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Evaluation of Electrical and Energetic Variables of Induction Motor Drives for Electric Vehicle

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ABSTRACT

Any energy and environmental effort have to deal with transportation. So, we find about 97% of all energy consumed by our cars, sport vehicles, vans, airplanes.. is still petroleum-based. [1]
The urgent need is to reverse resources for the next two decades in order to avoid serious global warming and oil depletion. Thus, we have to make our vehicles less polluting. The electric vehicle seemed to be an alternative solution that preserves clean and efficient propulsion. Otherwise, the progress of electric vehicle is rising slowly with hesitative steps for many reasons related to its problems such as the autonomy and the price.
Indeed, the major challenge of automobile manufacturers now and the researchers is to incorporate in the one hand this type of vehicle in our daily life and to improve in the other hand the autonomy of the batteries and the stability of its costs. Actually, this paper deals with the improvement of an induction motor efficiency used in electric propulsion.

Key words:- Electric vehicle, Induction motor, Optimization, Indirect Field control, SIMULINK.

I. NOMENCLATURE

p: Number of poles
Rs : Stator resistance (Ω)
Rr : Rotor resistance (Ω)
M =M_{sr}: Mutual inductance (H)
Ls : Stator inductance (H)
Lr : Rotor inductance (H)
τr = Lr/rr (s)
σ = (LsLr - Lm2)/Lr : Leakage factor (H)
Iqs : Quadrature stator current (A)
Ids : Direct stator current (A)
Vqs : Quadrature stator voltage (V)
Vds : Direct stator voltage (V)
Ce : Electromechanical torque (N·m)
C_r : Load torque (N·m)
θ_e : Electrical angle (rad)
ωe : Electrical frequency (rad/s)
ωr : Rotor speed (rad/s)
ωrm : Mechanical speed (rad/s)
ωsl : Slip frequency (rad/sΩ : mechanical speed N: Nominal speed (rpm)
ωe: Synchronous speed
φ_S: Stator flux linkage
φ_r :Rotor flux linkage
IFOC : Indirect Flux Oriented Control

II. INTRODUCTION

The motor, which drives the conventional vehicles, is called internal combustion engine (ICE) [5]. The vehicle is named the electric vehicle (EV) if an electric motor or a few electric motors are used to drive wheels of a vehicle. A system schematic of EVs is illustrated next in Fig. 1:

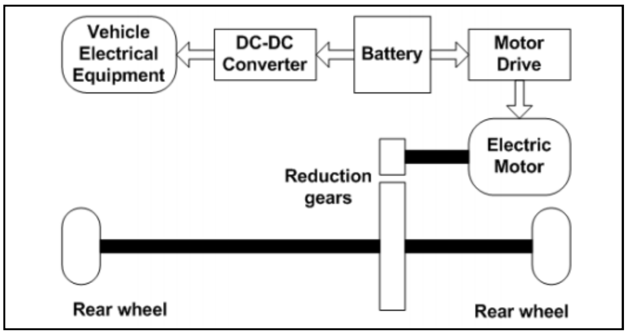


Fig. 1. Typical system of Electrical vehicle

The electric motor eliminates the necessity for a motor to be inactive while at a stop, it is allowed to produce large torque at low speed, and it offers a wide range of speed variations.
Researchers and automobile constructors had launched many challenges to integrate the electrical vehicle in our practical mobility practice. There for, they tried to increase the efficiency of electric drive used and reduce its cost in order to surmount major problems. There for, this paper deals with the optimization strategies of induction motor drive efficiency. Known of its simple construction, reliability, low

maintenance and cost, ability to operate in hostile environments induction motors are one of the best motor ever used in electric cars.

Speed variations of induction motors are achieved by changing the frequency of voltage. However, the improvement of electronic converters and variation of semi-conductors played an important role in the development of using this kind of motors. While, the implementation of control strategies this type of engine contains many inabilities such us the variation of machine parameters by motor saturation. Additionally, the disability of decoupling the flux and torque related to the current represents a permanent inability of asynchronous motors.

The control of induction motor is an area of research that has been in importance for major time now. Recent advances in this field have made it possible to replace the DC motor by induction machines, even in applications that demand a fast dynamic response.

