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A new approach of Sliding mode observer for sensorless control applied in Induction machine*

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***Abstract*—In this paper, a new idea is proposed to the Sliding Mode Observer for the flux and speed applied to the induction motor and it is also controlled by the Sliding Modes as a function of the orientation of the rotor flux. The error between the measurements of the currents and their estimates converges to zero in finite time, which guarantees the accuracy of the observed flux. The rotor speed and the time constant of the rotor are determined by the estimated stator currents and the rotor flux. The speed estimate is used as feedback to control the rotation of the speed of the induction machine. The control strategy is based on the Sliding Mode approach, while the Lyaponov method is introduced to prove the stability of the system. The results of the numerical simulations verify the validity of the proposed strategy and prove the robustness of the controller despite the disturbances of the load torque and the uncertainties of the parameters. Therefore, this strategy can find practical use in many applications for induction motor drive systems over a wide speed range without the use of mechanical sensor.**

***Index Terms*—Induction motor drive, Field oriented control, Sliding Mode Control, Sensorless control, Non-linear control, Liyaponov function,parameters robustness.**

I. Introduction

HE induction motor is the more used in applications of the variable speed. The main advantages of the speed Sensorless control are the reduction of the costs, the size of the system, and its maintenance, as well as the increase in the reliability of the overall system. The main reasons of its success are its simplicity of conception, its reliability and the absence of collector. But his mathematical model is complex, multivariable, with strong non-linearities, and varying parameters. In some applications, these sensors are often difficult to install and they are sensitive to noise, mechanical vibrations and electromagnetic disturbances [1].The estimation techniques use estimators or state observers to reconstruct the velocity from exclusively stator currents and voltages, which can be measured. The estimators are designed by solving the equations of the dynamic model, and their structures have no feedback. Therefore, they are open-loop reconstructs. The implementation of their algorithms being simple, whereas their dynamic performances are limited. State observers reconstruct the state variables of an observable system from measurable inputs and outputs. They generally provide a good dynamics and accurate estimation, but their low parametric robustness is still their major disadvantage [2], Several studies have shown that when the induction machine is associated with a Sensorless control, the quality of estimation of speed is due to some challenges appearing at low speed [3] - [4]. In fact, if the rotor speed is measured, the performance of the machine is ensured. In fact, the observability space generated by the measured quantities and their derivatives correspond to the rank of the system. The mathematical model of the motor is then locally observable. It is therefore possible to reconstruct the state variable, such as electrical (currents and flux) and mechanical (speed, position, and load torque). When the speed measurement is not allowed, the observability of the model cannot be established if the mechanical velocity is constant and the pulsation of the stator voltages and currents is zero (Necessary condition for loss of observability) [5]. This is due to a law speed operating. On the other hand, at low speed the waking induction phenomena, the electromotive forces decrease and become too weak. The flux obtained by integration is then unusable, so the speed information disappears. In addition, low speed operation means that the inverter generates low voltages (a few tens of Volts), which are then greatly disturbed by switching faults (dead times) and by voltage drops at the terminals of the switches static of the converter [6].

Finally, the dependence on parametric variations can greatly reduce the performance level and considerably affect the convergence and accuracy of the estimate. In the scientific literature, several techniques have been proposed to solve the problems of Sensorless control of induction motor. They are commonly classified in two categories: Methods with mathematical models and Methods without a model. Thus, the methods based on the model of induction motor most often use the MRAS Estimators exploiting the fluxes, the currents or the powers [6] -[7] -[8], the Adaptive Observers [9] -[10], the High-Gain Observers [11], the Sliding Modes Observers [12] or the Stochastic Observers as the Kalman Filter [13]. These techniques offer interesting performance, but they show a few limits at low speed and mostly when the parameters of the motor vary [14]. The main works based on the methods without model involve the artificial intelligence techniques, such as Artificial Neural Network Estimators and Hybrid Fuzzy Logic Estimators [15]- [16]. The Sliding Modes approach is like one of techniques simplest to implement for controlling non-linear systems with an imprecise model[17]. This control has many advantages, such as an excellent trajectory tracking, disturbance rejection and robustness despite modelling uncertainties.

