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Impedance Source Inverter Based AC–AC Converter System

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Abstract

This paper presents a new topology of uninterruptible power supply (UPS) by using a Z-source inverter, where a symmetrical LC network is employed to couple the main power circuit of an inverter to a battery bank. Using passive diode rectifier is known to constrain the converter to operate in only the forward power transfer mode, and generally support only voltage buck or boost operation, which to some extent constrains its disturbance ride through ability. The Z-source converter overcomes the conceptual and theoretical barriers and limitations of the traditional voltage-source converter and current-source converter. The Z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. With this new topology, the proposed UPS can maintain the desired ac output voltage at the significant voltage drop of the battery bank with high efficiency, low harmonics, fast response, and good steady-state performance. The entire system is simulated by MATLAB\ SIMULINK and the results are verified experimentally.

1 Introduction

Uninterruptible Power Supplies (UPSs) are widely used to supply critical loads, such as airline computers and life-support systems in hospitals providing protection against power failure or anomalies of power-line voltage. In this type of UPSs, the ac output voltage is higher than that of the battery bank; thus, a step-up transformer is required to boost voltage Due to the presence of the step-up transformer, the inverter current is much higher than the load current, causing high current stress on the switches of the inverter as shown in Figure 1.

The transformer also increases the weight, volume and cost of the system. The second one couples a battery bank to a dc/dc booster with a full bridge inverter as shown in Figure. 2. In this type of UPSs, the additional booster is needed, leading to high cost and low efficiency[1].

In this type of UPSs, the additional booster is needed, leading to high cost and low efficiency. The controlling of the switches in the booster also complicates the system. Furthermore, the dead time in the Pulse Width Modulation (PWM) signals to prevent the upper and lower switches at the same phase leg from shooting through has to be provided in the fore mentioned two types of UPSs, and it distorts the voltage waveform of the ac output voltage[2].

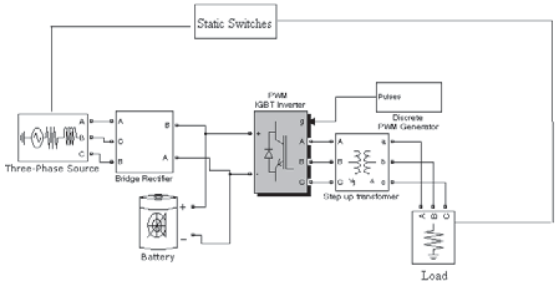


Figure 1: DC/AC Traditional Inverter with Transformer

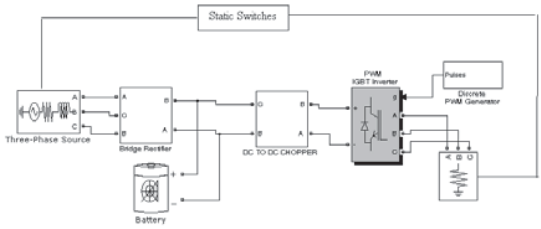


Figure 2: DC/DC Booster with DC/AC Traditional Inverter

2 Impedance Source Inverter

To overcome the above limitations of the traditional V-source and I-source inverter, this paper deals an impedance-source inverter and its control method for impedance dc-to-ac power conversion shown in Figure. 3. This paper also deals with how to overcome the limitations of voltage source inverter and current source inverter. A symmetrical impedance network consists of two identical inductors and two identical capacitors connected in a specific manner to achieve the desired properties. It allows the VSI to be operated in a new state called the Shoot-Through state in

which the two switching devices in the same leg are simultaneously switched-on to effect a short-circuit of the dc link. During this state, energy is transferred from the capacitors to inductors, thereby giving rise to the voltage boost capability of the ZSI[3-5].

