Simulation of non linear adaptive observer for sensorless induction motor control

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ABSTRACT--**This paper presents a model reference adaptive system based sensorless induction motor drive. In this scheme, an adaptive full order flux observer is used. The simulation result show that with the large PI gain for the adaptive scheme, the convergence for the speed estimation is fast and very well, however higher harmonics and noises are included in the estimated speed. Usually noises caused by inverter. Simulation results show that proposed scheme can estimate the motor speed under various adaptive PI gains and estimated speed can replace to measured speed in sensorless induction motor.**

Keywords: Induction motor; Sensorless control; Pole placement; MRAS speed estimation; Lyapunov function.

1. INTRODUCTION

Three phase induction motor is widely used in many industries, mainly due to its rigidness, maintenance free operation, and relatively low cost. In contrast to the commutation dc motor, it can be used in aggressive or volatile environments since there are no risks of corrosion or sparks. However, induction motor constitute a theoretically challenging control problem since the dynamical system is non linear, the electrical rotor variable are not measurable, and the physical parameters are most often imprecisely known. [1]-[2]-[3]-[6].

It is well known from control theory that a state estimator, called also state observer, is a dynamic system that is driven by the input-output of the considered system, estimate asymptotically its unmeasurable state variable. It uses an adaptive mechanism involving as input, the error between the measured and estimated output value of the system. It is a "software sensor"that plays an important role in the estimation of the unmeasurable state variables that are essential not only in the sensorless control techniques.

As au result, the drive has a wider adjustable speed range and can be operated at very low speed. This paper presents the simulation results of the proposed scheme which has been implanted on a 0.75KW induction motor driver.The systematic of this paper consist of four sections. Section I describes the overview of the observation and control system structure of induction motor under studies. Section II discusses with the model of adaptive flux observer while section III describes the adaptive scheme for speed estimation. Section V depicts the simulation results of the designed induction motor control. Finally, section VI gives the conclusion of this paper.

2. MATHEMATICAL MODELS FOR INDUCTION MOTOR AND ADAPTIVE FLUX OBSERVER

II.1. Dynamic model of induction motor

For an induction motor, if the stator current $\boldsymbol{i_s}$ and rotor flux $\boldsymbol{\emptyset_r}$ are selected as the state variables equations can be expressed as (1)in the stationary reference frame[2]

$$\frac{d}{dt}\begin{bmatrix} i_s \\ \emptyset_r \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}\begin{bmatrix} i_s \\ \emptyset_r \end{bmatrix} + \begin{bmatrix} B_1 \\ 0 \end{bmatrix} v_s \quad (1)$$

$$i_s = Cx \quad (2)$$

Where

$i_s = [i_{ds} \quad i_{qs}]^T$ is stator current

$\emptyset_r = [\emptyset_{dr} \quad \emptyset_{qr}]^T$ is rotor flux

$v_s = [v_{ds} \quad v_{qs}]^T$ is stator voltage

$x = [i_s \quad \emptyset_r]^T$

$$A_{11} = -\left\{\frac{R_s}{\sigma L_s} + \frac{1-\sigma}{\sigma \tau_r}\right\} I = a_{r11} I$$

$$A_{12} = \frac{L_m}{\sigma L_s L_r}\left\{\frac{1}{\tau_r} I - \omega_r J\right\} = a_{r12} I + a_{i12} J$$

$$A_{21} = \left(\frac{L_m}{\tau_r}\right) I = a_{r21} I$$

$$A_{22} = \left(\frac{1}{\tau_r}\right) I + \omega_r J$$

$$B_1 = \frac{1}{\sigma L_s} I \ , \qquad C = [I \quad 0]$$

$\sigma = 1 - \frac{L_m^2}{L_s L_r}$ is the inductance leakage coefficient

$$I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \ and \ J = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$$

Where R_s , R_r and L_s , L_r are stator and rotor resistances and self inductances ,respectively, L_m is mutual inductance, τ_r is the rotor time constant $\frac{L_r}{R_r}$ and ω_r is electrical motor angular speed.