This work is dedicated to the new design of the flux and speed Sliding Mode Observer. A flux surface is added to the Sliding

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Mode for better control of the induction machine in low-speed (the major problem of the Sensorless control). The objective is to obtain an accurate estimate with better convergence and robustness against the load torque disturbances and the parameter variations. The error between the actual and estimated currents must converge to zero in finite time and thus guarantee the accuracy of the observed flux. The rotor speed and rotor time constant are determined by the estimated stator currents and rotor flux. Once the flux convergence is guaranteed, the rotor speed and its time constant are estimated and converge to their actual values. Finally, the estimated quantities are used for the speed regulation of IM.
This paper is organized as follows. In section 2, the mathematical models of the induction motor are presented, first in the reference frame rotating at the synchronous speed, and then in the stationary stator reference frame. In Section 3, the principle of rotor flux orientation is presented, Sliding Modes theory and its application to induction motor control are also developed. Section 4 describes the design of the conventional Sliding Mode Observer and the flux and speed observer proposed in this work. In Section 5, some simulation results showing the performances of the proposed observer, associated with motor control are presented and discussed. Finally, Section 6 provides some comments and a conclusion.

II. Induction motor modelling

A. Dynamical Model of IM in $(d\text{-}q)$ Reference Frame

In a similar way, the mathematical model of the induction motor ,expressed in the(α, β) stationary stator reference frame is described by:

$$\left\{\begin{array}{lll}\frac{di_{s\alpha}}{dt} & = & a_1 i_{s\alpha} + a_2\psi_{r\alpha} - a_3\omega_r.\psi_{r\beta} + a_6 v_{s\alpha} \\ \frac{di_{s\beta}}{dt} & = & a_1 i_{s\beta} + a_3\omega_r\psi_{r\alpha} + a_2\psi_{r\beta} + a_6 v_{s\alpha} \\ \frac{d\psi_{r\alpha}}{dt} & = & a_4 i_{s\alpha} + a_5\psi_{r\alpha} - \omega_r\ \psi_{r\beta} \\ \frac{d\psi_{r\beta}}{dt} & = & a_4 i_{s\beta} + \omega_r\ \psi_{r\alpha} + a_5\psi_{r\beta}\end{array}\right. \tag{1}$$

where

$$a_1 = -\left(\frac{1}{\sigma.T_s} + \frac{(1-\sigma)}{\sigma.T_r}\right); a_2 = \frac{L_m}{\sigma.L_s.L_r}.\frac{1}{T_r}$$

$$a_3 = -\frac{L_m}{\sigma.L_s.L_r}; a_4 = \frac{L_m}{T_r}; a_5 = -\frac{1}{T_r}$$

$$a_6 = \frac{1}{\sigma.L_s}; \sigma = 1 - \frac{L_m^2}{L_s.L_r}; a_7 = \frac{3}{2}.\frac{n_p^2 \cdot L_m}{J \cdot L_r}$$

The electromagnetic torque is given by the following expression:

$$T_e = \frac{3}{2} \cdot \frac{n_p \cdot L_m}{L_r} \cdot (\psi_{rd} \cdot i_{sq} - \psi_{rq} \cdot i_{sd}) \tag{2}$$

III. Sliding Mode Control for IM

A. Rotor flux orientation

The idea of the vectorial control is to control the stator current in a reference mark $(d\text{-}q)$ turning at the speed of synchronism by fixing the axis d on the vector of flux, and he will directly controlled by the component d of the stator current and the couple by the component q. All the strategy of control depends on the good chock of the reference mark $(d\text{-}q)$, and thus of the knowledge of the angle of Park.

$$\psi_{rq} = 0 \Longrightarrow \psi_r = \psi_{rd} \tag{3}$$

-Either by direct measurement of a magnitude enabling direct calculation of the angle by the Hall effect sensors.
-The estimation of the park angle of the oriented model.

