Comparative Performances Study of a Variable Speed Electrical Drive

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Abstract- This paper presents the comparative performances of a variable speed electrical drive. We considered two cases: First, the induction motor is fed by a matrix converter and after it is fed by three-phase voltage inverter. The control strategies of each configuration is presented and simulation results are analyzed and interpreted. The simulation results are carried out using the package Matlab/Simulink.

Keywords- Matrix converter, voltage inverter, induction motor, control, simulation.

1. Introduction

Generally, the AC induction motors are the most used in many industrial applications. The converters are required for variable speed electrical drives to ensure a variable amplitude and frequency [1]. In this paper, we study the performances of variable speed drive when the induction motor is supplied by a matrix converter (MC) or by three-phase voltage inverter [2].

However, induction motors (IM) can only run at their speed when they are connected to the power supply. This is the reason why variable frequency drives are needed to vary the rotor speed of an IM. In addition, The AC to AC matrix converter is the subject of lots of research for its simple topology of greater power density and easy control of the input power factor [3,4]. These features make the matrix converter a suitable alternative to traditional voltage source inverter in induction motor drive.

In the following sections, we present the model and the control strategy for the two structures studied. Least Mean Square Error (LMSE) technique strategy is used to control the matrix converter and pulse with modulation (PWM) strategy for three phase voltage inverter [5].Under this consideration, the performance of these two structures are evaluated through simulations.

2. Modelling and Control of Matrix Converter

The considered topology of matrix converter is composed from a matrix with nine bidirectional switches using IGBTs [6] as shown in Fig 1.

The three inputs phases of the network are connected to three output phase matrix converter at any time [3].

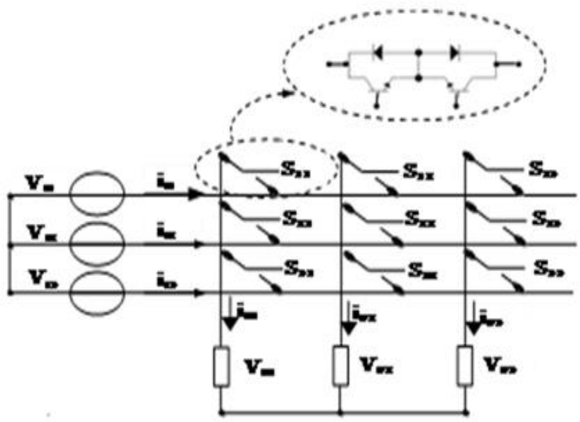

Fig. 1. Matrix converter schema

The matrix converter allows three possible configurations (see Table 1).

Table 1. Possible configurations

Configurations	Electrical quantities
E_1	$V_{01}=V_{i1}$
E_2	$V_{02}=V_{i2}$
E_3	$V_{03}=V_{i3}$

Assuming that the switches (S_{ij}) are ideal, we can consider a connection function f_{ij} defined by:

$$\begin{cases} f_{ij}(t)=1 \; if \;\; switch \; S_{ij} \;\; is \; close \\ f_{ij}(t)=0 \; if \;\; switch \; S_{ij} \;\; is \; open \end{cases} \tag{1}$$

With,

i=1,2,3 and *j=1, 2,3*.

The connection matrix [F] is given by:

$$[F]=\begin{bmatrix} f_{11} & f_{12} & f_{13} \\ f_{21} & f_{22} & f_{23} \\ f_{31} & f_{32} & f_{33} \end{bmatrix} \tag{2}$$

The conversion applied to the voltage source can be expressed as:

$$\left[U_i\right]=\left[F\right].\left[U_0\right] \tag{3}$$

And, the input phase currents are related to the output phase by:

$$\left[i_i\right]=\left[F\right]^T.\left[i_0\right] \tag{4}$$

With:

$\left[i_0\right]=\left[i_{0A} \quad i_{0B} \quad i_{0C}\right]^T$: vector currents switched;

$\left[i_i\right]=\left[i_{ia} \quad i_{ib} \quad i_{ic}\right]^T$: vector modulated currents;

$\left[U_0\right]=\left[U_{0A} \quad U_{0B} \quad U_{0C}\right]^T$:vector voltage witched;

$\left[U_i\right]=\left[U_{ia} \quad U_{ib} \quad U_{ic}\right]^T$: vector modulated voltage.

