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Comparison of Three Phase Voltage Back to Back Converter and Matrix Converter

C.Kalaiselvi[1], M.Bhuvaneswari[2], A.Divya Vinoth Raja[3]

Assistant Professor, Dept. of ICE, RatnaVel Subramaniam College of Engineering and Technology, Dindigul, India[1]

Assistant Professor, Dept. of ECE, RatnaVel Subramaniam College of Engineering and Technology, Dindigul, India[2]

Assistant Professor, Dept. of EIE, RatnaVel Subramaniam College of Engineering and Technology, Dindigul, India[3]

ABSTRACT: This paper presents a comparative evaluation of three phase Voltage Back to Back Converter (VBBC) and three phase Matrix Converter (MC)fed Induction Motor (IM) drive. These two topologies are developed using Space Vector Modulation (SVM) technique and simulated in MATLAB/SIMULINK. Both the topologies are functionally equivalent in terms of input power quality and energy regeneration capabilities but need to be compared in terms of performance as well as complexity due to the high number of switches involved in these two converters. In particular, the Total Harmonic Distortions (THD) of the two converters are compared. Although The Matrix Converter has a higher number of semiconductor switches, the absence of energy storage elements reduces the size of the circuit topology.

KEYWORDS: Comparative evaluation, Voltage Back-to-Back Converter (VBBC), Matrix Converter (MC), Space Vector Modulation (SVM), Induction Motor (IM)

I. INTRODUCTION

Power electronic converters are used for a wide power range and in various applications to get controllable power output. The number of such systems is large and still growing. The need for power converters will keep increase in future. The electric power conversion is from ac (alternating current) to dc (direct current), from dc to ac, from dc to dc and from ac to ac. The ac to ac conversion is widely used in industrial adjustable-speed drives, since around 80% of them are AC drives.

The available AC-AC converter structures can be divided into two schemes such as direct and indirect. The indirect topology of the power converter of the regenerative drives uses two identical bridges in the rectifier and inverter stage, connected through a dc-link bus with a small capacitor connected across it, and is usually known as a Voltage back-to-back converter (Fig.1) [1-3].The Direct topology to achieve the same goal in those applications is to employ a matrix converter which implements a direct ac-ac conversion without the need to have separate rectifier and inverter stages (Fig.2) [4-5].

Matrix Converter (MC) is a variable voltage, variable frequency power converter. Compared to the other AC-AC converter topologies, the MC has many significant features that converter may be operated to give sinusoidal line currents, for sinusoidal currents, the dc-link voltage must be higher than the peak main voltage, the dc-link voltage is regulated by controlling the power flow to the ac grid and finally, the inverter operates on the boosted dc-link, making it possible to increase the output power of a connected machine over its rated power. are well documented in the literature [4–5].The advantages are near sinusoidal input and output waveforms, unity input displacement factor, bidirectional power flow, natural four quadrant operation, potential for compact design because of the absence of dc-link capacitors and the input power factor can be fully controlled. However, MC has some disadvantage. The voltage transfer ratio is limited to 0.866, to obtain sinusoidal output waveforms. It requires more semiconductor devices compared to conventional AC–AC indirect converter. Moreover, MC is sensitive to disturbances of the input voltage system [6].

The Space Vector Modulation (SVM) control technique is used for both the converter fed Induction Motor.SVM technique is more popular than all other conventional technique because of more dc bus utilization, lower harmonics, less switching losses and higher efficiency [7-9]. The indirect modulation topology is implemented in MC. The SVM technique based on the indirect topology of the MC was first proposed by Huber and Borojevic [7].

II. CONVERTER TOPOLOGIES

I. Three phase voltage back to back converter (VBBC)

The three phase VBBCconsists simplyof a controlled bridge rectifier and a force- commutated inverter connected with a common dc-link, shown in Fig.1.

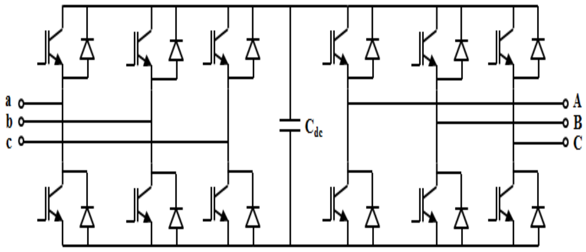

Fig.1.Three Phase Voltage Back to Back Converter

The properties of this combination are well known the line-side

II. Three phase to three phase Matrix Converter

A three phase Matrix Converter topology is shown in Fig 2.