B. Sliding Mode Control

The design of the Sliding Mode can be divided into three stages: the choice of the Sliding surface, the establishment of the convergence condition and the definition of the control law. The surface is adjusted according to the error of the variable to be regulated (x).

$$S(x) = (\frac{d}{dt} + \lambda_x)^{r-1} \cdot e_x \tag{4}$$

with $e(x) = (x^* - x)$:is the error of the variable to be regulated λ_x: is a positive constant and r: is the relative degree, equal to the necessary number of the derivative to to make appear the control inputs.

C. Sliding Mode Control based IM

The variables to be adjusted are the speed ωr and the rotor flux ψ_r. The relative degree $r = 2$, thus two surfaces are necessary to obtain the expression of control variant v_{sd} and v_{sq}. The convergence is to assure by a Lyapunov function given by:

$$V(x) = \frac{1}{2} \cdot S^2(x) \tag{5}$$

And its time derivative as:

$$V(x) = \dot{S}(x) \cdot S(x) \tag{6}$$

So to ensure the attractiveness and invariance of the surface $S(x)$, the following condition must be satisfied:

$$\dot{S}(x) \cdot S(x) \prec 0 \tag{7}$$

Considering the vector $x = [\omega_r\ \psi_r]$:

$$\left\{\begin{array}{lll} e(\omega_r) & = & \omega_r^* - \omega_r \\ e(\psi_r) & = & \psi_r^* - \psi_r \end{array}\right. \tag{8}$$

The two surfaces are defined as:

$$\left\{\begin{array}{lll} S(\omega_r) & = & (\frac{d}{dt} + \lambda_{\omega_r}) \cdot e_{\omega_r} \\ S(\psi_r) & = & (\frac{d}{dt} + \lambda_{\psi_r}) \cdot e_{\psi_r} \end{array}\right. \tag{9}$$

where λ_{ω_r} and λ_{ψ_r} are positve constants.
The derivatives of the surfaces are deduced as:

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$$\begin{cases} \dot{S}(\omega_r) &= \ddot{\omega_r^*} + \lambda_{\omega_r}.\dot{\omega_r^*} + \frac{n_p}{J}.T_l + (\frac{B}{J} - \lambda_{\omega_r}).\dot{\omega_r} \\ & -a_7.\dot{i_{qs}}(a_4.i_{ds} + a_5.\psi_r) - a_7.\psi_r(\omega_s.i_{ds} \\ & +a_1.i_{qs} + a_3.\omega_r \cdot \psi r + a_6.v_{qs}) \\ \dot{S}(\psi_r) &= (\ddot{\psi_r^*} + \lambda_{\psi_r}.\dot{\psi_r^*}) - (a_5 + \lambda_{\psi_r})\psi_r \\ & -a_4[a_1.i_{sd} + \omega_r.i_{sq} + a_3.a_5.\psi_r + a_6.v_{sd}] \end{cases} \tag{10}$$

$$\begin{cases} \dot{S}(\omega_r) &= \ddot{\omega_r^*} + \lambda_{\omega_r}.\dot{\omega_r^*} + \frac{n_p}{J}.T_l + (\frac{B}{J} - \lambda_{\omega_r}).\dot{\omega_r} \\ & -a_7.i_{sq}(a_4.i_{sd} + a_5.\psi_r) - a_7.\psi_r(-\omega_s.i_{sd} \\ & +a_1.i_{sq} + a_3.\omega_r \cdot \psi r + a_6.v_{sq}) \\ \dot{S}(\psi_r) &= \ddot{\psi_r^*} + \lambda_{\psi_r}.\dot{\psi_r^*} - (a_5 + \lambda_{\psi_r})\dot{\psi_r} \\ & -a_4[a_1.i_{sd} + \omega_r.i_{sq} + a_3.a_5.\psi_r + a_6.v_{sd}] \end{cases} \tag{11}$$

