DIRECT AND INDIRECT SPACE VECTOR MODULATED MATRIX CONVERTER

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***Abstract*— The Matrix Converter stands as an alternative in power conversion by directly connecting input terminals with output through bidirectional switches. It has low higher order harmonics as well as no sub-harmonics. Different modulation methods are available for matrix converter like space vector modulation method. Direct and indirect space vector modulation methods are chosen here for the analysis of switching patterns of a three phase matrix converter. Here, the effectiveness of two modulation methods is simulated in Matlab environment.**

Keywords—Matrix Converter, Space Vector Modulation, Direct Space Vector Modulation, Indirect Space Vector Modulation.

I. INTRODUCTION

With the recent evolution of power electronics devices and the growth of large power integration circuits, Matrix Converter (MC) has become extremely attractive as they are gifted of sinusoidal input current with near unity power factor as well as sinusoidal output voltage with varying amplitude and frequency [1]. MC is also known as silicon AC-AC power converters, contain an array of bi-directional semiconductor switches, which are associations of power semiconductors consisting of a pair of devices with turn-off capability, usually IGBTs, in either a common collector or a common emitter back to- back arrangement, each one connected with an anti parallel diode [2]. In the past decades, an AC with particular voltage and frequency is converted to another level by the help of a rectifier and inverter [3]. But if results a lots of harmonics in the electrical system. That is why, the matrix converters are to be considered as superior to conventional rectifier- inverter system.Moreover, the MC allows a compact design due to the absence of dc-link capacitors for energy storage.

Two different mathematical approaches have been considered for the pulse generation, namely, the Modulation Duty Cycle Matrix (MDCM) approach and the space-vector modulation (SVM) approach. MDCM can be further classified into Alesina - Venturini Modulation (AV method), optimum AV method plus Scalar Modulation method. In the same way, SVM method can be classified as Direct Space vector Modulation and Indirect Space Vector Modulation method. A new representation of the switch state of the matrix converter, based on the DCSV approach, has been presented in [4-5]. Different control methods can be incorporated with MC DTC and sliding mode control show various differences as well as similarities. So both DTC and sliding mode control use the same switch configurations of groups 3 and 4 (vectors with fixed additionally angular position and zero vectors) while DCC uses the rotating vectors of groups 1& 2 additionally [6].

In this paper, two SVM methods are simulated in Matlab and analyzed the properties of various parameters in the matrix converter. So in the following sections, after a short introduction to matrix converter principles and switching constraints in section II In section III the basic ideas of the direct space vector modulation is described. In section IV, Indirect space vector modulation is explained, the simulation results are presented in Section V and in section VI follows a conclusion.

II. MATRIX CONVERTER

Ideal three phase matrix converters may be considered as an array of nine bi-directional switches as per Fig. 1.Representing each switch as Skj, where k, j Î{1, 2, 3} [7]. It has two possible states: Skj=1 if the switch is closed (ON) and Skj=0 if it is open (OFF). Since there are nine bidirectional switches, there will be 2^9 combination of switching states [8-9]. But the switching states are reduced to 27it is because of that input terminals should not be short circuited and output terminals should not be open circuited. MC is compact due to the absence of DC link capacitors.

The relation between the input and output voltage and current of matrix converter with respect to the switching states can be stated as,

$$V_0 = S^* V_I \quad (1)$$

$$I_I = S^T * I_o \quad (2)$$

Where S is the trasformation matrix which gives the idea about switching states at each instant.

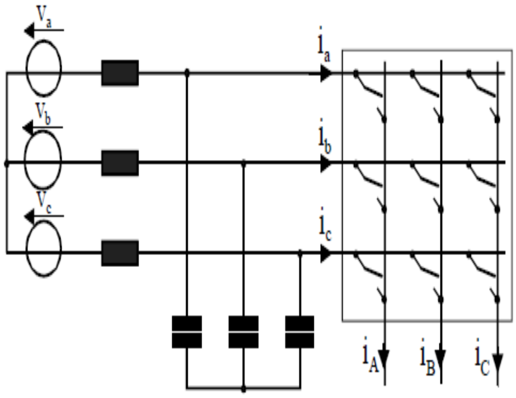

Fig. 1. Cırcuıt Diagram of a 3X3 Matrix converter

III. DIRECT SPACE VECTOR MODULATION

Space Vector Modulation (SVM) consists of a set of instantaneous space vectors of input and output voltage as well as current with low THD [10]. In the direct space vector modulation, we are providing constant voltage and current. Here, Clarke transform is used to convert abc three phase components to alpha-beta components. Next step is to calculate angles for sector division and get six active voltage vectors [11]. This sector division should be done on both voltage and current model. It is done by calculation of duty ratios from both current and voltage Model.