We note that the connection matrix in equation (3) is a transpose of the respective matrix in equation (4). The MC should be controlled using a specific and appropriately timed sequence of de f_{ij}.

The matrix converter is composed of 3x3 switches. This number allows 512 combinations of switching states for the converter to operate safely. We must, through its order to avoid combinations that cause a short-circuit power and those that cause open circuits of the load. For this purpose the 512 combinations of states will be reduced to only 27 states can come true. Table 2 shows the different modes of the MC.

Table 2. Operation modes

Mode	Switches	U_{o1}	U_{o2}	U_{o3}
1	S_{11} S_{22} S_{33}	U_{i1}	U_{i2}	U_{i3}
2	S_{12} S_{23} S_{31}	U_{i3}	U_{i1}	U_{i2}
3	S_{13} S_{21} S_{32}	U_{i2}	U_{i3}	U_{i1}
4	S_{13} S_{22} S_{31}	U_{i3}	U_{i2}	U_{i1}
5	S_{11} S_{23} S_{32}	U_{i1}	U_{i3}	U_{i2}
6	S_{12} $S_{21}S_{33}$	U_{i2}	U_{i1}	U_{i3}
7	S_{11} S_{22} S_{23}	U_{i1}	U_{i2}	U_{i2}
8	S_{21} S_{32} S_{33}	U_{i2}	U_{i3}	U_{i3}
9	S_{12} S_{13} S_{31}	U_{i3}	U_{i1}	U_{i1}
10	S_{12} S_{13} S_{21}	U_{i2}	U_{i1}	U_{i1}
11	S_{22} S_{23} S_{31}	U_{i3}	U_{i2}	U_{i2}
12	S_{11} S_{32} S_{33}	U_{i1}	U_{i3}	U_{i3}
13	S_{12} $S_{21}S_{23}$	U_{i2}	U_{i1}	U_{i2}
14	S_{22} S_{31} S_{33}	U_{i3}	U_{i2}	U_{i3}
15	S_{11} S_{13} S_{32}	U_{i1}	U_{i3}	U_{i1}
16	S_{11} S_{13} S_{22}	U_{i1}	U_{i2}	U_{i1}
17	S_{21} S_{23} S_{32}	U_{i2}	U_{i3}	U_{i2}
18	S_{12} S_{31} S_{33}	U_{i3}	U_{i1}	U_{i3}
19	S_{13} $S_{21}S_{22}$	U_{i2}	U_{i2}	U_{i1}
20	S_{23} S_{31} S_{32}	U_{i3}	U_{i3}	U_{i2}
21	S_{11} S_{12} S_{33}	U_{i1}	U_{i1}	U_{i3}
22	S_{11} S_{12} S_{23}	U_{i1}	U_{i1}	U_{i2}
23	S_{21} S_{22} S_{33}	U_{i2}	U_{i2}	U_{i3}
24	S_{13} $S_{31}S_{32}$	U_{i3}	U_{i3}	U_{i1}
25	S_{11} S_{12} S_{13}	U_{i1}	U_{i1}	U_{i1}
26	S_{21} S_{22} S_{23}	U_{i2}	U_{i2}	U_{i2}
27	S_{31} S_{32} S_{33}	U_{i3}	U_{i3}	U_{i3}

The control strategy that we implement for the three phases of the MC is based on the difference between measured values and desired outputs:

E_1, where K_{11}, K_{22}, K_{33} are closed (Mode 1),

E_2, when K_{12}, K_{23}, K_{31} are closed (Mode 2),

E_{27} when K_{31}, K_{32}, K_{33} are closed (Mode 27).