During the Sliding Mode, the derivative is equal to zero, hence the equivalent commands $v_{sd,eq}$ and $v_{sq,eq}$ can be written as follow:

$$\begin{cases} v_{sd,eq} &= \frac{1}{a_4.a_6}[\ddot{\psi_r^*} + \lambda_{\psi_r}.\dot{\psi_r^*} - (a_5 + \lambda_{\psi_r})\dot{\psi_r} \\ & -a_4(a_1.i_{sd} + \omega_r.i_{sq} + a_3.a_5.\psi_r)] \\ v_{sq,eq} &= \frac{1}{a_7.a_6.\psi_r}[\ddot{\omega_r^*} + \lambda_{\omega_r}.\dot{\omega_r^*} + \frac{n_p}{J}.T_l \\ & +(\frac{B}{J} - \lambda_{\omega_r}).\dot{\omega_r} - a_7.i_{sq}(a_4.i_{sd} + a_5.\psi_r) \\ & -a_7.\psi_r(-\omega_s.i_{sd} + a_1.i_{sq} + a_3.\omega_r \cdot \psi r)] \end{cases} \tag{12}$$

From the command

$$v = v_n + v_{eq} \tag{13}$$

To check the condition of attractiveness, it is assumed that:

$$\begin{cases} v_{dsn} &= -K_d.sign(S\psi_r) \\ v_{qsn} &= -K_q.sign(S\omega_r) \end{cases} \tag{14}$$

where $K_d \succ 0$ and $K_q \succ 0$ are the control gains.

IV. Sliding Mode Observer

A. Conventional Sliding Mode Observer

The Sliding Mode Observer consists in forcing, using discontinuous functions, the dynamics of the errors in estimation of a nonlinear system of n order having *p* outputs to converge on a variety of orders (*n-p*) known as Sliding surface. The attractiveness and the invariance of the Sliding surface are ensured by conditions called the Sliding conditions. The dynamics of the Sliding surface are calculated by the method of the equivalent control [12].Thus, for the nonlinear systems. A structure of observer by Sliding Mode is written:

$$\begin{cases} \frac{d_x}{dt} &= f(\hat{x}, U) - K.sign(\hat{y} - y) \\ \hat{y} &= h(\hat{x}) \end{cases} \tag{15}$$

B. Proposed Sliding Mode Observer

The proposed algorithm guarantees a good estimation of the speed and the rotor constant of the time and a very great robustness especially at low speed. The estimation of the rotational speed and the time constant of the rotor are ensured by the convergence of the currents and the fluxes observes. Ensuring the convergence of the current observer. Then, it is used in the flux observation to produce fluxes along the α and β axes. Once the flux values are found, the equivalent control is produced by using a low pass filter, then the rotor speed and rotor time constant are estimated by using observed fluxes. For the synthesis of observation, the model of the IM in the reference mark$(\alpha, \beta)$is used for the synthesis of the observation, to make the model simpler and for c.
Considering that $a_2 = k.\frac{1}{T_r}$ with $k = \frac{L_m}{\sigma.L_s.L_r}$

$$\begin{bmatrix} \frac{di_{s\alpha}}{dt} \\ \frac{di_{s\beta}}{dt} \end{bmatrix} = k.\begin{bmatrix} \frac{1}{T_r} & \omega_r \\ -\omega_r & \frac{1}{T_r} \end{bmatrix} \begin{bmatrix} \psi_{r\alpha} \\ \psi_{r\beta} \end{bmatrix} - a_1.\begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} + a_6.\begin{bmatrix} v_{s\alpha} \\ v_{s\beta} \end{bmatrix} \tag{16}$$

$$\begin{bmatrix} \frac{d\psi_{r\alpha}}{dt} \\ \frac{d\psi_{r\beta}}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{1}{T_r} & -\omega_r \\ \omega_r & -\frac{1}{T_r} \end{bmatrix} \begin{bmatrix} \psi_{r\alpha} \\ \psi_{r\beta} \end{bmatrix} + a_4\begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} \tag{17}$$

$$\begin{bmatrix} \frac{d\hat{i}_{s\alpha}}{dt} \\ \frac{d\hat{i}_{s\beta}}{dt} \end{bmatrix} = k.\begin{bmatrix} \phi_{is\alpha} \\ \phi_{is\beta} \end{bmatrix} - a_1.\begin{bmatrix} \hat{i}_{s\alpha} \\ \hat{i}_{s\beta} \end{bmatrix} + a_6.\begin{bmatrix} v_{s\alpha} \\ v_{s\beta} \end{bmatrix} \tag{18}$$

