A Comparative Study of Switching Strategies for Single Phase Matrix Converter

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Abstract: AC-AC power conversion particularly for speed control of AC drives is done with single phase cyclo-converters. In this work the single-phase matrix converter (SPMC) topology is used as a cyclo-converter. IGBT are used as power switches. The sinusoidal pulse width modulation has been used for generation of pulses. This paper presents three different switching strategies for SPMC. A comparison is made between these three strategies based on parameters such as type of load to which the strategy is restricted, number of switches kept ON during single time interval, output voltage waveform of SPMC and its THD.

Keywords: Sinusoidal Pulse Width Modulation (SPWM), Insulated Gate Bipolar Transistor (IGBT), Single Phase Matrix Converter (SPMC), Pulse Width Modulation (PWM), Complementary of PWM (cPWM).

Introduction

AC-AC conversion consist of converting fixed ac voltage with fixed frequency to variable ac voltage with variable frequency, which can be done by two methods: 1) Indirect method and 2) direct method. Indirect method is the most common approach for the ac-ac power conversion which consist of a rectifier at supply side and inverter at the load side. Such an arrangement would require energy storage element like capacitor or an inductor in the intermediate dc link. These element make the converter bulky and useless in application requiring regenerative operation. These limitation can be overcome by the direct method for ac-ac conversion without any intermediate dc link [1]. Such an operation is performed by a cyclo-converter which converts the ac power at one frequency directly to another frequency. The most desirable features for any power frequency changer are: 1) Simple and compact power circuit 2) Generation of load voltage with arbitrary amplitude and frequency 3) Sinusoidal input and output currents 4) Operation with unity power factor for any load 5) Regeneration capability. These characteristics are not fulfilled by the conventional cyclo-converters, which leads to the use of matrix converter topology as it fulfills the ideal features. The matrix converter provides an “all silicon” solution for direct ac-ac conversion without any intermediate dc link thus eliminating the use of reactive energy storage elements. It consists of bidirectional switches which allows any output phase to be connected to any input phase. The topology was first proposed by Gyugyi. In recent years, matrix converter has gained a lot of attention for the traction application. The commutation between the switches in a matrix converter results in current spikes which are their major drawback [2]. Development of three phase matrix converter started with the work of Venturini and Alesina published in 1980 [4]. The SPMC was first developed by Zuckerberger [5]. Study of other SPMC topology had been carried out by Hossieni [6] and Abdollah Khoei [7] and Saiful [8]. Due to the absence of natural free-wheeling paths commutation issues need to be resolved in any PWM type of converter [9]. When inductive loads are used there may be switching spikes [10]. Switching arrangements for safe commutation is proposed by Zahiruddin. [11]. Amongst previous development of the cycloconverter includes; work on improvements of harmonic spectrum in the output voltage with new control strategies [12], new topology [13] and study of the cyclo-converter behaviour [14]. In this work, three different switching strategies are studied for obtaining AC-AC conversion from 50Hz to 150Hz. A computer simulation model on SPMC for cyclo-converter operation using MATLAB/Simulink (MLS) software package is developed. The simulation results for all three strategies have been portrayed and studied in this paper with all their advantages and limitation.

The single phase matrix converter as a cyclo-converter

The SPMC requires four bi-directional switches capable of blocking voltage and conducting current in both directions for its cyclo-converter operation. The basic circuit diagram is shown in Figure. 1. Currently due to the unavailability of any such discrete semiconductor device which could fulfil the needs, hence Common Emitter anti-parallel IGBT, diode pair is used as shown in Figure. 2. Diodes are used to provide reverse blocking capability to the switch module. IGBT’s are used due to its high switching capabilities and high current carrying capacities for high power applications

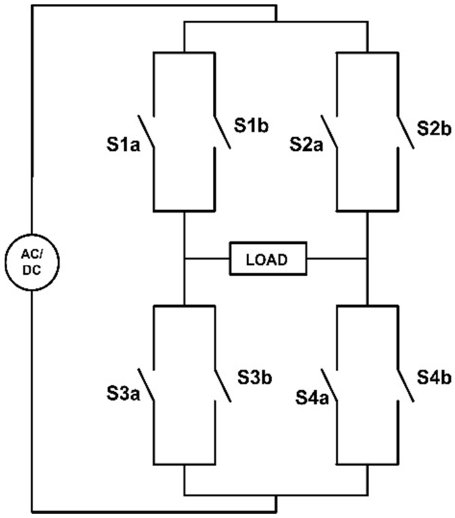

Figure 1: Basic circuit diagram of SPMC

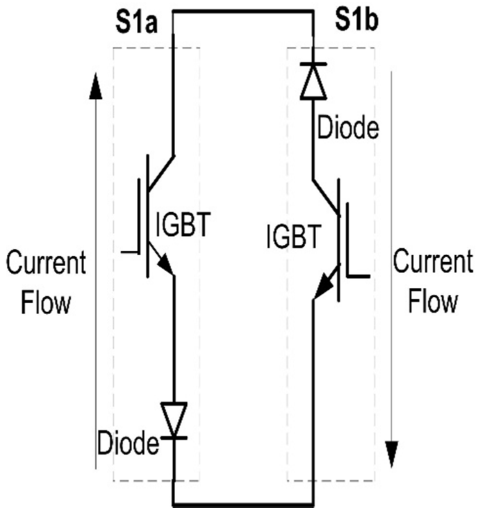

Figure 2: Bidirectional switch

Switching strategies for SPMC as cyclo-converter

Strategy I

In this strategy only two switches are kept on at a time. One of the two switch is provided with a PWM pulse and other switch is modulated with a continuous pulse. The switching sequence is shown in Table 1.