The equations of E_1, E_2,....., E_{27}, are represented by:

Step 1

$E_1(t) = (U_{o1}(t)- U_{i1}(t))^2 + (U_{o2}(t)- U_{i2}(t))^2 + (U_{o3}(t)- U_{i3}(t))^2$

$E_2(t) = (U_{o1}(t)- U_{i3}(t))^2 + (U_{o2}(t)- U_{i1}(t))^2 + (U_{o3}(t)- U_{i2}(t))^2$

$E_3(t) = (U_{o1}(t)- U_{i2}(t))^2 + (U_{o2}(t)- U_{i3}(t))^2 + (U_{o3}(t)- U_{i1}(t))^2$

$E_4(t) = (U_{o1}(t)- U_{i3}(t))^2 + (U_{o2}(t)- U_{i2}(t))^2 + (U_{o3}(t)- U_{i1}(t))^2$

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$E_{24}(t) = (U_{o1}(t)- U_{i3}(t))^2 + (U_{o2}(t)- U_{i3}(t))^2 + (U_{o3}(t)- U_{i1}(t))^2$

$E_{25}(t) = (U_{o1}(t)- U_{i1}(t))^2 + (U_{o2}(t)- U_{i1}(t))^2 + (U_{o3}(t)- U_{i1}(t))^2$

$E_{26}(t) = (U_{o1}(t)- U_{i2}(t))^2 + (U_{o2}(t)- U_{i2}(t))^2 + (U_{o3}(t)- U_{i2}(t))^2$

$E_{27}(t) = (U_{o1}(t)- U_{i3}(t))^2 + (U_{o2}(t)- U_{i3}(t))^2 + (U_{o3}(t)- U_{i3}(t))^2$

Step 2

If (min(E₁,E₂,E₃…E₂₇=E₁)then(S_{11} S_{22} S_{33})=On,($U_{i1}(t)$,$U_{i2}(t)$,$U_{i3}(t)$)

If(min(E₁,E₂,E₃…E₂₇=E₂)then(S_{12} S_{23} S_{31})=On,($U_{i3}(t)$,$U_{i1}(t)$,$U_{i2}(t)$)

If(min($E_1,E_2,E_3 \ldots E_{27}=E_3$*)then(*$S_{13}\ S_{21}S_{32}$)=On,($U_{i2}(t),U_{i3}(t),U_{i1}(t)$)

If(min($E_1,E_2,E_3 \ldots E_{27}=E_4$*)then(*$S_{13}\ S_{22}\ S_{31}$)=On,($U_{i3}(t),U_{i2}(t),U_{i1}(t)$)

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If(min($E_1,E_2,E_3 \ldots E_{27}=E_{24}$*)then(*$S_{13}\ S_{31}S_{32}$)=On,($U_{i3}(t),U_{i3}(t),U_{i1}(t)$)

If(min($E_1,E_2,E_3 \ldots E_{27}=E_{25}$*)then(*$S_{11}\ S_{12}\ S_{13}$)=On,($U_{i1}(t),U_{i1}(t), U_{i1}(t)$)

If(min($E_1,E_2,E_3 \ldots E_{27}=E_{26}$*)then* ($S_{21}\ S_{22}\ S_{23}$)=On,($U_{i2}(t),U_{i2}(t),U_{i2}(t)$)

If(min($E_1,E_2, E_3 \ldots E_{27}=E_{27}$*)then (*$S_{31}\ S_{32}\ S_{33}$)=On,($U_{i3}(t),U_{i3}(t),U_{i3}(t)$)

The relations between the input and output currents of the three phases are shown in the Table3.

