Direct AC-AC Z-Source Matrix Converter for Single Phase Induction Motor

Hridhya Mereena George and Ragam Rajagopal

Abstract--- *The paper focuses on a novel method of direct ac – ac conversion so as to obtain a variable voltage – stepped change frequency output. The topology uses a single phase matrix converter (SPMC) together with a Z-source network. The switching strategy of matrix switches decides the output frequency (step up, step down or constant frequency). This topology eliminates the need of a large dc link capacitor used in indirect ac – ac conversion thereby causing a reduction in both size and cost of the converter. The converter can be used for driving a single phase induction motor for application which requires a stepped change in frequency (eg. Fan application). The circuit is simulated in MATLAB and the result obtained verifies its operation as a variable voltage-stepped change frequency converter.*

Keywords--- *Bidirectional Switch, Single Phase Matrix Converter, Shoot through, Z- Source Network*

I. INTRODUCTION

SINGLE Phase Induction Motors (SPIM) is the kind of electric motors which we first make out or witness from around in our day to day life. They are the most widely used in fractional and sub-fractional horsepower range targeted for use in consumer as well as industrial applications. Compressors, centrifugal pumps, washing machine, fan blowers etc are a few that comes under the list. In spite of the emergence of superior motors like brushless dc (BLDC) motors and Permanent magnet synchronous motors (PMSM), researches are still made on enhancing the performance of SPIMs keeping in view the large production volume and also due to the penetration of adjustable speed SPIM drives in the industry.

Low cost and compactness are the two major considerations for any domestic application. The paper is intended to propose a novel topology for SPIM drive that claims for the above considerations. The circuit topology makes use of a Single Phase Matrix Converter together with a Z- source impedance network.

A. Single Phase Matrix Converter & Bidirectional Switch

A matrix converter is a flexible converter that can be used for different kinds of power conversion (i.e.) AC-DC, DC-AC, DC-DC and from AC-AC. The basic building block of a matrix converter is the bidirectional switch. SPMC requires four such switches forming an H-bridge structure. Figure 1 shows the layout of SPMC fed from an AC supply. Switches S1 to S4 are bidirectional in operation capable of blocking voltage and conducting current in both directions. 'A' switches permits the forward direction of current flow during the positive half cycle of input voltage and 'B' switches operates during the negative half cycle of input voltage to allow current flow in reverse direction. A single bidirectional switch cell is also shown in the insight of Figure 1. Each of these switches is constructed using two MOSFET switches and two diodes. Diodes provide for the reverse voltage blocking capability. A matrix converter offers several advantages like bidirectional power flow, increased life span, compact size with sinusoidal input and output current. Compactness of the converter is the highlight when it comes to small domestic applications. Four quadrant operations are also achievable with a matrix converter.

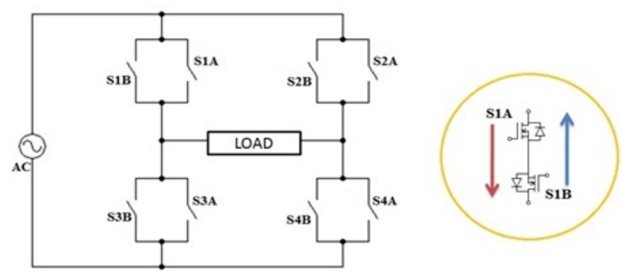

Figure 1: Single Phase Matrix Converter & Bidirectional Switch

B. Z – Source Impedance Network

Z – Source impedance network is a unique combination of two identical inductors and capacitors forming a symmetrical passive network. It is generally used to couple a source of power with a main converter circuit as shown in Figure 2 and is applied in areas where a voltage regulation is needed.

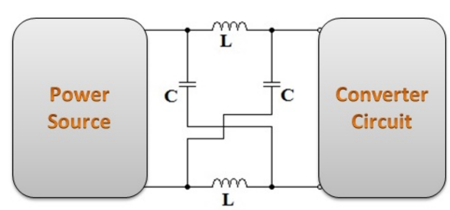

Figure 2: Z – Source Impedance Network

II. LITERATURE SURVEY

A survey on the SPIM drives puts forth various existing converter topologies that can be used in adjustable speed drives (ASD) for SPIM [2]. Based on a comparison made among them, the paper has arrived at the conclusion that