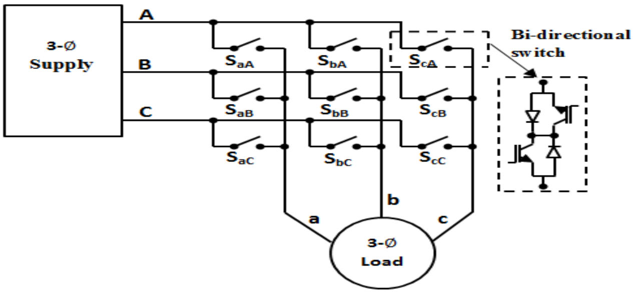

Fig.2. Three phase Matrix Converter topology

In its three-phase to three-phase version, a matrix converter consists in an array of nine bidirectional switches, which are used to directly connect the power supply to the load without using any dc-link or large energy storage elements. Each bidirectional switch being usually made by two anti-paralleled IGBT with series diodes.

Taking into account that the converter is supplied by a voltage source and usually feeds an inductive load, two constraints must be regarded when applying different switching states to the MC at any switching time.

- The input phases must never be shorted.
- The output phases must never be opened.

Owing to the above constraints, the switching states reduce to 27 (3^3) different switching combinations for connecting output phases to input phases. Consequently, it is necessary that one and only one switch per column closed at each instant. These conditions can be stated in a more compact form as follows

$$\sum_{i=\{a,b,c\}} S_{ij}(t) = 1; \qquad j = \{A, B, C\} \qquad (1)$$

The output voltages v_o(v_a, v_b and v_c) and the input currents i_i (i_A, i_B and i_C) are therefore derived directly from the input voltages v_i (v_A, v_B and v_C), and the output currents i_o(i_a, i_b and i_c) as follow.

$$[v_o] = [S] \cdot [v_i] \qquad (2)$$

$$[i_i] = [S]^T \cdot [i_o] \qquad (3)$$

where S is the modulation matrix of the switches.

$$S = \begin{bmatrix} S_{aA} & S_{aB} & S_{aC} \\ S_{bA} & S_{bB} & S_{bC} \\ S_{cA} & S_{cB} & S_{cC} \end{bmatrix} \tag{4}$$

III. CONTROL AND MODULATION

A. SVM methodof three phase VBBC

This work is focused on the inverter side of VBBC and the SVM technique is used for pulse generation. In SVM inverters, six fixed active voltage vectors and two zero vectors are used to

B. SVM method of three phase matrix converter

The SVM technique constructs the desired sinusoidal output three-phase voltage by selecting the valid switching and synthesize the rotating desired output voltage vector [7]. The switch duty cycles are calculated according to the position of the desired output voltage vector with respect to the two adjacent active fixed vectors. The three phase components can be represented into two phase component using Clark's transformation. Space vector representation of the 3 phase quantity,

$$U(t) = U_\alpha + jU_\beta = \frac{2}{3}(U_a + a \cdot U_b + a^2 \cdot U_c) \tag{5}$$

Where $a = e^{j2\pi/3}$;

$$\begin{pmatrix} U_\alpha \\ U_\beta \end{pmatrix} = {}^2/_3 \begin{pmatrix} 1 & -{}^1/_2 & -{}^1/_2 \\ 0 & \sqrt{3}/_2 & -\sqrt{3}/_2 \end{pmatrix} \begin{pmatrix} U_a \\ U_b \\ U_c \end{pmatrix} \tag{6}$$

From the voltage source inverter, maximum switching states are eight. The reference voltage magnitude and angle is calculated based on the adjacent of two active vectors as shown in Fig.3. The magnitude of the first six voltage vectors is equal to $\frac{2}{3}V_{dc}$and last two voltage vectors magnitude is equal to zero. So, first six voltage vectors are called ACTIVE states and reaming last two voltage vectors are called NULL states. Average value of voltage space vector trace a circle and active states produces the output voltage.

