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SVM Based on Fuzzy Logic Control to Enhance Output Performances of Matrix Converter

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Abstract—*this research paper studies the performances improvement of matrix converter using space vector modulation based on the fuzzy logic controller, our objective was to study and order a direct AC/AC converter with matrix topology, named 3\3 phase matrix converter. Phase's variable in amplitude and frequency. It is useful in applications for variable speed drive of induction machines. The 3\3 phase matrix converter controlled by vector modulation using fuzzy logic controller has all the advantages of the classic three-phase converter. To achieve this objective, we were first interested in 3/3 matrix converters in general and then we developed the model of this converter for its control. In the second part, we presented the control technique applied to the 3\3 phase matrix converter vector modulation based on fuzzy logic. In vector modulation using a space vector representation of the inputs currents and the outputs voltages are imposed using a limited set of switching vectors. This process makes it possible to modulate in a very precise way the input current as well as the voltage of the load by ensuring their sinusoidal waveforms. After having determined the control signals to be injected into the gates of the various switches constituting the 3\3 phase matrix converter, we carried out some simulation tests under the MATLAB/Simulink environment and this on different types of load (RL, induction machine,..) as well as for different frequency values at the output. One of the most important advantages provided by the CM is the fact of having an adjustable voltage transfer ratio between input and output voltages. The results obtained with this technique are satisfactory given the quality of the performances obtained for the different types of load. The simulation results showed this property.*

Keywords: *Matrix converter; Space vector modulation; Fuzzy logic; voltage transfer ratio, performances.*

Introduction

The matrix converter (MC) is a direct frequency converter. It generates three-phase voltages that vary in amplitude and frequency from the three-phase voltages at its input. A continuous intermediate circuit is not necessary. Its operating principle is based on a matrix topology connecting each input phase to each output phase by a bidirectional power switch. The power circuit of the CM is composed of nine (9) switches placed in a matrix hence the name of the matrix converter [1-3], as shown in the diagram in figure 1.

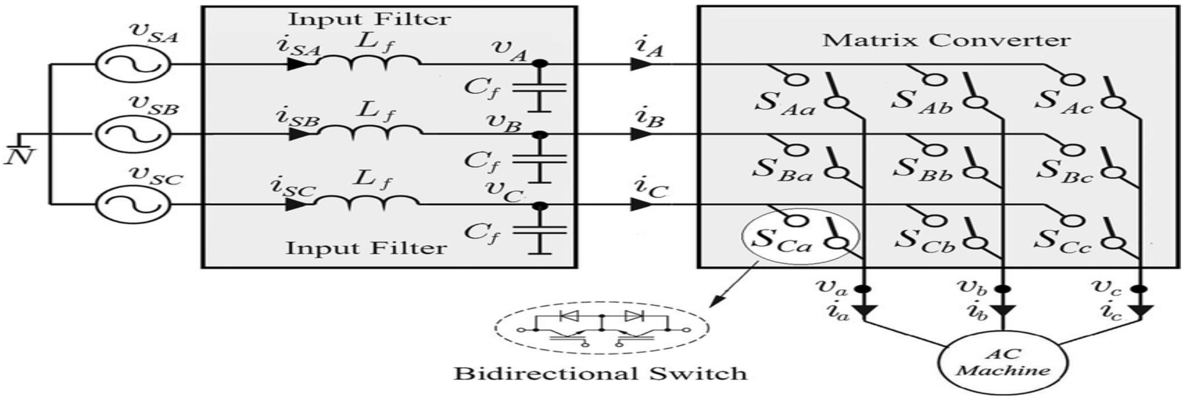

Figure 1 Power Circuit Configuration

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This type of converter has several advantages over conventional converters since it is a direct frequency converter, the continuous intermediate circuit characterizing conventional converters is not necessary. The passive energy storage elements that form the intermediate circuit are eliminated. It is thus possible to considerably reduce the construction effort and the volume of the converter. But, it has some disadvantages, such as the voltage transfer ratio between the magnitudes of the output and the input voltage vectors are limited at 0.866 in the majority of topologies and control strategies. [4-7].

The use of the input passive filter for MC system: to reduce the high harmonic components in the main power supply current and to improve the input voltage distortion for MC [8]. The problem of controlling the matrix converter is to find the pulse sequences so that the moving averages of the phase voltages at the output are sinusoidal modulated. The amplitude and frequency of the fundamental wave of the voltages must be variable. Vector modulation (SVM) of power electronic converters is very often used in variable speed drives. The objective of this control strategy is to synthesize the output voltages by input voltages and the input currents by output currents [9-13].

In this paper, the direct space vector modulation based on fuzzy logic control is presented. The fuzzy logic controlled voltage transfer ratio under different values, which performs close loop control of the output current to improve the output performance of the matrix converter. The proposed technique not only reduces the total harmonic distortion, but also ensures over-current protection control, a better static and dynamic response in induction machine drive. Simulation results are presented to prove the effectiveness of the proposed system.

Basic theory

The matrix converter can be switched to connect any output line to any input line provided that short circuit of the input and open circuit of the output are avoided [14-19]. The input voltage source and the input currents of the matrix converter are given by:

$$v_i(t)=\begin{cases} v_A(t)=v_{im}\cos(\omega_i t) \\ v_B(t)=v_{im}\cos(\omega_i t-\frac{2\pi}{3}) \\ v_C(t)=v_{im}\cos(\omega_i t-\frac{4\pi}{3}) \end{cases}$$

(1)

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

(2)

The matrix converter will be designed and controlled for desired output voltage and output currents, they are determined respectively by following equations:

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

(3)

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

(4)

The switching function of a switch S_{ij} in Figure 1 can be defined as

$$S_{ij}(t) = \begin{cases} 0 \quad if \;\; S_{ij} \; open \\ 1 \quad if \;\; S_{ij} \; closed \end{cases}$$

(5)

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

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

$$m_{ij}(t) = \frac{1}{T_c}\int_0^T S_{ij}(t)dt \quad with \quad 0 \le m_{ij}(t) \le 1$$

(6)

$T_c = 1/f_c$ is the period switching.

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

(7)

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

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

(8)

The conversion matrix of MC connects as follows:

$$v_j(t) = M(t) \cdot v_i(t)$$

(9)

$$i_i(t) = M^T(t) \cdot i_j(t)$$

(10)

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

Direct Space Vector Modulation Algorithm

Space vector pulse width modulation is applied to output voltage and input current control (see figures 2 and 3). This method is an advantage because of increased flexibility in the choice of switching vector for both input current and output voltage control. For convenience, the output voltage and the currents space vectors are defined as follows:

$$\begin{cases} \vec{v}_0 = \frac{2}{3}(v_a + a \cdot v_b + a^2 \cdot v_c) = |V_0| \cdot e^{j\theta_v} \\ \vec{i}_i = \frac{2}{3}(i_A + a \cdot i_B + a^2 \cdot i_C) = |i_i| \cdot e^{j\theta_i} \end{cases}$$

(11)

$$a = e^{j\frac{2\pi}{3}}$$

For the three phases matrix converter it has been shown that there are 27 possible switching states, but 21 only can be usefully employed in the SVM algorithm and can be represented as shown in Table .1. The first 18 switching active configurations having fixed directions determine an output voltage vector and an input current vector. The last 3 switching zero configurations determine zero input current and output voltage vectors [20-25].

