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A comperative study on quality changes in positive, negative and combined switching strategies in control of three Phase Matrix Converter

Mohammad Sarvi, Iman Soltani[*] and Hossein Faramarzi

Faculty of Technical and Engineering, Imam Khomeini International University, Qazvin, Iran
*Corresponding Author's E-mail: *i_soltani@ikiu.ac.ir*

Abstract

In this paper has used positive, negative and combined switching strategies for three phase ac/ac matrix converter.the author compares these strategies. The performance comparison of these three strategies is made under balanced operation. The simulation of three phase matrix converter feeding a three phase load was accomplished by means of the matlab/simulink software. After the simulation the comparison of the waveforms THD in three switching sequence is done. It must be mentioned that the duty cycle of the whole switches in the converter is according to Venturini switching algorithm.

Keyword: Three Phase Matrix Converter**,** Switching strategies, THD

1. Introduction

AC-AC converters are frequency converters. They produce an AC voltage in which both the frequency and voltage can be varied directly from the AC line voltage, e.g, from a 60-or 50 Hz source. There are two major classes of AC-AC, or so-called direct static frequency converters:

1. Cycloconverter, whichis constructedusing naturally commuted thyristors.The commutation voltage is ensured by supply voltage. These are so-called line commuted converters.

2. Matrix converter, which are constructed using full-controlled static devices, such as transistors or GTOs. Matrix converter with bi-directional on/off control switches can

provide independent control of magnitude and frequency of generated output voltage as well as sinusoidal modulation of output voltage and current [3,6,7].

2. Matrix converter

2.1. Definition

The matrix converter is a single stage direct ac-ac converter, which has an array of m×n bi-directional power switches that can directly connect an m-phase voltage source to an n-phase load. A three phase matrix converter consist of 9 bi-directional switches that allow any phase of the load to be connected to any phase of input voltage, e.g, the zero value of the load phase voltage is maintained by connecting all load phases to the same input phase [5].

2.2. Advantages

- Inherent four quadrant operation and regeneration capability due to the use of bidirectional switch andhence it can be used as an alternative ton PWM inverter drive for three phase frequency control.
- It offers sinusoidal input and output waveforms
- It has bi-directional switches, so it can offer bidirectional power flow
- Input power factor in this converter is controllable and displacement factor is unity
- It has a compact design and high drive performance and long life [1, 5].

2.3. Disadvantages

- Matrix converters require the use of numerous switches and well-established control methods
- For the safe commutation of the switches, some elements like snubber circuit and clamp circuit are required
- Ac output voltage cannot exceed the ac input voltage; usually its maximum is close to the input voltage.

- Both bidirectional switches of any phase leg can never be turned on at the same case these disadvantages of matrix converters prevent their use in industrial application [1, 5]. The main purpose of this paper is to show that three phase matrix converter that is producing variable output voltages with positive, negative and combined switching strategies, has output currents that are not symmetrical. Therefore the input and output currents consist of some undesirable harmonics, also the THD for input and output quantities are high. It must be noticed that the undesirable current harmonics cause many problems, such as heating and reduction of life in transformers and induction machines and degradation of system voltage waveform. This paper compares the THD of the waveforms in the input and output sides of converter.

3. Switching strategies

The basic power circuit of a three phase matrix converter is shown in Fig.1; it is composed of nine bidirectional switches. The three phase input voltages of the converter are given by:

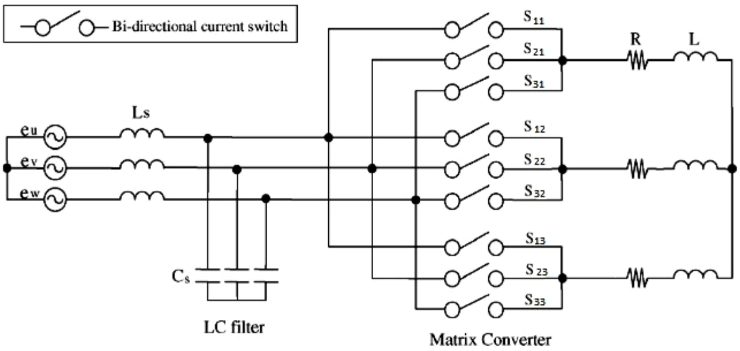

Fig.1. three phase matrix converter.

The input and output voltage vectors of the matrix converter can be given by:

$$[V_i] = V_{im} \begin{bmatrix} \cos(\omega_i t) \\ \cos(\omega_i t + 2\pi/3) \\ \cos(\omega_i t \ + 4\pi/3) \end{bmatrix} \tag{1}$$

$$[V_o] = V_{om} \begin{bmatrix} \cos(\omega_o t) \\ \cos(\omega_o t + 2\pi/3) \\ \cos(\omega_o t + 4\pi/3) \end{bmatrix} \tag{2}$$

Where ω_i and ω_o are the frequencies of input and output voltages of matrix converter respectively.

With nine bi-directional switches the matrix converter can theoretically assume 512 (2^9) different switching state combinations. But not all of them can be usefully employed. Regardless to the control method used, the choice of matrix converter switching state combination to be used must comply with two basic rules. Taking into account that the converter is supplied by a voltage source and usually feed an inductive load, the input phases should never be short-circuited and the output currents should not be interrupted. This can be achieved by using VenturiniModulation Algorithm .by using this algorithm, in a three phase to three phase matrix converter 27 are the permitted switching combinations, in this paper three switching states are employed. These states are positive, negative and combined switching strategies.

