

CONCEPTION OF AN HYBRID CONTROL OF INDUCTION MOTOR WITH AN ADAPTIVE LUENBERGER SPEED CONTROLLER USING PARAMETERS MACHINE ESTIMATION

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Abstract: Direct Torque Control (DTC) is a method, which is used to control the flux and torque of a motor. This method uses a flux and torque estimator. The major problem that is usually associated with DTC drive is the high torque ripple because of the two hysteresis controllers of flux and torque. The stator resistance is used in the flux and torque estimator. So the stator resistance deviation from its set value, might affect DTC performance especially at low speed.

To overcome these problems, this paper presents an improved direct torque control based on fuzzy logic technique (FLDTC), where the torque and flux hysteresis controllers are replaced by fuzzy controllers. The input variables of the fuzzy logic identifier are flux error, torque error and flux position. An active and reactive power using stator and rotor model stator to calculate resistance estimator is proposed.

The fuzzy proposed controller is shown to be able to reducing the torque and flux ripples and to improve performance DTC especially at low speed.

An adaptive Luenberger observer controller scheme is designed to robustly drive a sensorless IM even for the case of low frequencies. Combining the fuzzy DTC control strategy. Finally, some simulation test results are given on the framework of a specific sensorless induction motor benchmark.

Key words: Induction motor (IM), direct torque control, fuzzy logic, parameters motor estimation, adaptive Luenberger speed controller.

1. Introduction.

This paper proposes improvement of DTC using FLC as switching state selector based on modified classical DTC and Luenberger speed observer.

The main advantages of conventional DTC (C-DTC) are robust and fast torque response, no requirements for coordinate transformation no requirements for PWM pulse generation and current regulators.

Conventional DTC [1], does not require any mechanical sensor or current regulator and coordinate transformation is not present, thus reducing the complexity. Fast and good dynamic performances and robustness has made DTC popular and is now used widely in all industrial applications.

Despite these advantages it has some disadvantages such as, high torque ripple and slow transient response to step changes during start up. The major problem in a DTC-based motor drive is the presence of ripples in the motor developed torque and stator flux.

Generally, there are key techniques to reduce the

torque ripples. The first one is to use a multilevel inverter which will provide the more precise control of motor, torque and flux. However, the cost and complexity of the controller increase proportionally. The other method is space vector modulation [2]. Its drawback is that the switching frequency still changes continuously.

Advantages of intelligent controllers such as fuzzy logic, neural network, etc., are well known as their designs do not depend on accurate mathematical model of the system and they can handle nonlinearity of arbitrary intricacy. Among different intelligent algorithms, fuzzy logic is the simplest, which does not necessitate intensive mathematical analysis [3].

This paper introduces the design of a fuzzy logic controller in conjunction with direct torque control strategy for an induction motor.

The Fuzzy Logic (FL) method, which is based on the language rules [4], is employed to work out this non-linear issue. The ripples can be reduced if the errors of the torque and the flux linkage and the angular region of the flux linkage are subdivided into several smaller subsections. Since the errors are divided into smaller sections different voltage vector is selected for small disparity in error, so a more accurate voltage vector is selected and hence the torque and flux linkage errors are condensed.

On the other hand, ongoing research has concentrated on the elimination of the speed sensor at the machine shaft without deteriorating the dynamic performance of the drive control system. The advantages of speed sensorless induction motor drives are reduced hardware complexity and lower cost, reduced size of the drive machine, elimination of the sensor cable, better noise immunity, increased reliability and less maintenance requirements [8-10]. In this study the rotation speed is estimated by a Luenberger observer.

The paper is organized as follows: The induction model is presented in the second section, the DTFC based Fuzzy logic is developed in the third section, the stator resistance estimator design is performed in the fourth section, section five presents a speed Luenberger observer and section six is devoted to illustrate by simulating the performances of this control strategy, a conclusion and reference's list end the paper.

