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Generation of Switching pulses for a 3 x 3 Matrix Converter

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***Abstract*—A 3x3 matrix converter is a direct ac to ac converter uses a matrix of semiconductor bidirectional switches, with a switch connected between each input terminal to each output terminal. With proper arrangement of switches, the power flow through the converter can be reversed. Since energy storage element is absent here, so the instantaneous input power must be equal to the output power assuming zero loss switches. The switching functions while operating such a converter must ensure that, the switches do not short circuit the voltage sources and do not open circuit the current sources. Pulsing these nine switches according to an appropriate pattern, the necessary amplitude modulation and frequency conversion for the output voltage are achieved with simultaneous control of input displacement factor.**

This paper describes a detailed study for the generation of the desired switching pulses for the 3x3 Matrix Converter. For this, the duty cycle calculation and gate signal generation for the nine bidirectional switches of Matrix converter, MATLAB, SIMULINK has been used.

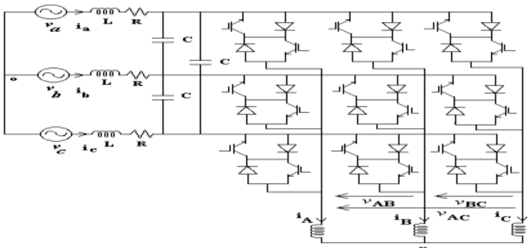
Keywords- Matrix Converter; ISVM; Modelling; Simulation

I. INTRODUCTION

Matrix Converter is an array of bi-directional switches, which directly interconnects the power supply to the load, without any dc-link. The 3-phase ac-ac matrix converter with an input LC filter and an inductive load is shown in Fig.1. Here bidirectional switches interconnects each input phase to all the output phases.

In this paper the details of operation of a 3x3 matrix converter and its switching constraints and realization of the switch cell are described. The necessary analytical relations are established.

Figure.1.The simplified topology of 3x3 matrix converter



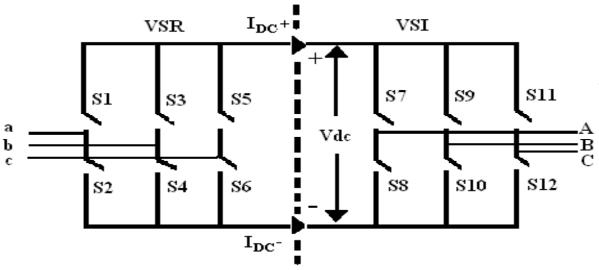


Figure.2. Equivalent circuit of 3x3 matrix converter

II. SWITCHING CONSTRAINTS OF MATRIX CONVERTER

There are certain constraints in the power conversion. The input is a voltage source and the output is connected to load of inductive nature. Simultaneous closing of more than one switch connected to any output phase A, B or C as shown in Fig.3. will short circuit the respective input phases. Also, if at-least one switch connected to each output phase is not ON, current path will be broken. This will cause over voltages to appear across the devices.

The basic constraints for a 3x3 matrix converter can be stated as follows:

$$S_{Aa} + S_{Ab} + S_{Ac} = 1 \quad (1)$$
$$S_{Ba} + S_{Bb} + S_{Bc} = 1 \quad (2)$$
$$S_{Ca} + S_{Cb} + S_{Cc} = 1 \quad (3)$$

where the function of the switches can be defined as

S_{jk} = 1, switch S_{jk} closed
= 0, switch S_{jk} open

where j= A, B, C and k= a, b, c

Figure 3: switch matrix of 3 phase MC

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In a 3x3 matrix converter with nine bidirectional switches, 512 different switching states can be assumed.To avoid circulating currents to the input side of the matrix converter, only one switch in one group must be turned on at a time. Furthermore, if the load is inductive in nature, then it is essential that the inductive load current is never interrupted. This means that each switch group must have one switch turned on at any instant. Considering these two basic rules, the no. of valid switch states gets reduced to 27. Here, each switching state is denoted by a three letter code. These three letters identifies the connection in between each input and output phase. 27 allowable switching combinations of a 3x3 matrix converter is shown in table.1. Here the switching combinations are divided into three groups.

Group I

The first group consists of six switching combinations, where each output phase is connected with different input phase.

Group II

Second group is having eighteen combinations, with only two output phases shorted.

Group III

Third group consists of three combinations where all the output phases are shorted.

From table 1, it is seen that for each combination of group I, output voltage vector having a phase angle α_0, which is dependent on phase angle, α_i of the corresponding input voltage vector. Similarly the input current vector has a phase angle β_i which is related to the phase angle β_0 of the output current vector. Therefore, for applying space vector modulation technique, these combinations are not useful and stationary vectors only takes part to form the rotating space vectors. The expected output is synthesized from Group II 18 active vectors and from Group III 3 zero vectors.

