COMPARATIVE STUDY WITH AND WITHOUT SENSOR OF SPEED OF A COMMAND BY DTC OF A VARIABLE RELUCTANCE MOTOR WITH SMOOTH STATOR

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ABSTRACT
This paper describes a comparative study with and without sensor of speed by simulation of an control by the Direct Torque Control of switched reluctance motor (SRM) with a smooth stator and massive rotor. Because of the design and reluctant effect between the stator and rotor, the torque of is pulsating. The great difficulty is to control these undulations which are undesirable and generally vermin with the good performance of the device.

Keywords: DTC, switched reluctance motor (SRM), modeling, with sensor and without sensor of speed,

1. INTRODUCTION
In recent years, especially the need for variable speed in servo applications has increased the interest to theSRM. The major reasons of these interests for SRM are robustness, high efficiency, low cost, high speed, simple structure, easy to maintain, high torque in low speed, simple power converter circuits with reduced number of switches, excellent controllability and smaller dimension of the motor in comparison to the other motors.

Although it has been known for a long time, SRM has not been very often used because of acoustic noise that comes from torque dip and detection of rotor position [KIM]. SRM has been started to be used with the development of power electronic devices. If the problems of the SRM can be solved,

The method of control of order DTC is based on the algorithmic principles of the vectorial orders applied to the electric actuators of the asynchronous, synchronous motor type and other motorizations with alternative source. Here, decoupling between flow and the couple are obtained by preparing a logical table of the orders of commutation of the inverter (sa,sb,sc) [Kioyyur].

The calculation of the flow quantities (ϕsq, ϕsd,) and torque is obtained from the acquisition and processing, through the Concordia transform, only electrical voltage (uo) and currents (isa , isb). Controls dynamic flux quantities (ϕref) and torque (Celm) are made from two simple hysteresis comparators and a calculation of the sectoral location of the flux [Ameur].

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2. PRINCIPLE OF OPERATION OF A MRV
The operation of variable reluctance machines is based on the principle of magnetic attraction. It can be described from a single basic structure similar to that presented in Figure 1 [KIM].

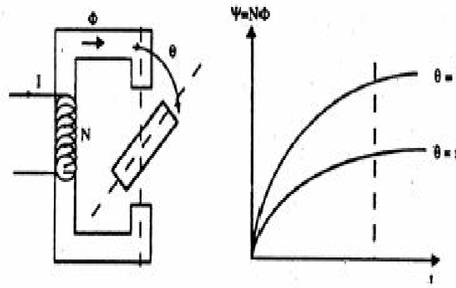

Figure1: Elementary structure of a réluctant system

Consider the simple magnetic circuit of Figure 1, consisting of a fixed ferromagnetic cylinder and a mobile ferromagnetic part of which the axis is indicated by the angle θ,

The transition from an I in N turns of the coil, creating a magnetomotive force fmm defined by [KIM]:

$$F = NI$$

The Flow through the N turns of the coil depends on the strength of different portions of the circuit, this resistance is called reluctance R, it is the sum of the reluctances of the cylinder head and the moving part, as that of the air-gap which is generally dominant.

The reluctance can be represented by another parameter known as perméance, and defined by [KIM] :

$$P = \frac{1}{R}$$

By considering a flux variation Ψ compared to current I, we can write [KIM]:

$$\Psi = L\,I = N^2 I\,P$$

L: is the inductance of the coil clean..

For a current I in rolling up, the variation of the air-gap defines two limiting values of flow (see Figure 1). For θ=0 and θ=π , flow is maximum, and it becomes minimal for θ = ± π/2.

This structure has two remarkable rotor positions. A position of opposition, for which the magnetic circuit presents a maximum reluctance.

A position of conjunction where the magnetic circuit has a minimal reluctance [Kioyyur].

If the rotor is in an intermediate position between the opposition and the conjunction, the injection of a current in the exciting winding modifies the state of the system which tends to minimize its energy and thus to obtain a minimal reluctance. Thus the rotor turns of an angular step to take the position of conjunction.