2. Induction motor model

The torque developed from induction motor [1] is

$$T_e = \frac{3p}{4} \frac{L_m}{L_r} \phi_r \frac{1}{L_\sigma} \phi_s \sin \theta \quad (1)$$

Where:

ϕ_s , ϕ_r are stator and rotor flux linkage space vector respectively.

L_m , L_r are respectively the magnetizing inductance, and the rotor inductance.

L_σ the rotor leakage inductance,

θ torque angle.

p denotes number of pairs of poles.

The stator flux is affected directly by impressed stator voltage u_s :

$$\phi_s = \int (u_s - R_s i_s) \quad (2)$$

In stator reference frame, (α, β) coordinates:

$$\phi_s = \begin{pmatrix} \phi_s \alpha \\ \phi_s \beta \end{pmatrix}, u_s = \begin{pmatrix} u_s \alpha \\ u_s \beta \end{pmatrix} \text{ and } i_s = \begin{pmatrix} i_s \alpha \\ i_s \beta \end{pmatrix}$$

The output of a PWM inverter has only 6 non-zero voltage vectors and 2 zero voltage vectors.

The stator flux increment $\Delta\phi_s$, can be obtained by neglecting the voltage drop over R_s

$$\Delta\phi_s \approx u_s \Delta T = \begin{cases} \frac{2}{3} V_{dc} e^{j(k-1)\frac{\pi}{3}} & k = 1, \dots, 6 \\ 0 & k = 0, 7 \end{cases} \quad (3)$$

Where:

ΔT , the voltage vectors lasting time over a sample period, and V_{dc} , is DC voltage source.

It follows from equ.(3) and figure 1 that u_s can directly change both the magnitude and rotating speed of the flux ϕ_s .

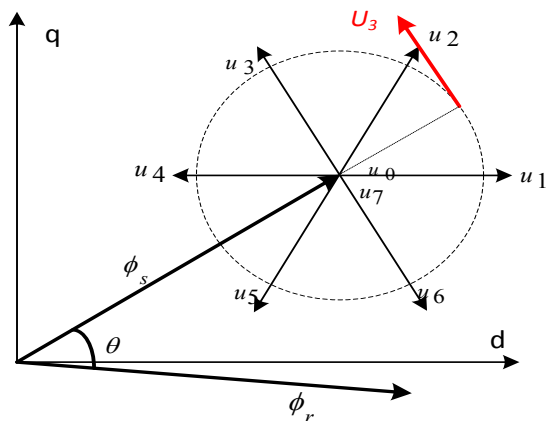


Fig. 1. Example of how to choose a stator voltage vector u_s

In order to make torque control easier, like the vector control scheme, the magnitude of ϕ_s is to be kept constant in DTC, which then ensures ϕ_r is remaining constant as well.

Therefore the motor instantaneous torque will change directly with the variation of the torque angle θ , which is affected by the relative movement of ϕ_s and ϕ_r .

In figure 1 if ϕ_s is greater than the given value ϕ^* , a voltage vector forcing ϕ_s to decrease is selected. On the other hand, if ϕ_s is less than ϕ^* , a voltage vector increasing ϕ_s is exerted.

An asterisk (*) is added to indicate command signals.

In this way the flux ϕ_s can be controlled at its given value provided the PWM switching frequency is high enough, which will result in ϕ_r also at a stable value.

Under the condition of flux magnitude being kept at given value, according to equation.(1) the torque can be controlled by changing the torque angle θ

Suppose rotor flux ϕ_r is behind stator flux ϕ_s a certain angle θ as depicted in figure 1.

From equation.(3) one can see that rotating speed of ϕ_s is directly determined by the voltage vector.

Hence rapid change in torque can be obtained by altering the rotating speed of ϕ_s .

To increase torque requires enlarging θ . This can be done by selecting the voltage vector that both can keep $|\phi_s|$ and increase θ .