The electromechanical equation of induction motor is given by

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\left(\emptyset_{dr} i_{qs} - \emptyset_{qr} i_{ds}\right) \tag{3}$$

II.2. Adaptive flux observer

The APFO flux observer can be written as fellows [1]:

$$\frac{d}{dt}\hat{\imath}_s = \hat{A}_{11}\hat{\imath}_s + \hat{A}_{12}\hat{\emptyset}_r + B v_s + G(\hat{\imath}_s - i_s) \tag{4}$$

$$\frac{d}{dt}\hat{\emptyset}_r = \hat{A}_{21}\hat{\imath}_s + A_{22}\hat{\emptyset}_r \tag{5}$$

Where $\boldsymbol{i_s}$ and $\boldsymbol{v_s}$ are measured values of stator current vector and stator voltage vector, respectively, G is the full order observer gain matrix which is also determined to make (3) stable and "^ "denote the estimated values. The observer is the closed loop system, which is obtained by driving estimated model of the induction motor by the residual of the current measurement, $\boldsymbol{e_{is}}$.

$$e_{is} = i_s - \hat{\imath}_s \tag{6}$$

The estimation of stator currents is conducted by a closed loop observer with [4X2] feedback gain matrix G as in (3), whereas the estimation of the rotor fluxes is carried out by an open loop observer of (4) without the flux error. Therefore, the real and estimated rotor fluxes are assumed the same.

$$\emptyset_r = \hat{\emptyset}_r \tag{7}$$

The observer gain matrix is chosen as:

$$G = \begin{bmatrix} g_1 & g_2 & g_3 & g_4 \\ -g_2 & g_1 & -g_4 & g_3 \end{bmatrix}^T \tag{8}$$

Where the observer gain matrix G is calculated based on the pole placement technique. The selection of the observer poles is a compromise between the rapidity of error responses and the sensitivity to disturbances and measurement noises. In practice, the eigenvalues of the observer are selected to be negative, so that the state of the observer will converge to the state of the observed system, and they are chosen to be somewhat more negative than the eigenvalues of the observed system so that convergence is faster than other system effects. Based on the above mentioned criteria the author chose [1],

$$g_1 = (k-1)(a_{r11} + a_{r22}) \tag{9}$$

$$g_2 = (k-1)a_{i11} \tag{10}$$

$$g_3 = (k^2 - 1)(c a_{r11} + a_{r21}) - c(k-1)(a_{r11} + a_{r22}) \tag{11}$$

$$g_4 = c(k-1)a_{i22} \tag{12}$$

$$c = \sigma L_s L_r / L_m \tag{13}$$

3. ADAPTIVE SCHEME FOR SPEED ESTIMATION

Consider the lyapunov function candidate [9]:

$$V = V_1 + V_2 \tag{14}$$

$$V_1 = e^T e \quad V_2 = \frac{{e_\omega}^2}{\lambda} \tag{15}$$

With $(\lambda > 0)$, is the positive constant ensuring the positive definiteness of V_2 and which will be tuned in (19) to improve observer dynamics. $e_\omega = \omega_r - \hat{\omega}_r$ and

$e^T = \left[i_{sd} - \hat{\imath}_{sd} \ i_{sq} - \hat{\imath}_{sq} \ \ 0 \ \ 0\right]$ Because we supposed that $\emptyset_r = \hat{\emptyset}_r$

The derivatives of this lyapunov candidate function in thus:

$$\frac{dV}{dt} = e^T[(A-GC)^T + (A-GC)]e \quad (16)$$

$$-2(\omega_r - \hat{\omega}_r)\left[K\left(e_{isd}\,\hat{\emptyset}_{rq} - e_{isq}\hat{\emptyset}_{rd}\right) - \frac{1}{\lambda}\frac{d}{dt}\hat{\omega}_r\right]$$

$$e^T[(A-GC)^T + (A-GC)]e < -Q \quad (17)$$

With $Q = \varepsilon I_n$ and $\varepsilon > 0$

The stability of adaptive observer has proved if we respect two conditions as follows:

-The eigenvalue of the observer are selected to have negative real parts so that the states of the observer will converge to the desired states of the observed system.

