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PWM with Three Intervals and Fuzzy Logic Control Technique for Matrix Converter Fed Induction Motor

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Authors' contributions

This work was carried out in collaboration between all authors. Author AB designed the study, performed the fuzzy logic development and analysis and wrote the first draft of the manuscript and managed literature searches. Author TB revised the analyses of the study and reviewed the draft manuscript carefully. Author DD supervised over all research and finalized the manuscript. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

One of the most interesting members of the power electronic equipment is the matrix converter (MC), This converter is an attractive AC/AC direct power conversion topology. It has main advantages of adjustable speed and power quality compensation compared to AC/DC/AC conventional conversion in following, High quality in input and output current sinusoidal waveforms, zeros consumption of reactive power, and it has a high variable frequency. This paper proposes the application of a matrix converter to an induction motor drive system, where the matrix converter generates three phase pulses width modulation voltage pulses (PWM), to obtain high waveforms sinusoidal input/output current with high performance dynamic of induction motor. The control of the system is insured by a fuzzy logic controller (FLC), which performs closed loop control of the output current waveforms of the matrix converter by regulating the voltage transfer ratio, which is the relationship between the output voltage and the input voltage.. The objective of Venturini algorithms is to control the amplitude of the output voltage; so, by adding the third harmonics to the input and output voltages, the voltage transfer ratio, can be

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increased up to the desired output voltage amplitude. Simulations results will be presented.

Keywords: Matrix converter; PWM; Venturini control algorithm; Fuzzy logic; power quality; Induction motor drives system;

1. INTRODUCTION

Matrix converters (MC) is advanced solution for the most appropriate remediation at both the AC-AC power conversion. The general concept of the matrix converter is a single-stage converter, constructed by nine bidirectional power IGBTs switches. The basic topology of matrix converter was first described in 1976 by Gyugyi and Pelly [1]. The development of MCs started when Alesina and Venturini proposed the basic principles of operation in the early 1980's [2]. This converter has main advantages over traditional (AC/DC/AC) rectifier-inverter type power frequency converters, as following allows both absorbance sinusoidal current networks, low consumption of reactive power, high power density, high capacity and potentially and high reliability [3],[4],[5]. Matrix converter is an array of controlled IGBTs switches that directly connect each input phase to each output phase, without any intermediate DC link compared to the(AC/DC/AC) converter, the passive input passive filter (RLC) to entry used in order to reduce the input harmonics current pollution [6],[7],[8],[9],[10]. The nine bi-directional power switches made of matrix converter usually IGBTs transistors with anti parallel diodes [5]. In order to obtain high performance dynamic control, this work presents a control strategy based on a three intervals PWM and Fuzzy logic controller applied to a model containing an Induction motor drives supplied via a matrix converter. The aim of this paper is to present the simulation results of a MC fed induction motor as shown in Fig. 1.

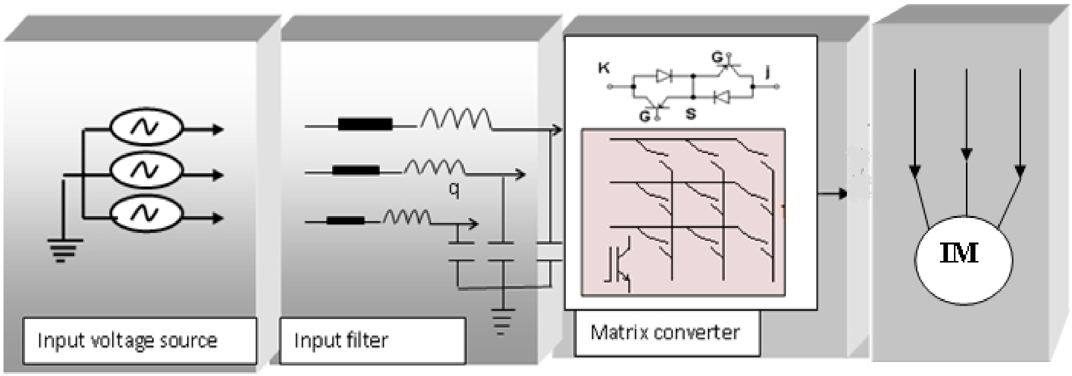


Fig. 1. Schematic of proposed system

2. MATRIX CONVERTER ANALYSIS

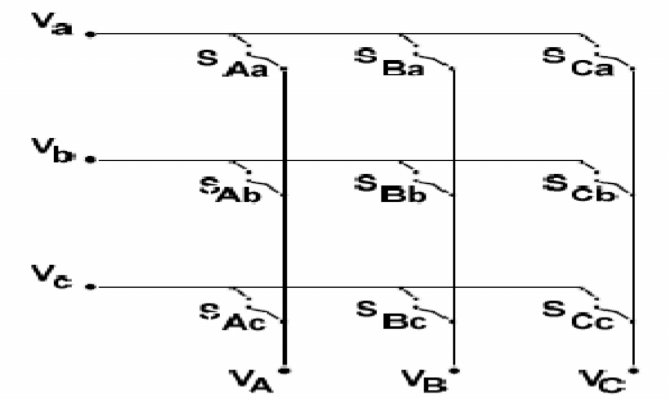


Fig. 2. Structure of matrix converter

The input voltage source of matrix converter as shown in Fig. 2 is given by:

$$v_i(t) = \begin{cases} v_{AN}(t) = v_{im}\cos(\omega_i t) \\ v_{BN}(t) = v_{im}\cos(\omega_i t - \frac{2\pi}{3}) \\ v_{CN}(t) = v_{im}\cos(\omega_i t - \frac{4\pi}{3}) \end{cases} \tag{1}$$

