Deterministic Observer of Direct Field Orientation Control Induction Motor Drive

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ABSTRACT

When driven by a filed oriented controller, an induction motor behaves like a separately excited DC machine where the torque and the flux are controlled independently. Based on the direct field orientation control induction motor (DFOCIM) model, the stator current ,rotor flux and rotor speed of induction motor are estimated simultaneously using linear Luenberger observer for stator current and rotor flux and Adaptive linear luenberger observer for stator current ,rotor flux and rotor speed. The salient advantage of the linear Luenberger observer is the accuracy of the observed stator current and rotor flux and that of Adaptive linear luenberger observer is the accuracy of the stator current, rotor flux and rotor speed observation. The validity of the proposed method is verified by the simulation results using matlab software.

Keyword: Induction Motor, Field Orientation Control, linear Luenberger observer, Adaptive linear luenberger observer

INTRODUCTION

Over the last few years, the increasing availability of low cost digital processing hardware has arisen great interest in the application of field oriented control to induction motors, which, in consequence, behave like direct current motors. However, the full advantages of field orientation are obtained only if the instantaneous magnitude and orientation of the rotor flux vector is defined as accurately as possible. This information can be obtained by a direct or an indirect measurement procedure [1]. In most speed and torque controlled drive systems; closed loop control is based on the measurement of speed or position of the motor using a shaft encoder. However, in some cases it is difficult (e.g. a compact drive system) or extremely expensive (e.g. submarine applications) to use sensors for speed measurement. Eliminating the speed sensor and measurement cables results in a lower cost, and at the same time increases the reliability and ruggedness of the overall drive system. Over the past decade, speed sensorless control strategies have aroused great interest among induction motor control researchers. In these strategies, the motor speed is estimated and used as a feedback signal for closed-loop speed control [2]. In this paper, is proposed a stator current and rotor flux observer based on the linear luenberger observer and Adaptive linear luenberger observer to estimate the stator current, rotor flux and rotor speed.

A review of previous work

There are a lot of papers dealing with luenberger observer. R. Bojoi et al. [3] presents a Rotor Field Oriented Control (RFOC) of a low-voltage, high-current dual-three phase induction machine and a

Luenberger observer has been used for rotor flux estimation. T. Kulworawanichpong [4] proposes algorithm development of a speed observer for single-phase induction motor drives by using a full-order extended Luenberger observer. Kyo-Beum Lee et al. [5] Presents a new sensorless vector control system for high-performance induction motor drives fed by a matrix converter with nonlinearity compensation and a reduced-order extended Luenberger observer is employed to bring better response in the whole speed operation range, and a method to select the observer gain is presented. Zhang Yongchang et al. [6] proposes an Extended Luenberger Observer (ELO) for speed sensorless vector control of induction motor drive fed by a three-level neutral point clamped (NPC) inverter. Tae-Sung Kwon et al. [7] investigates the problem of a conventional speed sensorless SFO system due to the delay of the estimated speed in the field weakening region and proposes a method to estimate exactly speed by using Luenberger observer. S. M. Nayeem Hasan et al. [8] proposes a novel Luenberger–sliding mode observer with parameter adaptation algorithm to compensate for the parameter variation effects. T. Pană et al. presents [9] a method of choosing the proportionality coefficient between the eigenvalues of the motor and the eigenvalues of the Luenberger Observer. T.C. Pana et al. [10] presents the asymptotic stability of a vector control system for a squirrel-cage induction motor that contains in its loop an extended Luenberger observer. In the present work, two schemes of estimators have been used in direct field orientation control induction motor (DFOCIM), linear luenberger observer and Adaptive linear luenberger observer for estimating stator current, rotor flux and rotor speed.

Dynamic Model of IM

To establish a good compromise between the stability and the simplicity of the observer, it is appropriate to take a stator reference frame (α,β). Then, the position of rotor flux is calculated in a direct way starting from the observation of its components in a stator reference frame and its determination by using the integration of ω_s [11, 12].

1 - Linear discrete state

In what follows, the mathematical model for discrete and continuous is presented in matrix form [11-14]:

1-1 discrete model:

The discrete model of the IM results from the continuous model [11]

$$\left.\begin{array}{l}\dot{X} = A(P\Omega)X + BU \\ Y = CX\end{array}\right\} (1)$$

Where X, U and Y are state vector, input vector and output vector and they are given by

$$X = \begin{bmatrix} I_{s\alpha} & I_{s\beta} & \Phi_{s\alpha} & \Phi_{s\beta} \end{bmatrix}^T$$

$$U = \begin{bmatrix} V_{s\alpha} & V_{s\beta} \end{bmatrix}^T$$

$$Y = \begin{bmatrix} I_{s\alpha} & I_{s\beta} \end{bmatrix}^T$$

$$A(P\Omega) = A(\omega) = \begin{bmatrix} -\frac{1}{\tau'_\sigma} & 0 & \frac{K_r}{\tau'_\sigma R_\sigma \tau_r} & \frac{K_r}{\tau'_\sigma R_\sigma} P\Omega \\ 0 & -\frac{1}{\tau'_\sigma} & -\frac{K_r}{\tau'_\sigma R_\sigma} P\Omega & \frac{K_r}{\tau'_\sigma R_\sigma \tau_r} \\ \frac{M}{\tau_r} & 0 & -\frac{1}{\tau'_\sigma} & -P\Omega \\ 0 & \frac{M}{\tau_r} & P\Omega & -\frac{1}{\tau'_\sigma} \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{1}{\tau'_\sigma R_\sigma} & 0 \\ 0 & \frac{1}{\tau'_\sigma R_\sigma} \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

$$\tau'_\sigma = \sigma \frac{L_s}{R_\sigma} \quad K_r = \frac{M}{L_r} \quad R_\sigma = R_s + K_r^2 . R_r$$

$$\tau_r = \frac{L_r}{R_r} \qquad \sigma = 1 - \frac{M^2}{L_s L_r}$$

One can discretize Eq (1) to give

$$\left.\begin{aligned} X_{k+1} &= A_k X_k + B_k U_k \\ Y_k &= C_k X_k \end{aligned}\right\} (2)$$

Where

A_k and B_k are matrices of the discrete system and can be given by [11,12]

$$\left.\begin{aligned} A_k &= \exp(A(P\Omega)T_e) \approx I_4 + A(P\Omega) + \frac{(A(P\Omega)T_e)^2}{2} \\ B_k &= (A(P\Omega))^{-1}(A_k - I_4)B \approx T_e\left(I_4 + \frac{A(P\Omega)T_e}{2}\right)B \\ C_k &= C \end{aligned}\right\} (3)$$

T_e being the period of sampling; the variables with the indices (k) and (k+1) respectively express the values of these variables at the moments (t_k) and (t_{k+1}).

