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Open Loop DTC-SVM Control of Wind Conversion Chain output inverter

L. Bouras
Electrotechnique department
University of 20 Aout 1955 Skikda
Laboratory LES Skikda, Algeria
Bouras_nour @yahoo.fr

F. Bourourou
Electrotechnique department
University of 20 Aout 1955 Skikda
Skikda, Algeria
Farescdt2@yahoo.fr

M. Mordjaoui
electrotechnique Departement
University of 20 Aout 1955 Skikda
(LES) Skikda, Algéria
Mordjaoui_mourad@yahoo.fr

Abstarct — **The presented paper deals with the implementation of the direct torque control DTC for the synchronous machine supplied with a rectifier installed on the output of the PMSM after the voltage regulation loop. And the study and control of output voltage of a conversion chain based on wind conversion PMSM using a PI controller integrated into the system, and presents a mathematical model that allows the simulation of all under the Matlab environment, this with an open loop regulation, to show the effectively of this kind of control in the amelioration of the power quality.**

***Keywords - DTC; PMSM*; wind power; PI; Simulation; inverter; SVM.**

I. INTRODUCTION

System control is the control follow a reference system using a command Although adapted to the behavior and characteristics of adjusted system. The literature presents several command structures, from simple to more elaborate structures. The choice of a correction structure among many others may be guided by various criteria including simplicity of implementation, the continuation of the deposit and the disturbance rejection.

In general, each technique is directed to a particular class process. Current techniques can be divided into two main groups: conventional techniques (PI, PID, state feedback, etc.) and unconventional techniques.

In other side the The direct torque control (DTC) proposed by Takahashi in1986 and Deponbrock in 1988 is a solution of the vectorial control problems [1]. The current rise of the technique of vectorial control of the machines with AC current encourages the development of new strategies for the static inverters control.

In the choice of a strategy of pulse width modulation, a vectorial approach of the inverter which offer a direct bond with the transformation used in modern controls. Thus the methods known as space vector modulation (SVM) appeared.

The variation of the commutation frequency according to the speed and of the torque of a few tens of HZ at low speed with a few KHZ average speed in the direct torque control led us to make resorts to the SVM where we can maintain the commutation frequency constant. The vectorial PWM is the reference strategy. Its principle is the continuation of the voltage vector. In this article we developed the DTC with SVM based on hysteresis regulator.

Our study presents the architecture "structure" of regulating the voltage delivered by a PMSM driven by a wind conversion chain by a PI regulator, after we present the model of each part of the conversion chain and the results of wind variation influence on the stability of PMSM output voltage amplitude. To supplied a PMSM from the rectifier installed on the output of the conversion chain via a power inverter controlled by DTC with SVM technique to minimize the commutation losses.

II. DESCRIPTION & MODELING OF THE CONVERSION CHAIN

Fig.1 present an overall scheme which describe the various essential parts dedicated to the conversion of the of the wind power into electrical energy based on permanent magnet synchronous machine mechanically coupled with a wind turbine via a reduction gear, the latter is driven by a wind profile that will be modeled.

Figure 1. Wind conversion Principle.

From the distribution point of view wind is necessary in wind project, through it we can estimate the rate of electrical energy production and profitability of the system operated so knowledge of dynamic properties of the wind are crucial to the study the entire chain as the power conversion wind under optimal conditions is the cube of the Wind speed [2].