The input line current of matrix converter is given by:

$$i_i(t) = \begin{cases} i_A(t) = i_{im}\cos(\omega_i t + \varphi_i) \\ i_B(t) = i_{im}\cos(\omega_i t - \frac{2\pi}{3} + \varphi_i) \\ i_C(t) = i_{im}\cos(\omega_i t - \frac{4\pi}{3} + \varphi_i) \end{cases} \tag{2}$$

The effective approach to obtain sinusoidal output voltage and currents determined respectively by following equations:

$$v_j(t) = \begin{cases} v_{aN}(t) = v_{om}\cos(\omega_o t) \\ v_{aN}(t) = v_{om}\cos(\omega_o t - \frac{2\pi}{3}) \\ v_{cN}(t) = v_{om}\cos(\omega_o t - \frac{4\pi}{3}) \end{cases} \tag{3}$$

$$i_j(t)=\begin{cases} i_a(t)=i_{om}\cos(\omega_o t+\varphi_o) \\ i_b(t)=i_{om}\cos(\omega_o t-\frac{2\pi}{3}+\varphi_o) \\ i_c(t)=i_{om}\cos(\omega_o t-\frac{4\pi}{3}+\varphi_o) \end{cases} \tag{4}$$

The nine switches S_{ij} of matrix converter are constructed a connection function $S_{ij}(t)$ defined by the following equations [11],[12] :

$$S_{ij}(t)=\begin{cases} 0 \quad if \text{ switch } S_{ij} \ open \\ 1 \quad if \text{ switch } S_{ij} \ closed \end{cases} \tag{5}$$

With *i = A, B, C* and *j = a, b, c*

We define the nine average value $m_{ij}(t)$ of the connection function $S_{ij}(t)$ generation function of the nine switches S_{ij} defined by :

$$m_{ij}(t)=\frac{1}{T_p}\int_0^T S_{ij}(t)dt \quad with \ \ 0<m_{ij}(t)>1 \tag{6}$$

T_p : period of switching

The Matrix Converter is fed by a voltage source, so, in this case the input terminals should not be short-circuited, on the other hand, the load has typically an inductive nature and for this reason an output phase must never be opened [5].

$$\begin{cases} m_{Aa}(t)+m_{Ba}(t)+m_{Ca}(t)=1 \\ m_{Ab}(t)+m_{Bb}(t)+m_{Cb}(t)=1 \\ m_{Ac}(t)+m_{Bc}(t)+m_{Cc}(t)=1 \end{cases} \tag{7}$$

All the generation functions form a matrix called modulation matrix M (t) as:

$$M(t)=\begin{bmatrix} m_{Aa}(t) & m_{Ba}(t) & m_{Ca}(t) \\ m_{Ab}(t) & m_{Bb}(t) & m_{Cb}(t) \\ m_{Ac}(t) & m_{Bc}(t) & m_{Cc}(t) \end{bmatrix} \tag{8}$$

The conversion matrix of MC connects the electrical as follows:

$$v_j(t)=M(t)\cdot v_i(t) \tag{9}$$

$$i_i(t)=M(t)^T\cdot i_j(t) \tag{10}$$

Where, $M(t)$ and $M(t)^T$ are modulation matrix and its transposed.

3. PWM WITH THREE INTERVALS USING VENTURINI CONTROL ALGORITHM

In the Venturini control algorithm method, to obtain the maximum value of transfer ratio voltage ‘’*q*’’ (which is the ratio of the output voltage to the input voltage), it’s necessary to add a third harmonic frequency in the input and output voltage. So, in this case, ‘’q’’ can be increased up to 0.866 against a maximum value of 0.5 without third harmonic injection [13],[14],[15],[16],[17]:

$$v_j(t)=\begin{cases} v_{aN}(t)=qv_{im}(\cos(\omega_o t)-\frac{1}{6}\cos(3\omega_o t)+\frac{1}{2\sqrt{3}}\cos(3\omega_i t)) \\ v_{bN}(t)=qv_{im}(\cos(\omega_o t+\frac{2\pi}{3})-\frac{1}{6}\cos(3\omega_o t)+\frac{1}{2\sqrt{3}}\cos(3\omega_i t)) \\ v_{cN}(t)=qv_{im}(\cos(\omega_o t+\frac{4\pi}{3})-\frac{1}{6}\cos(3\omega_o t)+\frac{1}{2\sqrt{3}}\cos(3\omega_i t)) \end{cases} \tag{11}$$

when, ‘’*q* ’’ is the transfer ratio voltage between the output v_{jm} and input voltage v_{im}, determinate by the flowing equation :

$$q=\frac{v_{jm}}{v_{im}} \qquad with \quad 0<q\geq 0.86 \tag{12}$$

Similarly, the modulations function according to the optimal amplitude is given by [9]:

$$m_{ij}(t)=\frac{1}{3}\cdot\begin{vmatrix} 1+\frac{2v_i v_j}{v^2{}_{im}}+\frac{4q}{3.\sqrt{3}}\sin(\omega_i t)\sin(3\omega_i t) \\ 1+\frac{2v_i v_j}{v^2{}_{im}}+\frac{4q}{3.\sqrt{3}}\sin(\omega_i t+\frac{2\pi}{3})\sin(3\omega_i t) \\ 1+\frac{2v_i v_j}{v^2{}_{im}}+\frac{4q}{3\sqrt{3}}\sin(\omega_i t+\frac{4\pi}{3})\sin(3\omega_i t) \end{vmatrix} \tag{13}$$

When the switching time were calculated using the following equation:

$$t_{ij}(t)=\frac{m_{ij}(t)}{T_p} \tag{14}$$

The carrier signal is tooth an equation defined by:

$$u_p(t)=\frac{1}{T_p}t \qquad 0\leq t\geq T_p \tag{15}$$

Finally, the nine impulsion switches of matrix converter are obtained by using a simple logic binary:

$$\begin{cases} G_{Aj} = X_j \\ G_{Bj} = \overline{X}_j \ \ et \ \ Y_j \\ G_{Cj} = \overline{X}_j \ \ et \ \ \overline{Y}_j \end{cases} \quad (16)$$

$j = a, b, c$

The sequence algorithm of control switches for matrix converter, as shown in Figs. 3. 4.