$$\begin{bmatrix} \frac{d\hat{\psi}_{r\alpha}}{dt} \\ \frac{d\hat{\psi}_{r\beta}}{dt} \end{bmatrix} = \begin{bmatrix} \phi_{\psi r\alpha} \\ \phi_{\psi r\beta} \end{bmatrix} + a_4\begin{bmatrix} \hat{i}_{s\alpha} \\ \hat{i}_{s\beta} \end{bmatrix} \tag{19}$$

with

$$\phi_{is\alpha} = h_{sd}.sign(S_{is\alpha}); \qquad \phi_{is\beta} = h_{sq}.sign(S_{is\beta});$$

$$\phi_{\psi_{r\alpha}} = H_{rd}.sign(S_{\psi_{r\alpha}}); \qquad \phi_{\psi_{r\beta}} = H_{rq}.sign(S_{\psi_{r\beta}});$$

Where $[h_{sd}, h_{sq}, H_{rd}, H_{rq}]$ are control gains. The convergence of the stator currents estimated $\hat{i}_{s\alpha}$ and $\hat{i}_{s\beta}$ to The actual currents $i_{s\alpha}$ and $i_{s\beta}$ assure the estimation of rotor flux $\hat{\psi}_{r\alpha}$ and $\hat{\psi}_{r\beta}$ and from the esteemed rotor flux can esteem the rotor speed $\hat{\omega}_r$ And $\hat{T}_r$ the rotor constant of time .
$\hat{i}_{s\alpha}$,$\hat{i}_{s\beta}$ and $\hat{\psi}_{r\alpha}$, $\hat{\psi}_{r\beta}$ are used to generate the Sliding Mode. Furthermore, the surfaces of Sliding Mode are selected in this way:

$$S_{is\alpha} = \hat{i}_{s\alpha} - i_{s\alpha}; \qquad S_{is\beta} = \hat{i}_{s\beta} - i_{s\beta};$$

$$S_{\psi_{r\alpha}} = \hat{\psi}_{r\alpha} - \psi_{r\alpha}; \qquad S_{\psi_{r\beta}} = \hat{\psi}_{r\beta} - \psi_{r\beta};$$

and the Sliding Mode surface is defined as:
$S_n = [S_{is\alpha}\ S_{is\beta}\ S_{\psi_{r\alpha}}\ S_{\psi_{r\beta}}]^T$
By selecting The gains $[h_{sd}, h_{sq}, H_{rd}, H_{rq}]$ of the attractive commands and they are larger than the errors to ensure the attractiveness of the observed signal around the reference and are found by the condition of existence, Sliding Mode $(S_n = 0)$ will occur. To solve the $\frac{dS_n}{dt} = 0$ for discontinuous control, it gives the equivalent continuous command.
However, the equivalent control depends on parameter machine and to be difficult to implement. Consequently, it is reasonable to suppose that an equivalent control is close to the slow component of the real control, which can be diverted by filtering the high Frequency using a low-pass filter. The structure of the low-pass filter is implemented::

$$\phi_{\psi_{r\alpha}}^{eq} = \frac{1}{\mu.s + 1} \tag{20}$$

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Vol.7 pp.44-49

where μ is the time-constant of the filter and it should be sufficiently weak for Component slow without distortion, but enough large to eliminate the component with high frequency. The exit of the low-pass filter will be equal Controls equivalent on the slip surface [18]. The concept of equivalent control supposes flux observed $\hat{\psi}_{r\alpha}$ and $\hat{\psi}_{r\beta}$ equal to real flux $\psi_{r\alpha}$,$\psi_{r\beta}$ and in the regime permanent we can written:

$$\begin{bmatrix} \phi^{eq}_{\psi_{r\alpha}} \\ \phi^{eq}_{\psi_{r\beta}} \end{bmatrix} = \begin{bmatrix} -\frac{\hat{1}}{T_r} & -\hat{\omega}_r \\ \hat{\omega}_r & -\frac{\hat{1}}{T_r} \end{bmatrix} \begin{bmatrix} \hat{\psi}_{r\alpha} \\ \hat{\psi}_{r\beta} \end{bmatrix} \tag{21}$$

