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Control of a PMSG Dedicated to Wind Energy Conversion System Based on SVM

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***Abstract*— The interest for the use of renewable energies has increased, because of the increasing concerns of the environmental problems. Among renewable energies, wind energy is now widely used. Wind turbines based on an asynchronous generator with a wound rotor present the inconvenience of requiring a rings system and brooms and a multiplier, inferring significant costs of maintenance. To limit these inconveniences, certain manufactures developed wind turbines based on synchronous machines with large number of pairs of poles coupled directly with the turbine, avoiding using the multiplier. If the generator is equipped with permanent magnets, the system of rings and brooms is eliminated. The control of the permanent magnet synchronous generator (PMSG) can be affected with the implementation of various techniques. This paper present a new approach mainly based on the control strategy of power production system based on the PMSG. In fact, a mathematical model that simulates in the environment Matlab of the chain was established with the introducing of control techniques, such as direct torque control (DTC) based on space vector modulation (SVM) to control the load side converter (LSC), the turbine speed control and the DC-bus voltage ensured by PI regulator. To show the performance of the used correctors, some simulation results of the system were presented and analyzed.**

***Keywords*— PMSG, DTC, SVM, Wind turbine**

I. INTRODUCTION

It is well known that electric power generation using wind energy source is receiving considerable attention, since it is inexhaustible, safe, environmental friendly and able to supplying significant amount of power [1]. Wind power generation systems are growing rapidly in renewable energy applications [2].Along with such a quick growth, an enormous volume of research and development is being undertaken in the academy and industry on wind energy conversion systems (WECS). Different configuration of grid-connected WECS have been reviewed in a numerous papers and books based on generators kind and the employed power electronic converter [3,4]. However, there are, referring to the best knowledge of authors, insufficient review and comparative studies on off-grid WECS [5]. Several control techniques are mentioned in the literature, such as, in variable-speed WECS or maximum power point tracking (MPPT) technique which has been used to adjust the speed of the generator. For induction motor (IM) fed by WECS, direct field oriented, indirect field oriented, and direct torque controls are used to ensure an efficient control. In this work, a direct torque control (DTC) strategy has been opted for, because it is quite different from that of the field-oriented control (FOC) or vector control, which does not need complicated coordination transformations and decoupling calculation [6,7]. Also it presents other advantages which can be summarized by a torque response time diminution, even better than vector controller and absence of modulator block, as well as other controllers such as proportional-integral-derivative (PID) for flux torque.

In the same framework, the direct-drive permanent magnet wind turbine system has been a research hotspot in recent years, and the permanent magnet synchronous generator (PMSG) has been widely used for its good control precision, high efficiency, low maintenance and many other advantages [8].

This paper is directed towards modelling and behavioural Matlab simulation, after the description of the respective conversion chain based on PMSG considering the wind profile variation influence on the generator output voltage amplitude. It proposes to introduce different adequate controls techniques, acting on the power electronic interface so as to feat the system in order to have good energy efficiency and performance.

II. DESCRIPTION & MODELING OF THE CONVERSION CHAIN

Figure 1 present an overall scheme of the various essential parts dedicated to convert wind power to electrical energy. This conversion is achieved by the use of a permanent magnet synchronous machine mechanically coupled with a wind turbine via a reduction gear driven by a wind profile that will be modeled.

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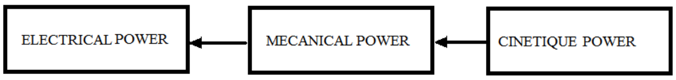

