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A Z-source single phase matrix converter with safe commutation strategy

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Abstract
This paper presents a type of converter that can buck and boost with step-changed frequency called a Single-Phase Z-Source Buck-Boost Matrix Converter. It employs a safe-commutation strategy which results in the elimination of voltage spikes on switches without the need of a snubber circuit. This is facilitated through proper switching control algorithm. The operating principles of this converter are described and the circuit behaviour is confirmed by MATLAB / Simulink simulation results.

Keywords: Single phase matrix converter, Z-source, Step-up and step-down frequency, Buck-boost voltage.

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 generalised 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, 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 researches have also focused on Z-source AC/AC converters [10-12] which mainly finds applications where only voltage regulation is needed.
In this paper, the Z-source concept is applied to a Single-Phase Matrix Converter with a safe-commutation technique that is very simple to implement. 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. This Z-source Single-Phase Matrix Converter provides a wide-range of output AC voltages in buck-boost mode with step-up / step-down frequencies. The operation and basic behaviour of this converter is examined through computer simulation. Results show promising prospect of using this

Z-Source Single Phase Matrix Converter for voltage applications that require step-changed frequency or variable amplitude.

2. Z-source single phase matrix converter

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 a variable amplitude. The LC input filter is required to reduce the switching ripple in an input current.

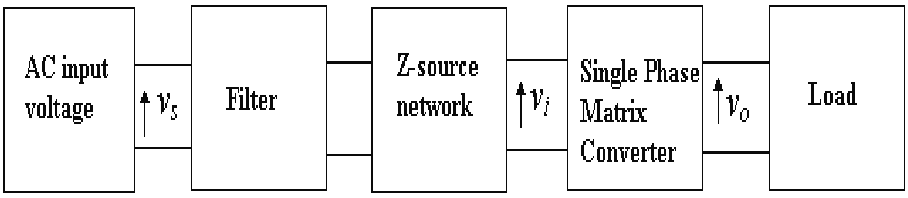


Figure 1. Block diagram of Z-source SPMC

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.

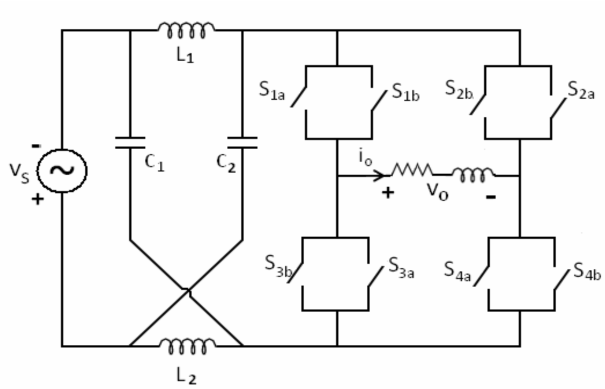


Figure 2. Circuit of the Z-source SPMC

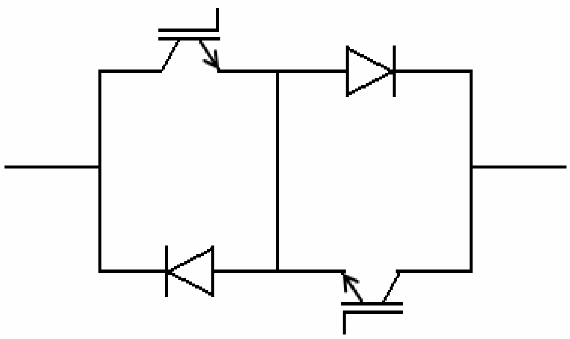


Figure 3. Common emitter BDS topology

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.

3. 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.

The sequence of switching control for output frequencies 100Hz, 50Hz and 25Hz in boost mode with safe commutation is given in Table 1. The switching pattern in boost mode for 100 Hz and 25 Hz is shown in Figure 5.