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adjustable frequency Pulse Width Modulation (PWM) inverter is the most apt choice for SPIM drives. This method of indirect ac-ac conversion is a two stage process involving a rectifier unit at the front end followed by a large energy storing DC link capacitor and inverter. DC link capacitor increases the size and cost of the converter. For a direct ac-ac conversion, Matrix converter is a solution. Studies have proven that matrix converter can be successfully implemented for all possible forms of power conversion [3] to provide multiple functions of inverter, rectifier, cycloconverter, chopper and buck & boost converter. The flexible operation of matrix converter is achieved by simply varying the switching strategy of the matrix bidirectional switches. Pulse Width Modulation technique is applied considering its simplicity and matrix converter responds well to it [4]. Problems associated with the commutation of switches for inductive loads are studied and a safe switching strategy is used to overcome its adverse effects [5], [6]. Studies on Z- Source inverter (ZSI) prove its capability of boosting the voltage [8], [9] and moreover it could also be used with any form of power conversion similar to a matrix converter. This is the idea behind combining a matrix converter together with a Z- source network for obtaining a variable voltage and stepped change in frequency from a single converter circuit [1].

III. Circuit Topology

A. Block Diagram

The basic block diagram of the proposed topology is given in Figure 3. Single phase AC is the supply source which is fed to the Z- source matrix converter. A passive LC input filter has been designed satisfying the requirements [7] for reducing the ripple at the input side current. Z- Source network produces a variable voltage at its output and the SPMC changes the frequency by varying the switching strategy.

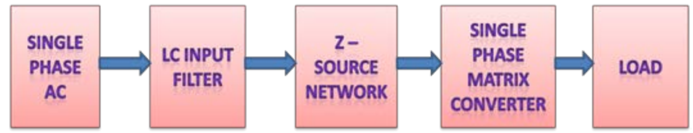

Figure 3: Block Diagram

B. Circuit Diagram

The circuit topology of the proposed converter is shown in Figure 4. Lin and Cin constitute the input filter. Bidirectional switch Ssa and Ssb are used as driver switches for positive and negative input half cycle respectively. Z source network is a unique combination of two identical inductors and capacitors (L1=L2 & C1=C2) whose values can be chosen to be small owing to large switching frequency. Output of Z-source network is applied to SPMC.

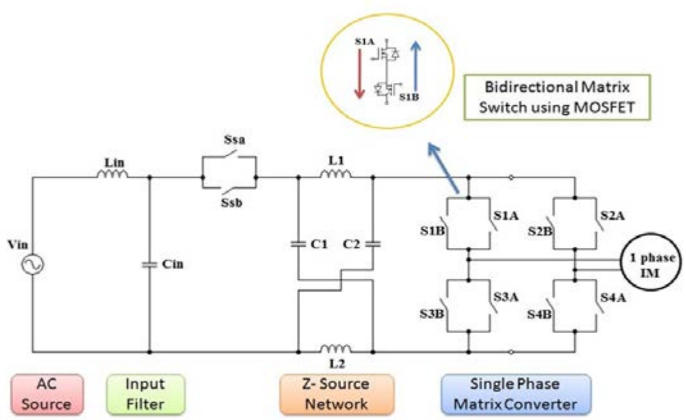

Figure 3: Circuit Topology

IV. Switching Strategy

Single Phase Matrix Converter switches are operated in a proper sequence so as to obtain the output at three different frequencies (f, f/2 and 2f, where 'f' is the frequency of input supply). A variation in the switching strategy thus provides for the frequency changer operation of SPMC. Pulse Width Modulation (PWM) technique is applied owing to its simplicity.

In order to attain an output frequency of 50 Hz, the entire switching operation can be divided into 2 modes: Mode 1- during the positive half cycle of input supply when the switches S1A and S4A are turned ON and Mode 2- during the negative half cycle of input supply when S1B and S4B switches are turned ON. For a frequency changer operation, (i.e.) to obtain output frequencies of 25 Hz and 100 Hz, there are four different modes of operation. Details of the four Modes of operation are given in Table 1. It can be observed that Mode 2 and Mode 3 are simply interchanged for a step down and step up frequency operation. All the four modes are referred to as the Active State of operation. It can thus be summarized that the 'A' switches are turned ON during the positive half cycle of input and 'B' switches are turned ON during the negative half cycle of input supply.

Difficulty in the above switching strategy arises when the load is inductive in nature which is the case in most applications. Under this circumstance, an additional freewheeling path has to be provided for circulating the load current during the turn OFF of the active switches. To achieve the same, the existing switching sequence is modified to provide for a safe commutation of the matrix switches. In the revised switching strategy, all the switches themselves are involved in safe commutation with the upper switches being used for providing commutation in the positive half cycle of input supply while the lower switches are used in the negative half cycle of input supply. Use of bidirectional matrix switch for safe commutation in the four modes of operation for 100 Hz frequency output is shown in Figure 5(a) to 5(d).

