

## **SIMULATION AND FABRICATION OF SINGLE PHASE Z-SOURCE INVERTER FOR RESISTIVE LOAD**

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*A Z-source inverter has ability to buck and boost voltage in single stage operation using inductors and capacitors. Simulation of Z-Source network was carried out using shoot through condition. This paper presents a comparison and analysis of simulation results and hardware results of Z-Source inverter. Simulation was carried out in MATLAB Simulink. The results were fairly in agreement. A new topology using an additional switch across the impedance network for creating shoot through condition is presented.*

**Keywords:** Simulation, Fabrication, Z-Source Inverter, Buck-Boost

### **1. Introduction**

For the control of electric power, the conversion of electric power from one form to another is necessary. Switching characteristics of the power devices enable these conversions. A DC to AC converter is called inverter. The function of an inverter is to change a DC input voltage to a symmetrical AC output voltage of desired voltage and frequency.

From the literature survey it was clear that the traditional ways for the power conversion process have limitations based on their range of operation, efficiency, reliability, etc. In an attempt to overcome these disadvantages, from the year 2002 a new concept was introduced which combines the effects of both voltage source and current source. The basic concept of impedance network was developed by Fang Z. Peng in 2002, [1]. In his paper, he presented an impedance source power converter (abbreviated as ZSC) and its control method for implementing power conversion. It employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, thus providing unique features that cannot be obtained in the traditional voltage source and current source converters where a capacitor and an inductor are used respectively. The ZSC overcomes the conceptual and theoretical barriers and limitations of the

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traditional voltage source converter and current source converter and provides a novel power conversion concept. The advantages, disadvantages and limitations of the impedance network, are presented in [2]. Here, the superiority of Z-Source inverter is presented and is compared to traditional solutions. Miaosen Shen, Alan Joseph et. al. compared the traditional inverters with the Z-Source Inverter (ZSI) in [3]: three different inverters, a traditional PWM inverter, a DC-DC boosted PWM inverter, and a Z-source inverter were investigated and compared using fuel cell vehicle and photo-voltaic domestic application as examples. Total switching device power, passive component requirement, and constant power speed ratio of each of these inverters were calculated. The efficiencies of different systems for traction drive and photo-voltaic residential application were also compared. The comparisons show that ZSI is very promising. The operating modes and characteristics of ZSI are explained in [4]. In this paper, different operating modes of the impedance network are described. Also, the analysis and control methods provided in the literature are based on an assumption that the inductor is relatively large and the inductor current is continuous with small ripple. To facilitate understanding of ZSI modulation, a detailed analysis is presented in [5], showing how various conventional pulse width modulation strategies can be modified to switch a voltage source inverter either continuously or discontinuously, keeping all the harmonics generated from these conventional modulation strategies. In [5], firstly an analysis of the modulation requirements of an H-bridge inverter has been done then it has been expanded for the Z-Source inverter. The theoretical and modulation concepts presented have been verified both in simulation and experimentally.

In this paper, the simulation of single phase Z-Source inverter and its comparison with hardware is presented. A new topology of an additional switch across the impedance network is described. It is useful during the shoot through state. Also, it acts as a protection for the inverter bridge from excess current or inrush current from the inductor during switching of the states.

## **2. Limitations on traditional inverters and advantages of Z-Source inverter**

Traditional power inverters use either voltage source or current source configuration. This type of inverter is shown in fig.1. However, these types of inverters have few limitations.

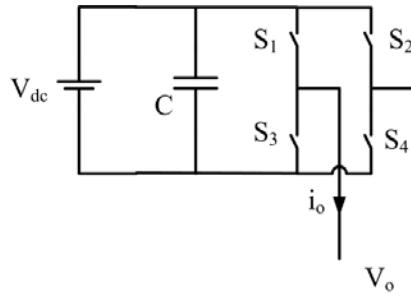


Fig.1a. Voltage Source Inverter [1]

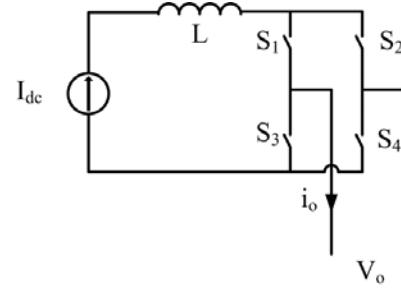


Fig.1b. Current Source Inverter [1]

The limitations of this type of inverter are:

- It behaves as a boost or a buck converter only; thus the output voltage range is limited, either smaller or greater than the input voltage,
- It is vulnerable to EMI noise and the devices get damaged in either open or short circuit conditions,
- The combined system of DC-DC boost converter and the inverter have lower reliability.
- The main switching device of VSI and CSI are not interchangeable [1, 2, 3, 4].