3.1. Venturini switching algorithm

The Venturini algorithm controls the the switches S_{11}, S21, S31 according to the desired output voltage and output frequency. The switches on each output phase are closed sequentially and repetitively.9-during any ith sequence, the sampling period, T^i_s, will be divided to three-time intervals t^i_1, ti2 and t^i_3 as shown in Fig.2,and T^i_s is related with these time intervals as follows:

$$T^i_{s}= t^i_1+t^i_2+ t^i_3 \tag{3}$$

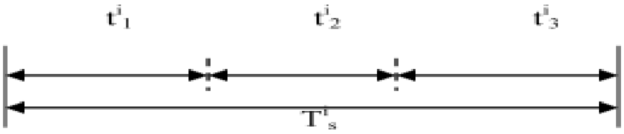

Fig.2. sampling period in three phase matrix converter.

This paper presents three switching strategies for producing output voltages:

- The positive switching strategy
- The negative switching strategy
- The combined switching strategy

3.2. The positive switching strategy

The output voltage can be synthesized by switching the input voltage according to the algorithm shown in Fig.3.

This algorithm has three rules:

During time interval $t^i_{1, p}$: S_{11}, S_{22} and S_{33} must be on, and the remaining switches must be off.

During time interval $t^i_{2, p}$: S_{12}, S_{23} and S_{31} must be on, and the remaining switches must be off.

During time interval $t^i_{3, p}$: S_{13}, S_{21} and S_{32} must be on and the remaining switches must be off.

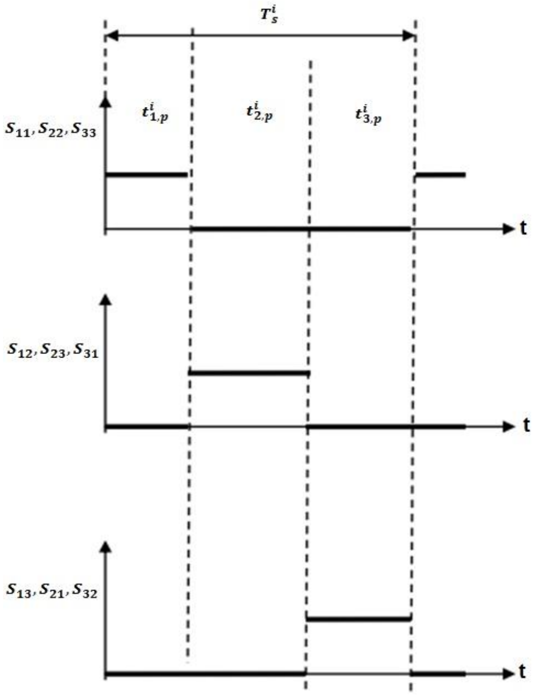

Fig.4. switches commands for positive switching strategy.

By defining the following switch patterns:

$$P_1 = \frac{t1,p}{Ts} \quad (4)$$

$$P_2 = \frac{t2,p}{Ts} \quad (5)$$

$$P_3 = \frac{t3,p}{Ts} \quad (6)$$

In expression of the relation between input and output quantities, a matrix is defined as low frequency transfer matrix and it is given by

$$M(t) = \begin{array}{c} m_{11} m_{12} m_{13} \\ m_{21} m_{22} m_{23} \\ m_{31} m_{32} m_{33} \end{array} \quad (7)$$

m_{kj} (t) is the duty cycle of switch S_{kj} ,it is specified as $m_{kj}(t)=t_{kj}/T_s$, switch can accept the following values:

$$Vo(t)=M(t).Vi(t) \qquad \textbf{(8)}$$

$$I(t)=M(t)^{T}.Io(t) \qquad \textbf{(9)}$$

$m_{kj}(t)$ can accept the following values:

$$0< m_{kj}(t) <1 \quad k= \{1, 2, 3\}, j= \{1, 2, 3 \qquad \textbf{(10)}$$

In definition of the switch patterns we can assume that:

$$P_1= m_{11} \qquad \textbf{(11)}$$

$$P_2= m_{31} \qquad \textbf{(12)}$$

$$P_3= m_{21} \qquad \textbf{(13)}$$

It is obvious that:

$$m_{11} + m_{31} + m_{21} = 1 \qquad \textbf{(14)}$$

$$T_s = m_{11}T_s + m_{31}T_s + m_{21}Ts \qquad \textbf{(15)}$$

$$Fs = \frac{1}{T_s} \qquad \textbf{(16)}$$

where f_s is the switching frequency which should be 20 times higher than the output frequency so as to have low harmonic content in the output voltage.

3.3. The negative switching strategy

The output voltage can be synthesized by switching the input voltage according to the algorithm shown in Fig.5.

This algorithm has three rules:

During time interval $t^{i}_{1,n}$: S_{11}, S_{22} and S_{33} must be on, and the remaining switches must be off.

During time interval $t^{i}_{2,n}$: S_{12}, S_{23} and S_{31} must be on, and the remaining switches must be off.

During time interval $t^{i}_{3,n}$: S_{13}, S_{21} and S_{32} must be on, and the remaining switches must be off.

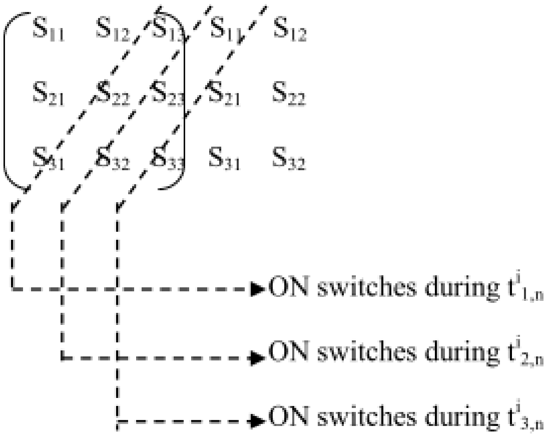

Fig.5. switching pattern in negative switching strategy.

Fig.6 shows the switches commands during i the sampling period.

