

Comparative study between SVPWM-DTC and Classical DTC applied to Induction Motor

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ABSTRACT - direct torque control (DTC) is one of the most effective methods for controlling the induction motor. In direct torque control, motor flux and torque are considered as reference quantities, and are controlled by optimal selection of inverter switching vectors. Using the direct torque control method, you can reduce the field oriented control (FOC) constraints and complexities. The direct torque control has a very fast torque response and is resistant to sudden load variations.

The simulation results obtained for the two types of control (the DTC-classic and the DTC-SVPWM) show a considerable reduction in ripples on the torque and flux responses for the DTC-SVPWM control, for a two-level inverter, on front of classic DTC-SVM control; which reduces the ripples on the torque and consequently a marked improvement in the quality of the current.

Keywords — DTC, SVPWM, SVM, hysteresis comparator, PI, PWM

1. INTRODUCTION

Most industrial processes make extensive use of motors for the drive. However foremost, these motors must respond effectively to variations in set points (speed, position, torque). The direct current motor responds very well to these requirements. This is explained by the natural decoupling between the flow and the torque [4].

due to the disadvantages of DC motors (such as High initial cost, Increased operation and maintenance cost due to the presence of commutator and brush gear, it Can't operate in explosive and hazard conditions due to sparking occur at brush (risk in commutation failure)

Moreover, new technology of modern semiconductor devices, in particular insulated gate bipolar transistor (IGBT) and digital signal processor (DSP), DC motors are progressively replaced by AC motors [5].

In the mid-1980s, a new strategist for torque induction motors was presented by I. Takahashi and T. Noguchi as direct torque control (DTC).

DTC is a control technique exploiting the possibility of imposing torque and flux on AC machines in a decoupled manner [1] [2] [3], In this paper the DTC-SVM and DTC SVPWM diagrams are proposed for induction motor drive. The DTC -SVPWM scheme gives good dynamic control of flux and torque. DTC is a control technique exploiting the possibility of imposing torque and flux on AC machines in a decoupled manner [1] [2] [3], In this paper the DTC-SVM and DTC SVPWM diagrams are proposed for induction motor drive. The DTC -SVPWM scheme gives good dynamic control of flux and torque.

2. SIMULATION

2.1. CLASSICAL DIRECT TORQUE CONTROL

The basic idea of DTC is to achieve efficient control, as well in steady state than in transient state through the combination of different switching strategies. The appropriate selection of the voltage vector, at each sampling period, is made to keep the torque and the flux within the limits of the two hysteresis bands.

2.1.1. Stator Flux Vector Estimators:

The Flux can be estimated from measurements of stator current and machine voltage. The stator flux in the stationary coordinates system (fixed to the stator) is given by the following equation [8]:

$$\phi_s = \int_0^t (V_s - R_s * I_s) dt \quad (1)$$

We obtain the components α , β of the vector ϕ_s :

$$\phi_s = \phi_s \alpha + j \phi_s \beta \quad (2)$$

$$\begin{cases} \phi_s \alpha = \int_0^t (V_s \alpha - R_s * I_s \alpha) dt \\ \phi_s \beta = \int_0^t (V_s \beta - R_s * I_s \beta) dt \end{cases} \quad (3)$$

$$\begin{bmatrix} v_{s\alpha}(t) \\ v_{s\beta}(t) \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{bmatrix} \quad (4)$$

We write the stator flux modulus as follows:

$$\phi_s = \sqrt{\phi_s^2 \alpha^2 + \phi_s^2 \beta^2} \quad (5)$$

2.1.2. Torque Estimation:

The induction motor output torque can be expressed as a function of the stator flux and the rotor flux spatial vectors as follows [6]:

$$T_e = \frac{3p}{4} (\phi_s \alpha^* I_{s\beta} - \phi_{s\beta}^* I_{s\alpha}) \quad (6)$$

2.1.3. The flux corrector:

The output of the corrector represented by a Boolean variable Cflx directly indicates the amplitude of the flux, which must be increased (Cflx = 1) or decreased (Cflx = 0) so that maintain the equation [7]:

$$|(\phi_s)_{ref} - \phi_s| \leq \Delta \phi_s \quad (7)$$

2.1.4. Electromagnetic torque corrector:

Three levels comparators:

the torque regulation can be realized using three-level hysteresis comparator. In order to control the motor in the two directions of rotation, its output also represented by a Boolean variable, the torque amplitude must be increased in absolute value when ccpl=1, and the motor rotate in the positive order, when

Ccpl=-1, the motor rotate in the negative order, or decrease when Ccpl=0 [11].

