Comparative Study of DSVM and ISVM for Matrix Converter

CH. Amarendra	P. V. Pattabhi Ram
Student, Electrical and Electronics Engineering, K.L.University, Vaddeswaram, Guntur.	Associate Professor, Electrical and Electronics Engineering, K.L.University, Vaddeswaram, Guntur.

ABSTRACT *The matrix converter (MC) stands as an alternative in power conversion, performing the energy conversion by direct connecting input with output phases through bidirectional switches. The main advantage of MCs is the absence of bulky reactive elements that are subject to ageing, reduce the system reliability. Furthermore MCs provide bidirectional power flow nearly sinusoidal input and output waveform and controlled input power factor. Space vector switching methods for matrix converter classified into two different strategies 1.indirect space vector modulation which takes the advantages of a virtual dc link 2. Direct space vector modulation that provides direct conversion. In this paper two modulation methods, direct and indirect space vector modulation on direct matrix converter are reviewed. Simulation and comparison are done under the same conditions of the input power supply and output load.*

INTRODUCTION

The matrix converters, fed by three - phase sinusoidal source with constant frequency and amplitude are an array of controlled nine bidirectional semi-conductor switches connected in the matrix form. Each output line is linked to each input line via a bidirectional switch. These switches provide to acquire voltages with variable amplitude and frequency at the output side by switching input voltage with various modulation algorithms [1], [2]. Recently, the most popularly used switching algorithm is space vector modulation algorithm that allows the control of input current and output voltage vectors independently. Space vector modulation algorithm has many advantages with respect to the traditional modulation techniques such as, being able to obtain maximum voltage ratio (0 <q<0.866) without adding third harmonics, being able to minimize the switching numbers that are required for commutation process, being more easily implemented due to facilitated control algorithm, easily being able to comprehend the commutation process and being easily operated under unbalanced conditions [3], [4].

Different approaches of switching of MCs have been proposed in literatures [2-5]. Many aspects such as output harmonic spectrum, total harmonic distortion (THD) switching, complexity of implementation, and number of switching plays important role in determination of an appropriate modulation strategy. Space vector modulation has been successively improved in recent years and is considered as a standard technique in matrix converter modulation. [2, 5].space vector modulation is still ambiguous for engineers to completely comprehend its operating principle.

INTRODUCTION TO MATRIX CONVERTER

The matrix converter is a single stage converter which has an array of m×n bidirectional power switching to connect directly. A m-phase voltage source to an n-phase load. The matrix converter of 3 ×3 switches shown in fig.1 has highest practical interest because it connects a three phase voltage source with a three phase load.
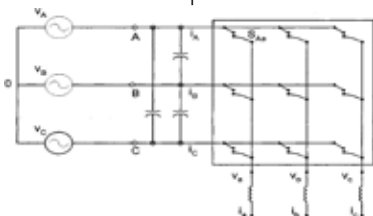

Figure 1: 3×3matrix converter topology

Normally, the matrix converter is fed by a voltage source and, for this reason the input terminals should not be shorted. On the other hand the load has typically an inductive nature and for this reason an output phase must never opened. Defining the switching function of a single switch

$$S_{kj}=\begin{cases}1 & switch\ Skj\ closed \\ 0, & switch\ Skj\ open\end{cases} \quad K = \{A,B,C\}$$

$$j = \{a,b,c\}$$

The restriction is expressed as

$$SAj + SBj + SCj = 1 \qquad j = \{a,b,c\}$$

The input and output voltage can be expressed as vectors defined by

$$V_o = \begin{bmatrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{bmatrix} \qquad V_i = \begin{bmatrix} v_A(t) \\ v_B(t) \\ v_C(t) \end{bmatrix}.$$

The input and output current can be expressed as vectors defined by

$$I_i = \begin{bmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{bmatrix} \qquad I_o = \begin{bmatrix} i_A(t) \\ i_B(t) \\ i_C(t) \end{bmatrix}$$

The relationship between load and input voltage can be expressed as

$$\begin{bmatrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{bmatrix} = \begin{bmatrix} S_{Aa}(t) & S_{Ba}(t) & S_{Ca}(t) \\ S_{Ab}(t) & S_{Bb}(t) & S_{Cb}(t) \\ S_{Ac}(t) & S_{Bc}(t) & S_{Cc}(t) \end{bmatrix} \begin{bmatrix} v_A(t) \\ v_B(t) \\ v_C(t) \end{bmatrix}$$

By considering that the bidirectional power switches work with high switching frequency, a low-frequency output voltage of variable amplitude and frequency can be generated by modulating the duty cycle of the switches using their respective switching function.