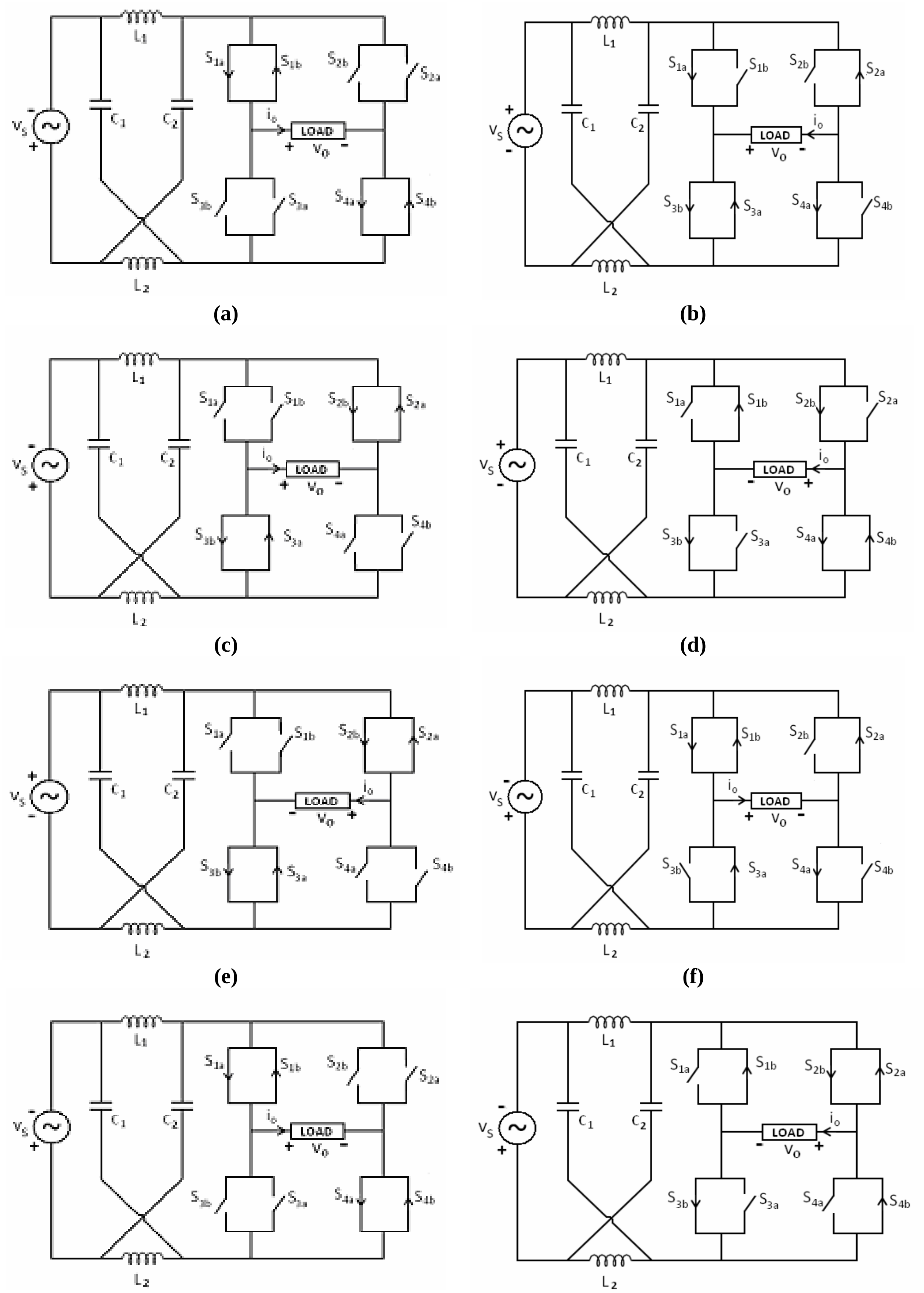
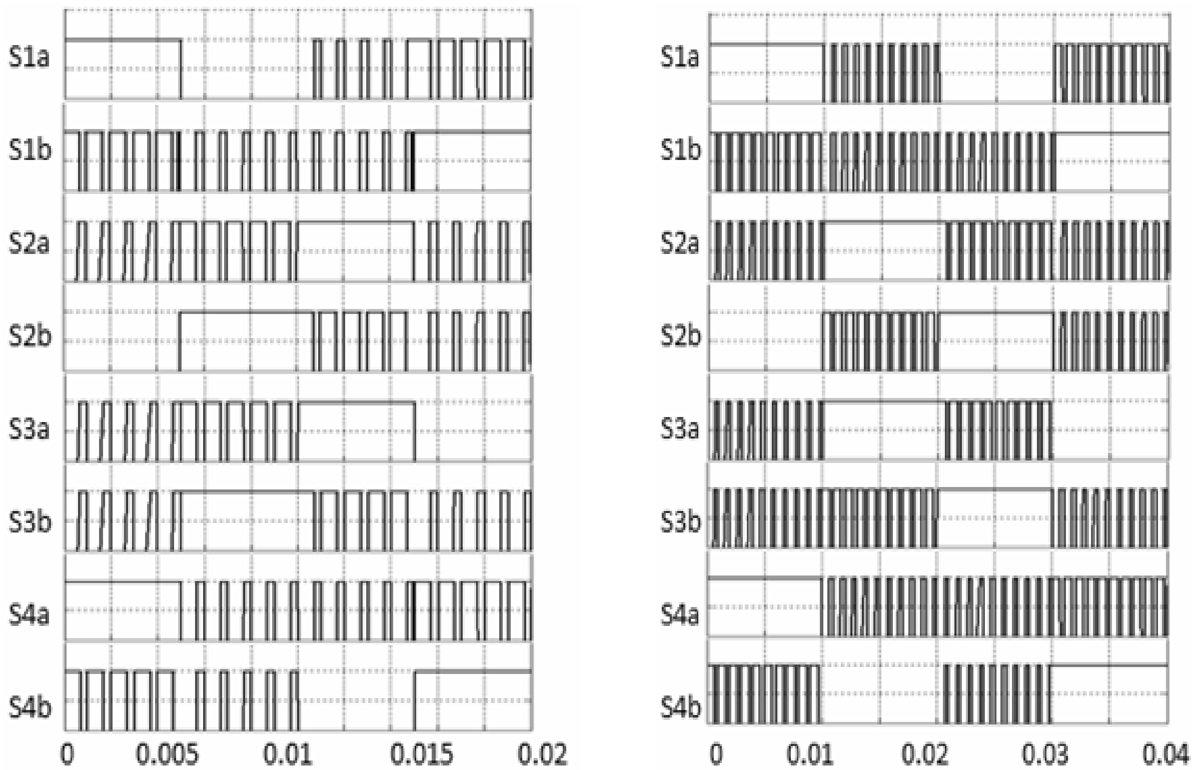