1-2 Non linear discrete model

This model is deduced from the nonlinear continuous model .This model is given by the system of equation according to [11, 14]:

$$\left.\begin{aligned} X^e &= \begin{bmatrix} I_{s\alpha} & I_{s\beta} & \Phi_{r\alpha} & \Phi_{r\beta} & \Omega \end{bmatrix}^T \\ U^e &= \begin{bmatrix} V_{s\alpha} & V_{s\beta} \end{bmatrix}^T \\ Y^e &= \begin{bmatrix} I_{s\alpha} & I_{s\beta} \end{bmatrix}^T \end{aligned}\right\} (4)$$

If the nonlinear model is given by

$$\left.\begin{aligned} \dot{X}^e &= F(X^e, U^e) \\ Y^e &= H(X^e) \end{aligned}\right\} (5)$$

Where:

$$F(X^e, U^e) = \begin{bmatrix} -\frac{1}{\tau'_\sigma} I_{s\alpha} + \frac{K_r}{\tau'_\sigma R_\sigma \tau_r}\Phi_{r\alpha} + \frac{K_r}{\tau'_\sigma R_\sigma} P\Omega\Phi_{r\beta} + \frac{1}{\tau'_\sigma R_\sigma} V_{s\alpha} \\ -\frac{1}{\tau'_\sigma} I_{s\beta} + \frac{K_r}{\tau'_\sigma R_\sigma \tau_r}\Phi_{r\alpha} + \frac{K_r}{\tau'_\sigma R_\sigma \tau_r}\Phi_{r\beta} + \frac{1}{\tau'_\sigma R_\sigma} V_{s\beta} \\ \frac{M}{\tau_r} I_{s\alpha} - \frac{1}{\tau_r}\Phi_{r\alpha} - P\Omega\Phi_{r\beta} \\ \frac{M}{\tau_r} I_{s\beta} + P\Omega\Phi_{r\alpha} - \frac{1}{\tau_r}\Phi_{r\beta} \\ 0 \end{bmatrix}$$

$$, \quad H(X^e) = \begin{bmatrix} I_{s\alpha} \\ I_{s\beta} \end{bmatrix}$$

The discrete model of state nonlinear is summarized in matrix form as

$$\left.\begin{aligned} X^e_{k+1} &= F_k(X^e_k, U^e_k) \\ Y^e_k &= H_k(X^e_k) \end{aligned}\right\} (6)$$

The step of the linearization has been used since the suggested observer only tackles with linear model

$$\left.\begin{aligned} X^e_{k+1} &= A^e_k X^e_k + B^e_k U^e_k \\ Y^e_k &= C^e_k X^e_k \end{aligned}\right\} (7)$$

Where

$$A^e_k = \left.\frac{dF_k}{dX^e}\right|_{X^e_k = \hat{X}^e_k}$$

$$B^e_k = \left.\frac{dF_k}{dU_k^e}\right|_{X^e_k = \hat{X}^e_k}$$

$$C^e_k = \left.\frac{dH_k}{dX^e}\right|_{X^e_k = \hat{X}^e_k}$$

The discrete models of state of the IM, in the stator reference frame (α, β), are used as a basis for construction of the observers of state (the observer of Luenberger), for the estimate stator current, rotor flux and speed.

Deterministic Observer of Luenberger

The deterministic observer of Luenberger, makes it possible to reconstitute the state of an observable system starting from the measurement of the entries and the exits. It is used when whole or part of the vector of state cannot be measured. It allows the estimate of the variable or unknown parameters of a system. The theory of this observer, for the linear models, was presented by David G Luenberger. Wide versions were proposed to be applied to the asynchronous motor (IM) [15, 16].

Luenberger Observant in discrete time

In what follows two types of observers of Luenberger in discrete time will be represented: a linear observer of Luenberger (estimate of $I_{s\alpha,\beta}$ and $\Phi_{s\alpha,\beta}$) and a linear observer of Luenberger with adaptation for (estimate of $I_{s\alpha\beta}, \Phi_{s\alpha\beta}$, and Ω) [15,16] .

1 - Observant of linear Luenberger in discrete time

To simulate the linear observer of Luenberger in discrete time shown in Eq. (2 and 3). The estimate can take the form of corrector. If a correct observer is considered, the moment t_{k+1}, must be available to correct the state at the same moment:

$$\left.\begin{aligned} &\hat{X}_{p,k+1} = A_k \hat{X}_k + B_k U_k \\ &\hat{Y}_{k+1} = C_k \hat{X}_{p,k+1} \\ &\hat{X}_{k+1} = \hat{X}_{p,k+1} + K(Y_{k+1} - \hat{Y}_{k+1}) \end{aligned}\right\} (8)$$

The estimate $\hat{Y}_{k+1}$ is supposed the best that one can obtain at the moment t_{k+1} , starting from the prediction of the state $\hat{X}_{p,k+1}$. The matrix of transition from the observer is $A_k - KC_k A_k$. The observation is made, therefore, in two phases; the two terms of the error in estimation are given by

Error of prediction

$$\varepsilon_{k+1} = X_{p,k+1} - \hat{X}_{p,k+1} = A_k \varepsilon_k (9)$$

Error of correction

$$\varepsilon_{k+1} = X_{k+1} - \hat{X}_{k+1} = (I_4 - KC_k) A_k \varepsilon_k (10)$$

If the equation of state is exact and stable, and if the initial state is perfectly known, the exact estimate of the state of the process will be possible. However when the initial state is not known, but that the model is stable, one limited period related to the dynamics of the model is present on the estimate. If the conditions of observability are checked, the dynamics of the observation is determined by the choice of the matrix of profit K which defines the Eigen values of the matrix of transition from the observer. To ensure the stability of the observation, it should be calculated the profit K so that the Eigen values of the matrix $A_k - KC_k A_k$ remain in the unit circle. In this case, the error in estimation converges asymptotically towards zero, when time tends towards the infinite one. With regard to the matrix of profit K, this one is obtained by placement of the poles of the discrete observer in the unit circle P_d according to the following equation:

$$\varepsilon_{k+1} = X_{k+1} - \hat{X}_{k+1} = (I_4 - KC_k) A_k \varepsilon_k (11)$$

2- Observer of linear Luenberger in discrete time with estimate speed

When the speed is not measured, it is regarded as an unknown parameter in the system of equations of the observer. In order to estimate speed of machine rotor, an adaptive mechanism will be derived based on Lyapunov theory .the observer model in continuous form is given by [6, 17].

$$\left.\begin{aligned} &\dot{\hat{X}} = A\hat{X} + BU + K(Y - \hat{Y}) \\ &\hat{Y} = C\hat{X} \end{aligned}\right\} (12)$$

The error in estimation on the stator current and the rotor flux which is not other than the difference between the observer and the model of the IM.

$$\frac{d\varepsilon}{dt} = \frac{d(X - \hat{X})}{dt} = (A - KC)(A - \hat{A})\hat{X} = (A - KC)\varepsilon - \Delta A\hat{X} \, (13)$$

Where

$$\Delta A = \hat{A} - A = \begin{bmatrix} 0 & -(\hat{\Omega} - \Omega) J \dfrac{M}{\sigma L_S L_r} \\ 0 & (\hat{\Omega} - \Omega) J \end{bmatrix} (14)$$

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

$$C=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\end{bmatrix}$$

To establish the algorithm of speed estimation, one can define the Lyapunov function:

$$V=\varepsilon^T\varepsilon+\frac{1}{\lambda}(\hat{\Omega}-\Omega)^2 \quad (15)$$

Where

λ is a positive constant.

