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A REVIEW ON MODULATION TECHNIQUES FOR MATRIX CONVERTER

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***Abstract:** This paper represents the matrix converter is an AC-AC converter which a replacement for conventional AC-Dc-AC conversion which is a two step conversion. It is an array of nine bidirectional switches that connect directly the three phase source to three phase load. Different methods are analyzed for matrix converter like venturini method, Scalar method, space vector modulation method carrier based modulation method. These methods are used to generate sinusoidal input and output current on both the sides.*

***Keywords:** Matrix converter, modulation techniques, and AC-AC conversion.*

I. INTRODUCTION

MC is a direct AC-AC power converter that consists of an array of nXm bidirectional power switches. The main characteristics of MC are: input/output sinusoidal waveforms with variable output voltage amplitude and frequency, operation with unity power factor , regeneration capability, no DC link capacitor or inductor is required, four quadrant operation. Mc presents some limitation like with maximum value of voltage transfer ratio is 0.86, large number of semi conductor devices in the power stage.

II. MATRIX CONVERTER FUNDAMENTALS

MC consists of an array of nine bidirectional switches that connects directly to the supply to the load. A basic structure of the power circuit in a matrix converter which is shown in fig.1. This figure shows the bidirectional switches and an input filter for smoothing source currents. From the figure the control stage will be implemented by nine switching functions which is shown in equation (1).

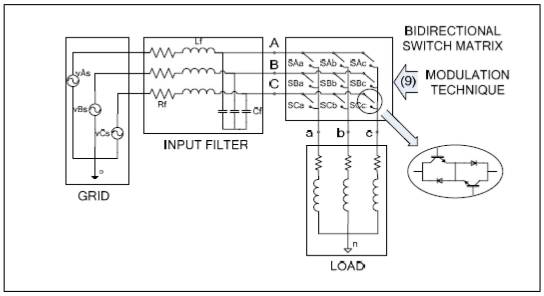


Figure 1: Three phase matrix converter

$$S_{kj}=\begin{cases}1, \text{ switch } S_{kj} \text{ closed} \\ 0, \text{ switch } S_{kj} \text{ open}\end{cases} \qquad K=\{A,B,C\} \quad j=\{a,b,c\} \qquad (1)$$

The mathematical expression that represents basic operation of MC applying Kirchhoff's voltage and current law : Where

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

$$\begin{bmatrix} i_A(t) \\ i_B(t) \\ i_C(t) \end{bmatrix} = \begin{bmatrix} S_{Aa}(t) & S_{Ba}(t) & S_{Ca}(t) \\ S_{Ab}(t) & S_{Bb}(t) & S_{Cb}(t) \\ S_{Ac}(t) & S_{Bc}(t) & S_{Cc}(t) \end{bmatrix}^T \cdot \begin{bmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{bmatrix}$$

Va, Vb and Vc are the output phase voltages and ia, ib and ic represents input currents to the matrix. For these equations the below expression has to be taken in to consideration:
SAj + SBj + SCj = 1 , j = $\{a,b,c\}$
The above expression says that at any time one and only one switch must be closed in an output branch. If two switches were closed simultaneously a short circuit would be generated between two phases. If all the switches in an output branch were open the load current would be suddenly interrupted and due to the inductive nature of the load an over voltage will be produced in the converter.

III. MATRIX CONVERTER MODULATION

A. Venturini method

The first highly relevant method is called venturini method and the output voltage is obtained by the product of the input voltage and the transfer matrix converter. The objective of the modulation is to generate variable frequency and variable amplitude sinusoidal output voltages from the fixed frequency and amplitude.

If tij is defined as the time during which switch Skj is on and Ts as sampling interval, we can express;

$$V_{jN} = ((t_{Aj}\, v_A) + (t_{Bj}\, v_B) + (t_{Cj}\, v_C))/T_s$$

Where vjN is the low frequency component of the jth output phase and changing sampling interval.

$$T_s = t_{Aj} + t_{Bj} + t_{Cj}$$

mAj(t)= tAj/Ts , mBj=tBj/Ts , mCj=tCj/Ts. The below matrix shows its switching sequence;

$$\mathbf{M}(t) = \begin{bmatrix} m_{Aa}(t) & m_{Ba}(t) & m_{Ca}(t) \\ m_{Ab}(t) & m_{Bb}(t) & m_{Cb}(t) \\ m_{Ac}(t) & m_{Bc}(t) & m_{Cc}(t) \end{bmatrix}.$$

This method is of practically 50% voltage ratio limitation.