With Z- source network, an additional operating state, known as the Shoot Through state, is also incorporated along with the Active state and free-wheeling state. Shoot Through state refers to turning ON both the upper and lower switches of a phase leg such that the load is short circuited for a short interval. Z- Source network utilizes this state for providing the buck-boost operation of the voltage.

The relation between input and output voltage of Z-source ac-ac converter can be explained as follows. Suppose that for Mode 1 operation to obtain an output frequency of 100 Hz, switches S1A and S4A are turned ON for Active state with S4A being sinusoidal pulse width modulated. If 'T' is the total time period of switching pulse and 'T_1' is the interval for which S4A conducts, then,

Modulation Index, $M = T_1 / T$

Switch S3A is modulated complementary to S4A and let 'T_0' be the interval, for which S3A conducts, then,

Duty Ratio, $D = T_0 / T$

And $M + D = 1$

Active state is thus same as the Non Shoot Through period. Analyzing the Z- source ac-ac converter operation for both the Shoot Through state and Non Shoot Through state, and considering that the voltage drop across the inductor is negligible,

$$V_a = (1- D/ 1- 2D)* V_{in}$$

'V_a' and 'V_{in}' are the rms values of voltage across SPMC and input AC voltage respectively.

The Different modes of operation along with improved switching strategy for safe commutation are summarized in Table 1.

Table 1: Switching Strategy

Output Frequency		*States of Operation*		
	Modes	*Active State*	*Free-wheeling State*	*Shoot Through State*
25 Hz	1 2 3 4	Ssa, S1A, S4A Ssb, S2B, S3B Ssa, S2A, S3A Ssb, S1B. S4B	S2B S4A S1B S3A	S1A,S3A S1B, S3B S2A, S4A S2B, S4B
50 Hz	1 2	Ssa, S1A, S4A Ssb, S1B, S4B	S2B S3A	S1A, S3A S2B, S4B
100 Hz	1 2 3 4	Ssa, S1A, S4A Ssa, S2A, S3A Ssb, S2B, S3B Ssb, S1B. S4B	S2B S1B S4A S3A	S1A, S3A S2A, S4A S1B, S3B S2B, S4B

- *Modes of Operation – Step Up Frequency*

The four modes for a step down frequency operation indicating the switches ON and direction of current through the load are as shown in Figure 5(a) to 5(d).