Wind speed can be modeled as a fractional scalar evolves over time.

$$v_v = f(t) \tag{1}$$

Wind speed can be represented as a function of harmonics as in (2). [2].

$$v_v(t) = A + \sum_{n=1}^{i} a_n \sin(b_n w_v t)$$

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(2)

$$v_v = 11 + 0{,}2\sin(0{,}10477t) + 2\sin(0{,}2665t) + \sin(1{,}2930t) + 0{,}2\sin(3{,}6645t) \quad (3)$$

This equation represent an uncertain wind profile evolve around a known medal value

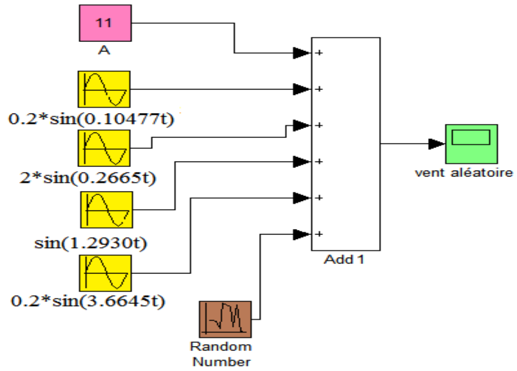

Figure 2. Simulation bloc of uncertain wind profile.

A. Wind turbine modeling

The wind turbine is a three-dimensional, with complex shapes in motion, immersed in a flow air; it converts the wind's kinetic energy and delivers mechanical power characterized by a rotating speed and mechanical torque and rotation [3].

Figure 3. Input and output model of wing.

The kinetic energy of a mass of air that moves with a velocity V is: [6]

$$E_c = \frac{1}{2} m V^2 \quad (4)$$

(5) Give the instantaneous power given by the turbine

$$P_v = \frac{1}{2} \rho S V^2 \quad (5)$$

So we obtain the power the coefficient, which is the ratio between the extracted power and the available power Pe

$$C_p = \frac{P_e}{P_v} \quad (6)$$

(7) give the get back wind power

$$P_e = 0{,}5 \rho S C_p V^3 \quad (7)$$

C_p : Power coefficient

ρ: Density of air (1.25 Kg/m3)

S : area swept by the turbine

V : Wind speed

The wind turbine is characterized by its curve Cp=f(λ) With λ is the ratio between the tip peripheral speed of blades and the wind speed

$$\lambda = \frac{R\Omega}{v} \quad (8)$$

Ω : angular speed

R : turbine rayon

According to the characteristic of the wing; Cp=f(λ) is represented by 6 order polynomial as:

$$C_p = C_c . \lambda \quad (9)$$

$$C_c = a_0 + a_1\lambda + a_2\lambda^2 + a_3\lambda^3 + a_4\lambda^4 + a_5\lambda^5 + a_6\lambda^6 \quad (10)$$

B. PMSM Modeling

After the mathematical development. The PMSM model in the Parck frame will be as presented in (11) and (12).

$$V_d = R_s i_d + L_d \frac{d}{dt} i_d + \omega_r L_q i_q \quad (11)$$

$$V_q = R_s i_q + L_q \frac{d}{dt} i_q + \omega_r (L_d i_d + \phi_f) \quad (12)$$

Where (13) present the matrice of Parck

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin(\theta) & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (13)$$

(14) and (15) give the coupling electromagnetic equations

$$\phi_d = L_d i_d + \phi_f \quad (14)$$

$$\phi_q = L_q i_q \quad (15)$$

(16) and (17) represent the electromagnetic Torque and the mechanical equations

$$C_{em} = \frac{3}{2} P \left[(L_d - L_q) I_d I_q + I_q \sqrt{\frac{3}{2}} K_1 \right] \quad (16)$$

$$J \frac{d\Omega}{dt} + f\Omega = C_{em} - C_{eol} \quad (17)$$

The simulation chain without control system we provides an output voltage fig.5 which it varies according to the wind profile variation fig.4, which makes the operation this kind of the conversion chain unnecessary in industrial applications.

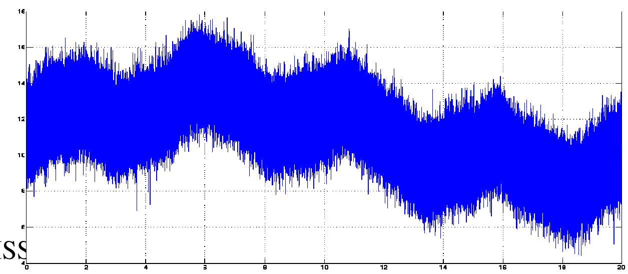

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Figure 4. uncertaint wind profile.