Switching durations T_1, T_2 and T_0 can be determined by using the volt-sec balance equation

$$|U| \cdot T_X = U_1 \cdot T_1 + U_2 \cdot T_2 + U_0 \cdot T_0 \tag{7}$$

In a sector φ varies between $0 \leq \varphi \leq 60°$. Therefore,

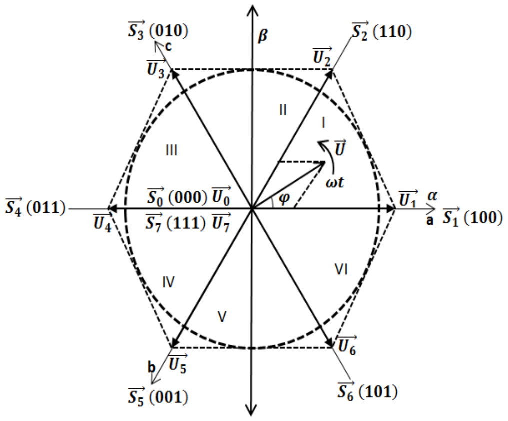

Fig.3. Space vector voltages and switching patterns

$$T_1 = \frac{m_a \cdot T_X \cdot \sin(\pi/_3 - \varphi)}{\sin \pi/_3} \quad and \quad T_2 = \frac{m_a \cdot T_X \cdot \sin\varphi}{\sin \pi/_3} \tag{8}$$

Where $T_X = \frac{T_{sw}}{2} = \frac{1}{2 * f_{sw}}$ and $m_a = \frac{|U|}{\frac{2}{3} \cdot V_{dc}}$

$$T_0 = T_X - T_1 - T_2 \tag{9}$$

calculating their corresponding on-time durations. The following expressions are used for analysis of balanced three phase system,

$$V_i = \frac{2}{3}(v_{AB} + a \cdot v_{BC} + a^2 \cdot v_{CA}) = |v_i|e^{j\alpha_i} \tag{10}$$

$$V_o = \frac{2}{3}(v_{ab} + a \cdot v_{bc} + a^2 \cdot v_{ca}) = |v_o|e^{j\alpha_o} \tag{11}$$

Whereα_i, α_o are the desired angles of input and outputvoltages, and 'a' is a complex factor defined as

$$a = e^{j2\pi/3} \tag{12}$$

The output voltage space vectors are calculated for each switching case of the allowed 27. These are 6 rotating switching vectors, 18 active switching vectors and 3 zero vectors. The implementation of this technique is difficult because of the presence of different six switching state vectors for each sector in addition to three-zero vectors. To avoid this difficulty, the indirect modulation technique has been used.

C. Indirect modulation

The indirect MC may be viewed as a double-pulse-width modulation converter (rectifier–inverter combination) without any dc link storage elements as shown in Fig. 4. It provides bidirectional power flow capability because of its symmetrical topology.

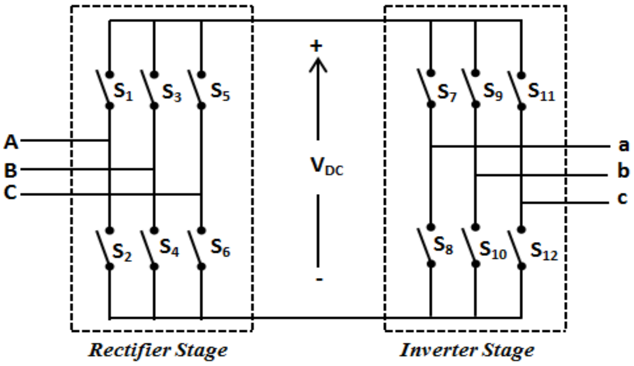

Fig.4.Indirect three phase MC topology

The basic idea of the indirect modulation technique is to decouple the control of the input current and the control of output voltage. This is done by splitting the modulation matrix S for the converter into the product of a rectifier transfer function R and an inverter transfer function I [8–9].The modulation matrix for the MC is thus defined as follows

$$\boldsymbol{S} = \boldsymbol{I} \cdot \boldsymbol{R} \tag{13}$$

$$\text{Where } \boldsymbol{R} = \begin{bmatrix} S_1 & S_3 & S_5 \\ S_2 & S_4 & S_6 \end{bmatrix} \text{and} \quad \boldsymbol{I} = \begin{bmatrix} S_7 & S_8 \\ S_9 & S_{10} \\ S_{11} & S_{12} \end{bmatrix} \tag{14}$$

