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Research Article

Implementation of a Single Phase Z-Source Buck-Boost Matrix Converter using PWM Technique

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Abstract

This paper presents a single phase z-source buck-boost matrix converter which can buck and boost the output voltage with step change frequency i.e. both the voltage and the frequency can be steeped up or steeped down. Also, this converter uses a safe-commutation technique to conduct current in a continuous path, resulting in the elimination of voltage spikes on switches without the need for a snubber circuit. It has no energy storage devices, performing the energy conversion by directly connecting input with output phases through bidirectional switches. For this reason, it is known as all-silicon power converters. In the proposed scheme, dsPIC30F2010 controller is used to produce PWM signals. The operating principles, analysis and experimental results of the proposed single phase z-source buck-boost matrix converter are described and the experimental results show that the output voltage can be obtained at three different frequencies—100, 50, and 25 Hz in the buck–boost amplitude mode. Textronics TDS2024B storage oscilloscope is used to store the gate pulses and waveforms.

Keywords: *Buck–boost voltage, single-phase matrix converter, Step-up and step-down frequency, Z-source converter*

1. Introduction

Matrix converter is an AC-AC converter that can directly convert a fixed AC voltage to variable voltage, variable frequency AC without a large energy storage element. The first matrix converter was introduced by Pelly and Gyugyi in 1976. In 1980 Venturni and Alesina presented the first algorithm capable of synthesizing output sinusoidal reference voltages from a balanced three phase voltage source connected to the converter input terminals [M. K. Nguyen, Y. G. Jung, Y. C. Lim, and Y. M. Kim, *A, (*Feb. 2010)]. The first study of a single phase matrix converter was performed by Zuckerberger on a frequency step up and fundamental voltage step down converter.

Recent research on matrix converters has extended its operation to inverter, controlled buck rectifier, boost rectifier and buck-boost rectifier [X. P. Fang, Z. M. Qian, and F. Z. Peng, (2005),]. In other topologies, the AC output voltage cannot exceed the AC input voltage. Furthermore, it is not possible to turn both the bidirectional switches of a single phase leg on at the same time, as the current spikes generated by this action will destroy the switches. Both of these limitations can be overcome by using Z-source topology. Many researchers have also focused on Z-source AC-AC converters [X. P. Fang, Z. M. Qian, and F. Z. Peng, (2005), Y. Tang, C. Zhang, and S. Xie, (2007),Z. Idris, M. K. Hamzah, and M. F. Saidon, (2006)] which mainly finds applications where only voltage regulation is needed. In primary converter model topology, amplitude of output voltage can't be greater than amplitude of input voltage. Z-source converters solve this problem [Z. Idris, M. K. Hamzah, and M. F. Saidon, (2006)].

The single phase Z-source AC-AC converters has several advantages such as providing large range of output voltages with the buck-boost mode, reducing inrush and harmonic currents. In this project work we apply the Z-source concept to a single phase matrix converter to create a new type of converter called a single phase Z-source buck-boost matrix converter. In contrast to the existing single phase PWM AC-AC converters, this proposed single phase Z-source buck-boost matrix converter can provide a wide range of output AC voltages in buck-boost mode with step up/step down frequencies [P. Deivasundari and V. Jamuna (*2011)*, X. P. Fang, Z. M. Qian, and F. Z. Peng, (2005), Y. Tang, C. Zhang, and S. Xie, (2007)].

The safe commutation scheme establishes a continuous current path in dead time to eliminate voltage spikes on the switches without a snubber circuit. Applications of single-phase matrix converters have been described for induction motor drives, radio-frequency induction heating, audio power amplification, and compensation voltage sags and swells. It has been reported that the use of safe-commutation switches with pulse width modulation (PWM) control can significantly improve the performance of AC-AC converters [Y. Tang, C. Zhang, and S. Xie, (2007).