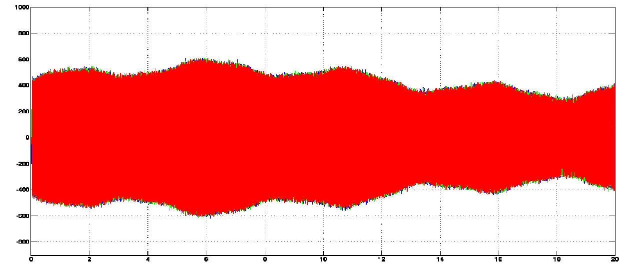


Figure 5. PMSM output voltage with uncertain wind profil.

This requires us to use structures controls that have been a stable voltage at the output system regardless of variation of the energy of the wind.

III. PROPOSED STRUCTURE

The voltage regulation of the conversion chain presented can be performed with the help of a PI regulator based on the diagram in fig.6.

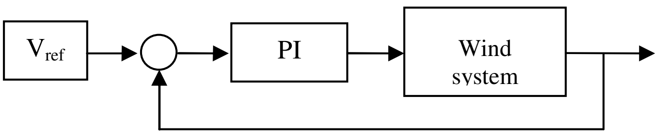


Figure 6. PI regulator control principle.

This will be implanted in the system according to the diagrams shown by fig.7 where the regulator based on the obtained error after the Parck transformation of the output voltages V_a, V_b, V_c to the rotor refrence frame V_d, V_q.

This regulator will be integrated with our wind conversion chain as it is presented on fig.7.

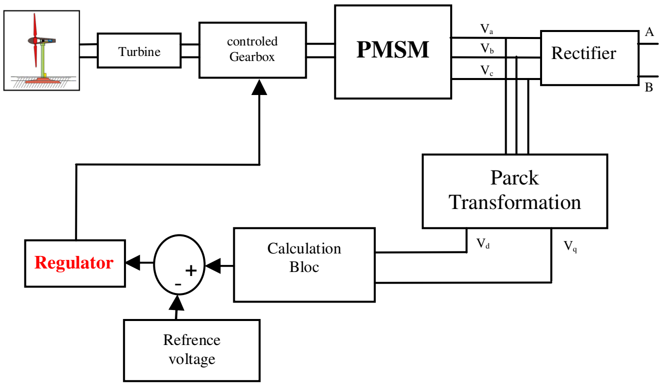


Figure 7. wind chain voltage regulation principle.

The principle of the proposed regulation is to make a Parck transformation of the PMSM output voltages which will subsequently injected into a block calculation, we can extrere current amplitude voltages supplied by the machine, to be compared with a reference voltage is desired that gives us an error.

A PI regulator generates a command according to the last error to controlling the drive speed of the PMSM with a controlled gearbox which provides controllable a rapport of variable transformation between the rotational speed of the turbine and the generator speed.

Where the power circuit and DTC control bloc coupled to points A and B is presented on fig.8

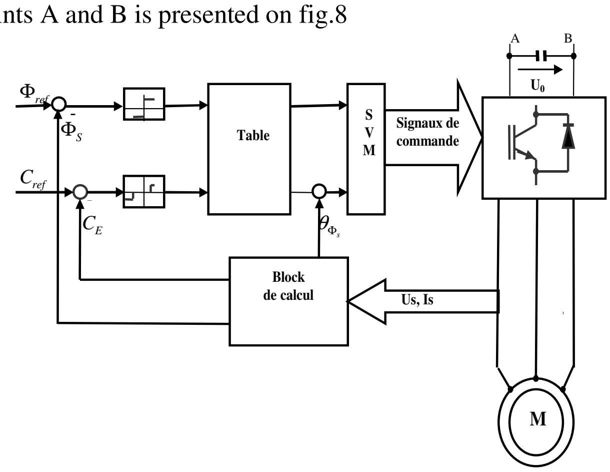


Figure 8. DTC with SVM4 based on hysteresis regulator.