Let Mkj(t)be the duty cycle of switch Skj defined as Mkj(t)=tkj/Tseq. Which can hav the following values

$$0 < m_{kj} < 1$$

$$k=\{A,B,C\}, \; j = \{a,b,c\}.$$

DIRECT SPACE VECTOR MODULATION (DSVM)
At any switching time, there are 27 different switching combinations for connecting output phase to input phases. These switching combinations can be analyzed in three groups. Each output phase is directly connected to three input phases interns with six switching combinations in the first group

The phase angle of output voltage vector depends on the phase angle of the input voltage vector similar condition is also valid for current vectors. For the space vector modulation technique, these switching states are not used in the matrix converter since the phase angle of both vectors cannot be controlled independently.

There are 18 switching combinations in the second group, in which the active voltage vector is formed at variable amplitude and frequency .amplitude of the output voltage depends on the selected input line voltages. in this case, the phase angle of the output voltage space vector does not depend on the phase angle of the input voltage space vector similar condition is also valid for current vectors are shown in fig2 and fig3.

Last group with 3 switching combinations consists of zero vectors. In this case, all of the output phases are connected to the same input phase.

Output line voltage and input current space vectors are used in the application of the space vector modulation (SVM) to the matrix converter.
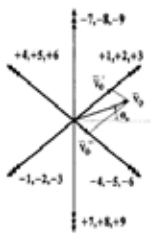

Fig. 2 - Output voltage space vectors corresponding to the permitted switching combinations.
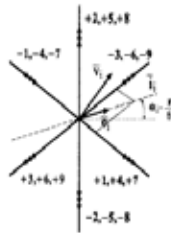
Fig. 3 - Input current space vectors corresponding to the permitted switching combinations.

The duty cycle for the four non-zero vectors

$$\delta_1 = (-1)^{k_o+k_i+1} \frac{2m}{\sqrt{3}} \frac{\cos\left(\emptyset'_o - \frac{\pi}{2}\right)\cos\left(\emptyset'_i - \frac{\pi}{2}\right)}{\cos(\Delta\emptyset)}$$

$$\delta_2 = (-1)^{k_o+k_i} \frac{2m}{\sqrt{3}} \frac{\cos\left(\emptyset'_o - \frac{\pi}{2}\right)\cos\left(\emptyset'_i + \frac{\pi}{6}\right)}{\cos(\Delta\emptyset)}$$

$$\delta_3 = (-1)^{k_o+k_i} \frac{2m}{\sqrt{3}} \frac{\cos\left(\emptyset'_o + \frac{\pi}{6}\right)\cos\left(\emptyset'_i - \frac{\pi}{2}\right)}{\cos(\Delta\emptyset)}$$

$$\delta_4 = (-1)^{k_o+k_i+1} \frac{2m}{\sqrt{3}} \frac{\cos\left(\emptyset'_o + \frac{\pi}{6}\right)\cos\left(\emptyset'_i + \frac{\pi}{6}\right)}{\cos(\Delta\emptyset)}$$

Where m is the modulation index, is the displacement angle between the measured input voltage vector V_i and I_i, k_v and K_i are the voltage and current sectors respectively

If the sign of any duty cycle is negative then the vector of group II must have a negative sign. The duty cycle of the zero vector Vso and Iso is much that the total duty cycle must be the unit at a fixed sampling frequency

$$\delta_o = 1-\delta_1-\delta_2-\delta_3-\delta_4.$$

Table no.1
position switching vectors of group 2 in terms of the voltage and current sectors, for each non-zero vector

Current sector	Voltage 1or4	sector 2or5	3or6
1or4	9,7,3,1	6,4,9,7	3,1,6,4
2or5	8,9,2,3	5,6,8,9	2,3,5,6
3or6	7,8,1,2	4,5,7,8	1,2,4,5
name	S_1,S_2,S_3,S_4	S_1,S_2,S_3,S_4	S_1,S_2,S_3,S_4

Assuming a displacement power factor(DPF) i.e. the maximum modulation index is m=0.866.in order to know which vector corresponding to a given non-zero duty cycle, it is necessary to define voltage and current sector that depend on the angle of the angle of the reference current and voltage sectors. With the sector defined in fig.2,fig.3.