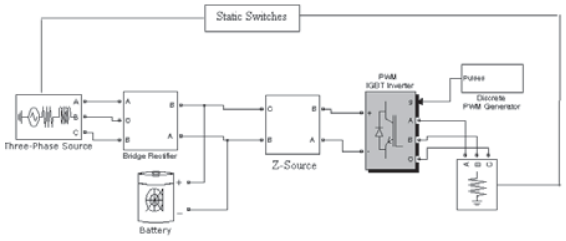


Figure 3: Z-Source Inverter based UPS system

2.1 Proposed UPS System

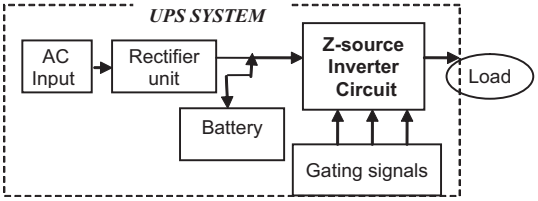


Figure 4: Block diagram for proposed UPS system

2.2 Analysis and Design of the Impedance Network

Open-1, Active-1, Shoot-Through-1 states are the desired states in practical applications. The three states, Open-2, Active-2 and Shoot-Through-2 are undesirable and are to be avoided by proper sizing of the inductors and capacitors of the impedance network. The impedance network in general can be written as

$$V_l = L\left(\frac{dl_l}{dt}\right); L_c c\left(\frac{dV_c}{dt}\right) \quad (1)$$

$$V_s = V_c + V_l, \quad I_s = I_c + I_l \quad (2)$$

$$V_i = V_c - V_l, \quad I_i = I_l - I_c \quad (3)$$

A. Open -1 state

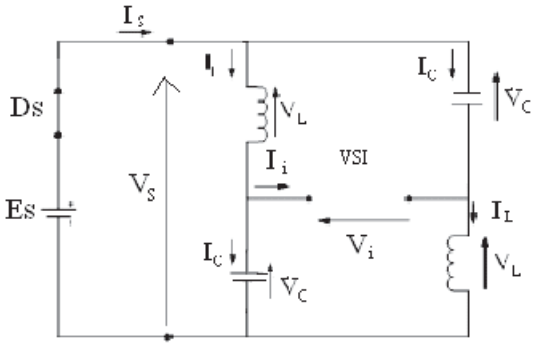


Figure 5: Equivalent circuit of ZSI during Open-1 state

The equations that define the open-1 state are given by,

$$V_s = E_s; I_i = 0 \quad (4)$$

The inductor voltage and output voltage in this state are given by,

$$V_l = E_S - V_c \quad (5)$$

$$V_i = 2V_c - E_s \quad (6)$$

B. Open-2 state

In the Open-2 state, the diode remains in the Off states and the VSI in the Open state. Therefore, the state defining equations can be written as,

$$I_s = 0; \quad I_i = 0 \quad (7)$$

In order to avoid this state, the necessary condition for the minimum value of inductor current (I_{lomin}) can be seen as

$$I_{lomin} > 0$$

C. Active-1 state

As seen in the equivalent circuit given in the Figure.6, the only difference between Open-1 state is the presence of the constant current source Io across the input terminals of the VSI.

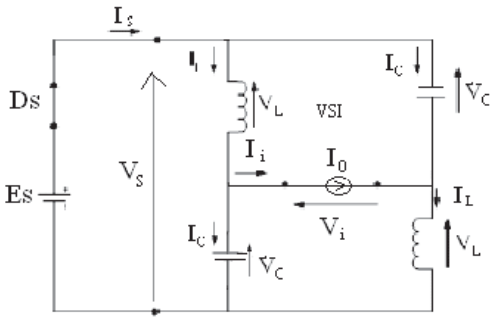


Figure 6: Equivalent circuit of ZSI during Active-1 state

The state defining equations for Active-1 state are,

$$V_s = E_s \quad (8)$$

$$I_i = I_o \quad (9)$$

It can be seen that the current through the diode, I_s, will be zero and the diode will turn off when,

$$I_l = -I_c = \frac{I_o}{2} \quad (10)$$

This makes the end of Active-1 state and the beginning of Active-2 state.