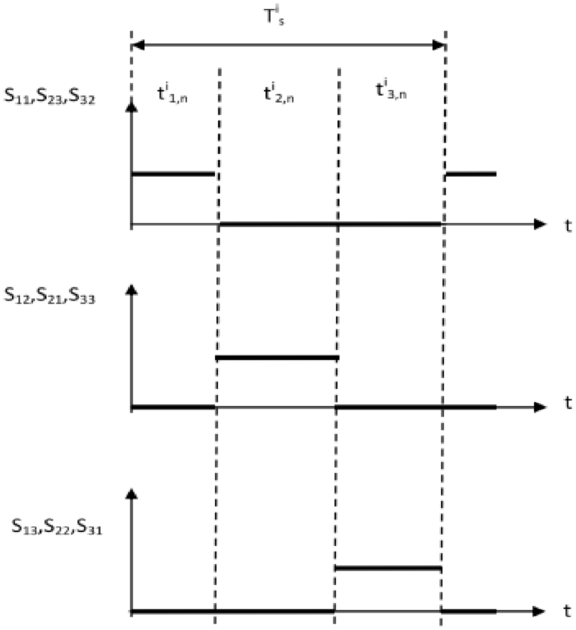

Fig.6. switches commands for negative switching strategy.

By defining the following switch patterns:

$$N_1 = \frac{t1,n}{Ts} \qquad \textbf{(17)}$$

$$N_2 = \frac{t2,n}{Ts} \qquad \textbf{(18)}$$

$$N_3 = \frac{t3,n}{Ts} \qquad \textbf{(19)}$$

In defining the switch patterns we can assume that:

$$N_1 = m_{13} \qquad \textbf{(20)}$$

$$N_2 = m_{23} \qquad \textbf{(21)}$$

$$N_3 = m_{33} \qquad \textbf{(22)}$$

It is obvious that:

$$m_{13} + m_{23} + m_{33} = 1 \qquad \textbf{(23)}$$

3.4. The combined switching strategy

Since positive and negative switching strategies produce in general, the same output voltages, these voltages can be formed by any combination of these switching strategies. Fig.7 shows the switching patterns for combined positive and negative switching strategies. As it can be seen, the output can be established from α part of positive strategy and β part of negative strategy.

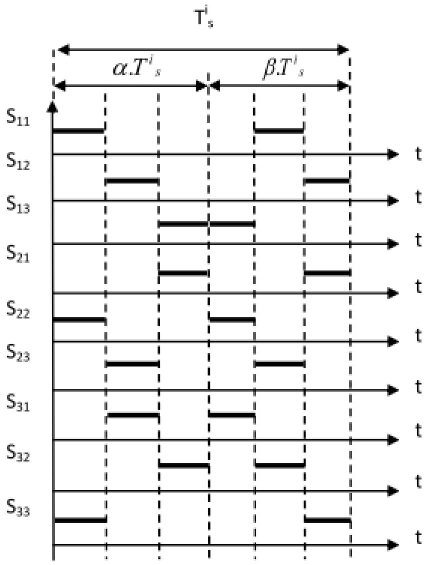

Fig.7. switches commands for combined switching strategy.

4. Software implementation of three phase ac/ac matrix converter

The matrix converter shown in Fig.1 has been simulated by matlab software. the main parameters of the matrix converter are listed in table 1.

Table 1. Main parameters of the matrix converter.

parameter	value
V_{im}	311 V
V_{om}	155.5 V
f_i	50 Hz
f_o	60 Hz
f_s	10 KHz
R	10 Ω
L	30 mH
C_f	100 µf
L_f	0.1 mH
R_s	30 Ω
C_s	3 mf
α	0.5
β	0.5

The matrix converter requires nine bi-directional switches with capability of blocking voltage and conducting current in both directions. Thereare several arrangement can be used to create such bi-directional switch. Fig.8 presents a number of these connections. The advantages and disadvantages of each structure are referred in refrence.1.with considering of these advantages and disadvantages, the common emitter configuration is often preferred to create the matrix converter bi-directional switch. So we choose this configuration to use in the proposed matrix converter.

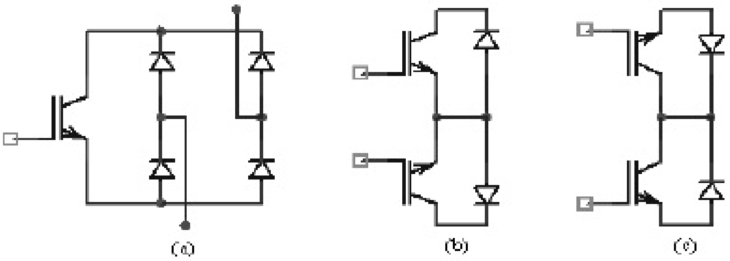

Fig.8. bi-directional switch topologies:

a) diode embedded, b) common emitter (CE), c) common collector (CC)

4.1. Control Algorithm

The required voltage transfer ratio (q), input frequency (f_i), output frequency (f_o), maximum transfer ratio (q_m), input and output voltages are the input required for calculation of the duty cycle matrix M. the duty cycle calculations for voltage transfer ratio of .5 is realized in the form of m-file in matlab . The switching time for the switch connected between the input phase β and output phase γ is;

$$T_{\beta\gamma} = Ts[\frac{1}{3} + \frac{2V_{o\gamma}V_{i\beta}}{3V_{im}{}^{2}} + \frac{2q}{9q_m}\sin(\omega_i t + \psi_\beta)\sin(3\omega_i t)] \tag{24}$$

where ψ_β is 0, $\frac{2\pi}{3}$, $\frac{4\pi}{3}$ corresponding to the input phases A,B,C, respectively q_m is the maximum voltage ratio(0.866). γ Represents output phase a, b, c, and β represents input phase A, B or C.

4.2. System simulation

The simulated model of loaded matrix converter using MATLAB/SIMULINK is shown in Fig. 9.