-the term in factor of $(\omega_r - \hat{\omega}_r)$in the equation (15) must be zero. The expression of the derivative of estimated speed becomes then:

$$K\left(e_{isd}\,\hat{\emptyset}_{rq} - e_{isq}\hat{\emptyset}_{rd}\right) - \frac{1}{\lambda}\frac{d}{dt}\hat{\omega}_r = 0 \quad (18)$$

$$\frac{d}{dt}\hat{\omega}_r = \lambda K\left(e_{isd}\,\hat{\emptyset}_{rq} - e_{isq}\hat{\emptyset}_{rd}\right) \quad (19)$$

However this adaptive law of the speed

$$\hat{\omega}_r = K_i \int_0^t \left(e_{isd}\,\hat{\emptyset}_{rq} - e_{isq}\hat{\emptyset}_{rd}\right)dt$$

Has obtained for the satatorique frame his dynamic has adjusted by K_i (finite positive constant). For augmented the dynamic of this observer during the transitory phase of rotor speed, we esteem the speed by PI regulator; we added (en ajoutant) a supplementary term proportional of error. Then

$$\hat{\omega}_r = K_p\left(e_{isd}\,\hat{\emptyset}_{rq} - e_{isq}\hat{\emptyset}_{rd}\right) + \\ + K_i \int_0^t \left(e_{isd}\,\hat{\emptyset}_{rq} - e_{isq}\hat{\emptyset}_{rd}\right)dt \quad (20)$$

Where K_p and K_i are adaptive gains for speed estimator. An identification system for speed is shown in Fig.1, which is constructed from a linear time-invariant forward block and a nonlinear time-varying feedback block.

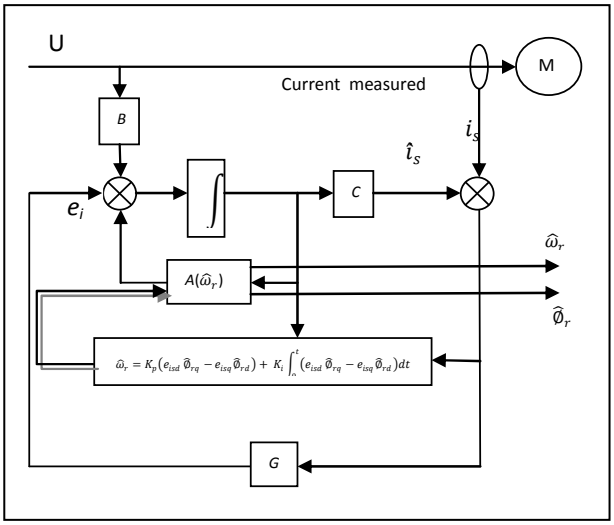


Figure.1: Speed adaptive observer

4. SIMULATION RESULTS

The basic configuration of speed estimation of sensorless induction motor drive is shown in figure (2).this configuration will be used for both simulations. All reference or command preset values are subscripted with a " * " in the diagram.IM speed will be estimated by (19) and will be compared with the reference speed in order to create the error speed. The proposed full order flux observer for induction motor states estimations has been developed and applied in the direct field oriented control of induction motor.

TABLE 1: Induction motor parameters

Symbol	Quantity	N. Values
P_a	Power	O.75KW
F	Supply frequency	50HZ
P	Number of pair poles	2
V	Supply voltage	220V
R_s	Stator resistance	10Ω
R_r	Rotor resistance	6.3Ω
L_s	Stator inductance	0.4642H
L_r	Rotor inductance	0.4612H
L_m	Mutual inductance	0.4212H
ω_r	Rotor angular velocity	157rd/s
J	Inertia coefficient	0.02Kg^2/s
f	Friction coefficient	0N.s/rd