Fig.1. Wind power conversion principle

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 operated system, so knowledge of dynamic properties of the wind are crucial to the study of 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 [2] by the following equation:

$$v_v(t) = A + \sum_{n=1}^{i} a_n \sin(b_n w_v t) \tag{2}$$

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

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

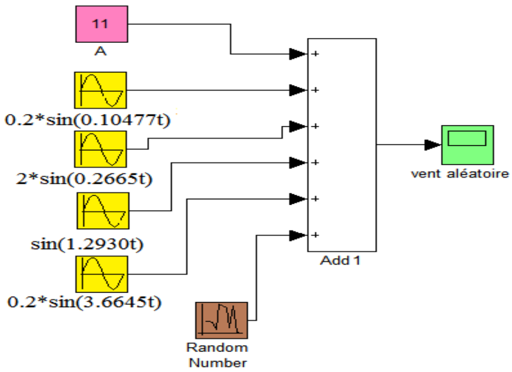

Fig.2. Uncertain wind profile simulion bloc

A. Wind turbine modeling

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

Fig.3 Model of wing input and output

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

$$E_c = \frac{1}{2} mV^2 \tag{4}$$

(5) Give the instantaneous power given by the turbine

$$P_v = \frac{1}{2}\rho S V^2 \tag{5}$$

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

$$C_p = \frac{P_e}{P_v} \tag{6}$$

(7) give the get back wind power

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

C_p : Power coefficient

ρ: air Density (1.25 Kg/m^3)

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

$$\lambda = \frac{R\Omega}{v} \tag{8}$$

Ω : angular speed

R : turbine rayon

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

$$C_p = C_c.\lambda \tag{9}$$

$$C_c = a_0 + a_1\lambda + a_2\lambda^2 + a_3\lambda^3 + a_4\lambda^4 + a_5\lambda^5 + a_6\lambda^6 \tag{10}$$

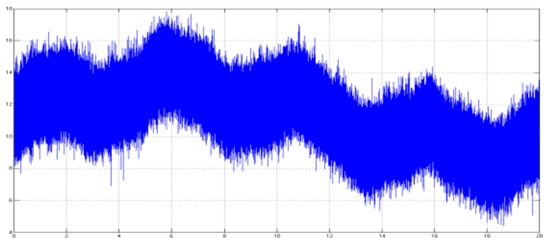

Fig.4. Uncertain wind profile.

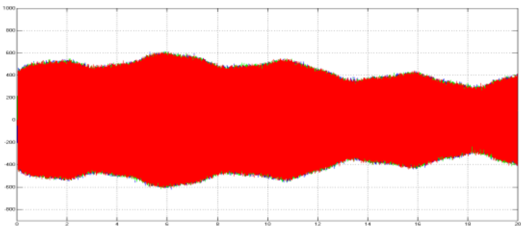

Fig.5. PMSM output voltage due to uncertain wind profile.

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

III. PROPOSED STRUCTURE OF THE CONVERSION CHAIN

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

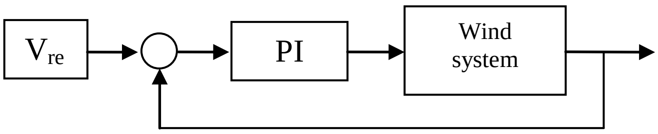


Fig.6. PI regulator control principle.

This will be implanted in the conversion system according to the diagrams shown by fig.7 where the regulator based on the obtained error after the Park 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.

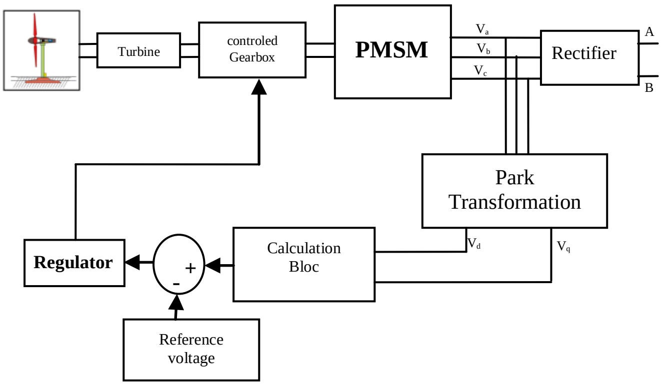


Fig.7. wind chain voltage regulation principle.

The principle of the proposed regulation structure is to make a Park transformation of the PMSM output voltages which will subsequently injected into a calculation block; thereafter we extract actual voltages supplied by the machine in order to compare the obtained amplitudes with the desired reference voltage that gives a minimum error.