3. MODELING OF THE SRM

The model of the SRM with smooth stator is [Kioyyur], is made up mainly in the electric equations of the machine given by:

$$\begin{aligned} v_d &= R_s i_{sd} + \frac{d\phi_d}{dt} - p\frac{d\theta}{dt}\phi_q \\ v_q &= R_s i_{sq} + \frac{d\phi_q}{dt} + p\frac{d\theta}{dt}\phi_d \end{aligned} \qquad (1)$$

Where flows following the axis d and the axis q are given by:

$$\begin{bmatrix} \phi_d \\ \phi_q \end{bmatrix} = \begin{bmatrix} L_d & 0 \\ 0 & L_q \end{bmatrix} \begin{bmatrix} I_{sd} \\ I_{sq} \end{bmatrix} \qquad (2)$$

The matrix form of (1) is:

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = R_s \begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} + \begin{bmatrix} L_d & 0 \\ 0 & L_q \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} + p\Omega \begin{bmatrix} 0 & -L_q \\ L_d & 0 \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} \qquad (3)$$

The torque of a SRM can be expressed by:

:

$$C_e = p(\phi_d i_{sq} - \phi_q i_{sd}) = p((L_d - L_q) I_{sd} I_{sq}) \qquad (4)$$

On the other hand, the mechanical equation of the machine is:

$$J\dot{\Omega} = C_e - C_r - f_r\Omega \qquad (5)$$

4. DESCRIPTION OF THE DIRECT TORAUE CONTROL

The method of Direct Torque Control (DTC) was introduced in 1985 by Takahashi and Depenbrock especially for asynchronous machines [KIM]. Then, several studies have developed more precise knowledge of this command. This technique of command was also applied on the variable reluctance machines. The direct control of a couple of MRV is based on identifying "direct" in the command sequence used to switch a voltage inverter. This choice is usually based on the use of hysteresis regulators whose function is to control the system state, namely here by the amplitude of stator flux and electromagnetic torque. This type of strategy is therefore classified in the category of orders in amplitude, In opposed to the laws of contracts in duration more traditional and time-based adjustment of the average value of voltage vector pulse width modulation (PWM) [Takahashi],[Zhong].

The method of estimate consists to measure the currents and the stator tensions of the machine, and to employ them in the law of direct order of couple (DTC). This method uses the figuration of order flow and torque for determining the sequence of power to impose the three-phase PWM inverter vector [Takahashi] and [Zhong].

The classical DTC proposed by Takahashi, is based on the following algorithm:

1. To divide the time domain during Te reduced period of duration (of the order of tens of μs);
2. For each shot clock, measuring the line currents and voltages in phase of SRM;
3. Reconstruct the components of stator flux vector;
4. Estimate the electromagnetic torque of SRM, through the estimate of the vector of flow stator and the measurement of the currents of lines;
5. To introduce the difference Δ□s between the flow of reference □s* and the flow estimated □s^ into a comparator at hysteresis at two levels, which generates at its output value +1 to increase flow and 0 to reduce it.

5. APPLICATION OF THE DTC TO THE SRM

The reference mark related to the stator makes it possible to estimate flow and the couple, which allows the knowledge of the amplitude and the position of stator flow.

$$\begin{cases} \phi_{s\alpha} = \int_0^t (v_{s\alpha} - R_s i_{s\alpha})dt \\ \phi_{s\beta} = \int_0^t (v_{s\beta} - R_s i_{s\beta})dt \end{cases} \qquad (6)$$

The DTC is deduced while being based on the two approximations described by the formulas (7) et (8) [Takahashi] :

$$\bar{\phi}_s(k+1) \approx \bar{\phi}_s(k) + \bar{V}_s T_E \quad \rightarrow \Delta\bar{\phi}_s \approx \bar{V}_s T_E \qquad (7)$$

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$$\begin{cases} \hat{\phi}_s = \sqrt{\hat{\phi}_{s\alpha}^2 + \hat{\phi}_{s\beta}^2} \\ \angle \hat{\phi}_s = arctg \dfrac{\hat{\phi}_{s\beta}}{\hat{\phi}_{s\alpha}} \end{cases} \qquad (8)$$

According to the formula (6), we can neglect the voltage drop private to the resistance of the stator. With this assumption, the variation of the flux is proportional to the applied stator voltage.. A voltage applied in the same direction as the flux vector increases the module to it and vice versa.

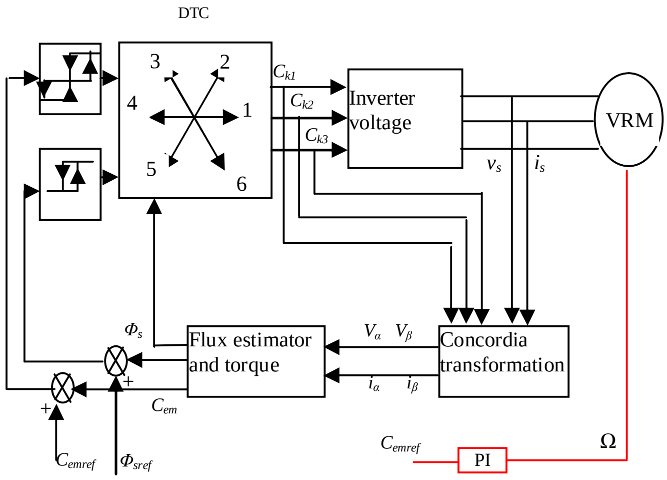

Figure 2: Diagram of an order From a DTC of a SRM Powered by a voltage inverter three-phase PWM sensorless From speed.