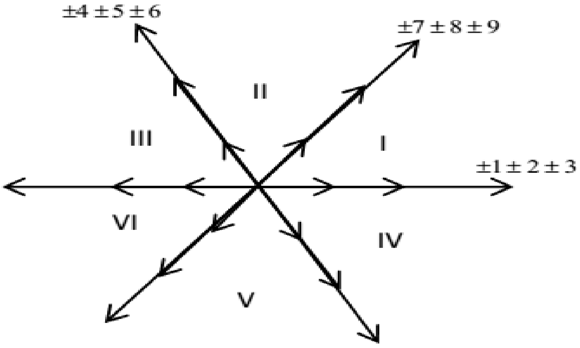


Figure 2 Output voltage space vector hexagons

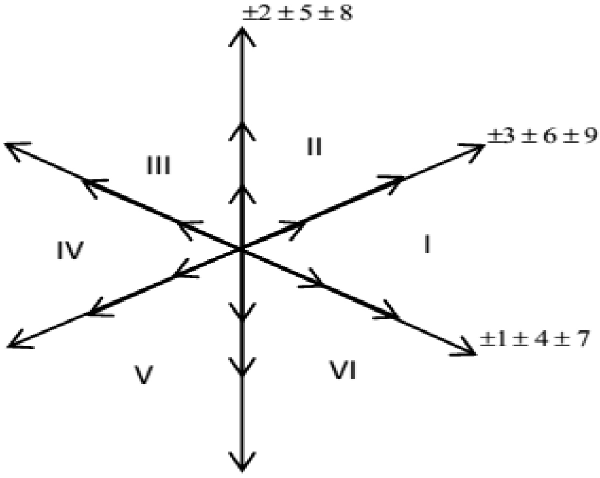


Figure 3 Input current space vector hexagons

States	Switches on	$\vec{v}_0$		$\vec{i}_i$	
		$\lvert V_0 \rvert$	$\angle\theta_v$	$\lvert V_0 \rvert$	$\angle\theta_i$
ABB +1	S_{Aa},S_{Bb},S_{Cb}	(2/3).V_{ab} .	0	(2/√3).i_A	$-\frac{\pi}{6}$

BAA -1	S_{Ab},S_{Ba},S_{Ca}	$-(2/3).V_{ab}$.	0	$-(2/\sqrt{3}).i_A$	$-\frac{\pi}{6}$
BCC +2	S_{Ab},S_{Bc},S_{Cc}	$(2/3).V_{bc}$.	0	$(2/\sqrt{3}).i_A$	$\frac{\pi}{2}$
CBB -2	S_{Ac},S_{Bb},S_{Cb}	$-(2/3)V_{bc}$	0	$-(2/\sqrt{3}).i_A$	$\frac{\pi}{2}$
CAA +3	S_{Ac},S_{Ba},S_{Ca}	$(2/3)V_{ca}$	0	$(2/\sqrt{3}).i_A$	$\frac{7\pi}{6}$
ACC -3	S_{Aa},S_{Bc},S_{Cc}	$-(2/3)V_{ca}$	0	$-(2/\sqrt{3}).i_A$	$\frac{7\pi}{6}$
BAB +4	S_{Ab},S_{Ba},S_{Cb}	$(2/3)V_{ab}$	$\frac{2\pi}{3}$	$(2/\sqrt{3}).i_B$	$-\frac{\pi}{6}$
ABA -4	S_{Aa},S_{Bb},S_{Ca}	$-(2/3)V_{ab}$	$\frac{2\pi}{3}$	$-(2/\sqrt{3}).i_B$	$-\frac{\pi}{6}$
CBC +5	S_{Ac},S_{Bb},S_{Cc}	$(2/3)V_{bc}$	$\frac{2\pi}{3}$	$(2/\sqrt{3}).i_B$	$\frac{\pi}{2}$
BCB -5	S_{Ab},S_{Bc},S_{Cb}	$-(2/3)V_{bc.}$	$\frac{2\pi}{3}$	$-(2/\sqrt{3}).i_B$	$\frac{\pi}{2}$
ACA +6	S_{Aa},S_{Bc},S_{Ca}	$(2/3)V_{ca}$	$\frac{2\pi}{3}$	$(2/\sqrt{3}).i_B$	$\frac{7\pi}{6}$
CAC -6	S_{Ac},S_{Ba},S_{Cc}	$-(2/3)V_{ca}.e^{j2\pi/3}$	$\frac{2\pi}{3}$	$-(2/\sqrt{3}).i_B$	$\frac{7\pi}{6}$
BBA +7	S_{Ab},S_{Bb},S_{Ca}	$(2/3)V_{ab}$	$\frac{4\pi}{3}$	$(2/\sqrt{3}).i_C$	$-\frac{\pi}{6}$
AAB -7	S_{Aa},S_{Ba},S_{Cb}	$-(2/3)V_{ab}$	$\frac{4\pi}{3}$	$-(2/\sqrt{3}).i_C$	$-\frac{\pi}{6}$
CCB +8	S_{Ac},S_{Bc},S_{Cb}	$(2/3)V_{bc}$	$\frac{4\pi}{3}$	$(2/\sqrt{3}).i_C$	$\frac{\pi}{2}$
BBC -8	S_{Ab},S_{Bb},S_{Cc}	$-(2/3)V_{bc.}$	$\frac{4\pi}{3}$	$-(2/\sqrt{3}).i_C$	$\frac{\pi}{2}$
AAC +9	S_{Aa},S_{Ba},S_{Cc}	$(2/3)V_{ca}$. $e^{j4\pi/3}$	$\frac{4\pi}{3}$	$(2/\sqrt{3}).i_C$	$\frac{7\pi}{6}$
CCA -9	S_{Ac},S_{Bc},S_{Ca}	$-(2/3)V_{ca.}$ $e^{j4\pi/3}$	$\frac{4\pi}{3}$	$-(2/\sqrt{3}).i_C$	$\frac{7\pi}{6}$
AAA 0	S_{Aa},S_{Ab},S_{Ac}	0	-	0	-
BBB 0	S_{Ba},S_{Bb},S_{Bc}	0	-	0	-
CCC 0	S_{Ca},S_{Cb},S_{Cc}	0	-	0	-

Table 1 Possible switching configuration available in matrix converters

For duty cycle determination the following relationships:

$$\begin{cases} \delta_I = \frac{2}{\sqrt{3}} q \frac{\cos(\theta_v - \pi/3)\cos(\theta_i - \pi/3)}{\cos\varphi_i} \\ \delta_{II} = \frac{2}{\sqrt{3}} q \frac{\cos(\theta_v - \pi/3)\cos(\theta_i + \pi/3)}{\cos\varphi_i} \\ \delta_{III} = \frac{2}{\sqrt{3}} q \frac{\cos(\theta_v + \pi/3)\cos(\theta_i - \pi/3)}{\cos\varphi_i} \\ \delta_{IV} = \frac{2}{\sqrt{3}} q \frac{\cos(\theta_v + \pi/3)\cos(\theta_i + \pi/3)}{\cos\varphi_i} \end{cases}$$

(12)

θ_v and θ_i respect are the output voltage and input current phase angle measured with respect to the bisecting line of the corresponding sector,

Where: $-\frac{\pi}{6} < \theta_v < +\frac{\pi}{6}$ and $-\frac{\pi}{6} < \theta_i < +\frac{\pi}{6}$

q is the voltage ratio

Taking the sum of these duty cycles then gives

$$|\delta_I| + |\delta_{II}| + |\delta_{III}| + |\delta_{IV}| \leq 1$$

(13)

The zero configurations are applied to complete the sampling period.

$$\delta_0 = 1 - \delta_I + \delta_{II} + \delta_{III} + \delta_{IV}$$

(14)

Four modulation times can be defined [6, 16-22]:

$$\delta_I = \frac{t_1}{T_s},\ \delta_{II} = \frac{t_2}{T_s},\ \delta_{III} = \frac{t_3}{T_s}, and\ \delta_{VI} = \frac{t_4}{T_s}$$

(15)

Where:

$$t_1 + t_2 + t_3 + t_4 = T_s$$

(16)

Fuzzy logic controlled magnitude output current

The voltage transfer ratio can be enhanced at 86% using fuzzy logic controller, is proposed which performs close loop control of the output current to improve the output performance of the matrix converter [26-30]. The two inputs of (FLC) are the error of the amplitude value of the output current and its variation. The controller output corresponds to the command, named voltage transfer ratio. These three quantities are normalized as follows:

The amplitude output current is given by:

$$|i_{abc}| = \sqrt{\frac{2}{3}(i_a^2 + i_b^2 + i_c^2)}$$

(17)

The error and its variation are given by the following expression:

$$e(k) = i_{abc-ref} - i_{abc}$$

(18)

$$\Delta e(k) = (e(k) - e(k-1))$$

(19)

A saturation block has been supplemented, due to the voltage transfer ratio *q(k)* limited between $0 \le q(K) \le 0.86$. It's expressed according to following equation:

$$q(k) = q(k-1) + \Delta q(k)$$

(20)

Block diagram of the FLC based feedback system is clearly given in figure 4.