The PI regulator generate command according to the last error to controlling the PMSM speed drive with a controlled gearbox which provide controllable 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

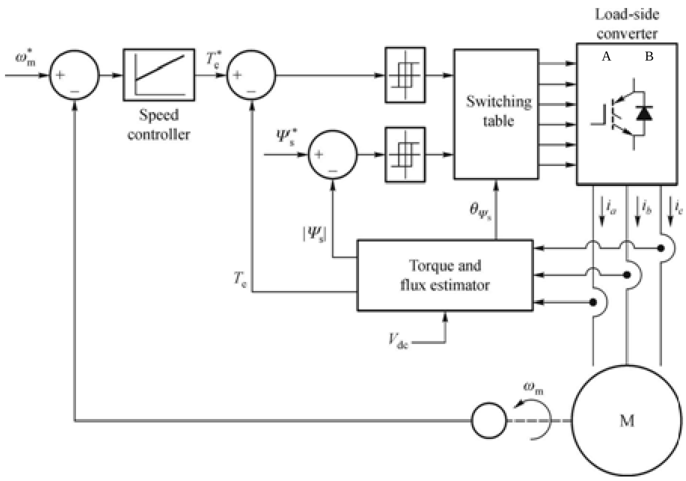


Fig.8. DTC with SVM4 based on hysteresis regulator.

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 the others, define six angular sectors of π/3 rad. If we note the sector by an index i, then the vectors can be expressed by the following relations:

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

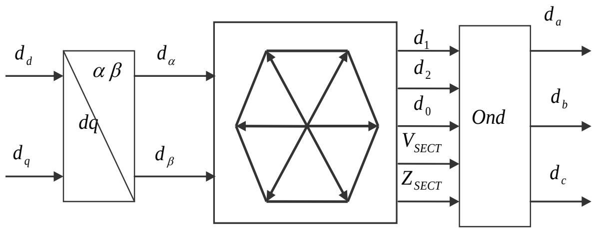
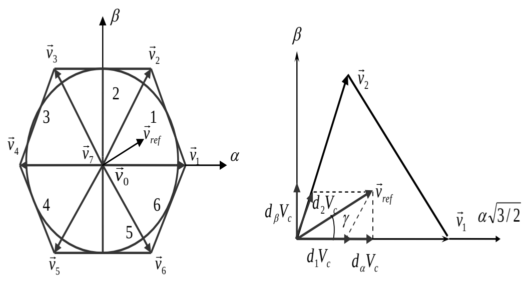


Fig.9. Regulation diagram of the vectorial PWM applied to the DTC



(a) (b)

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

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The eight voltage 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:

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

If we take the case of the first sector, by projection we obtain the passage matrix 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).

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

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

TABLE.1 VARIOUS SECTORS PASSAGE MATRICE

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

Once the validity of vectors 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 $\vec{v}_1, \vec{v}_2, \vec{v}_0$, and by the use of an hysteresis band 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.2 COMMUTATION TABLE

Ccpl	**Cflx**	**Tension Vector**	
		Angle $\Delta\theta$	***Amplitude*** $\lvert V \rvert$
-1	0	-2/3π	2/3 Vc
	1	-1/3 π	2/3 Vc
0	0	0	0
	1		
1	0	2/3π	2/3 Vc
	1	1/3π	2/3 Vc

IV. SIMULATION OF THE PROPOSED STRUCTURE

Simulation Bloc implanted under Matlab Simulink of a wind chain controlled by PI regulator is shown in figure 11.

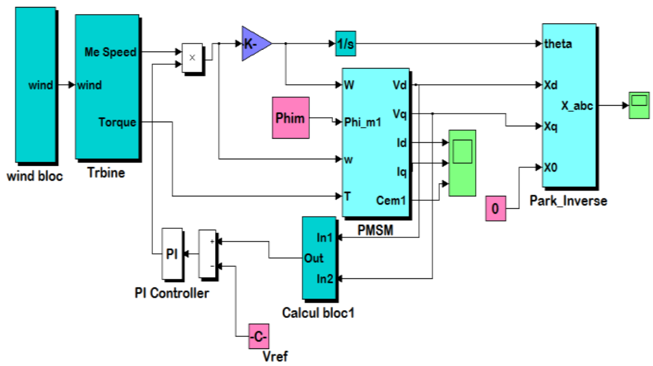


Fig.11. Simulation Bloc of wind chain controled by PI regulator.