Figure 4. Equivalent Circuits for (a) Mode-1, State-1, (b) Mode-1, State-2, (c) Mode-2, State-1, (d) Mode-2, State-2, (e) Mode-3, State-1, (f) Mode-3, State-2, (g) Mode-4, State-1, (h) Mode-4, State-2

Table 1. Sequence of switching control

Input Freq	Output Freq.	Mode	Switches "ON"		
			State-1	State 2	
				Shoot-through	Free-wheeling
50Hz	100Hz	1	S_{1a},S_{4a}, S_{4b},S_{1b}	S_{1a}, S_{3b}	(S_{1a}, S_{2a}) (S_{4a}, S_{3a})
		2	S_{2b},S_{3b}, S_{3a}, S_{2a}	S_{2b}, S_{4a}	(S_{2b},S_{1b}) (S_{3b},S_{4b})
		3	S_{3a},S_{2a}, S_{3b},S_{2b}	S_{3a}, S_{1b}	(S_{3a}, S_{4a}) (S_{2a}, S_{1a})
		4	S_{4b},S_{1b}, S_{1a}, S_{4a}	S_{4b}, S_{2a}	(S_{4b},S_{3b}) (S_{1b},S_{2b})
	50Hz	1	S_{1a},S_{4a}, S_{4b},S_{1b}	S_{1a}, S_{3b}	(S_{1a}, S_{2a}) (S_{4a}, S_{3a})
		4	S_{4b},S_{1b}, S_{1a}, S_{4a}	S_{4b}, S_{2a}	(S_{4b},S_{3b}) (S_{1b},S_{2b})
	25Hz	1	S_{1a},S_{4a}, S_{4b},S_{1b}	S_{1a}, S_{3b}	(S_{1a}, S_{2a}) (S_{4a}, S_{3a})
		3	S_{3a},S_{2a}, S_{3b},S_{2b}	S_{3a}, S_{1b}	(S_{3a}, S_{4a}) (S_{2a}, S_{1a})
		2	S_{2b},S_{3b}, S_{3a}, S_{2a}	S_{2b}, S_{4a}	(S_{2b},S_{1b}) (S_{3b},S_{4b})
		4	S_{4b},S_{1b}, S_{1a}, S_{4a}	S_{4b}, S_{2a}	(S_{4b},S_{3b}) (S_{1b},S_{2b})



(a) **(b)**

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

4. Circuit equations

The Z-source Single Phase Matrix Converter has two operating states in one switching period: State 1 and State 2 as shown in Figure 4. Since the inductors and capacitors of the Z-network have the same inductances (L) and capacitances (C), the Z-source network becomes symmetrical.

Then as explained in [12], in State 1, the AC source charges the Z-network capacitors, while the inductors discharge and transfer energy to the load. The interval of the converter operating in this state is (1-D)T, where D is the duty ratio of the switches and T is the switching Period.

$$v_c = v_i - v_L \; and \; v_o = v_i - 2v_L \tag{1}$$

where v_c is the voltage across the capacitor, v_i is the input voltage and v_L is the voltage across the inductor.

In State 2, the Z-network capacitors discharge, while the inductors charge and store energy. The interval of the converter operating in this state is DT. Thus

$$v_c = v_L \; and \; v_o = 0 \tag{2}$$

The average voltage of the inductors (V_L) over one AC line period in steady state should be zero, ignoring the fundamental voltage drop. Thus,

$$V_L = \int_0^{DT} v_c . dt + \int_0^{(1-D)T} (v_i - v_c).dt = 0 \tag{3}$$

$$Or \frac{v_c}{v_i} = \left| \frac{1-D}{1-2D} \right| \tag{4}$$

Assuming that the filter inductor and the inductor in the Z-network are very small and there is no line frequency voltage drop across the inductor, the voltage across the load should equal to Vc, the voltage across the capacitor of the Z-network.