This topology is based on the power inverter given by the fig.9, according to the position of the possible switches, this inverter, give eight configurations. [4]

Fig.10-a present the eight voltage vectors of the stator in the αβ frame, it is noticed that the vectors $\vec{v}_7$ and $\vec{v}_0$ are null. When in the others, they define six angular sectors of π/3 rad. If we refrence sector by an index I, so vectors can be express by the following relations:

$$\begin{cases} \vec{v}_i = \sqrt{2/3} \cdot V_c \cdot e^{\left((i-1)\frac{\pi}{3}\right)}, \quad i = 1..6, \\ \vec{v}_7 = \vec{v}_0 = \vec{0} \end{cases} \tag{18}$$

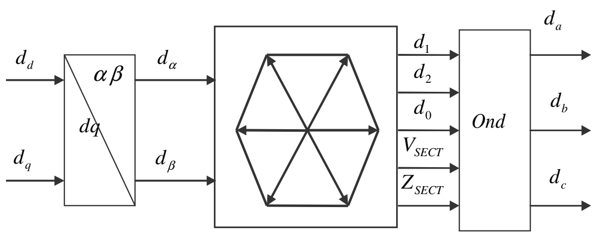
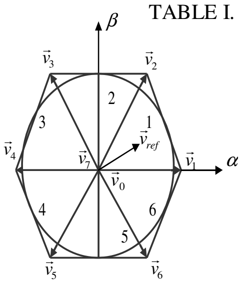
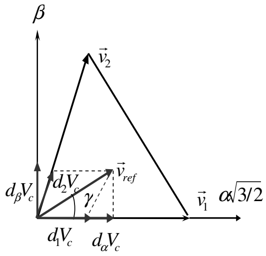


Figure 9. Regulation diagram of the vectorial PWM applied to the DTC

4	5	6
$\begin{bmatrix} -1 & 1/\sqrt{3} \\ 0 & -2/\sqrt{3} \end{bmatrix}$	$\begin{bmatrix} -1 & -1/\sqrt{3} \\ 1 & -1/\sqrt{3} \end{bmatrix}$	$\begin{bmatrix} 0 & -2/\sqrt{3} \\ 1 & 1/\sqrt{3} \end{bmatrix}$





(a) (b)

Figure 10. Diagram of the vectorial control of the inverter output voltages

The eight voltages vectors which we defined correspond to the voltage which we can measure if the switches remained in a state corresponding to a given vector. But, the purpose of the method is to obtain tension according to the imposed references. For that, we will apply over one modulation period T a vector $\vec{v}_i$ during a time T_i then a vector $\vec{v}_{i+1}$ during T_{i+1}. In this manner, on average, we can obtain any desired tension.

Fig.10-b shows the principle of application of each vector according to its weight. Which we summarize by the following relation:

$$d_1.\vec{v}_1 + d_2.\vec{v}_2 = \vec{V}_{ref} = m.V_c.e^{jy}$$
$$d_1 + d_2 + d_0 = 1 \tag{19}$$

If we take the case of the first sector, by projection we obtain the passage matrice of the vectors weights dα and dβ defined in reference mark αβ towards d1 and d2 (application during time of $\vec{v}_i$ and $\vec{v}_{i+1}$ vectors)(fig.10-b).

$$\begin{bmatrix} d_1 \\ d_2 \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{3} \\ 0 & 2/\sqrt{3} \end{bmatrix} . \begin{bmatrix} d_\alpha \\ d_\beta \end{bmatrix} \tag{20}$$

The following table summarize the passage matrices for the various vectors.

