

# SINGLE PHASE MATRIX CONVERTER AS AN 'ALL SILICON SOLUTION'

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**Abstract:** This paper presents the Single Phase Matrix Converter topology which offers many advantages with unrestricted switch control or with minimal reactive device use, as an all silicon solution. It elucidates the implementation of Single Phase Matrix Converter as an inverter and as a Controlled Rectifier. Also, with proper switching control algorithm, a type of converter that can buck and boost with step-changed frequency called a Single-Phase Z-Source Buck-Boost Matrix Converter is proposed. It employs a safe-commutation strategy which results in the elimination of voltage spikes on switches without the need of a snubber circuit. The operating principles of this converter for all these configurations are described and the circuit behaviour is confirmed by MATLAB / Simulink simulation results.

**Key words:** Single Phase Matrix Converter, Z-source, Step-up and Step-down frequency, Buck-Boost voltage, Inverter, Rectifier.

## 1. Introduction

A Matrix Converter is an ac/ac converter that can directly convert an ac voltage into an ac voltage of variable amplitude and frequency without a large energy storage element. The topology was first introduced by Gyugyi and Pelly [1] in 1976. In 1980, Venturini and Alesina described it as a generalized transformer – a bidirectional sinusoidal waveform frequency converter [2]. The single phase version called the Single-phase Matrix Converter (SPMC) was first introduced by Zuckerberger [3] based on direct AC-AC converter. Recent research on matrix converters has extended its operation to inverter, controlled rectifier, boost rectifier and buck-boost rectifier [4] - [7]. The research in [8] and [9] focused on step up / step down frequency operation with a safe-commutation strategy. However in all these topologies, the ac output voltage cannot exceed the ac input voltage (since no energy storage components are present between the input and output side and the output voltage waveform is synthesized by sequential piecewise sampling of the input voltage waveforms, the output voltage have to fit within the curve of the input voltage). Furthermore, it is not possible to turn both the bidirectional switches of a single phase leg on at the same time; otherwise 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 [10] – [12] which mainly find applications where only voltage regulation is needed.

In this paper, SPMC topology is shown as an 'All Silicon Solution' with proper switching control strategies that facilitate a safe commutation. SPMC is implemented to act as an Inverter and as a Rectifier. As this safe-commutation scheme, provides a continuous current path in dead time also, it eliminates voltage spikes on switches without the need for a snubber circuit. Also, the Z-source concept is applied to a Single-Phase Matrix Converter with a safe-commutation technique that is very simple to implement. The operation and basic behaviour of this converter is examined through computer simulation. Results show promising prospect of using this SPMC topology as an all-silicon solution – as a Z-Source Single Phase Matrix Converter for voltage applications that require step-changed frequency or variable amplitude, as an Inverter for DC-AC conversions and as a Rectifier for AC-DC conversion.

## 2. Z-Source SPMC

Figure 1 shows the block diagram of the Z-Source Single Phase Matrix Converter. The ac input voltage is boosted by the Z-source converter. The frequency of the input voltage is then modulated in SPMC. Thus, the output voltage is obtained with a step-changed frequency and variable amplitude. The LC input filter is required to reduce the switching ripple in an input current.

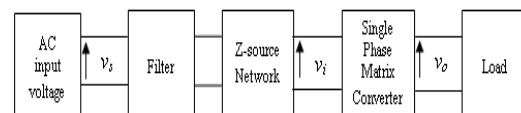


Fig.1 Block diagram of Z-source SPMC

Figure 2 shows the circuit of the Z-source Single-Phase Matrix Converter. It uses four bi-directional switches to serve as a SPMC. This arrangement has the advantage of independent control of the current in both directions. Since these bidirectional

switches are not available at present, they are substituted with two diodes and two IGBTs connected in antiparallel as shown in figure 3. IGBTs are used because of its high switching capabilities and high current carrying capabilities leading to high power applications. Diodes are included to provide the reverse voltage blocking capability.