Groups	A B C	v_{AB} v_{BC} v_{CA}	i_a i_b i_c	V_{om}	α_o	I_{im}	β_i
I	a b c	v_{ab} v_{bc} v_{ca}	i_A i_B i_C	V_{im}	α_i	i_o	β_o
I	a c b	$-v_{ca}$ $-v_{bc}$ $-v_{ab}$	i_A i_C i_B	$-V_{im}$	$-\alpha_i+4\pi/3$	i_o	$-\beta_o$
I	b a c	$-v_{ab}$ $-v_{ca}$ $-v_{bc}$	i_B i_A i_C	$-V_{im}$	$-\alpha_i$	i_o	$-\beta_o+2\pi/3$
I	b c a	v_{bc} v_{ca} v_{ab}	i_C i_A i_B	V_{im}	$\alpha_i+4\pi/3$	i_o	$\beta_o+2\pi/3$
I	c a b	v_{ca} v_{ab} v_{bc}	i_B i_C i_A	V_{im}	$\alpha_i+4\pi/3$	i_o	$\beta_o+4\pi/3$
I	c b a	$-v_{bc}$ $-v_{ab}$ $-v_{ca}$	i_C i_B i_A	$-V_{im}$	$-\alpha_i+4\pi/3$	i_o	$-\beta_o+4\pi/3$
II	a c c	$-v_{ca}$ 0 v_{ca}	i_A 0 $-i_A$	$-2/\sqrt{3}V_{ca}$	$\pi/6$	$-2/\sqrt{3}i_A$	$7\pi/6$
II	b c c	v_{bc} 0 $-v_{bc}$	0 i_A $-i_A$	$2/\sqrt{3}V_{bc}$	$\pi/6$	$2/\sqrt{3}i_A$	$\pi/2$
II	b a a	$-v_{ab}$ 0 v_{ab}	$-i_A$ i_A -0	$-2/\sqrt{3}V_{ab}$	$\pi/6$	$-2/\sqrt{3}i_A$	$-\pi/6$
II	c a a	v_{ca} 0 $-v_{ca}$	$-i_A$ 0 i_A	$2/\sqrt{3}V_{ca}$	$\pi/6$	$2/\sqrt{3}i_A$	$7\pi/6$
II	c b b	$-v_{bc}$ 0 v_{bc}	0 $-i_A$ i_A	$-2/\sqrt{3}V_{bc}$	$\pi/6$	$-2/\sqrt{3}i_A$	$\pi/2$
II	a b b	v_{ab} 0 $-v_{ab}$	i_A $-i_A$ 0	$2/\sqrt{3}V_{ab}$	$\pi/6$	$2/\sqrt{3}i_A$	$-\pi/6$
II	c a c	v_{ca} $-v_{ca}$ 0	i_B -0 $-i_B$	$-2/\sqrt{3}V_{ca}$	$5\pi/6$	$-2/\sqrt{3}i_B$	$7\pi/6$
II	c b c	$-v_{bc}$ v_{bc} 0	0 i_B $-i_B$	$2/\sqrt{3}V_{bc}$	$5\pi/6$	$2/\sqrt{3}i_B$	$\pi/2$
II	a b a	v_{ab} $-v_{ab}$ 0	$-i_B$ i_B 0	$-2/\sqrt{3}V_{ab}$	$5\pi/6$	$-2/\sqrt{3}i_B$	$-\pi/6$
II	a c a	$-v_{ca}$ v_{ca} 0	$-i_B$ 0 i_B	$2/\sqrt{3}V_{ca}$	$5\pi/6$	$2/\sqrt{3}i_B$	$7\pi/6$
II	b c b	v_{bc} $-v_{bc}$ 0	0 $-i_B$ i_B	$-2/\sqrt{3}V_{bc}$	$5\pi/6$	$-2/\sqrt{3}i_B$	$\pi/2$
II	b a b	$-v_{ab}$ v_{ab} 0	i_B $-i_B$ 0	$2/\sqrt{3}V_{ab}$	$5\pi/6$	$2/\sqrt{3}i_B$	$-\pi/6$
II	c c a	0 v_{ca} $-v_{ca}$	i_C 0 $-i_C$	$-2/\sqrt{3}V_{ca}$	$3\pi/2$	$-2/\sqrt{3}i_C$	$7\pi/6$
II	c c b	0 $-v_{bc}$ v_{bc}	0 i_C $-i_C$	$2/\sqrt{3}V_{bc}$	$3\pi/2$	$2/\sqrt{3}i_C$	$\pi/2$
II	a a b	0 v_{ab} $-v_{ab}$	$-i_C$ i_C 0	$-2/\sqrt{3}V_{ab}$	$3\pi/2$	$-2/\sqrt{3}i_C$	$-\pi/6$
II	a a c	0 $-v_{ca}$ v_{ca}	$-i_C$ 0 i_C	$-2/\sqrt{3}V_{ca}$	$3\pi/2$	$2/\sqrt{3}i_C$	$7\pi/6$
II	b b c	0 v_{bc} $-v_{bc}$	0 $-i_C$ i_C	$-2/\sqrt{3}V_{bc}$	$3\pi/2$	$-2/\sqrt{3}i_C$	$\pi/2$
II	b b a	0 $-v_{ab}$ v_{ab}	i_C $-i_C$ 0	$2/\sqrt{3}V_{ab}$	$3\pi/2$	$2/\sqrt{3}i_C$	$-\pi/6$
III	a a a	0 0 0	0 0 0	0	–	0	–
III	b b b	0 0 0	0 0 0	0	–	0	–
III	c c c	0 0 0	0 0 0	0	–	0	–

Table1. 27 allowable switching combination for 3x3 matrix converter

III INDIRECT SPACE VECTOR MODULATION OF 3x3 MATRIX CONVERTER

Space vector modulation is employed in both VSR and VSI parts of matrix converter.

SPACE VECTOR MODULATION FOR RECTIFIER STAGE

A voltage source rectifier converts AC input voltages to DC output voltage and current. Fig.4. shows the VSR part of the equivalent VSR-VSI model of a 3x3 matrix converter.