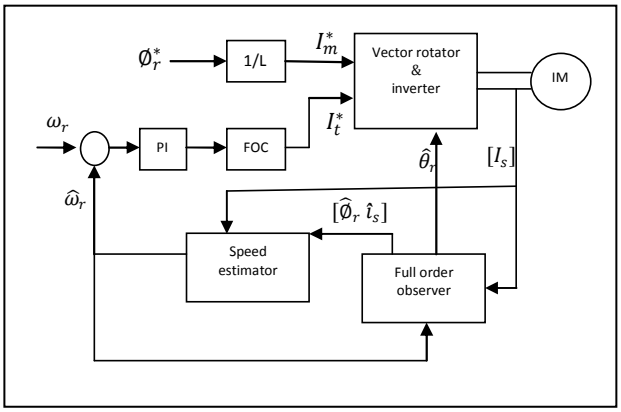


Figure.2: Block diagram of sensorless IM drive

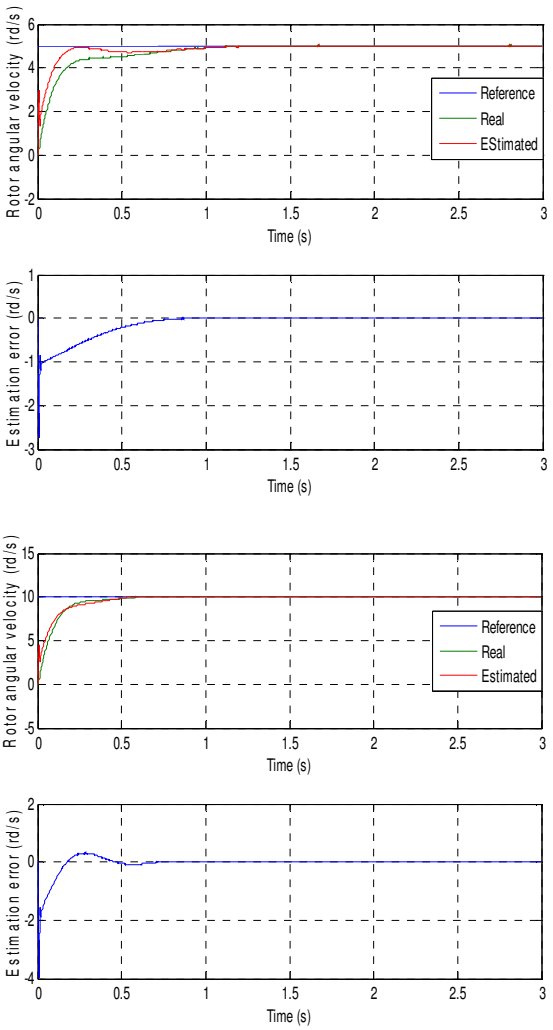


Figure.3: Measured and observed rotor angular velocity (very low speed)

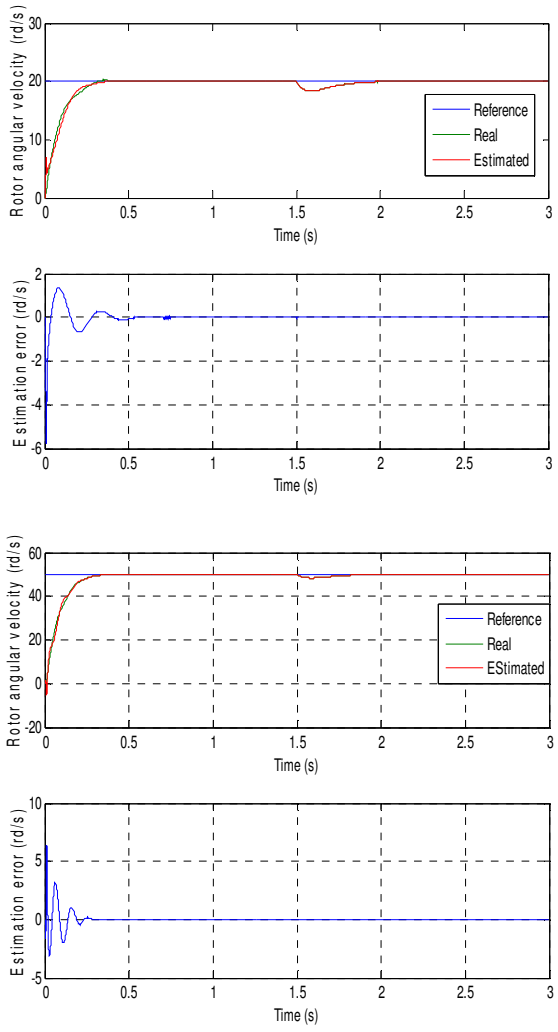


Figure.4: Measured and observed rotor angular velocity (low speed)