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

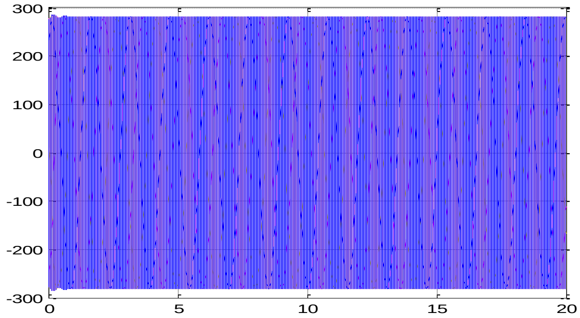


Fig.12. PMSM output voltage with PI regulation.

A. REGULATION EFFECTIVENESS:

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

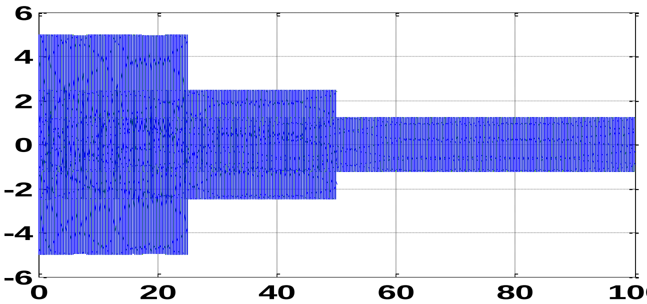


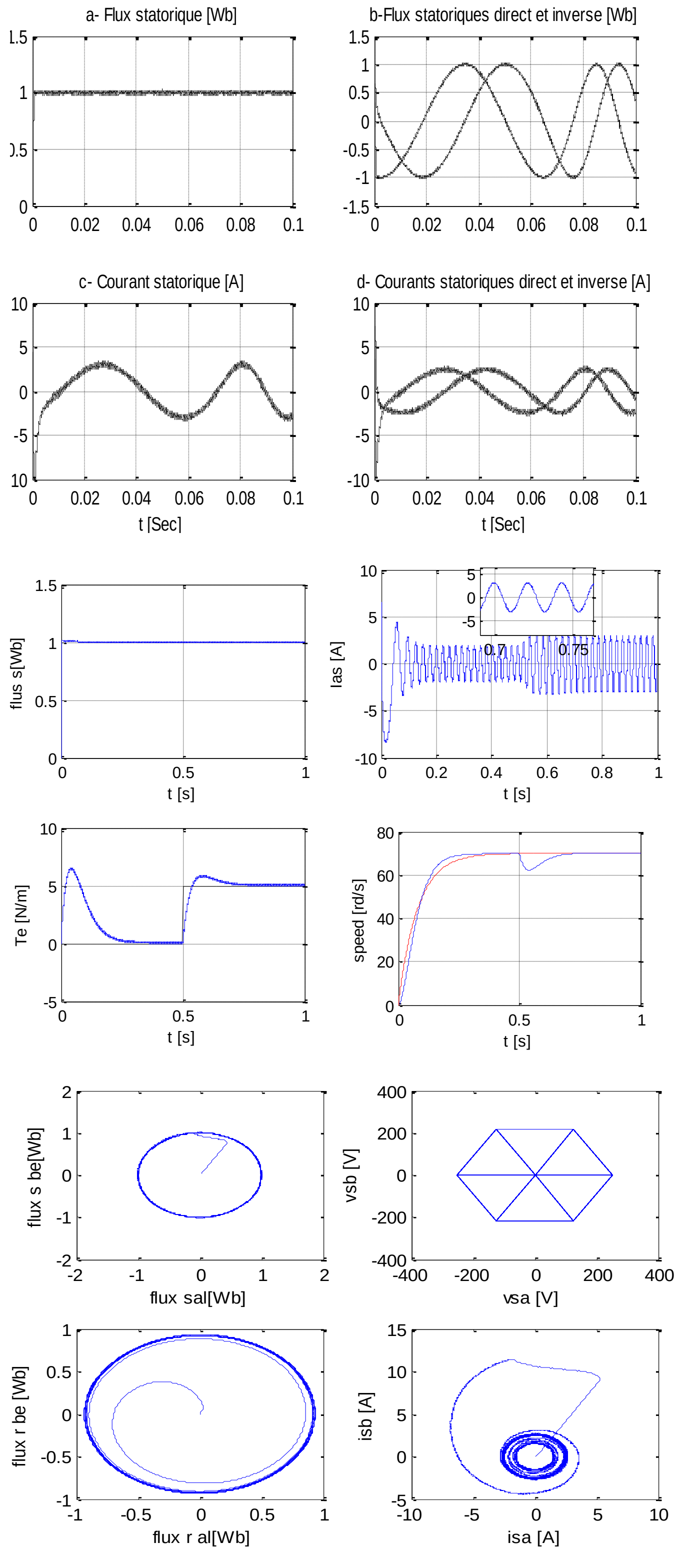
Fig. 13. PMSM Output voltage with a variable refrence controled by PI.