Taking the derivative of the above function with respect to time yield

$$\frac{dV}{dt}=\left[\frac{d\left(\varepsilon^T\right)}{dT}\right]\varepsilon+\varepsilon^T\left[\frac{d\varepsilon}{dt}\right]+\frac{1}{\lambda}\frac{d(\hat{\Omega}-\Omega)^2}{dt} \quad (16)$$

Substituting expression (13) in (16), one can obtain the following expression:

$$\frac{dV}{dt}=\varepsilon^T\left[(A-KC)^T+(A-KC)\right]\varepsilon-(\hat{X}\Delta A^T\varepsilon+\varepsilon^T\Delta A\hat{X})+\frac{2(\hat{\Omega}-\Omega)}{\lambda}\frac{d(\hat{\Omega}-\Omega)}{dt} \quad (17)$$

Finally derived it from the function of Lyapunov can be expressed as follows:

$$\frac{dV}{dt}=\varepsilon^T\left[(A-KC)^T+(A-KC)\right]\varepsilon-2\frac{M}{\sigma L_s L_r}(\hat{\Omega}-\Omega)(\varepsilon_{i\alpha}\hat{\Phi}_{r\beta}-\varepsilon_{i\beta}\hat{\Phi}_{r\alpha})-2(\hat{\Omega}-\Omega)(\varepsilon_{\Phi\beta}\hat{\Phi}_{r\alpha}-\varepsilon_{\Phi\alpha}\hat{\Phi}_{r\beta})+\frac{2(\hat{\Omega}-\Omega)}{\lambda}\frac{d(\hat{\Omega}-\Omega)}{dt} \quad (18)$$

To guarantee system stability according to Lyapunov theory, one should ensure that Eq. (18) must be at least negative definite. Supposing zero error of rotor flux, then the third terms can be set to zero. Therefore, the adaptation law of speed estimator can be obtained by equating the second and forth term to obtain:

$$\frac{d(\hat{\Omega}-\Omega)}{dt}=\frac{\lambda M}{\sigma L_s L_r}(\varepsilon_{i\alpha}\hat{\Phi}_{r\beta}-\varepsilon_{i\beta}\hat{\Phi}_{r\alpha}) \quad (19)$$

If it is supposed that speed estimated $\hat{\Omega}$ changes much, more quickly than Ω. Then the adaptive mechanism is further simplified as;

$$\frac{d\hat{\Omega}}{dt}=\frac{\lambda M}{\sigma L_s L_r}(\varepsilon_{i\alpha}\hat{\Phi}_{r\beta}-\varepsilon_{i\beta}\hat{\Phi}_{r\alpha}) \quad (20)$$

Where : $\varepsilon_{i\alpha}=I_{s\alpha}-\hat{I}_{s\alpha}, \varepsilon_{i\beta}=I_{s\beta}-\hat{I}_{s\beta}$

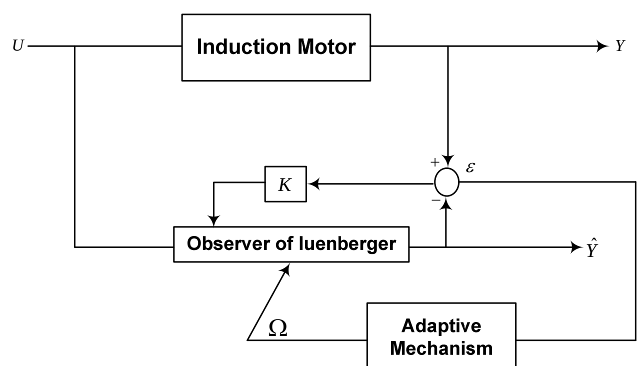
The law of speed matching is deduced under the condition that speed remains constant, but in practice it changes rather quickly. In order to improve the algorithm of speed matching, a term proportional can be added. The law of speed matching becomes then

$$\hat{\Omega}=K_p(\varepsilon_{i\alpha}\hat{\Phi}_{r\beta}-\varepsilon_{i\beta}\hat{\Phi}_{r\alpha})+K_i\int(\varepsilon_{i\alpha}\hat{\Phi}_{r\beta}-\varepsilon_{i\beta}\hat{\Phi}_{r\alpha})dt \quad (21)$$

Where:

$$K_p\rangle 0 \quad , \quad K_i=\frac{\lambda M}{\sigma L_s L_r} \quad , \lambda\rangle 0$$

The diagram block of the observer with the adaptive mechanism is given by [6, 18]



Block diagram (1) the observer with the adaptive mechanism

Structure of the DFOC IM provided with an observer of Luenberger

In figure (1) structure of Direct field orientation control induction motor (DFOCIM) with linear luenberger observer to estimate stator Current and rotor flux [12, 15]

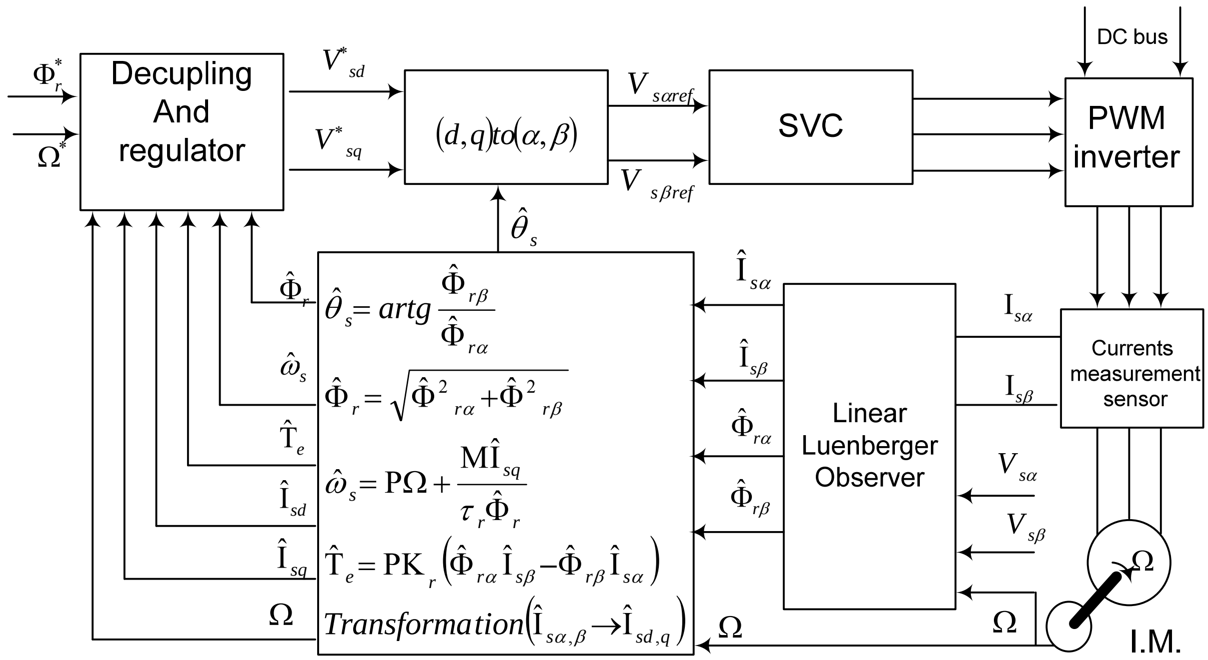


Figure (1) structure of Direct field orientation control induction motor (DFOCIM) with linear luenberger observer

