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Simulation of Three phase to three phase Matrix converter on Matlab/Simulation

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Abstract: Based on the traditional principle of two-line voltage synthesis, a modulation strategy is proposed to improve the output performance of matrix converter by changing the switching mode. According to the switching mode of the new strategy, under the premise that the input current and output voltage are sinusoidal, the modulation time of each switch of the matrix converter in one cycle is derived from the relationship between input and output current and voltage. Under the same conditions, the proposed modulation strategy is compared with the traditional two-line voltage synthesis strategy, and the corresponding MATLAB/simulation data given**.** The simulation results verify the correctness of the modulation strategy.

Index Terms: Matrix converter, modulation strategy, output performance, voltage harmonics.

I. INTRODUCTION

Three-phase to three-phase Matrix Converter is a compact voltage source converter which provide sinusoidal output voltages with varying amplitude and frequency, while drawing sinusoidal input currents with unity power factor from the ac source. Two approaches are widely used when developing modulation strategies for matrix converters. The first one is known as Venturini modulation strategy and the second one, which is known as indirect transfer function approach (ITF), is based on space vector modulation (SVM) technique. In ITF approach, Matrix Converter is modeled as a bidirectional Voltage Source Rectifier (VSI) stage in the supply side and a bidirectional Voltage Source Inverter (VSI) in the load side with a conceptual DC link in between them for power flow. In the chapter-4, simulation of Voltage Source Rectifier is done in the MATLAB/Simulink platform. The duty cycle and switching pulses of the switches for different sectors and position of the input current space vector are obtained with Space Vector Pulse Width Modulation (SVPWM) switching strategy. In the chapter-5, simulation of Voltage Source Inverter is done in the MATLAB/Simulink platform. The duty cycle and switching pulses of the switches for different sectors and position of the output voltage space vector are obtained with Space Vector Pulse Width Modulation (SVPWM) switching strategy. In this chapter, generation of switching pulses for three-phase to three-phase Matrix Converter based on ITF approach is discussed. The corresponding simulation scheme is presented and implemented in MATLAB/Simulink considering ITF approach. Matrix Converter is modeled as combination of voltage source rectifier and voltage source inverter. The duty cycle of the switches for the Matrix Converter is thus related to duty cycles of the switches of the two different conceptual converters. The analysis presented here describes the way how those separate duty cycles are combined to get the duty cycles of the nine bidirectional switches of the Matrix Converter.

Power frequency converter is an essential component in ac drive applications. From power quality point of view, it is desirable that the frequency changer must provide sinusoidal output voltages with varying amplitude and frequency, while drawing sinusoidal input currents with controllable displacement factor preferably unity from the ac source. The matrix converter offers a near ideal solution for AC-AC power conversion, removing the need for reactive energy storage components used in conventional rectifier-inverter based systems [1].

Basically, the matrix converter is nothing but a three-phase to three-phase forced commutated cyclo-converter. The matrix converter topology was originally presented in 1976 by Gyugyi-Pelly [1] but it was in 1980 that the basic configuration and control of three-phase matrix converter were introduced by Venturini in [2] [3].

A three phase to three phase matrix converter consists of nine bidirectional switches which are arranged in such a way that any of the input phases can be connected directly to the any of the output phases of the converter following a particular modulation of the duty cycles of the switches[4][5]. The arrangement of the switches is illustrated in Fig.1.