The DTC simulation results presented on the figure 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 figure 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 and lower limit of 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.



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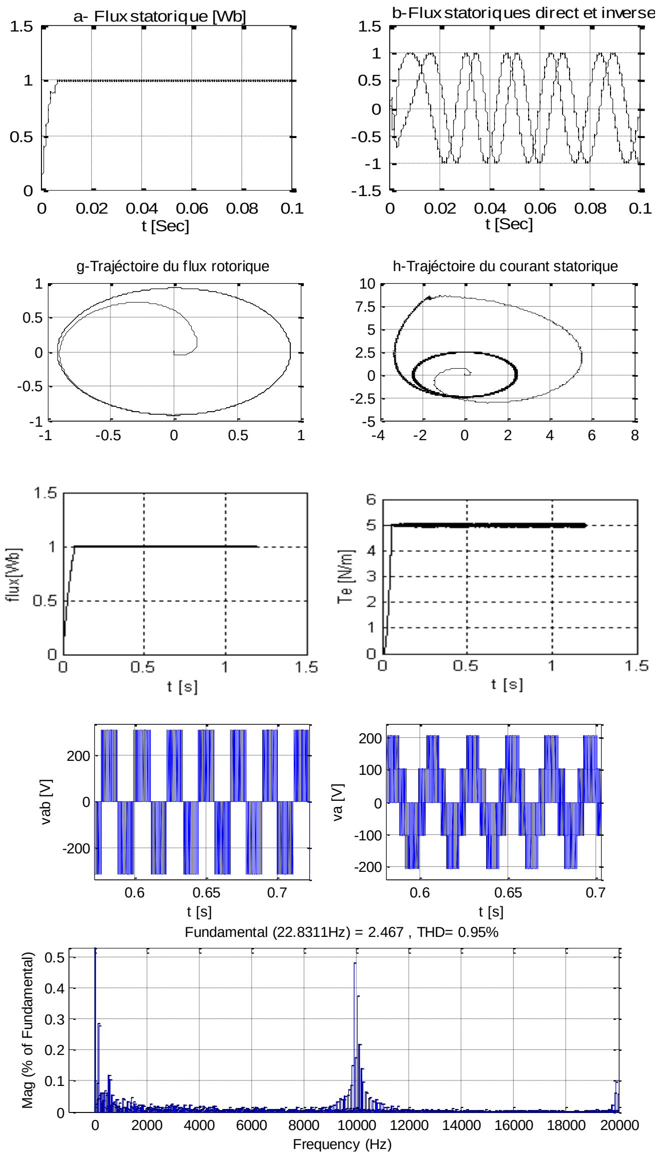

Fig. 15. Simulation result of the DTC with SVM+HYS

V. CONCLUSION

In this study we have present a strategy the command of the inverter voltage with the direct torque control technique, which is a combination between the SVM. The obtained Results by 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.

Also the work allows us to 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 obtained output voltage helped us to give the look of the 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.

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