Therefore the voltage transfer matrix is given by

$$\boldsymbol{v_o} = \boldsymbol{S} \cdot \boldsymbol{v_i} \tag{15}$$

The above transfer matrix shows that the output phases arecompounded by the product and sum of the input phasesthrough rectifier switches S1–S6 and inverter switches S7–S12.

a. Space-vector rectifier

This section introduces a SVM in the rectifier stagein the Fig.5. The input currents of the rectifier can be represented as

$$\begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix} = \begin{bmatrix} S_1 & S_2 \\ S_3 & S_4 \\ S_5 & S_6 \end{bmatrix} \cdot \begin{bmatrix} I_p \\ I_n \end{bmatrix} \tag{16}$$

Then the input current space-vector I_{IN} is expressed as space vectors using the transformation such as

$$I_{IN} = \frac{2}{3}(I_A + a \cdot I_B + a^2 \cdot I_C) = |I_{IN}|e^{j\alpha_i} \tag{17}$$

The rectifier switches, S_1–S_6 can have only nine allowed combinations to avoid an open-circuit at the dc-link terminals. The nine combinations can be divided into six non-zero input currents which are active vectors and three-zero input currents that are zero vectors. The reference input current vector within a sector of the current hexagon $I_{IN}^*$is synthesized by impressing the adjacent switching vectors I_γ and I_δ with the duty cycles d_γ and d_δ, respectively. If the input currents are considered constant during a short-switching interval T_S, the reference vector can be expressed by the current-time product sum of the adjacent active vectors.

$$I_{IN}^* = d_\gamma \cdot I_\gamma + d_\delta \cdot I_\delta + d_{oc} \cdot I_o \tag{18}$$

Thus the duty cycles d_γ, d_δ *and* d_{oc} are calculated by

$$d_\gamma = m_c \cdot \sin(\pi/3 - \theta_c) \;;\quad d_\delta = m_c \cdot \sin(\theta_c) \tag{19}$$

$$d_{oc} = 1 - d_\gamma - d_\delta \tag{20}$$

where θ_c indicates the angle of the reference currentvectorwithin the actual hexagon sector. The m_c is the currentmodulation index and defines the desired current transferratio as

$$m_c = I_{IN}^*/I_{DC} \,, \qquad 0 \le m_c \le 1 \tag{21}$$

b. Space-vector inverter

This section introduces a SVM in the inverter stage in the Fig.5. The output voltages of the inverter can be represented as

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} S_7 & S_8 \\ S_9 & S_{10} \\ S_{11} & S_{12} \end{bmatrix} \cdot \begin{bmatrix} +\frac{1}{2}V_{DC} \\ -\frac{1}{2}V_{DC} \end{bmatrix} \tag{22}$$

Then the output voltage space vector is expressed as space vectors using the complex transform as follows

$$V_{out} = \frac{2}{3}(V_a + a \cdot V_b + a^2 \cdot V_c) = |V_{out}|e^{j\alpha_o} \tag{23}$$

The inverter switches, S_7–S_{12} can have only eight allowed combinations to avoid a short-circuit through three-half bridges. The eight combinations can be divided into six non-zero output voltages that are active vectors and two zero output voltages that are zero vector. The reference voltage vector V_o^*within a sector of the voltage hexagon is synthesized by impressing the adjacent active vectors V_α and V_β with the duty cycles d_α *and* d_β respectively. If the output voltages are considered constant during a short switching interval T_S, the reference vector can be expressed by the voltage–time product sum of the adjacent active vectors.

$$V_o^* = d_\alpha \cdot V_\alpha + d_\beta \cdot V_\beta + d_{ov} \cdot V_o \tag{24}$$

Thus the duty cycles d_α, d_β *and* d_{ov} are calculated by

$$d_\alpha = m_v \cdot \sin(\pi/3 - \theta_v); d_\beta = m_v \cdot \sin(\theta_v) \tag{25}$$

$$d_{ov} = 1 - d_\alpha - d_\beta \tag{26}$$

$$m_v = \sqrt{3}V_{o,max}/V_{DC} \tag{27}$$

whereθ_v indicates the angle of the reference voltage vector within the actual hexagon sector, m_v is the voltage modulation index and $V_{o,max}$ is the desired output line voltage. The current modulation index m_c is often fixed to unity and the voltage modulation index m_v is variable according to the required overall voltage transfer gain.