- At any time't' only two switches S1a and S4a will be kept ON and conduct the current flow during the positive cycle of input source (state 1). (Ref Figure 3)
- At any time't' only two switches S1b and S4b will be kept ON and conduct the current flow during the negative cycle of input source (state 2). (Ref Figure 4)
- At any time't' only two switches S2a and S3a will be kept ON and conduct the current flow during the positive cycle of input source (state 3). (Ref Figure 5)
- At any time't' only two switches S2b and S3b will be kept ON and conduct the current flow during the negative cycle of input source (state 4). (Ref Figure 6)

The switching signals according to Table 1 is shown in Figure 7. Due to the turn off characteristics of IGBT the practical realization of the switching sequence in the SPMC is not instantaneous and simultaneous. Here the tailing off of the collector current will create a short circuit with the next switch turn ON especially when the inductive loads are used, resulting in switching spikes [16]. This strategy leads to two damaging effects which would lead to undue stress and destruction of switches: 1) current spikes are generated in the short circuit paths 2) voltage spikes will be induced due to change in current across inductance of load.

Table 1: Switching sequence for strategy I

Input frequency	Target output frequency	Time Interval	State	Switch modulated	PWM switch
50 Hz	150 Hz	1	1	S1a	S4a
		2	3	S2a	S3a
		3	1	S1a	S4a
		4	2	S1b	S4b
		5	4	S2b	S3b
		6	2	S1b	S4b

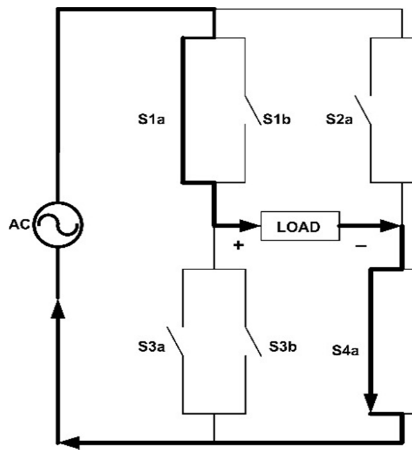

Figure 3: State 1 positive cycle

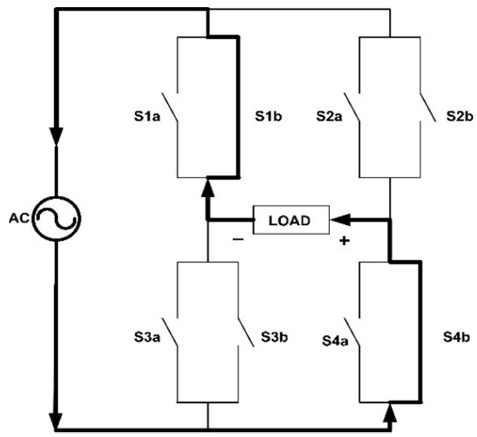

Figure 4: State 2 negative cycle

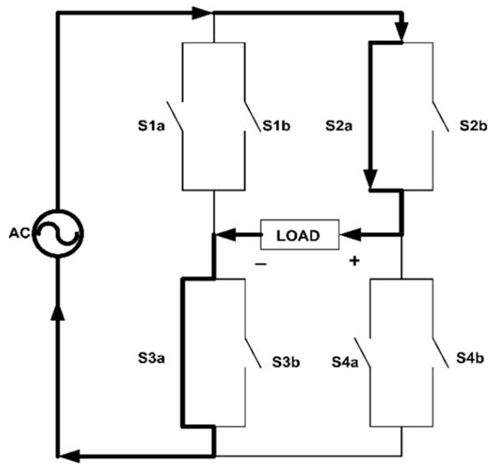

Figure 5: State 3 positive cycle

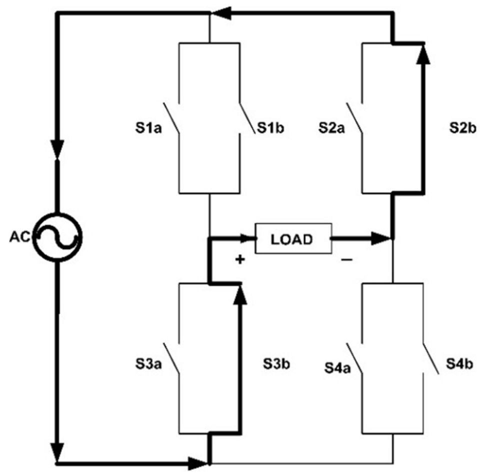

Figure 6: State 4 negative cycle

Both will subject the switches with undue stress leading to its destruction. Thus it cannot be used with RL load as it provides no path to discharge the energy across the inductor. Switching arrangements for safe-commutation as proposed by Zahirrudin can be used to eliminate the generation of switching spikes [17]. Refer Figure 8 to Figure 15 for the output voltage, current and their THD. Strategy II overcomes this limitation.