D. Active-2 state

The state defining equations for Active-2 state are

$$I_i = I_o; \quad I_s = 0 \quad (11)$$

In order to avoid Active-2 state in appearing during operation, the necessary condition for minimum inductor current in Active-1 period (I_{lAmin}) is

$$I_{lAmin} > \frac{I_o}{2} \quad (12)$$

E. Shoot-Through-1 state

As seen from Figure.6, the state defining equations for Shoot-Through-1 state are,

$$I_s = 0; \quad V_i = 0 \tag{13}$$

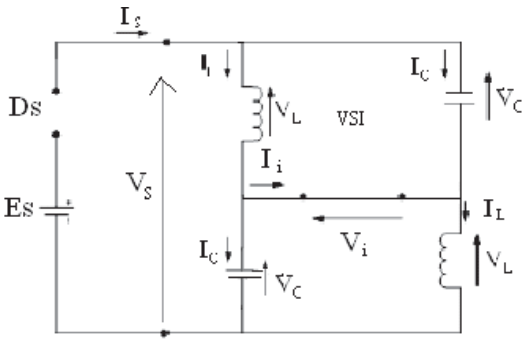


Figure 7: Equivalent circuit of ZSI during Shoot-Through-1 state

The energy stored in the capacitors during Open and Active state is transferred to inductors during Shoot-Through-1 state, thereby allowing the boosting of the voltage applied to the VSI.

F. Shoot-Through-2 state

The defining equations of Shoot-Through-2 state can be written as,

$$V_s = E_s \tag{14}$$

$$V_i = 0 \tag{15}$$

In order to prevent appearing of Shoot-Through-2 state during operation the necessary condition for minimum capacitor voltage (V_{cmin}) is

$$V_{cmin} > \frac{Es}{2} \tag{16}$$

From the preceding discussion it is clear that the Open-2, Active-2, Shoot-Through-2 states do not contribute to the power conversion process and should be avoided.

Shoot-Through time period

Shoot-Through time period is defined as the duration at which the two switches of the same-phase leg are gated on at the same time.

Boost factor

$$Vi = \left(\frac{T}{T - T_0}\right) * V_S \tag{17}$$

Where,
T_0 is the Shoot-Through time period in secs
T_1 is the non Shoot-Through time period
T is the Total time period in secs
V_s is the input source voltage

$$V_i = B\, V_o \tag{18}$$

Where B is the Boost factor resulting from the Shoot-through zero state Output peak phase voltage from the inverter can be expressed as,

$$V_{ac} = \frac{M.V_i}{2} \tag{19}$$

Where
M is the Modulation Index
V_{ac} is the output line voltage of ZSI
Using Equations (18) & (19) can be further expressed as,

$$V_{ac} = \frac{M.B.V_0}{2} \tag{20}$$

$$V_{ac} = \frac{B_b.V_0}{2} \tag{21}$$

Where, Bb is the buck boost factor

3 Simulation of the Impedance Source Inverter

Figure. 8 shows the entire simulated ZSI circuit with R-L load. The modified firing pulses for Z-source inverter switches are obtained from triggering circuit shown in the Figure. 9. A 3Φ, 50HZ AC input voltage is fed to 3Φ uncontrolled rectifier unit. On the diode rectifier AC input side, three small delta connected filter capacitor are added for filtering the three phase AC currents, so as to eliminate frequency high current peaks that are drawn by traditional diode rectifiers with large dc capacitor storages. The obtained DC output voltage is fed to Z- source inverter. The analyzed various AC input voltages and corresponding output voltages with DC voltages are shown in the Table-I which is shown below and its comparison is shown in the Figure. 15. The entire power circuit is simulated by MATLAB\SIMULINK.

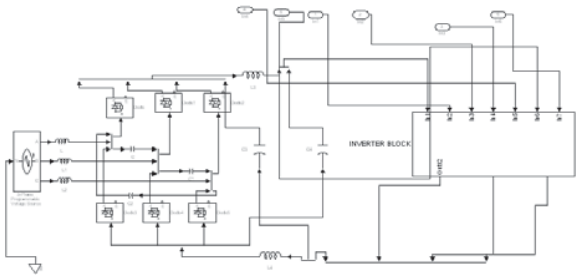


Figure 8: Simulation of impedance source inverter

Table 1: Analysis of Double Conversion (AC-DC-AC)

AC input in volts	DC output in volts	Obtained AC output from Z- source inverter in volts
85	135	220
155	250	415

3.1 Simulation Results

The modified switching pattern for inverter switches are to avoid shoot through state is shown in the Figure. 9.