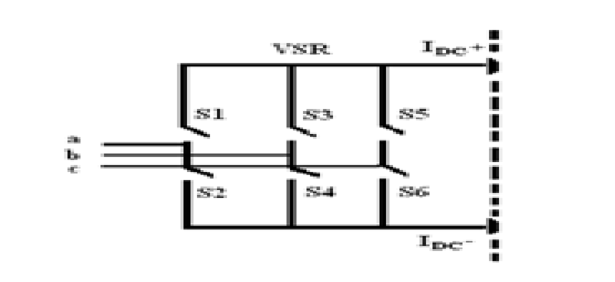

Figure.4.VSR part of VSR-VSI model of 3x3 matrix converter

The input three phase system is transformed into two orthogonal axis spatial co-ordinates by using the transformation as follows,

$$V_{in} = 2/3\ (\ V_{ab} + V_{bc}\, e^{j2\Pi/3} + V_{ca}\, e^{j4\Pi/3}\ ) \quad (4)$$

$$i_{in} = 2/3\ (\ i_a + i_b\, e^{j2\Pi/3} + i_c\, e^{j4\Pi/3}\ ) \quad (5)$$

The switch matrix corresponding to VSR part as,

$$\begin{bmatrix} S_1 & S_3 & S_5 \\ S_2 & S_4 & S_6 \end{bmatrix}$$

Below equations helps in finding input currents and the DC- link voltages,

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} S_1 & S_3 & S_5 \\ S_2 & S_4 & S_6 \end{bmatrix}^T \begin{bmatrix} i_{DC+} \\ i_{DC-} \end{bmatrix} \quad \textbf{(6)}$$

$$\begin{bmatrix} V_{DC+} \\ V_{DC-} \end{bmatrix} = \begin{bmatrix} S_1 & S_3 & S_5 \\ S_2 & S_4 & S_6 \end{bmatrix} \begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} \quad \textbf{(7)}$$

The list of possible switch states and the relevant currents space vectors are given in fig.5. In addition, the amplitude and angle of the input current space vectors are evaluated for 6 active vectors and 3 zero vectors. For obtaining a unity input power factor, the reference current space vector should be in phase with the input voltage vector. The current phasors obtained for each switching combination and the vector span is shown in Fig.6.

The expression for the desired input phase current to be generated in complex plane is ,

$$\overline{I}_{in} = I_{im}\ e^{\,j(\omega it-\Phi i)} \quad (8)$$

Number	$\begin{bmatrix} S_1 & S_3 & S_5 \\ S_2 & S_4 & S_6 \end{bmatrix}^T$	i_a	i_b	i_c	$\lvert\vec{i}_{in}\rvert$	$\angle \vec{i}_{in}$	Input current state space vector
1	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}^T$	$+I_{DC}$	0	$-I_{DC}$	$2/\sqrt{3}I_{DC}$	$\pi/6$	I_1
2	$\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}^T$	0	$+I_{DC}$	$-I_{DC}$	$2/\sqrt{3}I_{DC}$	$\pi/2$	I_2
3	$\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix}^T$	$-I_{DC}$	$+I_{DC}$	0	$2/\sqrt{3}I_{DC}$	$5\pi/6$	I_3
4	$\begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}^T$	$-I_{DC}$	0	$+I_{DC}$	$2/\sqrt{3}I_{DC}$	$-5\pi/6$	I_4
5	$\begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}^T$	0	$-I_{DC}$	$+I_{DC}$	$2/\sqrt{3}I_{DC}$	$-\pi/2$	I_5
6	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}^T$	$+I_{DC}$	$-I_{DC}$	0	$2/\sqrt{3}I_{DC}$	$-\pi/6$	I_6
7	$\begin{bmatrix} 1 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}^T$	0	0	0	0		I_0
8	$\begin{bmatrix} 0 & 1 & 0 \\ 0 & 1 & 0 \end{bmatrix}^T$	0	0	0	0		I_0
9	$\begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 1 \end{bmatrix}^T$	0	0	0	0		I_0

Figure.5: Generation of Current Space Vector

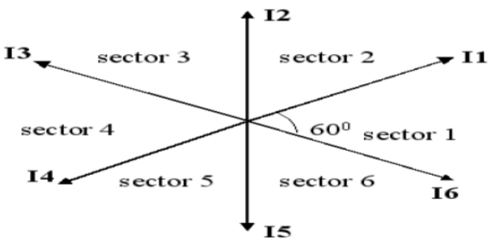

Figure 6: Current Space Vector

At any instant of time, the rotating input current vector , can be represented by two adjacent switching state vectors and zero switching state vector. The span for one set of vectors is shown on Fig.7. μ and γ directions show the active vectors, which arise from the switch combinations. The duty ratio of each combination of switch-states can be calculated using following equations:

$$d_\mu = m_{rec} (\sin\pi/3-\theta_{sc}) \quad (9)$$

$$d_\gamma = m_{rec} \sin \theta_{sc} \quad (10)$$

so that, $\bar{i}_{in} = I_1.d_\mu + I_2.d_\gamma + I_0.d_0$ (11)

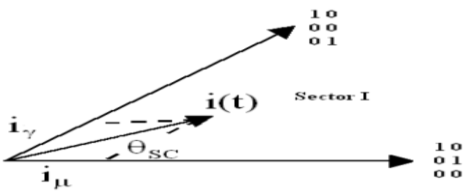

Figure.7. Vector span of current space vector in sector1

where $m_{rec} = I_{im}/I_{DC}$, The modulation index m_{rec} is usually chosen to be 1, as amplitude control of the current is not desired.