Strategy II

In this strategy three switches are used for a single interval out of which one is a PWM pulse and other two are modulated with a continuous pulse. The switching sequence are shown in the Table 2. Refer Figure 24 to Figure 27 respectively to understand the different operating states shown below.

- At any time‘t’, two switches S1a and S4a (PWM) will be kept ON and conduct the current flow during the positive cycle of input source, with S2b turn ‘ON’ for commutation purpose (state 1).
- At any time‘t’, two switches S4b and S1b (PWM) will be kept ON and conduct the current flow during the negative cycle of input source, with S3a turn ‘ON’ for commutation purpose (state 2)
- At any time‘t’, two switches S2a and S3a (PWM) will be kept ON and conduct the current flow during the positive cycle of input source, with S1b turn ‘ON’ for commutation purpose (state 3)
- At any time‘t’, two switches S3b and S2b (PWM) will be kept ON and conduct the current flow during the negative cycle of input source, with S4a turn ‘ON’ for commutation purpose (state 4)

This scheme can be used with R as well as RL load and is thus better than previous one. The THD can be further improved with proposed switching strategy. Figure 16 shows the switching signals according to Table 2. Refer Figure 17 – Figure 20 for the output voltage, current waveforms and their THD.

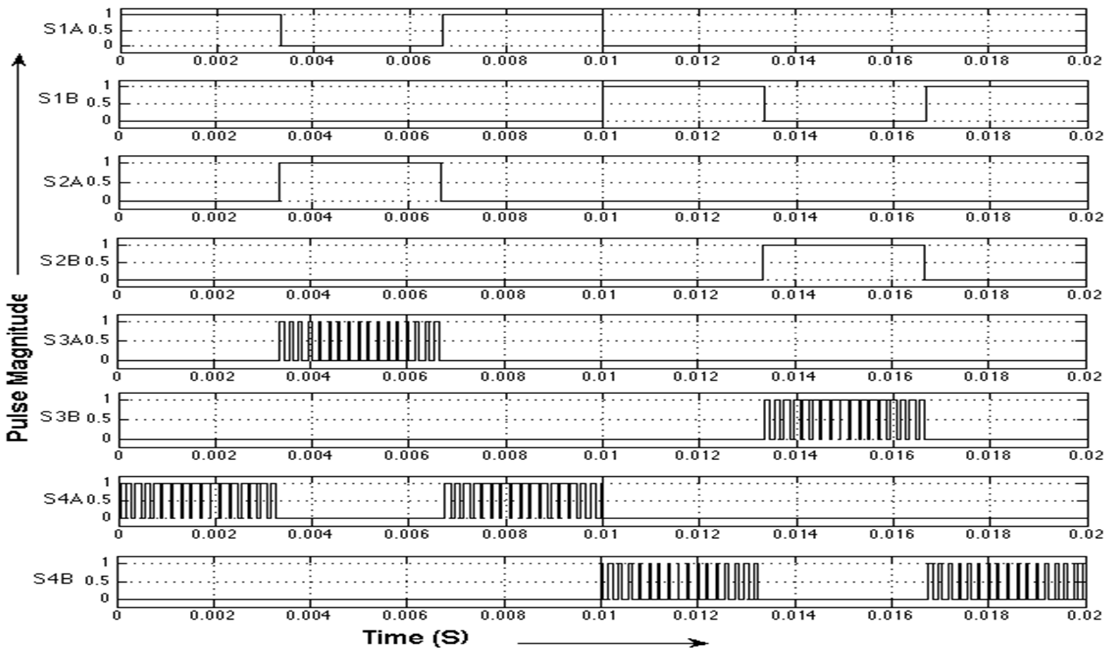

Figure 7: Switching signals for strategy I

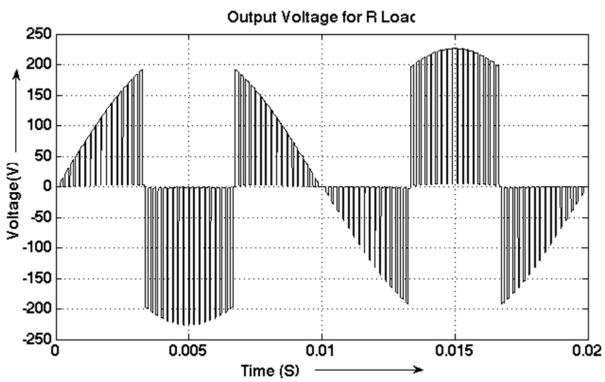

Figure 8: Output voltage for strategy I (R load)