Table 3. Input and output currents relations

Mode	$i_{i1}(t)$	$i_{i2}(t)$	$i_{i3}(t)$
1	$i_{o1}(t)$	$i_{o2}(t)$	$i_{o3}(t)$
2	$i_{o2}(t)$	$i_{o3}(t)$	$i_{o1}(t)$
3	$i_{o3}(t)$	$i_{o1}(t)$	$i_{o2}(t)$
4	$i_{o3}(t)$	$i_{o2}(t)$	$i_{o1}(t)$
5	$i_{o1}(t)$	$i_{o3}(t)$	$i_{o2}(t)$
6	$i_{o2}(t)$	$i_{o1}(t)$	$i_{o3}(t)$
7	$i_{o1}(t)$	$(i_{o2}(t)+ i_{o3}(t))$	0
8	0	$i_{o1}(t)$	$(i_{o2}(t)+ i_{o3}(t))$
9	$(i_{o2}(t)+ i_{o3}(t))$	0	$i_{o1}(t)$
10	$(i_{o2}(t)+ i_{o3}(t))$	$i_{o1}(t)$	0
11	0	$(i_{o2}(t)+ i_{o3}(t))$	$i_{o1}(t)$
.	.	.	.
.	.	.	.
23	0	$(i_{o1}(t)+ i_{o2}(t))$	$i_{o3}(t)$
24	$i_{o3}(t)$	0	$(i_{o1}(t)+ i_{o2}(t))$
25	$(i_{o1}(t)+ i_{o2}(t)+ i_{o3}(t))$	0	0
26	0	$(i_{o1}(t)+ i_{o2}(t)+ i_{o3}(t))$	0
27	0	0	$(i_{o1}(t)+ i_{o2}(t)+ i_{o3}(t))$

3. Inverter Modelling and Control Strategy

The voltage inverter consists of three the controls of two transistors from the same arm are complementary [7] (see Fig 2).

First, the combination of a transistor Ti to the diode Di is equivalent to a bidirectional component and secondly the control transistors are complementary. Therefore, it allows replacing each arm of the inverter via a switch to two positions as shown in Fig 3.

The output voltages are derived are simple expressions are:

$$\begin{cases} V_a = \dfrac{U_{ab}-U_{ca}}{3} \\ V_b = \dfrac{U_{bc}-U_{ab}}{3} \\ V_c = \dfrac{U_{ca}-U_{bc}}{3} \end{cases} \tag{5}$$

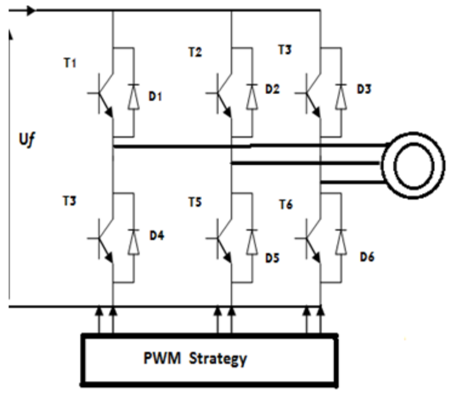


Fig. 2. PWM strategy control of the Inverter voltage inverter

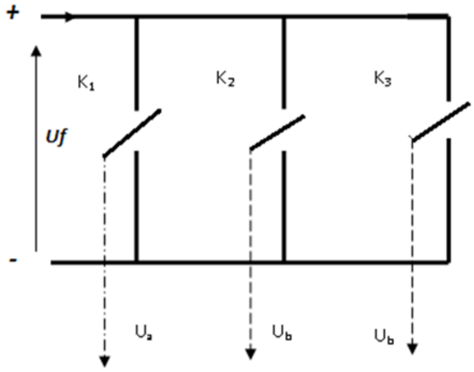


Fig.3. Representative of transistors by switch

Where:

$$\begin{cases} U_{ab} = V_a - V_b \\ U_{bc} = V_b - V_c \\ U_{ca} = V_c - V_a \end{cases} \tag{6}$$

Each K is associated to a logic function F_i ($i=1, 2, 3$) defined by :

$F_i=+1$ if K_i is connected to the (+) terminal of the source;

$F_i=-1$ if K_i is connected to the (-) terminal of the source.