INDIRECT SPACE VECTOR MODULATION (ISVM)
A space vector is obtained from there phase quantities through the following transformation

$$X = \frac{2}{3}(\chi_a + \bar{\alpha}\chi_b + \bar{\alpha}^2\chi_c),$$

$$\bar{\alpha} = e^{j(2\pi/3)} = \cos\left(\frac{2\pi}{3}\right) + j\sin\left(\frac{2\pi}{3}\right).$$

Many engineers are familiar with the space vector modulation for voltage source inverter (VSI). However, the modulation method for the high level of intricacy and limited materials to explain its fundamentals. Hence, it would be easier and more conceivable to illustrate the switching operation of matrix converter by adopting conventional VSI topology and SVM concept.

Where matrix converter was described to an equivalent circuit consisting of current source rectifier and voltage source inverter connected through virtual dc-link.the idea of the indirect modulation technique is to separate the control of the input current and output voltage .this is done by dividing the switching function S into the product of a rectifier and an inverter switching function.

Two space vector modulations for current source rectifier and voltage source inverter stages should be implemented and then the two modulation results should be combined.

$$\begin{bmatrix} S_{11} & S_{21} & S_{31} \\ S_{12} & S_{22} & S_{32} \\ S_{13} & S_{23} & S_{33} \end{bmatrix} = \begin{bmatrix} S_7 & S_8 \\ S_9 & S_{10} \\ S_{11} & S_{12} \end{bmatrix} \cdot \begin{bmatrix} S_1 & S_3 & S_5 \\ S_2 & S_4 & S_6 \end{bmatrix},$$

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} S_7 & S_8 \\ S_9 & S_{10} \\ S_{11} & S_{12} \end{bmatrix} \cdot \begin{bmatrix} S_1 & S_3 & S_5 \\ S_2 & S_4 & S_6 \end{bmatrix} \cdot \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}.$$

SVM for the rectifier stage
The rectifier part of the equivalent circuit can be assumed as a current source rectifier with the averaged value of I dc and is derived as follows

$$I_{dc} = \frac{\sqrt{3}}{2} I_{out}.m_v.\cos(\theta_{out}).$$

I_{out} is the peak value of output current Θ_{out} is the output load displacement angle and $m_v = V_{out}/V_{dc}$. The input current space vector Iref is extracted as

$$I_{ref} = \frac{2}{3}(I_a + \bar{\alpha}I_b + \bar{\alpha}^2 I_c).$$

The nine rectifier switches have nine permitted combinations avoid an open circuit at the DC-link. These combinations include three zero and six non zero input currents. The reference input current vector is synthesized by impressing the adjoining switching vectors (I_γ) and (I_δ) with duty cycle (d_γ) and (d_δ) respectively

$$I_{ref} = I_\gamma.d_\gamma + I_\delta.d_\delta$$

The duty ratios of active vectors are

$$d_\gamma = \frac{T_\gamma}{T_s} = m_c \sin\left(\frac{\pi}{3} - \theta_i\right),$$

$$d_\delta = \frac{T_\delta}{T_s} = m_c \sin(\theta_i),$$

$$d_{oc} = \frac{T_{OC}}{T_s} = 1 - d_\delta - d_\gamma,$$

Where Θ_i indicates the angle of the reference current vector the current modulation index mc defines the desired current transfer ratio such as
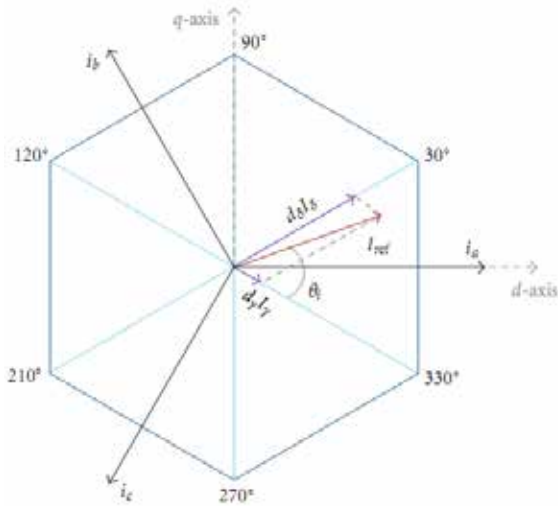
$$m_c = \frac{I_{ref}}{I_{DC}}; \ 0 \le m_c \le 1.$$

Figure 4: Input current space vector in complex plane.