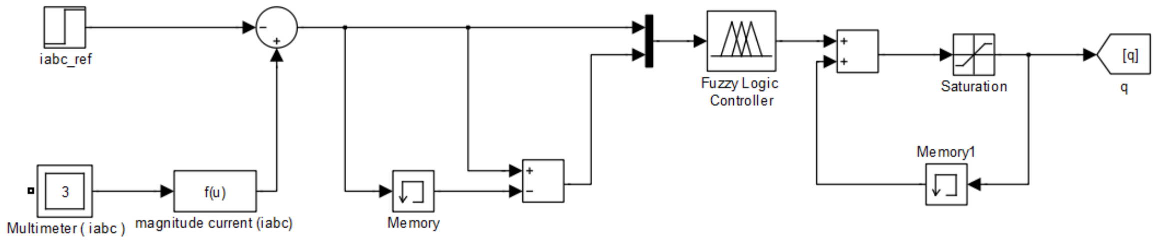


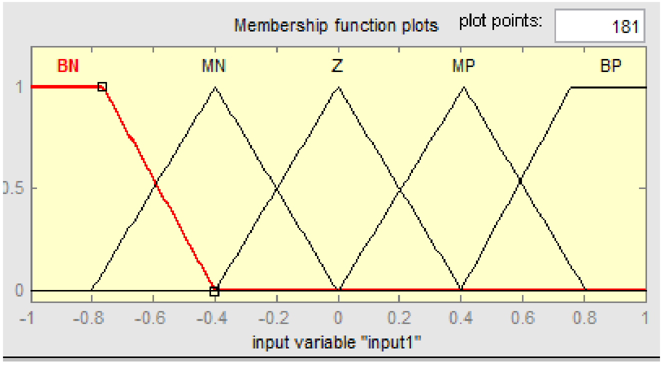
Figure 4 Block diagram of fuzzy logic controller

The input and output variables are represented respectively by five linguistic variables , namely, BN (Big Negative), MN (Medium Negative), Z (Zero), MP (Medium Postive), BP (Big Positive). The inference method used is a Mamdani algorithm based on Max-Min decision.

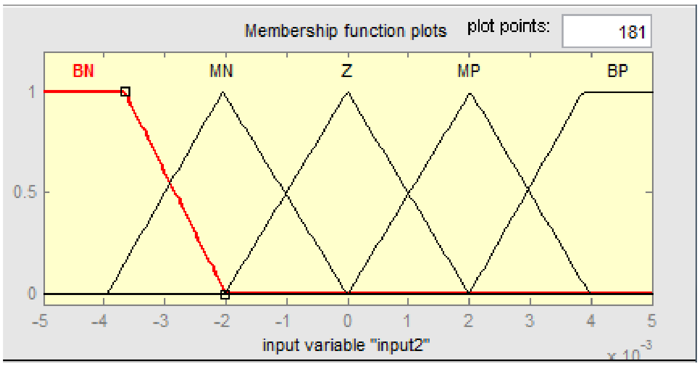
e **Δe**	**BN**	**MN**	**Z**	**MP**	**BP**
BN	BP	MP	MP	SM	MN
MN	PB	MP	SP	SM	MN
Z	MP	MP	Z	MN	BN
MN	MP	SP	SM	MN	BN
BN	MP	SP	MN	MN	BN

Table 2 Fuzzy rules

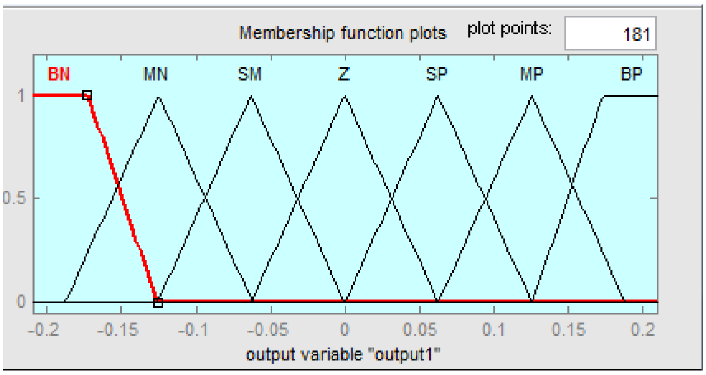
Triangular input and output membership function are selected from the defined range as shown in Figure. 5.



a) Membership functions of input variables (error)



b) Membership functions of input variables (change of error)



c) Membership functions of output variables (control)

Figure 5 Membership functions of input and output variables

Simulation results

To improve the output performance of the matrix converter using fuzzy logic space vector modulation, we have realized some simulations tests. In the first, a simulation was performed by assuming sinusoidal supply voltages fed RL load. In the second simulation, the input voltages were perturbed by the injection of the 5th and 7th harmonics. In the next simulation, the matrix converter feeding unbalanced RL load. Finally a last simulation was performed by adding a induction motor drive. The simulation parameters are shown in Table. 3.

System parameters	
Load (RL)	R=10Ω, L=30mH
Induction motor drive	Pn = 4kw, n = 1430tr/min
Input voltage source	Vrms ph-ph = 600V,
Input and output frequency	fi=fo = 50 Hz,
Input filter parameters	R = 0.1 Ω, L_f = 0.5mH; C_f = 35μF
Frequency cycle	fc = 10kHz.

Table 3 System parameters

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Matrix Converter connected to a balanced RL load

The Figures 6, 7 and 8 shows successfully the input voltage, output simple voltage and output line voltage of the matrix converter.