Impedance network concept was introduced in order to reduce the disadvantages of traditional inverters. The single phase Z-Source inverter is shown in fig. 2.

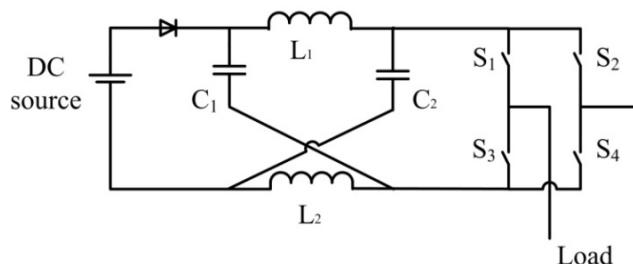


Fig.2. Single phase Z-Source Inverter [2]

The advantages of Z-Source inverter are:

- The source can be either a voltage source or a current source. The DC source of a ZSI can either be a battery, a diode rectifier or a thyristor converter, a fuel cell stack or a combination of these,
- The main circuit of a ZSI can either be the traditional VSI or the traditional CSI,

- It works as a buck-boost inverter,
- The load of a ZSC can either be inductive or capacitive or another Z-source network,
- The traditional inverter has only one control freedom that can be used to control the output AC voltage while ZSI has two independent control freedoms, shoot through duty ratio and modulation index, providing thereby the ability to produce any desired AC output voltage,
- The reliability of ZSI is much higher than the traditional inverter reliability as a momentary shoot-through cannot destroy the inverter i.e. both the devices of a phase leg can be on for a significant period of time [1-6].

### 3. Operations of Single Phase Z-Source Inverter

Normally, single phase inverters have 4 vector states (2 active states and 2 zero states). But ZSI along with these 4 normal vectors has an additional state known as the shoot through state, during which the switches of one leg are short circuited. In this state, energy is stored in the impedance network and when the inverter is in its active state, the stored energy is transferred to the load, thus providing boost operation, whereas, this shoot through state is prohibited in VSI.

The required PWM to achieve the buck-boost facility in ZSI is shown in fig.3. The normal Sinusoidal PWM (SPWM) is generated by comparing the carrier triangular wave with the reference sine wave. For shoot through pulses, the carrier wave is compared with two complementary DC reference levels. These pulses are added in the SPWM, highlighted in fig.3.

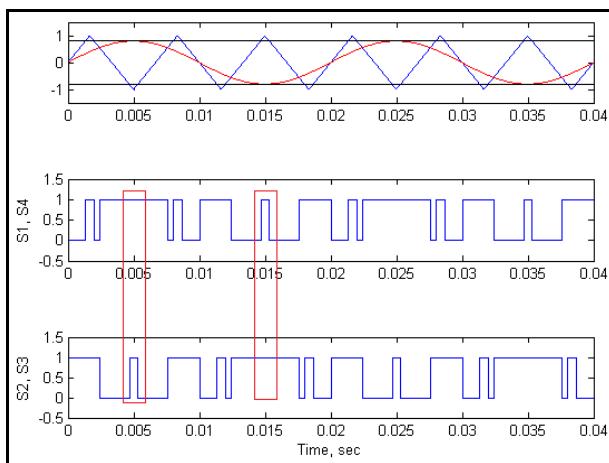


Fig.3. PWM for Single phase ZSI

ZSI has two control freedoms: modulation index of the reference wave which is the ratio of amplitude of reference wave to amplitude of the carrier wave and shoot through duty ratio which can be controlled by DC level [5].

Two zero states, two active states and one shoot through state are the five operating states of ZSI. These states are shown in table 1, where  $S_1$ ,  $S_2$ ,  $S_3$  and  $S_4$  are the switches of the inverter as shown in fig.1. “1” and “0” represent the ON and OFF state of the switches, respectively. Active state is the normal operating state of the inverter where the DC voltage occurs across the load, giving a finite output voltage. In zero state, load terminals are shortcircuited through either the upper or lower two devices. In shoot through state, the impedance network is short circuited to achieve boost operation. In zero state and shoot through state, the output voltage is zero, [4].

