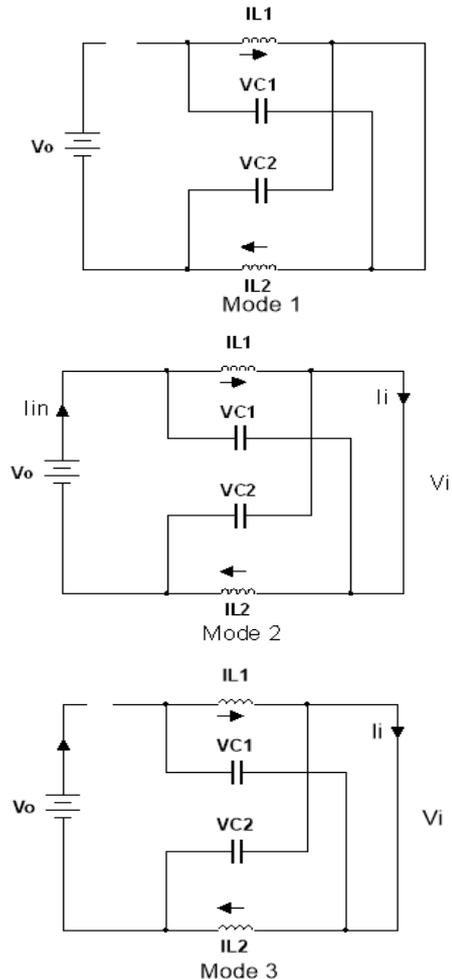
5) Mode 5

The inverter is switched to an active state after one of the traditional zero states. The inductor current may decrease to a level that is less than half I_i . After switched to an active state, the inverter cannot enter the active state immediately because that the inductor current is smaller than half of the inverter DC current (the condition of (2) does not hold true) and the inverter enters a freewheeling state. The two diodes in the equivalent circuit are the free-wheeling diodes of the inverter phase legs. This diode freewheeling state turns the inverter into a shoot through zero state.

During this shoot through zero state, all the equations of Mode 1 hold true and the inductor current increases linearly. This mode continues until the inductor current increases to half of the DC side current to the inverter.

In addition, the Z-source circuit enters Mode 3 and the inverter enters the intended active state.

The difference between this mode and Mode 1 that, the control signal is not intentionally created, but depends on the load current and the inductor current at the time of switching. With different control methods and different circuit parameters and load, the inverter can operate differently with different combination and sequence of the above modes, which yields different circuit characteristics. Fig. 5 shows operations mode circuits [10].



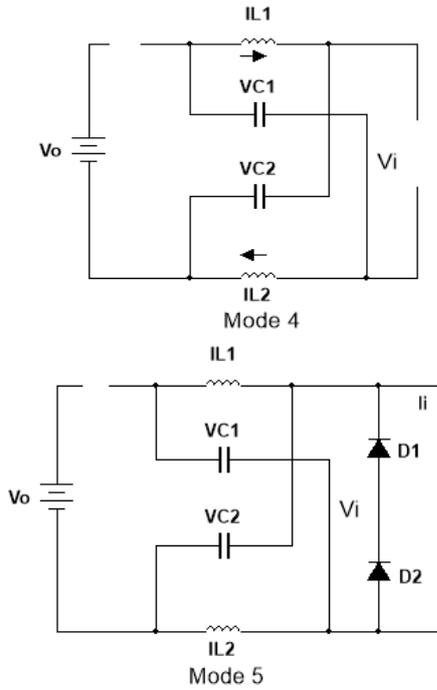


Figure 5. Operation modes

IV. SIMULATION RESULTS

We made our design in view of the typical house power utilization 5 kW with an input voltage of 217 V, and boosted to a desired yield voltage of 311 V with $ds=0.394$, $T_s = 4$ KHz, $L_f = 55$ mH, $C_f = 1$ μ F.

Fig. 4 shows the simulation circuit of Z- source inverter (transformer-less type) utilized for a home application. The circuit comprises of a PV array; a diode to protect the PV array from capacitor discharge voltage, Z source impedance network to boost the PV input voltage, a DC - AC inverter and an L-C filter. PV voltage V_{pv} has a wide voltage range, from 217 V to 315 V. The DC - AC inverter supplies the load with adequate voltage and current.

Case 1:

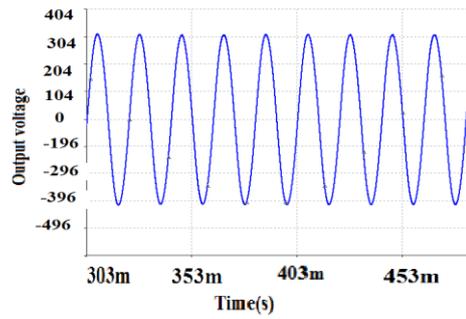
The circuit parameters as follows:

- Z source inductance $L = 20$ mH
- Z source capacitance $C = 200$ μ F
- Load resistance $R = 10$ Ω

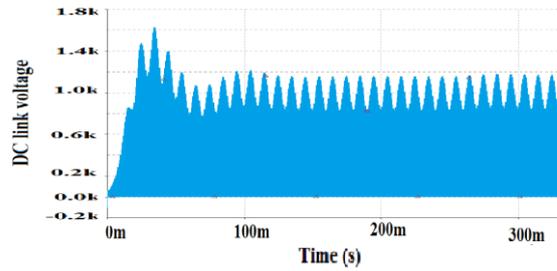
As we can see on Fig. 6, (a) an output of 325 v AC Peak is obtained from input 217 v DC. In addition, this result is according to the theoretical analysis with a linear load. The inverter input voltage and current in the dc link are dc, but the current contains high frequency switching noises and a low-frequency ripple [6].