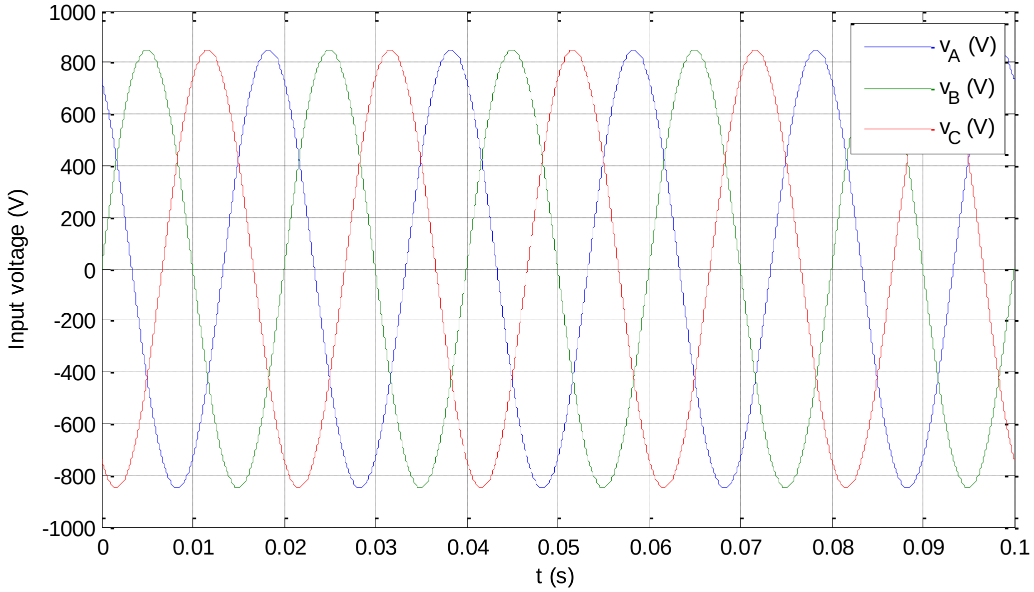

Figure 6 Input voltage

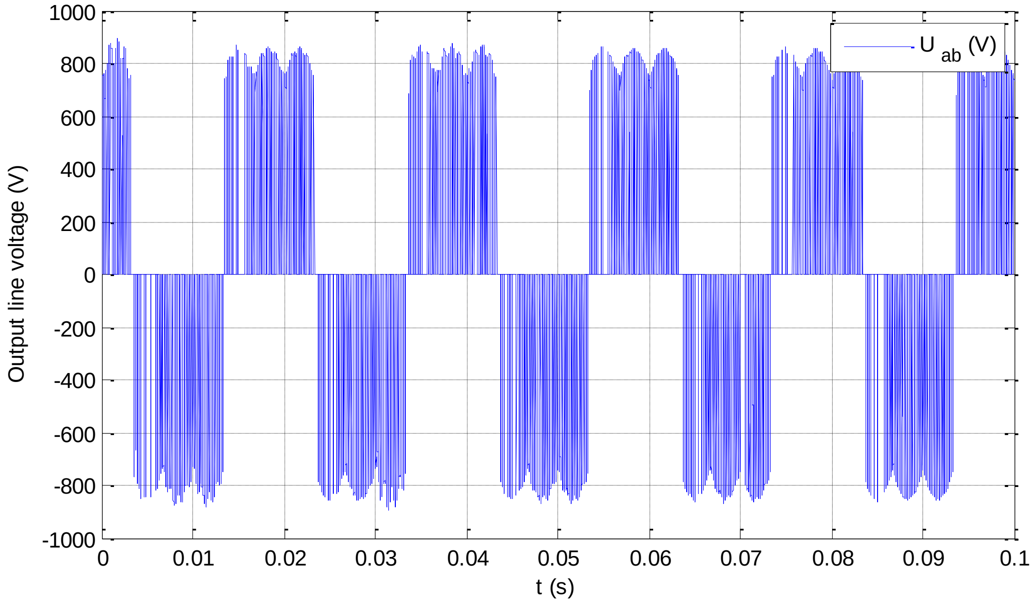

Figure 7 Output line voltage

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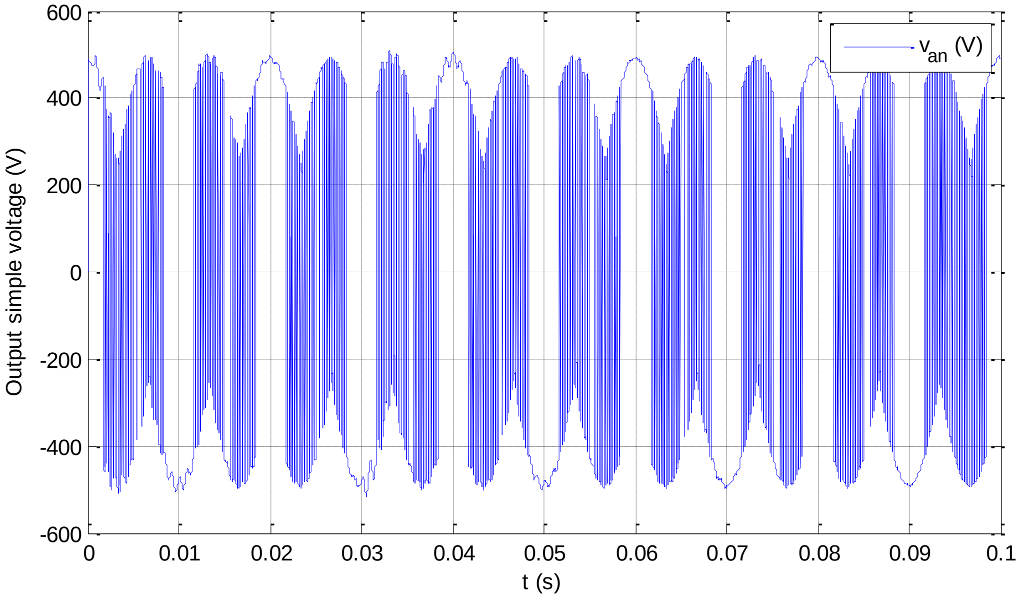

Figure 8 Output simple voltage

Figure 9 shows the output current when a change in the reference current from 8A to 10A occurs at 0.03s. Figure 10 proves the robustness of the fuzzy logic control is tested against the magnitude output current under step change. We can see that the magnitude output current value follows up its reference. In the next time in t= 0.07, we have changed the reference value from 10A to 8A, we can see that the magnitude output current follow up perfectly the reference.

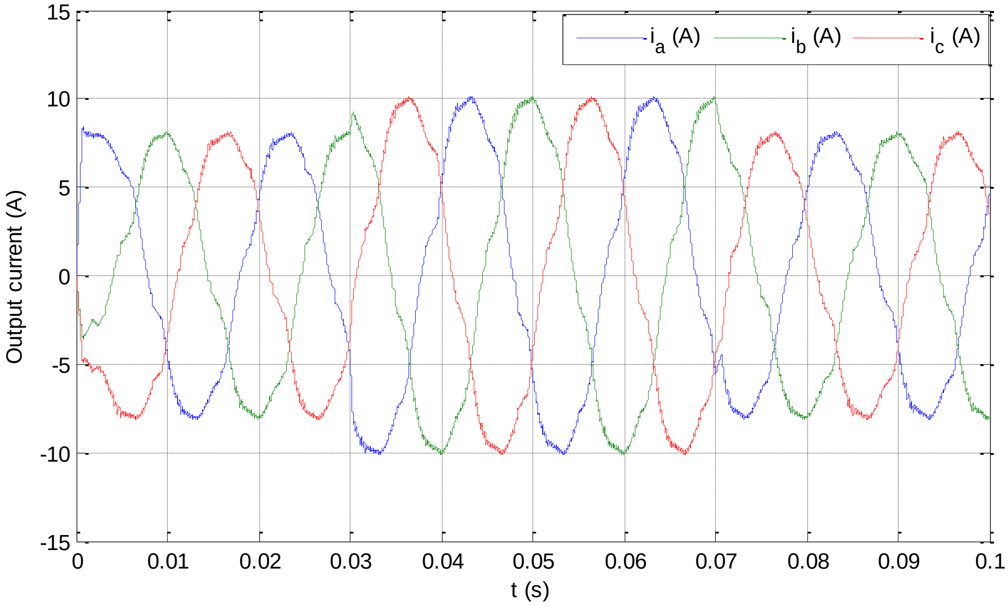

Figure 9 Output currents of load (RL)

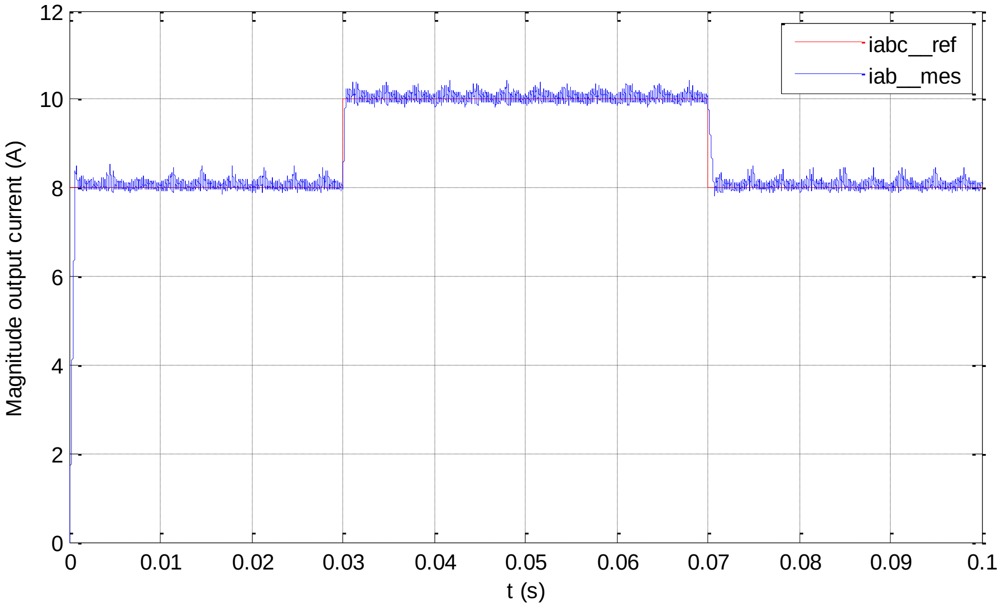

Figure 10 Magnitude output current and its reference

Matrix Converter connected to a balanced load (RL) under distorted supply voltage

For this test, the input voltages source are disturbed by adding the 5th and 7th harmonics. Similarly to the previous simulation, the figures 11, 12 and 13 show successfully the waveforms of disturbed input voltage, output simple voltage and output line voltage of the matrix converter. Simulation result confirms that voltage control loop is stable. The evolution of the output currents and the magnitude output current with the reference are presented in figures 14 and 15 respectively. In this case, the simulation results show clearly the effectiveness of the proposed fuzzy logic controller witch forces the magnitude output current to follow perfectly its reference, see figure 12. It was also verified that both output currents waveforms of matrix converter are nearly sinusoidal (see figure 12).