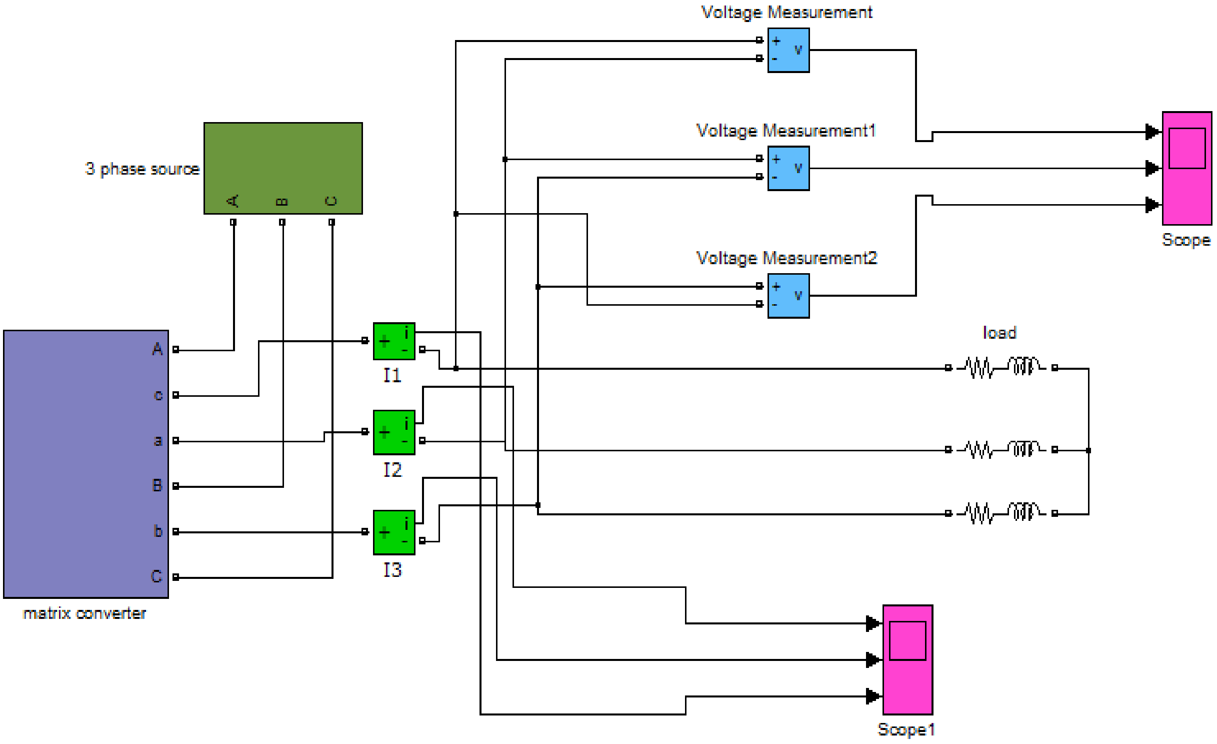

Fig.9. The simulated model of phase matrix converter.

5. Simulation results and discussion

The simulation of matrix converter is carried out using Power system block set. Likewise to the output voltages, the input currents are directly generated by the output currents, synthesized by sequential piecewise sampling of the output current waveforms. The simulation results are shown in Fig.10-18.

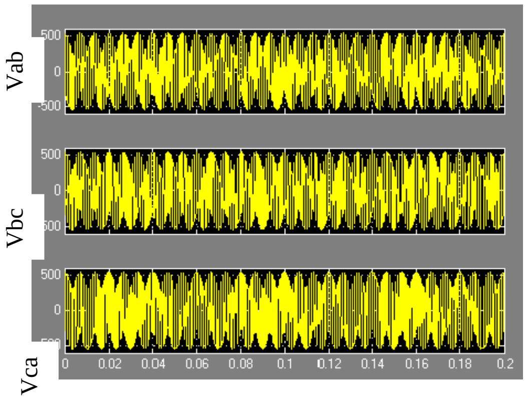

Fig.10. output line voltages in positive switching strategy.

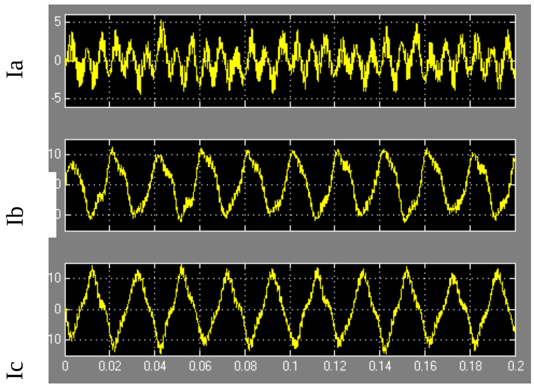

Fig.11. output currents in positive switching strategy.

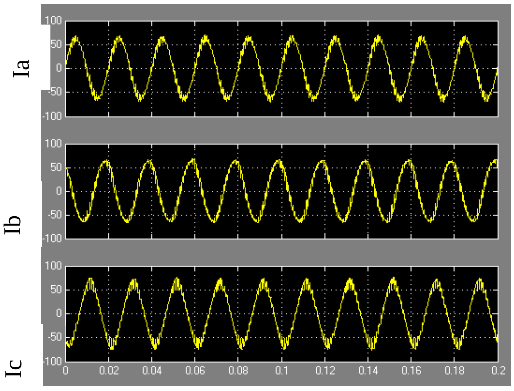

Fig.12. input currents in positive switching strategy.