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

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

5. Simulation model

This proposed control concept is verified through simulation using MATLAB / Simulink. For simulation, the parameters selected are $L_1 = L_2 = 1mH$, $C_1 = C_2 = 100\mu F$, $R = 10\Omega$, $L = 1mH$. The switching frequency is set to 1kHz. The input voltage is $40V_{rms}$ / 50Hz.

6. Results and discussions

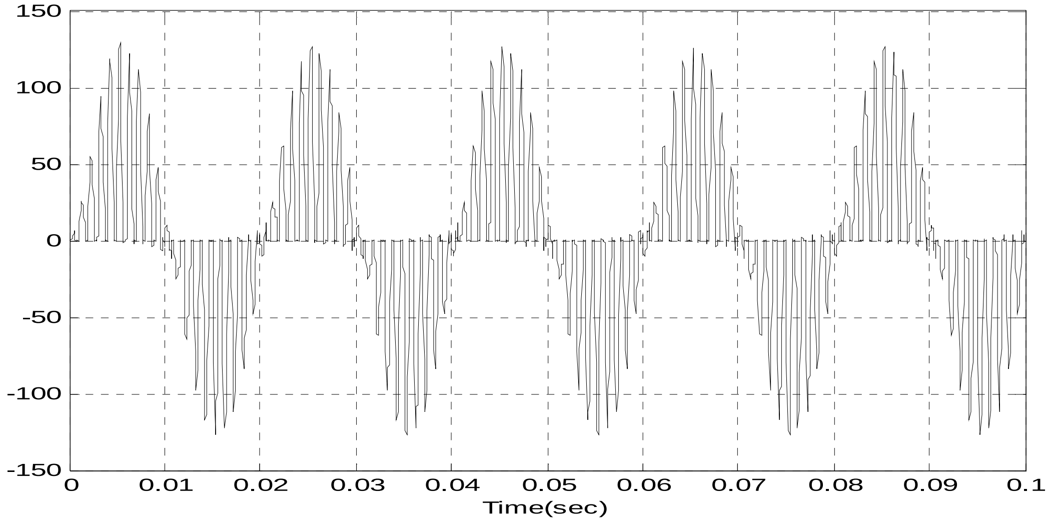
Simulation results in boost mode with D= 0.3 for output frequencies 50Hz, 100Hz and 25Hz are shown in Figures 6-8 respectively and it is observed that, the output voltage is greater than the input voltage with the output frequency modulated to 100Hz, 50Hz or 25Hz.

The Harmonic Analysis is done for the input current waveforms and is shown in Figure 9.

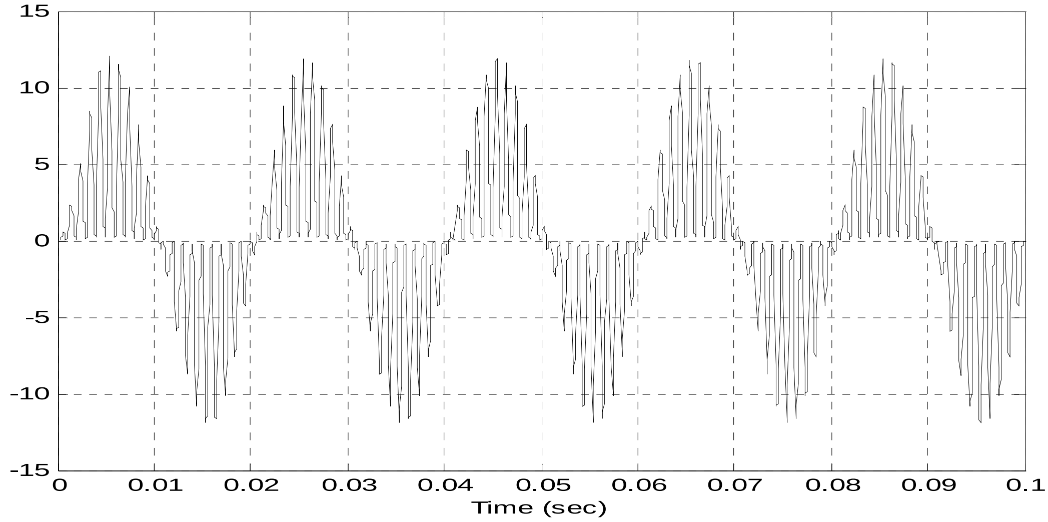
7. Conclusion

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.