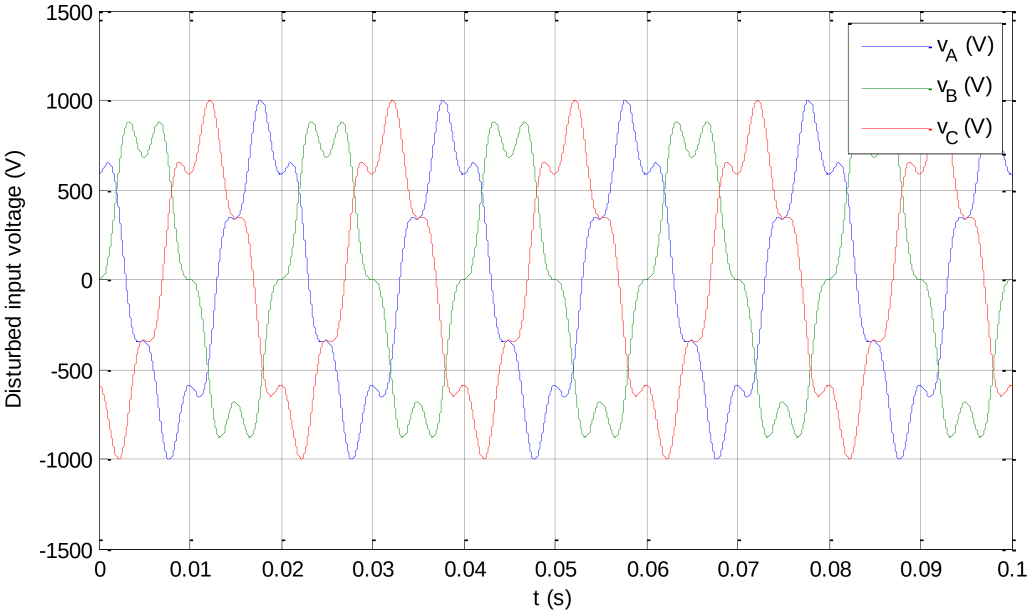

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Figure 11 disturbed input voltage

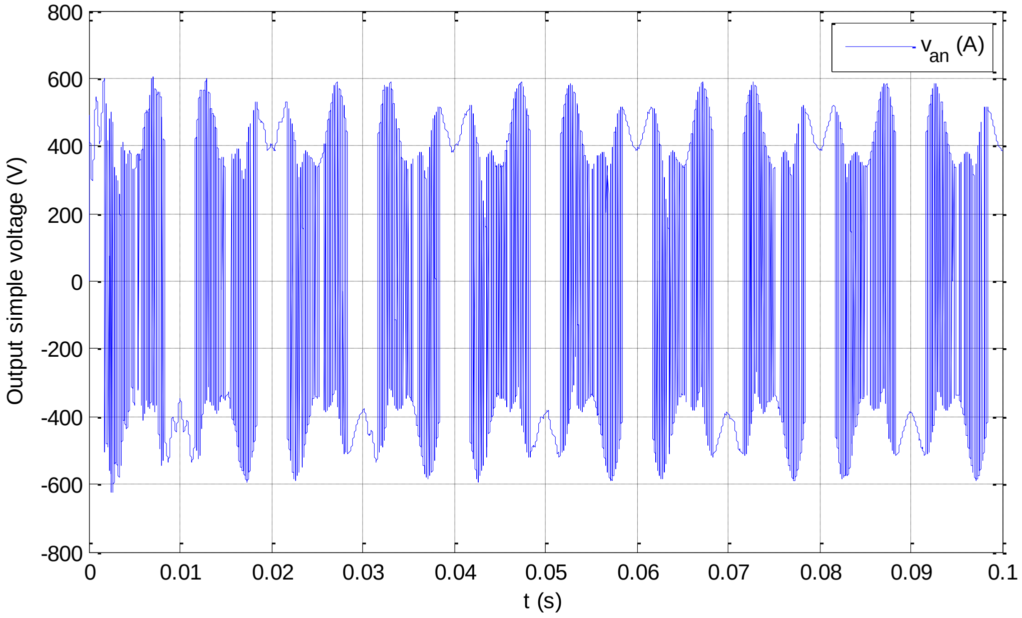

Figure 12 Output simple voltage under disturbed input voltage

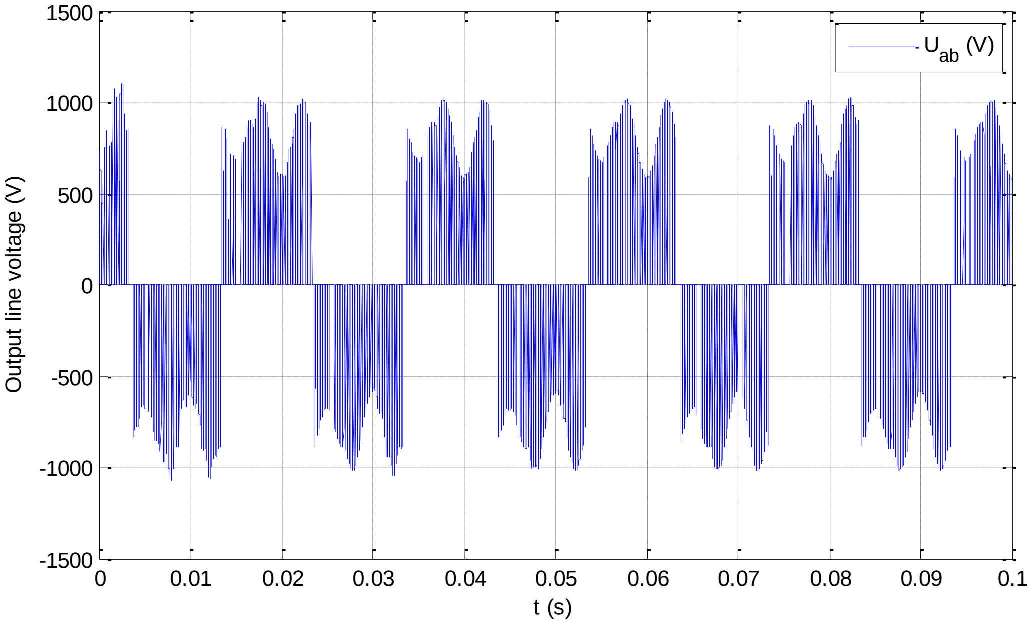

Figure 13 Output line voltages under disturbed input voltage

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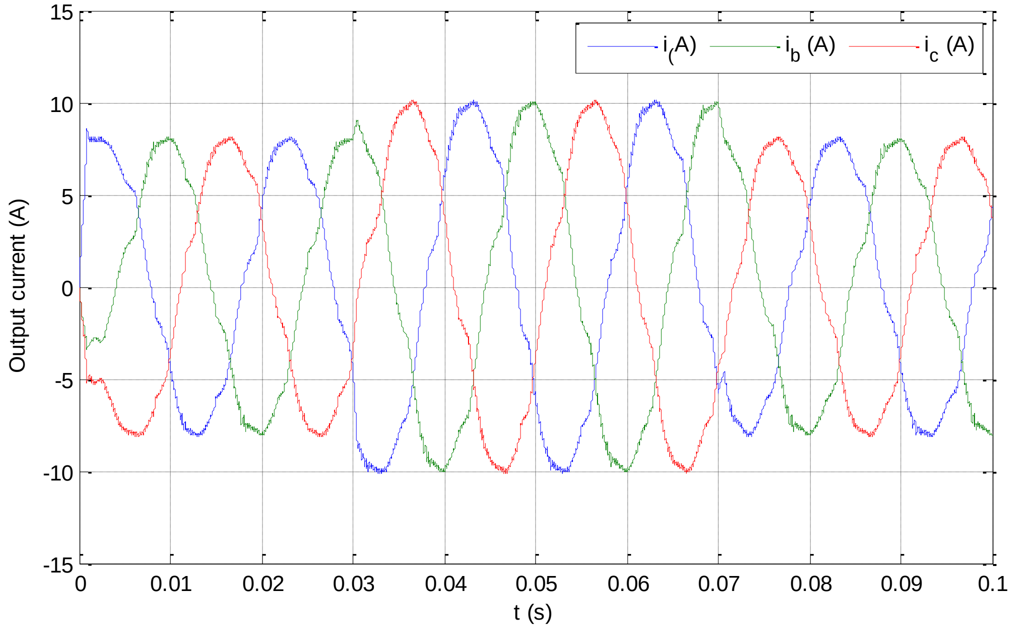

