A Study of SVM-DTC and Conventional DTC for Induction Motors Drive Fed by Five-level Inverter

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ABSTRACT

In order to reduce torque and flux fluctuations as well as harmonic currents distortion, two models were developed, the first is based on conventional DTC and the second is based on the SVM-DTC, controlling induction motor fed by a Five-level inverter. PI controller is employed for flux and torque control in order to obtain reference voltages V_d and V_q that will be used in the SVM algorithm.
The developed models were validated by simulation tests and the obtained results have showed the advantages of DTC-SVM control over conventional DTC in harmonic currents distortion, torque and flux fluctuations reductions.

1. INTRODUCTION

The recent progress in electric motor control systems is mainly due to the increased demand for motors with high torques and speeds and the advances in semiconductor power components. These recent components can satisfy the above requirements and have also high switching frequency under very high voltages and currents.

The improvements in the field of micro informatics (powerful and fast microcontrollers) have allowed the synthesis of converters control algorithms and machine became more powerful and more robust [1-3].

Industrial variable speed drives applications require high performance, maximum reliability and minimum cost. The application of static converters is due to the development of controlled power semiconductors during on (conduction) and off (blocking) states such as MOSFETs, IGBTs, GTOs [4].

The use of a conventional two-level inverter in the field of high power applications is not appropriate, as it requires electronic components capable of withstanding high reverse voltage and currents of high intensity [5-6].

The direct torque control (DTC) was initially developed for asynchronous machines during 1986-1988 by TAKAHASHI and DEPENBROCK, [6-9]. This type of control considers the association of inverter and machine as a set where the vector control is established from the semiconductors switching states. Its main advantages are the speed and the dynamic torque fast response as well as low dependence on machine parameters. However, two major disadvantages arise. The first is the determination of the switching states based on information concerning the evolution trends of the flux and the torque resulting from the nonlinear elements of hysteresis type. The second is related to torque and flux fluctuations, as the duration of the commutations is variable. In order to overcome the severe computation time constraints and improve the performance of conventional DTC control, another technique is developed, imposing a constant modulation frequency [10].

In this work, direct vector-based torque control (DTC-SVM) applied to an induction motor fed by a Five-level NPC inverter is presented. This control is capable to improve the switching strategy of the inverter, resulting in a large number of voltage vectors to reduce flux and torque fluctuations and switching frequency [11-13]. The design of this control technique is proposed to improve the performance of the drive systems by PI controllers associated with vector modulation technique (SVM).

In this paper, two control algorithms (classical DTC and DTC-SVM) are developed in order to compare and show the advantages of the proposed technique over conventional DTC control strategy.

The obtained results are very encouraging demonstrating an important reduction in harmonic ratio (THD) when DTC-SVM technique is employed.

2. GENERAL PRINCIPLES OF THE DIRECT TORQUE CONTROL

2.1 Induction motor modeling

Principal, theoretical developments and modeling of DTC are well covered in the literature [9]. Figure 1 below shows the structure of the DTC-SVM for induction motor fed by a multilevel inverter. For both models, PI controllers of flux and torque were inserted in order to obtain the reference voltages V_d and V_q which will be used in the SVM algorithm [4].
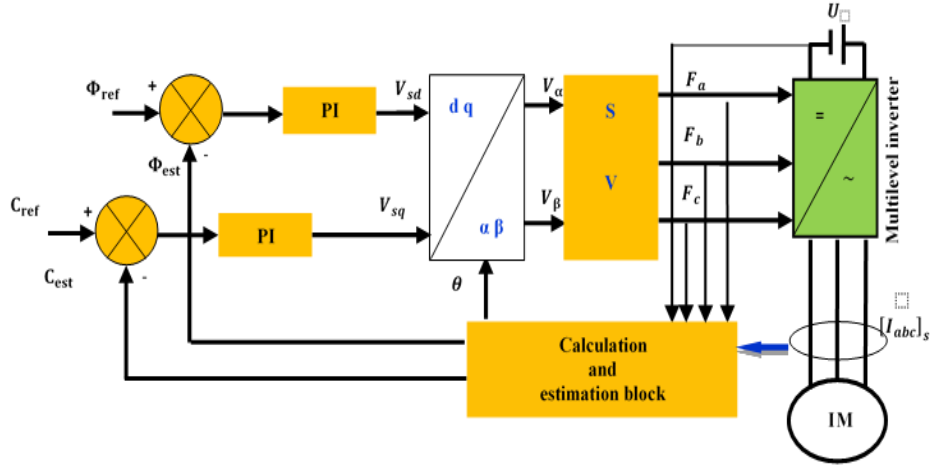
Figure 1. Induction motor DTC-SVM structure