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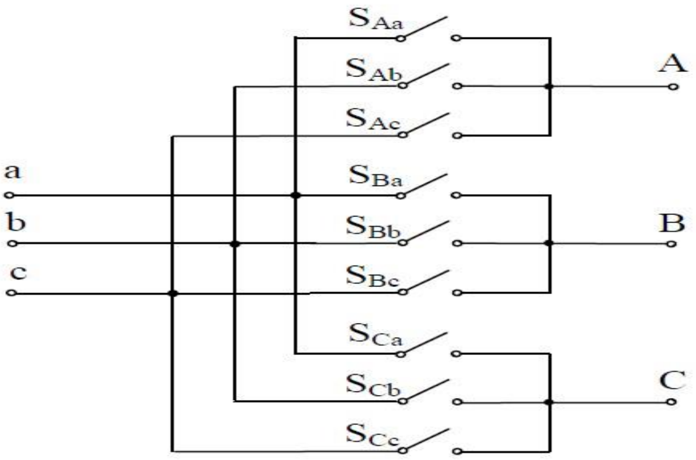

Figure 1: Schematic circuit of a three-phase to three-phase matrix converter [5]

II.PRINCIP LE OF NEW MODULATION STRATEGY

The instantaneous expression for output line to line voltages in terms of input phase voltages and switching function is,[6]

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

Similarly the instantaneous expression for input line currents in terms of output load current (load is delta connected) is, $= T_{phl} \overset{\rho}{v}_{iph}$

$$\overset{\rho}{i}_{iph} = \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} S_{Aa}-S_{Ba} & S_{Ab}-S_{Bb} & S_{Ac}-S_{Bc} \\ S_{Ba}-S_{Ca} & S_{Bb}-S_{Cb} & S_{Bc}-S_{Cc} \\ S_{Ca}-S_{Aa} & S_{Cb}-S_{Ab} & S_{Cc}-S_{Ac} \end{bmatrix}^T \cdot \begin{bmatrix} i_{AB} \\ i_{BC} \\ i_{CA} \end{bmatrix} \qquad (2)$$

Where, "[ ]^T" denotes the transpose of a matrix and "T_{phl}" is the instantaneous output line to line voltage to input phase voltage transfer function matrix of the 3-phase to 3-phase matrix converter[7-10]. $= T_{phl}^T \overset{\rho}{i}_{ol}$

The switching frequency (say 10 kHz) is usually much greater than the frequencies of input voltages and output voltages (say 50 Hz and 40 Hz respectively). The local averaged value of a switching function $S_{jk}(t)$ is the duty cycle of a switch S_{jk} denoted as d_{jk} multiplied by the quantity.

$0 \le d_{jk} \le 1$ Where $j \in \{A, B, C\}$

$k \in \{a, b, c\}$

$d_{ja} + d_{jb} + d_{jc} = 1$

Now, the instantaneous transfer function can be replaced by duty cycles of the switches as in (3)

$$T'_{phl} = \begin{bmatrix} d_{Aa}-d_{Ba} & d_{Ab}-d_{Bb} & d_{Ac}-d_{Bc} \\ d_{Ba}-d_{Ca} & d_{Bb}-d_{Cb} & d_{Bc}-d_{Cc} \\ d_{Ca}-d_{Aa} & d_{Cb}-d_{Ab} & d_{Cc}-d_{Ac} \end{bmatrix}. \qquad (3)$$

Now, the low frequency local average relationships can be expressed as in (4) and (5),

$$v'_{ol} = T'_{phl} \times v_{iph} \qquad (4)$$

$$i'_{ph} = T'_{phl} \times i_{ol} \qquad (5)$$

Let input voltage is expressed in (6)

$$v_{iph}=V_{im}\begin{bmatrix}\cos(\omega_i t-\phi_i)\\ \cos(\omega_i t-\phi_i-\frac{2\pi}{3})\\ \cos(\omega_i t-\phi_i+\frac{2\pi}{3})\end{bmatrix} \qquad (6)$$

Desired output voltage as in (7)

$$\vec{v}_{ol}=\begin{bmatrix}v'_{AB}\\ v'_{BC}\\ v'_{CA}\end{bmatrix}=\sqrt{3}\begin{bmatrix}V_{om}\cos(\omega_o t-\phi_o+\frac{\pi}{6})\\ V_{om}\cos(\omega_o t-\phi_o+\frac{\pi}{6}-\frac{\pi}{3})\\ V_{om}\cos(\omega_o t-\phi_o+\frac{\pi}{6}+\frac{2\pi}{3})\end{bmatrix} \qquad (7)$$