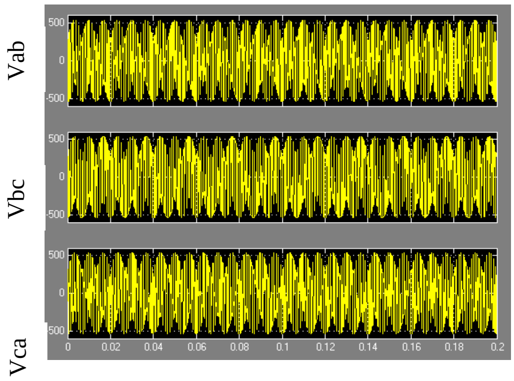

Fig.13. output line voltages in negative switching strategy.

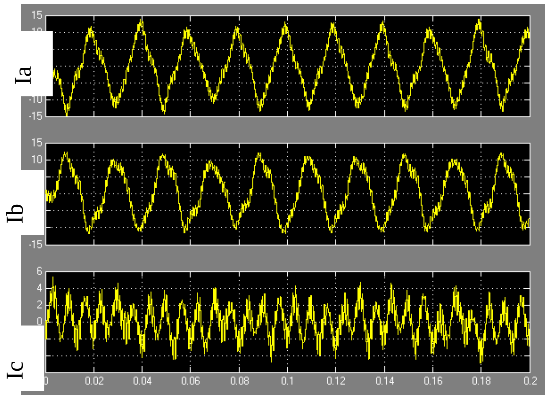

Fig.14. output currents in negative switching strategy.

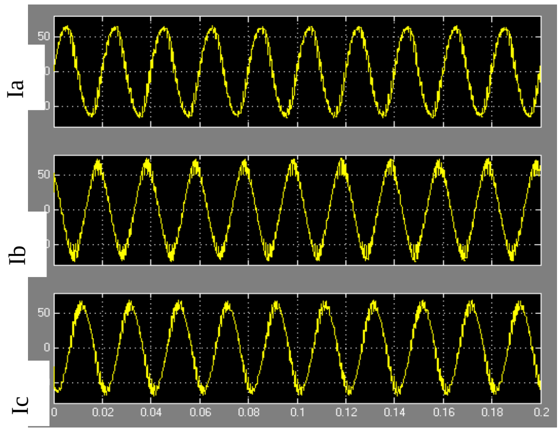

Fig.15. input currents in negative switching strategy.

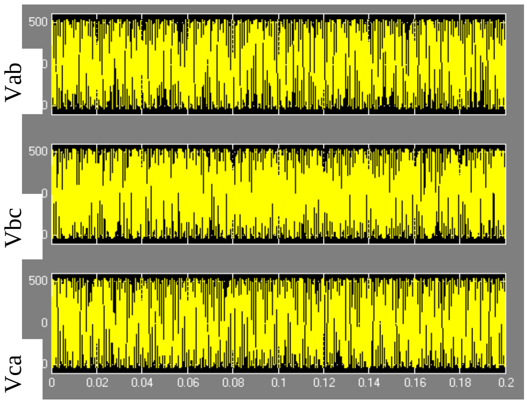

Fig.16. output line voltages in combined switching strategy.

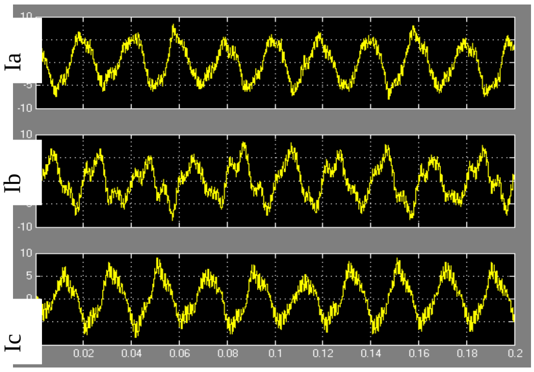

Fig.17. output currents in combined switching strategy.

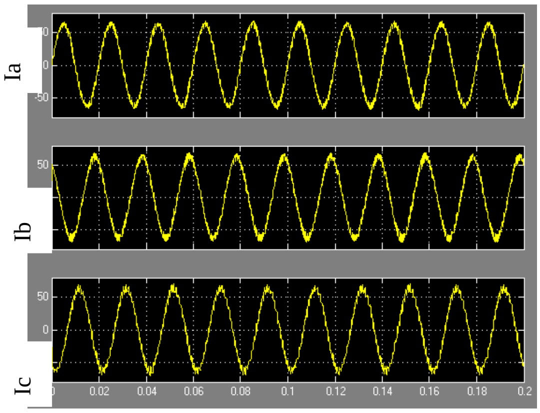

Fig.18. input currents in combined switching strategy.

Also, these figures show the output voltage. It can be seen, in all strategies the output current is not symmetrical and it has a considerable dc component. Therefore, in transformer applications it may cause saturation of transformer .the frequency spectrums of the input and output currents are shown in Fig.19-36.

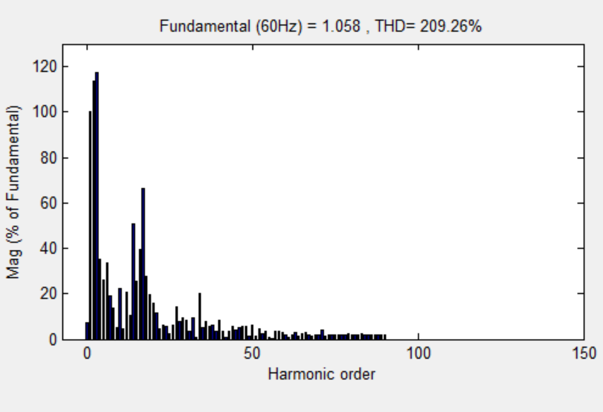

Fig.19. output current harmonics of phase (a), in positive switching strategy.