The motor stator voltage vector Vs can be expressed as follows [9]:

$$\overline{V}_s = \overline{R}_s.\overline{I}_s + \frac{d\overline{\varphi}_s}{dt} \tag{1}$$

Direct torque control is based on stator flux orientation. The expression of the stator flux in the reference frame according to motor stator is obtained by the following equation (2):

$$\overline{\varphi}_s = \overline{\varphi}_{s0} + \int_0^t \left(\overline{V}_s - \overline{R}_s.\overline{I}_s\right) dt \tag{2}$$

Neglecting the resistor voltage drop, the flux expression will become:

$$\overline{\varphi}_s(t) \approx \overline{\varphi}_s(0) + \int_0^t \overline{V}_s.dt \tag{3}$$

The electromagnetic torque can be expressed as follows:

$$C_e = p\frac{3}{2}\left(\varphi_{s\alpha}I_\beta - \varphi_{s\beta}I_\alpha\right) \tag{4}$$

3. FIVE-LEVEL INVERTER

The diode clamped inverter is chosen because of its simplicity compared to other types of multilevel inverters, Figure 2 [4].
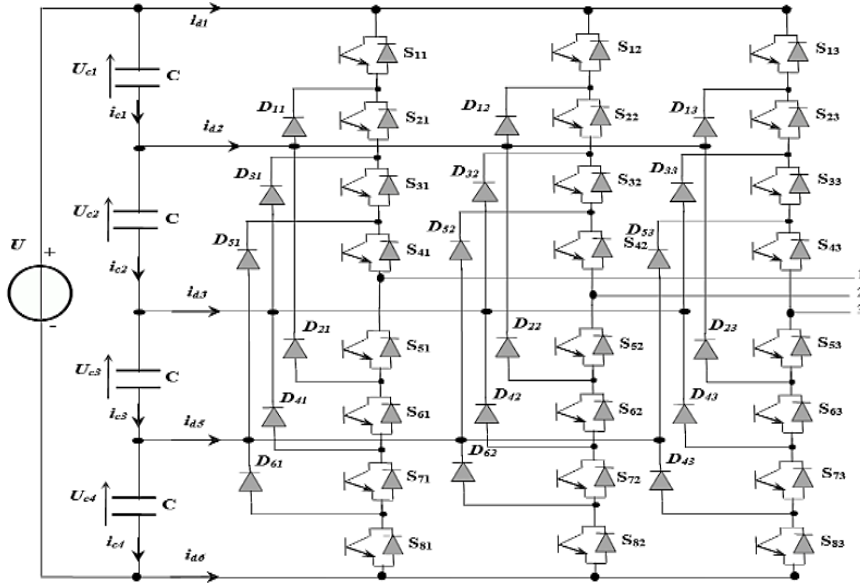

Figure 2. Structure of diode clamped Five-level inverter

Diode clamped five-level inverter has three symmetrical arms each consisting of eight bidirectional switches in series. These switches must not be ON or OFF simultaneously in order to avoid the short circuit of the inverter dc source. Each switch consists of a bi-commendable semiconductor and a diode connected in anti-parallel. Six diodes in each arm to ensure the application of different voltage levels at the output

of each arm. All arms are connected to a dc supply of electromotive force (4Uc), these four generators are equal. This inverter is a five-level because it delivers five voltage levels per arm (U/2, U/4, 0, -U/4, -U/2) [4].

Five-level inverter space vector diagram with sectors and regions are presented in Figure 3 and Figure 4 respectively. These figures illustrate how five-level space vector algorithm

is developed.