Table 1

Operating states for ZSI

Switch	Active States		Zero States		Shoot Through State	
	I	II	I	II		
$S_1$	1	0	1	0	1	1 or 0
$S_2$	0	1	1	0	1 or 0	1
$S_3$	0	1	0	1	1	1 or 0
$S_4$	1	0	0	1	1 or 0	1

The output voltage of ZSI is given by [1, 7],

$$V_o = BM \frac{V_{dc}}{2}$$

Where,

B is buck-boost factor,

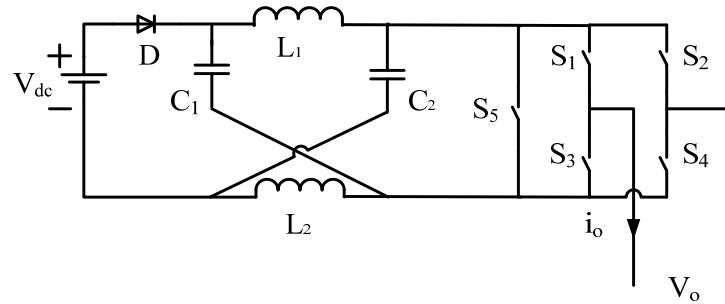
M is Modulation index,

$V_{dc}$  is DC link voltage.

For maximum boosting the duty ratio is given by [1, 7],

$$D = 1 - M$$

In our work we have introduced an additional switch across the impedance network. During the switching of states (active to shoot through and vice versa), the in rush current of the inductor can cause damage of IGBTs due to the high rate of change of current. Hence, to protect one leg of the inverter this additional switch  $S_5$ , as shown in fig.4 is provided. This switch is operational in shoot through condition. The shoot through current flows through the switch and also the in rush currents.

Fig.4. Single phase Z-Source inverter showing the additional switch  $S_5$ 

#### 4. Simulation and Hardware

The simulation of the single phase ZSI was done in MATLAB R2011a. The simulation model is shown in fig.5.

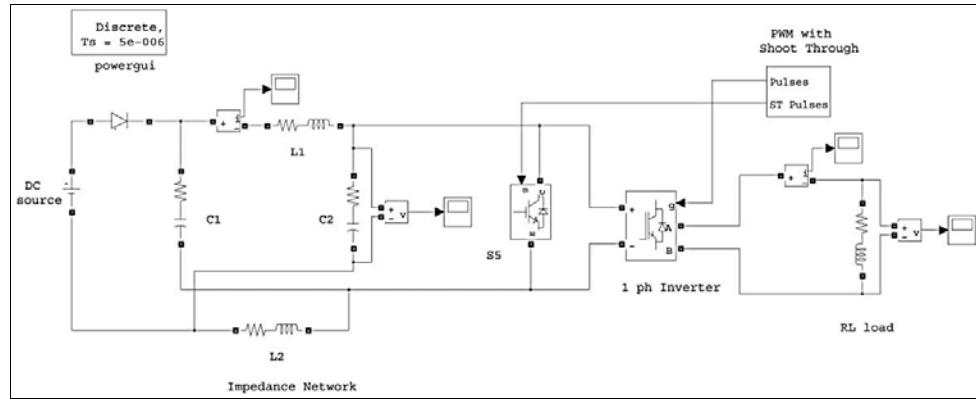


Fig.5. Simulation model

The hardware for ZSI was developed using components of appropriate ratings based on the simulation results. The parameters for both simulation and hardware are shown in table 2.

Table 2

Simulation and hardware parameters

Sr. No.	Parameter	Value	
		Simulation	Hardware
1	DC Supply, $V_{dc}$	52 V	52 V
2	Impedance Network Inductor, $L = L_1 = L_2$	1 mH	1 mH
3	Impedance Network Capacitor, $C = C_1 = C_2$	470 $\mu$ F	470 $\mu$ F

<b>4</b>	Resistive load	100 W	100 W
<b>5</b>	Reference Frequency	50 Hz	50 Hz
<b>6</b>	Modulation Index	0.6	0.6

The complete hardware setup is shown in fig. 6. The ZSI setup is explained in fig.7. The PWM shown in fig.3 can be directly used in single phase inverter bridge inverter, but, in this model, the shoot through pulses (highlighted in fig.3) passes through  $S_5$ .