In figure (2) structure of Direct field orientation control induction motor (DFOCIM) with Adaptive linear luenberger observer. to estimate stator Current, rotor Flux and rotor speed[12,15]

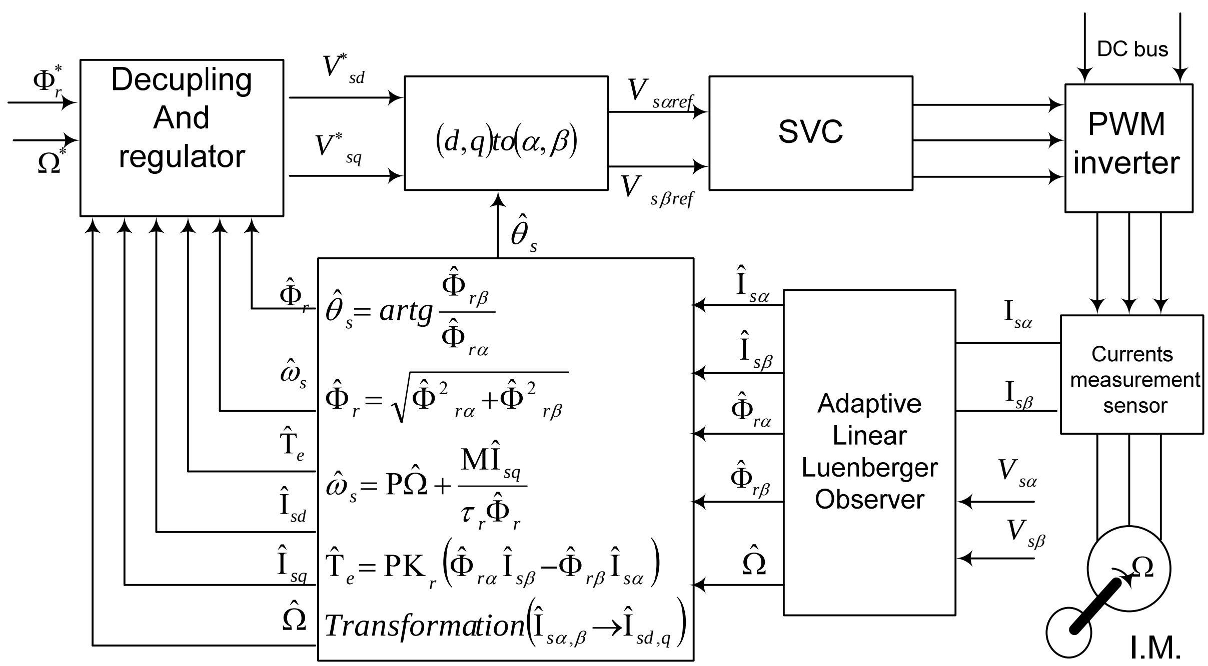
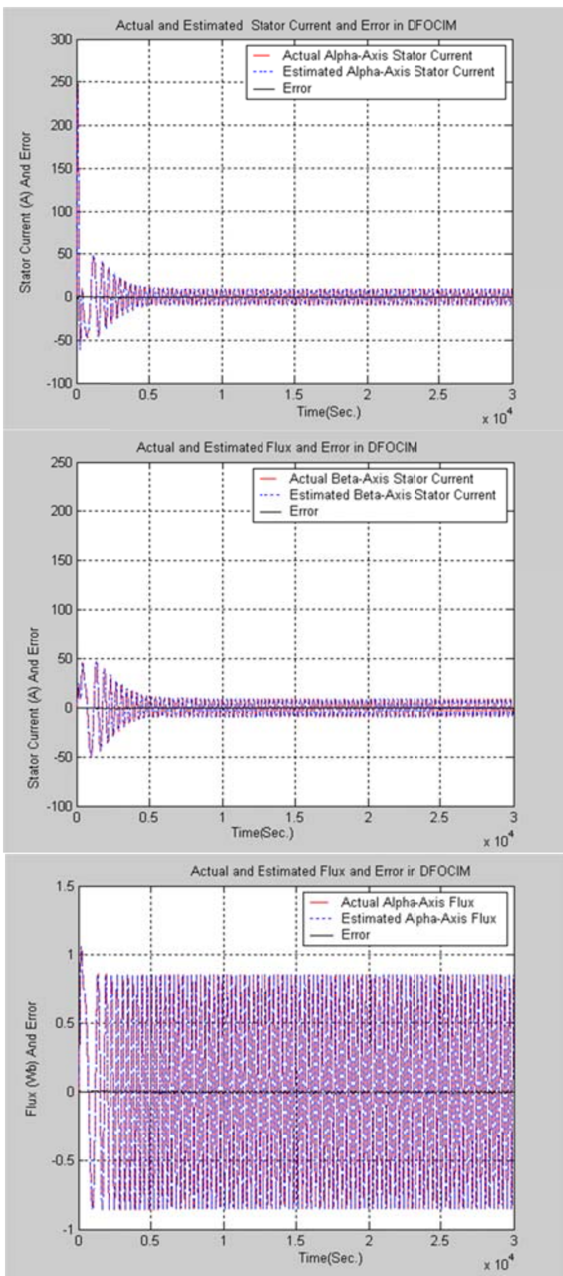