$$\begin{bmatrix} \frac{d\hat{\psi}_{r\alpha}}{dt} \\ \frac{d\hat{\psi}_{r\beta}}{dt} \end{bmatrix} = \begin{bmatrix} \phi^{eq}_{\psi_{r\alpha}} \\ \phi^{eq}_{\psi_{r\beta}} \end{bmatrix} + \frac{L_m}{\hat{T}_r}.\begin{bmatrix} \hat{i}_{s\alpha} \\ \hat{i}_{s\beta} \end{bmatrix} \tag{22}$$

$$\begin{bmatrix} \phi^{eq}_{\psi_{r\alpha}} \\ \phi^{eq}_{\psi_{r\beta}} \end{bmatrix} = \begin{bmatrix} -\hat{\psi}_{r\alpha} & -\hat{\psi}_{r\beta} \\ \hat{\psi}_{r\beta} & -\hat{\psi}_{r\alpha} \end{bmatrix} \begin{bmatrix} \frac{\hat{1}}{T_r} \\ \hat{\omega}_r \end{bmatrix} \tag{23}$$

$$\begin{bmatrix} \frac{\hat{1}}{T_r} \\ \hat{\omega}_r \end{bmatrix} = \frac{1}{\hat{\psi}^2_{r\alpha} + \hat{\psi}^2_{r\beta}} \begin{bmatrix} -\hat{\psi}_{r\alpha} & -\hat{\psi}_{r\beta} \\ \hat{\psi}_{r\beta} & -\hat{\psi}_{r\alpha} \end{bmatrix} \begin{bmatrix} \phi^{eq}_{\psi_{r\alpha}} \\ \phi^{eq}_{\psi_{r\beta}} \end{bmatrix} \tag{24}$$

From the above equation, the speed of the estimated rotor is equal to:

$$\hat{\omega}_r = \frac{1}{\hat{\psi}^2_{r\alpha} + \hat{\psi}^2_{r\beta}}.(\hat{\psi}_{r\beta}.\phi^{eq}_{\psi_{r\alpha}} - \hat{\psi}_{r\alpha}.\phi^{eq}_{\psi_{r\beta}}) \tag{25}$$

In addition, the constant of rotor time is equal to:

$$\frac{\hat{1}}{T_r} = \frac{1}{\hat{\psi}^2_{r\alpha} + \hat{\psi}^2_{r\beta}}.(-\hat{\psi}_{r\alpha}.\phi^{eq}_{\psi_{r\alpha}} - \hat{\psi}_{r\beta}.\phi^{eq}_{\psi_{r\beta}}) \tag{26}$$

V. SIMULATION RESULTS AND DISCUSSION

To evaluate the performance of the proposed structure,the implementation in the software MATLAB/SIMULINK environment has been considered. The computation numerical method adopted is based on the Runge-Kutta algorithm of order 4 with fixed step.

The parameters of both observer and controller are set in order to fulfil some objectives, such as convergence time and limitation of chattering.

This benchmark was chosen to show the performance and robustness of the proposed observer. These parameters are listed in Tables I, II .

TABLE I
GAINS OF THE SLIDING MODE CONTROL FOR IM

The gains of the command	λ_{ω_r}	λ_{ψ_r}	K_d	K_q
	70	60	2050	4050

TABLE II
GAINS OF THE SLIDING MODE OBSERVER FOR IM

The gains of the observer	h_{sd}	h_{sq}	H_{rd}	H_{rq}
	100	100	80	80

The figure below shows the structure of the global system, the Sliding Mode Control and the observer propose in this paper.