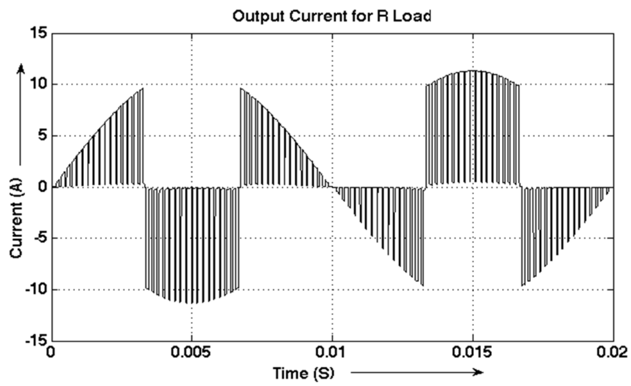

Figure 9: Output current for strategy I (R load)

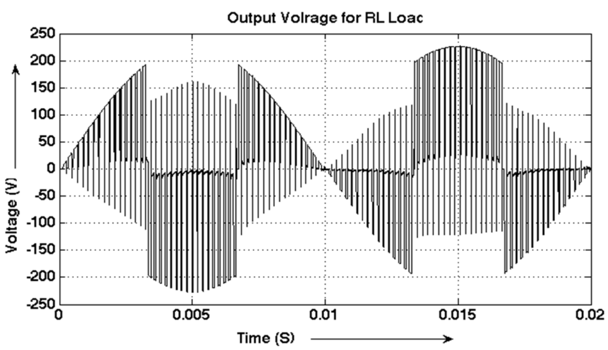

Figure 10: Output voltage for strategy I (RL load)

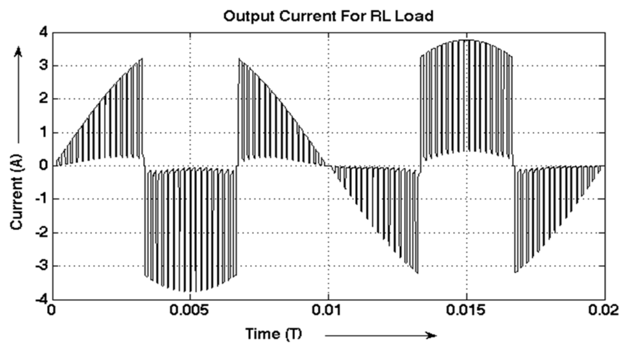

Figure 11: Output current for strategy I (RL load)