The mean value of the DC link voltage can be calculated by multiplying the duty cycles with the switch matrix as shown in Eqn.12. The switch states matrix can be replaced by the space vectors.

$$\begin{bmatrix} V_{DC}+ \\ V_{DC}- \end{bmatrix} = \left(d_\mu \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} + d_\gamma \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \right) \begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix}$$

(12)

SPACE VECTOR MODULATION FOR THE INVERTER STAGE

A DC voltage can be converter to three-phase AC voltage by using a three-phase voltage source inverter. Fig.8. shows the VSI part of the equivalent VSR-VSI conversion of matrix converter. Here the VSI is supplied by the DC voltage V_{DC} , derived from VSR part.

The switch matrix corresponding to VSI part as,

$$\begin{bmatrix} S_7 & S_9 & S_{11} \\ S_8 & S_{10} & S_{12} \end{bmatrix}$$

The output voltages can be calculated by multiplying virtual DC-link voltage andthe switch state of the inverter and at the same time the DC-link current can be calculated by using the transposed matrix as seen in the following equations.

$$\begin{bmatrix} V_{An} \\ V_{Bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} S_7 & S_8 \\ S_9 & S_{10} \\ S_{11} & S_{12} \end{bmatrix} \begin{bmatrix} V_{DC} + \\ V_{DC} - \end{bmatrix} \quad (13)$$

$$\begin{bmatrix} I_{DC} + \\ I_{DC} - \end{bmatrix} = \begin{bmatrix} S_7 & S_9 & S_{11} \\ S_8 & S_{10} & S_{12} \end{bmatrix} \begin{bmatrix} I_{An} \\ I_{Bn} \\ I_{Cn} \end{bmatrix} \quad (14)$$

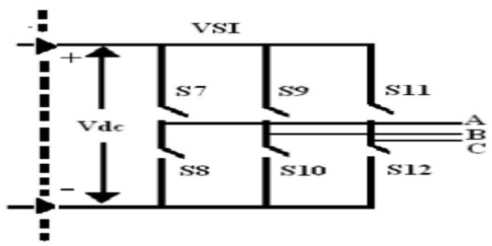

Figure8: VSI part of VSR-VSI model of MC

Fig.10. lists the possible switch combinations, corresponding switch matrix states, expressions of output line voltages in terms of DC link voltage and the resulting length and direction of output line voltage space vectors.

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Here the switching constraints are that two switches of a same leg of the inverter can never be "ON" simultaneously and at any instant any three switches of the 6-switch inverter will be "ON". The "ON" state and the "OFF" state of a switch are addressed by "1" and "0" respectively. Output voltage becomes zero, if all the upper switches or all the lower switches are "ON". The three-phase system is transformed into
spatial (two-axis) co-ordinates by using the transform,

$$\overline{V}_{out} = 2/3\ [\ V_{AB} + V_{BC}\ .\ e^{j2\pi/3} + V_{CA}\ .\ e^{j4\pi/3}\ ] \qquad (15)$$

$$\overline{I}_{out} = 2/3\ [\ i_A + i_B\ .\ e^{j2\Pi/3} + i_C\ .\ e^{j4\Pi/3}\ ] \qquad (16)$$

The VSI configuration and the phase voltage space vectors that are derived from the switch states are shown in Fig.9

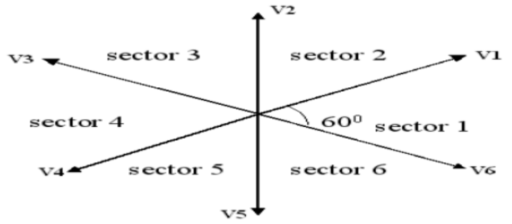

Figure.9. Voltage Space vector

Number	$\begin{bmatrix} S_7 & S_9 & S_{11} \\ S_8 & S_{10} & S_{12} \end{bmatrix}$	V_{AB}	V_{BC}	V_{CA}	$\lvert\vec{v}_{out}\rvert$	$\angle\vec{v}_{out}$	Output voltage space vector
1	$\begin{bmatrix} 1&0&0 \\ 0&1&1 \end{bmatrix}^T$	$+V_{DC}$	0	$-V_{DC}$	$2/\sqrt{3}V_{DC}$	$\pi/6$	V1
2	$\begin{bmatrix} 1&1&0 \\ 0&0&1 \end{bmatrix}^T$	0	$+V_{DC}$	$-V_{DC}$	$2/\sqrt{3}V_{DC}$	$\pi/2$	V2
3	$\begin{bmatrix} 0&1&0 \\ 1&0&1 \end{bmatrix}^T$	$-V_{DC}$	$+V_{DC}$	0	$2/\sqrt{3}V_{DC}$	$5\pi/6$	V3
4	$\begin{bmatrix} 0&1&1 \\ 1&0&0 \end{bmatrix}^T$	$-V_{DC}$	0	$+V_{DC}$	$2/\sqrt{3}V_{DC}$	$-5\pi/6$	V4
5	$\begin{bmatrix} 0&0&1 \\ 1&1&0 \end{bmatrix}^T$	0	$-V_{DC}$	$+V_{DC}$	$2/\sqrt{3}V_{DC}$	$-\pi/2$	V5
6	$\begin{bmatrix} 1&0&1 \\ 0&1&0 \end{bmatrix}^T$	$+V_{DC}$	$-V_{DC}$	0	$2/\sqrt{3}V_{DC}$	$-\pi/6$	V6
7	$\begin{bmatrix} 1&1&1 \\ 0&0&0 \end{bmatrix}^T$	0	0	0	0		V0
8	$\begin{bmatrix} 0&0&0 \\ 1&1&1 \end{bmatrix}^T$	0	0	0	0		V0