3.1 Switching functions

For each switch $S_{ij}(i = \overline{1-8},\ j = \overline{1-3})$, a switching function F_{ij} is defined as follows [4]:

$$Fij = \begin{cases} 1\ if\ S_{ij}\ is\ ON \\ 0\ if\ S_{ij}\ is\ OFF \end{cases} \quad (5)$$

The switches of the lower-half arm are complementary with the switches of upper half-arm

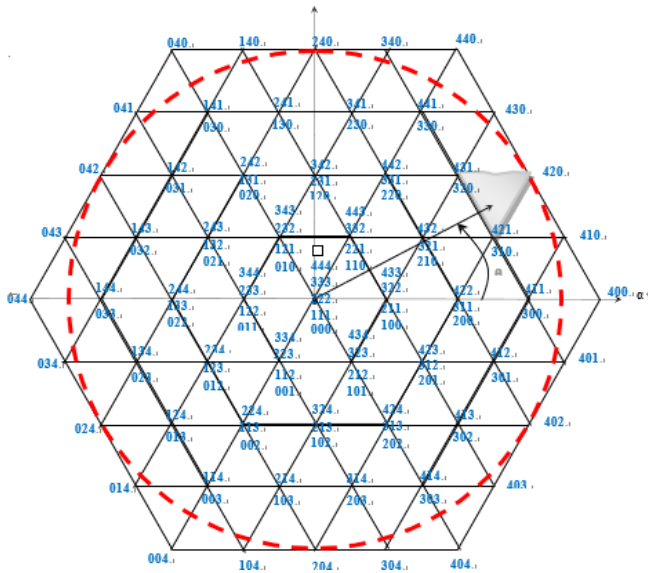$$F_{ij} = 1 - F_{(i-4)j}\ , i = \overline{5-8}\ ; j = \overline{1-4} \quad (6)$$

Figure 3. Inverter space vector diagram

Table 1. Switching state of one arm of five-level inverter [4]

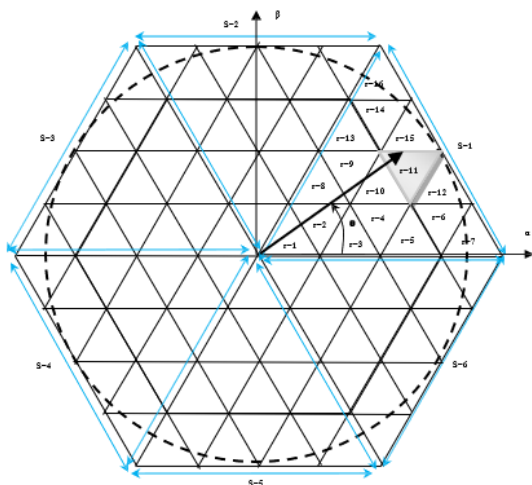| State	S_{1x}	S_{2x}	S_{3x}	S_{4x}	S_{5x}	S_{6x}	S_{7x}	S_{8x}	V_{0x}
4	1	1	1	1	0	0	0	0	U /2
3	0	1	1	1	1	0	0	0	U /4
2	0	0	1	1	1	1	0	0	0
1	0	0	0	1	1	1	1	0	-U /4
0	0	0	0	0	1	1	1	1	-U /2

Figure 4. Sectors and regions of space vector diagram

The motor parameters used in simulation are presented in Table 2.

Table 1. Motors parameters Asynchronous motor technical parameters

Parameters	Values
- Motor power	P_n= 1.1Kw
- Nominal frequency	F = 50Hz
- pole pair Number	P=2
- Supply voltage	u_n=220v
- Nominal current	I_n = 13A
- Nominal rotational speed	n_n = 1725tr/min
- Stator resistance	Rs = 6.75 Ω
- Rotor resistance	Rr = 6.21 Ω
- Stator inductance	Ls = 0.5192H
- Rotor inductance	Lr = 0.5192H
- Mutual inductance	Msr = 0.5H
- moment of inertia	J = 0.01240 Kgm^2
- Friction coefficient	f = 0.002 Kg m^2/s