The command table is built according to the state of the variables cfx, ccpl

Tableau 1. DTC commutation table [12]

N_i		1	2	3	4	5	6
CFLX = 1	Ccpl=1	V ₂	V ₃	V ₄	V ₅	V ₆	V ₁
	Ccpl=0	V ₇	V ₀	V ₇	V ₀	V ₇	V ₀
	Ccpl=-1	V ₆	V ₁	V ₂	V ₃	V ₄	V ₅
$\Delta \phi = 0$	Ccpl=1	V ₃	V ₄	V ₅	V ₆	V ₁	V ₂
	Ccpl=0	V ₀	V ₇	V ₀	V ₇	V ₀	V ₇
	Ccpl=-1	V ₅	V ₆	V ₁	V ₂	V ₃	V ₄

The classic DTC scheme for an induction motor powered by VSI has been developed as shown in Fig. 1

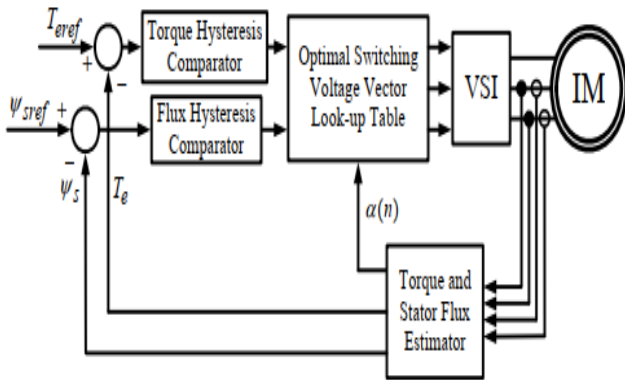


Fig.1. Classical DTC scheme implementation [10]

2.2. DTC-SVPWM command

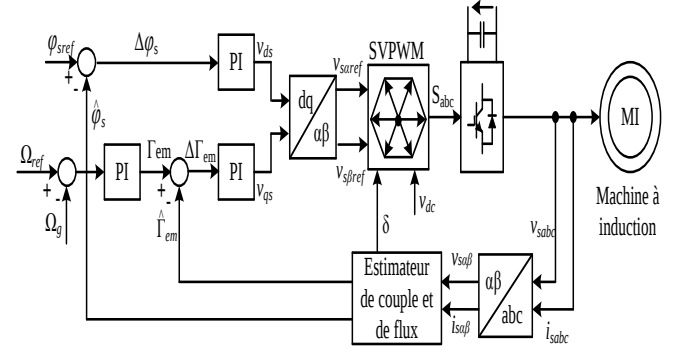


Fig.2. DTFC-SVPWM of an induction generator.

In this arrangement, there are two integral proportional type (PI) controllers, which regulate the torque and the modulus of the stator flux instead of the hysteresis band [9]. SVPWM technique uses full DC bus voltage hence, its output are more sinusoidal with lower harmonic distortion. In addition, this technique provides variable output voltage so that required voltage for motor can be obtained easily. It is one of the best PWM method for variable frequency drive application.

For a three-phase VSI (Voltage Source Inverter) and at two levels, there are eight possible voltage vectors [13], which can be represented in space, as shown in Figure (3).

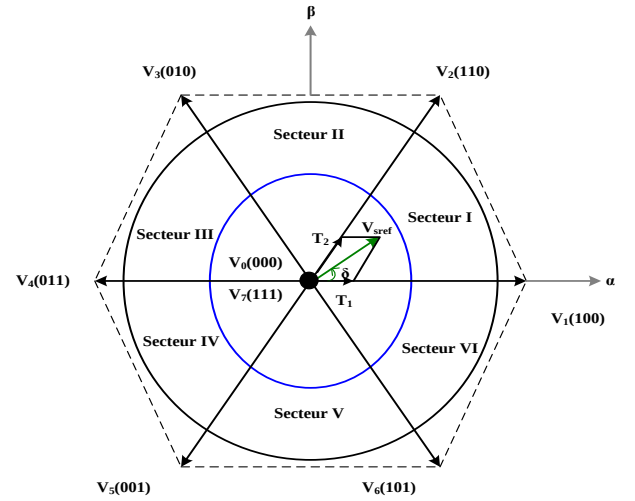


Fig. 3. Representation of the voltage vectors in the coordinate system (α , β).

