Comparison of Modulation Strategy for Three Phase Matrix Converter

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Abstract—This paper deal with design of three phase matrix converter. Matrix Converter is single stage power converter, which directly convert three phase ac voltage into variable magnitude output voltage with unrestricted frequency without using intermediate dc-link circuit. Matrix converter has some attractive features are bidirectional power flow, compact circuit and long life. Main feature of matrix converter is produced pure sinusoidal output voltage with fully controllable power factor. Among all these advantages matrix converters have some practical limitation such as bi-directional switch realization, complicated modulation scheme, low output voltage transformation ratio.

This paper attempts to presents the basic construction detail and operating principle of matrix. The main objectives of this paper to investigate direct and indirect modulation scheme for matrix converter to overcome the problem associated with low voltage gain ratio with minimum current harmonic distortion.

Index Terms—Three phase matrix converter, Venturini Modulation Scheme, Optimum Venturini Modulation Scheme, Indirect Space Vector Modulation Scheme.

I. INTRODUCTION

Research and development in the field of power electronics technology has taken special interest to design a modern power converter for industrial application with constraint are size, weight, cost, volume ratio of converter should be minimized. The output voltage from converter is in pure sinusoidal in nature with reduced current harmonic distortion so that overall efficiency of drive system is increased. The converter has high integration of complex solution in a single power module [1].The Matrix converter (MC) fulfills all these requirements of modern converter with following attractive features are [2]-[3]:

1) Simple and compact circuit due to absence of intermediate dc-link circuit
2) Bi-directional power flow is possible due bi-directional switches (BDS) which operated in four quadrants
3) Generation of load voltage with arbitrary amplitude and unrestricted frequency
4) Sinusoidal input and output current waveform with controllable power factor

Moreover, the MC operated at high temperature surroundings due to the lack of dc electrolytic capacitors, which is very vulnerable in high temperature and provide short lifetime to converter [3].

The MC is a very promising technology towards the development of modern power converter with evolution in modern power electronic building block (PEBB) [5]. Among all these advantages of MC is not fully matured technology for industrial application due to high level of complicated modulation scheme, output voltage transfer ratio limited up to 50% for pure sinusoidal output voltage waveform [6]. The other issues related to converter such as BDS realization, filter stability and clamp circuit solved in [7]-[9].

To overcome the limitations of voltage transfer ratio for MC some modulation schemes developed [10]-[11]. In 1980,[12] Alrsina and venturini developed first modulation scheme based on “ Direct transfer function ” approach known as Venturni Modulation technique of output voltage gain ratio up to 0.5. In 1983,[13] Alrsina and venturini present modulation stagey based up on “ Third harmonic injection pulse width modulation technique ” known as optimum amplitude venturini modulation strategy (OAV) with voltage gain ratio up to 0.866. In 1983,[14] Rodriguez developed modulation strategy based upon “Fictitious dc link” concept known as indirect space vector modulation (ISVM) with voltage gain ratio up to 0.866 without using third harmonic injection concept.

This paper presented under following sections is as follows: Section II and III describes fundamental construction and mathematical modeling of three phase matrix converter respectively, Section IV and V describe direct and indirect modulation scheme for matrix converter respectively. MATLAB/SIMULINK model along with simulation and results are presented in Section VI and VII. Finally conclusions are summarized in section VIII.

II. THREE PHASE MATRIX CONVERTER

Three phase MC consist of nine BDS which are directly connected source to load. The switches are arranged in 3*3 matrix form hence it is known as matrix converter. Fig.2 shows the systematic representation of three phase MC driving induction motor drive system, where a, b, c are input phases and A, B, C are motor terminals [15].