The DTC is based on the direct determination of the sequence of command used to switch a voltage inverter.

This choice is based on the use of hysteresis comparators whose function is to control the system state, namely the amplitude of stator flux and electromagnetic torque [Ameur], [Carlos].

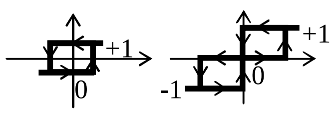

Figure 3: Hysteresis comparators used to control the flux and torque.

The equation (7) implies that the tip of the stator flux vector moves along a straight line whose direction is given by the vector of applied voltage, as shown in Figure (3).

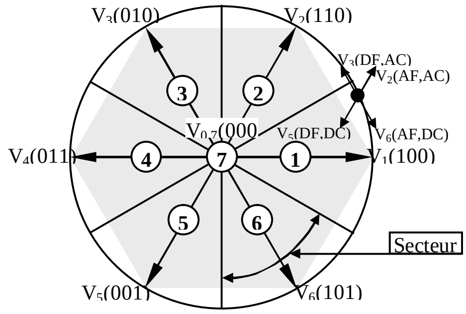

Figure 4: Evolution Of the extreme of ϕ_s

Table (I) presents the sequence for each position, knowing that the error between the reference flux and the estimated flux is introduced into a comparator with hysteresis at two levels, which delivers 1 if the error is positive and 0 if it is negative. Similarly, the error between the reference torque and estimated torque is introduced into a comparator with hysteresis at three levels, which delivers 1 if positive, 0 if zero, and -1 if it is negative [Ameur] and [Carlos].

Table 1: Table de localisation des vecteurs voltage

$\Delta\phi_s$	ΔC_e	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**
1	1	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_6	V_1	V_2	V_3	V_4	V_5
0	1	V_3	V_4	V_5	V_6	V_1	V_2
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_5	V_6	V_1	V_2	V_3	V_4

where, Si=1,…, 6 are the sectors of localization of the stator vector of flow

6. SIMULATION RESULTS

Presented in the following simulation results of an control by DTC of SRM, supplied by a three-phase inverter voltage vector to PWM. Without and with the regulation the speed which is done by a PI regulator.

For the same parameters of the regulator, we simulated a no load starting,step load change and we reversed the direction of speed.

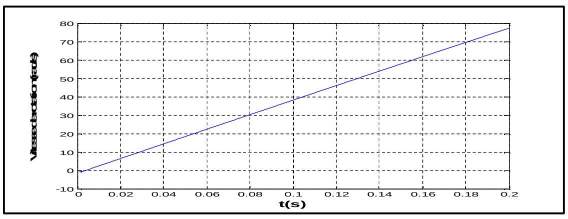

Figure.5: Starting without loop of regulation speed

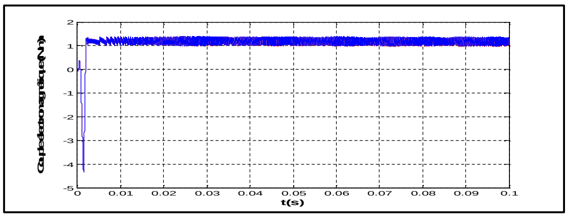

Figure.6: Electromagnetic torque (estimated and real)

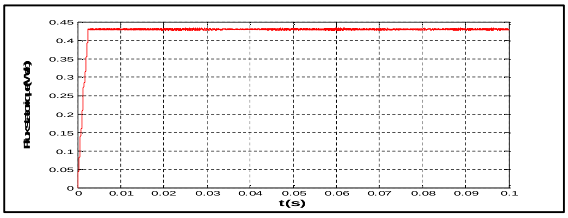

Figure.7: Stator flux (estimated and real)

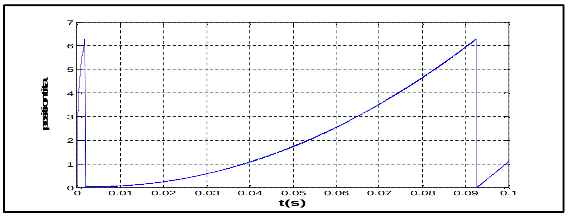

Figure.8 Evolution of the positon of the stator vector of flow (estimated and real)

The results of simulation presented by the Figures (5, 6, 7,8), for the starting without loop of regulation speed with a torque of reference of 1.2Nm, we find that the speed does not answer on the other increases and exceeds the value of 50 rad/s over against the stator flux (estimated and real) follows its reference of 0.43Web.