4. SIMULATIONS TESTS AND RESULTS ANALYSIS

In order to validate the conventional DTC and SVM-DTC

4.1 Conventional DTC applied to asynchronous machine fed by Five -level inverter

Developed algorithms with PI controllers for an induction motor supplied by five-level inverter are presented in Figures (5) to (15) Figure (5) illustrates the phase to neutral voltage. The torque curve presented in Figure (6), for conventional DTC having a transient state section from 0 to 0.16s, no load operation section from 0.16-0.5s, a load (6 N.m) operation section applied at 0.5s with a time response less than 0.11s and section for rotation reversing direction test with loaded motor at 0.75s and load elimination at 1.25s is presented to show motor speed response. SVM-DTC curve also has a transient state section from 0 to 0.14s, no load (0.00 N.m) operation section from 0.14-0.5s, a section of loaded (6 N.m) motor operation applied at 0.5s with a time response is less than 0.07s, and a section for rotation reversing direction test at 0.75s and load elimination at 1.25.

It can be noticed in Figure (7) an appreciable reduction of torque ripple as illustrated in zoomed torque response figure, the torque ripples in DTC-SVM are much less compared to conventional DTC torque ripples.

Figure (8) illustrates the speed responses for both conventional DTC and SVM-DTC techniques according to speed reference step of 120 rad/s with motor loaded at 0.5s and unloaded at 1.25s.

A speed reversal from positive to negative value (120 rad/s; –120 rad/s) is conducted at 0.75s. In Figure (9), the zoomed speed response shows that both techniques have similar speed response and load rejection when the same PI speed controller is used.

Figures (10) to (12) present respectively the stator phase current, its zoom (zoomed for comparison) and frequency spectrum. In addition, the results have confirmed that SVM-DTC has lower THD value (0.86 %) compared to the value of conventional DTC (2.22 %). The flux angle is shown in Figure (13).

In order to indicate the reversing direction of rotation, Figure (14) and (15) show the stator flux components and its trajectory where the magnitude is following its reference

(1Wb).

All simulations tests results are presented below for both techniques for comparison.

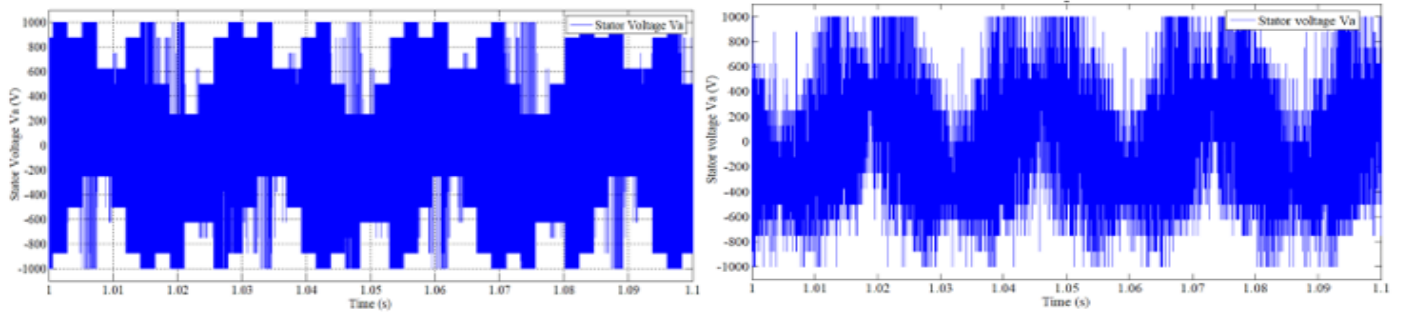**4.2 SVM-DTC to asynchronous machine fed by Five-level inverter**