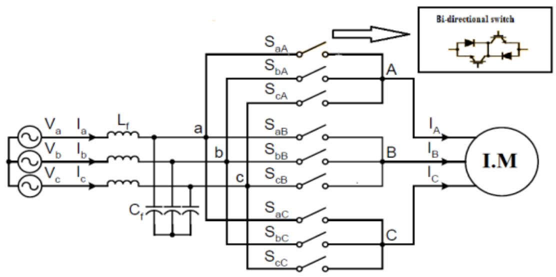

Figure 1. Matrix converter fed induction motor

III. MATHEMATICAL MODELING OF THREE PHASE MATRIX CONVERTER

Real work start on MC in 1980 by Alrsina and venturini, they developed first mathematical model of three phase MC of nine BDS. The mathematical expression (1) that is represents basic operating principal of MC in terms of switching function. The output voltage of variable magnitude and unrestricted frequency can be obtained by multiplying duty cycle (modulation index matrix) to input voltage of fixed frequency [10]-[21].

$$[v_{om}] = [m_{ij}] * [v_{in}] \qquad (1)$$

where, i represent a,b,c are input phase and

j represent A,B,C are output phase

v_{om} , v_{in} are output, input voltage respectively

m_{ij} is modulation index matrix of switch S_{ij}

$$[m_{ij}] = \begin{bmatrix} m_{aA} & m_{bA} & m_{cA} \\ m_{aB} & m_{bB} & m_{cB} \\ m_{aC} & m_{bC} & m_{cC} \end{bmatrix} = \begin{bmatrix} S_{aA} & S_{bA} & S_{cA} \\ S_{aB} & S_{bB} & S_{cB} \\ S_{aC} & S_{bC} & S_{cC} \end{bmatrix} \qquad (2)$$

$$[v_{om}] = v_m \begin{bmatrix} \cos(\omega_o t) \\ \cos(\omega_o t - 120) \\ \cos(\omega_o t + 120) \end{bmatrix} \text{ and } [v_{in}] = v_n \begin{bmatrix} \cos(\omega_i t) \\ \cos(\omega_i t - 120) \\ \cos(\omega_i t + 120) \end{bmatrix}$$

where, v_m and v_n are peak value of output and input voltages;

ω_o and ω_i are output and input frequency respectively

$$q = \frac{v_m}{v_n} \qquad (3)$$

q is voltage gain ration which is lies between (0<q<1) for any converter

$$m_{ij} = \frac{t_{ij}}{T_{seq}} \qquad (4)$$

where, t_{ij} is switch ON time for nine switches S_{ij}

$$T_{seq} = \frac{1}{f_s} \qquad (5)$$

where, f_s is switching frequency

Each switch is characterized by a switching function(6), defined as follows and can connect or disconnect phase i of the input stage to phase j of the load.

$$S_{ij} = \begin{cases} 1 \text{ opened} \\ 0 \text{ closed} \end{cases} \qquad (6)$$

$$S_{iA} + S_{iB} + S_{iC} = 1 \qquad (7)$$

According to (7) constraints there will be 27 switching configuration is possible.

For safe operation of MC, it is necessary that no two bi-directional switches of input line voltages turn ON at same time to avoid short circuit condition. No switch of output phase should be turned OFF at any time to avoid open circuit condition that means at least three switches will be turn ON at every instant of time [6].

For computing modulation index matrix various modulation scheme proposed [10]-[11].

IV. DIRECT APPROACH MODULATION SCHEME

A. venturini modulation technique

This modulation scheme is same as that of "Discreet Pulse Width Modulation" (DPWM) technique in which switch ON time is constant but predetermined value. This scheme is first introduced for MC by Venturini hence it is known as Venturini Modulation Technique [10].

Nine BDS ON time calculated on basis of "direct transfer function" approach (7).

$$m_{ij} = \frac{1}{3}\left[1 + \frac{2 v_{in} v_{om}}{v_n^2}\right] \qquad (8)$$

The limitation of this scheme is voltage gain ratio up to 0.5 and it is well operated for low frequency output voltage. Converters work as step down transformer [6].

B. Modified venturini modulation technique

This modulation scheme is similar to third harmonic injection sinusoidal pulse width modulation (THSPWM) technique of inverter. The third harmonic component is added into reference signal which is compared with carrier signal to increase modulation index of output voltage of inverter [10].