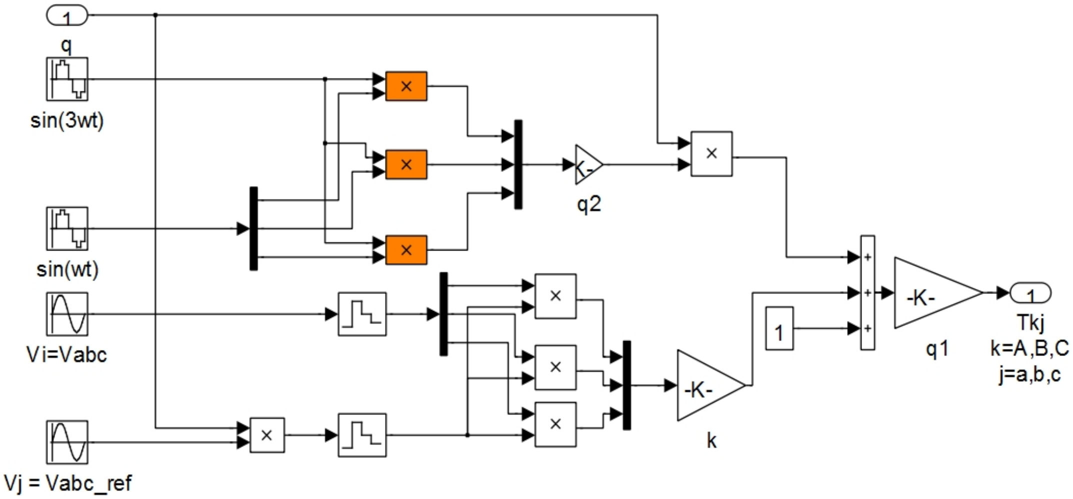


Fig. 3. Simulink model of duty cycle generation for three output phase of the matrix converter

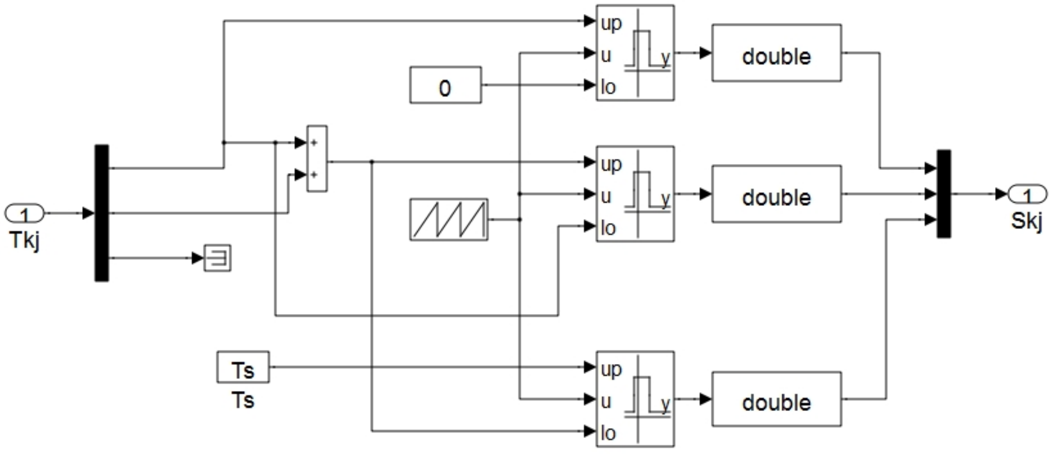


Fig. 4. Simulink model of sequence algorithm control switches for one output phase of the matrix converter

4. FUZZY LOGOC CONTROL FOR OUTPUT CURRENTS WAVEFORMS

A fuzzy logic controller (FLC) is an advanced control strategy, the based fuzzy rules are constructed by expert experience or knowledge database. The error e (k) and the change of error Δe (k) of the angular velocity have been placed to be the input variables of the fuzzy logic controller. The output variable of the (FLC) is the change of the voltage transfer ratio Δq [16],[18],[19],[20],[21], the type of fuzzy inference engine used is Mamdani and the linguistic input variables are defined as (NB, NS, Z, PS, PB,) for the error, and (N, Z, P) for change of error Δe ; when the output linguistic variables are defined as (PS, PB, Z, NS, NB) that means: positive small, positive big, zero, negative small, and, negative big respectively. The fuzzy rules are summarized in Table 1.

Table 1. The fuzzy rules

e(k) $\Delta e(k)$	*NB*	*NS*	*Z*	*PS*	*PB*
N	PB	PS	PS	Z	NB
Z	PB	PS	Z	NS	NB
P	PB	Z	NS	NS	NB

The measured output currents are used to calculate the magnitude “id0” according to the following equation:

$$i_{do} = \sqrt{\frac{2}{3}(i_a{}^2(t) + i_b{}^2(t) + i_c{}^2(t))} \tag{17}$$

The maximum value of the reference of “ i_{d0}” is obtained by:

$$i_{doref\_\max} = \frac{q \cdot v_{im}}{\sqrt{(R^2 + (L\omega)^2}} \tag{18}$$

By keeping “i_{d0} “ constant, the output of the converter is not affected by disturbances harmonics in the input voltages.

The instantaneous error *e(k)* between i_{do} and its reference is given by :

$$e(k) = (id_o(k)_{ref} - id_{oref}(k)) \cdot \alpha \tag{19}$$

The change of the error can be calculated by:

$$\Delta e(k) = (e(k) - e(k-1)) \cdot \beta \tag{20}$$

Where: α and β are the normalization coefficients [16].