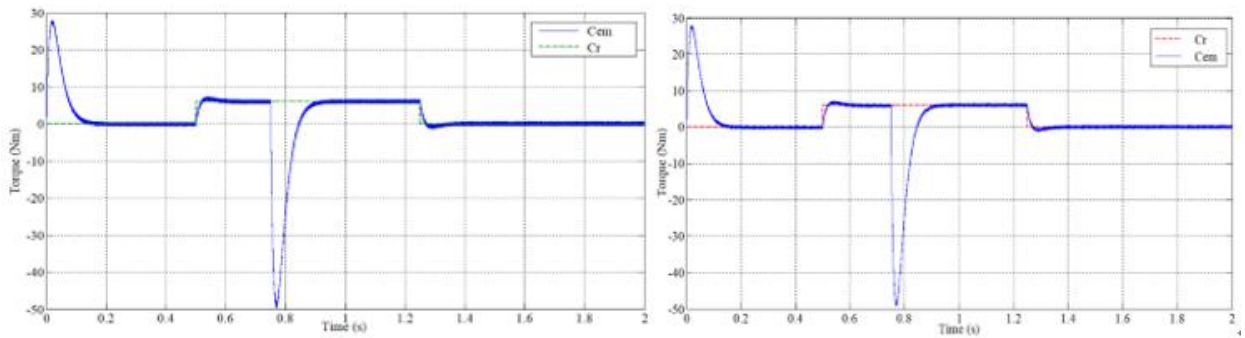**Figure 5.** Inverter output phase to neutral voltage Va

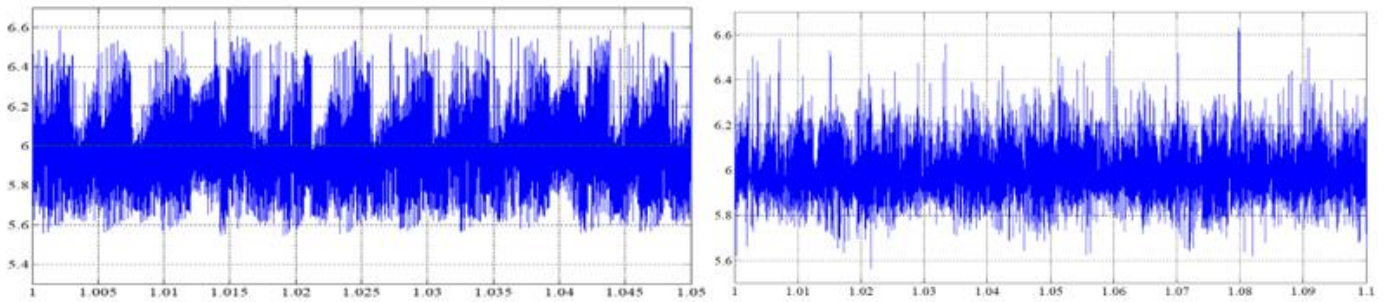**Figure 6.** Induction motor torque at transient and steady state

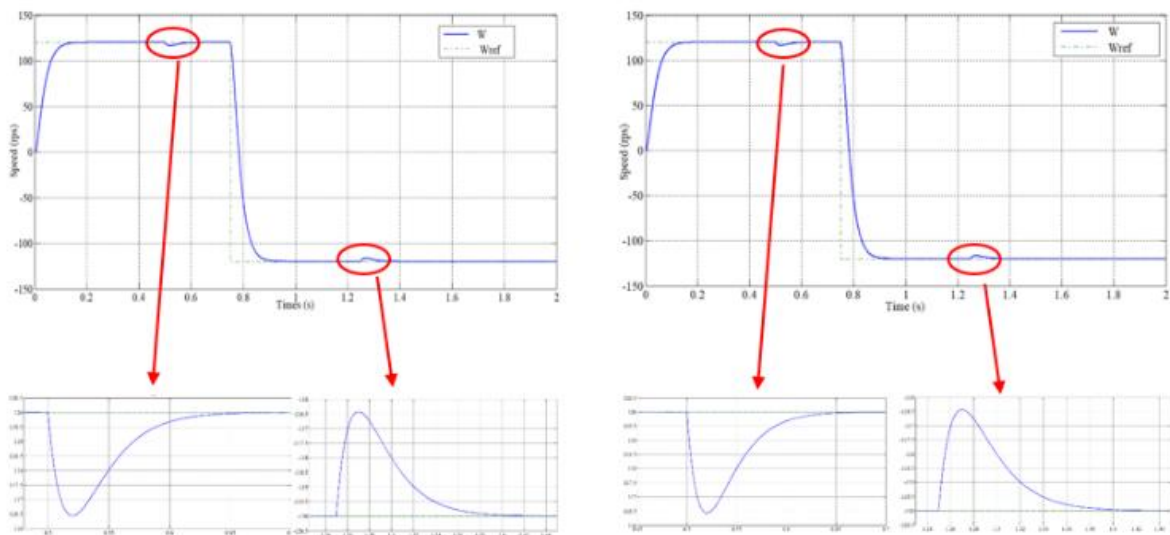**Figure 7.** Zoomed torque response for time interval 1sec to 1.1 sec