Figure 14 Output currents under disturbed input voltage

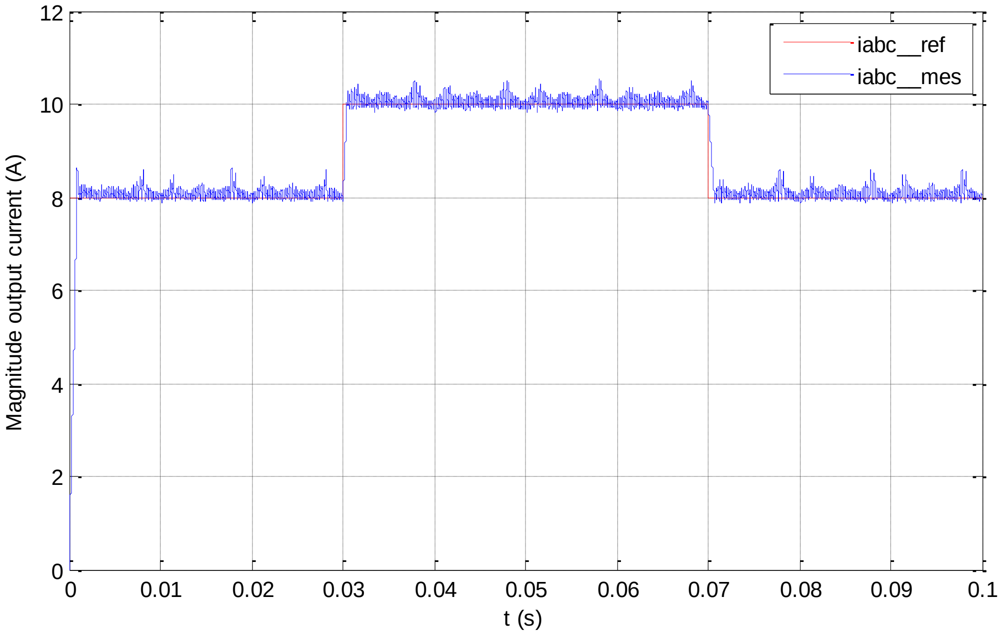

Figure 15 Magnitude output current and its reference under disturbed Input voltage

Matrix Converter connected to a unbalanced load

For this case, the matrix converter feeding unbalanced RL load, the figures 16, 17, 18 and 19 shows successfully the waveforms of output simple voltage, output line current, output current and magnitude output current and its reference. Simulation result confirms that voltage control loop rested stable. In this case, the simulation results show clearly the effectiveness of the proposed fuzzy logic controller witch forces the magnitude output current to follow up perfectly its reference, see figures 18 and 19 the output currents are nearly sinusoidal.

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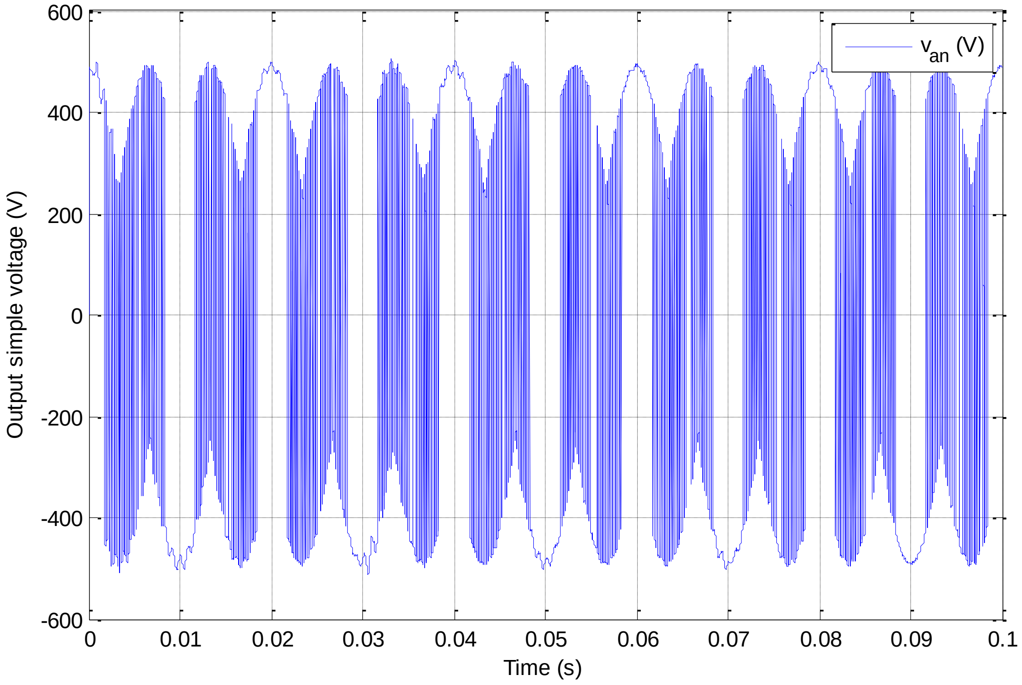