(a)



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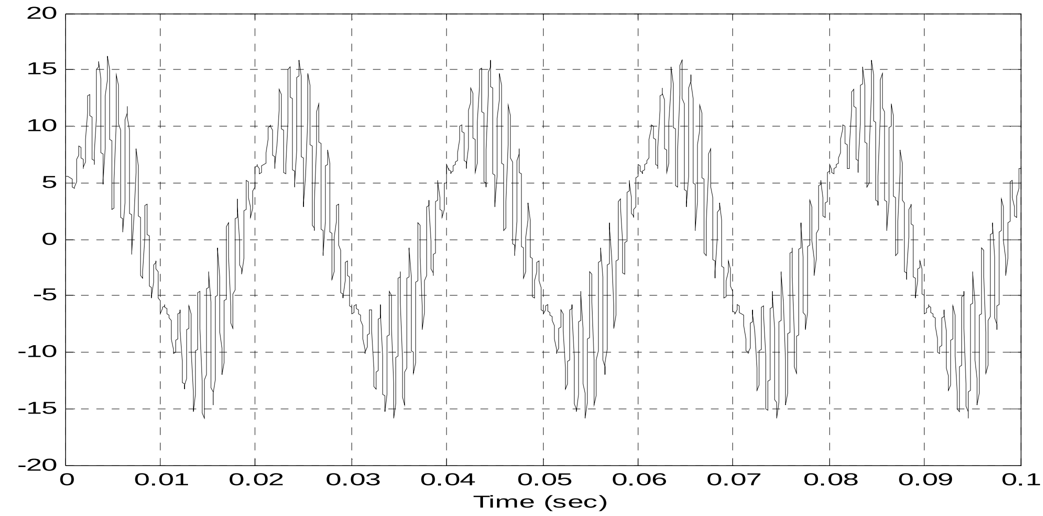
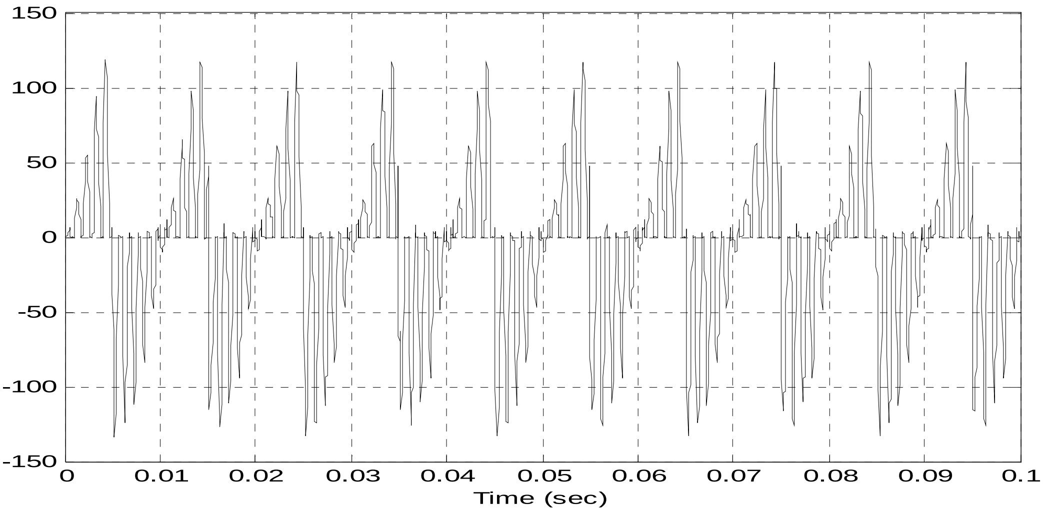


(c)

Figure 6. Simulated result at 50Hz frequency with D=0.3 Boost Mode. (a) output voltage, (b) output current, (c) input current



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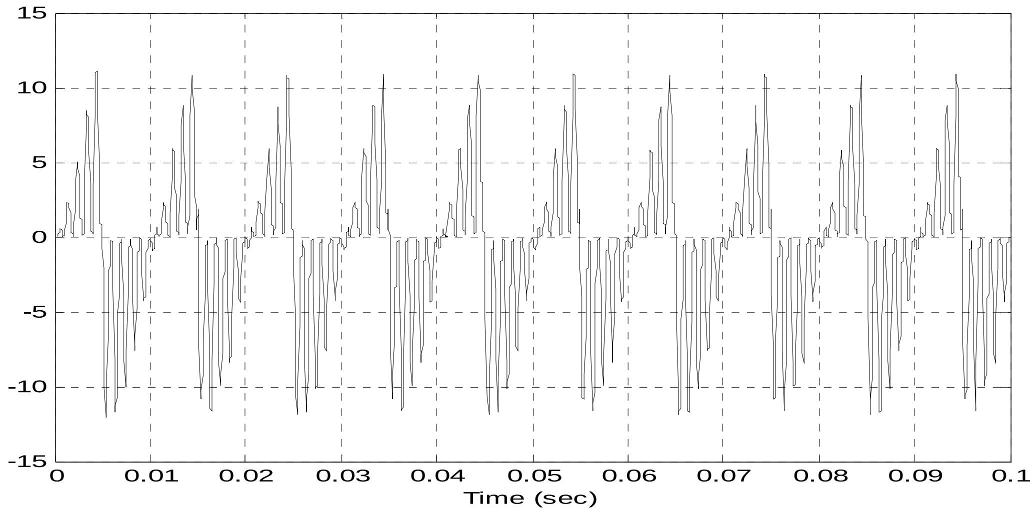