Figure 8. Induction motor speed with sense reversing direction at 0.75s   **Figure 9.** Zoom of speed response
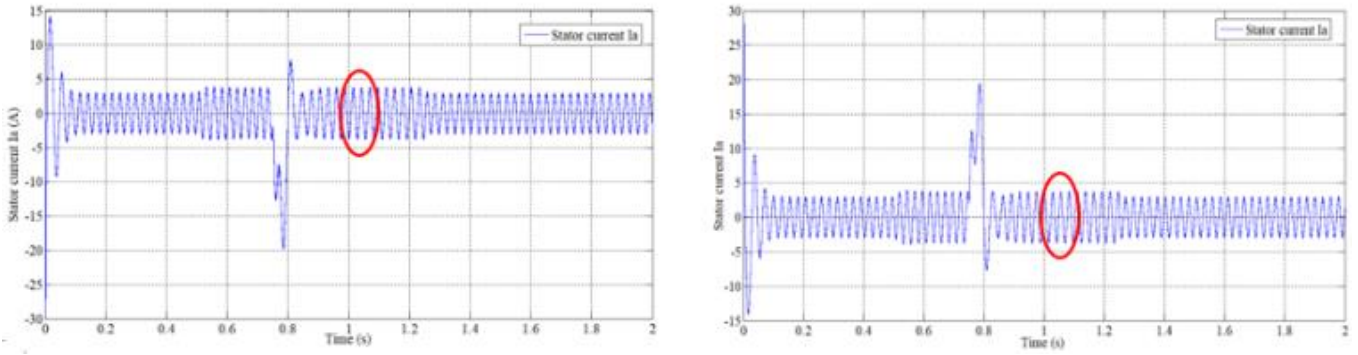
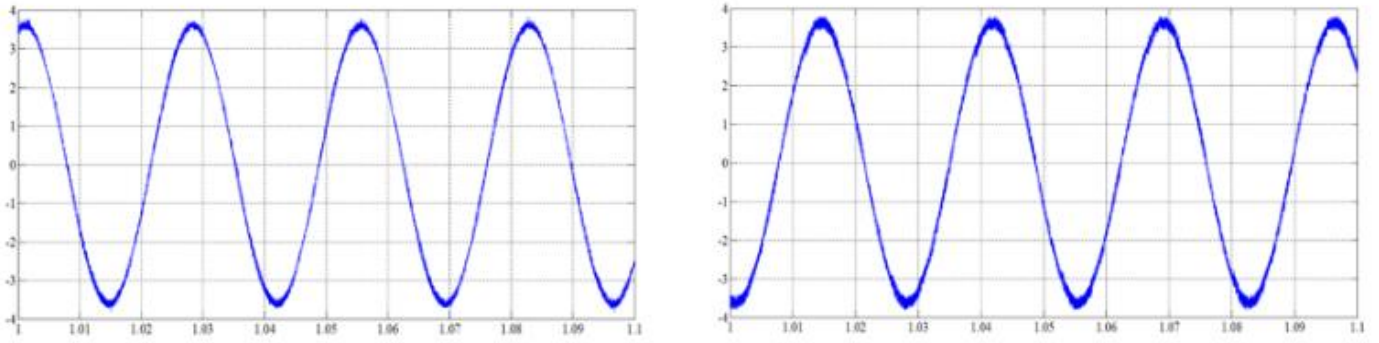**Figure 10**. Steady states stator current Ia

