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AC to AC Conversion Using Single Phase Matrix Converter

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ABSTRACT: *Indirect AC to AC conversion makes use of a DC linkwhich has severaldisadvantages. Matrix converteroffers a solution to the problems of a DC link by directlyconverting AC to AC with the use of forced commutation of semi-conductor switches such as IGBT and MOSFET. In thispaper, the basic working of a single phase matrix converter, its applications and modulation techniques have been discussed. Computer based simulation using MATLAB/SIMULINK wasperformed and the results have been shown. Matrix converteris an upcomingtechnologythat has much avenue for research.*

KEYWORDS:*single phase matrix converter (SPMC), AC to AC converter, power electronics, rectifier, inverter, cycloconverter, chopper*

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I. INTRODUCTION

In this century, power electronic converters have several applications such as in industries, railways, medical etc. Hence, the advancement and optimization in the field of power electronics is vital for the need of energy efficiency. Most AC to AC conversion techniques do not have direct AC to AC conversion but are AC/DC-AC converters i.e. having a rectifier-inverter system. They make use of a DC link which is bulky, decreases reliability, increases the cost and decreases the efficiency of the system. The matrix converter offers a solution to this problem by performing direct AC-AC conversion (see Fig.1) without using reactive energy storage components that are commonly used in the traditional rectifier-inverter systems. The matrix converter technology is a single stage of conversion from AC to AC that can generate the required amplitude and frequency. It has a sleek design due to the absence of DC links. It makes use of fully controlled bidirectional semi-conductor switches. The switches are arranged in the form of a matrix and hence it has the name matrix converter.

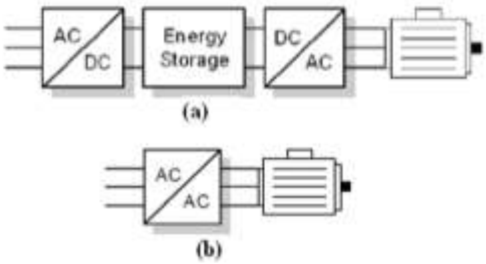


Fig.1(a) AC to AC conversion using normal techniques
(b) AC to AC conversion using matrix converter

II. SINGLE PHASE MATRIX CONVERTER

[1]A single phase matrix converter(see Fig.2)comprises of four bidirectional switches that allows current conduction in either direction. A single phase matrix converter can thus be operated as a rectifier, inverter, cycloconverter or a chopper using different switching sequences. At any time, only 2 switches are kept in the 'ON' condition.

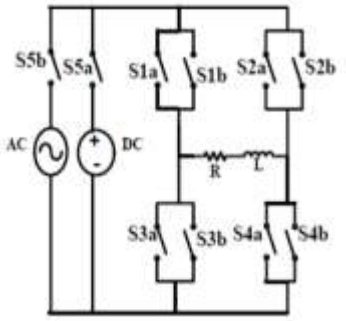
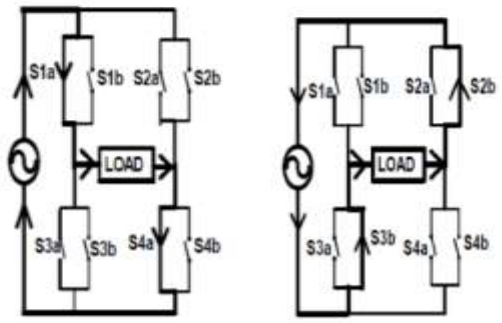


Fig. 2 Basic circuit of a single phase matrix converter

2.1 Single phase matrix converter as a rectifier

Rectification is the conversion of AC to DC. During the positive cycle of the input source, switches S1a and S4a are turned 'ON' and the current flow is as given in Fig.3(a). During the negative cycle of the input source, switches S3b and S2b are turned 'ON' and the current flow is as given in Fig.3(b).

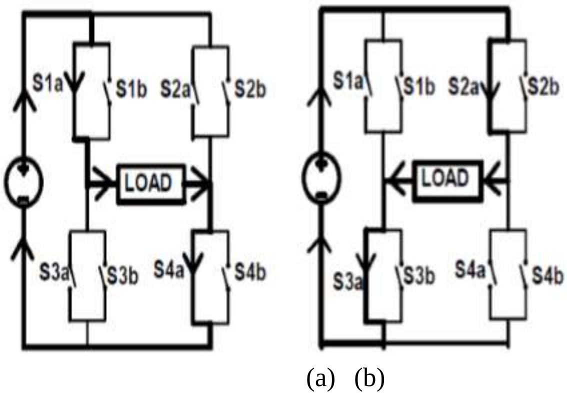


(a) (b)

Fig. 3 Single phase matrix converter as a rectifier

2.2 Single phase matrix converter as an inverter

Inversion is the opposite of rectification and is the conversion from DC to AC. During the positive cycle of the input source, switches S1a and S4a are turned 'ON' and the current flow is as given in Fig.4(a). During the negative cycle of the input source, switches S2a and S3a are turned 'ON' and the current flow is as given in Fig.4(b).