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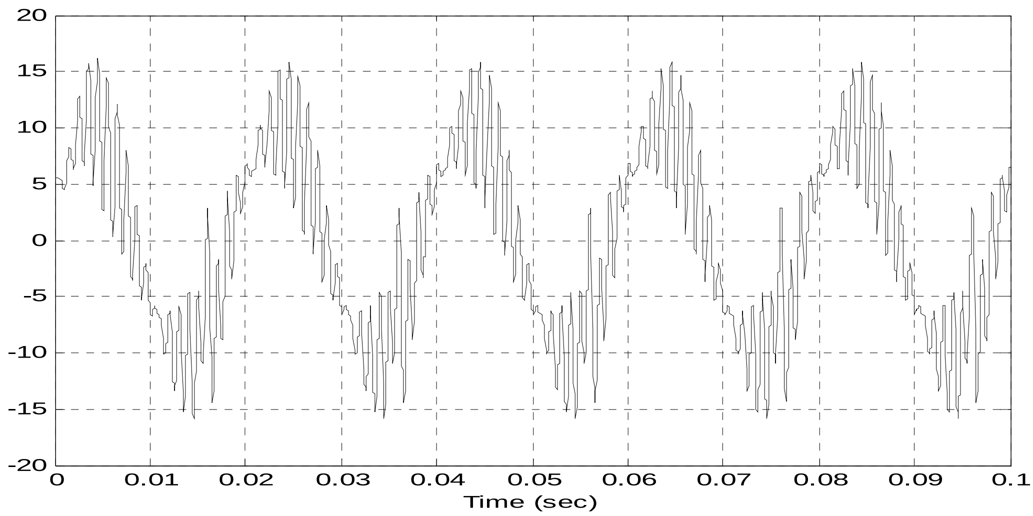
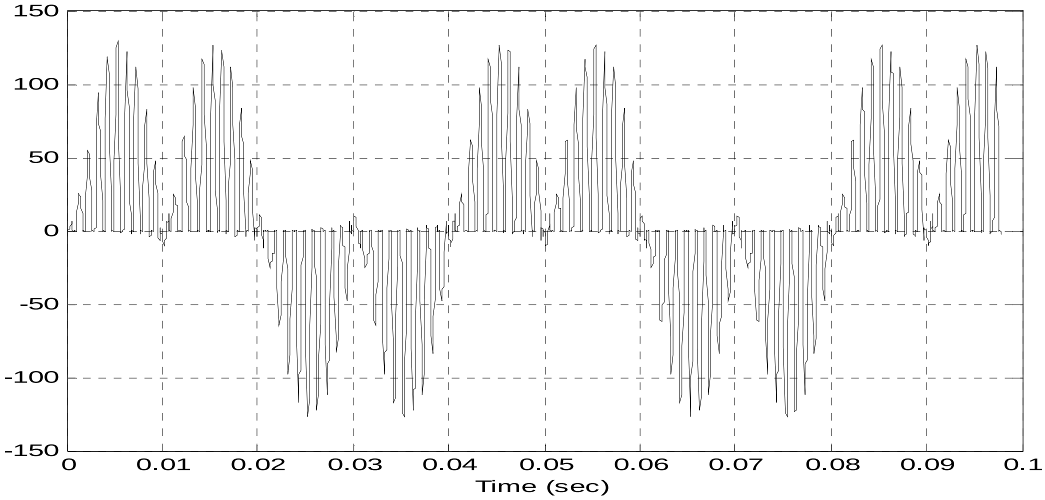
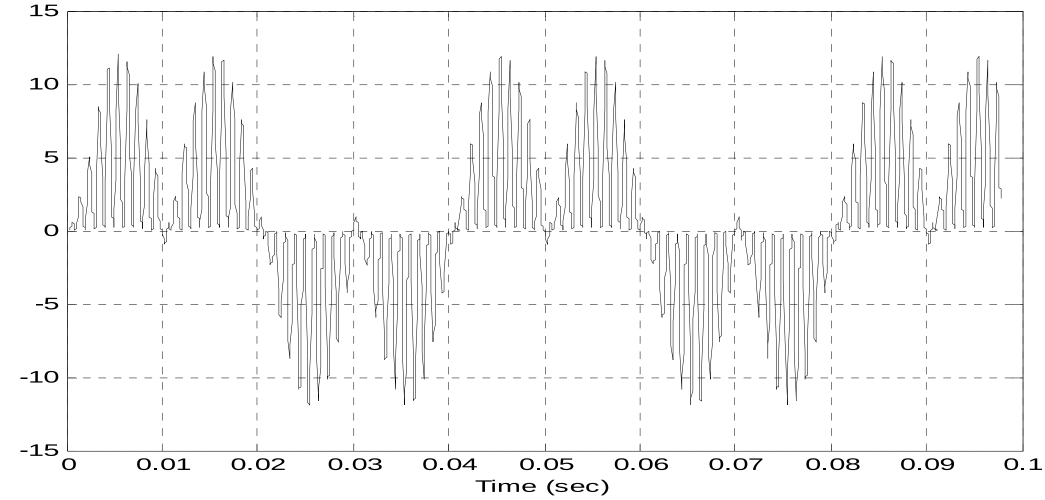