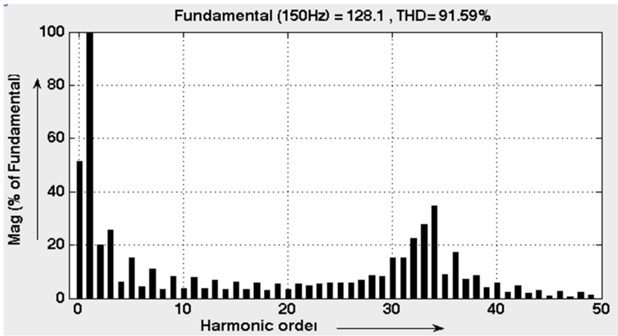

Figure 12: FFT analysis for output current with R load

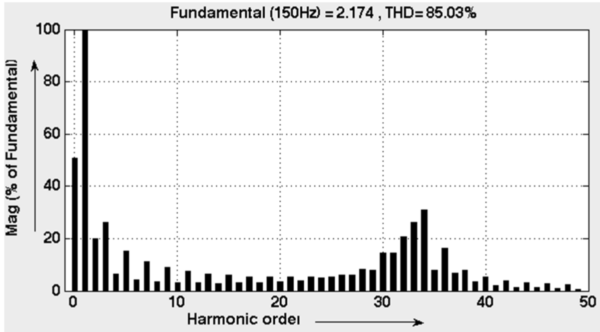

Figure 13: FFT analysis for output current with RL load

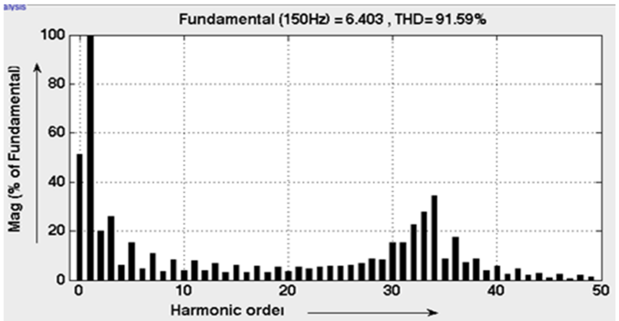

Figure 14 FFT analysis for output voltage with R load

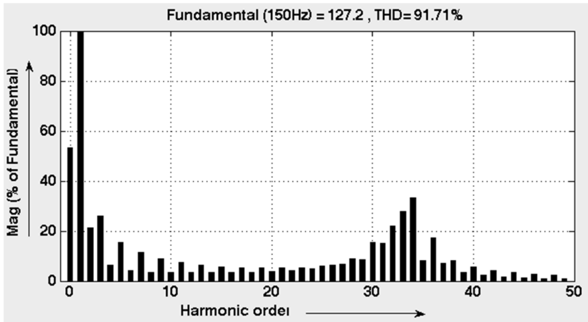

Figure 15 FFT analysis for output voltage with RL load

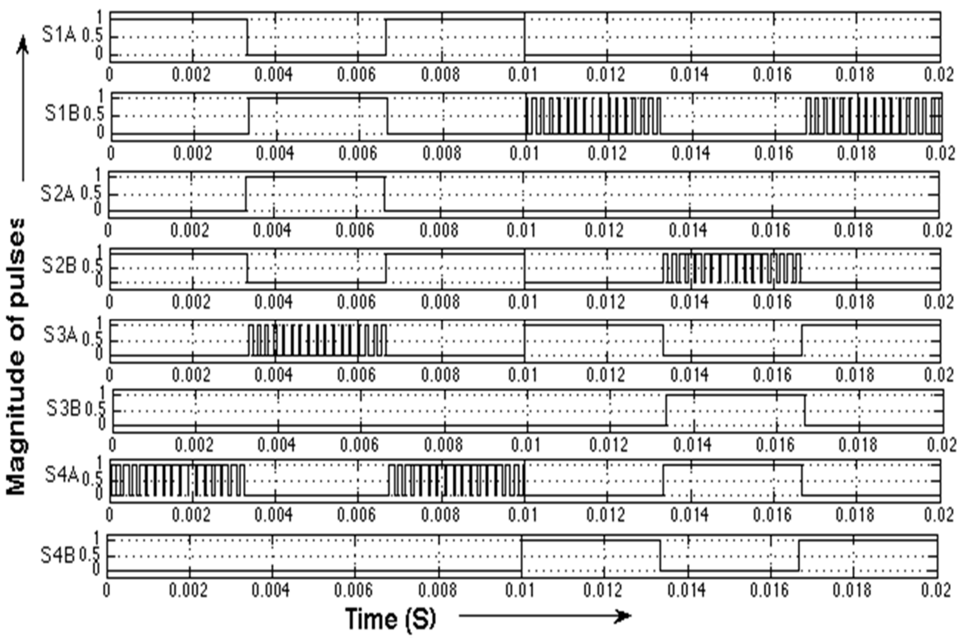

Figure 16 Switching signals for strategy II

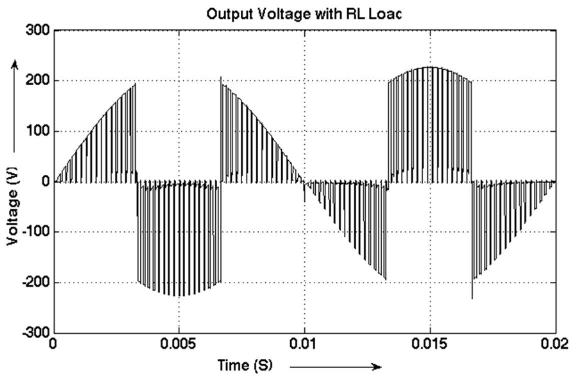

Figure 17 Output voltage for strategy II (RL load)

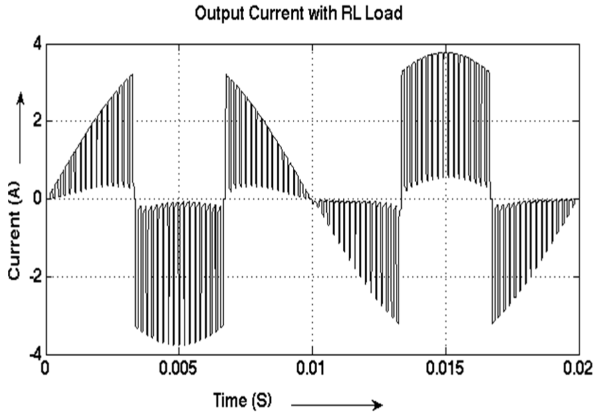

Figure 18 Output current for strategy II (RL load)