A. Calculation of Duty Ratio

The duty ratio for current and voltage model can be expressed as follow.

$$R_\alpha = M * \sin(\theta_v) * \sin(pi/3 - \theta_i) \quad (3)$$

$$R_\beta = M * \sin(\theta_v) * \sin(\theta_i) \quad (4)$$

$$R_\gamma = M * \sin(pi/3 - \theta_v) * \sin(pi/3 - \theta_i) \quad (5)$$

$$R_\delta = M * \sin(pi/3 - \theta_v) * \sin(\theta_i) \quad (6)$$

Where, M is the modulation index and α, β, ɣ and δ are the duty ratios. α, β, ɣ and δ are comparing with a reference frequency. Its output will be given in odd and even section to generate switching pulses for Matrix Converter. The total duty cycle must be the unit at a fixed sampling frequency.

$$d_0 = 1 - (R_\alpha + R_\beta + R_\gamma + R_\delta) \quad (7)$$

IV. INDIRECT SPACE VECTOR MODULATION

The indirect space vector modulation was first introduced with an equivalent circuit combining current source rectifier and voltage source inverter connected through virtual dc link as shown in Fig.2 by Borojevic et al in 1989 [12].

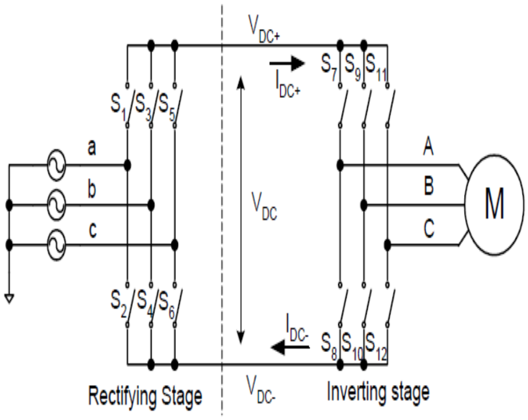

Fig. 2. The equivalent circuit for indirect modulation

The basic idea of the ISVM is to control the input current and the control of the output voltage by splitting the transfer function S for the matrix converter as shown below,

$$S = I * R \quad (8)$$

A. Calculation of Duty Cycle

In this paper, the duty cycles are calculated separately for inverter stage as well as rectifier stage then combine with a virtual DC link line [13]. Here we are taking a reference voltage and current vector at inverter stage and rectifier stage respectively.

Inverter stage

The inverter stage is modelled as voltage active vectors [14]. There are six voltage vectors which are 60^0 apart from adjacent active vector named as V_1 to V_6. Its vector representation is given in Fig. 3.

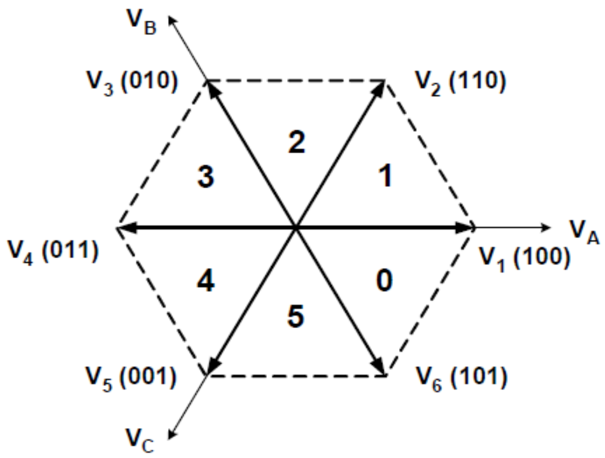

Fig.3: vector representation of Inverter voltage stage

Reference voltage vector can be expressed by,

$$V_o{}^* = d_\alpha \cdot V_\alpha + d_\beta \cdot V_\beta \quad (9)$$

The duty cycle of the active vectors in inverter stage is calculated by,

$$d_\alpha = T_\alpha \;/ T_s \;= M_v \sin(\Pi /3 - \theta_v) \quad (10)$$

$$d_\beta = T_\beta \;/ T_s \;= M_v \sin \theta_v \quad (11)$$

$$d_{ov} = T_{ov} \;/ T_s \;= 1- \; d_\alpha - d_\beta \quad (12)$$

Where, M_v is the modulation index of voltage vector and is equal to $\sqrt{3}\, V_o{}^*/ V_{dc}$.