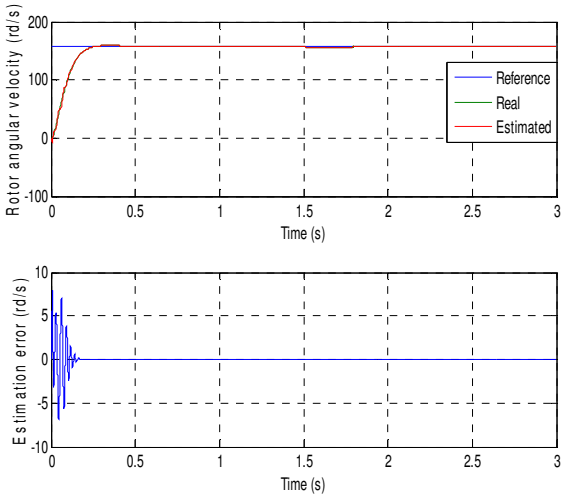


Figure.5: Measured and observed rotor angular velocity (nominal speed)

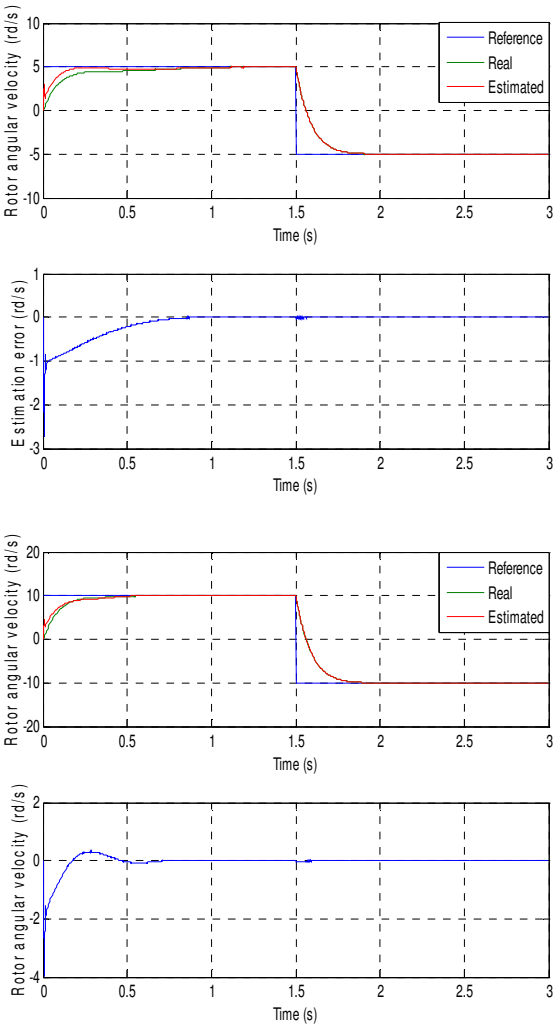


Figure. 6: Measured and observed rotor angular velocity (very low speed)