TABLE I. VARIOUS SECTORS PASSAGE MATRICE

Secteur : 1	2	3
$\begin{bmatrix} 1 & -1/\sqrt{3} \\ 0 & 2/\sqrt{3} \end{bmatrix}$	$\begin{bmatrix} 1 & 1/\sqrt{3} \\ -1 & 1/\sqrt{3} \end{bmatrix}$	$\begin{bmatrix} 0 & 2/\sqrt{3} \\ -1 & -1/\sqrt{3} \end{bmatrix}$

Once the vectors validity periods are calculated. It is necessary to determine the switches commutation moments, the problem being to determine several commutations for the same fundamental input. Each sequence produces harmonics and different losses in commutation.

Being given that the commutation losses are proportional to the current amplitudes in commutation, the SVM is an algorithm which minimizes the commutation losses of the advantage while being based on the choice to commutate the weakest current in module.

If we supposes that the voltage vector located in the first area, we use that vectors $\vec{v}_1$, $\vec{v}_2$ and $\vec{v}_0$, and using a band of hysteresis "B_{xi}" we request the $\vec{v}_1$ vector to decrease current in the phase B and C or the $\vec{v}_2$ vector to increase the currents in the phases A and C. which is enough to keep the three currents inside the hysteresis band.

A second larger hysteresis band "B_{x0}" is used to indicate the passage reference vector from an area to another. The commutation table is given by table 2, it gives the position and the amplitude of the voltage vector according to the hysteresis regulator outputs of the torque and flux.

TABLE II. COMMUTATION TABLE

Ccpl	Cflx	tension Vector	
		Angle $\Delta\theta$	*Amplitude* $\|V\|$
-1	0	-2/3π	2/3 Vc
	1	-1/3 π	2/3 Vc
0	0 1	0	0
1	0	2/3π	2/3 Vc
	1	1/3π	2/3 Vc

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IV. SIMULATION OF THE PROPOSED STRUCTURE

fig.11 present a simulation bloc of the proposed structure implanted under Matlab simulink.

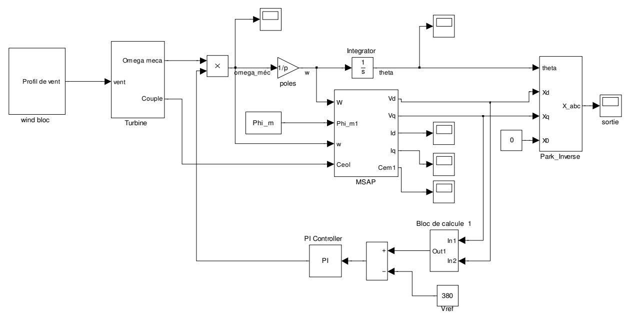


Figure 11. simulation Bloc of wind chain controled by PI regulator.

The integration of the controller with the wind conversion chain can stabilize the output voltage around the desired reference (V_{ref} = 380 v) fig.12, whatever the variation of the wind and ensures the possibility of operating a quality energy can be injected to the electric network.

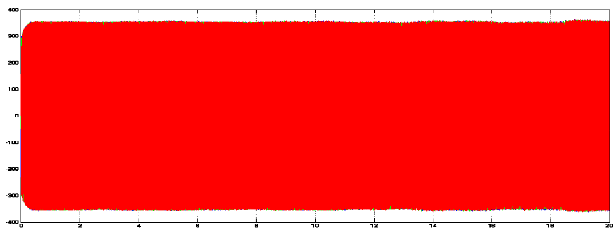


Figure 12. PMSM output voltage with PI regulation.

A. *regulation effectivenes:*

Fig.13 shows the robust of the PI controller in the pursuit of reference with a short response time (0.5s) and an acceptable depassement.