So the transfer function will be

$$T'_{phl}=m\begin{bmatrix}\cos(\omega_o t-\phi_o+\frac{\pi}{6})\\ \cos(\omega_o t-\phi_o+\frac{\pi}{6}-\frac{2\pi}{3})\\ \cos(\omega_o t-\phi_o+\frac{\pi}{6}+\frac{2\pi}{3})\end{bmatrix}\cdot\begin{bmatrix}\cos(\omega_i t-\phi_i)\\ \cos(\omega_i t-\phi_i-\frac{2\pi}{3})\\ \cos(\omega_i t-\phi_i+\frac{2\pi}{3})\end{bmatrix}^T \qquad (8)$$

So $V_{om}=\frac{\sqrt{3}}{2}\cdot V_{im}\cdot m\cdot\cos(\phi_i)$

Here, due to inductive load, the output line currents can be assumed sinusoidal and it is given by,

$$\vec{i}_{ol}=1/\sqrt{3}\begin{bmatrix}I_{om}\cos(\omega_o t-\phi_o-\phi_l+\frac{\pi}{6})\\ I_{om}\cos(\omega_o t-\phi_o-\phi_l+\frac{\pi}{6}-\frac{2\pi}{3})\\ I_{om}\cos(\omega_o t-\phi_o-\phi_l+\frac{\pi}{6}+\frac{2\pi}{3})\end{bmatrix} \qquad (9)$$

Where, "φ_l" is the load displacement angle and "ω_o" the output frequency. Then substituting eqn. (9), into (6), the local averaged input phase currents are obtained as,

$$i'_{iph}=\begin{bmatrix}i'_a\\ i'_b\\ i'_c\end{bmatrix}=I_{im}\begin{bmatrix}\cos(\omega_i t-\phi_i)\\ \cos(\omega_i t-\phi_i-\frac{2\Pi}{3})\\ \cos(\omega_i t-\phi_i+\frac{2\Pi}{3})\end{bmatrix} \qquad (10)$$

$$I_{im}=\frac{\sqrt{3}}{2}\cdot I_{om}\cdot m\cdot\cos(\phi_l) \qquad (11)$$

Unity input displacement factor is obtained for $\varphi_i = 0$ with m = 1, the maximum voltage gain will be $\sqrt{3}$ /2.Theoretically the only restriction is the equality of the input and output active powers assuming the switches are lossless. From the expressions of V_{om} and I_{im}.

$$\begin{aligned} P_i &= \frac{3}{2} V_{im} I_{im} \cos(\phi_i) \\ &= \frac{3}{2} V_{om} I_{om} \cos(\phi_l) \\ &= P_o \end{aligned} \tag{12}$$

This transfer matrix can be represented as product of two component transfer matrices:
One for the voltage source rectifier (VSR) and the other for the voltage source inverter (VSI)[11-15].
Thus we can write,

$$T'_{phl} = T'_{VSI}(\omega_o) \times T'_{VSR}(\omega_i) \tag{13}$$

$$T'_{VSR}(\omega_i{}^T)\overset{\rho}{V}_{iph} = V_{im} \begin{bmatrix} \cos(\omega_i t - \phi_i) \\ \cos(\omega_i t - \phi_i - \frac{2\Pi}{3}) \\ \cos(\omega_i t - \phi_i + \frac{2\Pi}{3}) \end{bmatrix}^T \cdot \begin{bmatrix} \cos(\omega_i t) \\ \cos(\omega_i t - \frac{2\Pi}{3}) \\ \cos(\omega_i t + \frac{2\Pi}{3}) \end{bmatrix} \tag{14}$$

It verifies that the first stage of conversion is rectification. And the second stage is inversion[18-25]. The schematic of the conceptual VSR and VSI connections is shown in Fig. 2.3.