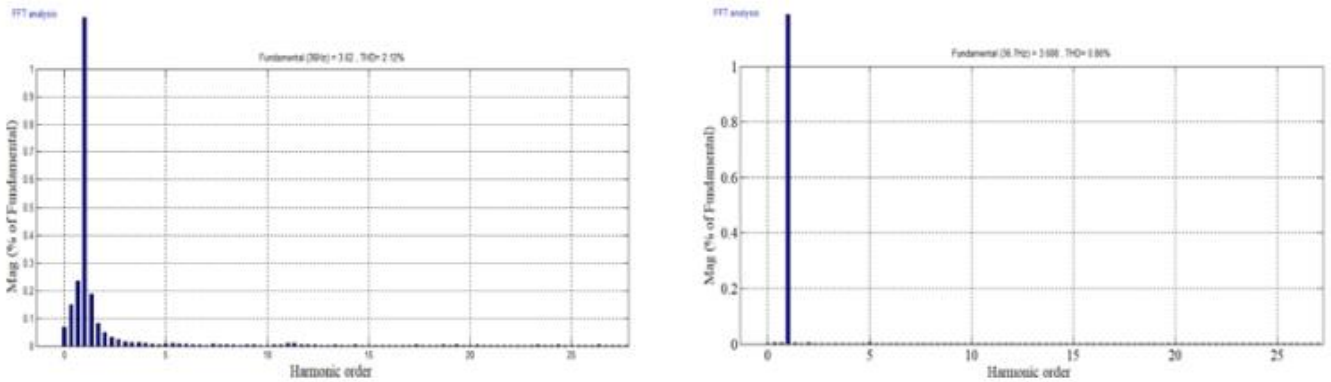**Figure 11.** Zoom of current (Ia) response time interval 1to1.1 sec
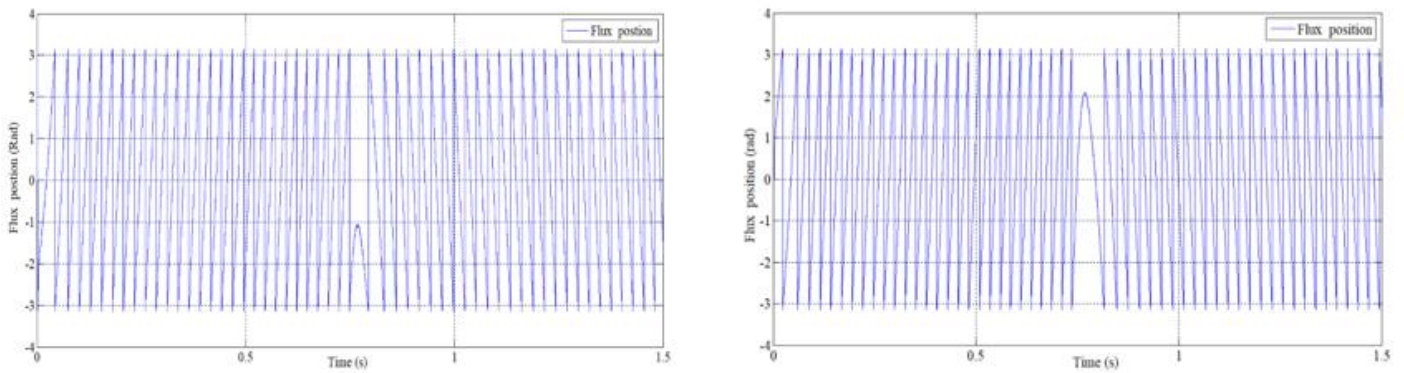