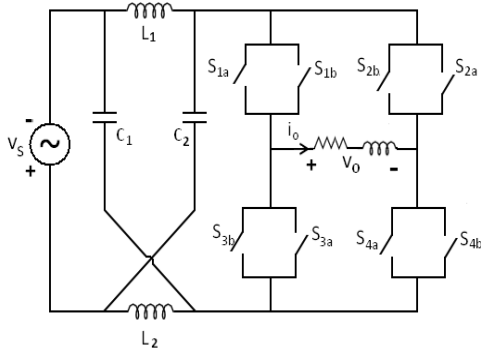


Fig. 2 Circuit of the Z-source SPMC

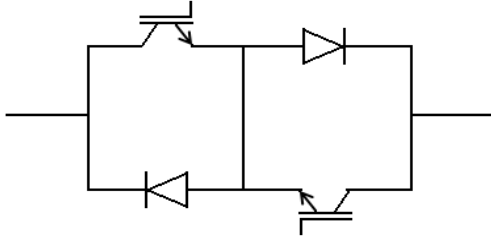


Fig. 3 Common Emitter BDS Topology

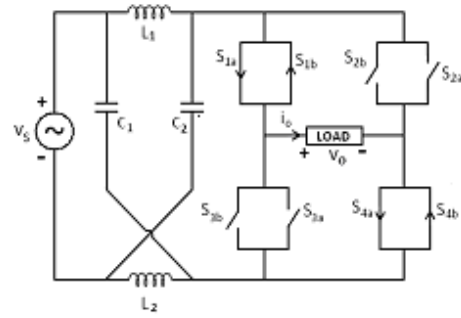
Implementing this Z-source SPMC requires different switching arrangements based on the desired amplitude and frequency. The amplitude of the output voltage is controlled by the shoot-through period and the frequency of the output voltage depends on the switching strategy. Furthermore, if inductive loads are used, a change in instantaneous current across the inductance will produce large voltage spikes that will destroy switches in use, due to stress. A systematic switching sequence is thus required that allows for the energy flowing in the IGBT's to dissipate within the system.

In this paper, the frequency of the input voltage is taken as 50Hz, and the desired output frequency is assumed to be 100Hz (step-up frequency), 50Hz (same frequency) or 25Hz (step-down frequency). The switching strategies for these desired output frequency in boost mode will be described.

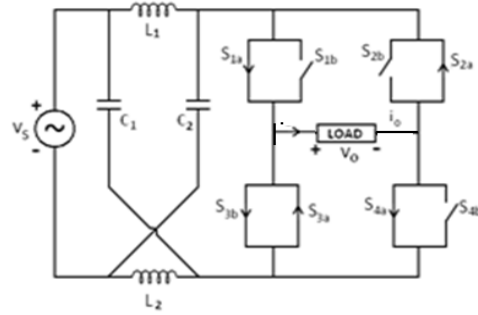
### Switching Strategies

The entire operation can be explained in four modes (figure 4). Each mode has two states – non-shoot-through state and shoot through state. The desired

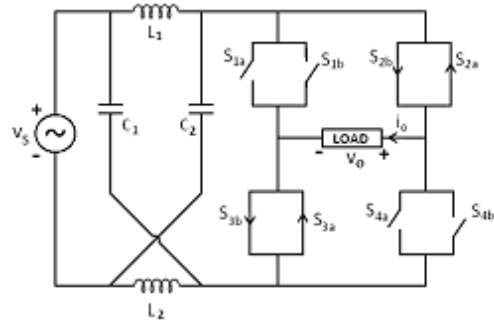
output frequency is then synthesized by proper sequencing of these four modes.



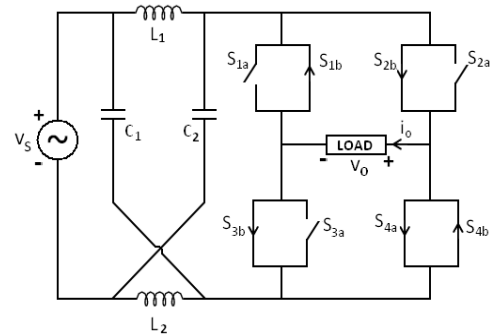
(a)



(b)



(c)



(d)