(a) (b)

Fig.4 Single phase matrix converter as an inverter

2.3 Single phase matrix converter as a chopper

A chopper converts fixed DC to variable DC. Switches S1a and S4a are kept in the 'ON' state and current flow is as given in Fig.5.

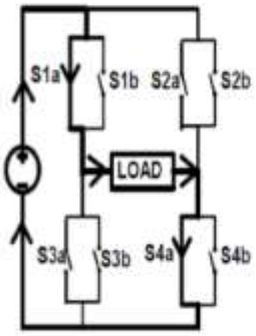


Fig.5 Single phase matrix converter as a chopper

2.4 Single phase matrix converter as a cycloconverter

Cycloconverters convert fixed AC power into variable AC power and hence are known as frequency changers.

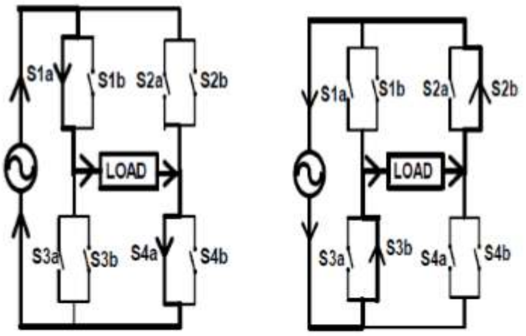


Fig.6(a)For positive output

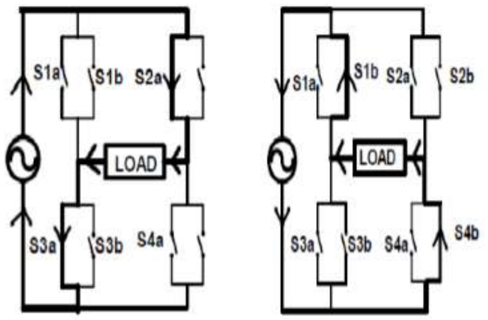


Fig.6(b)For negative output

The positive cycle(see Fig.6(a)) of the output is obtained when switches S1a and S4a conduct(positive input cycle) or if switches S3b and S2b conduct(negative input cycle).

The negative cycle(see Fig.6(b)) of the output is obtained if switches S2a and S3a conduct(positive input cycle) or if switches S1b and S4b conduct(negative input cycle).

III. MODULATION TECHNIQUES

The matrix converter was introduced in 1976. However, it was only after Venturini and Alesina published their papers that more avenues were opened for research on matrix converters. Several modulation techniques have been proposed using different switching sequences. Their objective is to improve the voltage transfer ratio of the matrix converter, to reduce output voltage harmonic distortions and decrease power loss.

Some methods of controlling a matrix converter are:

- Basic method
- Alesina-Venturini method
- Pulse width modulation
- Space vector modulation

IV. ALESINA-VENTURINI METHOD

[2][3][4]The Venturini method also known as the "Direct Method" is a pulse width modulation technique proposed by Venturini and Alesina (1980).The purpose of the modulation technique is to produce a variable frequency and variable amplitude sinusoidal output voltage (v_{jN}) from the fixed amplitude and frequency input voltages (V_i).In this method, for a given set of three-phase input voltages, a desired set of three phase output voltages can be synthesized by sequential piecewise sampling of the input waveforms. The duration of each sample is derived mathematically to ensure that the average value of the actual output waveform within each sampling cycle tracks the required output waveforms.The input and output voltage vectors are defined by the relationship between them and they are written as,

$$\overrightarrow{V_{in}} = \begin{bmatrix} V_a(t) \\ V_b(t) \\ V_c(t) \end{bmatrix}, \quad \overrightarrow{V_{out}} = \begin{bmatrix} V_A(t) \\ V_B(t) \\ V_C(t) \end{bmatrix} \qquad (1)$$

$$\overrightarrow{V_{out}} = \overrightarrow{M}.\overrightarrow{V_{in}} \qquad (2)$$

$$\begin{bmatrix} V_A(t) \\ V_B(t) \\ V_C(t) \end{bmatrix} = \begin{bmatrix} m_{11}(t) & m_{12}(t) & m_{13}(t) \\ m_{21}(t) & m_{22}(t) & m_{23}(t) \\ m_{31}(t) & m_{32}(t) & m_{33}(t) \end{bmatrix} \begin{bmatrix} V_a(t) \\ V_b(t) \\ V_c(t) \end{bmatrix} \qquad (3)$$

where,

$$\overrightarrow{M} = \begin{bmatrix} m_{11}(t) & m_{12}(t) & m_{13}(t) \\ m_{21}(t) & m_{22}(t) & m_{23}(t) \\ m_{31}(t) & m_{32}(t) & m_{33}(t) \end{bmatrix}$$