To verify the operation of the proposed converter, we constructed a laboratory prototype with the lamp load

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based on dsPIC30F2010, the experimental results show that the output voltage can be obtained at three different frequencies—100, 50, and 25 Hz in the buck–boost amplitude mode. Thus, the proposed single-phase Z-source buck–boost matrix converter can be used for voltage applications that require step-changed frequency or amplitude. In particular, it can be applied to the starting of an asynchronous motor as well as to the speed control of an induction motor, which needs a step-changed speed. The various graphs/waveforms are analyzed and studied on ***digital Storage Oscilloscope.***

2. Block Diagram and Its Explanation

A. System overview

The block diagram of the proposed single phase z-source buck-boost matrix converter is shown in figure 1. The ac voltage is applied to the Z-source network were the input Vi voltage is bucked or boosted and the output Va is given to the single-phase matrix converter Then, the single-phase matrix converter varies the frequency of Va depending on the switching sequence . The output voltage Vo is obtained with a step-changed frequency and a variable amplitude.

Fig. 2 shows the proposed single-phase Z-source buck–boost matrix converter. It has an *LC* input filter; a Z-source network, bidirectional switches, and a load. The *LC* input filter is required to reduce switching ripple included in input current. All the inductors and capacitors are small and are used to filter switching ripples. The symmetrical Z-source network, a combination of two inductors and two capacitors, is the energy storage/filtering element for the single-phase Z-source buck–boost matrix converter.

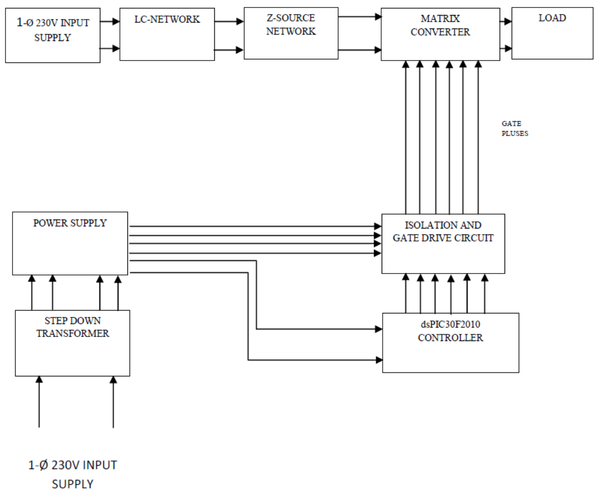


Fig.1 Block diagram of the proposed system

Since the switching frequency is much higher than the ac source (or line) frequency, the requirements for the inductors and capacitors should be low [X. P. Fang, Z. M. Qian, and F. Z. Peng, (2005)]. As shown in Fig. 2, the proposed single-phase Z-source buck–boost matrix converter requires 4 bidirectional switches S1*j*, S2*j* , S3*j* , and S4*j* (*j* = a, b) to serve as a single-phase matrix converter and one source bidirectional switch S*sj* (*j* = a, b), where a and b refer to drivers 1 and 2, respectively. All bidirectional switches are common emitter back-to-back switch cells. The five switches S*sj*, S1*j*, S2*j*, S3*j*, S4*j* (*j*=a, b) used in the single-phase Z-source buck–boost matrix converter are bidirectional switches, as shown in Fig. 2.
The bidirectional switches are able to block voltage and conduct current in both directions. Because these bidirectional switches are not available at present, they can be substituted for by combinations of two diodes and two insulated gate bipolar transistors (IGBTs) connected in antiparallel (common emitter back to back), as shown in Fig. 2. The diodes are included to provide the reverse blocking capability. The IGBTs are used because of their high switching capabilities and their high current-carrying capacities, which are desirable for high-power applications. As indicated in the figure, *D* refers to the equivalent duty ratio and *T* is the switching period.