IV.SIMULATION RESULTS

The simulation models were developed for a three phase VBBC and a MC in MATLAB/SIMLINK.The gate pulses for both the converters are generated using SVM technique for two different output frequencies (f_o=50Hz and 100Hz) with the switching frequency f_{sw}=10KHz. Both the converters are feeding a 5HP, 400V, three phase Induction motor driving a load of 0.4N-m. The Figures 8 to 16reflect the induction motor performance when fed from both converters for different output frequencies.These figures show clearly that the current, speed and torquecharacteristics are almost similar for both the VBBC and the MC. However the MC has more THD compared to VBBC.

A. *Three phase VBBCwithf$_o$=50Hz*

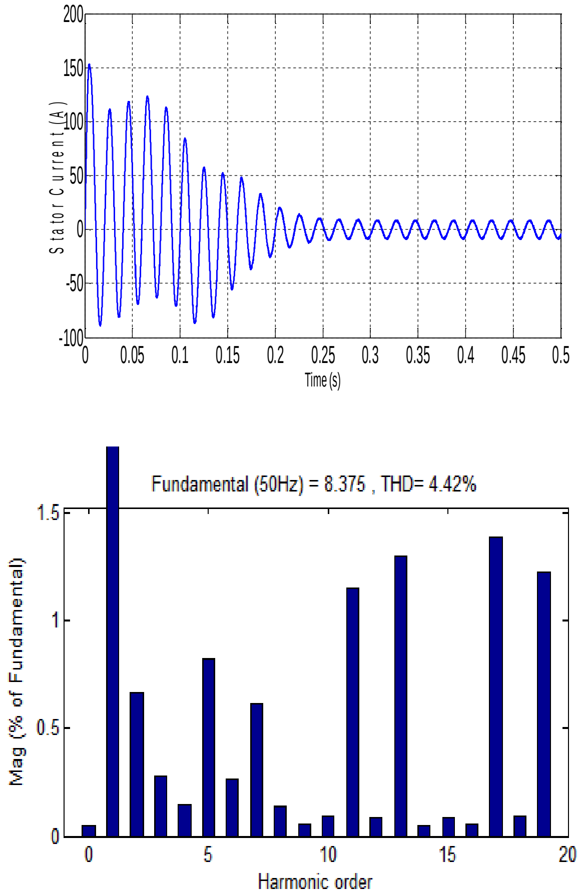

Fig.5. Stator current and its spectrum of VBBC fed IM for*f$_o$=50Hz*

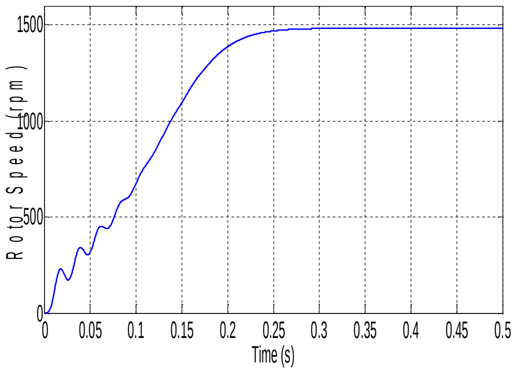

Fig.7. Rotor speed of VBBC fed IM for*f$_o$=50Hz*

B. Three phase Matrix Converter with fo=50Hz

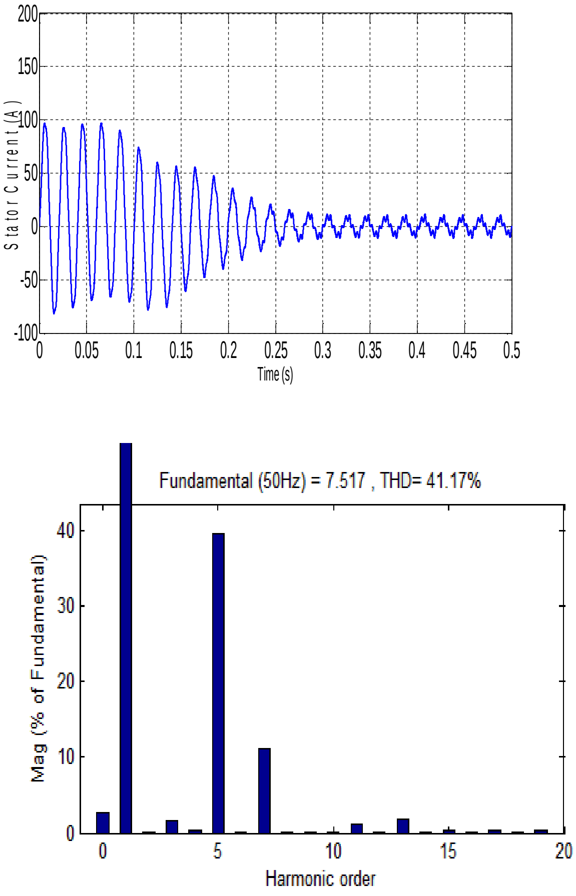

Fig.6. Stator current and its spectrum ofMC fed IM for*f$_o$=50Hz*

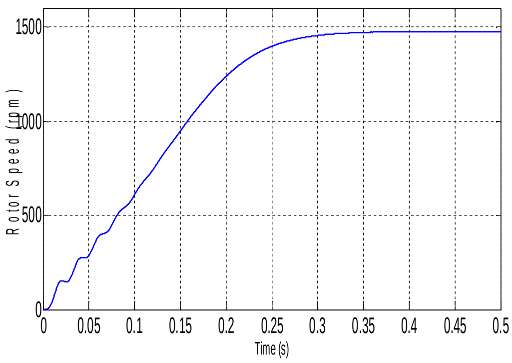

Fig.8. Rotor speed of MC fed IM for*f$_o$=50Hz*

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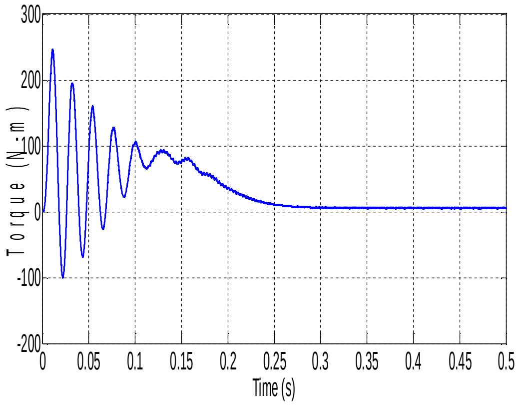


Fig.9. Torque of VBBC fed IM for $f_o=50Hz$

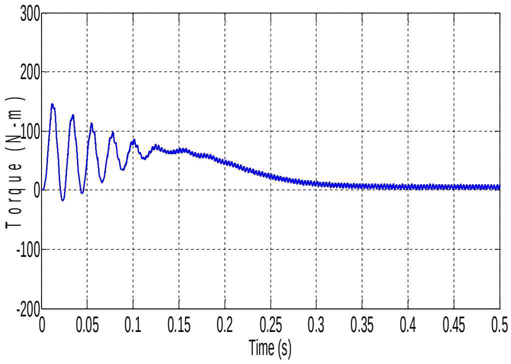
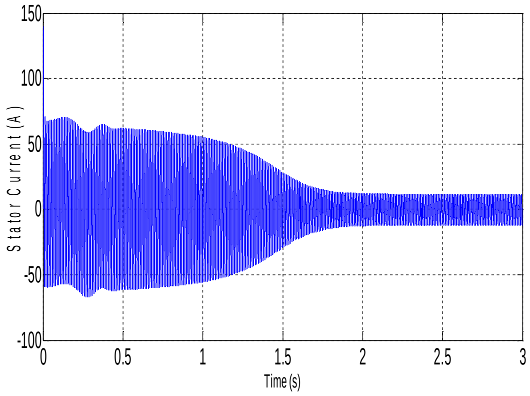