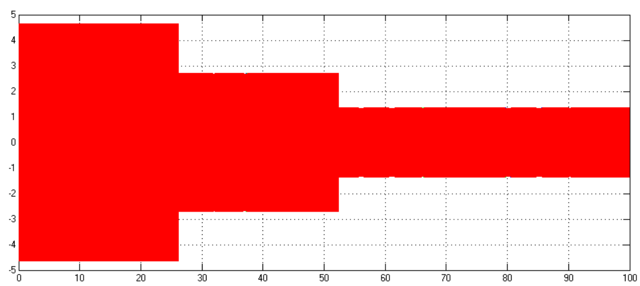


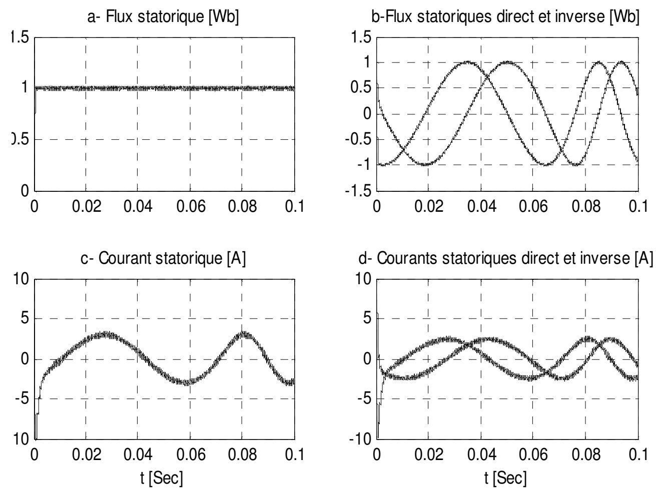
Figure 13. PMSM Output voltage with a variable refrence controled by PI.

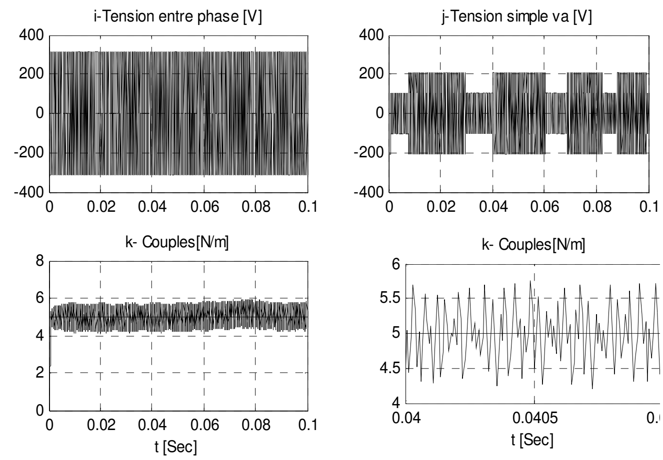
Where the DTC simulation results presented on the fig.14 show that the torque exceeds the upper limit and lower of the control band. A significant ondulation rate is noted but the flux reaches its reference with a small depassement of the control band. That is with the application of the null voltage vector without the knowledge of the initial rotor position and consequently that of stator flux.

In addition it is noted that the commutation frequency is variable on the other hand the results with the SVM in fig.8 show for a time of T_e=10 µs and a commutation frequency of Fs=10 KHz the dynamics of flux for the synchronous machine without mechanical sensor.

The stator flux trajectory is practically circular. The amplitude remains in the defined fork by the hysteresis band. In the same way for the stator current trajectory on the figure f. figures (b and d) show the evolution of the stator flux and currents vector components in the Concordia reference frame.

Thus the torque does not exceed the upper limit and lower control band. In addition we notes well in the fig.16 that the commutation frequency of the command with SVM is constant compared to that of DTC.