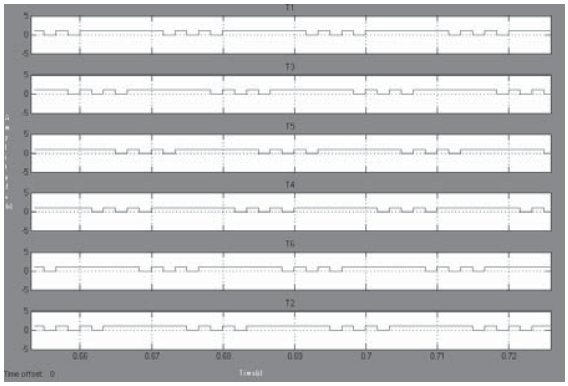


Figure 9: Triggering Pulses given to Z-Source Inverter

For the given input voltages, the various output voltage from the inverter across R-L load.

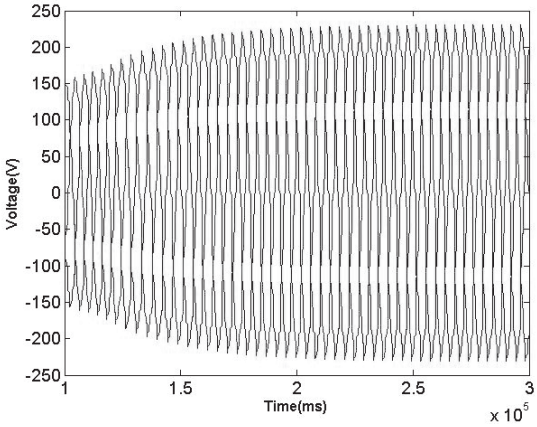


Figure 10: Output voltage-220V when input is 85V

Figure.10 shows the output voltage of 220V from the inverter circuit when the input is 85V. This voltage can be used for single phase load systems.

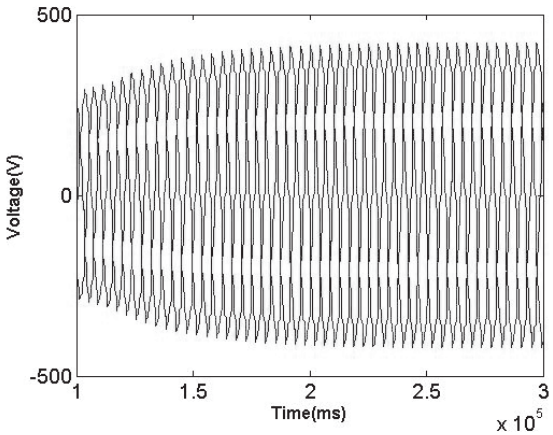


Figure 11: Output voltage-415v when input is 155v

Figure.11 shows the output voltage of 415v from the inverter circuit when the input is 155v. The output voltage has been boosted to 2.8 times the input voltage can be inferred from this result. This voltage can be used for three phase load systems.