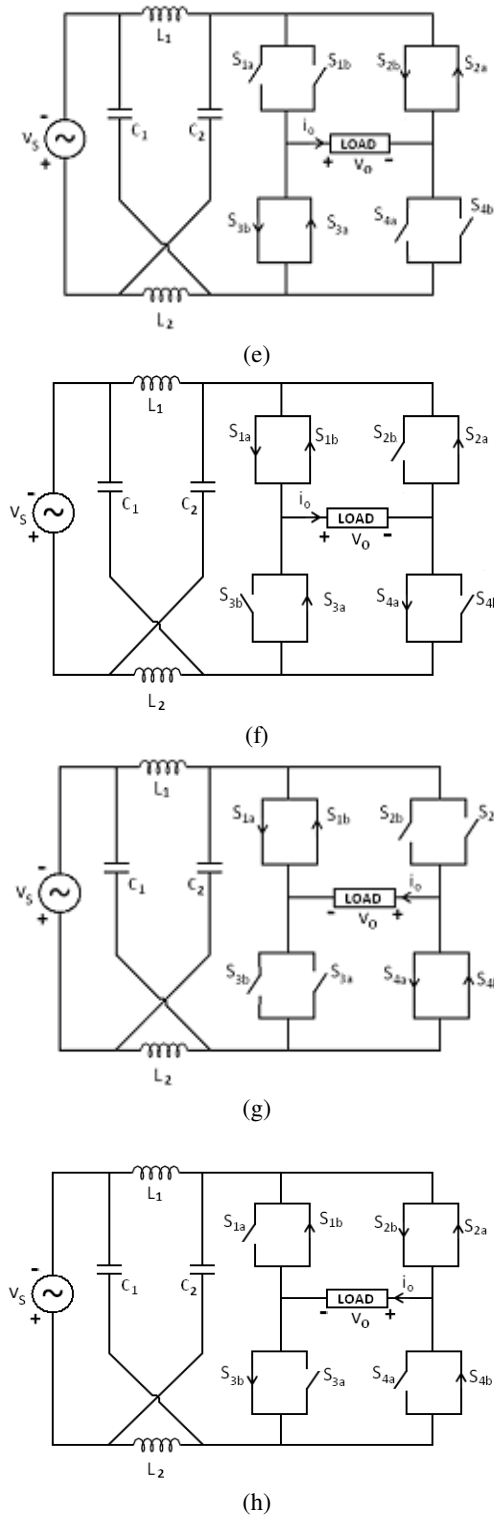


Fig.4 Equivalent Circuits for (a) Mode-1, State-1, (b) Mode-1, State-2, (c) Mode-2, State-1, (d) Mode-2, State-2, (e) Mode-3, State-1, (f) Mode-3, State-2, (g) Mode-4, State-1, (h) Mode-4, State-2

The sequence of switching control for output frequencies 100Hz, 50Hz and 25Hz in boost mode with safe commutation is given in Table 1.

Table 1 – Sequence of Switching Control

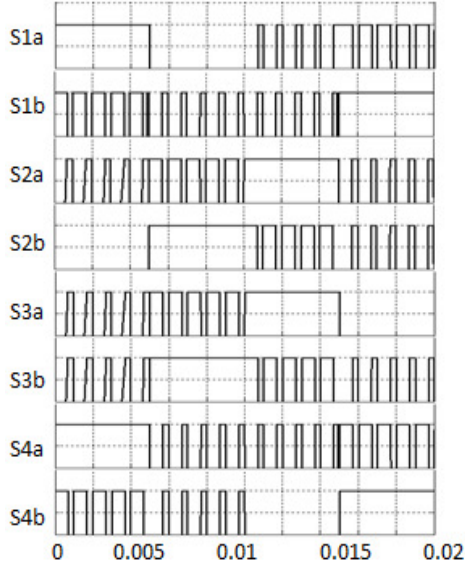
I/p Freq	O/p Freq	Mode	Switches “ON”		
			State-1	State 2	
				Shoot-through	Free-wheeling
50 Hz	100 Hz	1	S1a,S4a, S4b,S1b	S1a, S3b	(S1a, S2a) (S4a, S3a)
		2	S2b,S3b, S3a, S2a	S2b, S4a	(S2b,S1b) (S3b,S4b)
		3	S3a,S2a, S3b,S2b	S3a, S1b	(S3a, S4a) (S2a, S1a)
		4	S4b,S1b, S1a, S4a	S4b, S2a	(S4b,S3b) (S1b,S2b)
	50 Hz	1	S1a,S4a, S4b,S1b	S1a, S3b	(S1a, S2a) (S4a, S3a)
		4	S4b,S1b, S1a, S4a	S4b, S2a	(S4b,S3b) (S1b,S2b)
	25 Hz	1	S1a,S4a, S4b,S1b	S1a, S3b	(S1a, S2a) (S4a, S3a)
		3	S3a,S2a, S3b,S2b	S3a, S1b	(S3a, S4a) (S2a, S1a)
		2	S2b,S3b, S3a, S2a	S2b, S4a	(S2b,S1b) (S3b,S4b)
		4	S4b,S1b, S1a, S4a	S4b, S2a	(S4b,S3b) (S1b,S2b)