Venturini developed [12]-[13] modulation scheme based upon same concept to increase voltage gain ratio of MC. Three phase output voltage in terms of voltage gain ratio and third harmonic component injected into input signal is expressed (8).

$$V_{o} = qV_{in}\begin{bmatrix} \cos(\omega_o t) - \frac{1}{6}\cos(3\omega_o t) + \frac{1}{2\sqrt{3}}\cos(3\omega_i t) \\ \cos(\omega_o t + \frac{2\pi}{3}) - \frac{1}{6}\cos(3\omega_o t) + \frac{1}{2\sqrt{3}}\cos(3\omega_i t) \\ \cos(\omega_o t + \frac{4\pi}{3}) - \frac{1}{6}\cos(3\omega_o t) + \frac{1}{2\sqrt{3}}\cos(3\omega_i t) \end{bmatrix} \quad (9)$$

where,

$\cos(\omega_o t)$ is fundamental component of output phase A

$\cos(3\omega_i t)$ is third harmonic component of input phase a

$\cos(3\omega_o t)$ third harmonic component of output phase A

To bound desired output voltage of variable frequency in input voltage modulation index matrix is (10)

$$m_{ij} = \frac{1}{3}[1 + \frac{2 * v_{in} * v_{om}}{v_{in}^2} + \frac{4q}{3\sqrt{3}}\sin(\omega_i t + \beta_k)\sin(3\omega_i t)] \quad (10)$$

where, $\omega_i = 2*\pi*f_i$ and $\beta_k = 0, 2\pi/3, 4\pi/3$ and

k is order of cycle i.e. k=1,2,…

C. Switching Logic for direct modulation technique

For k^{th} switching cycle of sample time T_{seq} the output voltages given are (11).

$$V_{oi} = \begin{cases} V_{iA} & 0 \le t - (k-1)T_s < m_{11}^k T_s \\ V_{iB} & m_{11}^k T_s \le t - (k-1)T_s < (m_{11}^k + m_{12}^k)T_s \\ V_{iC} & (m_{11}^k + m_{12}^k)T_s \le t - (k-1)T_s < (m_{11}^k + m_{12}^k + m_{13}^k)T_s \end{cases} \quad (11)$$

$$m_{ij} = \frac{\textit{Time interval when } S_{ij} \textit{ is in ON state, during } k^{th} \textit{ cycle}}{T_s}$$

m has physical meaning of duty cycle

$$\sum_{j=1}^{3} m_{ij}^k = m_{i1}^k + m_{i2}^k + m_{i3}^k \quad (12)$$

$$0 < m_{ij}^k < 1$$

During every interval of time T_s all switch turn ON and OFF once and f_s is much higher than input and output frequency to avoid resonance condition [13].

V. INDIRECT MODULATION SCHEME

A. Space vector modulation technique

In space vector modulation (SVM) scheme the three phase quantizes transformed into their equivalent two phase quantizes (12) using parks transformation. From these two phase component reference vector magnitude (13) to be found which is used as modulating output of converter, the rotating speed (angle) of this vector decide (14) output frequency of output voltage[16].

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} * \begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} \quad (13)$$

$$[v_{ref}] = \sqrt{(v_d^2 + v_q^2)} \quad (14)$$

$$\alpha = \tan^{-1}\left(\frac{v_d}{v_q}\right) \quad (15)$$

B. Space vector modulation scheme for matrix converter

The ISVM for MC was first proposed in [14], where MC was described to an equivalent circuit combining current source rectifier and voltage source inverter connected through virtual dc link as shown in Figure (8). Inverter stage has a standard three phase voltage source inverter topology consisting of six switches, $S_{7\sim}S_{12}$ and rectifier stage has the same power topology with another six switches, $S_{1\sim}S_6$. Both power stages are directly connected through virtual dc-link [17]-[19].

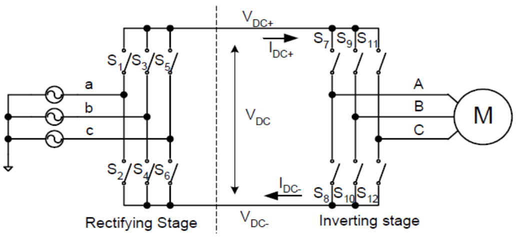

Figure 2. The equivalent circuit for indirect modulation

The basic idea of the indirect modulation technique is to decouple the control of the rectifier and inverting stages. This is done by splitting the switching function (2) into the product of a rectifier and an inverter switching function (16).