Today, induction motor drive especially cage ones is the most mature technology among diverse motor to be widely accepted as the potential candidate for the electric propulsion [3]. Vector control of induction motors can decouple its torque control from field control [6].

Then to minimize the losses of the motor, we have to fix an optimal rotor flux reference. Thus, the optimization mechanism is based on the machine total losses expression.

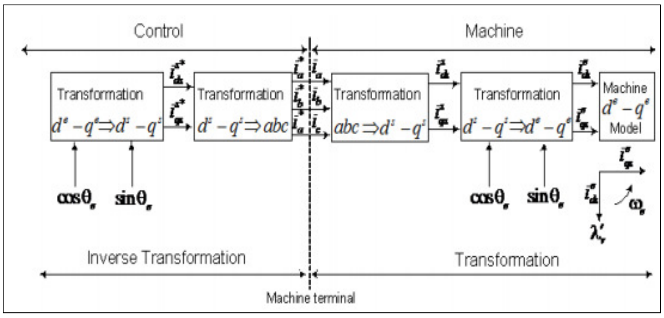
The present dissertation proposes a methodology for optimal design and uses it to design induction motor and improve its efficiency.

III. THE FIELD ORIENTED CONTROL OF INDUCTION MACHINE

The German F. Blaschke put vector control theory forward in 1971. It has been widely used in the field of modern electrical drive and became the mainstream of the AC Frequency Control System whit AC motor as its control object.

This technique equates AC motor to DC motor, which would derive the mathematical model and the induction motor torque control equation in rotor field-oriented rotating by coordinate transformation method. [7]

There are two essentially methods of vector control: one called the direct and the other known as the indirect one. These methods are different essentially by how the unit vector (cosθ_e) and (sinθ) is generated for the control. The execution of this method is explained next:



Whereas : λr′= rotor flux, (ia, ib, ic) are dictated by the currents (ia* ,ib* ,ic*) from the regulator. The machine terminal phase current (ia,ib,ic) are converted to i^s_{ds} and i^s_{qs} using the 3Φ/2Φ transformation. They are then converted to synchronous rotation represented by the vector components cos□$_e$ and sin□$_e$ just before applying the d^e-q^e machine model[4].

Indirect Field oriented control (IFOC), initiated in1970, is becoming the industrial control for induction motors torque [8]

The efficiency degrades mostly for two reasons: the variation of rotor resistance and operation to low loads used with a constant flux. For these reasons, a method was proposed to choose the optimal flux needed to minimize the total losses.

Induction motor drives are used without mechanical speed sensors at the shaft in order to have low cost and high reliability. To replace the sensor, the information on the rotor speed is extracted from measured stator voltages and currents at the motor terminals. It is then a decoupling torque and flux control method for ac motors. Using this technique, the induction motor will behave like a DC motor with independent control of torque and flux.[3] .The rotor voltage equations are given by:

$$\begin{cases} V_{ds} = R_s I_{ds} + \dfrac{d\varphi_{ds}}{dt} - \omega_s \varphi_{qs} \\ V_{qs} = R_s I_{qs} + \dfrac{d\varphi_{qs}}{dt} + \omega_s \varphi_{ds} \\ 0 = V_{dr} = R_r I_{dr} + \dfrac{d\varphi_{dr}}{dt} - \omega_r \varphi_{qr} \\ 0 = V_{qr} = R_r I_{qr} + \dfrac{d\varphi_{qr}}{dt} + \omega_r \varphi_{dr} \end{cases}$$

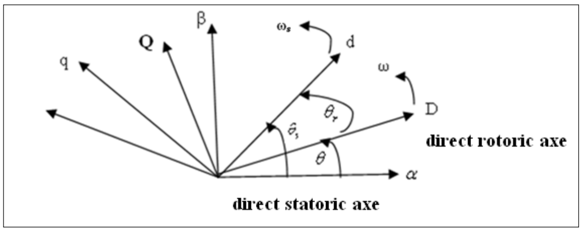


Fig. 2 d-q-axis system

In induction motor, we define different torque:

- The electromagnetic torque Ce.
- The load torque Cr.
- A torque of viscosity where $C_v = f\omega_r$ and f is the constant fluid viscosity.