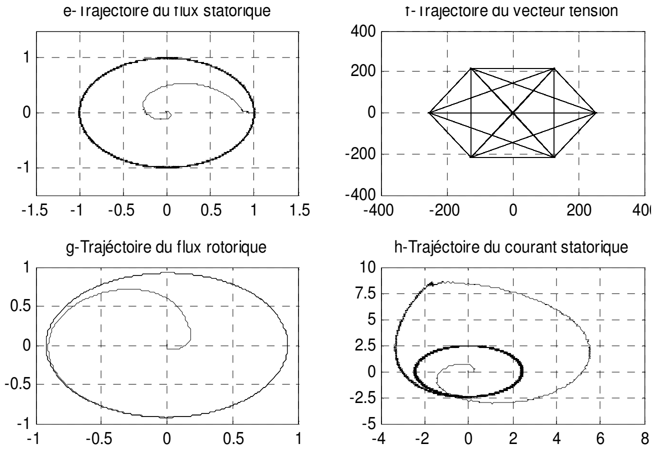


Figure 14. Simulation results of the DTC applied to the SM

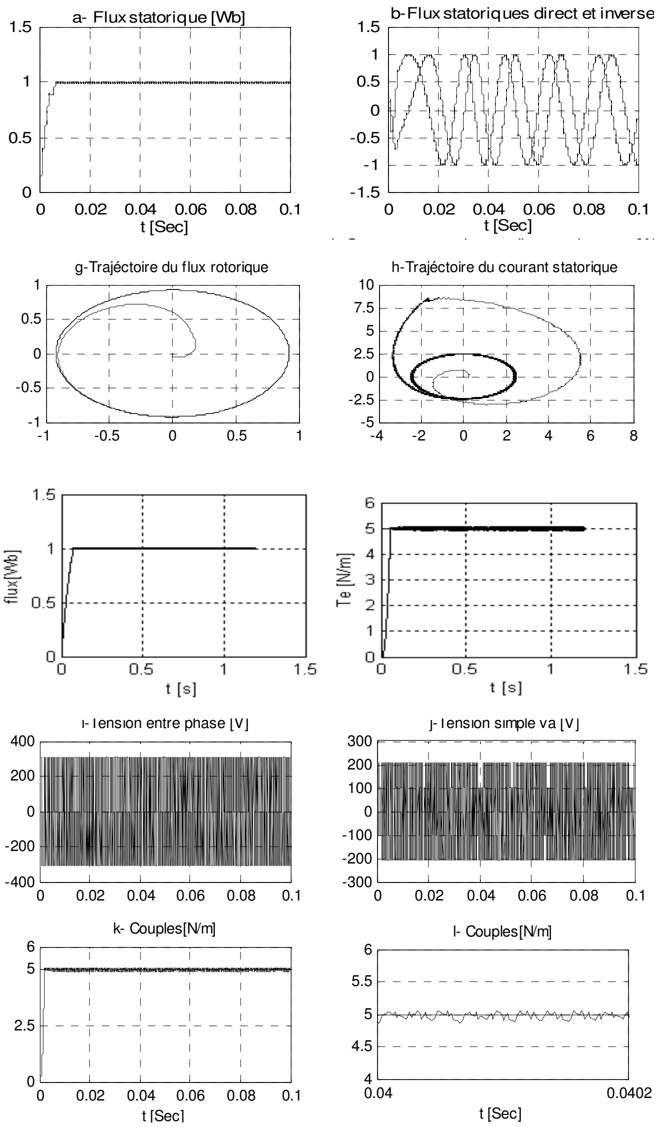


Figure 15. Simulation result of the DTC with SVM+HYS

V. CONCLUSION

The work presente a strategy the command of the voltage inverter with the direct torque control, which is a combination between the vectorial PWM and the hysteresis, the comparison between this strategy and the DTC thus show that the commutation frequency in the DTC is variable were in the SVM it is constant, this algorithm has the advantage of reducing the commutations losses.

This work allows us about simulate the dynamic behavior of the wind conversion chain using a random wind profile similar to a profile of the true wind, the waveform of the voltage output obtained helped us to give the look of a technique to make it comply with regulations production of energy required (constant amplitude), carrying use a PI controller, the heart of the control loop proposed.