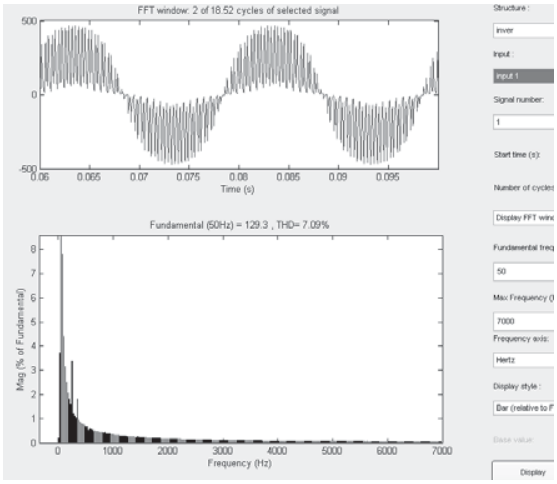


Figure 12: FFT Analysis

Figure.12 shows the FFT analysis of output voltage with THD of 7.09%

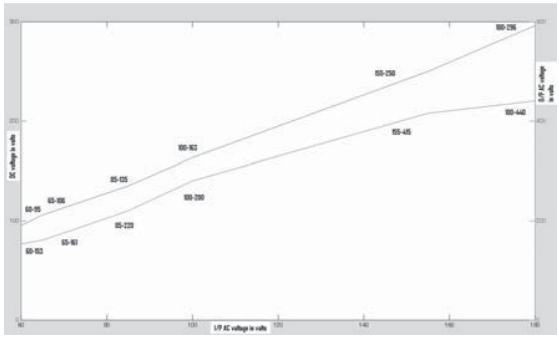


Figure 13: AC Input and DC Output analysis

Figure.13 shows the AC input and DC output analysis obtained by simulating impedance source inverter.

4 Experimental Analysis

The PIC16F877A CMOS FLASH-based 8-bit microcontroller is upward compatible with the PIC16C5x, PIC12Cxxx and PIC-16C7x devices. It features 200 ns instruction execution, 256 bytes of EEPROM data memory, self programming, an ICD, 2-com parators,8channelsof10bitAnalogtoDigital(A/D)converter, 2-capture/compare/PWM functions a synchronous serial port that can be configured as either 3-wire SPI or 2-wire I2C bus, a USART, and a Parallel Slave Port. PIC16F877A is a small piece of semiconductor integrated circuits. The package type of these integrated circuits is DIP package. DIP stand for Dual Inline Package for semiconductor IC. This package is very easy to be soldered onto the strip board. However using a DIP socket is much easier so that this chip can be plugged and removed from the development board. The input pulses to the switches of the inverter are taken from the pin 33, 34,35,36,37 and 38.

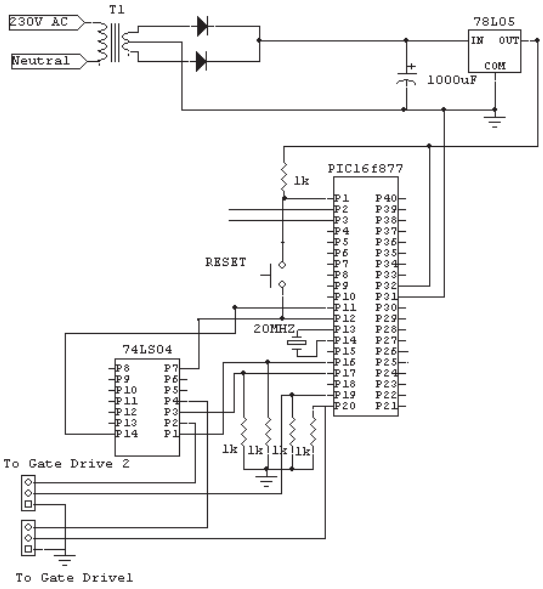


Figure 14: Controller Circuit

Figure.14 shows the controller circuit which is designed for producing firing pulses to suitable Z-source inverter switches.

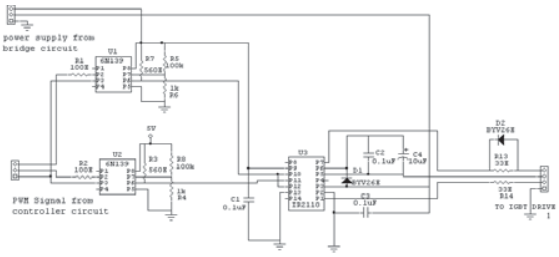


Figure 15: Gate driver Circuit

Figure.15 shows the gate driver circuit for Z-source inverter switches. This circuit acts as a pulse amplifier.