So, we can write:

$$\begin{cases} C_e = \dfrac{3}{2} p \dfrac{M}{L_r} (\varphi_{dr} I_{qs} - \varphi_{qr} I_{ds}) \\ J \dfrac{d\Omega}{dt} + f\,\Omega = C_e - C_r \\ \dfrac{d\theta_r}{dt} = \Omega \end{cases}$$

For this control, the controller imposes the orientation of the rotor flux (φr) with respect to the d-axis of the frame (d,q). Since the flux φ is aligned with the d-axis, we have $\varphi_r = \varphi_{dr}$ and $\varphi_{qr}=0$ while $\omega_{sl}=\omega_r$. Substituting these relations in (1) leads to the following equations:

$$\begin{cases} C_e = \dfrac{3M}{2L_r} p\varphi_r I_{qs} \\ \omega_r = \dfrac{M}{\varphi_r \tau} I_{qs} \end{cases}$$

Since the rotor resistance and magnetizing inductance are known to vary rather more than the other parameters, a parameter adaptive techniques are often employed to adjust the values used in an indirect field-oriented controller.
With the IFOC, the field, the torque and the angular velocity sliding ω_r are function of the stator current (i_{ds},i_{qs}):

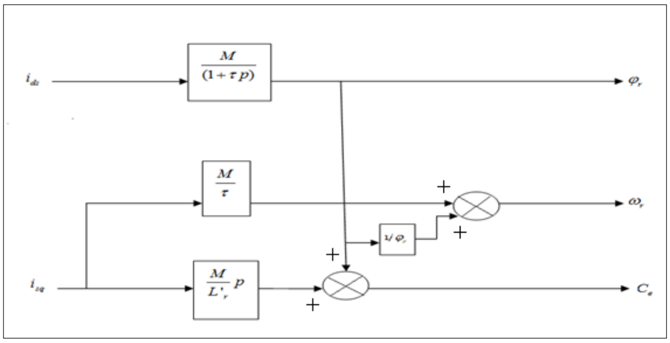


Fig. 3 Field oriented controller

IV. STRATEGIES OF ENERGY OPTIMISATION

To fix a stator current for a setting point seems to be so important to establish a variable field state and then enables optimized energy into electric chain drive. It is well acknowledged that the battery's anatomy of an electric vehicle is one of the major elements to improve in several researches. Hence, we focus in this dissertation on a strategy that optimizes losses and energy consumption. In the next paragraph, we will explain two strategies used to improve the use of induction machine in electric drive.

IV.1 Strategy S1:

The strategy S1 minimizes the component ids of stator current, which consequently reduce the Joules losses. Therefore, to every setting point (Ca, T, Ω, U_{bat}) we associate the current ids as low as possible to generate the lowest losses given by the equation:

$$P_{js} = 3R_s i_s^2 = R_s (i_{ds}^2 + i_{qs}^2)$$

Using the expression of torque (1) and with indirect field oriented control where:

$$\varphi_r = \varphi_{dr}; \varphi_{qr} = 0; k_t = P\frac{M^2}{L_r} = P(1-\sigma)L_s$$

$$\Longrightarrow \begin{cases} C_e = k_t i_{ds} i_{qs} \\ i_{qs} = \dfrac{C_e}{k_t i_{ds}} \end{cases}$$

Finally, we can impose a stator current is as :

$$i_s = \frac{1}{\sqrt{3}} \sqrt{i_{ds}^2 + \frac{(C_a + \frac{P_{meca}(\Omega)}{\Omega})^2}{k_t^2 i_{ds}^2}} \qquad (2)$$

Where the losses are given by: $P_{js} = R_s (i_{ds}^2 + \frac{(C_a + \frac{P_{meca}(\Omega)}{\Omega})^2}{k_t^2 * i_{ds}^2})$

The torque is determinate using this equation:

$$P_m = P_u + P_{mec} = C_a\Omega + C_{mec}\Omega = C_{em}\Omega$$

$$\Longrightarrow C_a = C_e - \frac{Pmec}{\Omega}$$

Thus, the efficiency of the machine is given by: $\eta = \frac{P_a}{P_a + P_{tot}}$

Where : P_a is the active power.