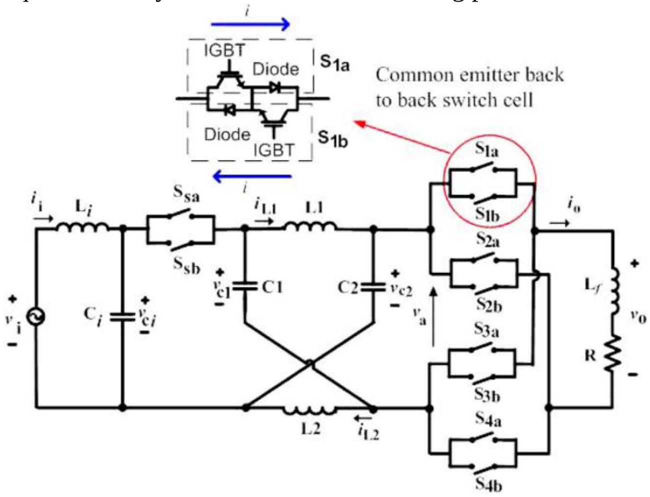


Fig.2 Proposed Single phase Z-source Matrix converter topology

Implementing the single-phase Z-source buck–boost matrix converter requires different bidirectional switching arrangements depending on the desired amplitude and frequency of the output voltage. The amplitude of the output voltage is controlled by the duty ratio *D*, while the frequency of the output voltage depends on the switching strategy. In this paper, the frequency of input voltage f_i is assumed to be 50 Hz, and the desired output frequency f_o is synthesized to be 100Hz (step-up frequency), 50Hz (same frequency), or 25Hz (step-down frequency).

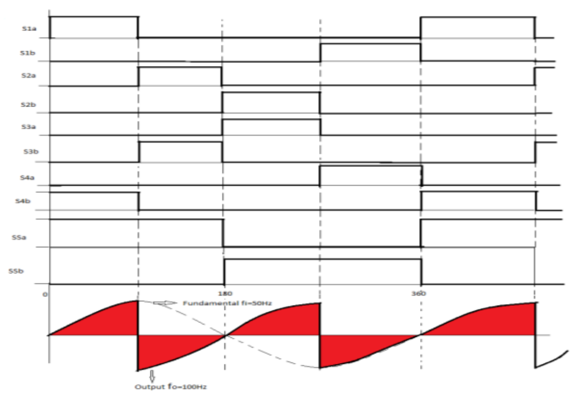


Fig. 3 Switching sequence for 100Hz in Buck mode

For example, Fig. 3 illustrates the converter's switching strategy over one cycle of input voltage for a 100-Hz output frequency in buck mode. To double output frequency of the input voltage, the operation of the converter is divided into four stages, as shown in the figure.

Fig. 4 illustrates stage 1 in the buck mode when both input voltage and output voltage are positive.

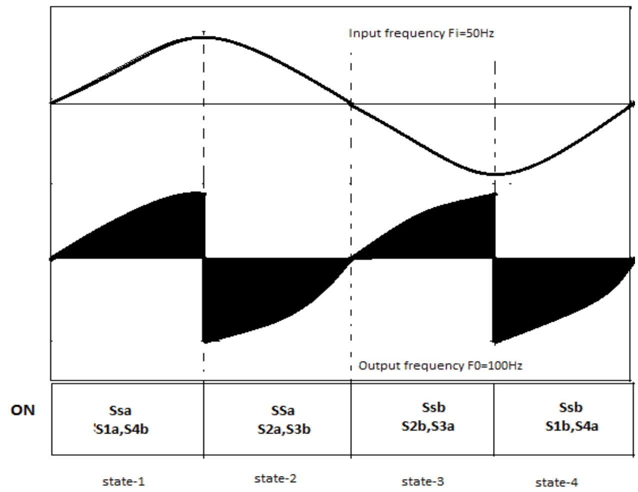
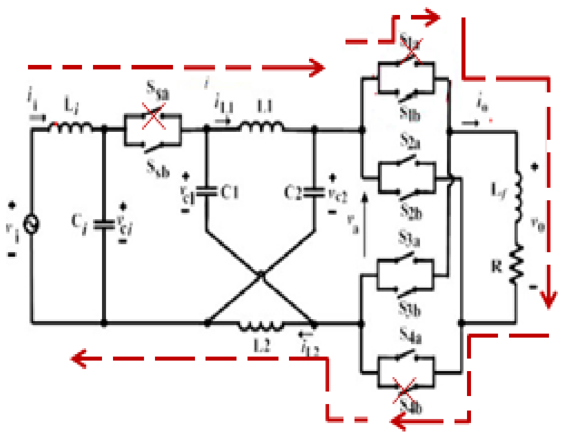
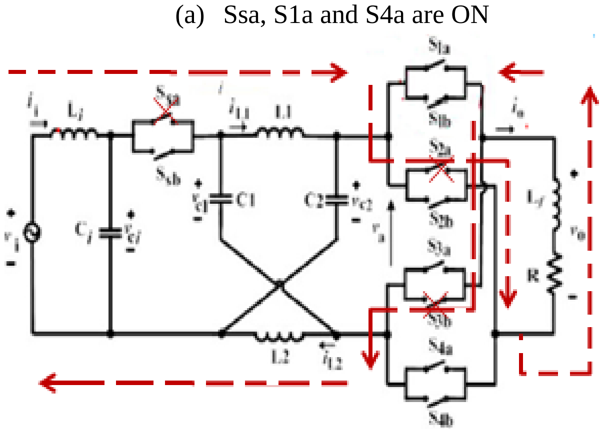


