Simulation Model of a Matrix Converter using Indirect Transfer Function Approach

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Abstract

A matrix converter is an AC-AC power converter topology which seems to be an alternative to conventional AC-DC-AC converter. It is an array of bidirectional controlled switches that couples directly the three phase sources to three phase balanced load without the need of bulky and limited lifetime energy storage elements. This paper discuss the operating principle and space vector modulation scheme for indirect transfer function matrix converter. The simulation and experimental result are shown to prove the ability of the converter to generate three phase output voltage and current of different frequency with respect to input three phase voltage and current frequency. Also the input power factor is maintained to near unity irrespective of load

Keywords – *Matrix converter (MC), Indirect Transfer Approach, AC-AC power conversion.*

1. Introduction

The most desirable characteristics of power converters are simple and compact power circuit, generation of load voltage of constant amplitude and frequency, cosinosodial input and output currents, operating with unity power factor for any load and regeneration capability. This all features are fulfilled by the matrix converter.

The Matrix Converter is an array of (m x n) fully controlled bidirectional switches which transform ‘m’ input voltage of particular frequency in to ‘n’ output voltage in to different frequency. The main advantage of using matrix converter is that it’s just eliminate the use of the bulky DC-link used in the conventional AC-DC-AC converters. Figure.1 represents the 3x3 matrix converter.

The most important elements in this converter is fully controlled bidirectional switches, which allow high frequency operations. These are capable of blocking voltage and conducting current in both directions. Unfortunately, there is no such devices currently available, so discrete device need to use to construct suitable switch cells.Figure 1 represents the Bidirectional switch.

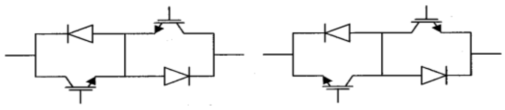


Figure 1. Bidirectional Switch

2. Methodology

The simplified matrix converter is shown in figure 2. Since the matrix converter is supplied by the voltage sources, the input phases must never be shorted, and due to inductive nature of load, the output phases must not be open left. If the switching function of a switch, s_{jk} can be defined as [6]

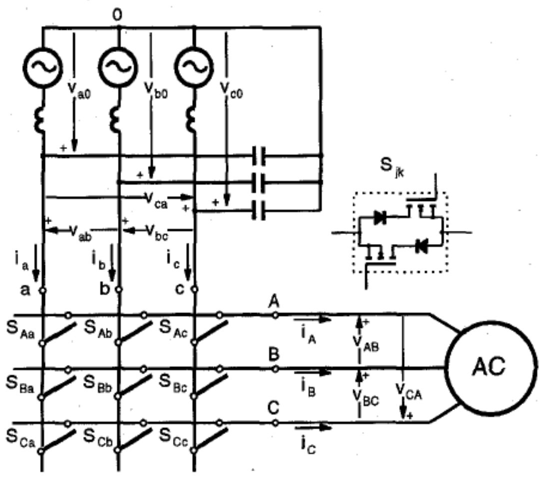


Figure 2. Represents 3x3 Matrix Converter.

$$S_{jk} = \begin{cases} 1, & S_{jk} \ \ closed \\ 0, & S_{jk} \ \ open \end{cases} \qquad j \epsilon \{A, B, C\}, \ \ k \ \epsilon \{a,b,c\}$$

the constraint can be expressed as

$$s_{ja} + s_{jb} + s_{jc} = 1 \qquad j \epsilon \{A, B, C\}$$

The output line voltage and input phase current is given by

$$V_{oL} = \begin{pmatrix} v_{AB} \\ v_{BC} \\ v_{CA} \end{pmatrix} = \begin{bmatrix} s_{Aa} - s_{Ba} & s_{Ab} - s_{Bb} & s_{Ac} - s_{Bc} \\ s_{Ba} - s_{Ca} & s_{Bb} - s_{Cb} & s_{Bc} - s_{Cc} \\ s_{Ca} - s_{Aa} & s_{Cb} - s_{Ab} & s_{Cc} - s_{Ac} \end{bmatrix} . \begin{bmatrix} v_{ao} \\ v_{bo} \\ v_{co} \end{bmatrix} \qquad (1)$$

and

$$i_{iPh} = \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = T_{PhL}^T . \begin{bmatrix} i_{AB} \\ i_{BC} \\ i_{CA} \end{bmatrix} = T_{PhL}^T . i_{oL} \qquad (2)$$

Where T_{PhL}^{T} is the instantaneous input-phase to output-line transfer function matrix of the 3Φ-3Φ MC.