The following algorithm determines the sectors:

Angle δ	Position of V_{sref} in sector
$0^\circ \leq \delta < 60^\circ$	sector I
$60^\circ \leq \delta < 120^\circ$	sector II
$120^\circ \leq \delta < 180^\circ$	sector III
$180^\circ \leq \delta < 240^\circ$	sector IV
$240^\circ \leq \delta < 300^\circ$	sector V
$300^\circ \leq \delta < 360^\circ$	sector VI

The voltage vectors V0 and V7 are known as zero voltage vectors and the remaining voltage vectors V1 to vectors V6 are known as active voltage vectors.

The principle of the SVPWM method is that the control voltage vector is approximately calculated using three adjacent vectors. Assuming that the voltages of the three-phase inverter are balanced, we have:

$$v_a(t) + v_b(t) + v_c(t) = 0 \quad (8)$$

Where $v_a(t)$, $v_b(t)$, and $v_c(t)$ are the instantaneous voltages of the three phases abc of the load. The transformation of the three phases abc to a two-phase system (α , β) is given by:

$$\begin{bmatrix} v_{s\alpha}(t) \\ v_{s\beta}(t) \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{bmatrix} \quad (9)$$

A space vector can be generally expressed in terms of two-phase armature voltages (α , β) by:

$$\vec{v}(t) = v_{s\alpha}(t) + jv_{s\beta}(t) \quad (10)$$

The reference voltage V_{sref} and the angle δ are obtained by:

$$\begin{cases} V_{sref} = \sqrt{v_{s\alpha}^2 + v_{s\beta}^2} \\ \delta = \tan^{-1} \left(\frac{v_{s\beta}}{v_{s\alpha}} \right) \end{cases} \quad (11)$$

Substituting (9) in (10), we have:

$$\vec{v}(t) = \frac{2}{3} \left[v_a(t)e^{j0} + v_b(t)e^{j2\pi/3} + v_c(t)e^{j4\pi/3} \right] \quad (12)$$

Each of the six active vectors can be derived

$$\vec{V}_k = \frac{2}{3} V_{dc} e^{j(k-1)\frac{\pi}{3}} \quad k = 1, 2, 3, \dots, 6 \quad (13)$$

For a given reference voltage, V_{sref} makes an angle δ concerning V_1 in sector I. Vector PWM consists in projecting the desired stator reference voltage vector V_{sref} onto the two corresponding adjacent voltage vectors V_1 and V_2 . If we note by T_1 and T_2 the two application times of these vectors, T_0 the application time of the zero vectors, their sum must be less than the switching period T_s of the inverter. The times T_1 T_2

and T_0 of the reference voltage vectors V_{sref} are calculated by the following relations:

$$\begin{cases} T_1 = \frac{2\sqrt{3}}{\pi} M_i \sin\left(\frac{\pi}{3} - \delta\right) T_e \\ T_2 = \frac{2\sqrt{3}}{\pi} M_i \sin(\delta) T_e \\ T_0 = T_e - T_1 - T_2 \end{cases} \quad (14)$$

Where the M_i is the modulation index and defined by $M_i = \pi V_{sref} / 2V_{dc}$.

The SVPWM method can be implemented by the following steps:

- ✓ Determine V_{α} , V_{β} by the system of equation (9), and therefore V_{sref} , and the angle δ by the system of equations (11).
- ✓ Determine the application times of the states of the inverter by the system of equations (14).
- ✓ Determine the pulse sequences for each arm of the inverter.

2.2.1. Speed regulator:

The speed controller makes it possible to determine the reference electromagnetic torque, in order to maintain the corresponding speed. The speed can be controlled by means of a PI regulator whose parameters can be calculated according to Figure (4).

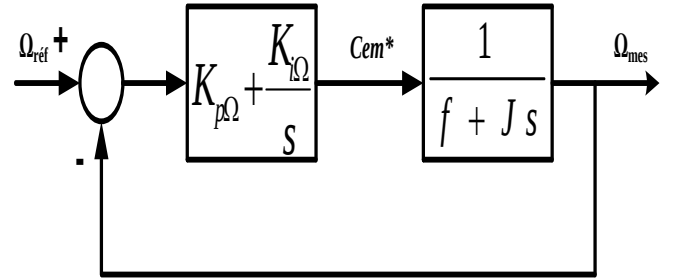


Fig. 4. Diagram of speed regulation

With:

$K_{p\Omega}$: proportional gain of the PI regulator for the speed loop.