Rectifier stage

The rectifier stage is modelled as current model. There are six current vectors which are 60^0 apart from adjacent active vector. Its vector representation is pictured in Fig.4.

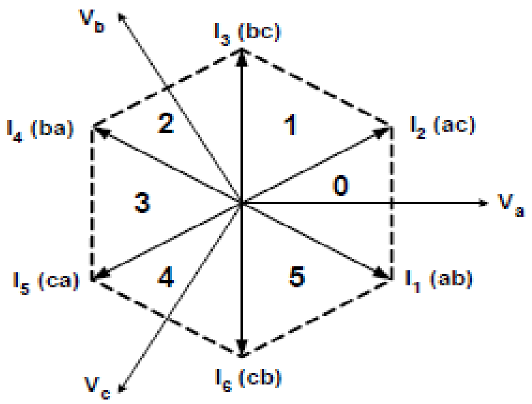

Fig. 4. Vector representation of Rectifier current stage

Reference current vector can be expressed by

$$I_o{}^* = d_\gamma \cdot V_\gamma + d_\delta \cdot V_\delta \quad (13)$$

The duty cycle of the active vectors is calculated by,

$$d_\gamma \;= T_\gamma / T_s \;= M_c \sin(\Pi/3 - \theta_i) \quad (14)$$

$$d_\delta \;= T_\delta / T_s \;= M_c \sin \theta_i \quad (15)$$

$$d_{oc} = T_{ov} / T_s \;= 1- \; d_\gamma - d_\delta \quad (16)$$

Where, $M_i = I_o{}^*/ I_{dc}$

B. ISVM for the entire MC

The simultaneous O/P voltage and I/P current SVM for the MC can be obtained by employing the inverter stage SVM sequentially in two virtual dc-link amplitudes determined by the rectifier SVM [15]. The 4 duty cycles for new active vector pair has be calculated and decide how the 4 active vectors are ordered within the switching period T_S If the sum of current & voltage hexagon sector is odd, then the O/P vector sequence is $\alpha\gamma$- $\beta\gamma$ - $\beta\delta$- $\alpha\delta$ - 0- $\alpha\delta$ – $\beta\delta$- $\beta\gamma$ - $\alpha\gamma$ Else, $\beta\gamma$ - $\alpha\gamma$- $\alpha\delta$ - $\beta\delta$ - 0- $\beta\delta$ - $\alpha\delta$ - $\alpha\gamma$ - $\beta\gamma$.

V. RESULTS AND DISCUSSION

The simulation is done on Matlab- Simulink environment for matrix converter in direct and indirect space vector modulation. The parameters used are given in Table.1. The matlab- Simulink model of the MC with pulses is shown in Fig.5. Fig.6 is the matlab- simulink model of pulse generation by DSVM for bidirectional switches. The sector representation and angle are given away in Fig.7 and Fig.8 for current and voltage model. The simulation waveform of duty ratio is depicted in Fig. 9. The reference pulse at 5 KHz is given in Fig. 10 and the nine switching pulses in the Matrix converter bidirectional switches are depicted in Fig. 11.

TABLE.1 PARAMETERS

Parameter	value
$U_a = U_b = U_c$	230V
$R_a = R_b = R_c$	14 Ω
$L_a = L_b = L_c$	1mH
$C_a = C_b = C_c$	40 micro F
V*	0.8V
I*	0.8A