Fig. 4 Switches turned ON during each state for 100Hz in Buck mode



(a) Ssa, S1a and S4a are ON



(b) Ssa, S2a and S3b are ON

Fig.5 Direction of current flow for 100Hz in Buck mode

In state 1, as shown in Fig. 5(a), Ssa, s1a and S4b turns on and conducts current flow during the increasing positive cycle of input voltage; In state 2 as shown in Fig. 5(b) Ssa, S*2a* and S3b turn on and conduct negative current flow from source to the load during positive half cycle, similarly Ssb, S2b and S3a conduct in state 3 and Ssb, S1b and S4a conduct in state 4.

B. Control circuit

The control circuit of the proposed scheme consists of a Digital signal Controller dsPIC30F2010.A Digital Signal Controller (DSC) is a single-chip, embedded controller that seamlessly integrates the control attributes of a Microcontroller (MCU) with the computation and throughput capabilities of a Digital Signal Processor (DSP) in a single core. The dsPIC DSC has the "heart" of a 16-bit MCU with robust peripherals and fast interrupt handling capability and the "brain" of a DSP that manages high computation activities, creating the optimum single-chip solution for embedded system designs. The dsPIC30F devices contain extensive Digital Signal Processor (DSP) functionality within high-performance 16-bit microcontroller (MCU) architecture. It also consists of ten opto-couplers for isolating the control and power circuits. In this work an optocoupler MCT2E is used to isolate the gate drive circuit and the IGBT-based power circuit. Ten IGBTs of the power circuit are controlled by the PWM signals generated by the control circuit.

3. Experimental Setup and its Results

The implementation of a single phase z-source buck-boost matrix converter is done successfully and the developed hardware is tested with load. The proposed control system is implemented by a DSC (dsPIC30F2010) based PWM inverter. C language is used to develop the program. The device is programmed using MPLAB Integrated Development Environment (IDE) tool. It is a free, integrated toolset for the development of embedded applications employing Microchip's PIC and dsPIC controllers. For execution of C-code, MPLAB compiler is used.

The hardware set is developed and tested in power electronics laboratory and the photograph of complete setup is shown in fig 6. In the complete experiment the oscilloscope used is Tektronix TDS2024B Digital Storage Oscilloscope (DSO) to store gate pulses and voltage waveforms.

Table 1: Experimental parameters

L-C input filter	L_i	0.1mH
	C_i	6.8μF
Z-Source Network	$L_1 = L_2$	1mH
	$C_1 = C_2$	1μF
Switching Frequency	20kHz	

Experimental results show that the output voltage can be obtained at three different frequencies 100, 50, and 25 Hz and in the buck–boost amplitude mode. Thus, the proposed single-phase Z-source buck–boost matrix converter can be used for voltage applications that require step-changed frequency or amplitude. In particular, it can be applied to the starting of an asynchronous motor as well as to the speed control of an induction motor, which needs a step-changed speed.