Figure.10. Generation of Voltage Space Vectors

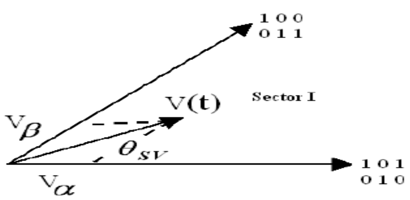

Figure.11. Vector Span of Voltage Space Vector in Sector 1

Below equations can be used for calculating the duty cycles for the adjacent vectors on Fig.11.

$$d_\alpha = m_{inv}\ (\sin\pi/3-\Delta_{inv}) \qquad (17)$$

$$d_\beta = m_{inv} \sin \Delta_{inv} \qquad (18)$$

$$d_0 = 1- d_\alpha - d_\beta \qquad (19)$$

where, $m_{inv} = V_{out}/V_{DC}$. In case of input converter calculated duty cycles can then be multiplied with the switch matrix. Switch states matrix are replaced by the space vectors.

For sector I the voltage equation will be as follows:

$$\begin{bmatrix} V_{An} \\ V_{Bn} \\ V_{Cn} \end{bmatrix} = \left(d_\alpha \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \end{bmatrix} + d\beta \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 1 \end{bmatrix} \right) \begin{bmatrix} V_{DC}+ \\ V_{DC}- \end{bmatrix} \qquad (20)$$

RELATIONSHIP BETWEEN MATRIX CONVERTER AND VSR-VSI MODEL

Here space vector modulations for rectifier and inverter stage should be merged into one modulation method for the nine bidirectional switched matrix converter. Now combining switching equation of inverter and rectifier we can write

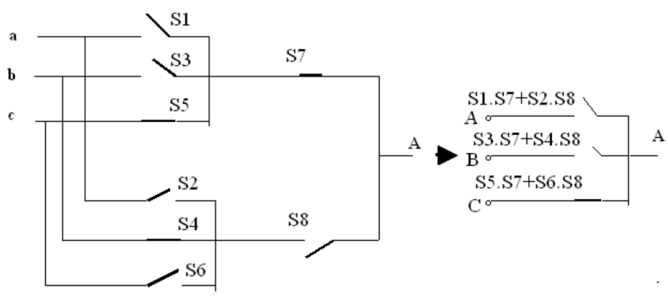

Figure.12. One phase VSI to one phase matrix converter

$$\begin{bmatrix} V_{An} \\ V_{Bn} \\ V_{Cn} \end{bmatrix} = \begin{bmatrix} S_7 & S_8 \\ S_9 & S_{10} \\ S_{11} & S_{12} \end{bmatrix} \begin{bmatrix} S_1 & S_3 & S_5 \\ S_2 & S_4 & S_6 \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix}$$

$$\begin{bmatrix} V_{An} \\ V_{Bn} \\ V_{Cn} \end{bmatrix} = \begin{bmatrix} S_7.S_1 + S_8.S_2 & S_7.S_3 + S_8.S_4 & S_7.S_5 + S_8.S_6 \\ S_9.S_1 + S_{10}.S_2 & S_9.S_3 + S_{10}.S_4 & S_9.S_5 + S_{10}.S_6 \\ S_{11}.S_1 + S_{12}.S_2 & S_{11}.S_3 + S_{12}.S_4 & S_{11}.S_5 + S_{12}.S_6 \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix}$$

$$\begin{bmatrix} V_{An} \\ V_{Bn} \\ V_{Cn} \end{bmatrix} = \begin{bmatrix} S_{Aa} & S_{Ab} & S_{Ac} \\ S_{Ba} & S_{Bb} & S_{Bc} \\ S_{Ca} & S_{Cb} & S_{Cc} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \qquad (21)$$

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$$\begin{bmatrix} V_{An} \\ V_{Bn} \\ V_{Cn} \end{bmatrix} = \left(d_\alpha \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \end{bmatrix} + d_\beta \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 1 \end{bmatrix} \right) \times \left(d_\mu \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} + d_\gamma \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \right) \times \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix}$$

$$\begin{bmatrix} V_{An} \\ V_{Bn} \\ V_{Cn} \end{bmatrix} = \left(d_\alpha d_\mu \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix} + d_\beta d_\mu \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \end{bmatrix} + d_\alpha d_\gamma \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix} + d_\beta d_\gamma \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \end{bmatrix} \right) \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix}$$