REFERENCES

[1] L. Bouras and M. Kadjouj ‘‘Vector Control of Induction Motor BasedSpace Vector Modulation" Volume 50, Number 1/2009 pp.37-41 (Acta Technica Napocensis – Electronics and Telecommunications). Rromania

[2] T.ahmed et A.abd el ghani et A.mouhamed et E.najib etC.magherbi, “La commande de la puissance active et réactive d’une éolienne à géneratrice synchrone,” ,” Revu des Energies Renouvlables, vol. 10, 2010, pp.327-335

[3] SBA. Abdelbaki, "Commande en temps réel d'un filtre actif de puissance utilisant la technique par logique floue", thèse de magistère, spécialité automatique, Université Ferhat Abbas- Sétif, Algerie, 2005

[4] L. Bouras and M. Kadjouj ‘‘ Commande directe du couple appliquée à la MAS : analyse et prévision de la fréquence de commutation’’ CEE’06 : 4th International Conference on Electrical Engineering 07 - 08 November 2006 Batna University, Algeria

[5] A. Mirecki,’Etude Comparative de Chaine de Conversion d’energie Dédiées à une Eolienne de petite puissance’, Thèse de Doctorat, Institut polytechnique de Toulouse, Avril 2005.

[6] Y.Soufi et T.Bahi et M.F Harkat et M.Mohamedi, “Optimisation De La Conversion De L’energie Eolienne,” Revu des Sciences Fondamentales et Appliquées, vol. 2, pp. 201–210, April 2010.

[7] H.faida et J.Saadi et M.Khaider et S.El Alami et M.Monkadel, “Etude et analyse des données du vent en vue de dimensionner un système de production d’énergie éolienne cas d’un site au nord du maroc,” Revu des Energies Renouvlables, vol. 13, 2010, pp.477–483.

[8] H.chennoufi et L.lamri et L.ahmed et K.abdemalek , “Contrôle d’une géneratrice synchrone à aimant permanant dédiée à la conversion de l’énergie éolienne par la commande directe du couple,” Revu des Energies Renouvlable, , 2010, pp. 115–124.

[9] Chee-Mun Ong,”Dynamic Simulation of ElectricMachinnery Using Matlab/Simulink”.Prentice Hall PTR.1997.

[10] D. Casadei, G. Grandi and G. Serra, ‘‘Study and implementation of a simplified and efficient digital vector controller for induction motors.’’ in Proc .EMD’93. Oxford. U.K. Sep.8-10, 1993, pp.196-201.

[11] D. Casadei, G. Serra and A. Tani, ‘‘Stator flux vector control for high performance induction motor drives using space vector modulation,’’ Electromotion, vol.2 no.2, pp.79-86.

[12] D. Casadei, G. Serra and A. Tani, ‘‘constant frequency operation of a DTC induction motor drive for electric vehicule.’’in proc, ICEM’96, vol.III, Vigo, Spain, Sept, 10-12, 1996,pp224-229.

[13] V. Himamshu Prasad, “Analysis and comparison of space vector modulation schemes for three leg an four leg voltage source inverters.” Master of science in electrical engineering Blacksburg, Virginia 1997.

[14] C. E.Cuadros O, “Modified space vector modulation for a zero voltage transition. Three phase to dc bidirectional converter.” Master thesis of science in electrical engineering Blacksburg, Virginia 96.

[15] B. H Kwan, Tae Woo Kim, “A novel SVM based hysteresis current controller” IEEE. Trans.power electronic, vol. 13, n02 March 89.

[16] N.Celanovic, “Space vector modulation and control of multilevel converters.” PHD. thesis in electrical engineering and computer engineering Blacksburg, Virginia 2000.

[17] Mk A H.Walt, “Control design and analysis of advanced inductor motor electrique vehicule drive.” Master thesis in science engineering Blacksburg, Virginia 1997.

[18] R.Rajendran, N.Devarajan, “Dynamically Reconfigurable Control Structure for Three Phase Induction Motor Drives”, International Journal of Power Electronics and Drive System (IJPEDS), Vol.2, No.1, pp. 43-50, March 2012.