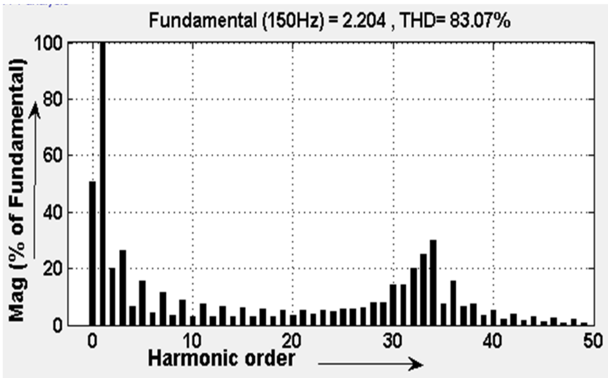

Figure 19 FFT analysis for output current with RL load

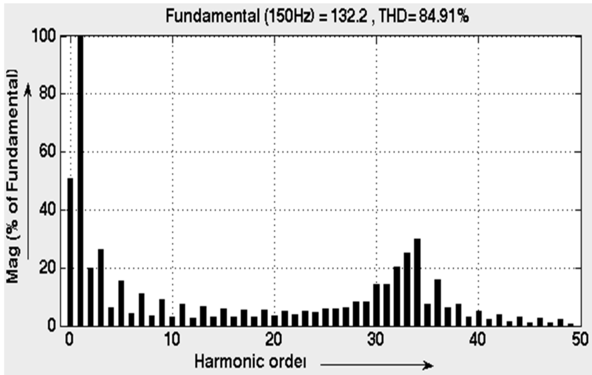

Figure 20 FFT analysis for output voltage with RL load

Strategy III - Proposed Strategy

In this strategy three switches will be used for a single time interval, out of which one switch will always be modulated with a continuous pulse and other two will be PWM switches. Thus one PWM signal is given to the switches used for free-wheeling (say PWM) and other PWM signal is given to the switch through which the load current would flow (say cPWM). These two PWM are generated such that one would be complementary of the other (only in that interval in which it is to be ON). Refer Figure 22, which clearly shows the three signals given to the switches of state 1. The two PWM signals in Figure 22 are zoomed in Figure 23, which shows that signal "cPWM" given to S2b is the complementary of signal "PWM" given to switch S4a, while S1a is modulated with a continuous pulse as shown in Figure 23. The switching sequence for proposed strategy is shown in Table 2.

- At any time't', two switches S1a and S4a (PWM) will be kept ON and conduct the current flow during the positive cycle of input source, with S2b (cPWM) turn 'ON' for commutation purpose (state 1). [ref fig 24]
- At any time't', two switches S4b and S1b (PWM) will be kept ON and conduct the current flow during the negative cycle of input source, with S3a (cPWM) turn 'ON' for commutation purpose (state 2). [ref fig 25]
- At any time't', two switches S2a and S3a (PWM) will be kept ON and conduct the current flow during the positive cycle of input source, with S1b (cPWM) turn 'ON' for commutation purpose (state 3). [ref fig 26]
- At any time't', two switches S3b and S2b (PWM) will be kept ON and conduct the current flow during the negative cycle of input source, with S4a (cPWM) turn 'ON' for commutation purpose (state 4). [ref fig 27]

As compared to strategy II we get an improved THD and also it can be used with both R load and RL load. Refer Figure 21 for the switching signals according to Table 2. The output voltage, current waveform and THD are shown in Figure 28 to Figure 31.

Table 2: Switching sequence for strategy II and proposed strategy

I/P Frequency	Target O/P Frequency	Time Interval	State	For Strategy II			For Strategy III (Proposed Strategy)		
				Switch modulated with continuous pulse		PWM Switch	Switch Modulated with continues pulse	PWM Switch	
					For Free Wheeling			PWM	cPWM
50 Hz	150 Hz	1	1	S1a	S2b	S4a	S1a	S4a	S2b
		2	3	S2a	S1b	S3a	S2a	S3a	S1b
		3	1	S1a	S2b	S4a	S1a	S4a	S2b
		4	2	S4b	S3a	S1b	S4b	S1b	S3a
		5	4	S3b	S4a	S2b	S3b	S2b	S4a
		6	2	S4b	S3a	S1b	S4b	S1b	S3a