$K_{i\Omega}$: integral gain of the PI regulator for the speed loop.

The transfer function of the mechanical speed of the asynchronous generator is given by:

$$\frac{\Omega_m}{\Gamma_{em}} = \frac{1}{Js + f} = \frac{1/J}{s + \frac{f}{J}} = \frac{G_\Omega}{s + p_\Omega} \quad (15)$$

Where:

$$G_\Omega = \frac{1}{J} \quad \text{et} \quad p_\Omega = \frac{f}{J}$$

Where G_Ω and p_Ω are respectively the static gain and the pole of the transfer function of the mechanical speed of the induction motor. s is the operator of LAPLACE.

The closed loop transfer function is given by:

$$G_{BF}(p) = \frac{G_{\Omega}[K_{p\Omega}s + K_{i\Omega}]}{s^2 + G_{\Omega}[K_{p\Omega} + p_{\Omega}]s + G_{\Omega}K_{i\Omega}} \quad (16)$$

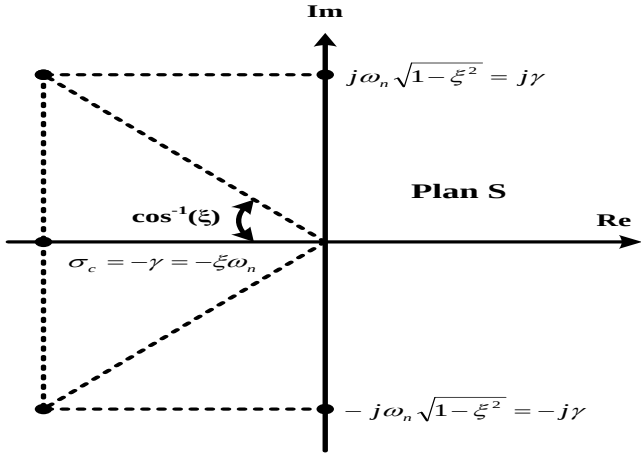


Fig. 5. Principle of the pole placement method.

The regulator coefficients are obtained by the pole placement method. We chose two conjugate complex poles, to simplify the calculations, and we imposed a damping coefficient ξ so that the real part and the imaginary part are equal as shown in Figure (5).

From Figure (5) we can write the two desired poles as follows:

$$s_{1,2} = -\sigma_c \pm j\omega_n\sqrt{1-\xi^2} = \gamma(-1 \pm j) \quad (17)$$

Where:

σ_c : The real part of the pole to be placed.

ω_n : The non-damped pulsation.

The calculation of σ_c and ω_n is based on the improvement in the closed-loop response time, three times over the open-loop time. The closed loop time constant is given by :

$$\tau_{BF} = \frac{\tau_{BO}}{3} \quad \text{with} \quad \tau_{BO} = \frac{3}{p_{\Omega}} \quad (18)$$

With:

τ_{BF} : The closed loop time constant.

τ_{BO} : The open loop time constant.

The closed loop response time is given by:

$$t_{rep5\%} = \frac{3}{\sigma_c} = \frac{3}{\tau_{BF}} \quad (19)$$

So we can calculate σ_c and ω_n by:

$$\sigma_c = \xi\omega_n \quad (20)$$

Finally, the desired polynomial can be described as follows:

$$P_d = (s - s_1)(s - s_2) = s^2 + 2\gamma s + 2\gamma^2 \quad (21)$$

By identifying the denominator of the transfer function of equation (16) with the desired polynomial P_d , we find:

$$\begin{cases} K_{p\Omega} = \frac{2\gamma - p_{\Omega}}{G_{\Omega}} = 2\gamma J - f \\ K_{i\Omega} = \frac{2\gamma^2}{G_{\Omega}} = 2\gamma^2 J \end{cases} \quad (22)$$

2.2.2. Flux Controller Design

The block diagram of the flux control loop is shown in

Fig.4.10.