Each entity of the instantaneous transfer function matrix, $m_{ij}(t)$ (i, j=1,2,3), represents the duty cycle function of a bi-directional switch within one switching period. The duty cycle functions are limited by the existence constraint

$$0 \le m_{ij}(t) \le 1 \; (i, j = 1,2,3)$$

and the restriction imposed on the matrix converter switches by

$$\sum_{j=1}^{3} m_{ij}(t) = 1 (i = 1,2,3)$$

The maximum voltage transfer ratio of input to output voltage was limited by 0.5 in the initial approach of the Venturini method. Later, this method was further modified to increase the maximum voltage transfer ratio to 0.866.

The transfer function matrix M is first found which consists of the duty cycle functions of the nine bi-directional switches. For a set of three phase input supply voltages

$$[V_i(t)] = \begin{bmatrix} V_a(t) \\ V_b(t) \\ V_c(t) \end{bmatrix} = \begin{bmatrix} V_{im}\cos(\omega_i t) \\ V_{im}\cos\left(\omega_i t - \frac{2\pi}{3}\right) \\ V_{im}\cos\left(\omega_i t + \frac{2\pi}{3}\right) \end{bmatrix} \qquad (4)$$

where, V_{im} is the amplitude of the input voltage. The output voltages are generated as average values of the piecewise sampling of the input supply waveforms by three switching sequences within sampling time T_s .

The three output phase voltages are related to the input supply voltages with the transfer function matrix given by

$$[V_o(t)] = \begin{bmatrix} V_A(t) \\ V_B(t) \\ V_C(t) \end{bmatrix} = \begin{bmatrix} V_{om}\cos(\omega_0 t + \theta_0) \\ V_{om}\cos\left(\omega_0 t + \theta_0 - \frac{2\pi}{3}\right) \\ V_{om}\cos\left(\omega_0 t + \theta_0 + \frac{2\pi}{3}\right) \end{bmatrix} \qquad (5)$$

where, $\begin{bmatrix} V_A(t) \\ V_B(t) \\ V_C(t) \end{bmatrix} = \begin{bmatrix} m_1(t) & m_2(t) & m_3(t) \\ m_2(t) & m_3(t) & m_1(t) \\ m_3(t) & m_1(t) & m_2(t) \end{bmatrix} \begin{bmatrix} V_a(t) \\ V_b(t) \\ V_c(\ ) \end{bmatrix}$

By solving the above equation, the following mathematical expressions of the switch duty cycles are obtained.

$$m_1(t) = \frac{T_1}{T_s} = \frac{1}{3} + \frac{2}{3} q \cos(\omega_o - \omega_i)t$$

$$m_2(t) = \frac{T_2}{T_s} = \frac{1}{3} + \frac{2}{3} q \cos\left((\omega_o - \omega_i)t - \frac{2\pi}{3}\right)$$

$$m_3(t) = \frac{T_3}{T_s} = \frac{1}{3} + \frac{2}{3} q \cos\left((\omega_o - \omega_i)t + \frac{2\pi}{3}\right)$$

where, q is the voltage transfer ratio $q = V_{om}/V_{im}$. These modulation functions are used to control the matrix converter switches to obtain sinusoidal input as well as sinusoidal output currents. For complete generation of the output voltage waveforms with any output frequency, the desired output voltages must be entirely contained within the continuous envelope formed by the input voltages.

V. SIMULATION RESULTS

[5][6]Simulation was obtained for a single phase matrix converter as a cycloconverter using MATLAB/SIMULINK. Switching sequences have been provided using a pulse generator.Results wereobtained for 50Hz to 50Hz, 50Hz to 25Hz and 50Hz to 100Hz with switching sequences as given in [TABLE 1].