To decrease the torque, θ should be reduced.[2]

3. Direct torque control using fuzzy logic.

From the discussion in the previous section the controller adopting DTC strategy is a type of hysteresis, which means the control action will be the same in the whole error range. To obtain better control effect a fuzzy logic controller has been introduced to replace the hysteresis controller [3-7].

A designer of Fuzzy logic controller must choose memberships for input and output variables and put the rules for the control process, the decision making is made according to fuzzified inputs and rule base which the designer put according to data base, then the output is defuzzified.

Generally speaking, a fuzzy logic controller consists of three main parts: fuzzification, fuzzy reasoning and defuzzification.

Fuzzification

The fuzzification is the process of a mapping from measured or estimated input to the corresponding fuzzy set in the input universe of discourse. In this system there

are three inputs, which are, $\Delta\phi_s$ (error of stator flux), ΔT_e (error of torque) and θ_s (stator flux angle). They are respectively defined in equation (4):

$$\begin{aligned}\Delta\phi_s &= \phi_s^* - \phi_s \\ \Delta T_e &= T_e^* - T_e \\ \theta_s &= \arctan \frac{\phi_s \beta}{\phi_s \alpha}\end{aligned}\quad (4)$$

The membership functions of the 3 inputs are represented in Figure 2.

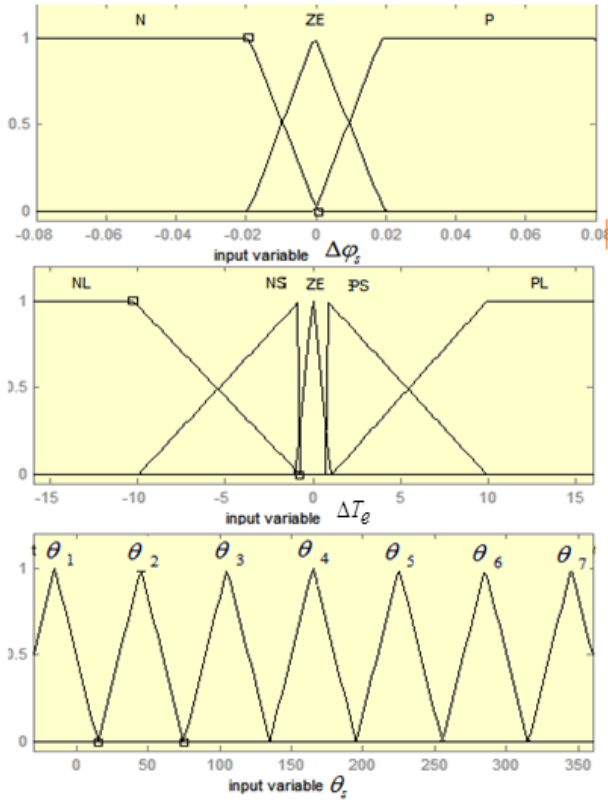


Fig. 2. Membership functions of three input variables.

The stator flux error membership function is decomposed in three fuzzy sets: N (negative), ZE (zero), P (positive)

The torque error membership function is decomposed in six fuzzy sets: NL (negative large), NS (negative small), ZE (zero), PS (positive small), PL (positive large)

The stator flux angle θ_s membership function is decomposed in seven fuzzy sets: θ_1 to θ_7

Control rules and fuzzy reasoning

Control rules are often expressed in the IF-THEN format. The i^{th} rule R_i can be written as:

$$\text{IF } \Delta\phi_s \text{ is } \tilde{A}_i; \text{ and } \Delta T_e \text{ is } \tilde{B}_i; \text{ and } \theta_s \text{ is } \tilde{C}_i \text{ THEN } u_s \text{ is } u_i \quad (5)$$

Where $\tilde{A}_i, \tilde{B}_i, \tilde{C}_i$ denote the fuzzy set

The control object is to maintain the stator flux at given value while the torque has fast response. It has been found difficult to select a stator voltage vector to meet the requirement of both the flux and torque control all the time.