The rotor flux used in the command is:

$$\begin{cases} \bar{\varphi}_r = \dfrac{M}{(1+\tau p)} \bar{i}_{ds} \\ \tau_r = L_r/R \end{cases} \qquad (3)$$

IV.2 Strategy S2

To limit the losses of a machine, it is necessary to impose an optimal flux. Thus, the optimization of the machine efficiency is based on its total losses. This type of strategy generates the optimum efficiency. Indeed, total losses are estimated in the next equation:

$$P_{tot} = P_{js} + P_{fs} + P_{jr} + P_{mec}$$

$$P_{tot} = R_s (i_{ds}^2 + \frac{(C_a + \frac{P_{meca}(\Omega)}{\Omega})^2}{k_t^2 * i_{ds}^2}) + R_f (i_{ds}^2 + \sigma^2 * \frac{(C_a + \frac{P_{meca}(\Omega)}{\Omega})^2}{k_t^2 * i_{ds}^2})$$
$$+(1-\sigma)L_s \frac{1}{\tau} \frac{(C_a + \frac{P_{meca}(\Omega)}{\Omega})^2}{k_t^2 * i_{ds}^2} + P_{mec}(\Omega) \qquad (4)$$

Driving equation (4), we find the optimal component i_{dsopt2}:

$$i_{dsop2} = \sqrt[4]{\frac{(C_a\Omega + P_{mec}(\Omega))^2}{k_t \Omega^2 (R_s + R_f)} (\frac{1}{P\tau} + \frac{(R_s + \sigma^2 R_f)}{k_t}} (5) \qquad (5)$$

V. SIMULATION PROCEDURE

We had chosen in our simulation the strategy S2 to develop. The model used is in Fig.4.The parameters of induction motor used in simulation are:

p=1; N=2800(rpm); Rs=0.6348(Ω); R_r=5.6(Ω); M_{sr}=0.6123 (H) ; Ls =0.6348 (H);L_r =0.6348(H);

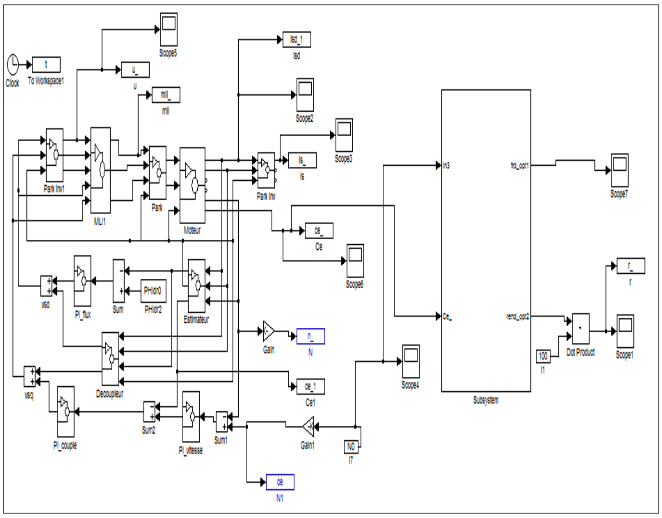


Fig.4 simulation model

Fig.4 shows the simulation results of the IFOC with constant flux and without rotor resistance variation. Rotor flux is fixed on 0.87 WB in the same way, the direct stator current takes its corresponding value (Ids = 1.75A).

The control system modeling is done by changing the command from a fixed flux (Φ_{dr0}=0.87Wb) to a flux calculated using the optimal current **(5)**. The subsystem used in the simulation is represented in the Fig.5. Hence, the inputs are the electromagnetic torque and the rotor speed and the output are the efficiency and the optimal flux due to i_{dsopt2}.