Figure 16 Output simple voltage under unbalanced load

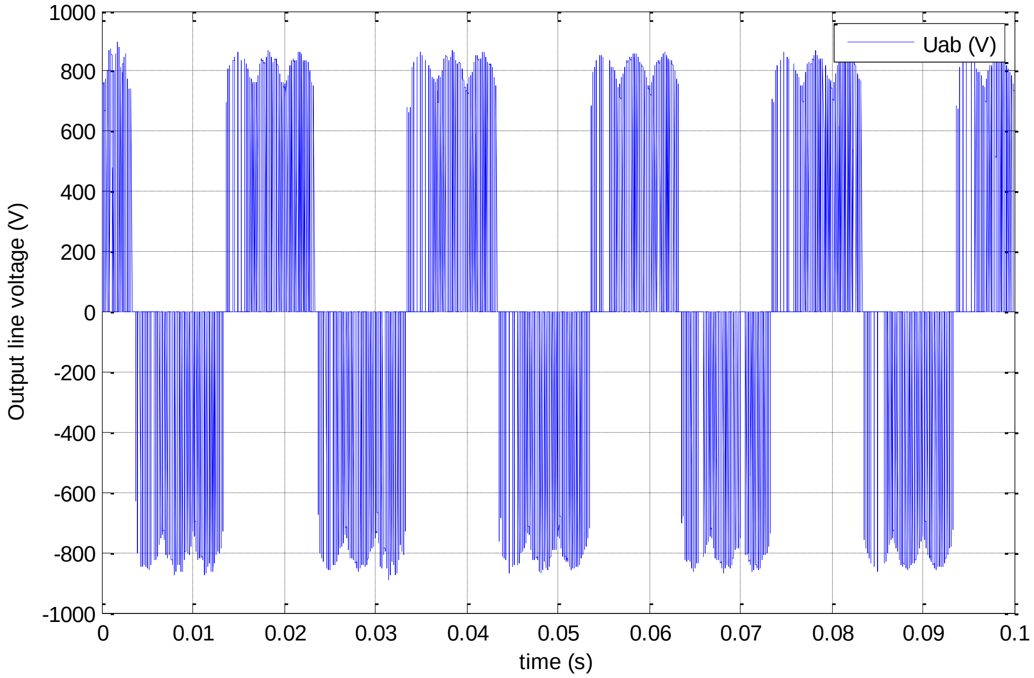

Figure 17 Output line voltages under unbalanced load

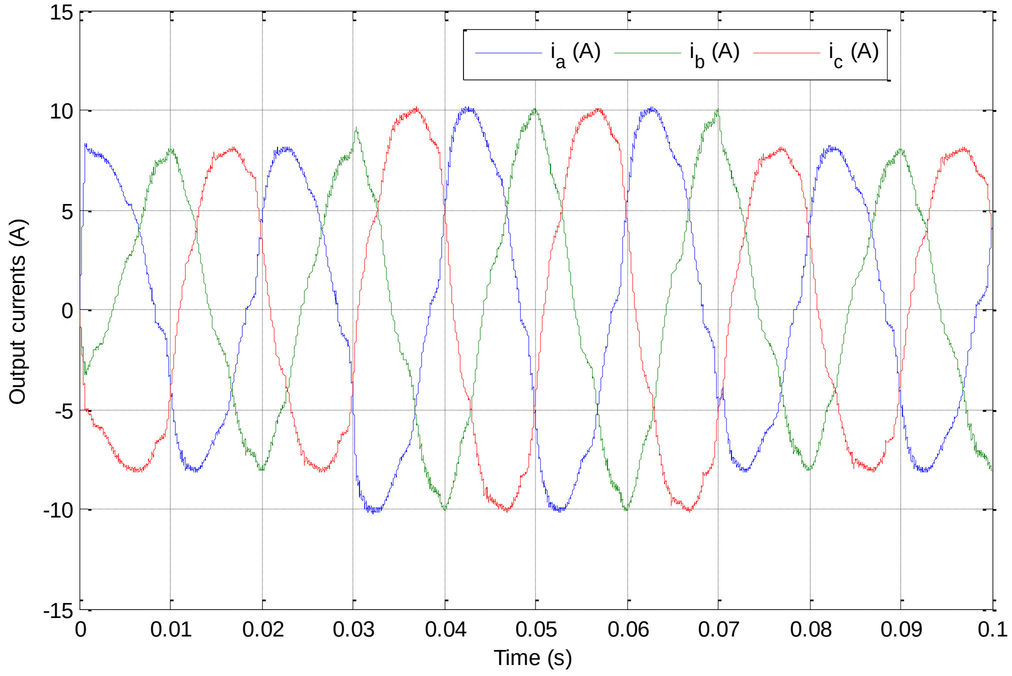

Figure 18 Output currents under unbalanced load

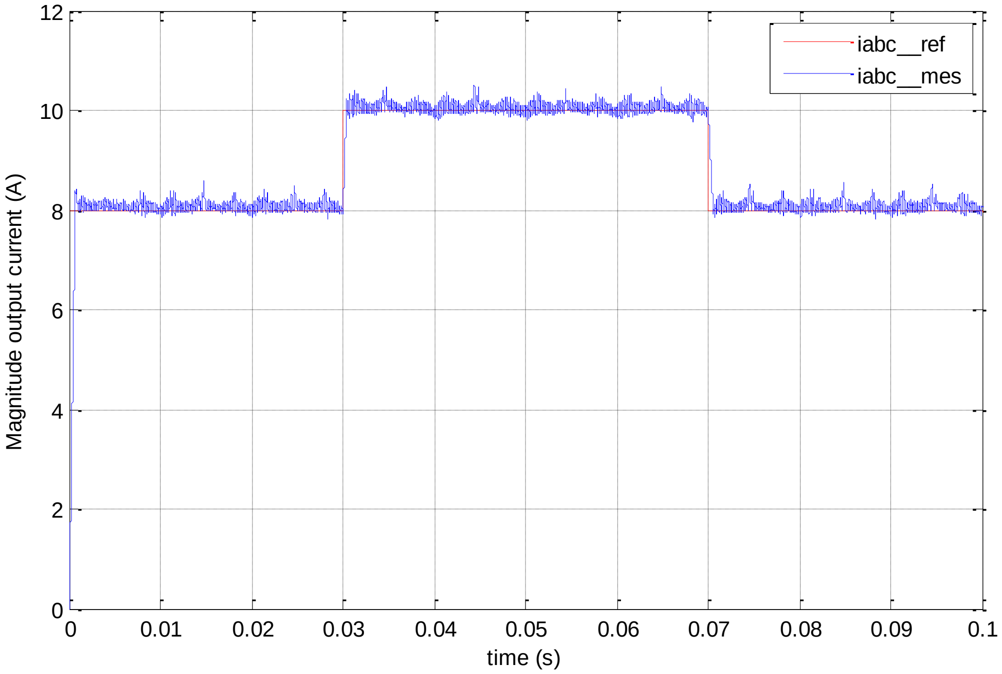

Figure 19 Magnitude output current and its reference under unbalanced load

Matrix Converter connected to a induction motor drive under distorted input voltage

Note, the electrical motor no-load start up, at time 0.5s, the load increases to 10 Nm. Simulation results are in accord with the performance characteristic, which proves the accuracy of the induction motor drive and provides a theory basis for the actual design of the control system. The best performance of induction motor show in figures below, respectively: the rotor currents, stator currents, rotor speed, and electromagnetic torque. We

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can see that the simulation results indicate the proposed fuzzy controller has a better speed response, the electromagnetic torque at 0.5 from 1s coincide its desired shaft mechanical torque (Tm=10Nm), where the output current value follows up the reference. All simulation results we regarded that the proposed fuzzy logic controller forces the magnitude output current space vector to be constant so that the output currents are perfectly sinusoidal.