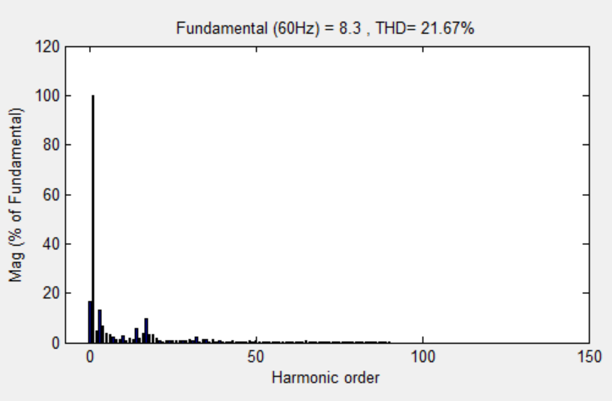

Fig.20. output current harmonics of phase (b), in positive switching strategy.

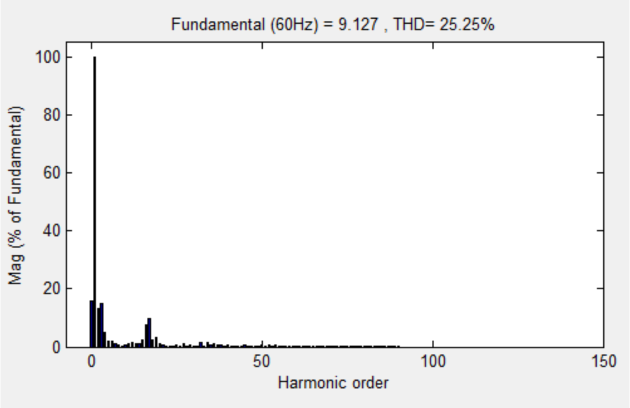

Fig.21. output current harmonics of phase (c), in positive switching strategy.

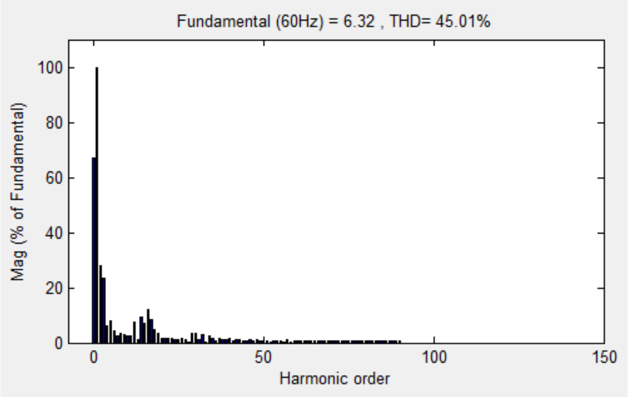

Fig.22. output current harmonics of phase (a), in negative switching strategy.

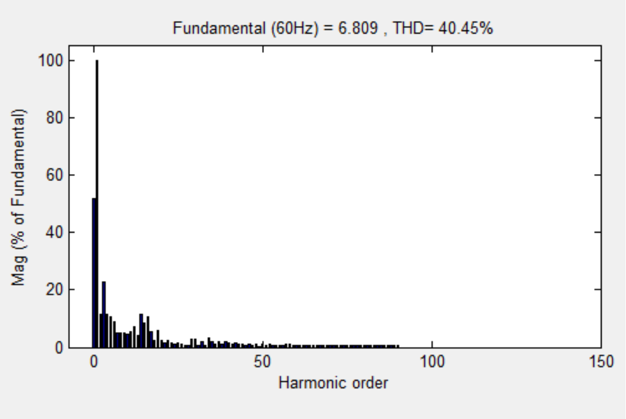

Fig.23. output current harmonics of phase (b), in negative switching strategy.

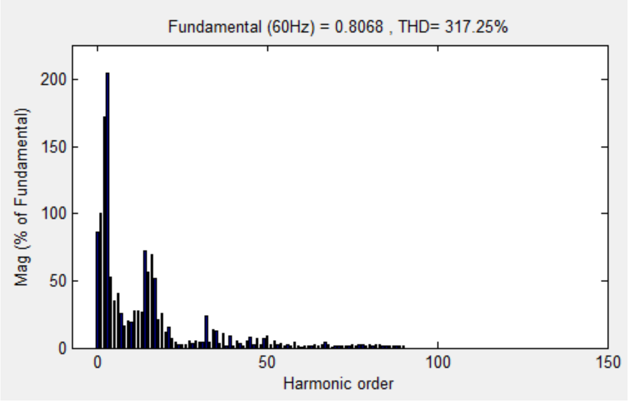

Fig.24. output current harmonics of phase (c), in negative switching strategy.

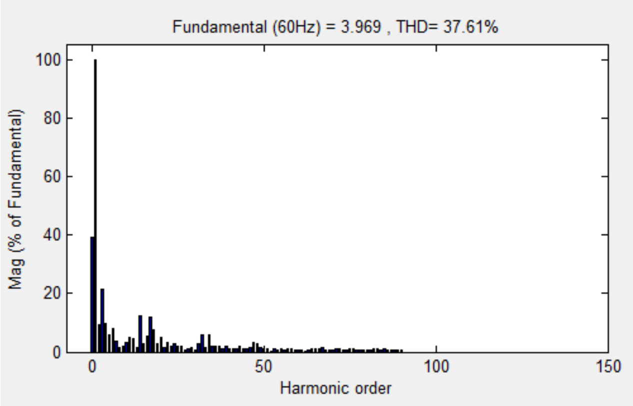

Fig.25. output current harmonics of phase (a), in combined switching strategy.