As the flux is easy to be kept at prescribed value, hence when there is a conflict between reducing torque error and flux error, we first choose a voltage vector that can reduce the torque error fast.

For example (see figure1):

IF $\Delta\phi_s$ is ZE and ΔT_e is PL and $(\theta_s = \theta_2)$ THEN $(u_s = u_3)$.

By considering the fuzzy set categories of three inputs and the control action above, the control rules were obtained and shown in figure 3.

Angle θ_1 and θ_7				Angle θ_2			
$\Delta\phi_s \backslash \Delta T_e$	P	ZE	N	$\Delta\phi_s \backslash \Delta T_e$	P	ZE	N
PL	V1	V2	V2	PL	V2	V3	V3
PS	V2	V2	V3	PS	V3	V3	V4
ZE	V1	V0	V4	ZE	V2	V0	V5
NS	V6	V5	V4	NS	V1	V6	V5
NL	V6	V5	V5	NL	V1	V6	V6
Angle θ_3				Angle θ_4			
$\Delta\phi_s \backslash \Delta T_e$	P	ZE	N	$\Delta\phi_s \backslash \Delta T_e$	P	ZE	N
PL	V3	V4	V4	PL	V4	V5	V5
PS	V4	V4	V5	PS	V5	V5	V6
ZE	V3	V0	V6	ZE	V4	V0	V1
NS	V2	V1	V6	NS	V3	V2	V1
NL	V2	V1	V1	NL	V3	V2	V2
Angle θ_5				Angle θ_6			
$\Delta\phi_s \backslash \Delta T_e$	P	ZE	N	$\Delta\phi_s \backslash \Delta T_e$	P	ZE	N
PL	V5	V6	V6	PL	V6	V1	V1
PS	V6	V6	V1	PS	V1	V1	V2
ZE	V5	V0	V2	ZE	V6	V0	V3
NS	V4	V3	V2	NS	V5	V4	V3
NL	V4	V3	V3	NL	V5	V4	V4

Fig. 3. Fuzzy control rules

The fuzzy reasoning used is Mandani method [4], that is Min-Max approach.

Defuzzification

After fuzzy reasoning we have a linguistic output variable which needs to be translated into a crisp value.

In this paper, we use, Center-of-Area (C-o-A). This method is often referred to as the Center-of-Gravity method because it computes the centroid of the composite area representing the output fuzzy term.

4. Parameters motor estimation

Equation (2) contains a stator resistance. At low speed the flux estimation is affected by the change of this

parameter.

An estimation of the IM parameters using stator and rotor model to calculate active and reactive power is used. The error between the two model estimates the motor parameters, and by an integral proportional regulator, using Hurwitz stability theory, we can obtain the estimate IM parameters.

The stator reactive power Q_s is given by:

$$\frac{2}{3}Q_s = -i_{s\beta} \left(v_{s\alpha} - \hat{R}_s i_{s\alpha} - \sigma L_s \frac{d}{dt} i_{s\alpha} + \sigma L_s \omega_s i_{s\beta} \right) + i_{s\alpha} \left(v_{s\beta} - \hat{R}_s i_{s\beta} - \sigma L_s \frac{d}{dt} i_{s\beta} - \sigma L_s \omega_s i_{s\alpha} \right) \quad (6)$$

An (\hat{x}) is added to indicate estimate parameter.