The input voltage is taken by the normal power supply 230v 50 Hz. The input is stepped down by the step-down transformer and is given to the LC filter. Depending on the desired output frequency, the Microcontroller generates ten control signals (four PWM signals to control four switches S1b, S2b, S3b, S4b, four I/O signals to control four switches S1a, S2a, S3a, S4a in the single-phase matrix converter, and two PWM signals to control source bidirectional switch S*sj* (*j* = a, b), where a and b refer to drivers 1 and 2, respectively.

Figs. 7-10 show the input voltage and output voltage for the experiments done in buck–boost mode with output frequencies of 100, 50, and 25 Hz, respectively.

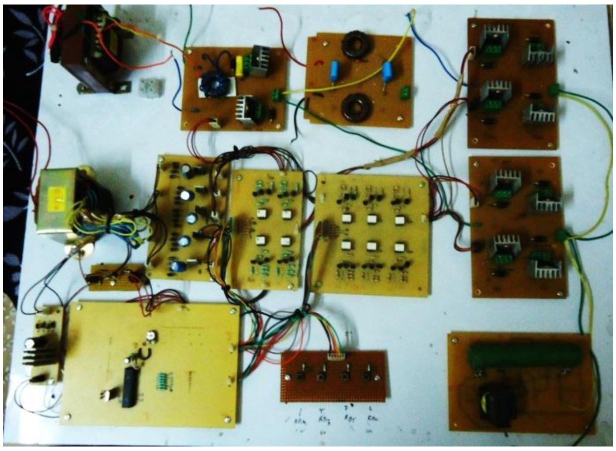


Fig. 6 Photograph of complete Experimental setup

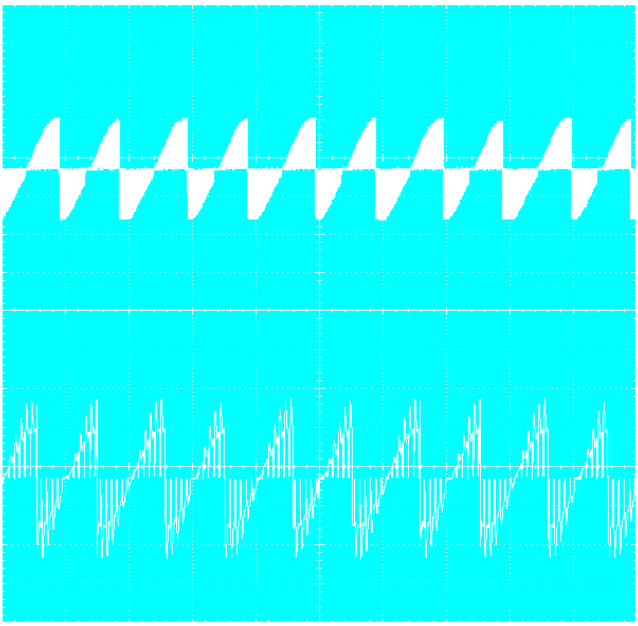


Fig.7 Experimental result at frequency of 100 Hz (top: $\mathbf{V_0}$ (100 Hz) (In Buck mode); bottom: $\mathbf{V_0}$ (100 Hz) (In boost mode)