It follows that it:

$$\begin{cases} U_{ab} = \dfrac{U_f}{2}(F_1 - F_2) \\ U_{bc} = \dfrac{U_f}{2}(F_2 - F_3) \\ U_{ca} = \dfrac{U_f}{2}(F_3 - F_1) \end{cases} \tag{7}$$

Therefore, the voltages phase V_a, V_b, V_c are expressed in terms of logic functions Fi with the following matrix relation:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{U_f}{6}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \tag{8}$$

The current at the input of the inverter is expressed as:

$$i_e=F_1.i_a+F_2.i_b+F_3.i_c \tag{9}$$

4. PWM Control Strategy

In this work, we focus on the first strategy; the principle consists in comparison of triangular shape of maximum amplitude V_p and frequency f_p with a reference V_r of sinusoidal shape [8].

The principal of this strategy is represented by figure 4:

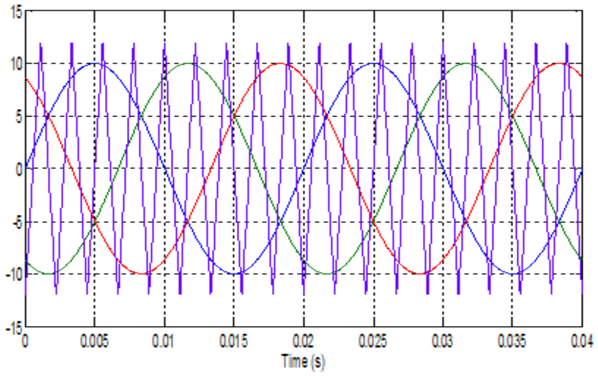


Fig.4. PWM Control Strategy

The closing time of the switches K_1 and K_2 are complementary (located in the same arm of the inverter) are determined by the intersections of the reference wave V_r, representing the desired output voltage of frequency f with the carrier.

The carrier frequency fp much higher is triangular wave amplitude V_{pm}.

The intersections of V_r with increasing V_p gives the time of K_2 and the beginning of intervals $Vs=Uf\ /2$. The intersections of V_r with decreasing V_p gives the Time of K_1.

Calculate the average value of the output voltage V_s for a period T_p of the wave modulation.

The incrising part of the equation V_p to:

$$V_p = \frac{V_{pm}}{2} + 2.\frac{V_{pm}}{T_p} \tag{9}$$

The descending part of V_p has the equation:

$$V_p = \frac{3.V_{pm}}{2} + 2.\frac{V_{pm}}{T_p} \tag{10}$$

The output voltage is set to average over this period of V_p:

$$V_{smoy} = \frac{1}{T_p}\left(\frac{U_f}{2}T_p - \frac{U_f}{2}(t_2 - t_1)\right) \tag{11}$$

Taking $V_{pm}=V_i$, and replacing t_2 and t_1 by their values, we obtain: $V_{smoy}=V_f$.

The PWM control is characterized by the following parameters [9]: the modulation index $m=f_p/f$ and duty cycle defined by $r= A_p/A_r$, where fp is carrier frequency.

The inverter is designed to provide power electric machines operate at variable speed.

5. Simulation Results

To study the performances of variable speed electric drive two cases are considered. First where it is fed by MC and then when it fed by PWM three phase voltage inverter for three zones of frequencies. First, we impose power supply frequency f=50Hz from (0:1)s followed by f=75 Hz between (1:2)s and finally a frequency f=25Hz is imposed.

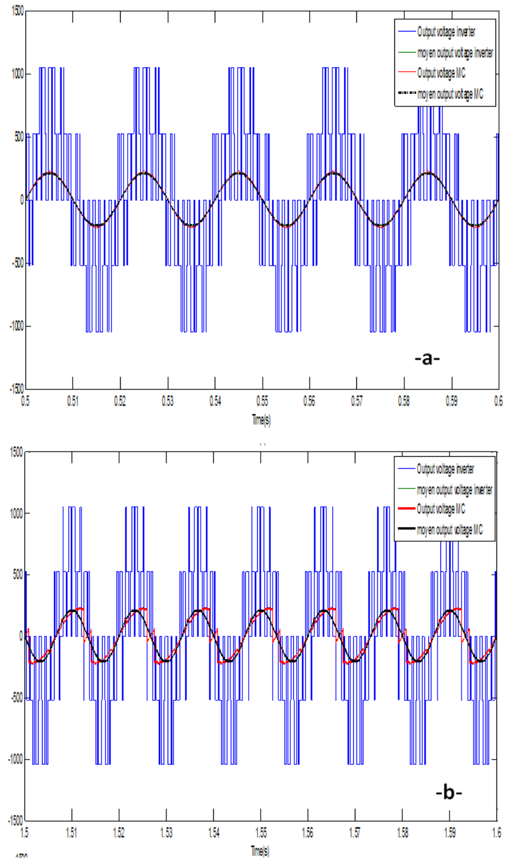
The following results were obtained from simulation of the proposed parameters. Figure 5 shows the output voltage of the matrix converter superposed to the average value. The figures 5a, b and c present respectively the voltage for the frequencies 50Hz, 75Hz and 25Hz.