The stator active power P_s is:

$$\frac{2}{3}P_s = -i_{s\alpha} \left(v_{s\alpha} - \hat{R}_s i_{s\alpha} - \sigma L_s \frac{d}{dt} i_{s\alpha} + \sigma L_s \omega_s i_{s\beta} \right) + i_{s\beta} \left(v_{s\beta} - \hat{R}_s i_{s\beta} - \sigma L_s \frac{d}{dt} i_{s\beta} - \sigma L_s \omega_s i_{s\alpha} \right) \quad (7)$$

The rotor reactive power Q_r :

$$\frac{2}{3}Q_r = \frac{L_m}{L_r} \left[i_{s\alpha} (\hat{a}_5 i_{s\beta} - \omega_{sl} \hat{\phi}_r) - i_{s\beta} (\hat{a}_5 i_{s\alpha} - \hat{a}_4 \hat{\phi}_r) \right] \quad (8)$$

The rotor active power P_r is:

$$\frac{2}{3}P_r = \frac{L_m}{L_r} \left[-i_{s\alpha} (\hat{a}_5 i_{s\alpha} - \hat{a}_4 \hat{\phi}_r) + i_{s\beta} (\hat{a}_5 i_{s\beta} - \omega_{sl} \hat{\phi}_r) \right] \quad (9)$$

With:

$$a_4 = \frac{1}{T_r} = \frac{R_r}{L_r}; \quad a_5 = a_4 L_m,$$

ω_{sl} : Slip frequency, ω_s : Synchronous speed, and, T_r : Rotor time constant.

Rotor Resistance Estimator

The estimation error of the rotor resistance R_r , is defined as follow:

$$\varepsilon_{Rr} = \frac{2}{3} \Delta Q = \frac{2}{3} (Q_s - Q_r) = G_{Rr}(s) \Delta a_4 \quad (10)$$

Where:

$$\Delta a_4 = (a_4 - \hat{a}_4)$$

$$G_{Rr}(s) = \frac{s^2 + \left(a_4 + \frac{\beta}{\hat{\phi}_r i_{s\beta}} \omega_{sl} \right) s + a_4 \frac{\beta}{\hat{\phi}_r i_{s\beta}} \omega_s + \omega_{sl} \omega_s}{D}$$

$$D = (s + a_4)^2 + \omega_{sl}^2$$

$$\beta = L_m i_{s\alpha}^2 - \hat{\phi}_r i_{s\alpha}, \quad s = d/dt$$

Finally the rotor resistance estimator is given by:

$$\hat{a}_4 = k_{iRr} \int \varepsilon_{Rr} dt \quad (11)$$

k_{iRr} is a positive gain

The stator resistance estimation error:

$$\varepsilon_{Rs} = \frac{2}{3} \Delta P = \frac{2}{3} (P_s - P_r) = \Delta R_s + G_{Rs}(s) \Delta a_4 \quad (12)$$

With:

$$G_{Rs}(s) = \frac{L_m \beta}{L_r i_s^2 D} \left[s^2 + \left(a_4 - \frac{\hat{\phi}_r i_{s\beta}}{\beta} \omega_{sl} \right) s - a_4 \frac{\hat{\phi}_r i_{s\beta}}{\beta} \omega_s + \omega_s \omega_{sl} \right]$$

$$\Delta R_s = R_s - \hat{R}_s$$

Finally the stator resistance estimator is given by:

$$\hat{R}_s = k_{iRs} \int \varepsilon_{Rs} dt \quad (13)$$

k_{iRs} is a positive gain

Load Torque Estimator

The speed estimation is given by:

$$\Delta \Omega = \Omega - \hat{\Omega} \quad (14)$$

The load torque estimation error:

$$\varepsilon_{\Gamma_L} = G(s) \Delta T_L + G_{T_L}(s) \Delta a_4 \quad (15)$$

With:

$$G(s) = \frac{1}{s}$$

$$G_{T_L}(s) = \frac{p \frac{L_m}{L_r} i_{s\beta} \hat{\phi}_r}{D_s} G_{\Omega}(s)$$

$$G_{\Omega}(s) = s + a_4 \left(1 - \frac{\omega_{sl}^2}{a_4^2} - L_m i_{s\alpha} \frac{(L_m i_{s\alpha} - \hat{\phi}_r)}{\hat{\phi}_r^2} \right)$$

$$\Delta T_L = T_L - \hat{T}_L$$

Finally the load torque estimator is given by:

$$\hat{T}_L = k_T \varepsilon_{T_L} \quad (16)$$

K_T is a positive gain

The proposed estimator of rotor resistance, stator resistance and load torque can be implemented as shown in figure4:

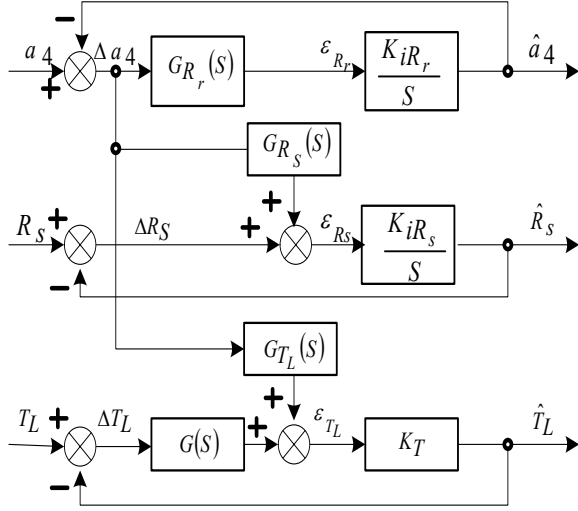


Fig. 4. Estimator of a_4 , R_s and T_L

5. Luenberger Speed Observer

An adaptive Luenberger observer order 4 is designed for the sensorless IM to estimate rotor flux and speed motor.[8-10]

Problem formulation:

In fixed frame α and β , the induction motor is described by:

$$\begin{cases} \dot{X} = AX + BU \\ Y = CX \end{cases} \quad (17)$$

Where:

$$x = \begin{bmatrix} i_{s\alpha} & i_{s\beta} & \phi_{r\alpha} & \phi_{r\beta} \end{bmatrix}^T, \quad y = \begin{bmatrix} i_{s\alpha} & i_{s\beta} \end{bmatrix}^T, \quad u = \begin{bmatrix} v_{s\alpha} & v_{s\beta} \end{bmatrix}^T$$

$$A = \begin{bmatrix} \begin{bmatrix} a_1 & 0 \\ 0 & a_1 \end{bmatrix} & \begin{bmatrix} a_2 & a_3\omega \\ -a_3\omega & a_2 \end{bmatrix} \\ \begin{bmatrix} a_4 & 0 \\ 0 & a_4 \end{bmatrix} & \begin{bmatrix} \omega & a_5 \\ a_5 & \omega \end{bmatrix} \end{bmatrix}, \quad B = \begin{bmatrix} \frac{1}{\sigma L_s} & 0 \\ 0 & \frac{1}{\sigma L_s} \\ 0 & 0 \\ 0 & 0 \end{bmatrix}, \quad C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

$$a_1 = -\left(\frac{1}{T_s\sigma} + \frac{(1-\sigma)}{T_r\sigma}\right), \quad a_2 = \frac{1}{T_r L_m} \frac{(1-\sigma)}{\sigma}$$

$$, \quad a_3 = \frac{1}{L_m} \frac{(1-\sigma)}{\sigma}, \quad a_4 = \frac{L_m}{T_r}, \quad a_5 = \frac{-1}{T_r}$$

Observability of IM

The observer matrix of IM is given by

$$\bar{\Theta} = \begin{bmatrix} \bar{c} \\ \bar{c}A \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \left(\frac{1}{T_s\sigma} + \frac{(1-\sigma)}{T_r\sigma}\right) & \left(\frac{L_m}{\sigma L_s L_r}\right) \left(\frac{1}{T_r} - j\omega\right) \end{bmatrix} \quad (18)$$

The determinant of the matrix is

$$\det \Theta = |\det \bar{\Theta}^2| = \left(\frac{L_m}{\sigma L_s L_r}\right)^2 \left(\frac{1}{T_r^2} - \omega^2\right) \neq 0 \quad (19)$$

We note that the process is observable in any point.