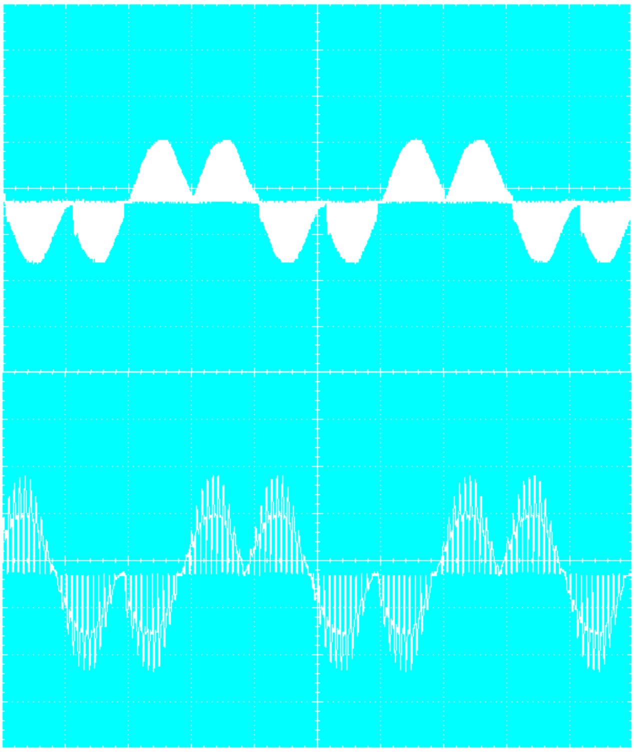


Fig.8 Experimental result at frequency of 25 Hz (top: $\mathbf{V_0}$ (25 Hz) (In Buck mode); bottom: $\mathbf{V_0}$ (25 Hz) (In boost mode).

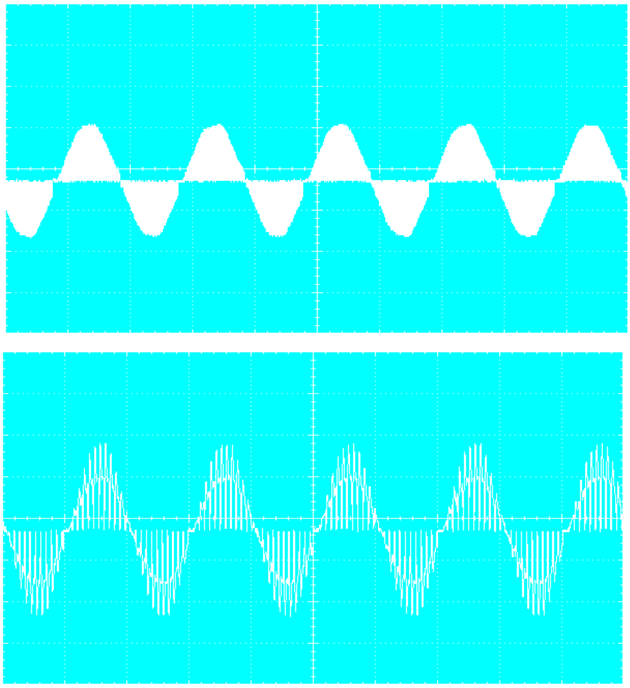


Fig. 9 Experimental result at frequency of 50 Hz (top: $\mathbf{V_0}$ (50 Hz) (In Buck mode); bottom: $\mathbf{V_0}$ (50 Hz) (In boost mode)

Conclusion

In this project work, we have presented a single-phase Z-source buck–boost matrix converter that can buck and boost to the desired output voltage with step-changed frequency. The output of this single-phase Z-source buck–boost matrix converter produces the voltage in buck–boost mode with a step-changed frequency, in which the output frequency is either an integer multiple or an integer fraction of the input frequency. It provides a continuous current path by using a commutation strategy, which avoids voltage spikes on the switches.

In traditional matrix converters conversion is done in two stages, using two power controllers one as converter (AC-to-DC) and other as inverter (DC-to-AC), but in this topology direct ac to ac conversion is done reducing the conversion stages.

We presented here the steady-state Analysis, operational stages and circuit analysis to verify the performance of this converter; we constructed a laboratory prototype with an input voltage of 50 Volts/50 Hz based on dsPIC30F2010. The experimental results with a lamp load showed that the output voltage can be produced at three different frequencies, 100, 50, and 25 Hz, and in the buck–boost amplitude mode.

This converter is particularly suitable for controlling the speed of a fan or a pump without the use of an inverter because for these applications, the input voltage frequency must be changed to control their speed by stages.

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