The switching pattern generated in boost mode for 100 Hz and 25 Hz with reference to Table 2 is shown in Fig 5. Equal PWM technique which compares a triangular carrier signal with a constant reference signal is used to generate the pulses.

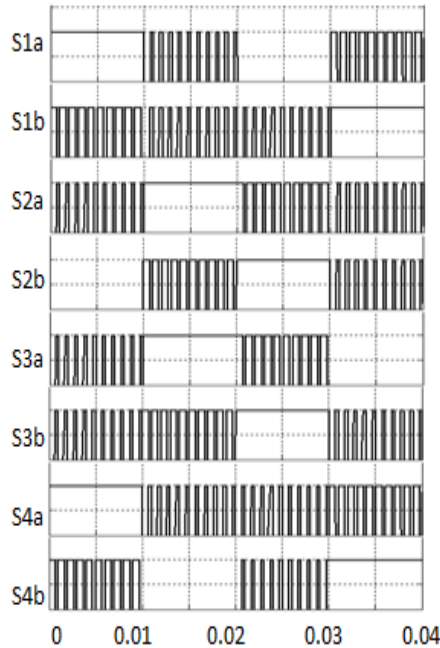
As explained in [12], assuming that the filter inductor and the capacitor in the Z-network are very small and there is no line frequency voltage drop across the inductor, the voltage across the load is given by equation (1).

$$v_o = \left| \frac{1-D}{1-2D} \right| v_i \quad (1)$$

Evidently, by controlling the duty ratio  $D$ , the output voltage of the Z-source SPMC can be bucked or boosted.



(a)

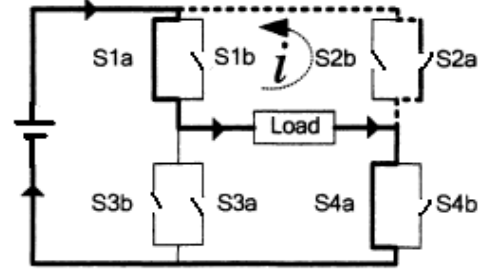


(b)

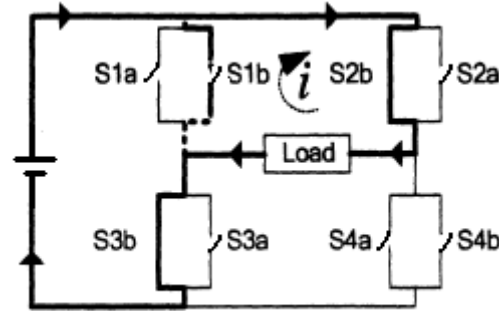
Fig.5 Switching Pattern of the Z-source Single Phase Matrix Converter in boost mode for (a) 100 Hz (b) 25Hz

### 3. SPMC as an Inverter

The entire operation of SPMC as an inverter can be explained in two modes (Figure 6 (a) and Figure 6 (b)).



(a)



(b)

Fig.6 Equivalent Circuits for operation of SPMC as an Inverter (a) Mode-1 (b) Mode-2

The modulation of switches for the operation of SPMC as an Inverter is given in table 2.

Table 2 – Modulation of Switches for Inverter Operation

Output State	Mode	Switches ON	Commutation Switch ON
Positive	1	S1a & S4a	S2a
Negative	2	S2b & S3b	S1b

In shunt active power filter applications where bidirectional control is required for energy transformation these single phase matrix converters operating as an inverter can be used. It also allows the motor loads to operate with regenerative capabilities supplying energy back to the supply.

#### 4. SPMC as a Rectifier

The entire operation of SPMC as a rectifier can be explained in two modes (Figure 7 (a) and Figure 7 (b)).