Where,

$$d_{\alpha\mu} = d_\alpha \cdot d\mu = m_{inv} \ \mathrm{Sin}(60^o - \theta_{sv}) \ . \ \mathrm{Sin}(60^o - \theta_{sc}) = T_{\alpha\mu}/T_s$$

$$d_{\beta\mu} = d_\beta \cdot d\mu = m_{inv} \ \mathrm{Sin} \ \theta_{sv} \ . \ \mathrm{Sin}(60^o - \theta_{sc}) = T_{\beta\mu}/T_s$$

$$d_{\alpha\gamma} = d_\alpha \cdot d_\gamma = m_{inv} \ \mathrm{Sin}(60^o - \theta_{sv}) \ . \ \mathrm{Sin} \ \theta_{sc} = T_{\alpha\gamma}/T_s$$

$$d_{\beta\gamma} = d_\beta \cdot d_\gamma = m_{inv} \ \mathrm{Sin} \ \theta_{sv} \ . \ \mathrm{Sin} \ \theta_{sc} = T_{\beta\gamma}/T_s$$

$$d_0 = 1 - d_{\alpha\mu} - d_{\beta\mu} - d_{\alpha\gamma} - d_{\beta\gamma}$$

So, in the practical case the switching sequence used is as follows:

$$d_{\alpha\mu/2} - d_{\beta\mu/2} - d_{\alpha\gamma/2} - d_{\beta\gamma/2} - d_0 - d_{\beta\gamma/2} - d_{\alpha\gamma/2} - d_{\beta\mu/2} - d_{\alpha\mu/2}$$

Because of the continuous rotation of the output voltage and input current space vectors, they goes from one sector combination to another sector combination.

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Now for avoiding the commutation problem, the switching sequences are required to be chosen here in such a way that in every step one change at a time takes place.

For smooth transition of space vectors from one sector to another sector, two sets of switching sequences for each input and output sector combination has been selected.

For example the first and second group of switching sequences of input sector 1 and output sector 1 combination are as follows:

IP SECTOR	OP SECTOR	GROUP	TIME	SWITCHES TO BE ON		
1	1	1	$0 - T_{\beta\mu/2}$ $T_{\beta\mu/2} - T_{\alpha\mu/2}$ $T_{\alpha\mu/2} - T_{\alpha\gamma/2}$ $T_{\alpha\gamma/2} - T_{\beta\gamma/2}$ $T_{\beta\gamma/2} - T_0$ $T_0 - T_{\beta\gamma/2}$ $T_{\beta\gamma/2} - T_{\alpha\gamma/2}$ $T_{\alpha\gamma/2} - T_{\alpha\mu/2}$ $T_{\alpha\mu/2} - T_{\beta\mu/2}$	S_{Aa} S_{Aa} S_{Aa} S_{Aa} S_{Ac} S_{Aa} S_{Aa} S_{Aa} S_{Aa}	S_{Bb} S_{Bb} S_{Bc} S_{Bc} S_{Bc} S_{Bc} S_{Bc} S_{Bb} S_{Bb}	S_{Cb} S_{Ca} S_{Ca} S_{Cc} S_{Cc} S_{Cc} S_{Ca} S_{Ca} S_{Cb}
1	1	2	$0 - T_{0/2}$ $T_{0/2} - T_{\beta\mu/2}$ $T_{\beta\mu/2} - T_{\alpha\mu/2}$ $T_{\alpha\mu/2} - T_{\alpha\gamma/2}$ $T_{\alpha\gamma/2} - T_{\beta\gamma}$ $T_{\beta\gamma} - T_{\alpha\gamma/2}$ $T_{\alpha\gamma/2} - T_{\alpha\mu/2}$ $T_{\alpha\mu/2} - T_{\beta\mu/2}$ $T_{\beta\mu/2} - T_{0/2}$	S_{Ab} S_{Aa} S_{Aa} S_{Aa} S_{Aa} S_{Aa} S_{Aa} S_{Aa} S_{Ab}	S_{Bb} S_{Bb} S_{Bb} S_{Bc} S_{Bc} S_{Bc} S_{Bb} S_{Bb} S_{Bb}	S_{Cb} S_{Cb} S_{Ca} S_{Ca} S_{Cc} S_{Ca} S_{Ca} S_{Cb} S_{Cb}

And the first and second group of switching sequences of input sector 1 and output sector 2 combination are as follows:

IP SECTOR	OP SECTOR	GROUP	TIME	SWITCHES TO BE ON		
1	2	1	$0 - T_{\alpha\mu/2}$ $T_{\alpha\mu/2} - T_{\beta\mu/2}$ $T_{\beta\mu/2} - T_{\beta\gamma/2}$ $T_{\beta\gamma/2} - T_{\alpha\gamma/2}$ $T_{\alpha\gamma/2} - T_0$ $T_0 - T_{\alpha\gamma/2}$ $T_{\alpha\gamma/2} - T_{\beta\gamma/2}$ $T_{\beta\gamma/2} - T_{\beta\mu/2}$ $T_{\beta\mu/2} - T_{\alpha\mu/2}$	S_{Aa} S_{Aa} S_{Aa} S_{Aa} S_{Ac} S_{Aa} S_{Aa} S_{Aa} S_{Aa}	S_{Bb} S_{Ba} S_{Ba} S_{Bc} S_{Bc} S_{Bc} S_{Ba} S_{Ba} S_{Bb}	S_{Cb} S_{Cb} S_{Cc} S_{Cc} S_{Cc} S_{Cc} S_{Cc} S_{Cb} S_{Cb}
1	2	2	$0 - T_{0/2}$ $T_{0/2} - T_{\alpha\mu/2}$ $T_{\alpha\mu/2} - T_{\beta\mu/2}$ $T_{\beta\mu/2} - T_{\beta\gamma/2}$ $T_{\beta\gamma/2} - T_{\alpha\gamma}$ $T_{\alpha\gamma} - T_{\beta\gamma/2}$ $T_{\beta\gamma/2} - T_{\beta\mu/2}$ $T_{\beta\mu/2} - T_{\alpha\mu/2}$ $T_{\alpha\mu/2} - T_{0/2}$	S_{Ab} S_{Aa} S_{Aa} S_{Aa} S_{Aa} S_{Aa} S_{Aa} S_{Aa} S_{Ab}	S_{Bb} S_{Bb} S_{Ba} S_{Ba} S_{Bc} S_{Ba} S_{Ba} S_{Bb} S_{Bb}	S_{Cb} S_{Cb} S_{Cb} S_{Cc} S_{Cc} S_{Cc} S_{Cb} S_{Cb} S_{Cb}