Fig.10. Torque of MC fed IM for$f_o=50Hz$

C. Three phase VBBC with fo=100Hz



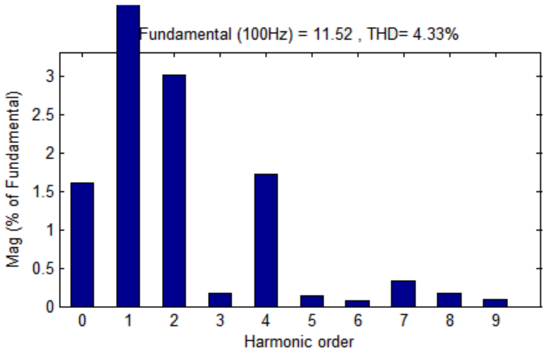


Fig.11.Stator current and its spectrum of VBBC fed IMfor$f_o=100Hz$

D. Three phase Matrix Converter with$f_o=100Hz$

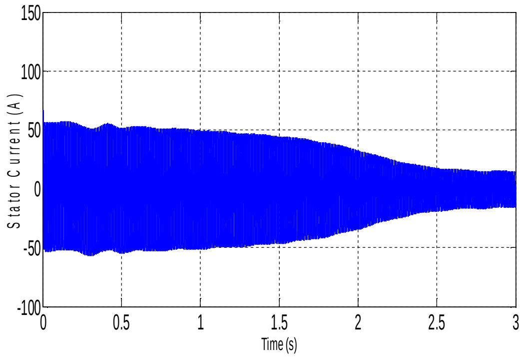
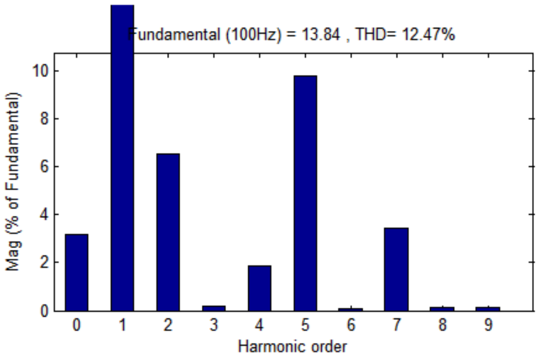
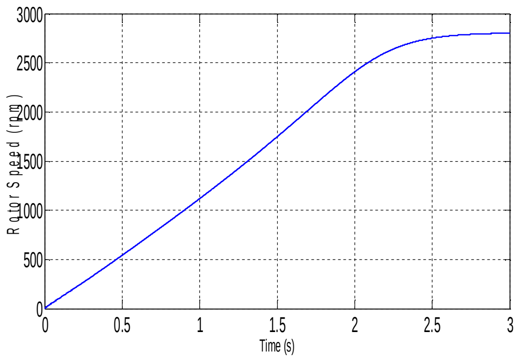