$$= \frac{3}{2} V_{im} \cos(\phi_i)$$

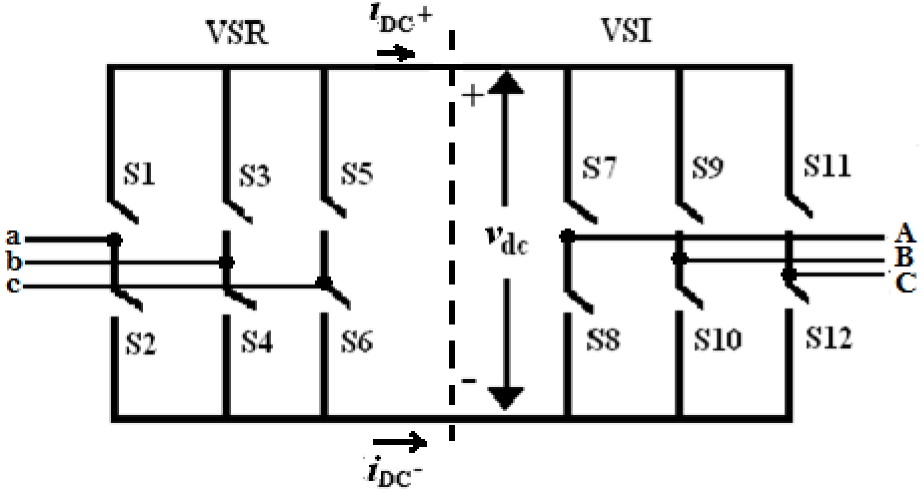

Fig. 2: conceptual VSR-VSI model of direct matrix converter[18]

III.SIMULATION RESULT

For the evaluation of the performance of control methodology a MATLAB- simulink model of a matrix converter connected to three-phase voltage sources and feeding a three-phase delta connected RL-load is built[26].

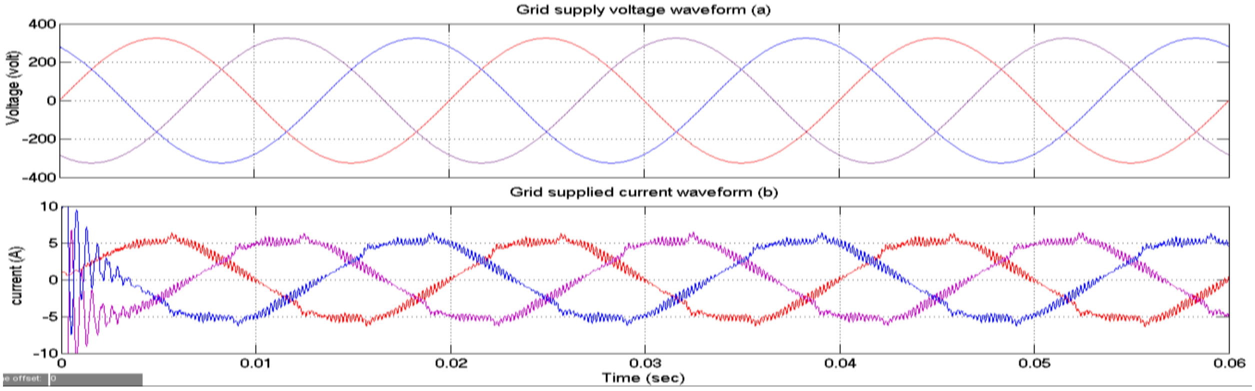

Fig.3: Grid input voltage (top) and current waveform (bottom)