(c)

Figure 7. Simulated result at 100Hz frequency with D=0.3 Boost Mode. (a) output voltage, (b) output current, (c) input current



(a)



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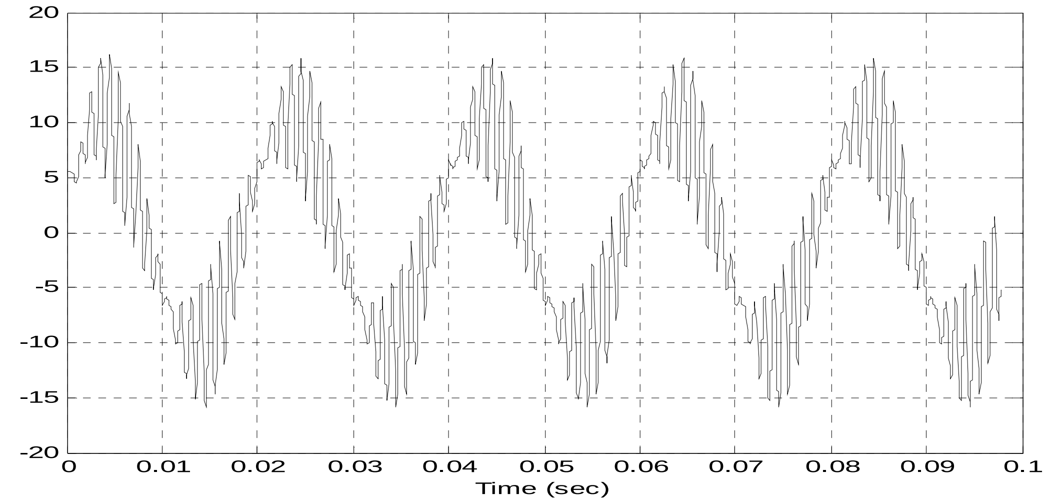
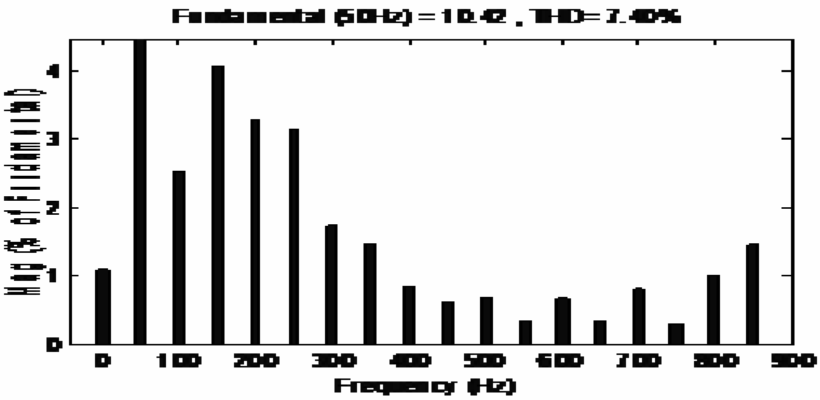
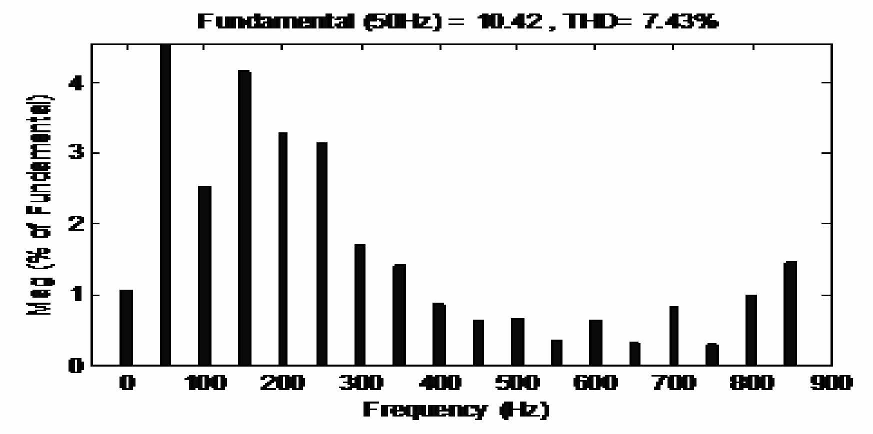