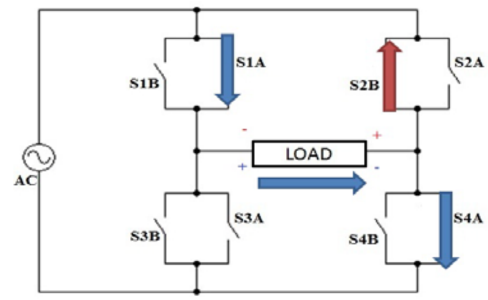

Figure 5(a): Mode 1 for Positive Half Cycle of Input

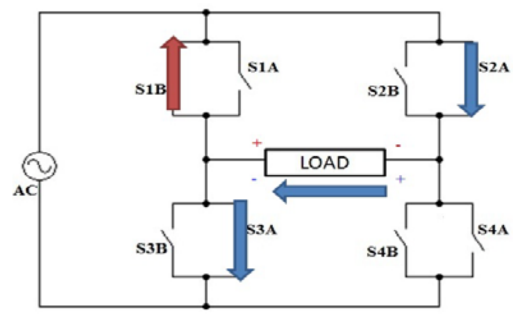

Figure 5(b): Mode 2 for Positive Half Cycle of Input

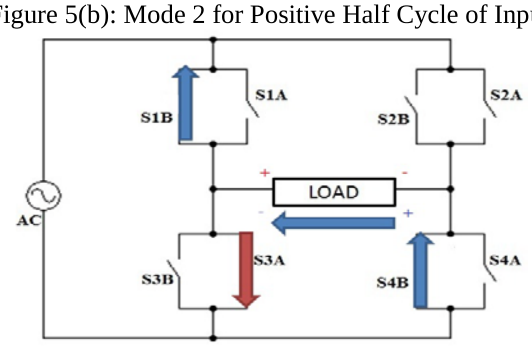

Figure 5(c): Mode 3 for Positive Half Cycle of Input

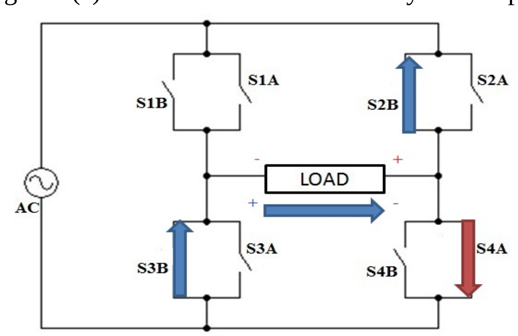

Figure 5(d): Mode 4 for Negative Half Cycle of Input

V. SIMULATION RESULTS

The circuit is simulated in MATLAB as shown in Figure 6 and its performance as a frequency changer can be verified based on the obtained waveforms described under three different cases as shown in Figure 7, Figure 8 and Figure 9 for a switching frequency of 5 kHz.

The simulation parameters of the input LC filter, Z-source network, and load are selected to be L_i = 0.1 mH, C_i = 6.8 uF, L_1 = L_2 = 1 mH, C_1 = C_2 = 1uF, R = 10 ohm. The source voltage is 40 Vrms/50 Hz. The output frequency is varied to either 100 Hz (step-up to twice frequency), 50 Hz (the same frequency), or 25 Hz (step-down to half frequency) from the input.

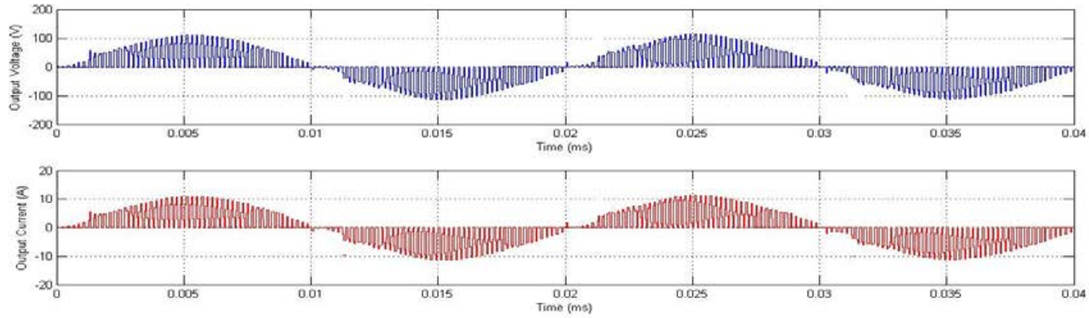

Figure 7: Simulated Output Voltage and Current waveforms for an output frequency of 50 Hz

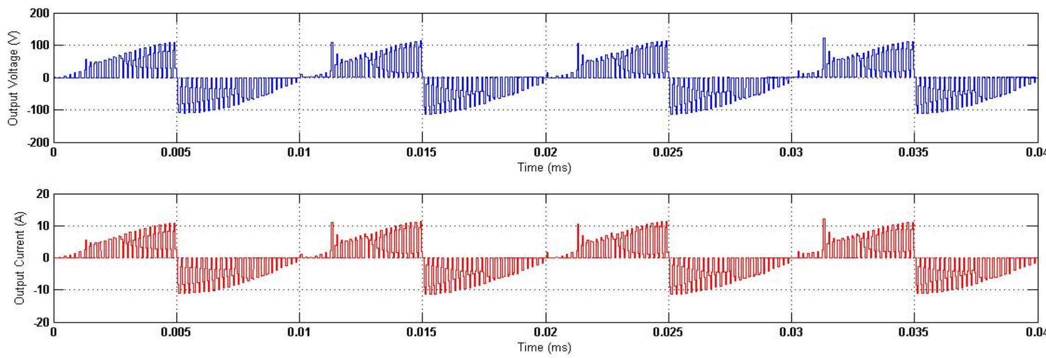

Figure 8: Simulated Output Voltage and Current waveforms for an output frequency of 100 Hz

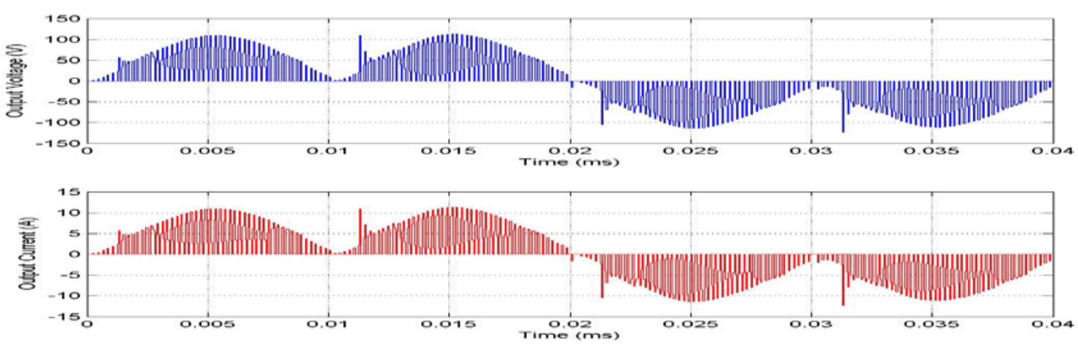

Figure 9: Simulated Output Voltage and Current waveforms for an output frequency of 25 Hz