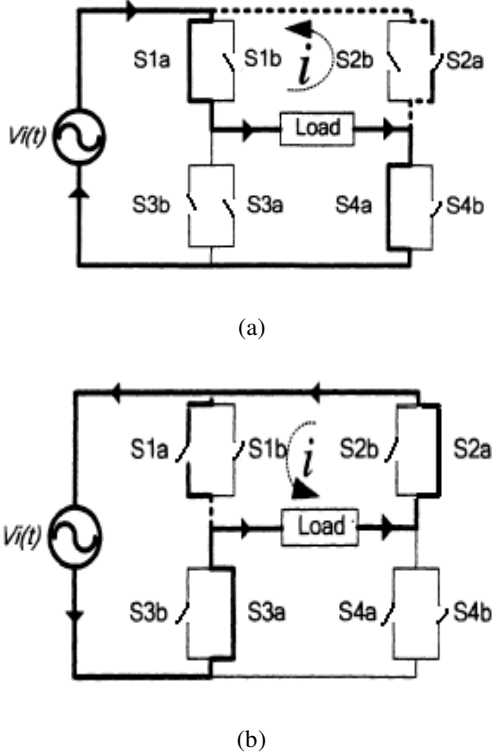


Fig.7 Equivalent Circuits for operation of SPMC as a Rectifier (a) Mode-1 (b) Mode-2

The modulation of switches for the operation of SPMC as an Inverter is given in table 3.

Table 3 – Modulation of Switches for Rectifier Operation

Input State	Mode	Switches ON	Commutation Switch ON
Positive	1	S1a & S4a	S2a
Negative	2	S2a & S3a	S1a

This arrangement in comparison with the conventional controlled rectifier has four bidirectional switches which have the advantage of independent control of current in both directions within each switch cell. The commutation problems that are inherent in SPMC are eliminated with the safe commutation strategy.

#### 5. Results and Discussions

The simulation results of Z-Source SPMC, SPMC as an Inverter and as a Rectifier are shown.

##### Z-Source SPMC

The parameters selected for simulation are  $L1 = L2 = 1\text{mH}$ ,  $C1 = C2 = 100\mu\text{F}$ ,  $R = 10\Omega$ ,  $L = 1\text{mH}$ . The switching frequency is set to 1 kHz. The input voltage is  $40\text{Vrms} / 50\text{Hz}$ . Simulation results in boost mode with  $D = 0.3$  for output frequencies 50Hz, 100Hz and 25Hz are shown in figure 8, figure 9 and figure 10 respectively and it is observed that, the output voltage is  $57\text{Vrms}$  which is greater than the input voltage with the output frequency modulated to 100Hz, 50Hz or 25Hz. Also the Capacitor voltages and Inductor Currents in the Z impedance are shown for output frequencies 50 Hz, 100 Hz and 25 Hz.

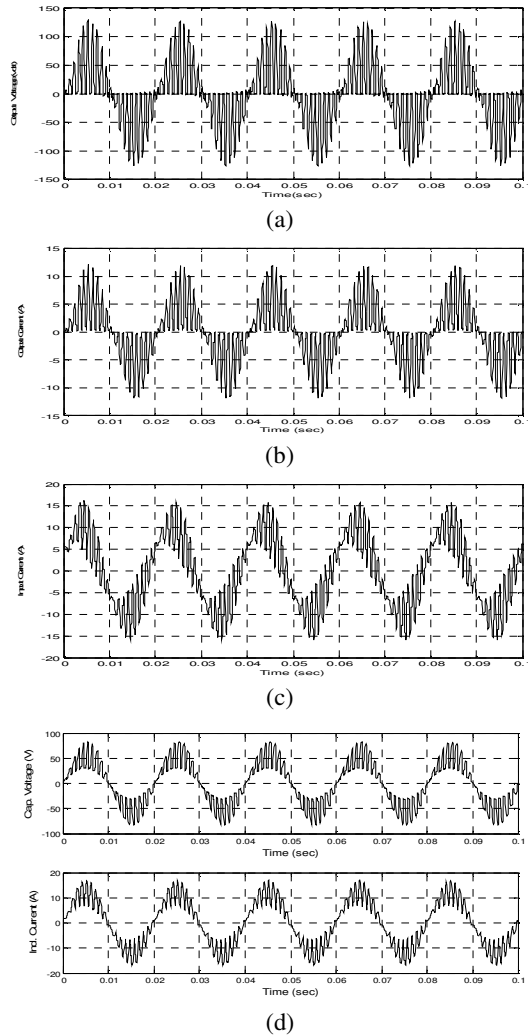


Fig.8 Simulated result at 50Hz frequency with  $D=0.3$  Boost Mode. (a) Output Voltage, (b) Output Current, (c) Input Current, (d) Capacitor Voltage & Inductor Current