The benchmark is chosen to see the response and reaction

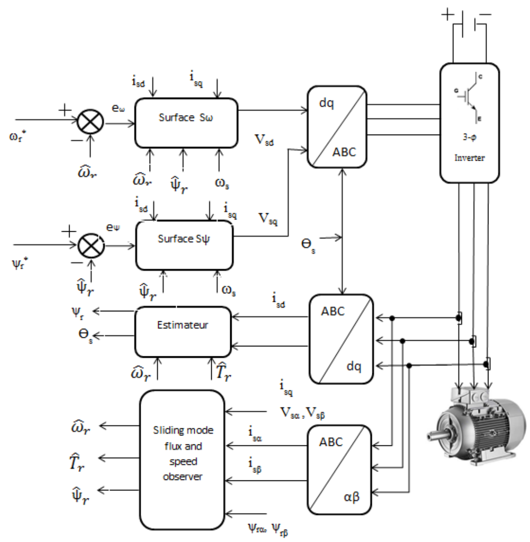

Fig. 1. Global block diagrams of the Sliding Mode Control and the proposed observer of the induction motor

of the system in different cases. The sensorless trajectories of the benchmark are such that: After that, the reference speed is increased to 150 rad/s (figure 2) and at 0.5 to 1.5 s a load torque of 5 $N.m$ is applied. This first step makes it possible to test the robustness of the observer at high speed the estimated speed converge to the actual speed in this step of the benchmark. Then the speed decelerates to 0 rad/s and remains Constant until t = 3 s. This second step is defined to test the controller in low speed (very low frequency). the reference speed equal to zero and the figure 5 shows the phenomenon of unobservability The importance of this test is to see the reaction of the observer in this zone and to see its robustness. Finally, from t=5 to 5.8 s and at 0.5 to 1.5 s a load torque of 5 $N.m$ is applied to test the reaction of the control and if the observer reacts well in this mode. All the estimated variables converge to their and disturbance rejection. Furthermore, all these figures present the best results obtained by the controller and the observer proposes in different modes. Finally, the tested robustness of our observer proposed against the parametric variation, especially the rotor resistance because it is the most influential parameter for the observation and this is conceived for all the spesialists of the domain; with an application of restive torque (5N.m) over of duration well presided. Firstly, one made test for nominal values of R_r the reference speed is increased to 100 rad/s and at 1 to 0.7 s a load torque of 5 N.m is applied, then Introducing a 15% error on R_r to see the influence of this parameter for the system, then an error of 20% was introduced to see the reaction and the robustness of the observer, well results are obtained.

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International Journal of Control, Energy and Electrical Engineering (CEEE)
Vol.7 pp.44-49

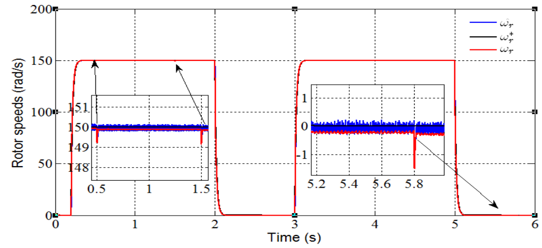

Fig. 2. Rotor speed [rad/s]

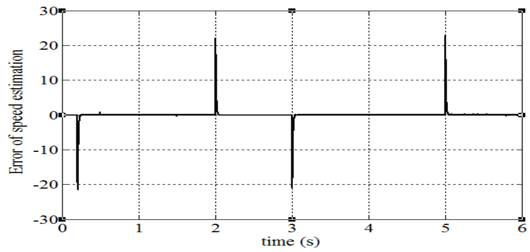

Fig. 3. Error between actual speed and estimated speed [rad/s],

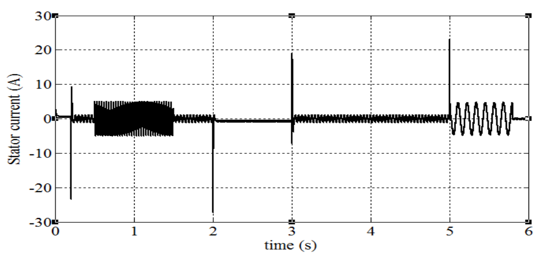

Fig. 4. Stator current of phase A [A]