Fig.6. Hardware setup

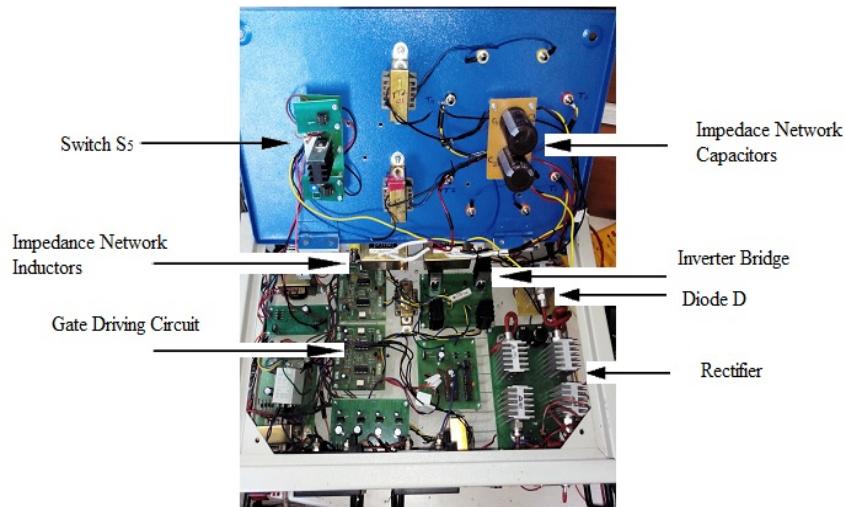


Fig.7. Single phase ZSI with rectifier

A sinusoidal PWM was used for the inverter operation. The shoot through pulses were developed by comparing a variable DC signal with a ramp signal generated at pin no. 2 of IC 555 when used as a astable multivibrator. The maximum duty ratio of the pulses obtained by IC 555 is of 50 %. Hence, for the

protection of the devices, the duty ratio was limited to 40 %. Thus, we made investigations for a minimum duty ratio of 0 % and a maximum limit of 40 %. For the PWM in the inverter, 7 pulse SPWM generated from Erasable Programmable Read Only Memory (EPROM) was used. The pulse widths were stored in EPROM. An IC 555 was used as a stable multivibrator to provide clock pulses to EPROM. Based on the frequency of the clock pulses, the frequency of SPWM was decided.

## 5. Results and Discussions

The results obtained for the parameters shown in table 2 are presented. The hardware setup was fed from AC mains using an auto transformer. The input AC was rectified to DC using a diode bridge. The output of the rectifier through a filter capacitor was connected to the impedance network and then to a bridge inverter using IGBTs. A tungsten filament lamp (resistive load) was connected between the two legs of the inverter. The output voltage when shoot through duty ratio is zero is shown in fig.8. The shoot through pulses is shown in fig.9. The output voltage when shoot through duty ratio is 40 % is shown in fig.10. For this case, inductor current and capacitor voltage are shown in fig.11 and fig.12 resp.