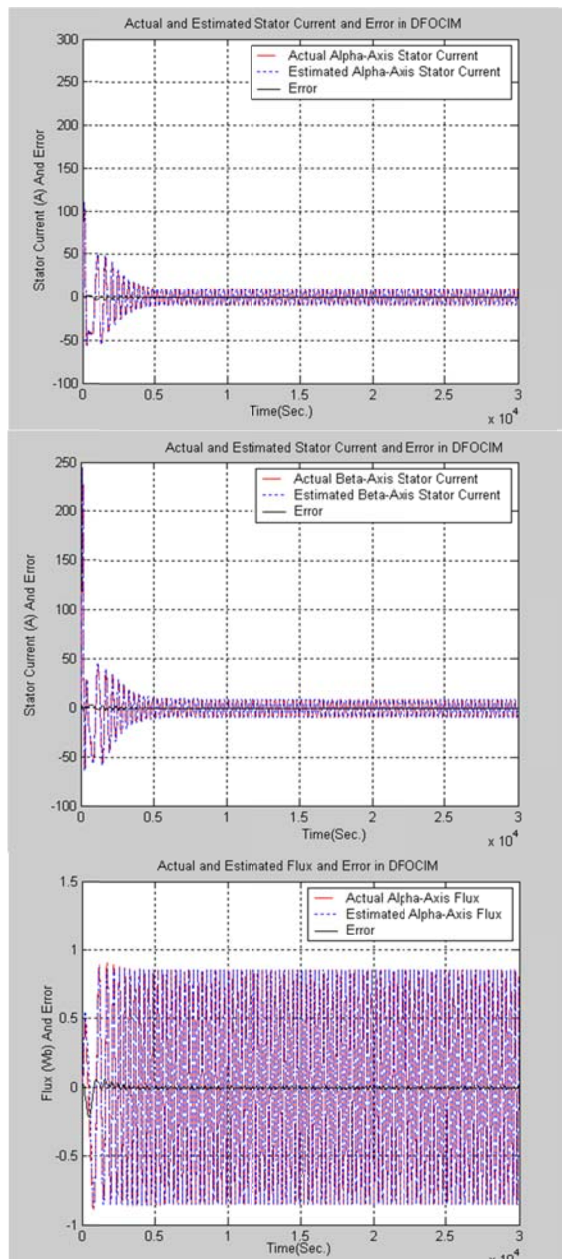
Figure (2) structure of Direct field orientation control induction motor (DFOCIM) with Adaptive linear luenberger observer

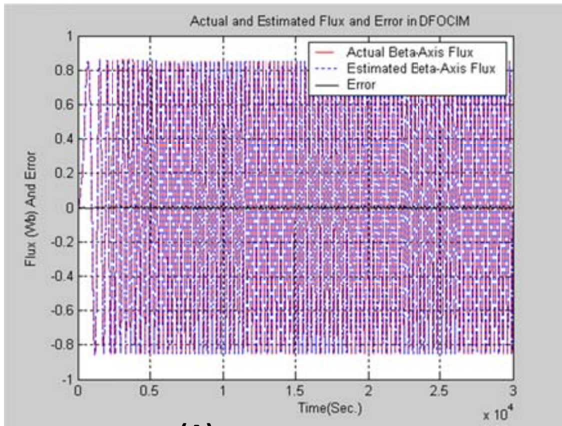
Simulated Result

1 -No load

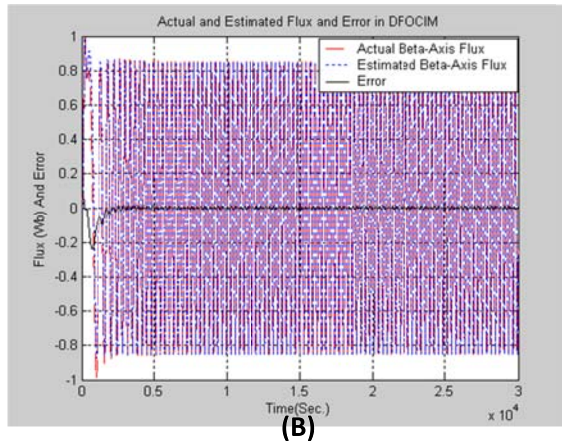
Figure (3) present the actual, estimated and error in stationary reference frame (α, β) for stator current and rotor flux at the reference speed 1000 tr/min. It is seen that the rotor flux estimate by linear Luenberger observer "measured speed" has an advantage over Adaptive linear luenberger observer "Estimated speed". This advantage materializes by a better convergence and a perfect continuation in amplitude and time of estimate of the first values of the components of the vector of state. In the same way for the stator current the amplitude as well as the extent of the oscillation of the estimated values, at the starting time strongly depends on the initial values of the components of the state vector. In any way the Luenberger observer (linear Luenberger observer and Adaptive linear luenberger observer) is good observation in stator current and rotor flux.







(A)