B. Roy's method

It consists of using instantaneous voltage ratio of specific input phase voltages to generate active and zero vectors switches.

$$v_{jN} = 1 / T_s\,(t_k v_k + t_L v_L + t_M v_M)$$

$$t_K + t_L + t_M = T_s$$

where M is assigned to input voltage which has a different polarity and L is for smallest of the other two input voltage magnitude and K is assigned for third input voltage. Compared to venturini method scalar method has q value is fixed at its maximum value.

C. Pulse width modulation method

The generation of PWM pulses requires reference sine wave and triangular wave which is shown in figure 2.

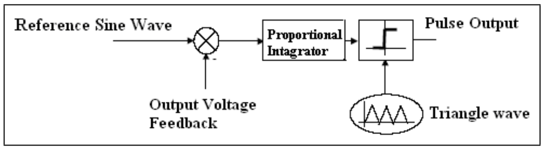


Figure 2: PWM Circuit

This signal is compared with triangular wave. As the sine wave is reaching its peak the pulses get wider which is shown in figure 3.

These above pulses are used for switch ON and OFF and to control both amplitude and frequency.

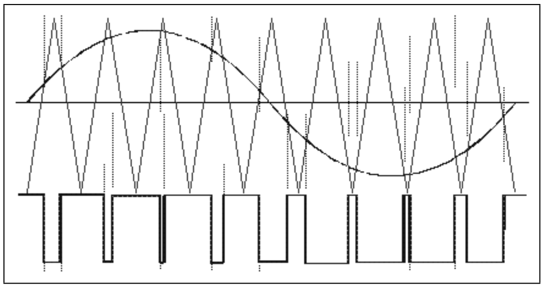
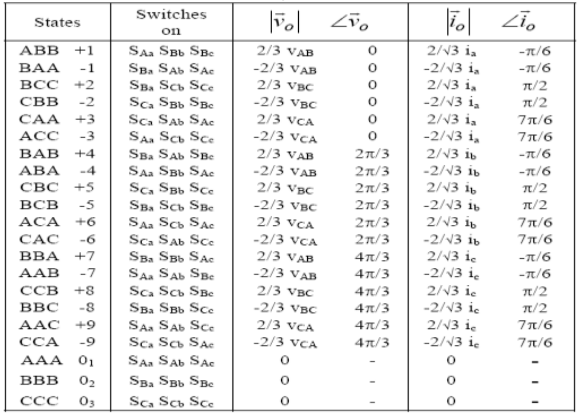


Figure 3: Comparison between sine and triangular wave pulses

D. Space vector modulation

SVM method has voltage transfer ratio is 86% and it is used for DSVM (direct space vector modulation). In direct space vector modulation method 21 of 27 combinations are used in matrix converter which is shown in below table I:

Table I Switching states for DSVM



States		Switches on	$\lvert\vec{v}_o\rvert$	$\angle\vec{v}_o$	$\lvert\vec{i}_o\rvert$	$\angle\vec{i}_o$
ABB	+1	$S_{Aa}\, S_{Bb}\, S_{Bc}$	$2/3\ v_{AB}$	0	$2/\sqrt{3}\ i_a$	$-\pi/6$
BAA	-1	$S_{Ba}\, S_{Ab}\, S_{Ac}$	$-2/3\ v_{AB}$	0	$-2/\sqrt{3}\ i_a$	$-\pi/6$
BCC	+2	$S_{Ba}\, S_{Cb}\, S_{Cc}$	$2/3\ v_{BC}$	0	$2/\sqrt{3}\ i_a$	$\pi/2$
CBB	-2	$S_{Ca}\, S_{Bb}\, S_{Bc}$	$-2/3\ v_{BC}$	0	$-2/\sqrt{3}\ i_a$	$\pi/2$
CAA	+3	$S_{Ca}\, S_{Ab}\, S_{Ac}$	$2/3\ v_{CA}$	0	$2/\sqrt{3}\ i_a$	$7\pi/6$
ACC	-3	$S_{Aa}\, S_{Cb}\, S_{Cc}$	$-2/3\ v_{CA}$	0	$-2/\sqrt{3}\ i_a$	$7\pi/6$
BAB	+4	$S_{Ba}\, S_{Ab}\, S_{Bc}$	$2/3\ v_{AB}$	$2\pi/3$	$2/\sqrt{3}\ i_b$	$-\pi/6$
ABA	-4	$S_{Aa}\, S_{Bb}\, S_{Ac}$	$-2/3\ v_{AB}$	$2\pi/3$	$-2/\sqrt{3}\ i_b$	$-\pi/6$
CBC	+5	$S_{Ca}\, S_{Bb}\, S_{Cc}$	$2/3\ v_{BC}$	$2\pi/3$	$2/\sqrt{3}\ i_b$	$\pi/2$
BCB	-5	$S_{Ba}\, S_{Cb}\, S_{Bc}$	$-2/3\ v_{BC}$	$2\pi/3$	$-2/\sqrt{3}\ i_b$	$\pi/2$
ACA	+6	$S_{Aa}\, S_{Cb}\, S_{Ac}$	$2/3\ v_{CA}$	$2\pi/3$	$2/\sqrt{3}\ i_b$	$7\pi/6$
CAC	-6	$S_{Ca}\, S_{Ab}\, S_{Cc}$	$-2/3\ v_{CA}$	$2\pi/3$	$-2/\sqrt{3}\ i_b$	$7\pi/6$
BBA	+7	$S_{Ba}\, S_{Bb}\, S_{Ac}$	$2/3\ v_{AB}$	$4\pi/3$	$2/\sqrt{3}\ i_c$	$-\pi/6$
AAB	-7	$S_{Aa}\, S_{Ab}\, S_{Bc}$	$-2/3\ v_{AB}$	$4\pi/3$	$-2/\sqrt{3}\ i_c$	$-\pi/6$
CCB	+8	$S_{Ca}\, S_{Cb}\, S_{Bc}$	$2/3\ v_{BC}$	$4\pi/3$	$2/\sqrt{3}\ i_c$	$\pi/2$
BBC	-8	$S_{Ba}\, S_{Bb}\, S_{Cc}$	$-2/3\ v_{BC}$	$4\pi/3$	$-2/\sqrt{3}\ i_c$	$\pi/2$
AAC	+9	$S_{Aa}\, S_{Ab}\, S_{Cc}$	$2/3\ v_{CA}$	$4\pi/3$	$2/\sqrt{3}\ i_c$	$7\pi/6$
CCA	-9	$S_{Ca}\, S_{Cb}\, S_{Ac}$	$-2/3\ v_{CA}$	$4\pi/3$	$-2/\sqrt{3}\ i_c$	$7\pi/6$
AAA	0_1	$S_{Aa}\, S_{Ab}\, S_{Ac}$	0	-	0	-
BBB	0_2	$S_{Ba}\, S_{Bb}\, S_{Bc}$	0	-	0	-
CCC	0_3	$S_{Ca}\, S_{Cb}\, S_{Cc}$	0	-	0	-

Output voltage vector and input current vectors which are shown below:

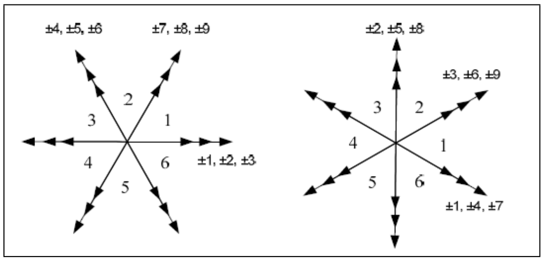
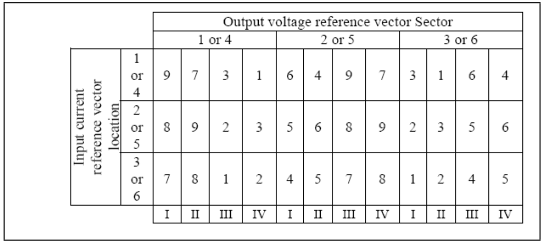


Figure 4: Output voltage and input current vector

According to the output voltage and input current vectors Table II.