The output phase voltage referred to input neutral and the input phase current can be expressed as

$$v_{oPh} = \begin{bmatrix} v_{Ao} \\ v_{Bo} \\ v_{Co} \end{bmatrix} = \begin{bmatrix} s_{Aa} & s_{Ab} & s_{Ac} \\ s_{Ba} & s_{Bb} & s_{Bc} \\ s_{Ca} & s_{Cb} & s_{Cc} \end{bmatrix} . \begin{bmatrix} v_{ao} \\ v_{bo} \\ v_{co} \end{bmatrix} = T_{pHpH} \, . v_{iPh} \; (3)$$

and

$$i_{iPh} = \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = T_{PhPh}^{T} . \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} = T_{PhPh}^{T} \, . i_{oPh} \, (4)$$

Where the matrix T_{pHpH} is the instantaneous input-phase to output-phase matrix and i_{oPh} is the output current, i_{iPh} is the input current. So if we want to obtain the desired output voltage and current, we just need to determine the converter matrix.

2.1. Space Vector Modulation Strategy of Matrix Converter

Space vector modulation use the high frequency technology for better output results. Indirect space vector modulation is based on concept of virtual DC-Link. The whole matrix converter is seems to be resolved in virtual voltage source rectifier (VSR) and voltage source inverter (VSI) as shown in figure3.

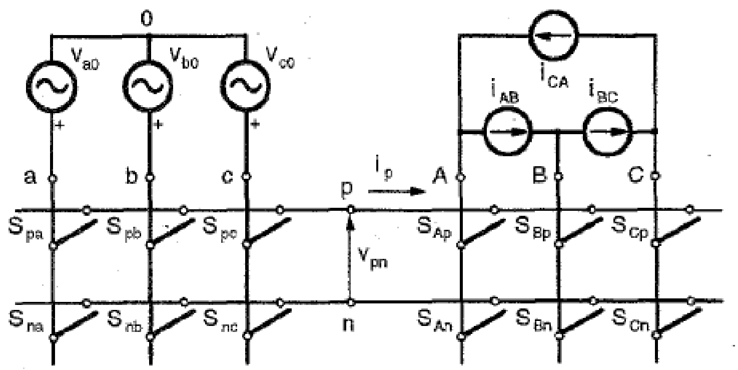


Figure 3. Virtual VSR and VSI of Matrix Converter.

2.2. VSR Space Vector Modulation

The space vector of input current is

$$\bar{I}_{iPh} = \frac{2}{3}\left(i_a + i_b e^{j\,120^0} + i_c e^{-j\,120^0}\right) \quad (5)$$

The control target of VSR space vector modulation algorithm is :

$$\bar{I}_{ref} = d_a \bar{I}_a + d_b \bar{I}_b + d_c \bar{I}_c \quad (6)$$

In this formula $d_\alpha = T_\alpha/T_s$, $d_\beta = T_\beta/T_s$ and $d_0 = T_0/T_s$ is the duty cycle of the PWM T_s. T_α, T_β, T_0 presents the two adjacent nonzero current vector and the zero current vectors in a PWM on-time period respectively. And:

$$\begin{cases} d_\alpha = \frac{T_\alpha}{T_s} = m_i.sin(60^0 - \theta) \\ d_\beta = \frac{T_\beta}{T_s} = m_i.sin(\theta) \\ d_0 = \frac{T_0}{T_s} = 1 - d_\alpha - d_\beta \end{cases} \quad (7)$$

Where :

$$m_i = \frac{2}{\sqrt{3}} . \frac{|\bar{I}_{ref}|}{|\bar{I}_a|} = \frac{2}{\sqrt{3}} . \frac{|\bar{I}_{ref}|}{|\bar{I}_\beta|} (8)$$

2.3. VSI Space Vector Modulation

The control target voltage of VSI is:

$$\bar{U}_{oL} = d_m \bar{U}_\alpha + d_n \bar{U}_\beta + d_{ov} \bar{U}_{ov} \quad (9)$$

In this formula, $d_m = T_m/T_s$, $d_n = T_n/T_s$, $d_{ov} = T_{ov}/T_s$ is the duty cycles of the PWM T_s. T_m, T_n , T_{ov} present the two adjacent non zero voltage vectors and the zero voltage vectors in a PWM on-time period respectively.