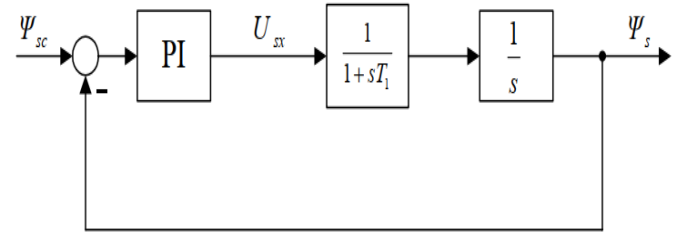


Fig. 6. Stator flux magnitude control loops

The optimal value of proportional gain is:

Flux controller proportional gain, $K_{pf}=200$

Integral gain of the flux controller, $K_{if}=1200$

2.2.3. Torque Controller Design

The block diagram of the torque control loop is shown in Fig. 7.

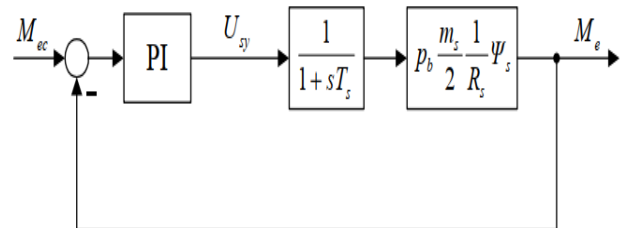


Fig. 7. Block diagram of the torque control loops[5]

The optimal value of proportional gain is:

Torque controller proportional gain, $K_{pt}=2$.

Integral gain of the torque controller, $K_{it}=150$

Tableau 2.Parameters of the induction motor.

<i>IM</i>	
Nominal power, $P_{g,n}$ [kW]	2
Nominal frequency, $f_{g,n}$ [Hz]	50
Stator resistance, R_s [Ω]	4.85
Stator leakage inductance, L_{ls} [H]	0.016
Rotor resistance, R_r [Ω]	3.805
Rotor leakage inductance, L_{lr} [H]	0.016
Cyclical mutual inductance, L_m [H]	0.258
Inertia, J [kg.m ⁻²]	0.031
Viscous friction coefficient, f [N.m.sec.rad ⁻¹]	0.00114
Number of pole pairs, p	2

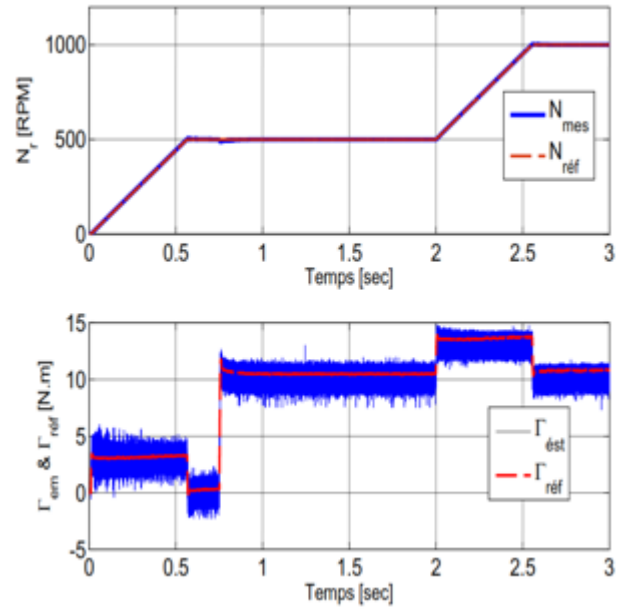
Tableau 3.Parameters of the classic DTC command & DTC-SVPWM

<i>DTC control block</i>	
Proportional gain of the speed controller, $K_{p\Omega}$	1
Integral gain of speed controller, $K_{i\Omega}$	15.872
Torque controller proportional gain, K_{pt}	2
Integral gain of the torque controller, K_{it}	150
Flux controller proportional gain, K_{pf}	200
Integral gain of the flux controller, K_{if}	1200
SVM switching frequency [Hz]	2000
Flux hysteresis band, $\Delta\phi$	0.01Wb
Torque hysteresis band, ΔC_{em}	± 0.5 N.m