(c)

Figure 8. Simulated result at 25Hz frequency with D=0.3 Boost Mode. (a) output voltage, (b) output current, (c) input current



(a)



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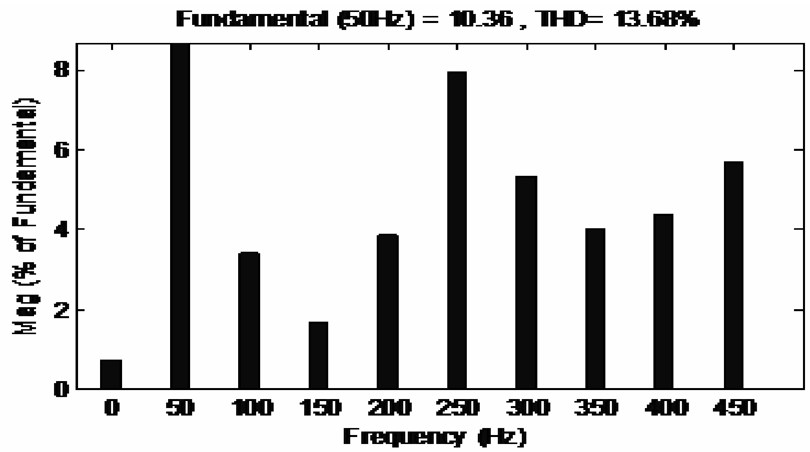

(c)

Figure 9. Harmonic Analysis of input current waveforms for simulated result at (a) 50Hz (b) 25Hz (c) 100Hz

References

[1] L.Gyugyi and B.R.Pelly, Static Power Frequency Changers: Theory, Performance and Application. New York: Wiley, 1976.

[2] M.Venturini and A.Alesina, "The generalized transformer: A new bidirectional sinusoidal waveform frequency converter with continuously adjustable input power factor," in Proc. IEEE PESC 1980, pp. 242-252.

[3] A.Zuckerberger, D.Weinstock and A.Alexandrovitz, "Single-phase matrix converter," in Proc. Inst. Electrical Engineering Electric Power Application, 1997, Vol. 144, pp. 235-240.

[4] Mohammed Noor, Siti Zaliha, M.K.Hamzah, R.Baharom, “A new single-phase inverter with bidirectional capabilities using SPMC”, IEEE PESC 2007, pp. 464-470.

[5] R.Baharom, Hasim M.K..Hamzah, Omar, “A new single-phase controlled rectifier using SPMC,” IEEE PECon 2006, pp. 453-458.

[6] R.Baharom, R.Hamzah, K.S.Hamzah, M.K.Muhammad, “Boost Rectifier using SPMC”, IEEE AECon 2008, pp.2205-2210.

[7] R.Baharom, R.Hamzah, K.S.Hamzah, M.K.Saparon, “SPMC operating as buck and boost rectifier”, IEEE AECon 2009, pp.3338-3342.

[8] Z.Idris, M.K. Hamzah and M.F. Saidon, “Implementation of SPMC as a direct ac-ac converter with commutation strategies,” IEEE PESC 2006, pp. 2240-2246.

[9] A.K..Gola and V.Agarwal, Implementation of an efficient algorithm for a SPMC,” J. Power Electron, Vol. 9, No.2, pp. 198-206, March 2009.

[10] Y.Tang, C.Zhang and S.Xie, “Single phase four switches Z-source ac-ac converters,” in Proc. IEEE APEC 2007, pp. 621-625.

[11] Y.Tang, S.Xie and C.Zhang, “Z-source ac-ac converters solving commutation problem,” IEEE Trans. Power Electron, Vol. 22, No. 6, pp. 2146-2154, Nov. 2007.

[12] X.P.Fang, Z.M.Qian and F.Z.Peng, “Single phase Z-source PWM ac-ac converters,” IEEE Power Electron. Lett. Vol. 3, No.4, pp. 121-124.

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