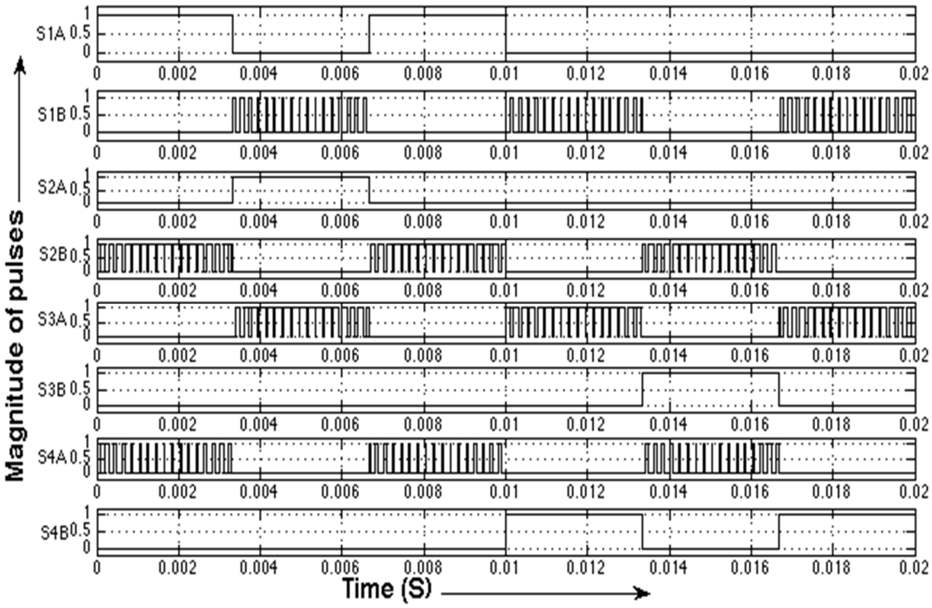

Figure 21: Switching signals for proposed strategy

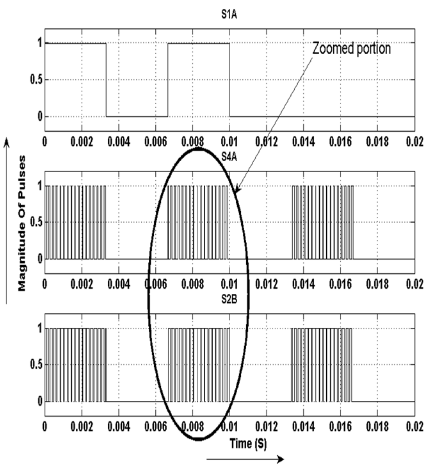

Figure 22 Switching signals for state 1 of proposed strategy

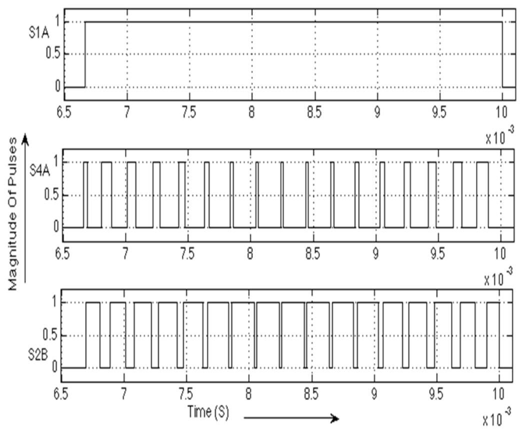

Figure 23 Zoomed view of Fig 22

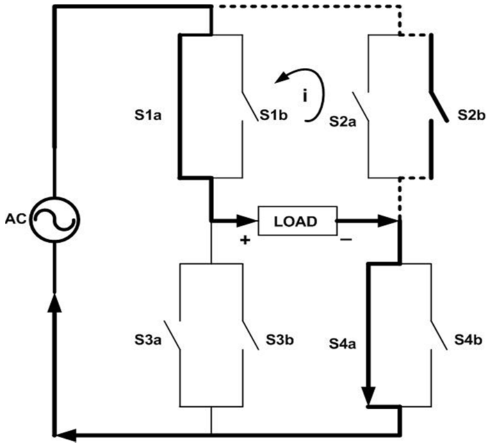

Figure 24 State 1 positive cycle

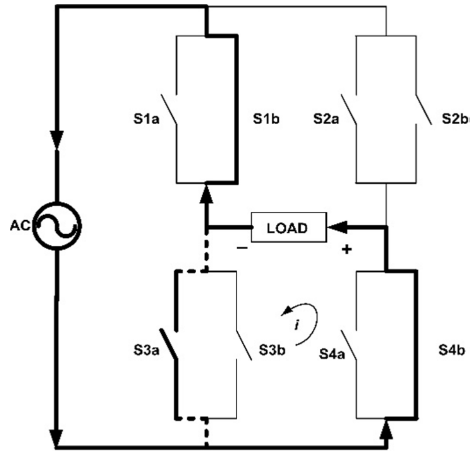

Figure 25 State 2 negative cycle

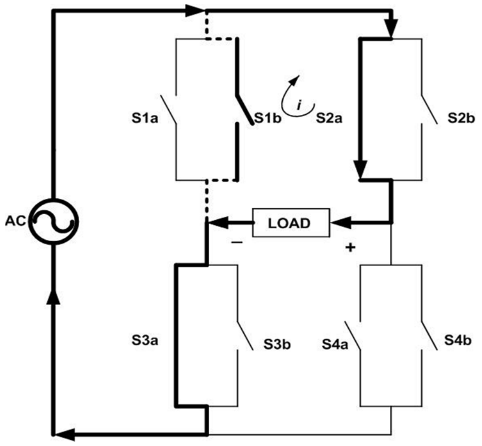

Figure 26 State 3 positive cycle

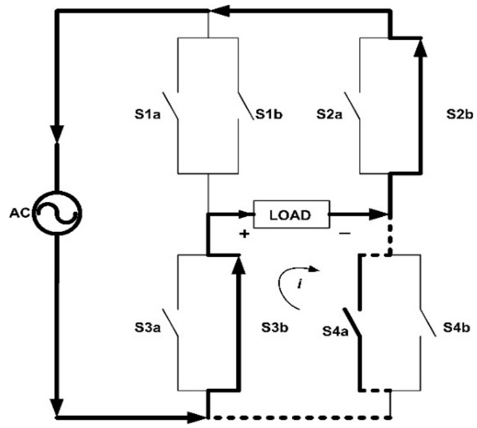

Figure 27 State 4 negative cycle

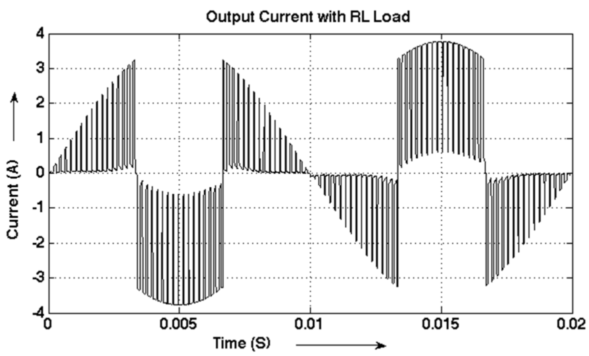

Figure 28 Output current for proposed strategy (RL load)

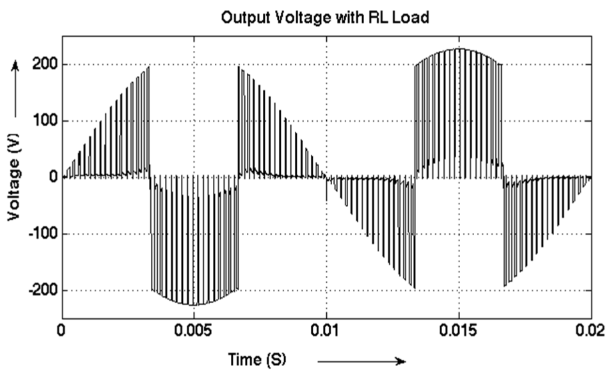

Figure 29 Output voltage proposed strategy (RL load)

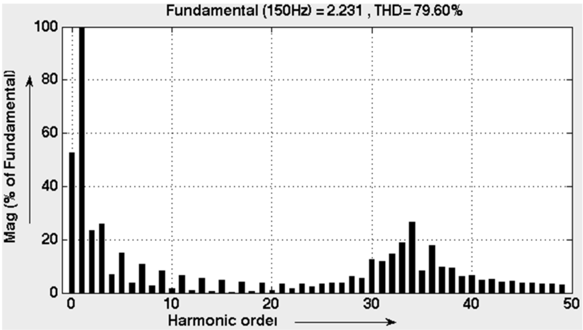

Figure 30 FFT analysis for output current

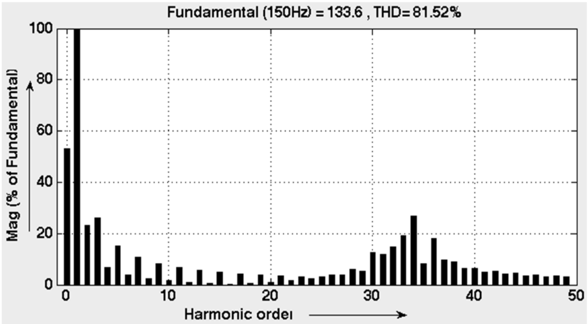

Figure 31 FFT analysis for output voltage

MATLAB Implementation

The matrix converter topology is developed in MATLAB/Simulink (MLS) software package as shown in Figure 32.