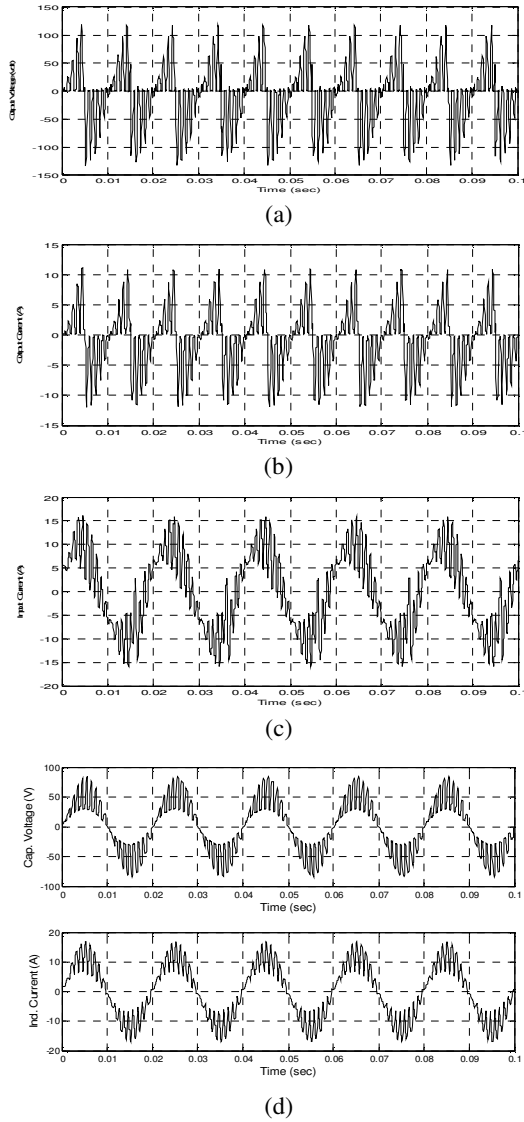


Fig.9 Simulated result at 100Hz frequency with  $D=0.3$  Boost Mode. (a) Output Voltage (b) Output Current (c) Input Current (d) Capacitor Voltage & Inductor Current

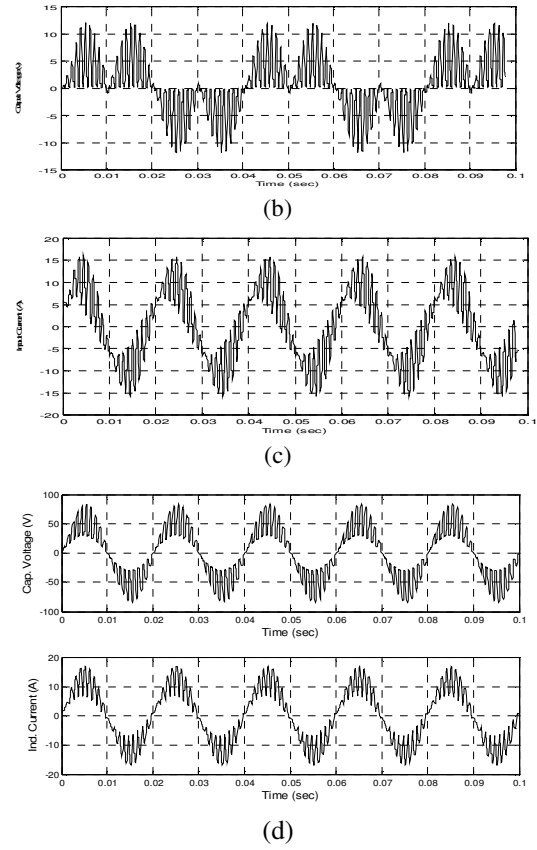
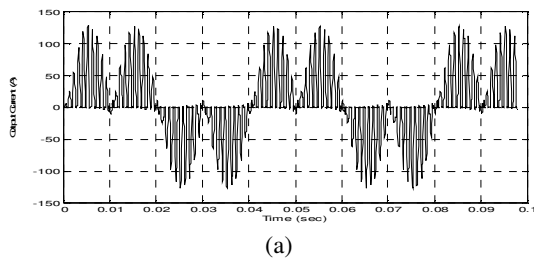