Duty cycles equations are obtained from output voltage and input current space vectors locations which are shown below:

Table II Active vector combination



		Output voltage reference vector Sector											
		1 or 4				2 or 5				3 or 6			
Input current reference vector location	1 or 4	9	7	3	1	6	4	9	7	3	1	6	4
	2 or 5	8	9	2	3	5	6	8	9	2	3	5	6
	3 or 6	7	8	1	2	4	5	7	8	1	2	4	5
		I	II	III	IV	I	II	III	IV	I	II	III	IV

$$d1 = (-1)^{Kv+Ki} \frac{2}{\sqrt{3}} * m * (\sin(\theta v) * \sin(\theta i))/cos\emptyset$$

$$d2 = (-1)^{Kv+Ki+1} \frac{2}{\sqrt{3}} * m * (\sin(\theta v) * \sin\left(\left(\frac{\pi}{3}\right) - \theta i\right)/ \cos\emptyset$$

$$d3 = (-1)^{Kv+Ki+1} \frac{2}{\sqrt{3}} * m * \left(\sin\left(\left(\frac{\pi}{3}\right) - \theta v\right) * \sin(\theta i)/ \cos\emptyset$$

$$d4 = (-1)^{Kv+Ki} \frac{2}{\sqrt{3}} * m * \left(\sin\left(\left(\frac{\pi}{3}\right) - \theta v\right) * \sin((\pi/3) - \theta i)\right)/cos\emptyset$$

Where Kv and Ki are the sectors where reference vectors are located , q is the voltage ratio and θv and θi are the phase angles and Φ is displacement angle between input voltage and current space vectors.

IV. SWITCHING STRATEGIES

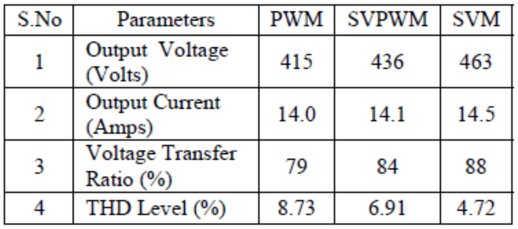
The three zero configurations produces two different types of techniques: Symmetrical SVM (SSVM) and Asymmetrical SVM (ASVM). ASVM uses only one of the three zero configurations in the middle of the sequence so that minimum switch commutations are achieved between one switching state. And SSVM utilized in the middle and at the beginning and end of the sequence. Sector 1 within their respective hexagons it can be seen that only possible double sided sequences that can be generated:

ASVM

ACC-AAC-AAA-AAB-ABB | ABB-AAB-AAA- AAC-ACC

SSVM

CCC-ACC-AAC-AAA-AAB-ABB-ABB- BBB | BBB-ABB-ABB-AAB-AAA-AAC-ACC- CCC



S.No	Parameters	PWM	SVPWM	SVM
1	Output Voltage (Volts)	415	436	463
2	Output Current (Amps)	14.0	14.1	14.5
3	Voltage Transfer Ratio (%)	79	84	88
4	THD Level (%)	8.73	6.91	4.72

Simple rules are proposed for ASVM and SSVM in order to simplify the model:

1. If Kv + Ki is even, the order for active vectors is **diii-di-dii-div**.
2. If Kv+Ki is odd, then the active vectors is **di-diii-div-dii**.

The below table shows its comparison for PWM, SVPWM and SVM method and from that SVM method has minimum THD level and voltage level is maximum.

V. CONCLUSION

From above four methods like venturini method, roy method, PWM method, SVM method. SVM method is more useful for matrix converter. This all methods are used to control the matrix converter to converts a three phase input voltages in to three phase output voltages of a desired frequency and magnitude. This converter has operation with unity power factor, regeneration capability, No bulk DC link capacitor are needed and simple and compact power circuit The important drawback of matrix converter is more number of semiconductors are required so to overcome this problem power modules are introduced.

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