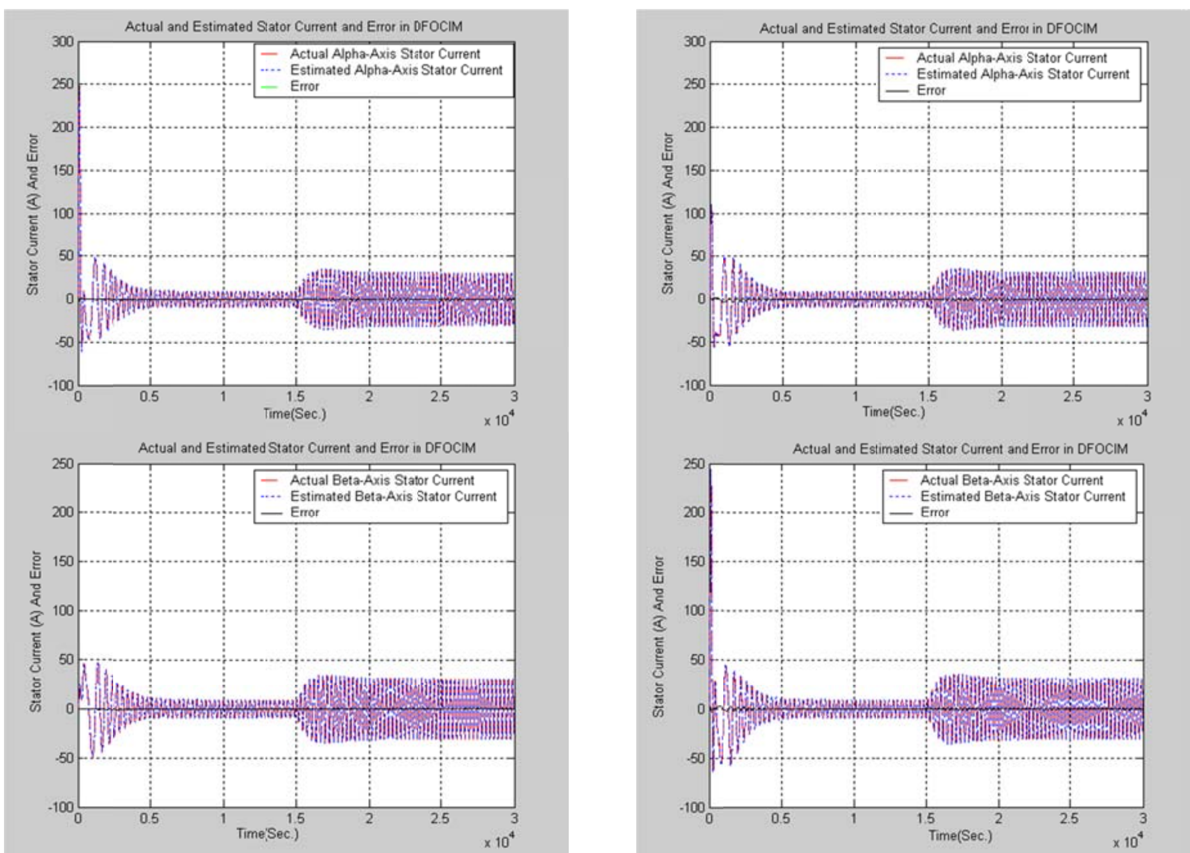


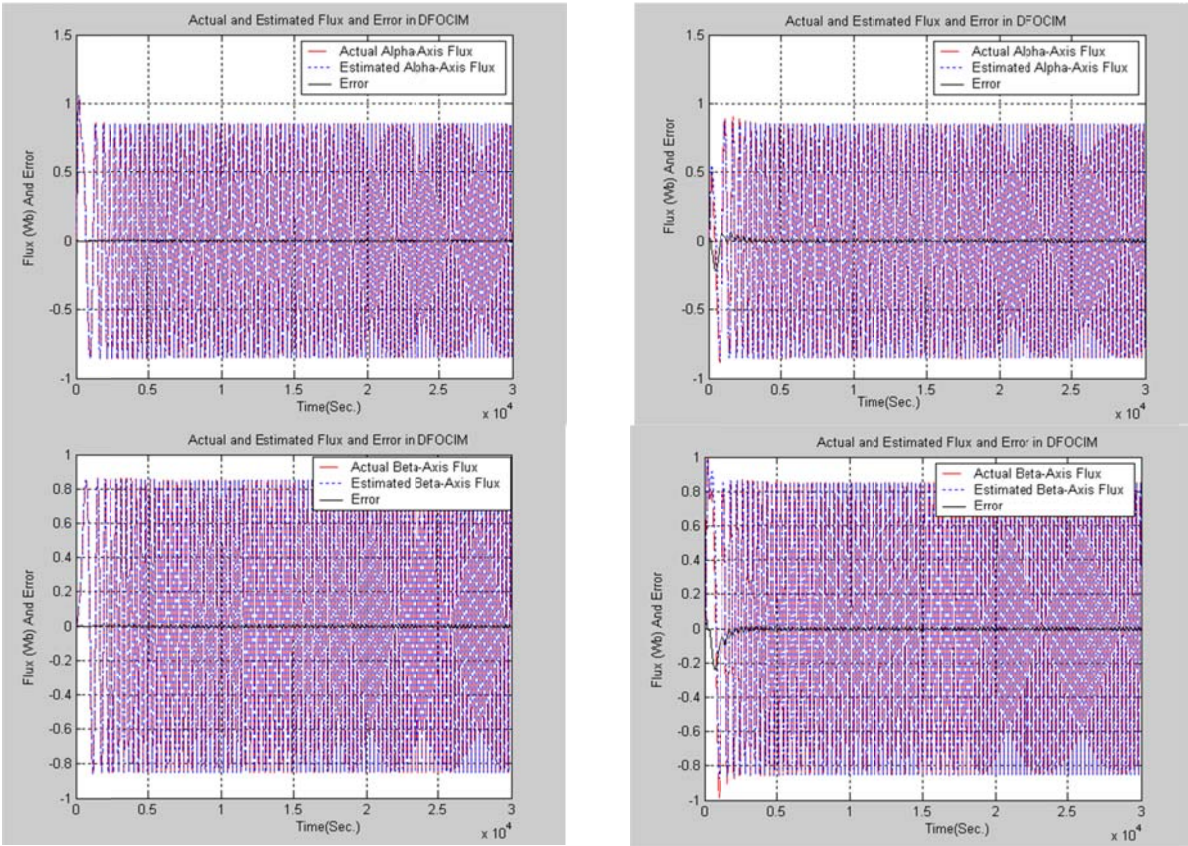
(B)

Fig.(3) Results of simulation obtained with the two observers of Luenberger for a speed of reference 1000 tr/min (No-load)
A- Linear Luenberger observer
B- Adaptive linear luenberger observer

2 -With Load

Figure (4) shows the actual, estimated and error of stator current and rotor flux, in stationary reference frame (α, β), produced by two observers as load of 50 Nm is exerted at time 1.5 Sec. It has been shown that the Luenberger observer (linear Luenberger observer and Adaptive linear luenberger observer) give satisfactory robust characteristics.