Table 3: THD results

Strategy	Current THD(%)	Voltage THD(%)
I (R Load)	91.59	91.59
I (RL Load)	85.05	91.71
II (RL Load)	83.08	84.91
III(RL Load) [Proposed Strategy]	79.60	81.52

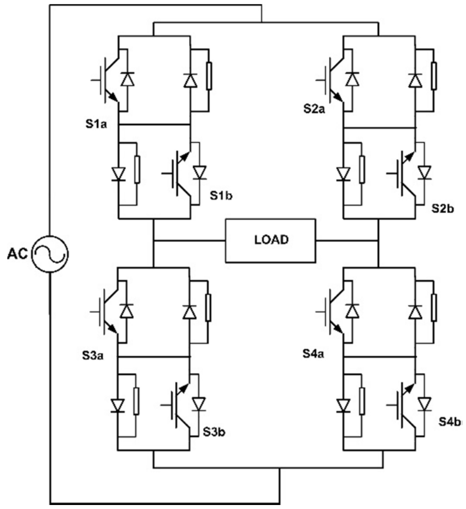

Figure 32 Simulation circuit diagram

The results in Table 3 shows that THD is improved with the proposed strategy. Moreover, it also provides us with a path for free-wheeling as three switches are kept ON for a single time interval.

Conclusion

Three different switching strategies have been presented in this paper. Comparison between all three strategies have been done and their advantages and limitations have been studied. The operational behavior is verified using MATLAB/Simulink with the SimPowerSystem Block Set. Results conclude that the strategy I can be used only for R load, strategy II can be used with R and RL load, proposed strategy (strategy III) provides better THD compared to strategy II.

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