Ref Frequency	5kHz
$R_A = R_B = R_C$	10 Ω
$L_A = L_B = L_C$	2mH

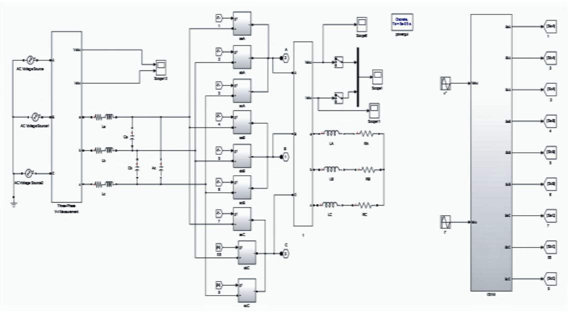

Fig. 5. Matlab model of matrix converter with pulses

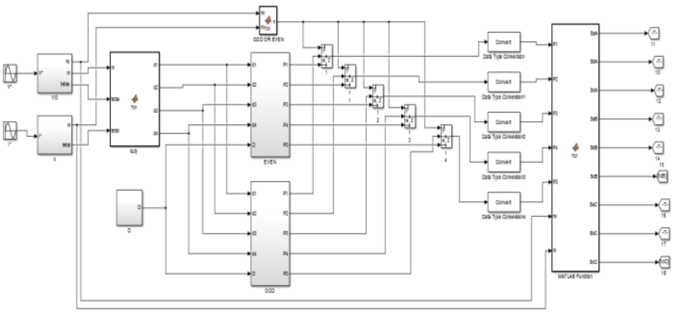

Fig. 6. MATLAB-SIMULINK model of pulse generation by DSVM

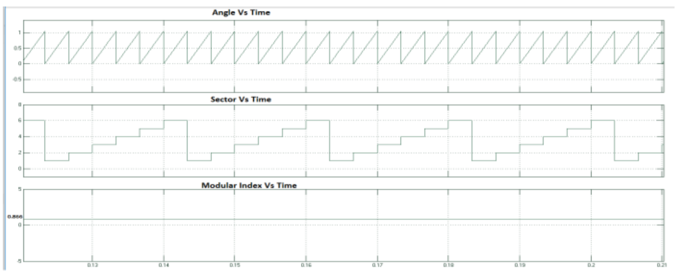

Fig. 7. Simulation waveformsof Angle, sector representation & modulation index for Voltage model.

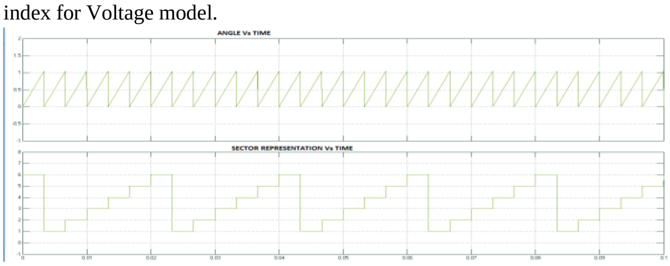

Fig. 8. MATLAB-SIMULINK Simulation waveformsof Angle & sector representation for current model.

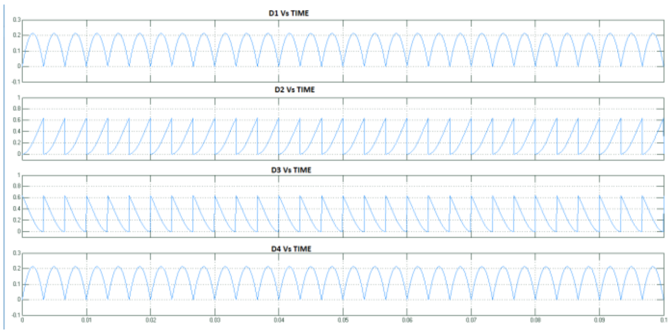

Fig. 9. Waveforms of Duty ratio(α, β, ɣ and δ)