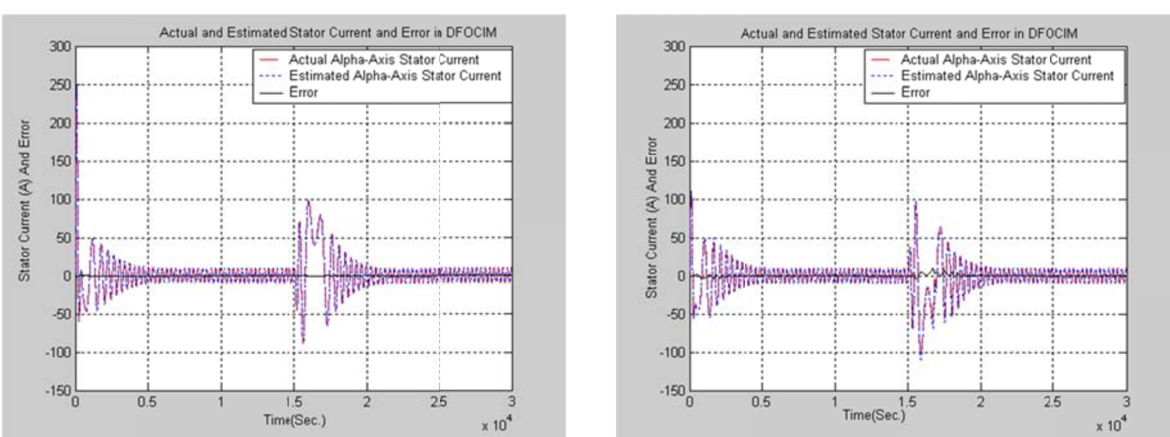


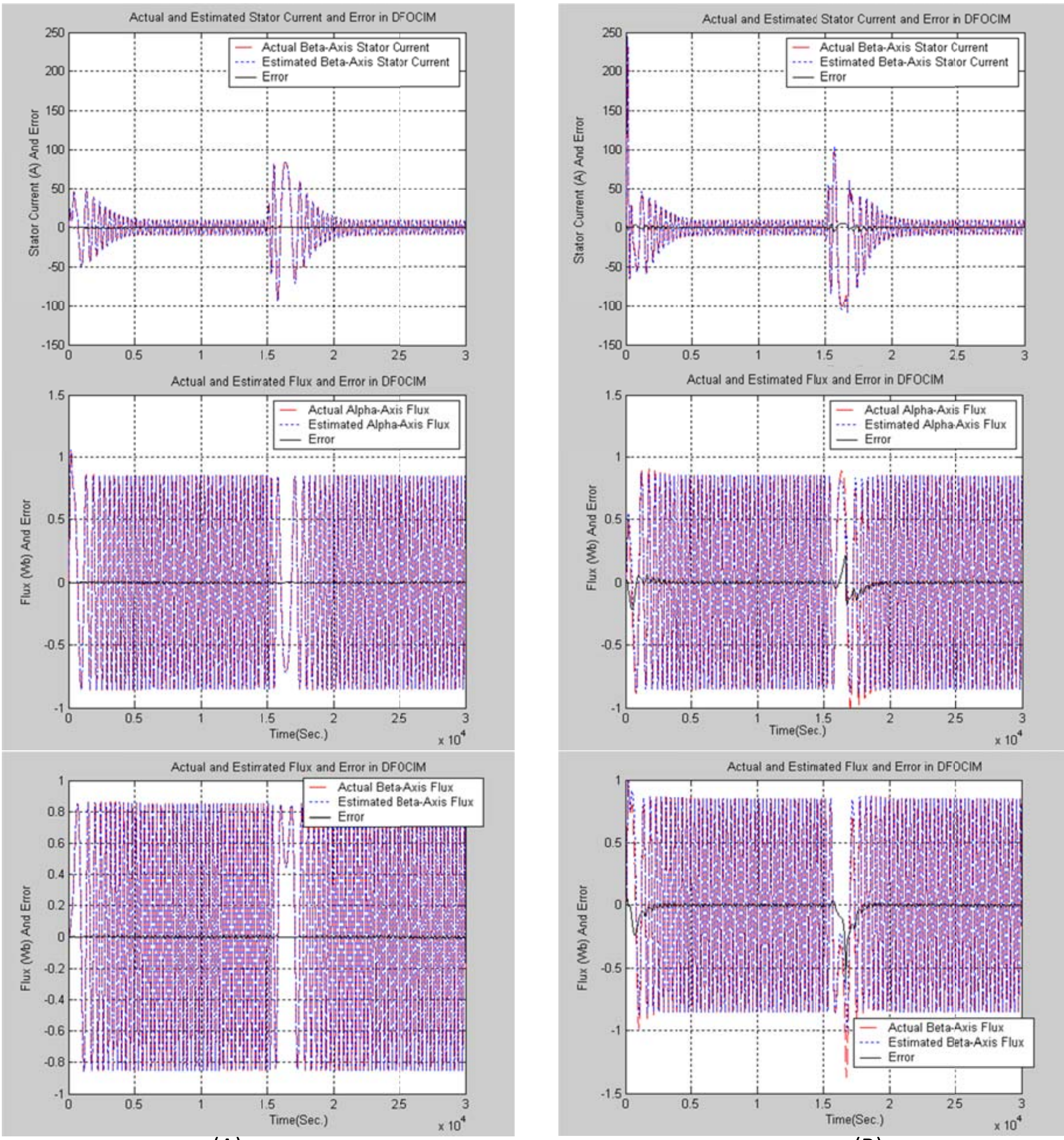
(A) **(B)**

Fig.(4) Results of simulation obtained with the two observers of Luenberger (load of 50 Nm to T =1.5s).
A- Linear Luenberger observer
B- Adaptive linear luenberger observer

3 Tracking Performance

Figure (5) shows that inversion of the direction of rotation of 1000 tr/min with -1000 tr/min to t=1.5 sec. . It is noted that linear Luenberger observer is most robust with respect to the abrupt variation the speed of reference. The peak of the rotor flux associated with the linear Luenberger observer is lower compared to that associated the Adaptive linear luenberger observer. In any way the Luenberger observer (linear Luenberger observer and Adaptive linear luenberger observer) is high performance in Tracking Performance.



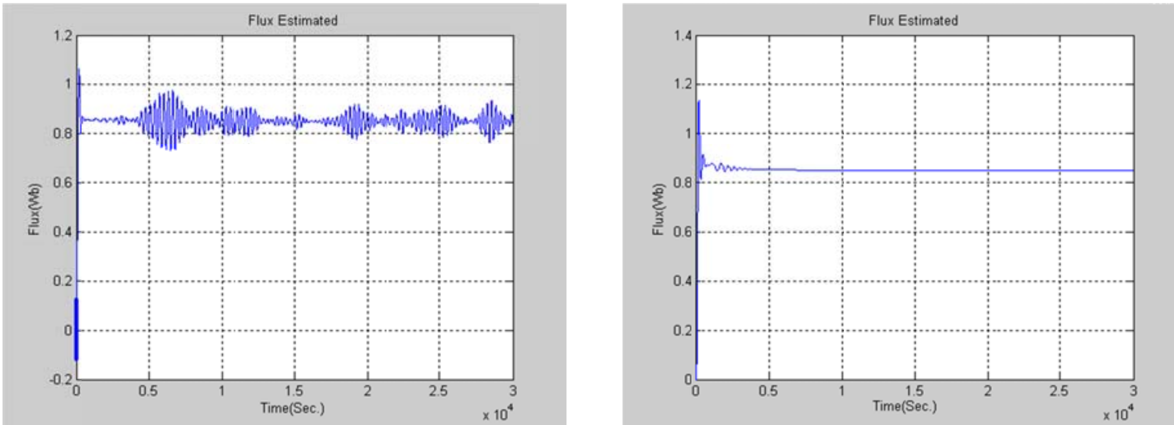


(A) (B)

Fig (5) Results of simulation obtained with the two observers of Luenberger (inversion of the direction of rotation of 1000 tr/min to -1000 tr/min to t=1.5s)
A- Linear Luenberger observer
B- Adaptive linear luenberger observer

4 Noise Injection

In fig (6) at reference flux 0.85 Wb , the noise rejection capabilities of suggested observers have been examined by injecting noise of variance 3A in stator current ($I_{s\alpha}$, $I_{s\beta}$) . It is clear from fig. (6) that the flux estimate resulting from Luenberger observer is more sensitive to such noise then adaptive Luenberger observer.

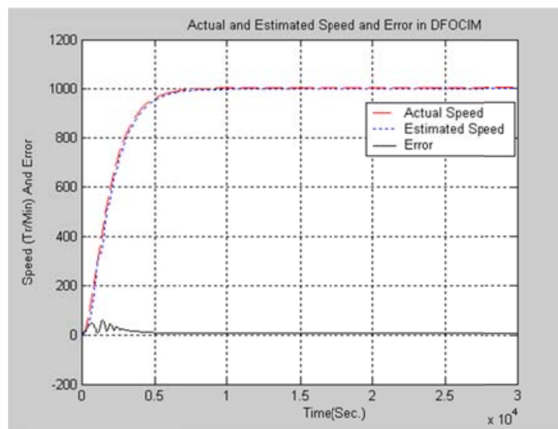


(A) (B)