The bloc diagram of FLC is illustrated in Fig. 3. The output of the fuzzy regulator gives the change of voltage transfer ratio “q”, so the actual value of “*q*” is obtained by adding the previous value q(k-1) and the change of the voltage transfer ratio $\Delta q(k)$, according to equation :

$$q(k) = q(k-1) + \Delta q(k) \tag{21}$$

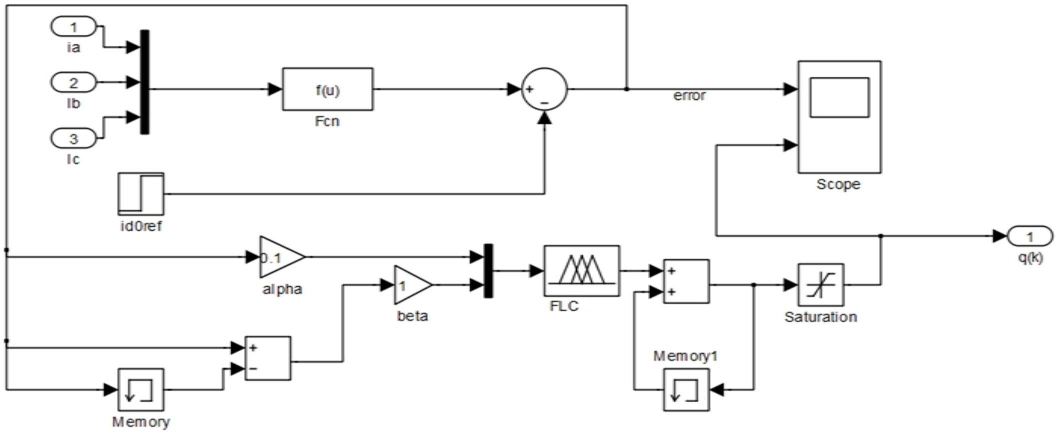
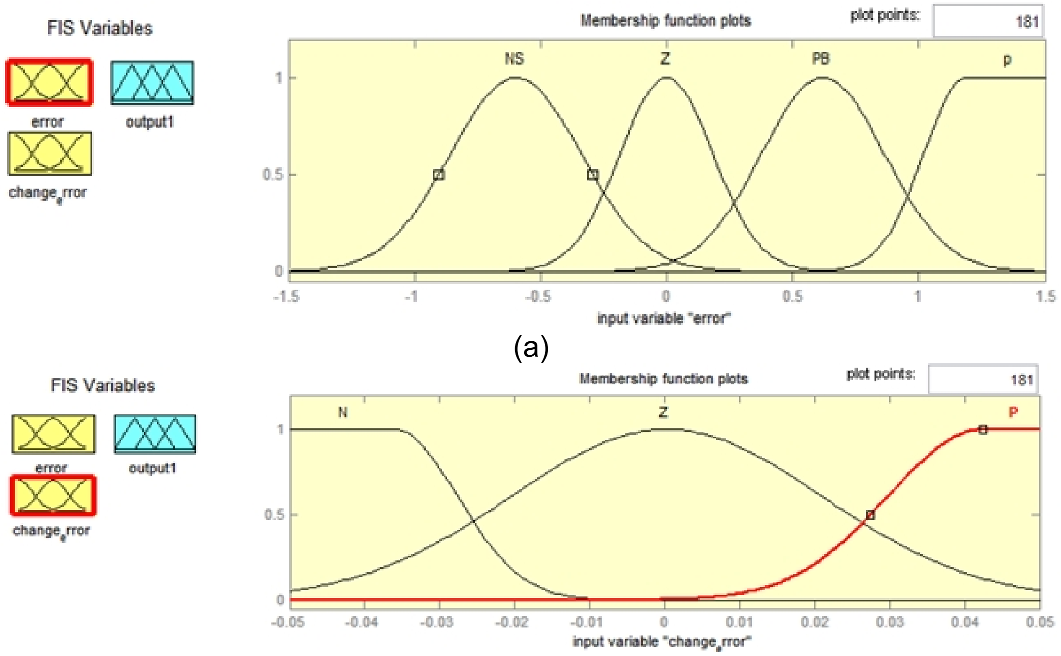


Fig. 5. Block diagram to obtain the voltage transfer ratio

The membership functions of the fuzzy logic controller are shown in Figs. 5, 6, 7. The fuzzy inference mechanism used in this work is presented as following.



(a)

(b)

Fig. 6. Input membership function

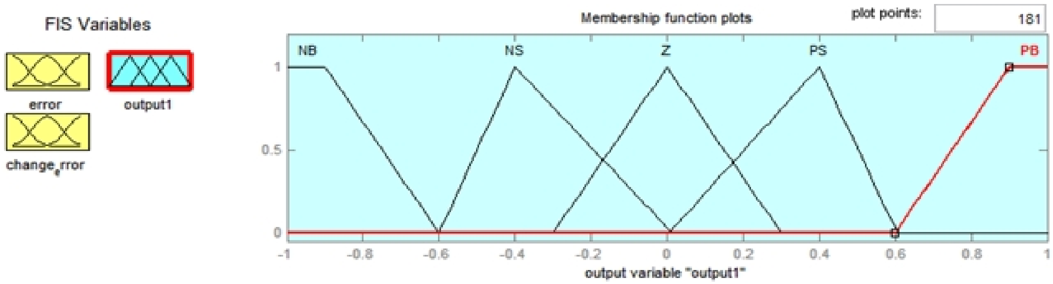


Fig. 7. Output variable membership function

5. MODELING OF INDUCTION MACHINE

The induction machine is an asynchronous squirrel-cage machine, it is characterized by the following equations [22],[23]:

5.1 Electrical System

The Voltage equations:

$$\begin{cases} v_{qs} = R_s i_{qs} + \dfrac{d}{dt}\varphi_{qs} + \omega\varphi_{ds} \\ v_{ds} = R_s i_{ds} + \dfrac{d}{dt}\varphi_{ds} - \omega\varphi_{qs} \end{cases} \tag{22}$$

$$\begin{cases} v_{qr} = 0 = R_s i_{qs} + \dfrac{d}{dt}\varphi_{qs} + (\omega - \omega_r)\varphi_{ds} \\ v_{dr} = 0 = R_s i_{ds} + \dfrac{d}{dt}\varphi_{ds} - (\omega - \omega_r)\varphi_{qs} \end{cases} \tag{23}$$

v_{ds}, i_{ds}, in d axis are respectively stator voltage and current
v_{qs}, i_{qs}, in q axis are respectively stator voltage and current
φ_{ds}, φ_{qs} *in d and q stator fluxes*
φ_{dr}, φ_{qr} *in d and q rotor fluxes*
R_s, R_r *:* are respectively the stator and rotor resistances.
d : is axis quantity
q : is axis quantity

Flow equations :

$$\begin{cases} \varphi_{qs} = L_s i_{qs} + L_m i_{qr} \\ \varphi_{ds} = L_s i_{ds} + L_m i_{dr} \end{cases} \tag{24}$$

$$\begin{cases} \varphi_{qr} = L_r i_{qr} + L_m i_{qs} \\ \varphi_{qr} = L_r i_{qr} + L_m i_{qs} \end{cases} \tag{25}$$

$$\begin{cases} L_s = L_r i_{qr} + L_m i_{qs} \\ L_r = L_r i_{qr} + L_m i_{qs} \end{cases} \tag{26}$$

Ls , *Lr:* are respectively the stator and rotor inductance.
Lm : is magnetizing inductance between stator and rotor.
Torque equation:

$$Te = \frac{\sqrt{3}}{2} p(\varphi_{ds} i_{qs} - \varphi_{qs} i_{ds}) \tag{27}$$

P : is the number of pole pairs

5.2 Mechanical System

The rotor speed

$$\begin{cases} \frac{d}{dt}\omega_m = \frac{1}{2H}(T_e - F\omega_m - T_m) \\ \frac{d}{dt}\theta_m = \omega_m \end{cases} \tag{28}$$

Te : Electromagnetic torque
Tm : Shaft mechanical torque
H: Combined rotor and load inertia constant. Set to infinite to simulate locked rotor.
F: Combined rotor and load viscous friction coefficient
ω_m : Angular velocity of the rotor
θ_m : Rotor angular position

6. SIMULATION RESULTS

The simulation results of the matrix converter feeding a induction motor drives have been obtained with using MATLAB/SIMULINK show in Fig.8, and compared with conventional (AC/DC/AC) converter, and results obtained in references [4],[5],[16],[21]. This software represents all the switches as ideal switches. The parameters of the converter for the MATLAB simulation are : Input voltage RMS V=220 V, frequency f i = 50Hz, Induction motor drives: Pn =4kw, 220/380 V, n=1430tr/min, Cr=30Nm. The bidirectional switches are controlled by using Venturini control algorithm where the voltage ratio, q is taken as0.866. Simulation results for various output frequencies are given in Figs below. The switching frequency was taken as 10 KHz.

Results shown in Figs.9, 10. Illustrate the input phase voltage and current of the matrix converter with the presence of an input passive filter. It can be clearly seen that the input voltage and current are sinusoidal waveforms and in phase.