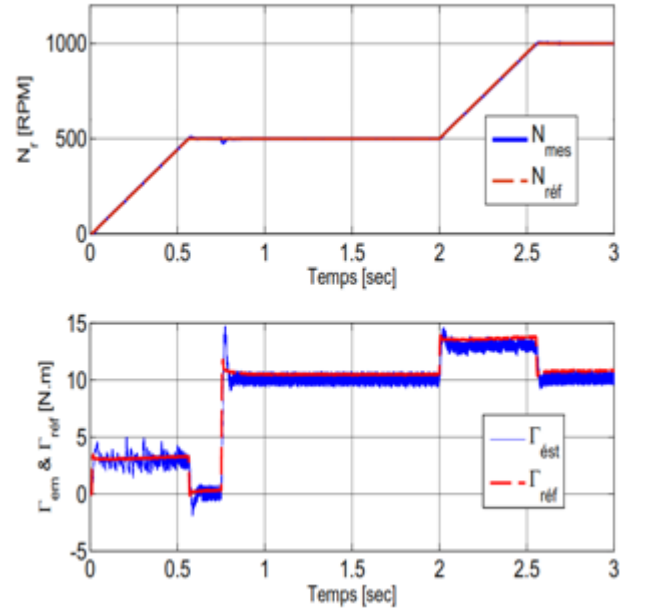
3. RESULTS AND DISCUSSION:

Figure (6) shows the simulation result of the electromagnetic torque for a 10Nm set point step at time $t = 0.75$ sec. The width of the hysteresis band of the torque comparator is in this case fixed at ± 0.5 and that of the flux at ± 0.01 . Through this simulation, we see that the torque perfectly follows the set point value and remains in the hysteresis band for DTC-classic control. However, ripples have appeared on the torque response time. For the DTC-SVPWM control there is a clear improvement in the quality of the torque. We also observe, in the same figure, the speed response to a step of (500 RPM for t from 0 to 2 s and 1000 RPM with $t = 2$ to 3 s) which

shows that the DTFC-SVPWM command has a high dynamic performance without overshoot at start-up.



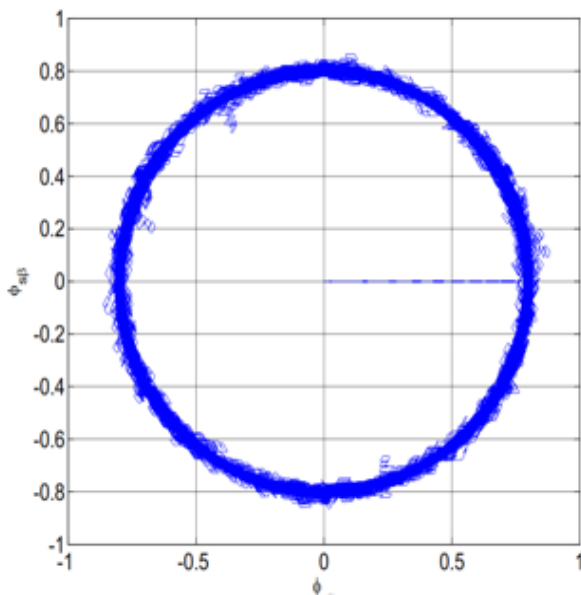
(a) classical-DTC



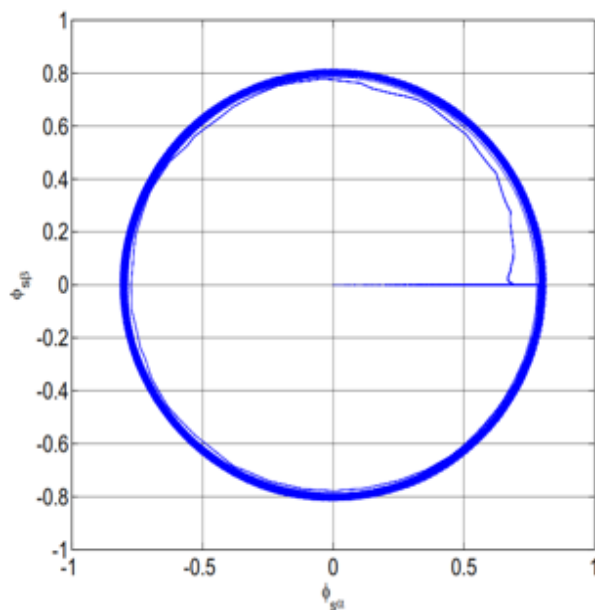
(b) DTFC-SVPWM

Fig.8. Response of the motor rotation speed as well as the electromagnetic torque