$$\begin{bmatrix} S_{aA} & S_{bA} & S_{cA} \\ S_{aB} & S_{bB} & S_{cB} \\ S_{aC} & S_{bC} & S_{cC} \end{bmatrix} = \begin{bmatrix} S_7 & S_8 \\ S_9 & S_{10} \\ S_{11} & S_{12} \end{bmatrix} \cdot \begin{bmatrix} S_1 & S_3 & S_5 \\ S_2 & S_4 & S_6 \end{bmatrix} \quad (16)$$

The three phase output voltage in terms of new switching function of modulation index matrix is (17)

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} S_7 S_1 + S_8 S_2 & S_7 S_3 + S_8 S_4 & S_7 S_5 + S_8 S_6 \\ S_9 S_1 + S_{10} S_2 & S_9 S_3 + S_{10} S_4 & S_9 S_5 + S_{10} S_6 \\ S_{11} S_1 + S_{12} S_2 & S_{11} S_3 + S_{12} S_4 & S_{11} S_5 + S_{12} S_6 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (17)$$

C. Space Vector Modulation Technique for Rectification

To obtain constant DC-link voltage at least two switches must be ON from dissimilar link out of three links other must be OFF, such switching combination formed active vector. If switches from common link ON output voltage will be zero, such switching combination formed zero vectors [17]-[19].

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} S_1 & S_2 \\ S_3 & S_4 \\ S_5 & S_6 \end{bmatrix} \begin{bmatrix} I_{DC+} \\ I_{DC-} \end{bmatrix} \text{ and } \begin{bmatrix} V_{DC+} \\ V_{DC-} \end{bmatrix} = \begin{bmatrix} S_1 & S_3 & S_5 \\ S_2 & S_4 & S_6 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (18)$$

From (18) Possible switching combinations for rectification stage are given in Table.1

Table 1. . Switch states and generated vectors for the rectifier

Type	$\begin{bmatrix} S_1 & S_3 & S_5 \\ S_2 & S_4 & S_6 \end{bmatrix}^T$	i_a	i_b	i_c	$\lvert \vec{I}_{in} \rvert$	$\angle \vec{I}_{in}$	v_{DC}
Active	$\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}^T$	0	i_{DC+}	i_{DC-}	$\frac{2}{\sqrt{3}} i_{DC}$	$\frac{\pi}{2}$	v_{bc}
	$\begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}^T$	0	i_{DC-}	i_{DC+}	$\frac{2}{\sqrt{3}} i_{DC}$	$-\frac{\pi}{2}$	$-v_{bc}$
	$\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix}^T$	i_{DC-}	i_{DC+}	0	$\frac{2}{\sqrt{3}} i_{DC}$	$\frac{5\pi}{6}$	$-v_{ab}$
	$\begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}^T$	i_{DC-}	0	i_{DC+}	$\frac{2}{\sqrt{3}} i_{DC}$	$-\frac{5\pi}{6}$	v_{ca}
	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}^T$	i_{DC+}	0	i_{DC-}	$\frac{2}{\sqrt{3}} i_{DC}$	$\frac{\pi}{6}$	$-v_{ca}$
	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}^T$	i_{DC+}	i_{DC-}	0	$\frac{2}{\sqrt{3}} i_{DC}$	$-\frac{\pi}{6}$	v_{ab}
Zero	$\begin{bmatrix} 1 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}^T \begin{bmatrix} 0 & 1 & 0 \\ 0 & 1 & 0 \end{bmatrix}^T \begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 1 \end{bmatrix}^T$				0		0

Space vector hexagon formed Tab. 1 as shown in Fig.3 (a)

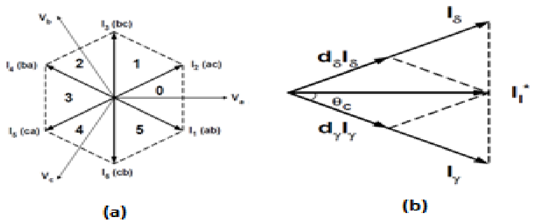

Figure 3. (a)Rectifier current hexagon (b) Synthesis of reference current vector

Fig. 3(b) shows the reference input current vector I_i* within a sector of the current hexagon. The I_i* is synthesized by impressing the adjacent switching vectors I_γ and I_δ with the duty cycles d_γ and d_δ, respectively. Using one such set vector the vector span i.e. V_{ref} and duty cycle for adjacent vector computed for all vector are (19)-(22).