Figure 6 illustrates the superposition of two obtained speed when the IM is fed by MC and PWM three phase voltage inverter.

Finally, the Fig 7, present the phases currents for the two studied cases. The spectral analysis of the obtained currents is shown in Table 4.

Table 4. THD% of current phase a

Frequency (Hz)	THD% with MC	THD% with inverter
50	0.45	60.23
75	32.52	62.10
25	35.60	64.84



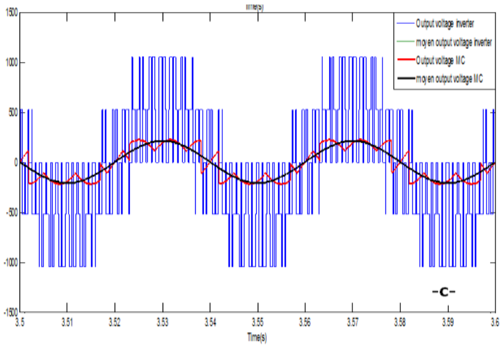


Fig.5. Output voltages

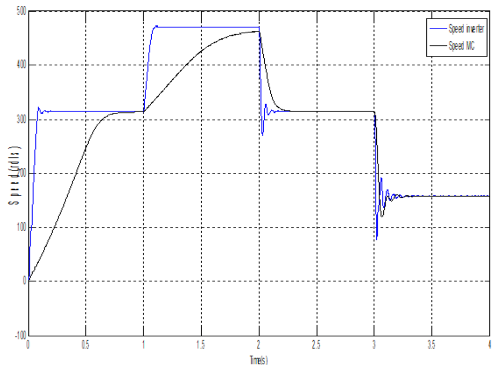


Fig.6. Speed variations

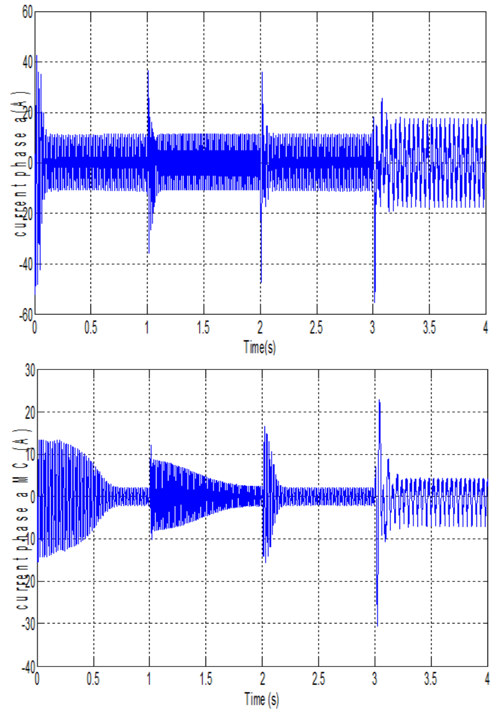


Fig.7. Output currents

6. Conclusion

In this paper, performance of two power supply of an induction machine was evaluated. We have considered the analysed the performances of variable speed electric drive for the study case by comparing the spectral analysis of currents. Simulation results have confirmed that the presented control technique exploits the matrix converter's present the static and dynamic performances are better regardless when the induction motor is fed by inverter.

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