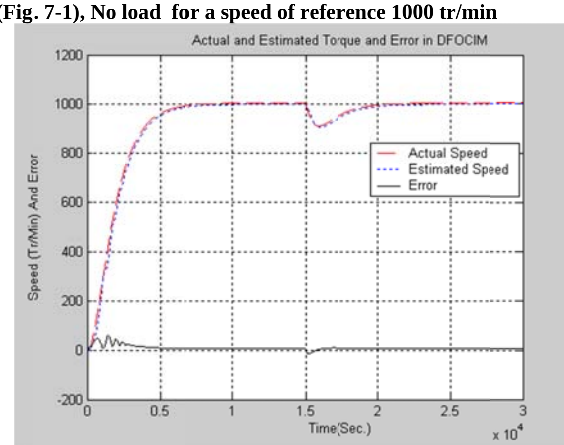
Fig (6) Comparison of the model of the rotor flux estimated by the two observers of Luenberger with the injection of a noise of measurement of variance of 3A
A- Linear Luenberger observer
B- Adaptive linear luenberger observer

5- Speed Estimation

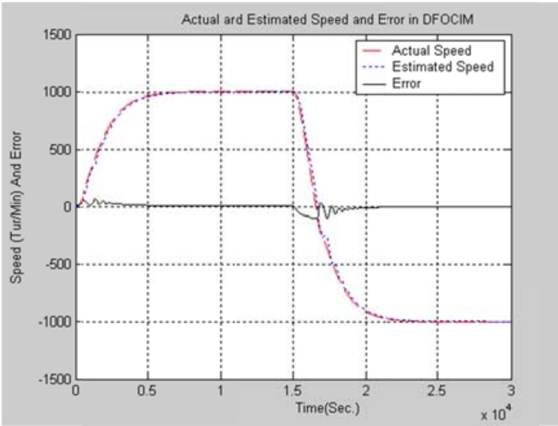
In order to check the behavior of the linear observer of Luenberger with adaptation for the estimate speed (Adaptive linear luenberger observer), figures (7-1,2,3) At no load , it is clear from (Fig. 7-1) that the estimation error is finally vanishes as time goes beyond steady state .similarly , the same result can be obtain when one exerts load of high 50 Nm after 1.5 sec. of starting . It is evident from (fig. 7-2) that the estimation error will grow at time of load exertion and then would finally die out to reach zero value therefore the Adaptive linear luenberger observer is very sensitive to change of system parameter (load). The same of argument as above can be concluded in (fig. 7-3) where tracking situation has been considered. The observer could successfully track the actual speed inversion and finally gives zero steady state estimation error



(Fig. 7-1), No load for a speed of reference 1000 tr/min



(Fig. 7-2), Load of 50Nm to t=1.5 s for a speed of reference 1000 tr/min



(Fig. 7-3), Inversion of the direction of rotation of 1000 tr/min with -1000 tr/min with t=1.5s

CONCLUSIONS

In this paper, a method for the direct field oriented control and two observers (linear Luenberger observer and Adaptive linear luenberger observer) have been presented. Based on simulation results, one can highlight the following conclusion:

1- The direct field orientation control could decouple the coupling between torque and flux to give high current/torque capabilities.
2- The results showed that linear Luenberger observer and Adaptive linear luenberger observer yield good estimation and observation characteristics , but linear Luenberger observer is more advantage in transient state than Adaptive linear luenberger observer due to estimate of first values of the components of the vector of state.
3- The Adaptive linear luenberger observer showed high performance in speed estimation.
4- The noise rejection due to Adaptive linear luenberger observer is higher than its counterpart linear Luenberger observer

Appendix I (The Information and Parameters of IM)

The model of the induction motor (IM) is elaborate on

1- The air-gap of the IM is thickness uniform, thus neglecting the effect of the notches.
2- the magnetic circuit unsaturated and with a constant permeability, the hysteresis and the eddy currents his negligible
3- Neglecting the effect of skin and the iron losses.
4- Three-phase winding of the induction motor is symmetrical.

Parameters of IM are listed in Table (1)

Table 1: Parameters of IM

Nominal power	P_n	7,5	Kw
Nominal speed	Ω_n	1450	tr/min
Nominal torque	T	50	Nm
Number of pole Paris	P	2	p.u
Stator resistance	R_s	0,63	Ω
Rotor resistance	R_r	0,4	Ω
Stator inductance	L_s	0,097	H
Rotor inductance	L_r	0,091	H
Mutual inductance	M	0.091	H
moment of inertia	J	0,22	$Kg.m^2$

List of Symbols

Symbol	Description
A	The state matrix.
B	The input matrix.
C	The output matrix.
E	Expected value.
ε	Error.
I	Identity matrix.
$i_{s\alpha}\ (I_{s\beta})$	α -axis (β -axis) of Stator current.
$i_{dr}\ (i_{qr})$	D-axis (q-axis) of rotor current.
$i_{sd}\ (i_{sq})$	D-axis (q-axis) of stator current.
K_i	Integral gain
K_P	Proportional gain
M	Magnetizing inductance.
L_r	Rotor self inductance.
L_s	Stator self inductance.
P	Number of motor pole pairs.
R_r	Rotor resistance.
R_s	Stator resistance.
U	Input vector.
$V_{sd}\ (V_{sq})$	D-axis (q-axis) of stator voltage.
$V_{s\alpha}\ (V_{s\beta})$	α -axis (β -axis) of stator voltage.
ω	Electrical speed.
x	State vector.
x_k	State vector at index k.
y	Output.
θ	Angle (rad).
θ_s	Stator angle.
Φ_r	Flux in rotor
$\Phi_{r\alpha}\ (\Phi_{r\beta})$	α -axis (β -axis) of rotor flux.
Ω	Mechanical speed
T	A Superscript indicates to Transpose.
d	Derivative.
k	A subscript indicates to the index of sampling time.
e	A Superscript indicates to Extended Vector.
^	A Superscript indicates to estimation.

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التخمين الجبري لمسوق المحرك الحثي ذو سيطرة توجيه المجال المغناطيسي المباشر

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الخلاصة:

عندما يكون مسوق المحرك الحثي ذو سيطرة توجيه المجال المغناطيسي المباشر يتصرف المحرك الحثي مثل محرك التيار المستمر ذو التغذية المنفصلة اي تكون سيطرة كل من العزم والفيض مستقلة . بالاستناد على نموذج المحرك الحثي ذو سيطرة المجال المغناطيسي المباشر تيار الجزء الثابت،فيض الجزء الدوار وسرعة الجزء الدوار للمحرك الحثي يمكن ان تخمن اي يمكن استخدام **(Linear Luenberger Observer)** لتخمين تيار الجزء الثابت وفيض الجزء الدوار للمحرك الحثي وايضا يمكن استخدام **(Adaptive Linear Luenberger Observer)** لتخمين تيار الجزء الثابت ،فيض الجزء الدوار وسرعة الجزء الدوار للمحرك الحثي . ان الفائدة البارزة لاستخدام **(Linear Luenberger Observer)** هي دقة التخمين لتيار الجزء الثابت و فيض الجزء الدوار بينما الفائدة البارزة لاستخدام **(Adaptive Linear Luenberger Observer)** هي دقة التخمين لتيار الجزء الثابت ، فيض الجزء الدوار وسرعة الجزء الدوار للمحرك الحثي . ان صلاحية الطريقة المقترحة محققة بأستخدام نتائج المحاكاه لبرنامج الماتلاب.