4.1 Experimental Results

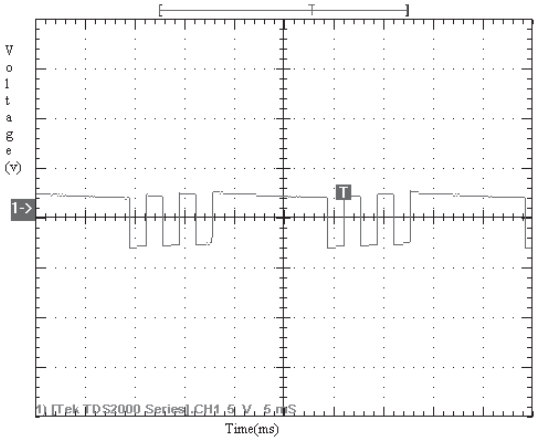


Figure 16: The pulse pattern which is given to switch T_1

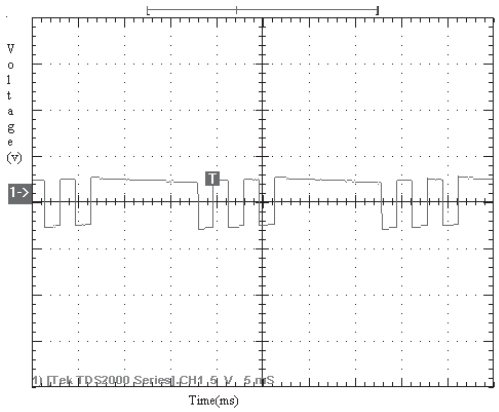


Figure 17: The pulse pattern which is given to switch T_3

Figure.16&17 shows the output pulse from PIC micro controller which is given to the ZSI switch (T_1) & (T_3). It is obtained by programming the microcontroller using High-tech C.

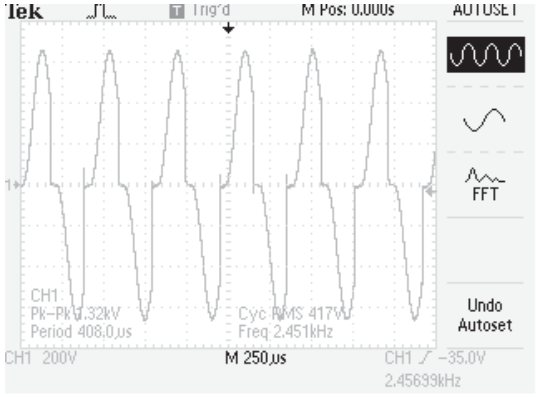


Figure 18: Z-Source output voltage

The output voltage range is not limited. The impedance source inverter is used as a buck-boost inverter. The impedance source inverter does not affect the electro magnetic interference noise. The impedance source inverter cost is low. The impedance source inverter provides the buck-boost function by two stage power conversion. Experimental output voltage of impedance source inverter is shown in the Figure .18

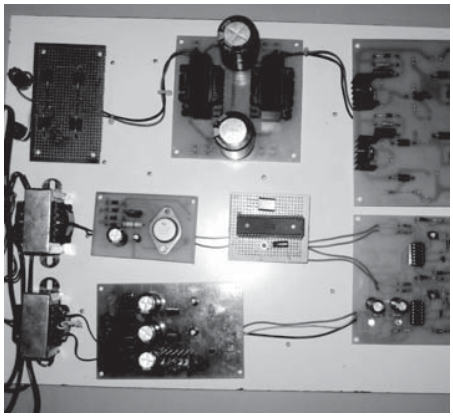


Figure 19: Experimental Set up

Figure.19 shows the prototype model of proposed system.

Table 2: Battery Requirement

Inverter system	AC input in volts	DC output in volts	AC output in volts	No. of Battery required (24V)
VSI	220	300	220	13
ZSI	85	135	220	6
VSI	415	535	415	20
ZSI	155	250	415	11

The number batteries required for three phase system is shown in the above table II. For obtaining 415V, 50HZ AC output through VSI system, number batteries utilized are around 20, but in the case of proposed ZSI system for obtaining same output number batteries utilized are around 11.

5 Conclusion

A new type of inverter for UPS application has been proposed to maximize the shoot through period without affecting the active switches by turning all zero zero states into the shoot through zero states thus maximum output voltage can be obtained. The overall cost of the system has been reduced by reducing the battery utility. The entire system has been simulated and the results are verified experimentally. The Unique features like single stage power conversion, improved reliability, strong EMI immunity and low EMI. The impedance source technology can be applied to the entire spectrum of power conversion.

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