Fig.12. Stator current and its s



pectrum ofMC fed IM for$f_o=100Hz$



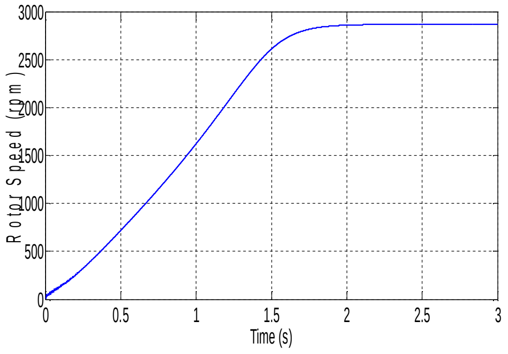


Fig.13. Rotor speed ofVBBC fed IM forf_o=*100Hz*

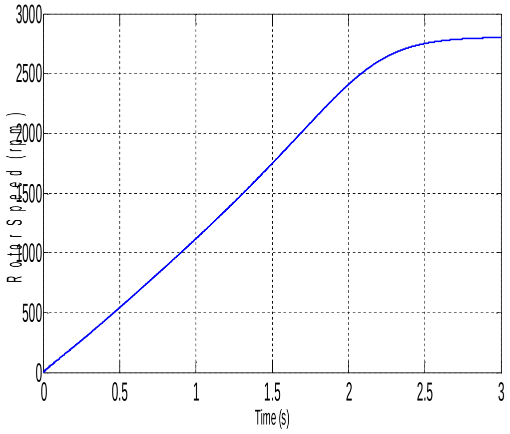


Fig.14. Rotor speed of MC fed IM forf_o=*100Hz*

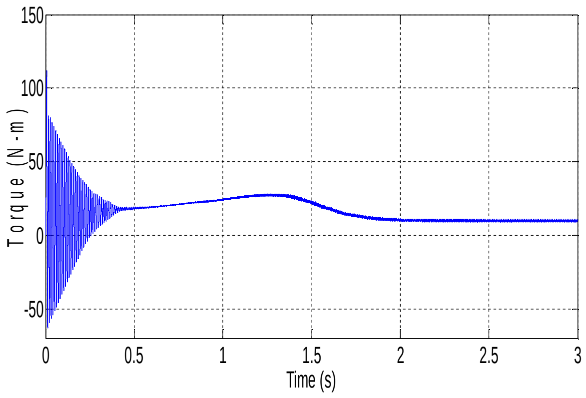


Fig.15. Torque of VBBC fed IM forf_o=*100Hz*

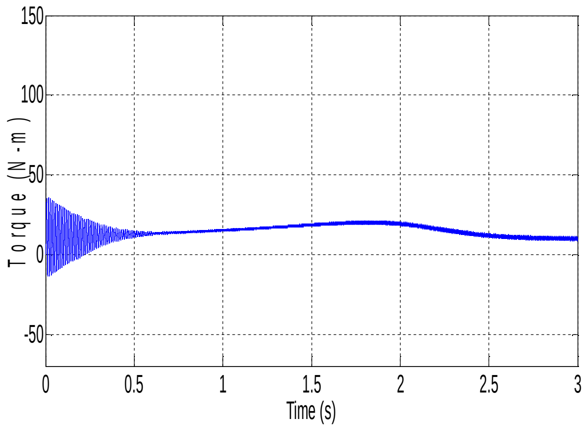


Fig.16. Torque of MC fed IMfor f_o=*100Hz*

IV. CONCLUSION AND FUTURE WORK

This paper proposed a comparitive evaluation of the performances of a three phase VBBC and a MC fed induction motor drive system. The SVM strategy for both the converters are explained in detail. From the performance results obtained from the VBBC and MC, it is observed that, the MC performances are almost similar to VBBC except THD. Current research on MC is mainly focused on reduction of THD. If this problem can be solved, then in near future MC will replace VBBC in most of the applications. In addition, MC has minimal higher order harmonics and has minimal energy storage requirements, which allows to get rid of bulky and lifetime- limited energy-storing capacitors. Both the converter topologies have the same basic functionality in terms of input power quality and regenerative capabilities for AC to AC power conversion applications. However the Matrix Converter solution offers the potential for a substantial increase in power density due to the reduction in the size of the energy storage elements within the circuit topology.

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BIOGRAPHY

C.KALAISELVI

The author is working as an Assistant Professor in department of Instrumentation and Control Engineering at RatnaVel Subramaniam College of Engineering and Technology, Dindigul. She received her BE(EEE) degree from PSNA College of Engineering and Technology, Dindigul, affiliated to Anna University, Chennai and M.E(Control & Instrumentation) from College of Engineering Guindy, Anna University, Chennai. Her research interests are Power Electronics, Digital Electronics & Electrical Machines.

M.BHUVANESWARI

The author is working as an Assistant Professor in department of Electronics and Communication Engineering at RatnaVel Subramaniam College of Engineering and Technology, Dindigul. She received her BE(ECE) & M.E(Computer Science Engineering) degree from RatnaVel Subramaniam College of Engineering and Technology, Dindigul, affiliated to Anna University, Chennai. Her research interest is Networking.

A.DIVYA VINOTH RAJA

The author is working as an Assistant Professor in department of Electronics and Instrumentation Engineering at RatnaVel Subramaniam College of Engineering and Technology, Dindigul. He received her BE(EEE) degree from PSNA College of Engineering and Technology, Dindigul, affiliated to Anna University, Chennai and M.E(Control & Instrumentation) from Kalasalingam University. His research interests are Power Electronics, control system & Electrical Machines.