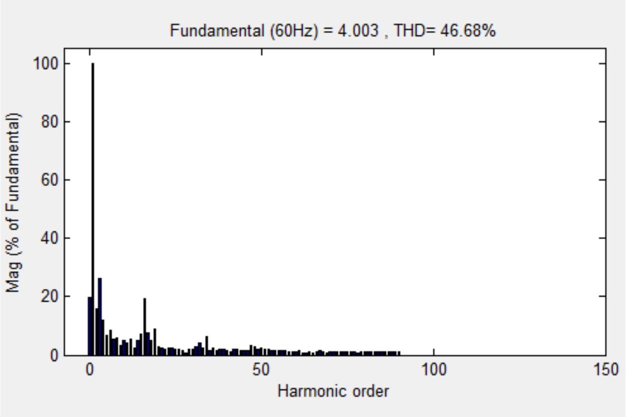

Fig.26. output current harmonics of phase (b), in combined switching strategy.

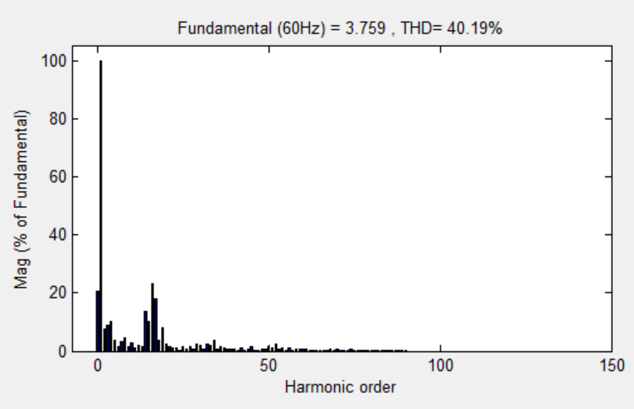

Fig.27. output current harmonics of phase (c), in combined switching strategy.

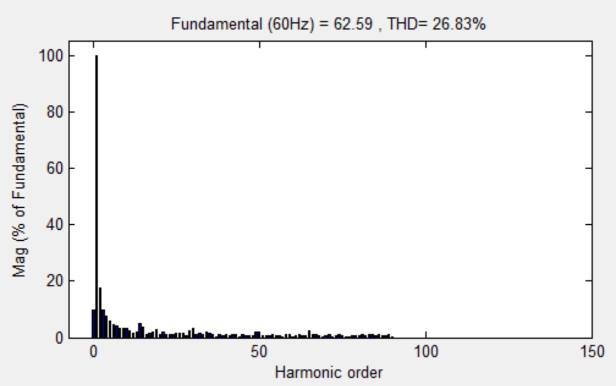

Fig.28. input current harmonics of phase (a), in positive switching strategy.

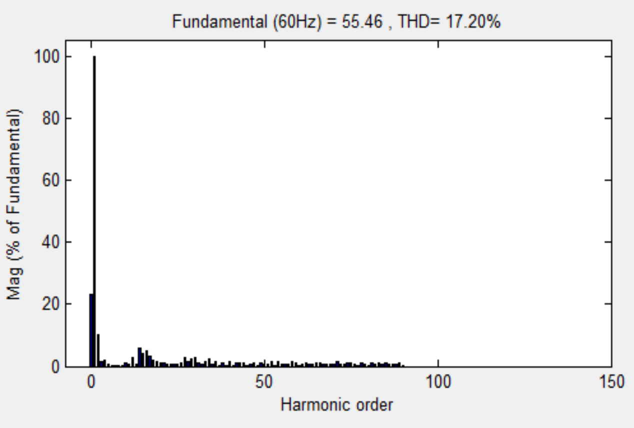

Fig.29. input current harmonics of phase (b), in positive switching strategy.

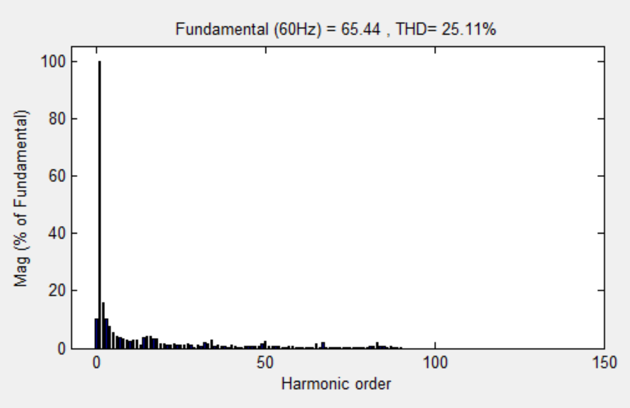

Fig.30. input current harmonics of phase (c), in positive switching strategy.

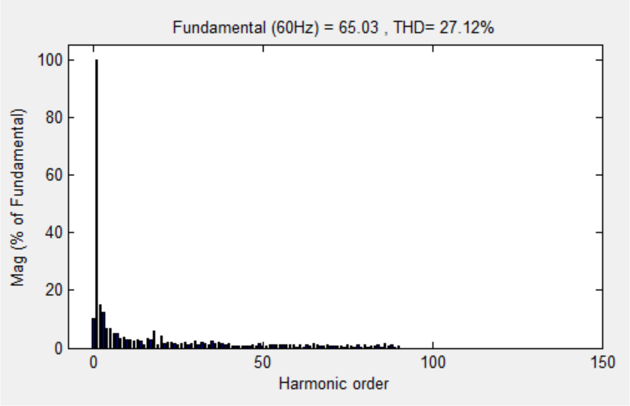

Fig.31. input current harmonics of phase (a), in negative switching strategy.

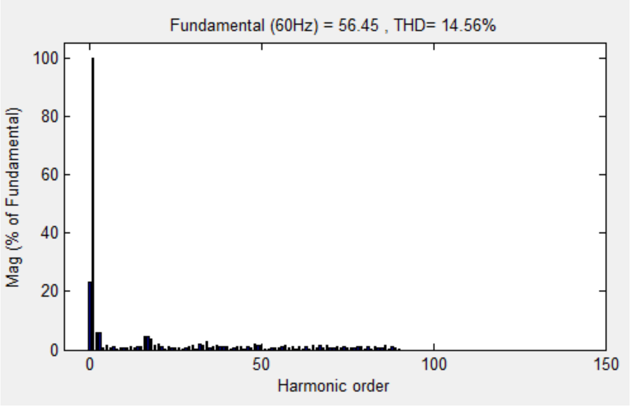

Fig.32. input current harmonics of phase (b), in negative switching strategy.