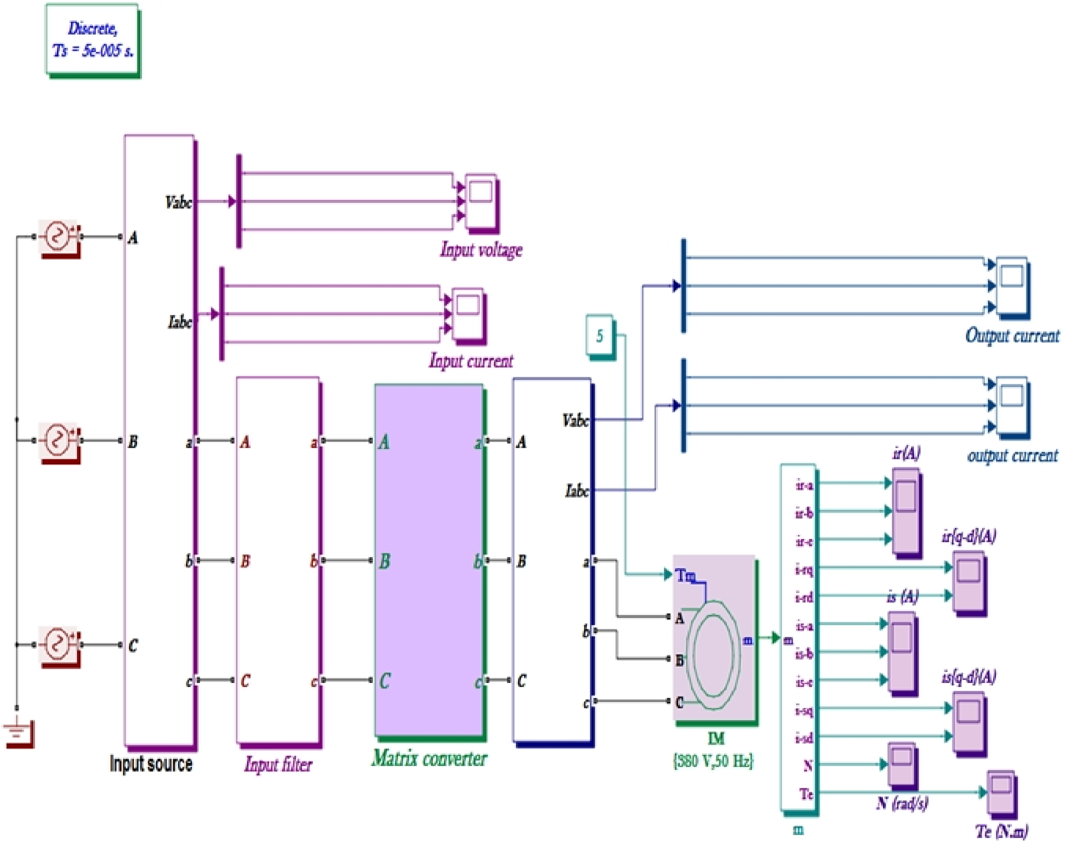


Fig. 8. Simulink model of the matrix converter fed induction motor drives

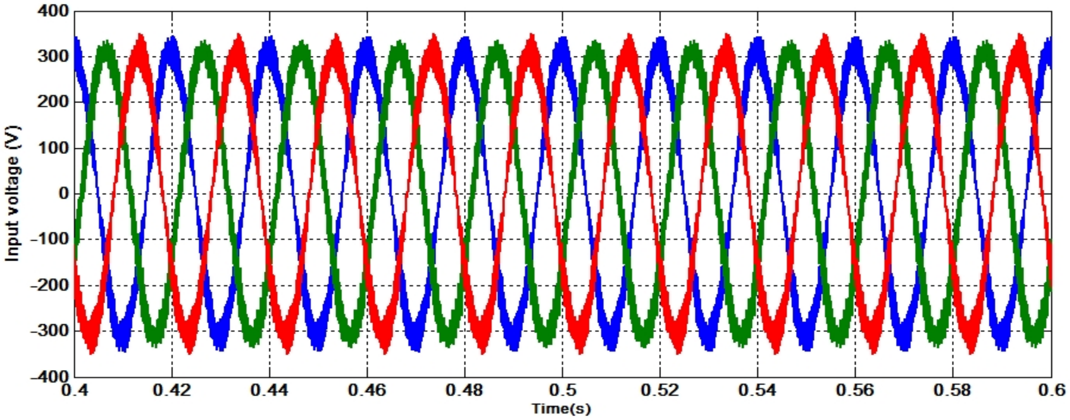


Fig. 9. Input voltage

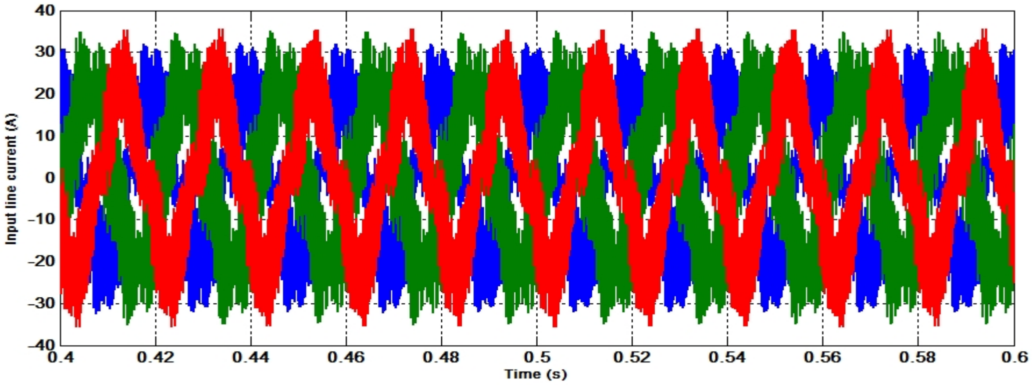


Fig. 10. Input line current of matrix converter

Results shown in Figs.11, 13, and 14 give respectively, the line to line output voltage, output simple phase voltage, and output current of the matrix converter, it can also be observed from this Figures that both line current and simple voltage are nearly sinusoidal, the output line-to-line voltages are gradually improved. The THD (total harmonic distortion) decrease to 4.59%, as show in Fig. 13. and respect IEEE519 standard.