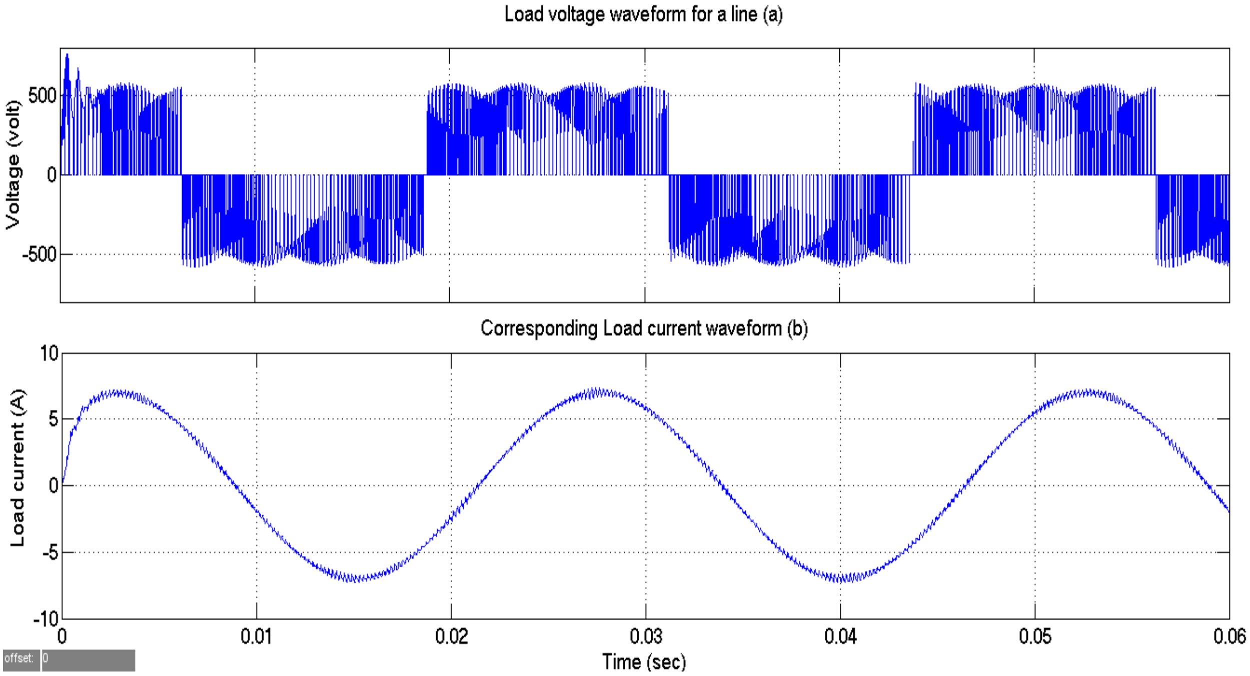

Fig.4: Load voltage waveform (top), corresponding load current waveform (bottom)