Figure (7) shows the circular stator flux path respectively for the classic DTC control, DTFC-SVPWM applied to a two-level inverter. The stator flux modulus reaches the value of 0.8Wb. Plotting the flux $\phi_s\alpha$ of the direct axis α against the flow $\phi_s\beta$ of the quadratic axis β takes the form of a circle. However, poor quality for DTC-classic compared to DTFC-SVPWM command



(a) classical-DTC



(b) DTFC-SVPWM

Fig.9. stator flux

4. CONCLUSIONS

This paper presented a Comparative study between SVPWM-DTC and Classical DTC applied to Induction Motor. for the classic DTC command, we observe a strong ripple on the torque with a deformed flux because the switching frequency of the inverter is not fixed while the implementation

of a command 'Direct Torque Control (DTC)' associated with a 'Space Vector Pulse Width Modulation (SVPWM)' effectively provides a fixed switching frequency which limits the range of the disturbance spectrum. So a good performance has been obtained by the DTFC-SVPWM.

5. ACKNOWLEDGMENT

I am indebted to my friend Dr Seddik zemmit for support and assistance.

Furthermore, I thank my colleagues from the Sustainable Development and Computer Science Laboratory (LDDI) for their support and friendly atmosphere. Finally, I would like thank to my whole family, particularly my parents for their love and patience.

6. REFERENCES

- [1] L.Baghli, "Modélisation et commande de la Machine Asynchrone, notes de cours," 2005.
- [2] D. Y-A-Chapuis, "commande direct de couple d'une machines asynchrone par le contro directe de son flux statorique," *journal de physique DL T 5,N°6*, 1995.
- [3] A. T. e. A. A. Houari Merabet Boulouiha, "Contrôle Direct Du Couple DTC-SVPWM Pour Une Génératrice Asynchrone A Cage D'écureuil Raccordée A Une Turbine Eolienne A Vitesse Variable," *Second International Conference on Power Eelectronics and Electrical Drives ICPEED '12 Oran à USTO-MB*, 2012.
- [4] Shilpa Susan Peter and Sandhya P, "Comparison of Classical DTC Scheme and a Simplified DTC Scheme with Flux Optimization for an Induction Motor Drive," *International Research Journal of Engineering and Technology (IRJET)* 07-July-2016.
- [5] Marcin Żelechowski, M. Sc, "Space Vector Modulated – Direct Torque Controlled (DTC – SVM) Inverter – Fed Induction Motor Drive," 2005.
- [6] J. Kang, S. Sul, "New direct torque control of induction motor for minimum torque ripple and constant switching frequency," *IEEE Transaction on Industry Applications*, Vol. 35, no. 5, pp. 1076-1082, septembre/October 1999.
- [7] Abdelkarim Ammar, Amor Bourek, Abdelhamid Benakcha, "Sensorless SVM-Direct Torque Control for Induction Motor Drive Using Sliding Mode Observers", *Brazilian Society for Automatics-SBA* 2016
- [8] ABDELKRIM Hamza & ELGHARBI Kamel, "Commande Directe du Couple DTC-SVM d'une Machine Asynchrone (MAS)" 2016 /2017
- [9] Abdelmalik Bendaikha1, Salah Saad, Abdelhak Abdou, Mabrouk Defdaf , Yahia Laamari, "A Study of SVM-DTC and Conventional DTC for Induction Motors Drive Fed by Five-level Inverter", *European Journal of Electrical Engineering*, Vol. 21, No. 1, February, 2019, pp. 85-91
- [10] Jagdish G. Chaudhari, Dr. M. V. Aware, Dr. S. G. Tarnekar, "Improved Direct Torque Control Induction Motor Drive", *IEEE International Conference power electronics*, 2006.
- [11] Abdesslem. Chikhi, Mohamed Djarallah, Khaled.Chikhi, "The Direct Torque Control of Induction Motor to Basis of the Space Vector Modulation"
- [12] G.S. Buja, and M.P. Kazmierkowski, "DTC of PWM Inverter-Fed AC Motors - A Survey", *IEEE Transactions on Industrial Electronics*, vol 54, pp. 744-757, 2004.
- [13] N.R.N. Idris and A.H.M.Yatim, "Direct torque control induction machine with constant switching frequency and reduced torque ripple", *IEEE transaction of industrial electronics*, vo.51, pp. 758-760, 2004.