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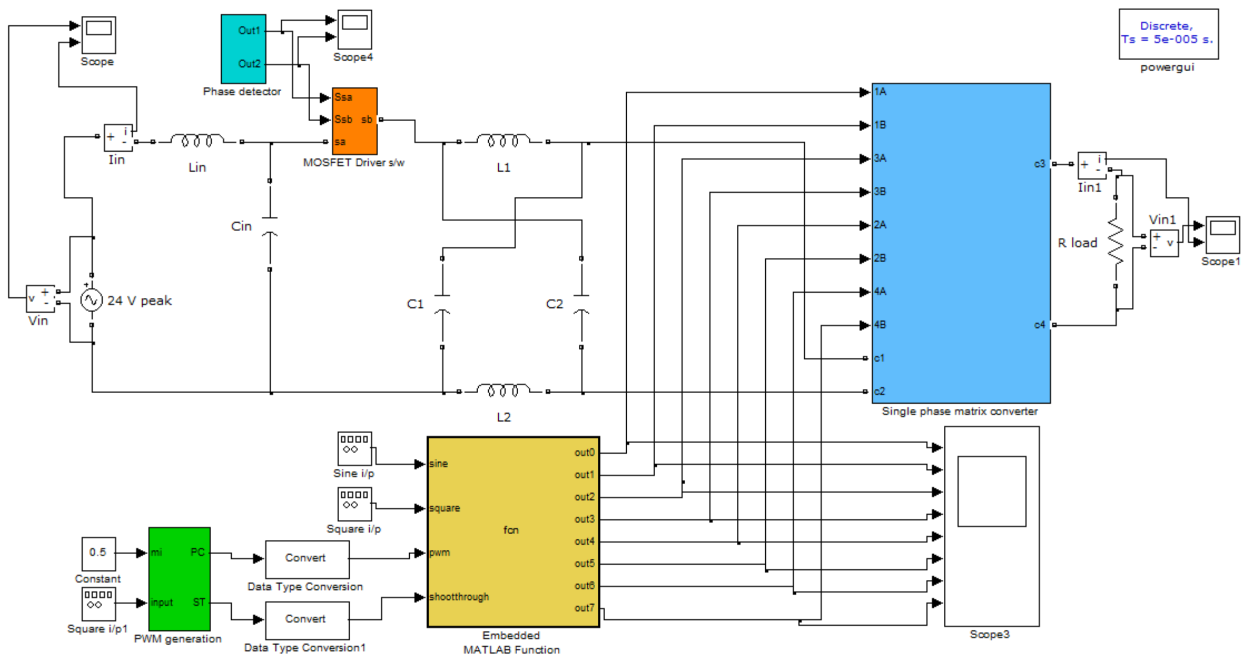

Figure 6: Simulation Diagram

VI. Conclusions

A new topology for a direct AC - AC conversion, the single-phase Z-source matrix converter is proposed that is capable of producing a stepped change frequency output. The output frequency is either an integer multiple or an integer fraction of the input frequency. The simulation was performed using MATLAB and results obtained with an R load showed the output voltage produced at three different frequencies of 100 Hz, 50 Hz and 25 Hz. The proposed topology is expected to cause a significant reduction in cost and size when compared to an indirect ac - ac converter due to the absence of large energy storage dc link capacitor.

A. Drawbacks of the Proposed Topology

Since bidirectional switches are not available as a single unit, each such switch requires two semiconductor switches (MOSFET) thus increasing the total number of switches. When it comes to extremely low power applications, the converter doesn't prove to be cost effective and hardware fabrication in that case can be bulky.

B. Applications

Almost 80 % of applications of SPIM require a stepped change in frequency. Such a conversion strategy can therefore be used in various applications as a single phase induction motor drive where the frequency change happens in steps or stages (e.g. Fan, refrigerator, mixer grinder, Air conditioners etc) because for these applications, the input voltage frequency must be changed in stages to control their speed.

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