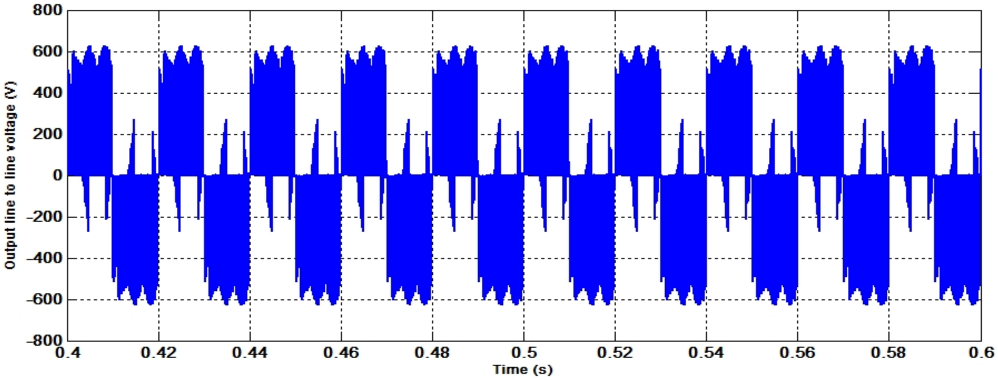


Fig. 11. Input voltage

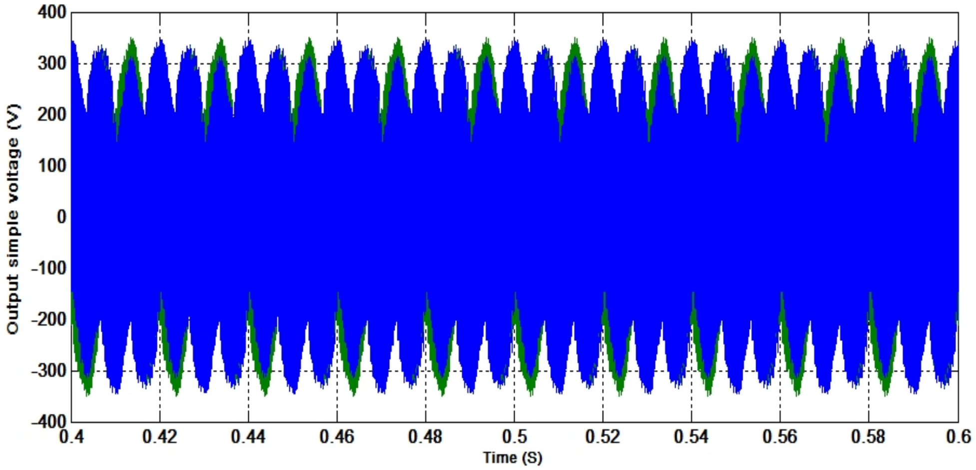


Fig. 12. Output simple voltage

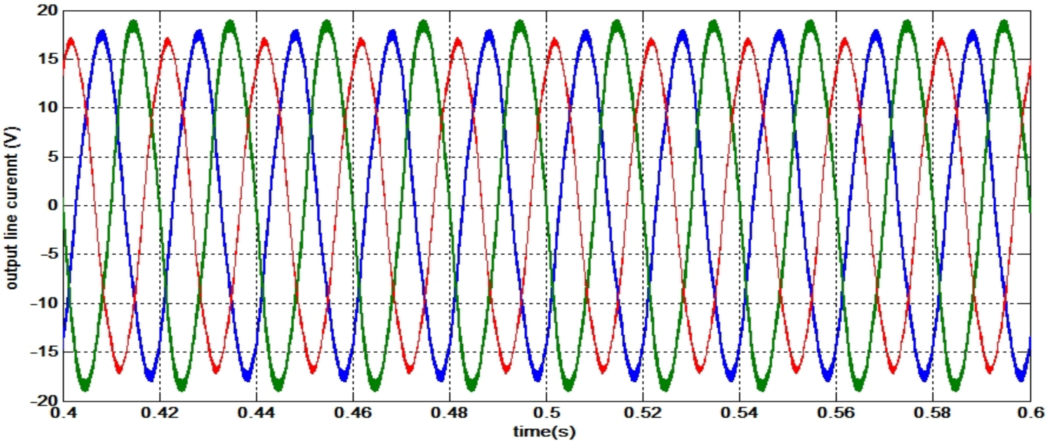


Fig. 13. load current of the Matrix Converter

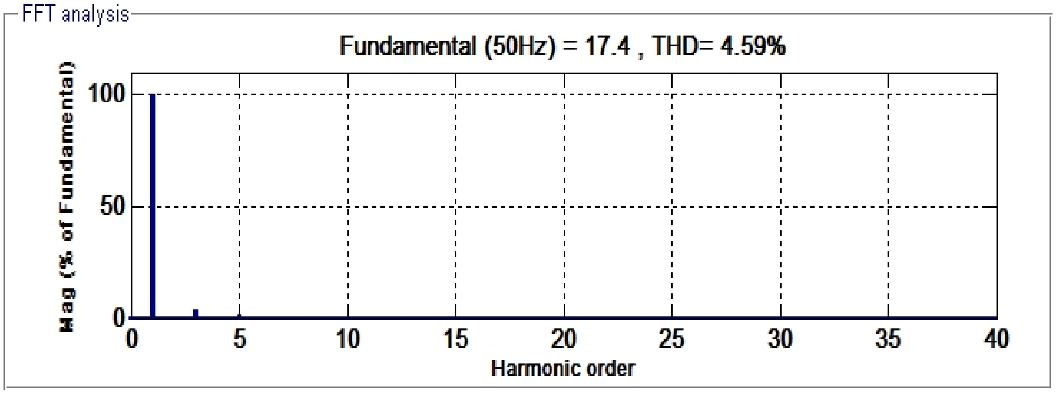


Fig. 14. harmonic spectrum of the load current

The figures below show, respectively: the rotor currents, stator currents, rotor speed, and electromagnetic torque of the asynchronous induction motor drives. Note that the using of matrix converter to fed induction motor gives good static and dynamic performances. As illustrated in Figs. 15, 16, the waveforms of stator and rotor currents are sinusoidal, the rotor speed stabilizes around 140 rad/s, and the steady state electromagnetic torque is about 30Nm. It can be seen that a such system based on matrix converter achieves good performs in driving induction motor using fuzzy controller and PWM technique, as is shown in Figs 17,18, the simulation results are in accord with the performance characteristic of induction motor.