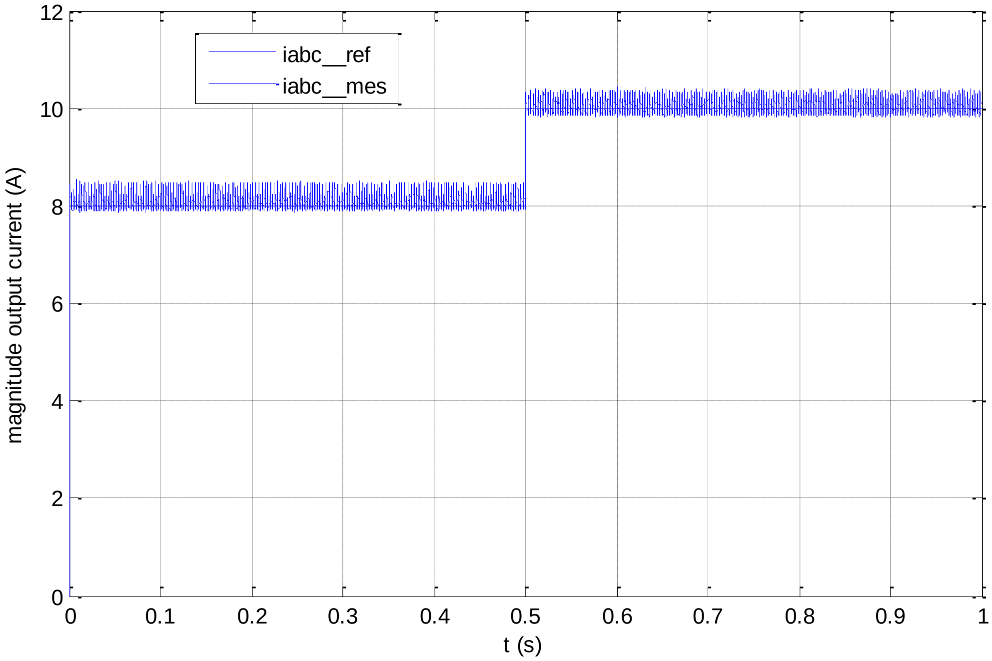

Figure 20 Magnitude output current and its reference

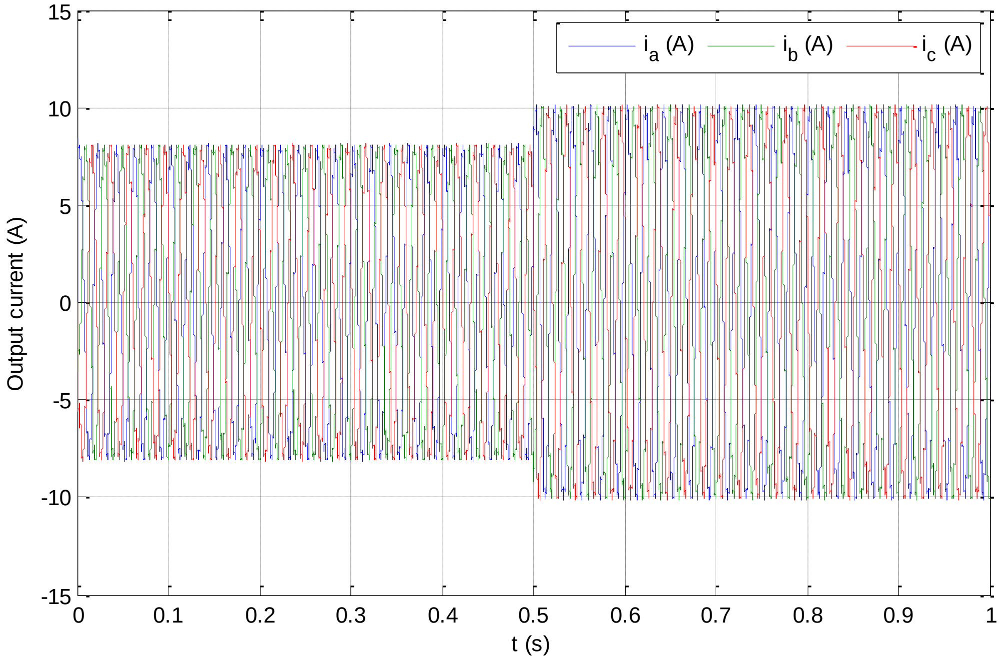

Figure 21 Output currents

https://doi.org/10.37896/pd92.5/92510

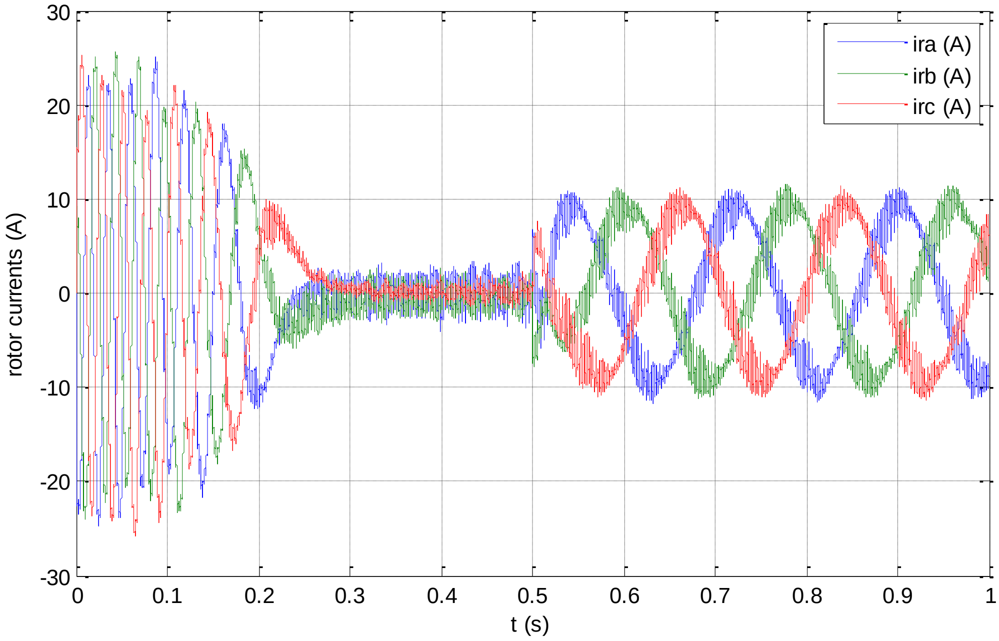

Figure 22 Rotor currents

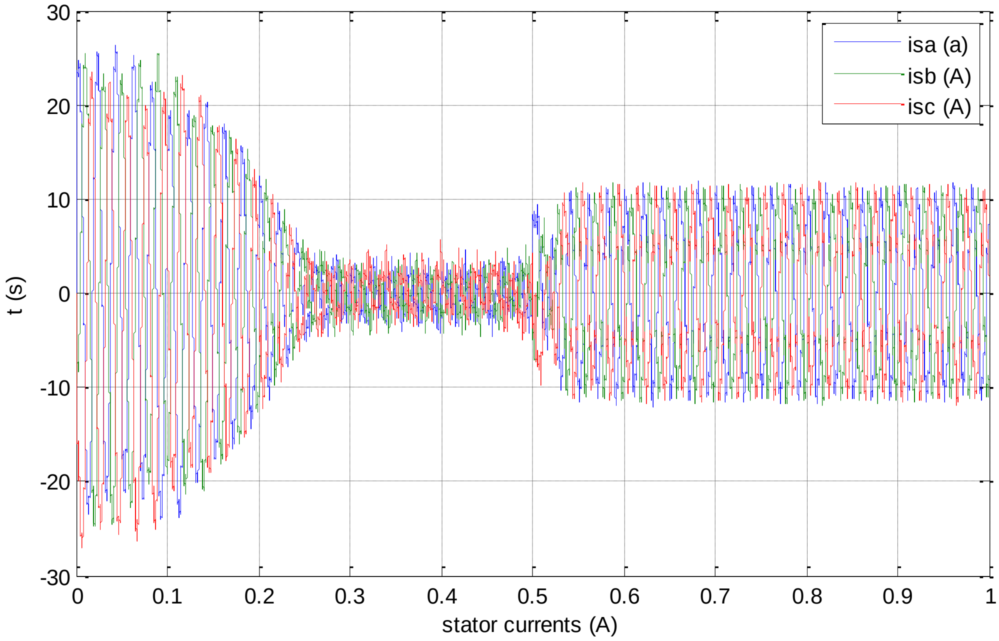

Figure 23 Stotor currents

https://doi.org/10.37896/pd92.5/92510

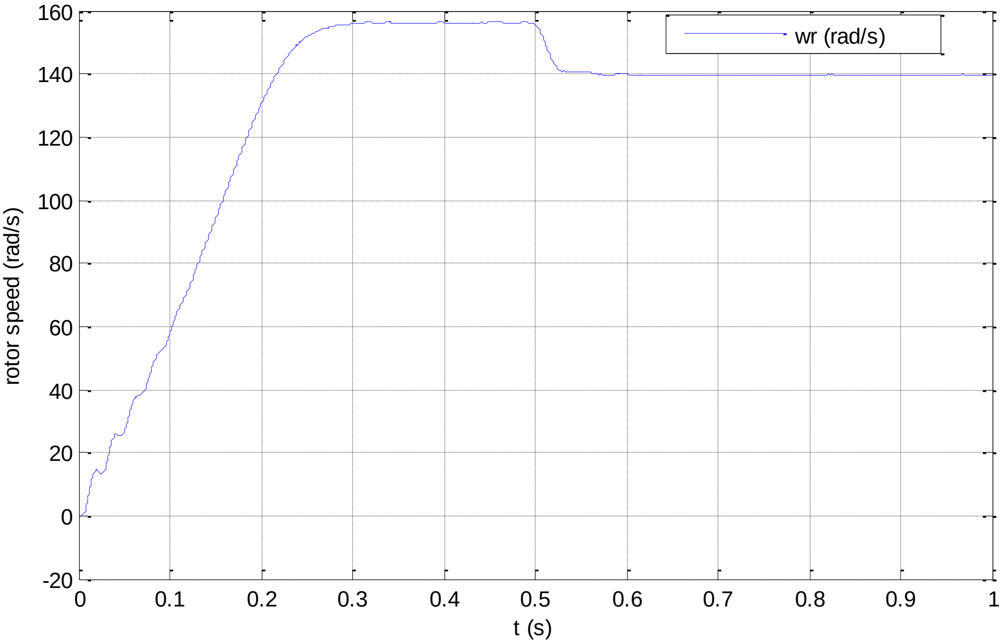

Figure 24 Induction motor speed response when load is increased

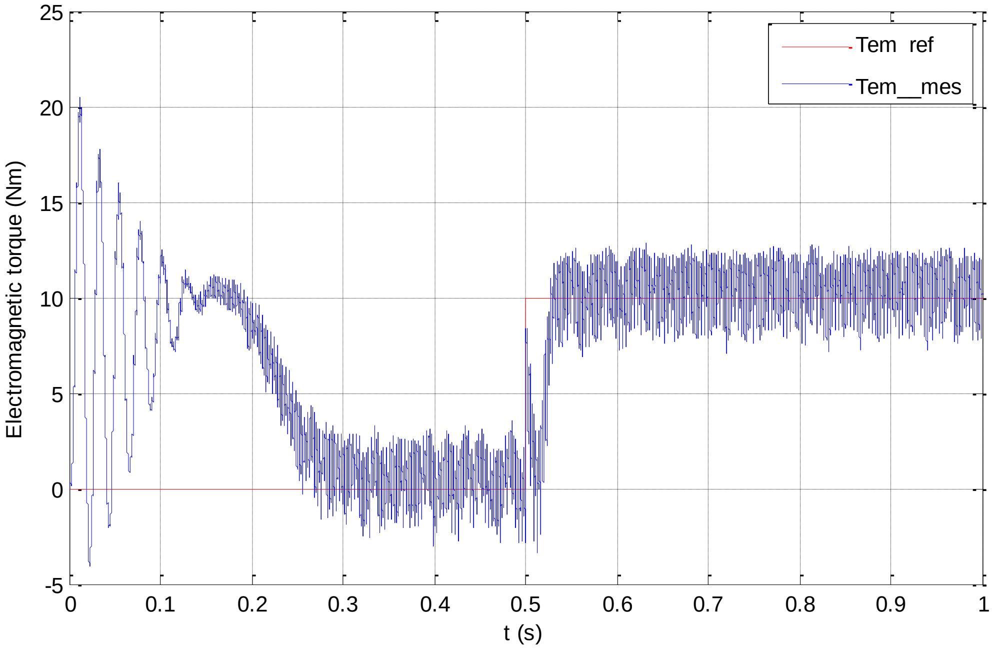

Figure 25 Electromagnetic torque with shaft mechanical torque: Tm=10N.m)

Conclusion

In this work, the matrix converter 3/3 powered by different types of load is studied, the mathematical model is given, based on the fuzzy logic controller, a voltage transfer ratio has been proposed to control the input and output currents of the matrix converter. The overall objective of the proposed system is to design a fuzzy logic controller capable of generating a sinusoidal matrix converter output current regardless of the degree of disturbance of the input voltages. It appears from the results of the simulation that the fuzzy logic control based on the SVM technique can achieve all the desired output performance, the setpoint tracking dynamics is satisfactory. The simulation results obtained show the good performance of this type of converter in terms of the quality of the electrical energy.

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