Figure 12. Stator current frequency spectrum

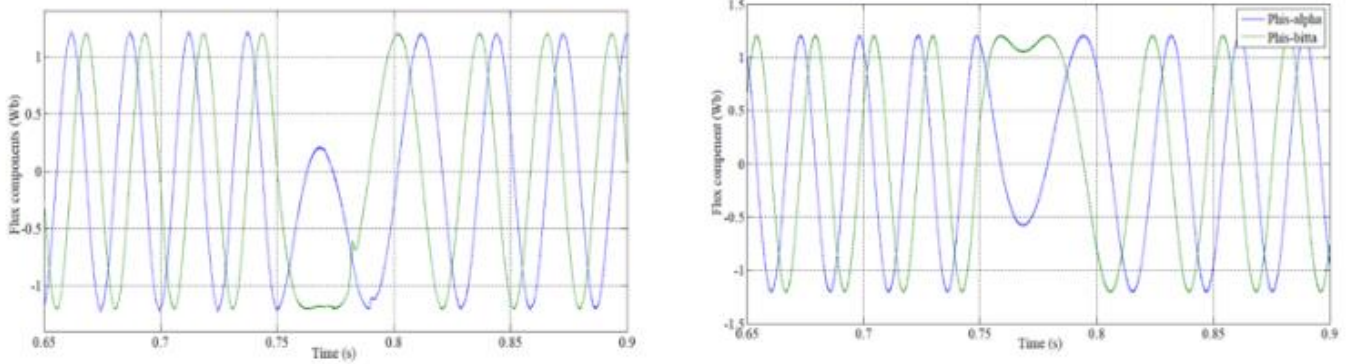**Figure 13.** Rotation reversing direction: stator flux position

Figure 14. Rotation reversing direction: Stator flux components (Wb)
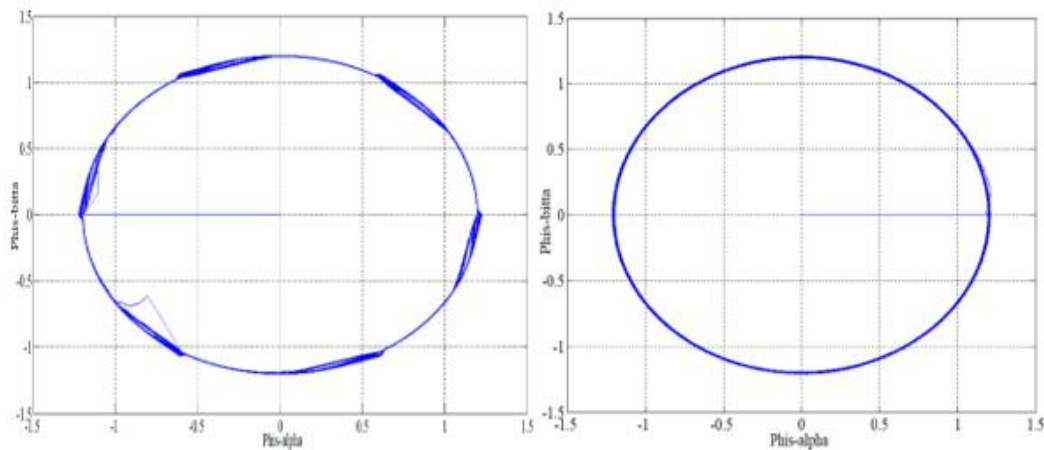

Figure 15. Stator flux trajectory (Wb)

5. CONCLUSIONS

In this paper a comparative study of two techniques, one based on SVM-DTC and the other is based on conventional DTC controlling an induction motor fed by five-level inverter is presented and discussed. The obtained results have showed the advantages of SVM-DTC over conventional DTC such as reduced THD value of stator current, torque ripples and flux fluctuations with better stator voltage waveform.

The speed disturbance rejection is quick and tracks its reference with high static performance. Moreover, SVM-DTC has better dynamic control under different operation conditions.Comparing the results of the present study to the results of the literature, it can be noticed that current THD value is well below the obtained values of [1, 13].

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NOMENCLATURE

DTC	Direct torque control
DTC-SVM	Direct torque control space victor modulation
SVPWM	space vector Pulse Width Modulation
U	Direct voltage source
Fij	switching function
Vs	Stator voltage vector
$I\alpha$, I_β	Stator voltages $\alpha\beta$ components
W	Induction motor speed Electromagnetic
Wref	Speed reference
Ce	Induction motor torque
Φs	Stator flux
Rs	Stator resistance
p	Number of pole pairs