$$I_i^* = d_\gamma I_\gamma + d_\delta I_\delta \quad (19)$$

$$d_{i\gamma} = \frac{T_\gamma}{T_s} = m_{iC} \sin(\frac{\pi}{3} - \theta_C) \quad (20)$$

$$d_{i\delta} = \frac{T_\delta}{T_s} = m_{iC} \sin(\theta_{iC}) \quad (21)$$

$$d_{i0C} = \frac{T_{i0C}}{T_s} = 1 - d_{i\gamma} - d_{i\delta} \quad (22)$$

where, θ_C indicates the angle of the reference current vector within the actual hexagon sector. The modulation index m_C, is often chosen to be 1, as no amplitude control.

D. Space Vector Modulation Technique for inverter stage

To obtain variable ac voltage from constant DC voltage at least three switches must be ON from dissimilar link out of three links other must be OFF.

$$\begin{bmatrix} V_{AB} \\ V_{BC} \\ V_{CA} \end{bmatrix} = \begin{bmatrix} S_7 & S_8 \\ S_9 & S_{10} \\ S_{11} & S_{12} \end{bmatrix} * \begin{bmatrix} V_{DC+} \\ V_{DC-} \end{bmatrix} \quad (23)$$

From (23) possible switching combinations for inverting stage are given in table 2.

Table 2. Switch states and generated vectors for the inverter

Type	$\begin{bmatrix} S_7 & S_9 & S_{11} \\ S_8 & S_{10} & S_{12} \end{bmatrix}^T$	v_A / v_{AB}	v_B / v_{BC}	v_C / v_{CA}	$\lvert \vec{V}_{out} \rvert$	$\angle \vec{V}_{out}$	i_{DC+}
Active	$\begin{bmatrix} 1 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}^T$	1/3v_{DC} / 0	1/3v_{DC} / v_{DC}	-2/3v_{DC} / $-v_{DC}$	$\frac{2}{\sqrt{3}} v_{DC}$	$\frac{\pi}{2}$	$-i_C$
	$\begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}^T$	1/3v_{DC} / v_{DC}	-2/3v_{DC} / $-V_{DC}$	1/3v_{DC} / 0	$\frac{2}{\sqrt{3}} v_{DC}$	$-\frac{\pi}{6}$	$-i_B$
	$\begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 0 \end{bmatrix}^T$	-2/3v_{DC} / $-v_{DC}$	1/3v_{DC} / 0	1/3v_{DC} / v_{DC}	$\frac{2}{\sqrt{3}} v_{DC}$	$-\frac{5\pi}{6}$	$-i_A$
	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 1 \end{bmatrix}^T$	2/3v_{DC} / v_{DC}	-1/3v_{DC} / 0	-1/3v_{DC} / $-v_{DC}$	$\frac{2}{\sqrt{3}} v_{DC}$	$\frac{\pi}{6}$	i_A
	$\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix}^T$	-1/3v_{DC} / $-v_{DC}$	2/3v_{DC} / v_{DC}	-1/3v_{DC} / 0	$\frac{2}{\sqrt{3}} v_{DC}$	$\frac{5\pi}{6}$	i_B
	$\begin{bmatrix} 0 & 0 & 1 \\ 1 & 1 & 0 \end{bmatrix}^T$	-1/3v_{DC} / 0	-1/3v_{DC} / $-v_{DC}$	2/3v_{DC} / v_{DC}	$\frac{2}{\sqrt{3}} v_{DC}$	$-\frac{\pi}{2}$	i_C
Zero	$\begin{bmatrix} 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}^T \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \end{bmatrix}^T$				0		0

Space vector hexagon formed Tab. 2 as shown in Fig.6 (a)