The DC-link does not exist in the actual matrix converter. In order to eliminate the DC link, the VSR and the VSI is the combined using high-frequency synthesis, the input phase current and output line voltage can be simultaneously modulated using indirect space vector modulation.

$$\begin{cases} d_m = \frac{T_m}{T_s} = m_v.sin(60^0 - \theta_v) \\ d_n = \frac{T_n}{T_s} = m_v.sin(\theta_v) \\ d_{ov} = \frac{T_{ov}}{T_s} = 1 - d_m - d_n \end{cases} \quad (10)$$

Where:

$$m_v = \frac{2}{\sqrt{3}} . \frac{|\bar{U}_{oL}|}{|\bar{U}_a|} = \frac{2}{\sqrt{3}} . \frac{|\bar{U}_{oL}|}{|\bar{U}_\beta|} \quad (11)$$

Where θ_v is the angle btween the output voltage and one adjacent non-zero vector. And the average of input current of DC side is given by:

$$i_p = T_{VSI}^T . I_{oL} = \frac{\sqrt{3}}{2} I_{om} m_v \cos(\emptyset_L) = constant \quad (12)$$

2.4. Indirect Space Vector Modulation

To eliminate the virtual DC part, VSR and VSI is composed in high frequency and the input phase current and output line voltage modulate simultaneously.The switch function of matrix converter is given by:

$$T_{PhL} = m_{MC} \begin{bmatrix} \cos(\theta_v - 30^0) \\ -sin(60 - \theta_v) \\ -sin(\theta_v) \end{bmatrix} \begin{bmatrix} \cos(\theta - 30^0) \\ -\sin(60 - \theta) \\ -\sin(\theta) \end{bmatrix}^T \quad (13)$$

The output line voltage is given by:

$$\begin{bmatrix} \bar{u}_{AB} \\ \bar{u}_{BC} \\ \bar{u}_{CA} \end{bmatrix} = \begin{bmatrix} d_m + d_n \\ -d_m \\ -d_n \end{bmatrix} \begin{bmatrix} d_\alpha + d_\beta \\ -d_\alpha \\ -d_\beta \end{bmatrix}^T \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \quad (14)$$

The input phase current is:

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} d_{m\alpha} \\ -d_{m\alpha} \\ 0 \end{bmatrix} (-i_B) + \begin{bmatrix} d_{n\alpha} \\ d_{n\alpha} \\ 0 \end{bmatrix} (i_A) + \begin{bmatrix} d_{n\beta} \\ 0 \\ -d_{n\beta} \end{bmatrix} (i_A) + \begin{bmatrix} d_{m\beta} \\ 0 \\ -d_{m\beta} \end{bmatrix} (-i_B) \quad (15)$$

Where

$$\begin{cases} d_{m\alpha} = d_m . d_\alpha = m_{MC} . \sin(60 - \theta_v) . \sin(60 - \theta) \\ d_{n\alpha} = d_n . d_\alpha = m_{MC} . \sin(\theta_v) . \sin(60 - \theta) \\ d_{m\beta} = d_m . d_\beta = m_{MC} . \sin(60 - \theta_v) . \sin(\theta) \\ d_{n\beta} = d_n . d_\beta = m_{MC} . \sin(\theta_v) . \sin(\theta) \end{cases} \quad (16)$$

And

$$d_o = 1 - \left(d_{m\alpha} + d_{n\alpha} + d_{m\beta} + d_{n\beta}\right) \quad (17)$$