The results of simulation presented by the Figures (9, 10, 11 and 12), for the (void) starting with inversion of the direction of rotation at the moment 0,25s of 50 rad/s to -50 rad/s, We note that satisfies the speed without overshoot and during the reverse rotation with a short response time because the machine is void and that the inertia is low. With starting, the electromagnetic torque reaches its maximum value limited (5Nm) and stabilizes at a value of almost zero in the regime established.

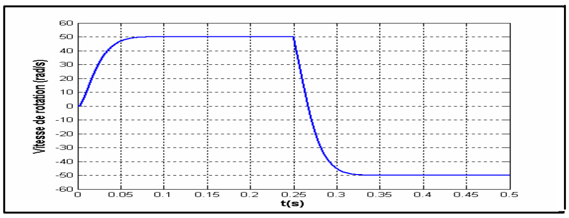

Figure.9: starting with inversion of the direction of rotation

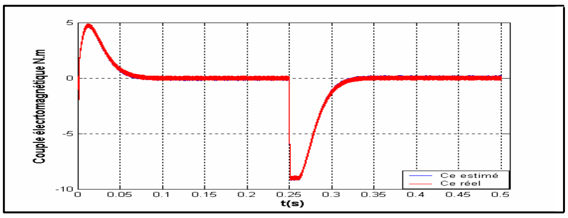

Figure.10: Electromagnetic torque (estimated and real)

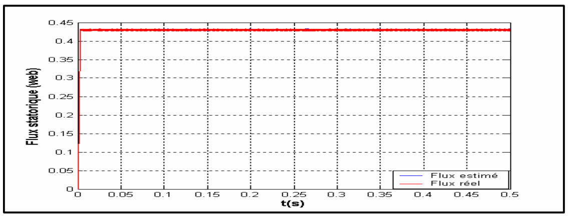

Figure.11: Stator flux (estimated and real)

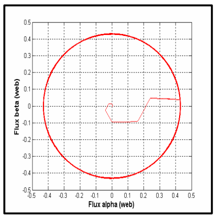

Figure.12: flux in the (α, β).

The following figures (13, 14, 15 and 16) show the introduction of a load at t = 2s. The machine is loaded by a resistant torque equal to (2 Nm). The electromagnetic torque reaches its maximum value limited (5 Nm) and stabilizes at a value of (2 Nm).

Note that the electromagnetic torque follows a decent record of the couple with relatively large undulations, while the flux follows well the reference speed and responds with a small overshoot at the introduction of resistant torque with a short response time. Figure (d) illustrates the flow in the (α, β).

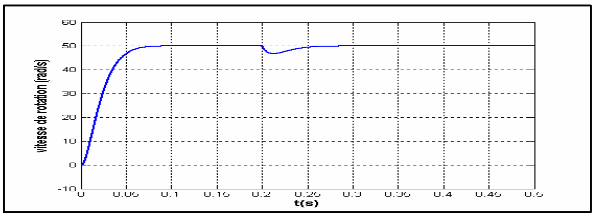

Figure.13: starting with introduction of a load

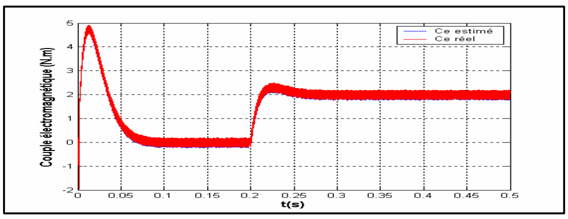

Figure.14 : Electromagnetic torque (estimated and real).

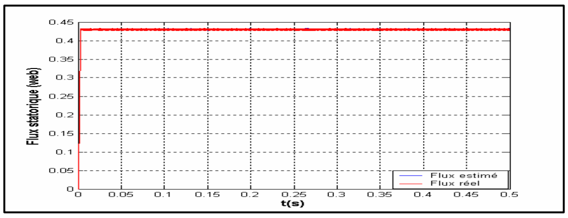

Figure.15: Stator flux (estimated and real)

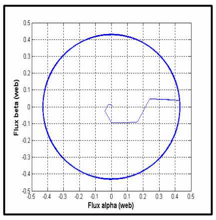

Figure.16 : flux in the (α, β).

7. CONCLUSION

In this article, we made a comparative study by simulation of the DTC applied to the reluctance variable machine with a smooth stator and massive rotor without and with the loop of the speed of the machine, and we showed that the machine meets soon start to empty and change of direction of rotation and the introduction of a resistant torque

Table 2: VRM parametrs [Zhong]

Symbole	Valeurs (S.I)
f	50
P_n	1000
p	2
r_s	1.0
L_d	0.072
L_q	0.028
J	0.003

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