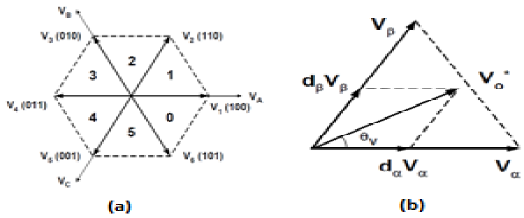

Figure 4. (a)Inverter voltage hexagon (b) Synthesis of reference voltage vector

Fig. 6(b) shows the reference voltage vector V_O* within a sector of the voltage hexagon. The V_O* is synthesized by impressing the adjacent active vectors V_α and V_β with the duty cycles $d\alpha$ and $d\beta$, respectively. Using one such set vector the vector span i.e. V_{ref} and duty cycle for adjacent vector computed for all vector are (24)-(27).

$$V_o^* = d_\alpha . V_\alpha + d_\beta . V_\beta \quad (24)$$

$$d_\alpha = \frac{T_\alpha}{T_s} = m_V \sin(\frac{\pi}{3} - \theta_V) \quad (25)$$

$$d_\beta = \frac{T_\alpha}{T_s} = m_V \sin(\theta_V) \quad (26)$$

$$d_{0V} = \frac{T_{0V}}{T_s} = 1 - d_\alpha - d_\beta \quad (27)$$

where, θ_V indicates the angle of the reference voltage vector within the actual hexagon sector. The m_V is the voltage modulation index and defines the desired voltage transfer ratio such as $0 \le m_v \le 1$ and

$$m_v = \frac{\sqrt{3}V_O^*}{V_{DC}} \tag{28}$$

E. Indirect space vector modulation for entire matrix converter

Two independent space vector modulations scheme of rectifier and inverter mode operation should be merged into one modulation scheme for the nine switches of MC is obtained (30)-(34) multiplying the corresponding duty cycle.

$$m = m_C * m_v \tag{29}$$

$$d_{\alpha\gamma} = d_\alpha . d_\gamma = m \sin(\frac{\pi}{3} - \theta_v)\sin(\frac{\pi}{3} - \theta_C) = \frac{d_{\alpha\gamma}}{T_s} \tag{30}$$

$$d_{\alpha\delta} = d_\alpha \, d_\delta = m_v \sin(\frac{\pi}{3} - \theta_v)\sin(\theta_C) = \frac{d_{\alpha\delta}}{T_s} \tag{31}$$

$$d_{\alpha\delta} = d_\alpha \, d_\delta = m_v \sin(\frac{\pi}{3} - \theta_v)\sin(\theta_C) = \frac{d_{\alpha\delta}}{T_s} \tag{32}$$

$$d_{\beta\gamma} = d_\beta \, d_\gamma = m_v \sin(\theta_v)\sin(\frac{\pi}{3} - \theta_C) = \frac{d_{\beta\gamma}}{T_s} \tag{33}$$

$$d_{\beta\delta} = d_\beta \, d_\delta = m_v \sin(\theta_v)\sin(\theta_C) = \frac{d_{\beta\delta}}{T_s} \tag{34}$$

During remaining part of the switching period $T_{s,}$ zero vectors is applied

$$d_0 = 1 - d_{\alpha\gamma} - d_{\alpha\delta} - d_{\beta\gamma} - d_{\beta\delta} = \frac{T_0}{T_s} \tag{35}$$

F. Switching logic for indirect space vector modulation for entire matrix converter

The modulation functions given by (30) - (35) state that four active and one zero vector is needed for the space vector modulator in each switching period. The distribution of the vectors is however free and this degree of freedom can be used to improve the harmonic distortion or limit the number of switching state [21].

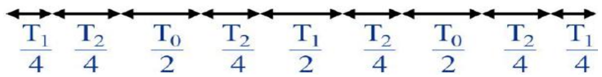

Figure 5. Switching patterns for indirect modulation scheme

VI. SYSTEM MODELLING

The simulation was performed with the help of MATLAB/Simulink software. Power circuit of MC has been modeled using power electronic toolbox in Matlab/Simulink/simpower system. Fig.6 shows the simulink model of MC fed RL load. The simulation model consists of two main parts. First part includes the design of MC as shown in Fig 7. The common emitter configuration bi-directional switch cell along with the central common connection was chosen to design a 3×3 matrix converter. The second part consists of switching sequence in which switch ON time for each output phase is calculated and then the control signals were generated.