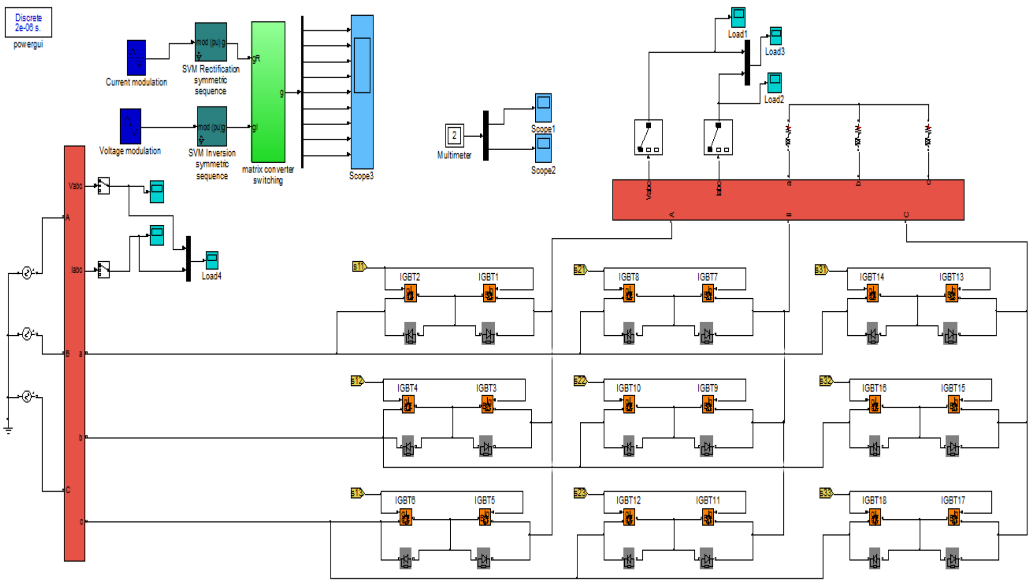


Figure 4. Simulation Block Diagram.

3. The Simulation Results

The simulation were done using Matlab R2017a simulation Software. The simulation results are obtained under different circumstances. The input filter is the integral part of the matrix converter. But in this paper, two different results are obtained, first in absences of input filter, and another one in the presence of input filter. The purpose for doing this is to get better understanding and analysis of voltage and current waveforms. The simulation result for MC connected to the RL load (R = 2Ω & L = 0.001H) will be presented. The figure-5 shows the simulation results in case of 25Hz input frequency and 50Hz output frequency. The parameters used in the simulation for figure-6 are given in the Table-1. The figure-6represents the simulation results in case of input phase voltage frequency sets to 50Hz and the output voltage frequency sets to 25Hz. The parameters used in simulation are given in Table-2.The figure 7 represents the output of MC, when input filters are used. The Table-3 describes the values of parameters used. The RL load is used (R = 2Ω & L = 0.001H). Form the figure 7 we can see that the input filter is very much effective in blocking the harmonics of input currents.

Table 1. Parameters values

Parameters	Values
Input Phase Voltage	200V
Output Phase Voltage	80V
Input Phase Current	5A
Output Phase Current	50A
Input Frequency	25Hz
Output Frequency	50Hz
Input Power Factor	1
Output Power Factor	Depends on RL load
Input Filter	Not used

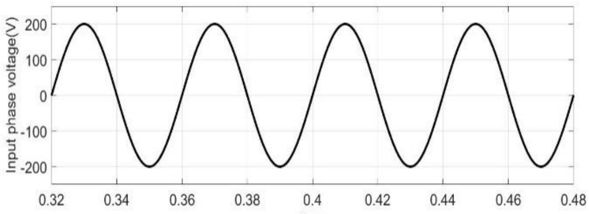
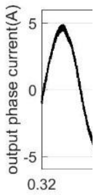


Figure.5.a Input Phase Voltage at 25Hz.

Figure 5.b Input Phase Current at 25Hz



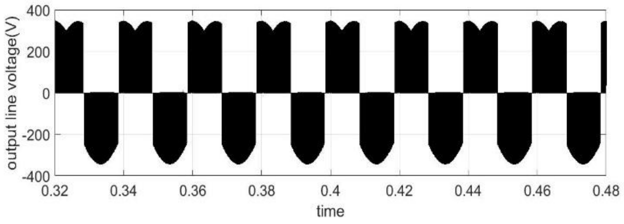
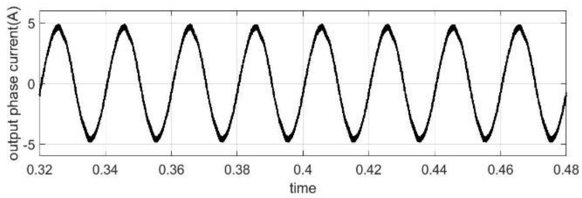


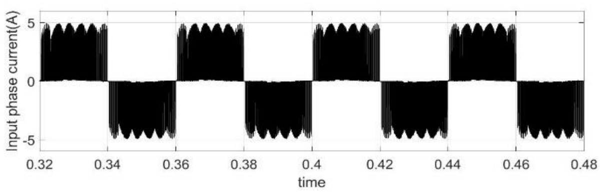
Figure 5.c Output Phase Current at 50Hz.

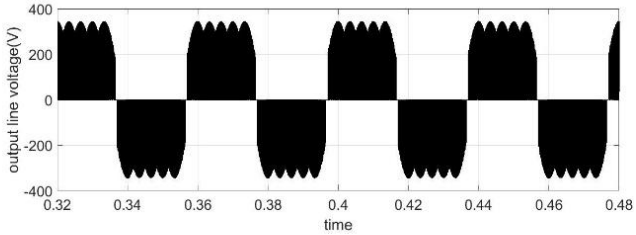
Figure 5.d Output Line Voltage at 50Hz.