In this way the space vectors can be smoothly shifted from one sector combination to another sector combination. All these transitions are shown in table 2. Here only the last combination of of one group and the first combination of another group has been shown which incorporate the smooth transition of space vector from one sector to another sector. Switching sequence and the first combination of second switching sequence is only mentioned. Since there are six sectors corresponding to input space vector and six sector to output space vector, there are 36 possible combination of sectors in which input and output space vector will lie during rotation.

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1/6 Gr1:SAa SBa SCa Gr2:SAa SBb SCa	1/1 Gr1: SAa SBb SCb Gr2: SAb SBb SCb	1/2 Gr1:SAb SBb SCb Gr2:SAb SBc SCb	1/3 Gr1:SAb SBc SCc Gr2:SAc SBc SCc	1/4 Gr1:SAc SBc SCc Gr2:SAc SBa SCc	1/5 Gr1:SAc SBa SCa Gr2:SAa SBa SCa	1/6 Gr1:SAa SBa SCa Gr2:SAa SBb SCa
2/6 Gr1:SAa SBa SCa Gr2:SAa SBa SCb	2/1 Gr1: SAa SBb SCb Gr2: SAb SBb SCb	2/2 Gr1:SAb SBb SCb Gr2:SAb SBb SCc	2/3 Gr1:SAb SBc SCc Gr2:SAc SBc SCc	2/4 Gr1:SAc SBc SCc Gr2:SAc SBc SCa	2/5 Gr1:SAc SBa SCa Gr2:SAa SBa SCa	2/6 Gr1:SAa SBa SCa Gr2:SAa SBa SCb
3/6 Gr1:SAa SBa SCa Gr2:SAa SBa SCb	3/1 Gr1: SAb SBa SCb Gr2: SAb SBb SCb	3/2 Gr1:SAb SBb SCb Gr2:SAb SBb SCc	3/3 Gr1:SAc SBb SCc Gr2:SAc SBc SCc	3/4 Gr1:SAc SBc SCc Gr2:SAc SBc SCa	3/5 Gr1:SAa SBc SCa Gr2:SAa SBa SCa	3/6 Gr1:SAa SBa SCa Gr2:SAa SBa SCb
4/6 Gr1:SAa SBa SCa Gr2:SAb SBa SCa	4/1 Gr1: SAb SBa SCb Gr2: SAb SBb SCb	4/2 Gr1:SAb SBb SCb Gr2:SAc SBb SCb	4/3 Gr1:SAc SBb SCc Gr2:SAc SBc SCc	4/4 Gr1:SAc SBc SCc Gr2:SAa SBc SCc	4/5 Gr1:SAa SBc SCa Gr2:SAa SBa SCa	4/6 Gr1:SAa SBa SCa Gr2:SAb SBa SCa
5/6 Gr1:SAa SBa SCa Gr2:SAb SBa SCa	5/1 Gr1: SAb SBb SCa Gr2: SAb SBb SCb	5/2 Gr1:SAb SBb SCb Gr2:SAc SBb SCb	5/3 Gr1:SAc SBc SCb Gr2:SAc SBc SCc	5/4 Gr1:SAc SBc SCc Gr2:SAa SBc SCc	5/5 Gr1:SAa SBa SCc Gr2:SAa SBa SCa	5/6 Gr1:SAa SBa SCa Gr2:SAb SBa SCa
6/6 Gr1:SAa SBa SCa Gr2:SAa SBb SCa	6/1 Gr1: SAb SBb SCa Gr2: SAb SBb SCb	6/2 Gr1:SAb SBb SCb Gr2:SAb SBc SCb	6/3 Gr1:SAc SBc SCb Gr2:SAc SBc SCc	6/4 Gr1:SAc SBc SCc Gr2:SAc SBa SCc	6/5 Gr1:SAa SBa SCc Gr2:SAa SBa SCa	6/6 Gr1:SAa SBa SCa Gr2:SAa SBb SCa
1/6 Gr1:SAa SBa SCa Gr2:SAa SBb SCa	1/1 Gr1: SAa SBb SCb Gr2: SAb SBb SCb	1/2 Gr1:SAb SBb SCb Gr2:SAb SBc SCb	1/3 Gr1:SAb SBc SCc Gr2:SAc SBc SCc	1/4 Gr1:SAc SBc SCc Gr2:SAc SBa SCc	1/5 Gr1:SAc SBa SCa Gr2:SAa SBa SCa	1/6 Gr1:SAa SBa SCa Gr2:SAa SBb SCa

Table 2 : Smooth transition of space vectors from one sector combination to another sector combination