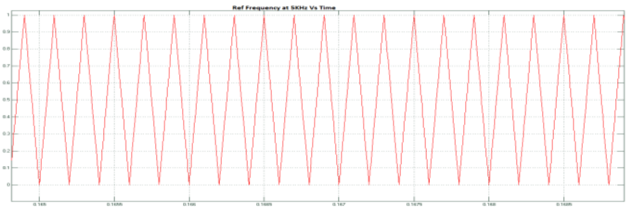

Fig. 10. Reference pulse at 5 KHz

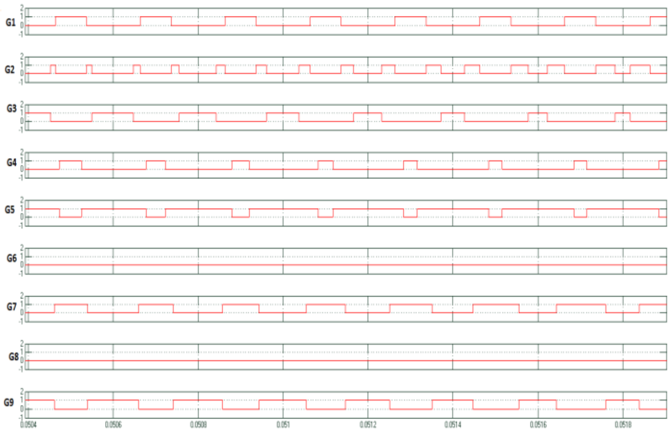

Fig. 11. swiching pulses for MC

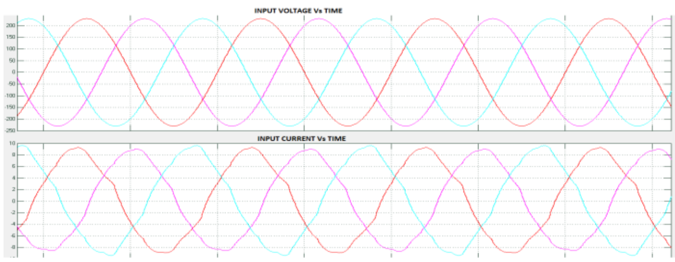

Fig. 12. Input voltage and current of MC

The input at 230V, 50 Hz supply is in Fig. 12. The output voltage can be varied by varying the input filter. So those variations can be seen in Fig.13 and the Fig.14 is given to study the variation in output current of MC. In some applications, it is very difficult to handle large load at low speed. We can overcome this problem by implementing a hybrid voltage – current model to generate pulses using DSVM.

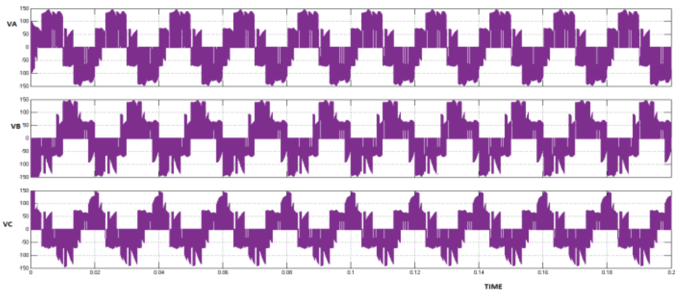

Fig. 13. Output voltage of MC

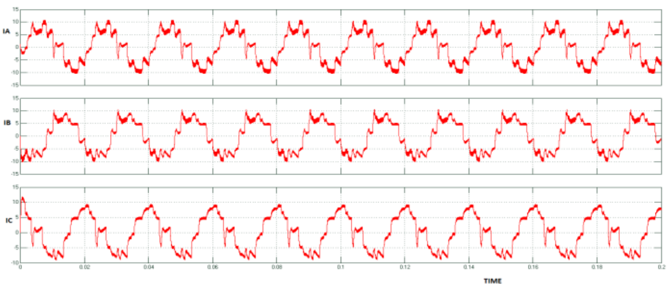

Fig. 14. Output voltage of MC

The matlab models and respective waveforms in indirect space vector modulation are given below. The Matlab- Simulink model of pulse generation by ISVM is shown in Fig.15.

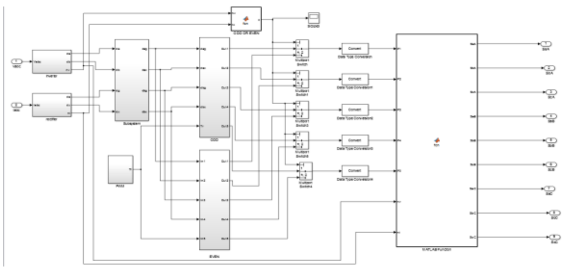

Fig. 15. Matlab- Simulink model of pulse generation by ISVM

The waveforms of rectifier and inverter stages are revealed in Fig.16 and Fig.17. As same way, a reference pulse is given to compare the duty ratios which are seen in Fig.18. The switching pulses are generated by comparing a function which checks at each time whether the sum of rectifier and inverter stages is odd or even. Gate pulses of nine switches in Matrix Converterv at 5KHz reference frequency is at Fig.19.

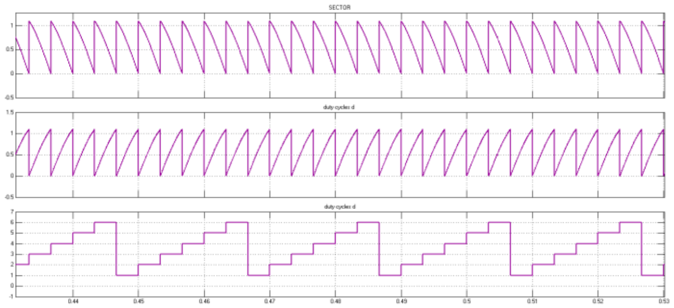

Fig. 16. Waveforms stage of Inverter, sectoridentification and dut cycles of γ and δ.