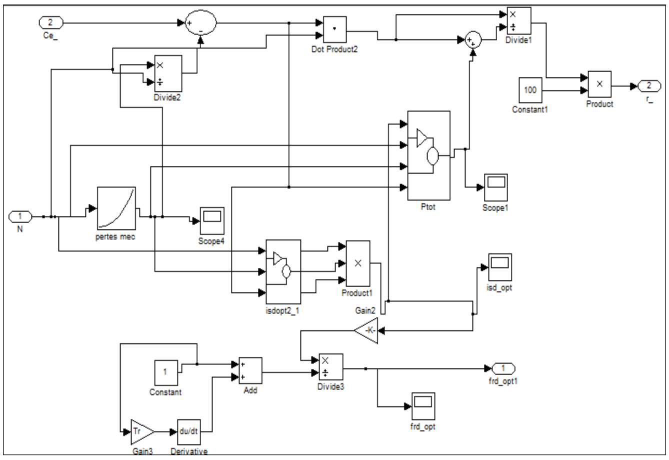


Fig.5 the subsystem model

VI. RESULTS

We fix in the beginning the flux Φ_{dr0}=0.87Wb and we simulate the model:

- The electromechanical torque

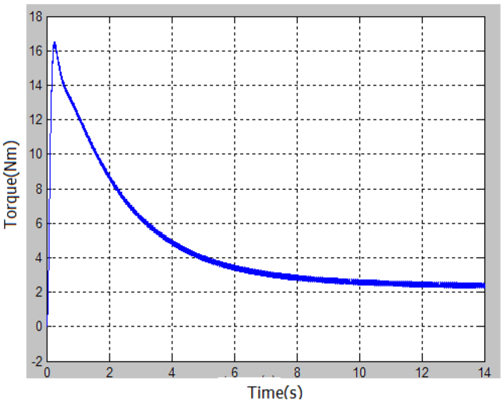


Fig.6. The electromechanical torque

- The rotor speed

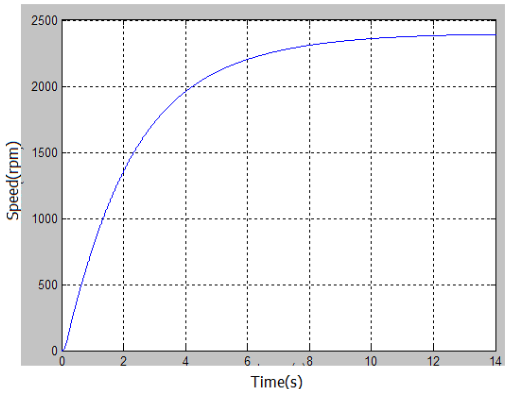


Fig.7 The rotor speed

- The stator current

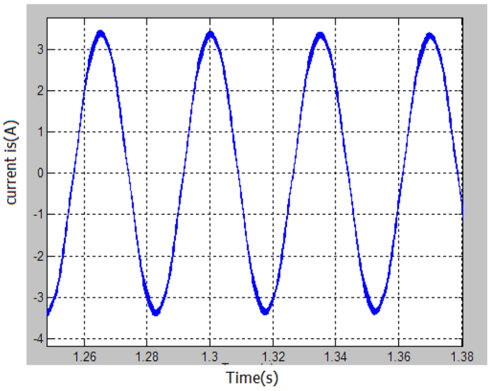


Fig.8 The current is (A)

- The stator voltage

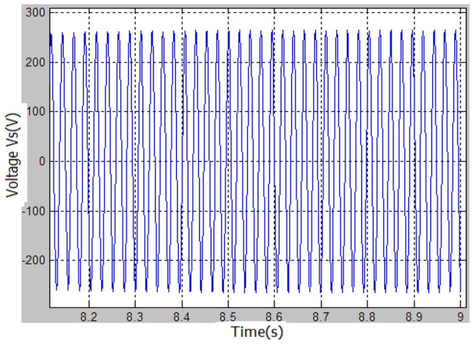


Fig.9 the stator voltage

- The efficiency

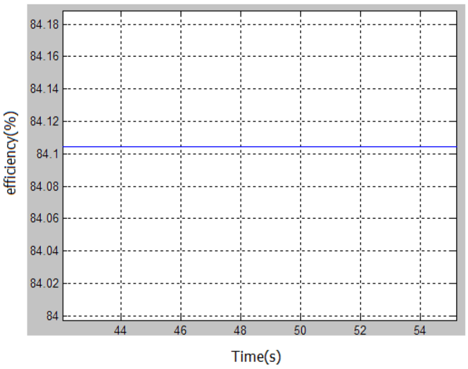


Fig. 10 The induction motor efficiency (84.3%)