The Luenberger observer is given by:

$$\begin{cases} \frac{d}{dt} \hat{x} = A_0 \hat{x} + Bu + Ly \\ \hat{y} = C \hat{x} \end{cases} \quad (20)$$

Where:

$A_0 = A - LC$: Dynamic matrix of the observer, and L , is the matrix gain

Calculate of Matrix L

The matrix of gain is given by

$$L = \begin{bmatrix} L_1 & L_2 & L_3 & L_4 \\ -L_2 & L_1 & -L_4 & L_3 \end{bmatrix}^T \quad (21)$$

$[]^T$ is the transpose matrix

By identifying the equation $\det(\lambda I - A_0) = 0$ to the desired reference we obtained:

$$\begin{cases} L_1 = (1-L) \left(\frac{1}{\sigma T_s} + \frac{1-\sigma}{\sigma T_r} + \frac{1}{T_r} \right) \\ L_2 = (L-1) \hat{\Omega} \\ L_3 = \frac{(1-L^2)}{a_3} \left(\frac{1}{\sigma T_s} + \frac{1-\sigma}{\sigma T_r} + \frac{a_3}{T_r} \right) \\ \quad + \frac{(L-1)}{a_3} \left(\frac{1}{\sigma T_s} + \frac{1-\sigma}{\sigma T_r} + \frac{1}{T_r} \right) \\ L_4 = \frac{(L-1)}{a_3} \hat{\Omega} \end{cases} \quad (22)$$

In order to obtain good performance of the motor, gain L will be chosen between values $1 \leq L \leq 1.5$. [10]

Conforming to equation (20), the Luenberger model yielding:

$$\frac{d}{dt} \begin{bmatrix} \hat{i}_{s\alpha} \\ \hat{i}_{s\beta} \\ \hat{\phi}_{r\alpha} \\ \hat{\phi}_{r\beta} \end{bmatrix} = \begin{bmatrix} a_1 & 0 & a_2 & a_3 p\Omega \\ 0 & a_1 & -a_3 p\Omega & a_2 \\ a_4 & 0 & a_5 & -p\Omega \\ 0 & a_4 & p\Omega & a_5 \end{bmatrix} \begin{bmatrix} \hat{i}_{s\alpha} \\ \hat{i}_{s\beta} \\ \hat{\phi}_{r\alpha} \\ \hat{\phi}_{r\beta} \end{bmatrix} + \begin{bmatrix} \frac{1}{\sigma L_s} & 0 \\ 0 & \frac{1}{\sigma L_s} \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} v_{s\alpha} \\ v_{s\beta} \end{bmatrix} + \begin{bmatrix} L_1 & -L_2 \\ L_2 & L_1 \\ L_3 & -L_4 \\ L_4 & L_3 \end{bmatrix} \begin{bmatrix} \tilde{i}_{s\alpha} \\ \tilde{i}_{s\beta} \end{bmatrix} \quad (23)$$

Where

$$\begin{bmatrix} \tilde{i}_{s\alpha} \\ \tilde{i}_{s\beta} \end{bmatrix} = \begin{bmatrix} i_{s\alpha} - \hat{i}_{s\alpha} \\ i_{s\beta} - \hat{i}_{s\beta} \end{bmatrix}$$

Adaptive Luenberger Observer

The estimate error on stator current and rotor flux is:

$$e = x - \hat{x} = \begin{bmatrix} \tilde{i}_{s\alpha} & \tilde{i}_{s\beta} & \hat{\phi}_{r\alpha} & \hat{\phi}_{r\beta} \end{bmatrix}^T$$

According to equation (17) and (20), the time derivative of the error is written in the following form

$$\dot{e} = \frac{d}{dt} e = (A - Lc)e + \Delta A \hat{x} \quad (24)$$

Where

$$\Delta A = A(\Omega) - A(\hat{\Omega}) = \begin{bmatrix} 0 & a_3 p \Delta \Omega \mathbf{J} \\ 0 & -p \Delta \Omega \mathbf{J} \end{bmatrix}, \quad \mathbf{J} = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix},$$

$$\Delta \Omega = \Omega - \hat{\Omega}$$

Using Lyapounov stability theory, we can construct a mechanism to adapt the mechanical speed from the asymptotic convergence condition of the state variables estimation errors.