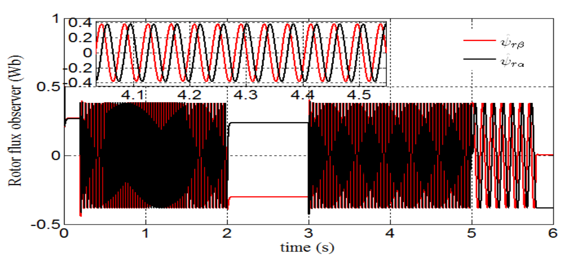

Fig. 5. Observed rotor flux [Wb]

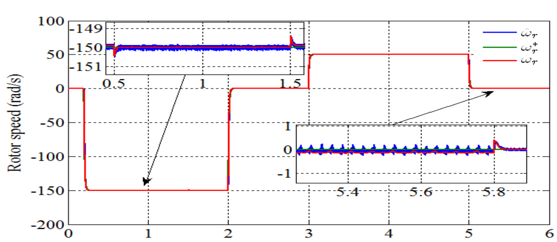

Fig. 6. Reversal rotor speed [rad/s]

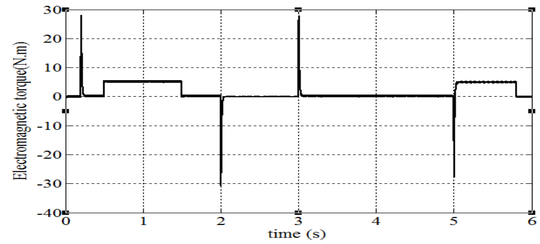

Fig. 7. Electromagnetic torque [N.m]

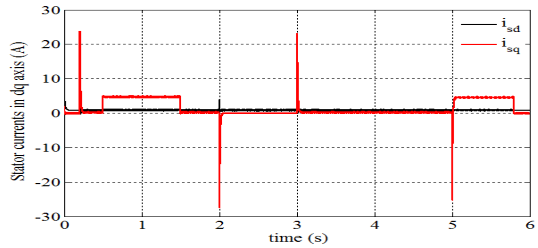

Fig. 8. Direct and quadrature stator current [A]

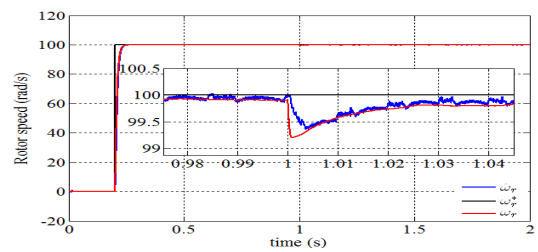

Fig. 9. Rotor speed [rad/s] for $Rr = R_{rn}$

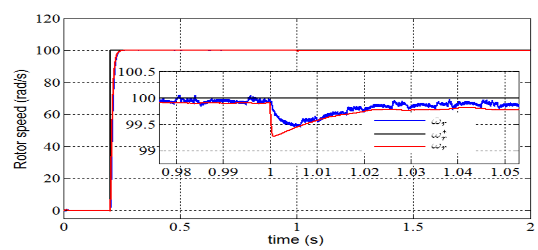

Fig. 10. Rotor speed [rad/s] for $R_r = 1.15 * R_{rn}$

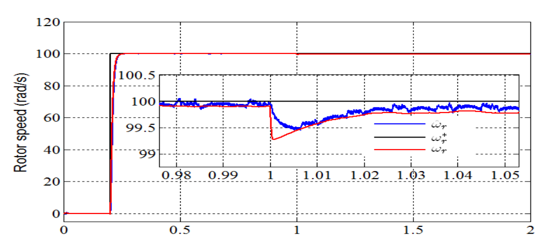

Fig. 11. Rotor speed [rad/s] for $R_r = 1.30 * R_{rn}$

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VI. Concluding Remarks

this paper presents Sliding Mode Control based on the orientation of indirect flux for sensorless control of induction motor A new structure Sliding-Mode current and flux observer has been proposed for speed, and rotor time constant estimations. The rotor time constant update algorithm will overcome the problem of rotor resistance variation; The proposed scheme is validated through simulation results.

It is concluded from the results presented that the proposed scheme performs well and robust for both high and low speeds It is also important that the new algorithm is robust to parameter changes and the load torques.

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