From the waveform, simulation of dc link voltage is shown on Fig. 6(b) the frequency ripple of the dc link is twice the output frequency [7].

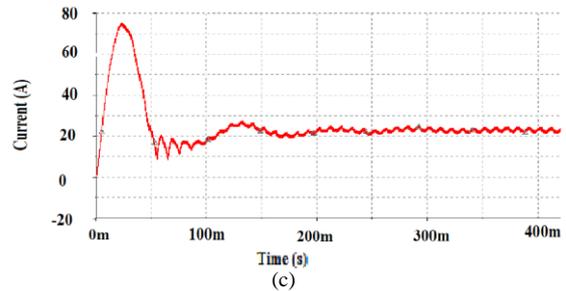
The ripple value of dc link voltage was (830 to 1150 V). Moreover, the inductor current takes a short time to reach the steady – state condition and the ripple value was (22.5 to 26.75 A) as shown in Fig. 6(c).



(a)



(b)



(c)

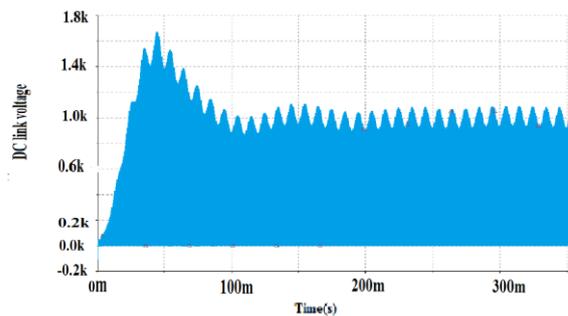
Figure 6. (a) Output voltage, (b) DC link voltage and (c) Inductor current

Case 2:

We changed the value of Z-source capacitance to 400 μ F and the other parameters still as same as the case 1. The purpose of this changing is to identify the effect of capacitance on the ripple.

We noticed that, there is no change in the output voltage, but the dc link voltage ripple decreased. [8]

After the steady – state condition, the value was from (930 to 1080 V) as shown in Fig. 7(a) In addition, the inductor current took more time to reach the steady – state condition than the case 1 and ripple value was (21.5 to 24.5 A) as shown in Fig. 7(b).



(a)

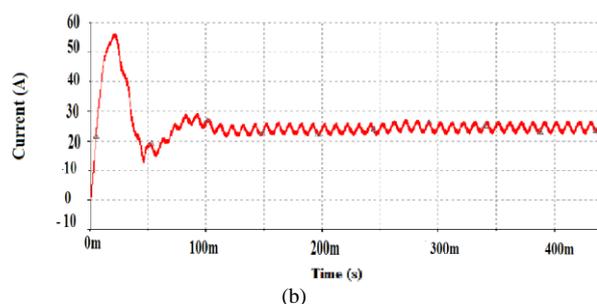


Figure 7. (a) DC link voltage and (b) Inductor current

Case 3:

The circuit parameters as follows:

Z source inductance $L = 40 \text{ mH}$

Z source capacitance $C = 400 \text{ }\mu\text{F}$

In this case, the values of the output voltage and dc link voltage same as the values of case 2, but the ripple value of inductor current was decreased (22 to 23.5 A) as shown in Fig. 8.

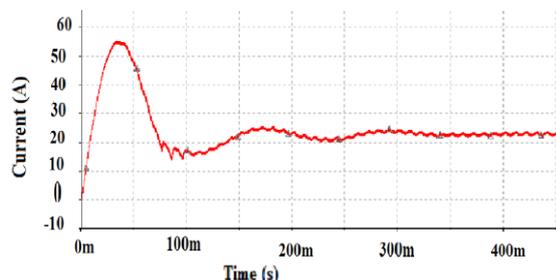


Figure 8. Inductor current

V. CONCLUSION

In this paper, we studied the modelling and simulation of Z- network single-phase full bridge inverter with PV for home application presented in Multisim Simulink to verify the calculation parameters.

The output voltage is achieved. The ripple of Z- source inverter elements, current and their harmonics profile are varied with values of capacitance and inductance. If the Z source capacitance value is increased, the ripple is decreased. The proposed system can deliver the PV power to the home application with high efficiency.

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Khalid Aboulajrass was born in Benghazi in 1972. He graduated from Engineering Higher Institute for Mechanical Professions, Electrical Engineering Department in 1999. Presently he is doing Post Graduation in Electrical and Electronics Engineering. He has 15 years experience as Second Electrical Construction Specialist II and he works for Mellitah Oil & Gas B. V. Company, Libyan Branch Oil Division.



Abobkr Nasr was born in Zwara in 1972. He graduated from the Civil Aviation High Institute, Aircraft Electrical Maintenance Department in 1993. Presently he is doing Post Graduation in Electrical and Electronics Engineering. He has 15 years of teaching experience in the Libyan Ministry of Higher Education.



Ibrahim Mahariq took his B.Sc. degree from department of electrical and computer engineering / Palestine Polytechnic University in 2003. He worked there as teaching assistant from 2003-2005. He received the M.Sc. in design of electrical machines, and his PhD in computational electromagnetics from Middle East Technical University, Ankara, Turkey. He was granted TUBITAK scholarship for his PhD studies in 2010. He is currently working on Photonics to earn his second PhD in the department of electrical and electronics engineering at TOBB University of Economics and Technology, Ankara, Turkey. Currently, he is serving as an assistant professor at the department of electrical and electronics engineering/ University of Turkish Aeronautical Association, Ankara, Turkey.