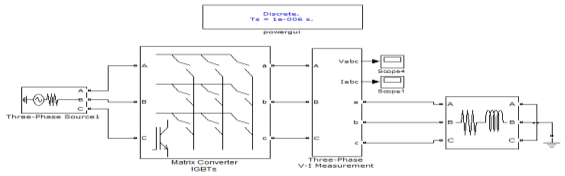

Figure 6. MATLAB simulink model of Matrix Converter driving Induction Motor

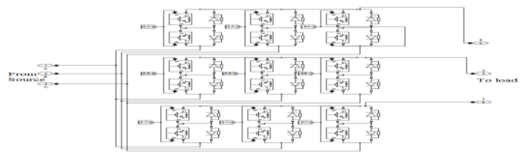

Figure 7. Three Phase Matrix Converter

Switching pulses for matrix converter generated through embedded matlab functional block in which (2) and (10) used for calculating modulation duty cycle and switching logic developed by (11).

A. Switching logic for direct modulation scheme

```
% Switching logic developed for Venturini modulation technique
if k*Ts<t && t<(m11+k)*Ts
    gAa=1;gAb=0;gAc=0;
elseif(m11+k)*Ts<t && t<(m11+m12+k)*Ts
    gAa=0;gAb=1;gAc=0;
elseif (m11+m12+k)*Ts<t && t<(1+k)*Ts
    gAa=0;gAb=0;gAc=1;
end
if k*Ts<t && t<(m21+k)*Ts
    gBa=1;gBb=0;gBc=0;
elseif (m21+k)*Ts<t && t<(m21+m22+k)*Ts
    gBa=0;gBb=1;gBc=0;
elseif (m21+m22+k)*Ts<t && t<(1+k)*Ts
    gBa=0;gBb=0;gBc=1;
end
if k*Ts<t<(k+m31)*Ts
    gCa=1;gCb=0;gCc=0;
elseif (m31+k)*Ts<t && t<(m31+m32+k)*Ts
    gCa=0;gCb=1;gCc=0;
elseif (m31+m32+k)*Ts<t && t<(1+k)*Ts
    gCa=0;gCb=0;gCc=1;
end
```

B. Switching logic for space vector modulation scheme

Space vector PWM can be implemented by the following steps:

1) Determine v_d,v_q,v_{ref} and angle θ

2) Determine the duty cycles d_γ ,d_δ

3) Determine the switching time of each transistor

VII. SIMULATION RESULT

The matrix converter is supplied by a 3 phase supply which has line voltage and frequency of 380V and 50Hz, respectively. Switching frequency f_s is 1 KHz. Simulation results were given in Fig.8-14.

Fig.11 shows the three phase line to line voltage which peak value is 280 volt for 0.76 voltage gain ratio. Fig.10 shows the THD analysis for modified venturini modulation scheme and it is found to be around 4.01%.

A. Venturini modulation strategy for voltage gain ratio (0.5)

Fig.8 shows three phases line to ground voltage which is chopped at 1 KHz frequency. Fig.9 shows the three phase line to line voltage which peak value is 190 volt for 0.5 voltage gain ratio. Fig.10 shows the THD analysis for venturini modulation scheme and it is found to be around 3.25%.