Table 2. Parameters values

Parameters	Values
Input Phase Voltage	200V







Output Phase Voltage	80V
Input Phase Current	5A
Output Phase Current	50A
Input Frequency	50Hz
Output Frequency	25Hz
Input Power Factor	1
Output Power Factor	Depends on RL load
Input Filter	Not used

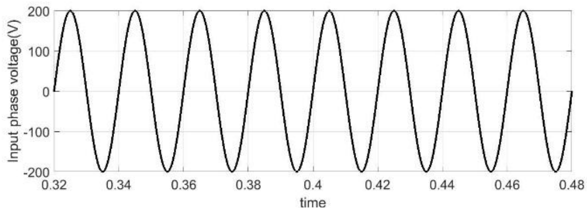


Figure 6.a Input Phase Voltage at 50 Hz.

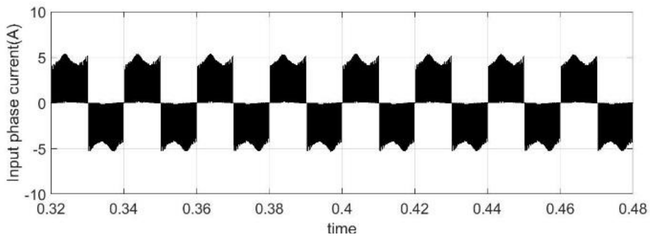


Figure 6.b Input Phase current at 50Hz.

Figure 6.c Output Line voltage at 25Hz.

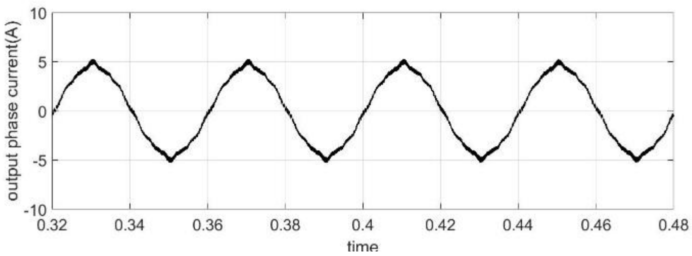


Figure 6.d Output Line current at 25Hz

Table 3. Parameters values

Parameters	Values
Input Phase Voltage	200V
Output Phase Voltage	80V
Input Phase Current	5A
Output Phase Current	50A
Input Frequency	50Hz
Output Frequency	25Hz
Input Power Factor	1
Output Power Factor	Depends on RL load
Input Filter	L_{in} = 0.01H C_{in} = 500μF

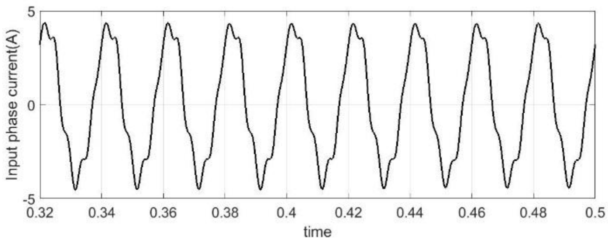


Figure 7.a Input Phase Current at 50Hz

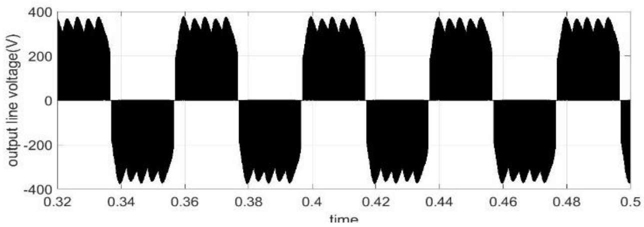


Figure 7.b Output Line Voltage at 30Hz

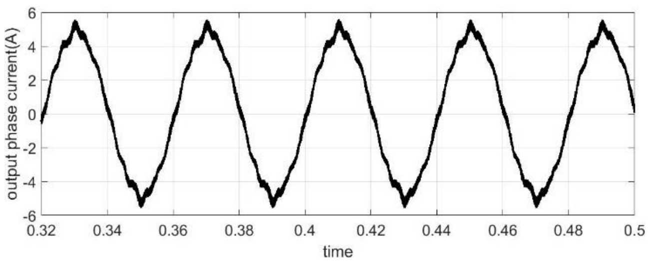


Figure 7.c Output Line Current at 30Hz.

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