SVM for the inverter stage
The inverter can be assumed as a separate VSI. The switching method is exactly similar to conventional VSI. But owing to its virtual DC-link Vdc should be defined as follows

$$V_{DC} = \frac{3}{2}V_{in}.m_c.\cos(\theta_{in})$$

V_{in} is the peak value of input voltage and Θ_{in} is the input displacement angle, the output voltage space vector, V_{ref} is evaluated as

$$V_{ref} = \frac{2}{3}(V_a + \bar{\alpha}V_b + \bar{\alpha}^2 V_c).$$

The inverter switches have eight permitted combinations to avoid a short circuit these combinations included two zero and six non zero input currents. The reference output voltage vector is synthesized by impressing the adjoining active vectors (V_α) and (V_β) with the duty ratios (d_α) and (d_β) respectively.

The reference vector can be expressed by the voltage –time product sum of the adjoining active vectors

$$V_{ref} = d_\alpha.V_\alpha + d_\beta.V_\beta$$

The duty cycles of the active vectors can be

$$d_\alpha = \frac{T_\alpha}{T_s} = m_v \sin\left(\frac{\pi}{3} - \theta_v\right),$$

$$d_\beta = \frac{T_\beta}{T_s} = m_v \sin(\theta_v),$$

$$d_{OV} = \frac{T_{OV}}{T_s} = 1 - d_\alpha - d_\beta.$$

Where Θv indicates the angle of the reference voltage vector mv is the voltage modulation index
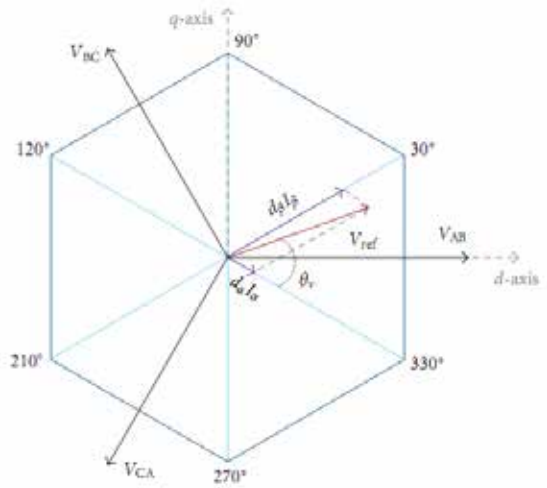

Figure5: Output voltage space vector in complex plane.

Simulation results
In order to compare the performances of the direct and indirect space vector modulation techniques, these methods are applied to an AC/AC matrix converter. This system consists of a simple source voltage that is connected to a resistive load through a matrix converter. The simulations were performed with Matlab/Simulink. the summary of results will be tabulated in table.no.2.

Table.no.2
Test case system parameters

PARAMETERS	VALUE
Source voltage (peak)	100V
System frequency	50Hz
Load resistance	10ohms
Switching frequency	2.5KHz
Modulation index	0.866

The double sided switching pattern is used for both direct and indirect matrix converter. The direct matrix converter is more appropriate choice for a lower harmonic distortion in spite of greater switching losses.

Table.no.3
THD and switching per cycle

	Direct matrix converter	Indirect matrix converter
THD	29.32	32.15
Number of Switching for each switch	192	159

CONCLUSIONS

This paper compares different switching patterns of direct and indirect space vector modulations for three-phase matrix converter. Two methods of indirect and direct space vector modulation of matrix converter were completely described. As expected the double-sided as well as symmetrical patterns produces lower harmonic distortions. However, the number of switching increases when using direct matrix converter.

REFERENCE [1] P.W.Wheeler, J. Rodríguez, J. C. Clare, M. L. Empringham, and A. Weinstein, "Matrix converters: a technology review," IEEE Transactions on Industrial Electronics, vol. 49, no. 2, pp. 276– 288. | [2] D. Casadei, G. Serra, A. Tani, and L. Zarri, "Matrix converter modulation strategies: a new general approach based on spacevector representation of the switch state," IEEE Transactions on Industrial Electronics, vol. 49, no. 2, pp. 370–381. | [3] M. Venturini and A. Alesina, "Generalised transformer: a new bidirectional, sinusoidal waveform frequency converter with continuously adjustable input power factor," the IEEE Power Electronics Specialists Conference (PESC '80), pp. 242–252, Atlanta, Ga, USA. | [4] A. Alesina and M. G. B. Venturini, "Analysis and design of optimum-amplitude nine-switch direct AC-AC converters," | IEEE Transactions on Power Electronics. | [5] L. Huber and D. Borojevic, "Space vector modulated three phase to three-phase matrix converter with input power factor | correction," IEEE Transactions on Industry Applications, vol. 31, no. 6, pp. 1234–1246, 1995. |