Fig.10 Simulated result at 25Hz frequency with  $D=0.3$  Boost Mode. (a) Output Voltage, (b) Output Current, (c) Input Current (d) Capacitor Voltage & Inductor Current

On comparison with the Rectifier – Inverter arrangement for voltage and frequency control, this proposed topology has minimal energy storage requirements by getting rid of the bulky, energy storing capacitors and also provides a bidirectional energy flow capability. So, the key benefit for this approach is the possibility of greater power density due to the absence of a DC link. Also the voltage spikes on switches are eliminated here with a safe commutation scheme without the need for a snubber circuit.

### SPMC as an Inverter

Simulation results of SPMC operating as an Inverter with an input voltage of 100 V DC for a RL Load is shown in figure 11. The switching frequency is set to 1 kHz.

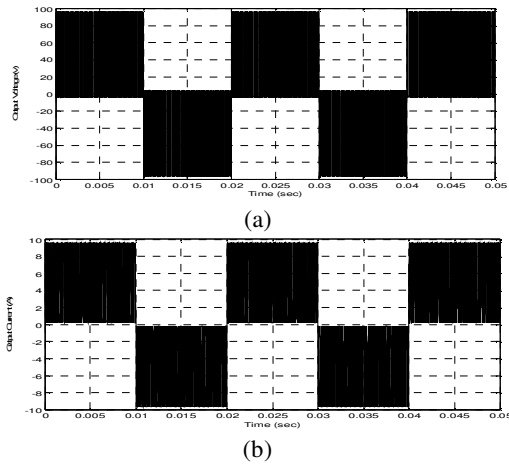


Fig.11 Simulated result of SPMC as an Inverter with Input Voltage = 100 v. (a) Output Voltage (b) Output Current

### SPMC as a Rectifier

Simulation results of SPMC operating as a Rectifier with an input voltage of 230 V, 50 Hz for a RL Load is shown in figure 12. The switching frequency is set to 1kHz.

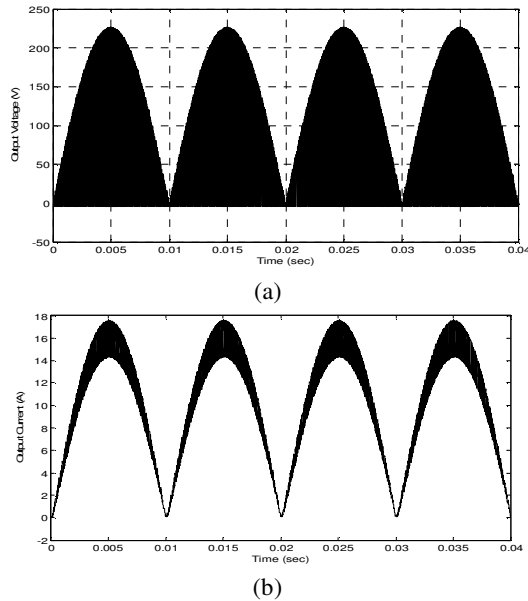


Fig.12 Simulated result of SPMC as a rectifier with Input Voltage = 230 v & 50 Hz. (a) Output Voltage, (b) Output Current

### 6. Conclusion

In this paper, a Z-source Single Phase Matrix Converter with a new safe commutation strategy has been proposed. This SPMC control produces output voltage in buck-boost mode with a step-changed

frequency. This safe commutation strategy avoids voltage spikes on switches without the use of a snubber circuit. This converter with the proposed strategy can be used as Dynamic Voltage Restorer (DVR) to compensate voltage sags and swells in AC/AC line conditioning without any energy-storage devices requirement. It can also be applied to the speed control of an induction motor which needs a step-changed speed.

Also, a single circuit is developed that performs both the rectifier and inverter operations. Commutation strategies are also implemented with reduction in spikes, a common phenomenon in matrix converter topologies. This single circuit can be made to operate as an Uninterruptible Power Supply Circuit.

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