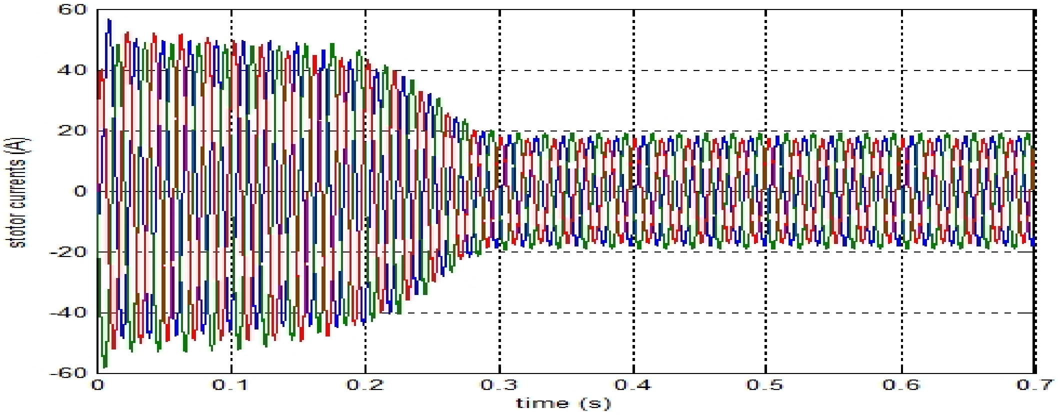


Fig. 15. Stator currents

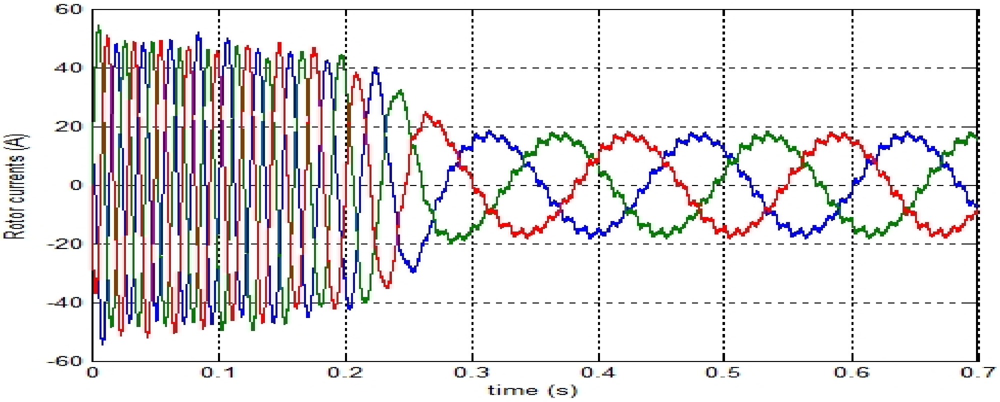


Fig. 16. Rotor currents

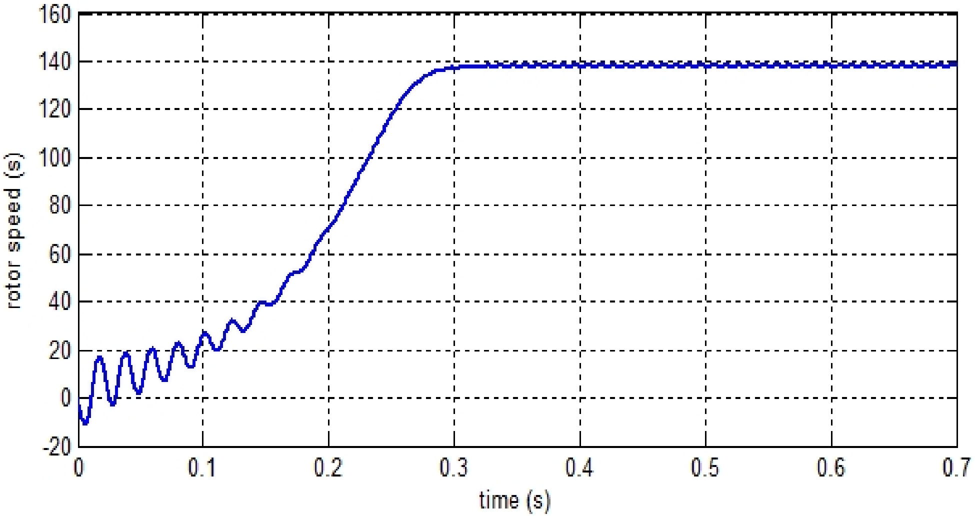


Fig. 17. Rotor Speed

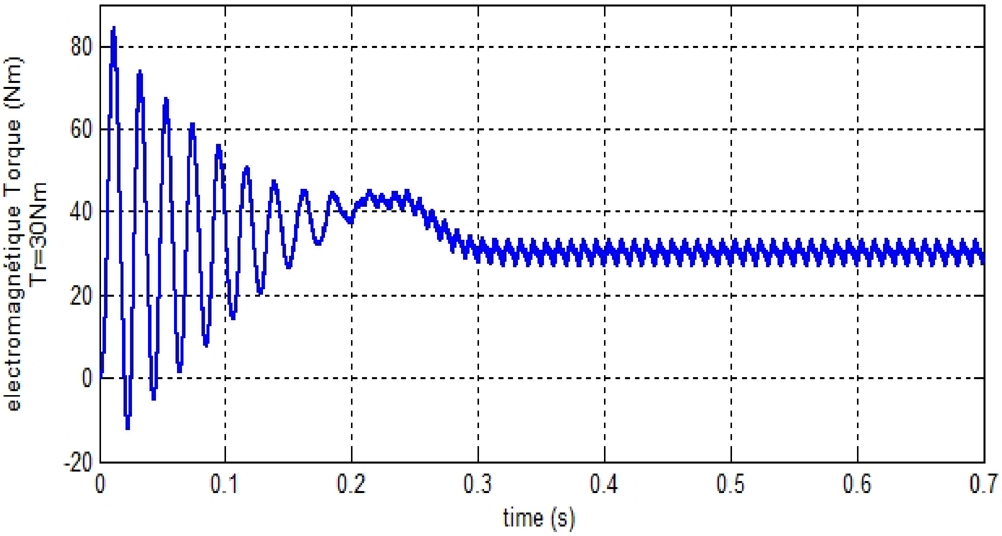


Fig. 18. Electromagnetic Torque

7. CONCLUSION

In this paper, three-phase to three-phase matrix converter using Venturini control algorithm has been analyzed, The simulations results presented show clearly that a matrix converter can be controlled by using a three intervals conventional sine-triangle three intervals PWM, combined with a fuzzy logic controller to drive an induction motor and obtain a good static and dynamic performances. In order to improve the performance of the previous modulation strategy in terms of maximum voltage transfer ratio, VENTURINI algorithm can be considered the best solution for the possibility to achieve the highest voltage transfer ratio. Finally, the proposed method has satisfactorily reduced harmonics in the output currents, the THD is very low that could lead to satisfy the IEEE519-1992 Standard.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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