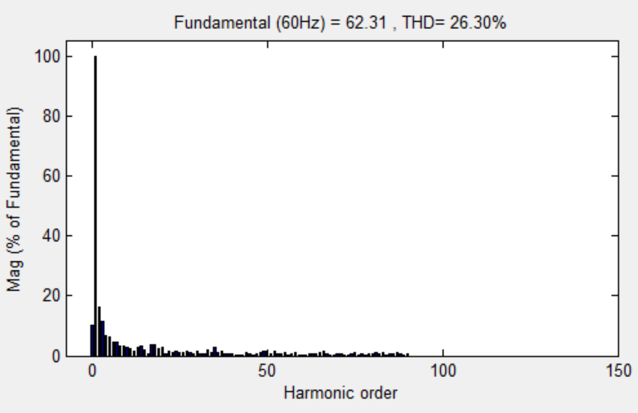

Fig.33. input current harmonics of phase (c), in negative switching strategy.

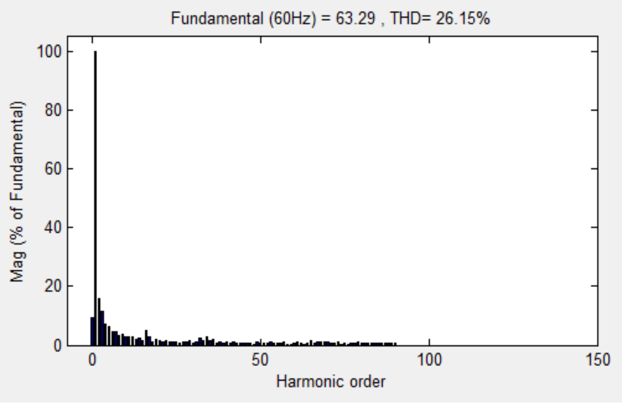

Fig.34. input current harmonics of phase (a), in combined switching strategy.

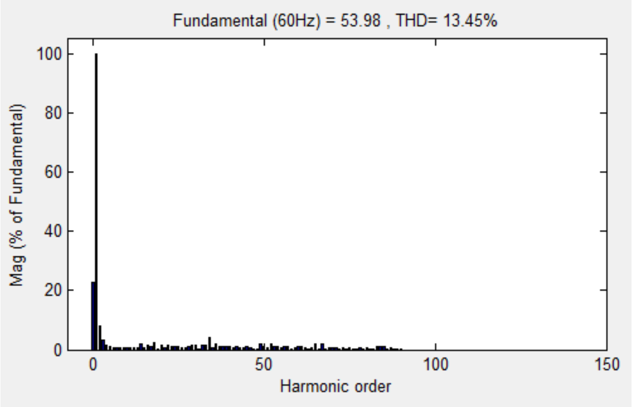

Fig.35. input current harmonics of phase (b), in combined switching strategy.

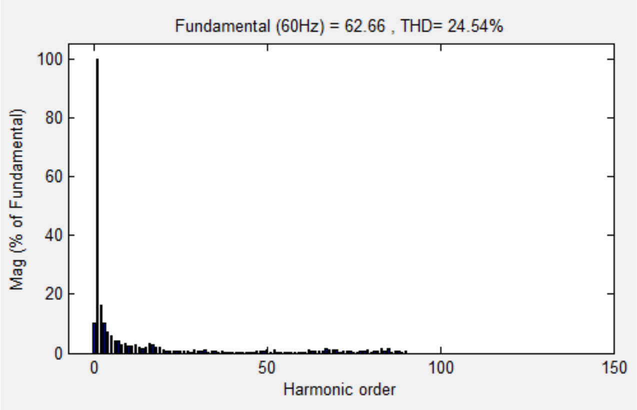

Fig.36. input current harmonics of phase (c), in combined switching strategy.

Paying attention to the input and output current waveforms and its frequency spectrums we can see that the waveforms have got a dc component and considerable low order harmonics.In power quality analysis, distortion of a waveform is often represented by its total THD:

$$THD = \frac{1}{m_1}\sqrt{\sum_{h=2}^{\infty} m_h} \qquad \textbf{(25)}$$

Here, m_1 is the rms value of the fundamental frequency component of the analyzed waveform; m_h is the rms value of its hth harmonic. Table 2, shows THD of current waveforms on input and output sides for three switching strategies based on simulation with amplitude of up to 150th harmonic.

Table 2. THD of output and input currents.

		positive	**negative**	**combined**
out	I_a	209.26	45.01	37.61
	I_b	21.67	40.45	46.68
	I_c	25.25	317.25	40.19
in	I_a	26.83	27.12	26.15
	I_b	17.20	14.56	13.45
	I_c	25.11	26.30	24.54

Conclusion

In this paper, a three phase ac/ac matrix converter has been simulated. looking at the basic features of matrix converter that have been briefly described in the previous sections it might be surprising to establish that converter, but the physical realization of the matrix converter is not straightforward. Although, with these problems the utilization of the converter is not wide, but these problem will be solved with development of technology. One of the features of this converter is the control algorithm.

This algorithm ensures that the switches do not short-circuit the voltage sources, and do not open-circuit the current sources. In this paper, positive, negative and combined switching strategies have been used to control the converter, after the simulation, results of the simulation have been analyzed and the THD of waveforms have been compared. Also simulation results show that using combined switching strategy to control the matrix converter will decrease THD of output currents.

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