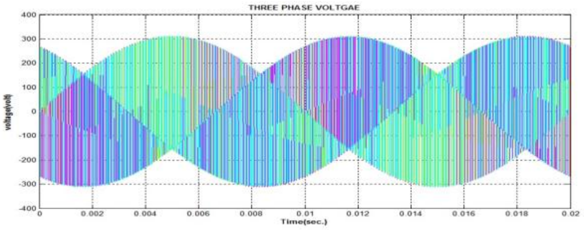

Figure 8. Three phase chopping voltage

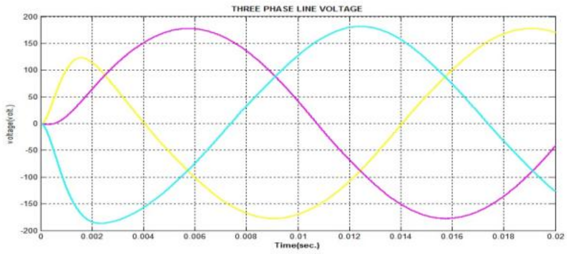

Figure 9. Three phase line to line voltage

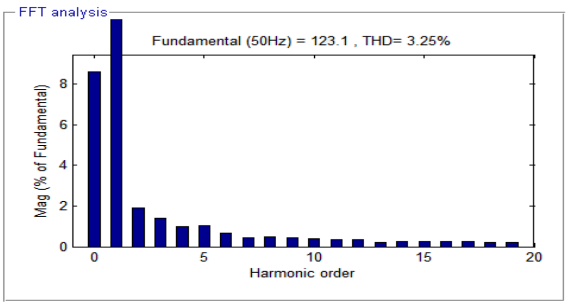

Figure 10. THD analysis

B. Modified Venturini modulation strategy for voltage gain ratio (0.86)

Fig.11 shows the three phase line to line voltage which peak value is 280 volt for 0.76 voltage gain ratio. Fig.10 shows the THD analysis for modified venturini modulation scheme and it is found to be around 4.01%.

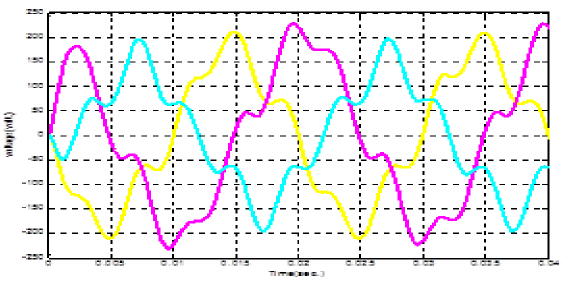

Figure 11. Three phase line to line voltage

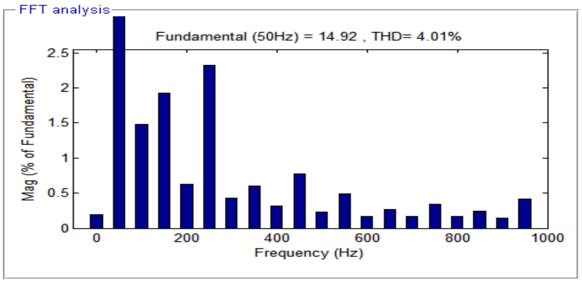

Figure 12. THD analysis

C. Indirect Space vector modulation

Fig.11 shows the three phase line to line voltage which peak value is 320 volt for 0.866 voltage gain ratio. Fig.10 shows the THD analysis for modified venturini modulation scheme and it is found to be around 2.63%.

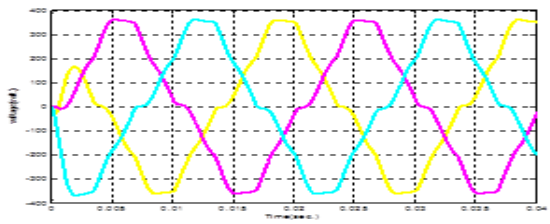

Figure 13. Three line to line voltage

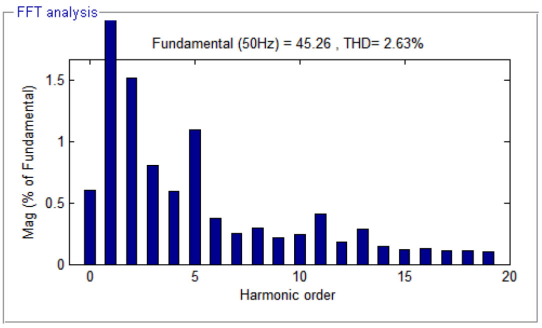

Figure 14. THD analysis

Comparing simulation result simulated result given in table bellow

Modulation scheme	Venturini	OAVM	ISVM
Voltage	110	220	330
THD	3.25%	4.01%	2.63%

VIII. CONCLUSION

From simulation result comparison, it is concluded that Indirect Space Vector Modulation scheme is better performance than direct modulation scheme for MC. It gives better voltage gain ratio with less harmonic distortion. Closed mathematical and theoretical descriptions of modulation scheme for matrix converter enable to use as a compact energy-saving converter providing clean power.

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