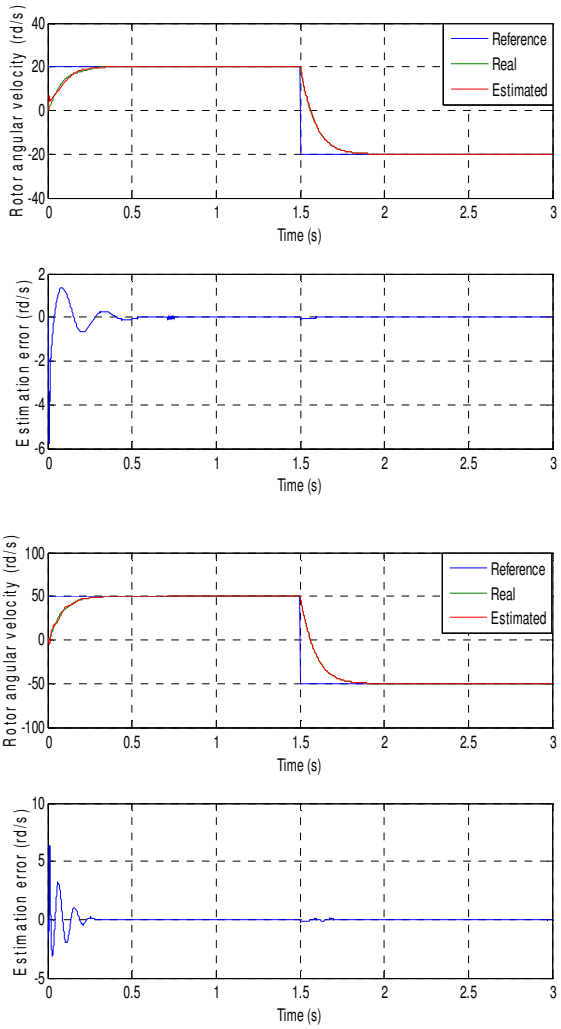


Figure.7: Measured and observed rotor angular velocity (low speed)

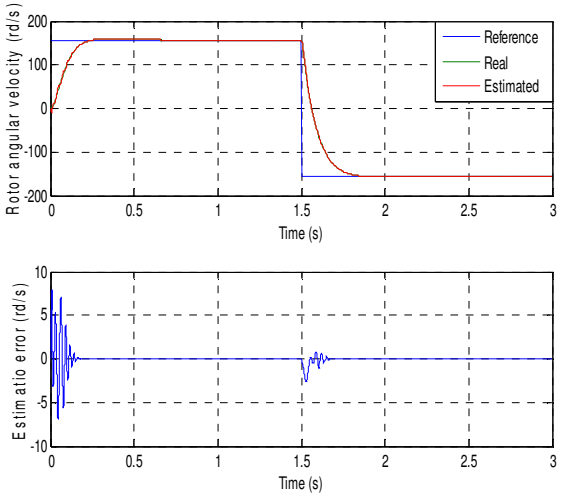


Figure.8: Measured and observed rotor angular velocity (nominal speed)

In fig.3 where the induction motor rotates at a constant very low speed (5 rd/s) and (10 rd/s) ,the observed speed also converge to real speed at the time (0.8s for 5 rd/s) and (0.6s for 10rd/s), at (1.5s for 20 rd/s) we applied a load torque , fig.3 shows that after a small speed drop both observed and real speeds converge very well.

In fig.4 where the induction motor rotates at a constant low speed(20 rd/s) (50 rd/s) ,the observed speed also converge to real speed at the time (0.45s for 20 rd/s) and (0.25s for 50rd/s), at (1.5s) we applied a load torque , fig.3 shows that after a small speed drop both observed and real speeds converge very well.

In fig.5 where the induction motor rotates at a medium (nominal) speed (157 rd/s), the observed speed converge to real speed at the time (0.2s) , at (1.5) we applied a load torque , fig.4 shows that after a small speed drop (negligible) both observed and real speeds converge very well.

In fig.6 where the command speed is first set at a very low speed (5 rd/s) and (10 rd/s), at (1.5s) the reference speed is changed to (-5 rd/s), (-10 rd/s). Fig.6 shows that both estimated and real speeds are in close agreement with each other in both the forward and reverse direction.

In fig.7 where the command speed is first set at a low speed (20 rd/s) and (50 rd/s), at (1.5s) the reference speed is changed to (-20 s) and (-50 s). The fig.7 shows that the observed speed converge to real speed faster than a case very low speed.

In fig.8 where the IM rotates at (157rd/s) after that (-157rd/s) the fig.8 shows that the observer work better.

6. CONCLUSION

This paper presents a MRAS-based adaptive full-order observer (AFFO) sensorless induction motor drive. This method has been applied to a direct field-oriented induction motor control without speed sensor. The simulation results demonstrated that with PI gains for the adaptive regulators, the convergence for the speed estimation is fast and well. The proposed observer can work accurately at very low speed region.

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