Now using the strategy S2, the flux (φ_{dr}) will be generated from i_{dsopt2}:

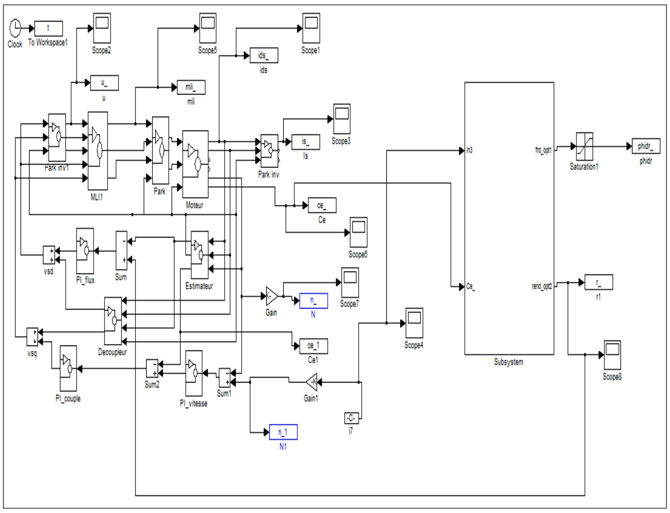


Fig.11 The simulation model using strategy S2

The results are shown next:

- The current i_{dsopt2}

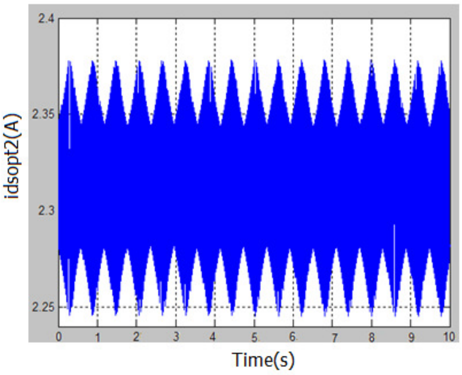


Fig. 12 the flux

- The losses

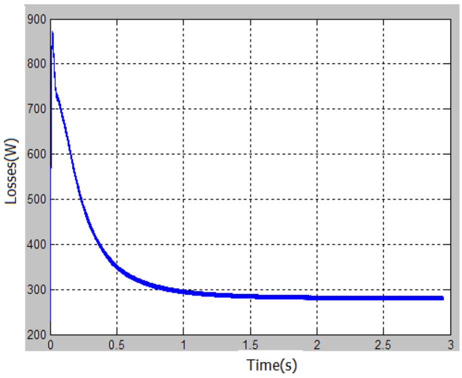


Fig.13 the losses

- The efficiency

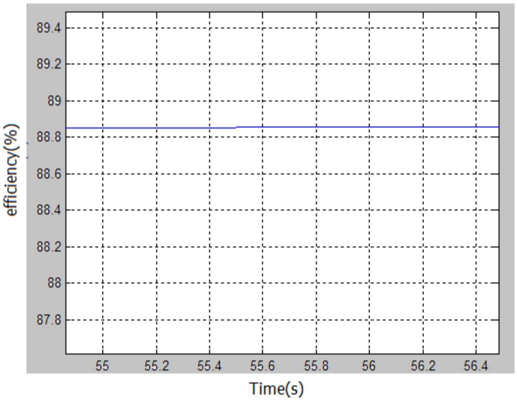


Fig. 14 The efficiency (88.8%)

The Fig.12 emphasizes the flux given by the equation (5).Indeed, the flux generated by the subsystem shown in Fig.6 will be injected in the mechanism of indirect field in Fig.14. The efficiency measured was 88.8%.

CONCLUSION

Improving the efficiency of an electric drive induction motor was the subject of this dissertation. The proposed model is simulated in first time to command an induction motor drive as infield oriented control with a fixed flux (φ_{dr0}).In the second time, we had applied the strategy S2 using the optimized current i_{dsopt2}. Consequently, we had improved the efficiency of the induction motor a fact that could resolve the problem of anatomy of drive electric system.

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