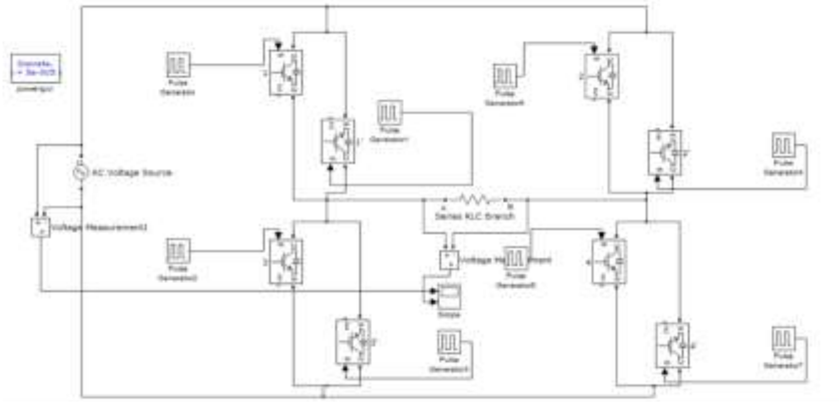


Fig.8 Circuit for single phase matrix converter used for simulation

TABLE 1 Sequence of switching control

Input Frequency	Output Frequency	Time period (seconds)	Conducting switches		Time delay (seconds)	Current Direction (Across load)
50Hz	25Hz	0.04	1	4	0	A to B
			3’	2’	0.01	A to B
			2	3	0.02	B to A
			4’	1’	0.03	B to A
	50Hz	0.02	1	4	0	A to B
			4’	1’	0.01	B to A
	100Hz	0.01	1	4	0	A to B
			2	3	0.005	B to A
			3’	2’	0.01	A to B
			4’	1’	0.015	B to A

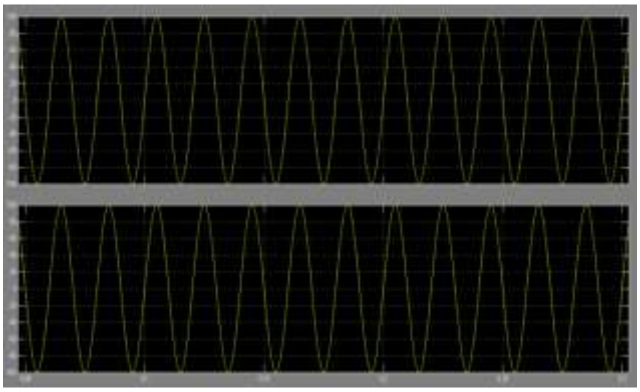


Fig.9 Output of 50Hz obtained for an input of 50Hz

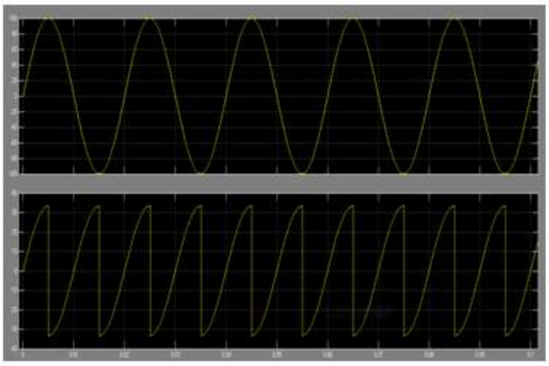


Fig. 10 Output of 25Hz obtained for an input of 50Hz

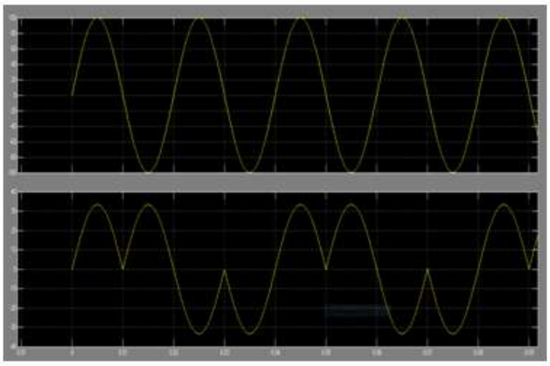


Fig.11 Output of 100Hz obtained for an input of 50Hz

VI. RESULTS AND CONCLUSION

Results were obtained after performing simulation in MATLAB/SIMULINK. The output voltage is lower than the input voltage because the magnitude of the carrier wave is less than the input wave. Also, the output wave obtained is not smooth due to the use of pulse generators. This can be solved using the Sine PWM method to generate pulses. Hence, matrix converter is an easy and quick method to perform AC to AC Conversion. However, matrix converter has a few drawbacks such as the maximum input-output voltage ratio being limited to 0.877, the requirement of a large number of switches and the complex control of these switches. Nevertheless, it is a convenient to perform AC-AC conversion.

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