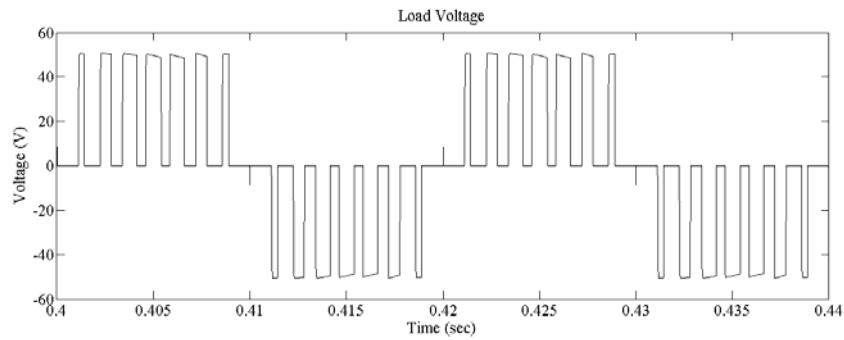


Fig.8a. Output Voltage obtained from simulation

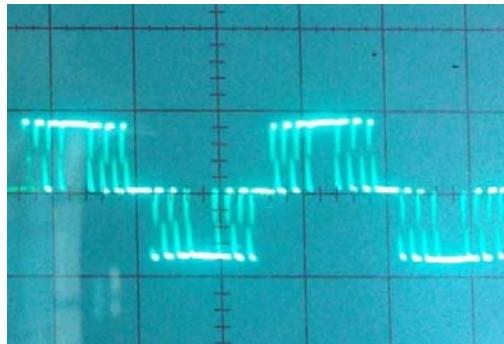


Fig.8b. Output Voltage obtained from hardware

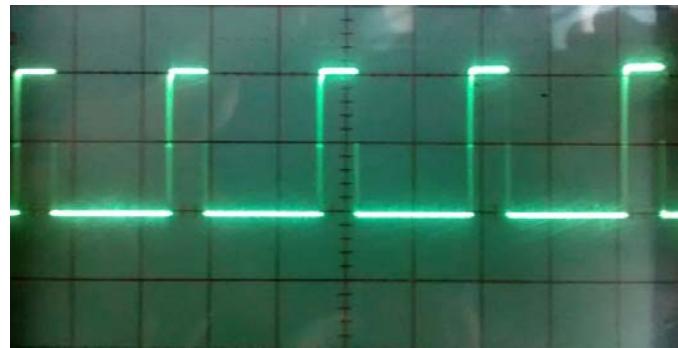


Fig.9. Shoot through pulses (40 % duty ratio) applied to switch  $S_5$

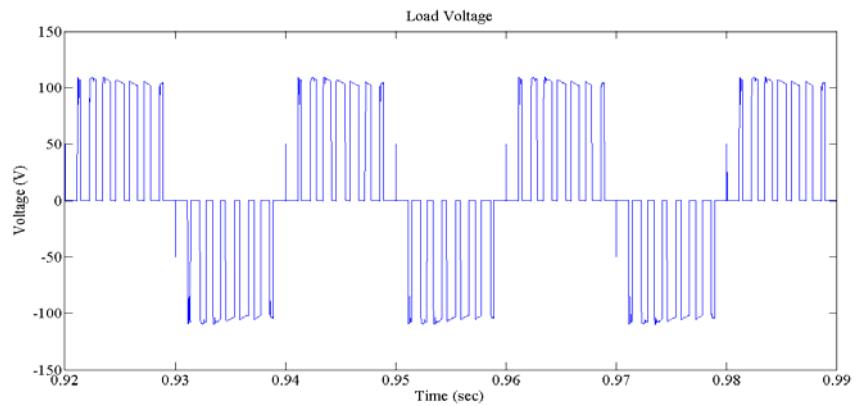


Fig.10a. Output Voltage obtained from simulation

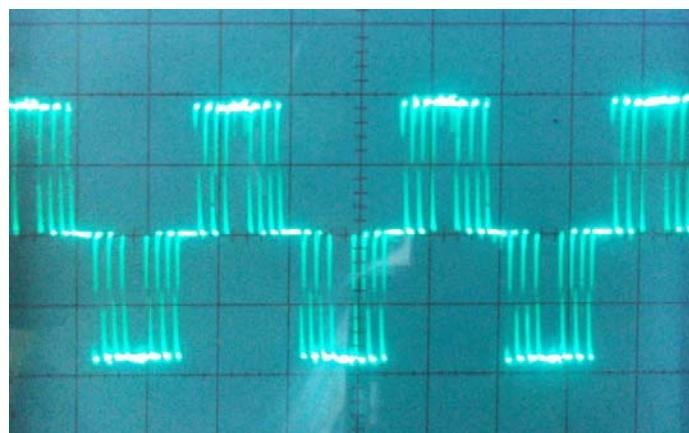


Fig.10b. Output Voltage obtained from hardware

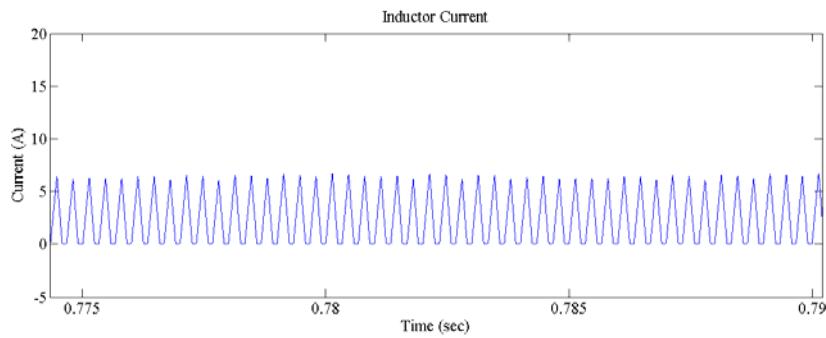


Fig.11a. Inductor current obtained from simulation

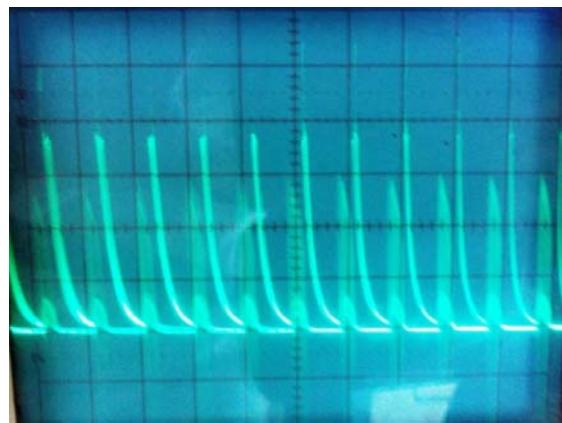


Fig.11b. Inductor current obtained from hardware

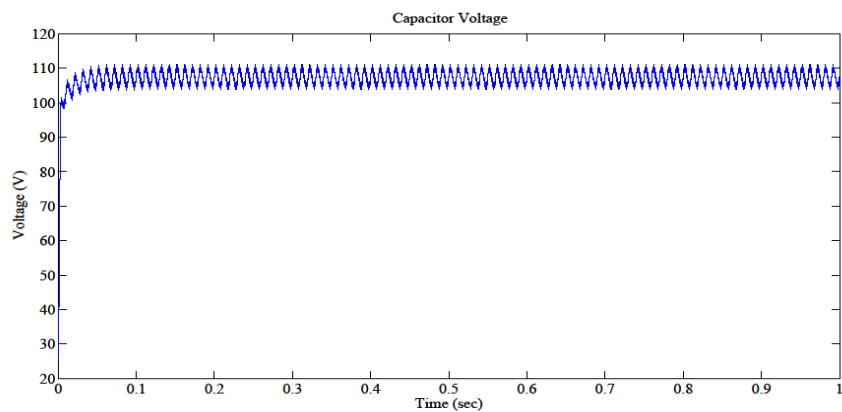


Fig.12a. Capacitor voltage obtained from simulation

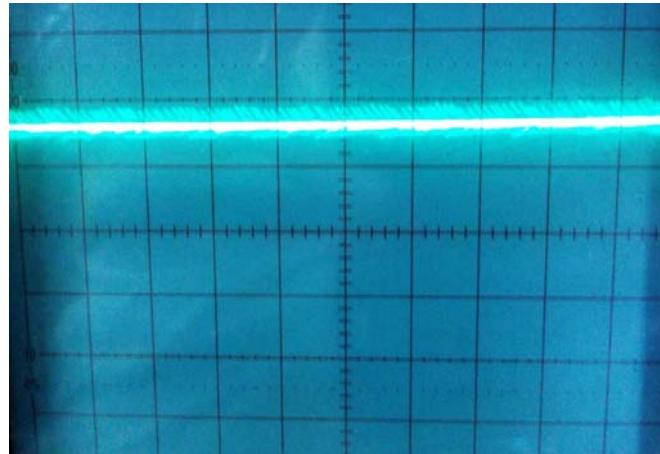


Fig.12b. Capacitor voltage obtained from hardware

The observed values for different parameters are shown in table 3.

Table 3

Comparison of simulation and hardware

Sr. No.	Parameter	Simulation	Hardware
1	DC supply Voltage	52 V	52 V
2	Load Voltage with $D = 0\%$	31.7 Vrms	32.5 Vrms
3	Load Voltage with $D = 40\%$	67.3 Vrms	73.1 Vrms

From table 3, it is clear that, during the shoot through state, the charging of the impedance network occurs and, during the next active state, boosts the output voltage. Thus, buck-boost feature can be obtained using a single stage ZSI.

## 6. Conclusions

The performance of single phase ZSI was studied for resistive load using simulation and hardware implementation. It was clear that ZSI has the advantage of single stage buck-boost operation. The simulation results were comparable with the hardware results. The impedance network concept can also be applied to other types of power converter circuits.

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