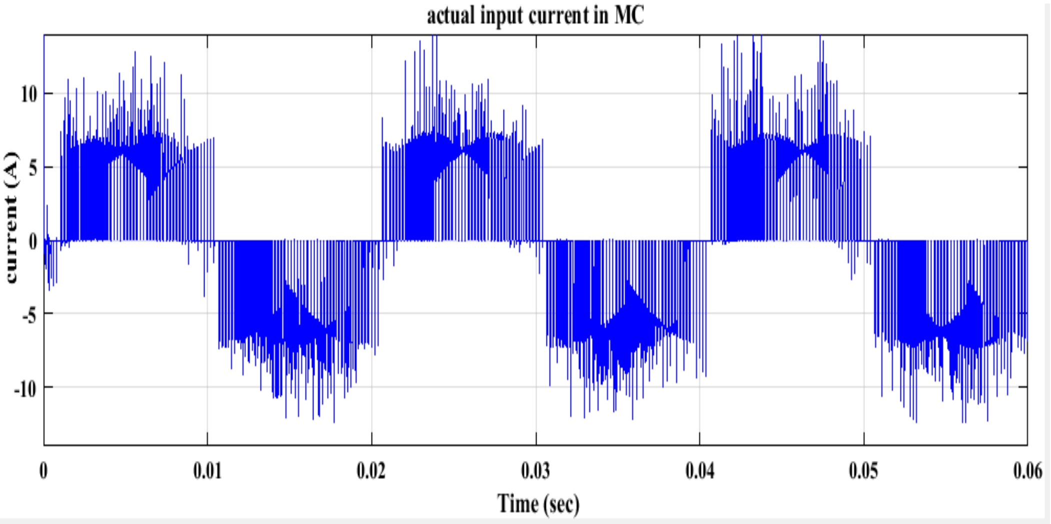

Fig.5: actual input current waveform in MC

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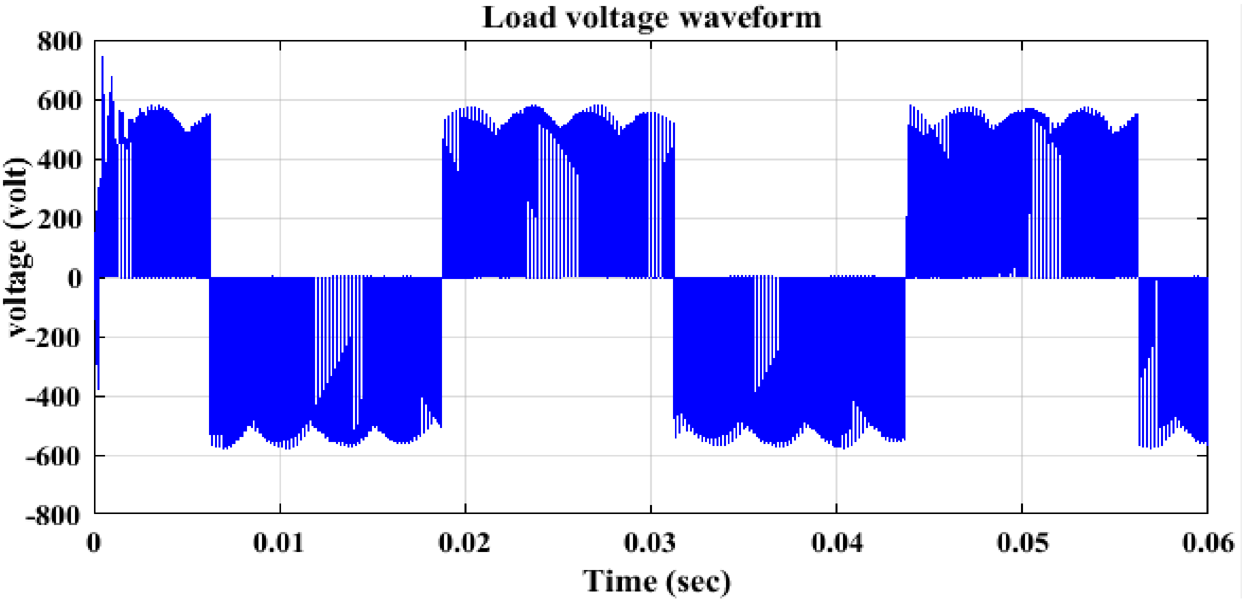

Fig.6: Load voltage waveform of MC

From the simulation result, it can be seen that input power factor control can be started from simulation starting point because initially we put the actual displacement angle in VSR part. Through the simulation we can see it maintain unity power factor at grid side.

IV.CONCLUSION:

Here three phases to three phase direct matrix converter are described. One of the advantages of matrix converter is that input and output current waveforms are sinusoidal. Here indirect modulation technique is used. To satisfy sinusoidal input output current waveform appropriate switching combinations are also used. Due to presence of input current filter, grid side angle will be leading power factor angle. The detailed analytical derivation of the damping resistor losses is provided in this present work, input power factor is compensated. Four different strategies are implemented in Matlab simulink platform. For each method, there are advantages and disadvantages. But by using all four methods, input power factor is compensated and become a unity power factor grid operation. Different simulations blocks are analyzed with their input output waveforms and these are compared with theoretical result.

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