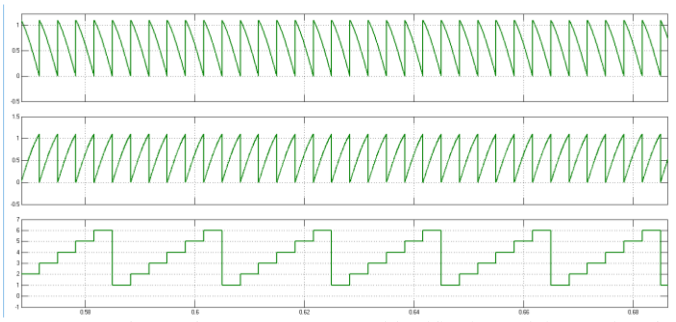

Fig. 17. Waveforms of Inverter stage, sectoridentification and duty cycles of α and β.

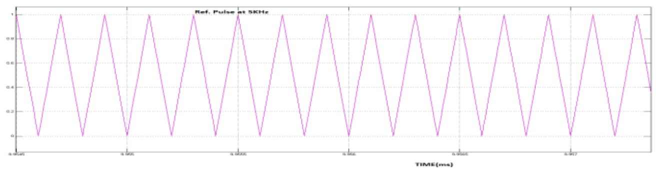

Fig.18. Ref frequency waveform at 5KHz

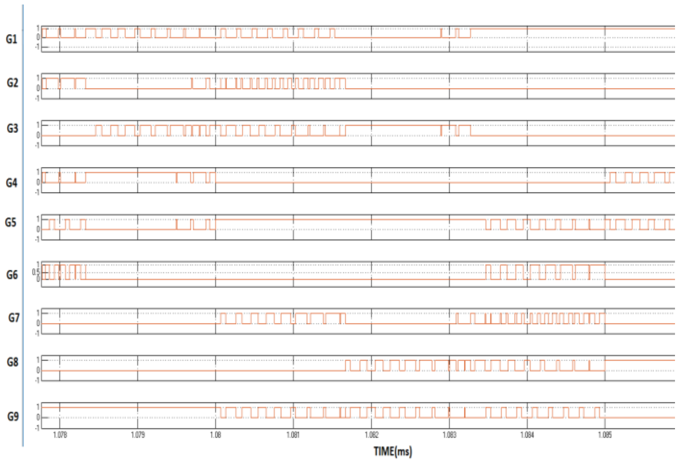

Fig. 19. Gate pulses of nine switches in Matrix Converterv at 5KHz reference frequency.

Fig.20 and Fig.21 are given to explian the variation of output voltage with respect to the input voltage and input current.

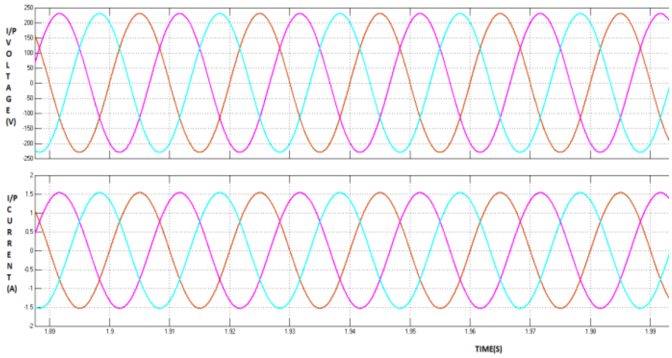

Fig. 20. Input voltage and current of MC at 230V supply

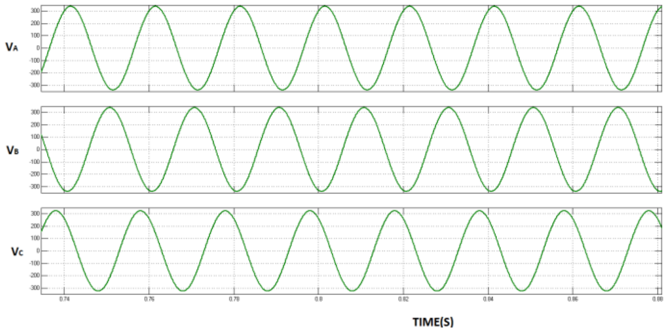

Fig.21. Output voltage of MC at 230V Input Voltage

VI. CONCLUSION

This paper compares different switching patterns of MC, direct and indirect space vector modulations. Here, the duty ratios are calculated in voltage and current model separately for both techniques. However, the number of switching increases when using direct matrix converter. As a future scope, different control techniques like FOC, DTC etc can be associated with any AC motors and can control speed, torque, flux etc of the machine.

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