IV VERIFICATION BY SIMULATION

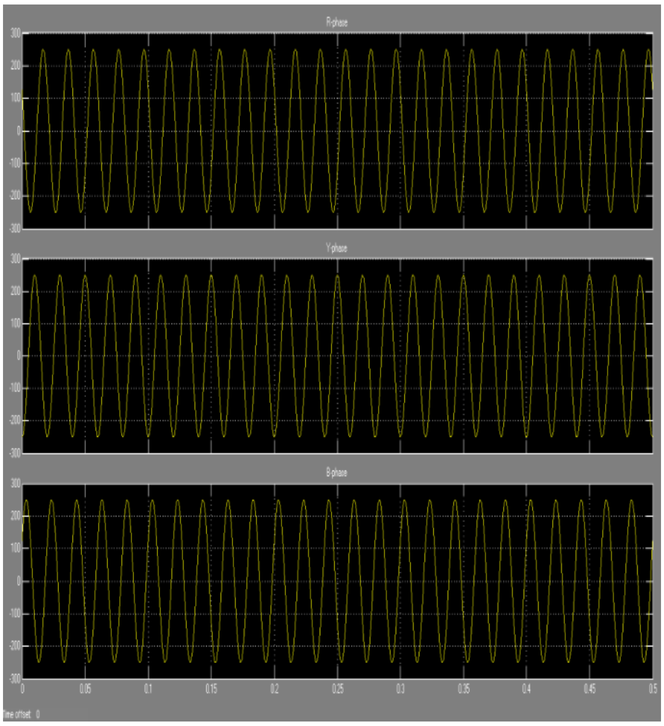

Figure.13.Three phase sine wave generated to the matrix converter

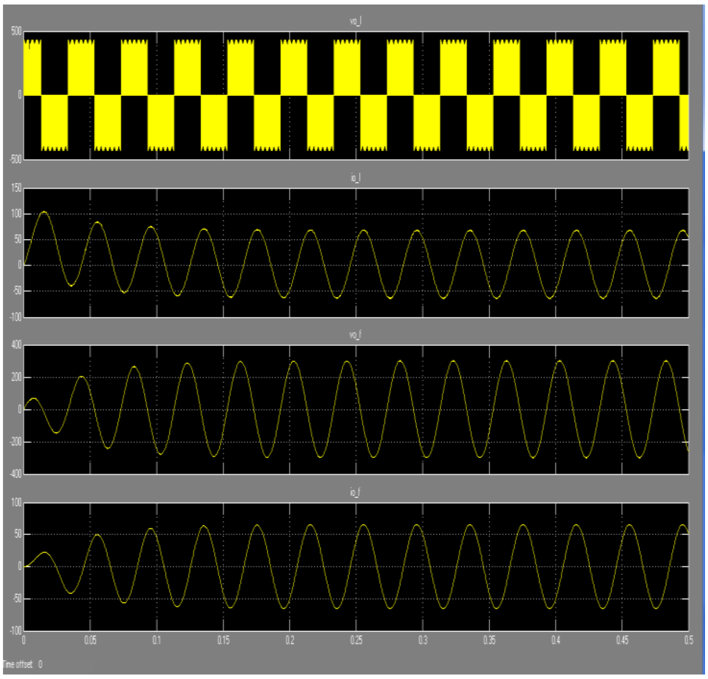

Figure 14: Captured waveform of output voltage, output line current, filtered output voltage and current for the filtered output line current for $f_i = 50$ Hz and $f_0 = 25$ Hz

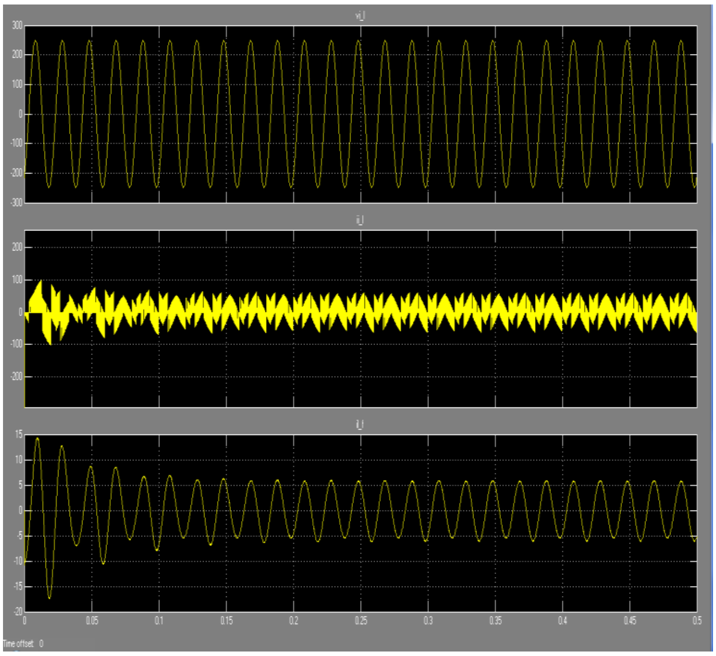

Figure 15. Captured waveform of input phase voltage, unfiltered input phase current and filtered input phase current for $f_i = 50$ Hz and $f_0 = 25$ Hz

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V CONCLUSION

In this paper the implementation technique for generation of switching pulses for a 3x3 matrix converter in MATLAB simulink have been discussed. The simulation of PWM pulse generation and it's distribution using MATLAB simulink have been done.

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