Lyapounov function is given:

$$V = e^T e + \frac{|\Delta \omega|^2}{\lambda} \quad (25)$$

λ , is a positive constant

$\omega = p\Omega$, denotes electrical angular rotor speed.

Deriving equation (25) we obtain:

$$\frac{dV}{dt} = e^T \left\{ (A - LC)^T + (A - LC) \right\} e - 2a_3 \Delta \omega (\tilde{i}_{s\alpha} \hat{\phi}_{r\beta} - \tilde{i}_{s\beta} \hat{\phi}_{r\alpha}) + \frac{2}{\lambda} \Delta \omega \frac{d\hat{\omega}}{dt} \quad (26)$$

From equation (26), we can establish the low command of the speed observer as follow

$$\dot{\hat{\omega}} = k_p (\tilde{i}_{s\alpha} \hat{\phi}_{r\beta} - \tilde{i}_{s\beta} \hat{\phi}_{r\alpha}) + k_i \int (\tilde{i}_{s\alpha} \hat{\phi}_{r\beta} - \tilde{i}_{s\beta} \hat{\phi}_{r\alpha}) dt \quad (27)$$

k_p, k_i , are positive gains of PI controller.

The proposed Luenberger observer can be implemented as shown in figure5:

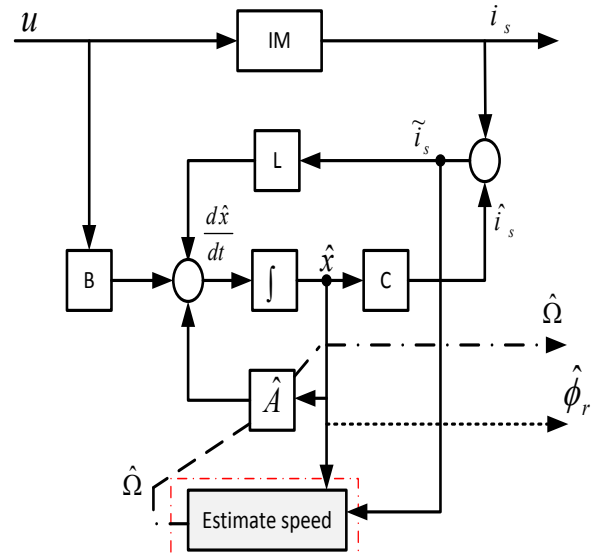


Fig. 5. Adaptive Luenberger speed observer

Where, the bloc estimated speed, given by equation (27).is detailed on figure6

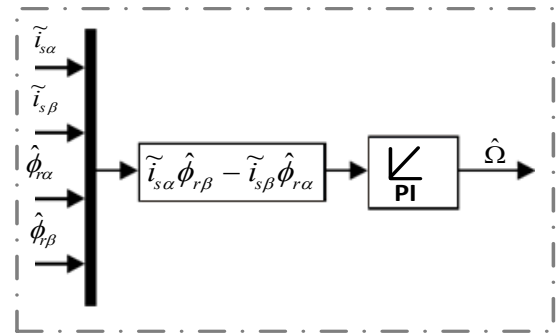


Fig. 6. Speed observer

The proposed control scheme (FLDTC of IM with sensorless control and parameters motor estimation) is on illustrate on Figure 7. The torque and flux hysteresis controllers are replaced by fuzzy controllers.

Where, the bloc stator flux and torque estimator is given respectively by equation (2), equation (1).

The bloc rotor speed estimator is given by equation (27) and the bloc resistance stator estimator is given by

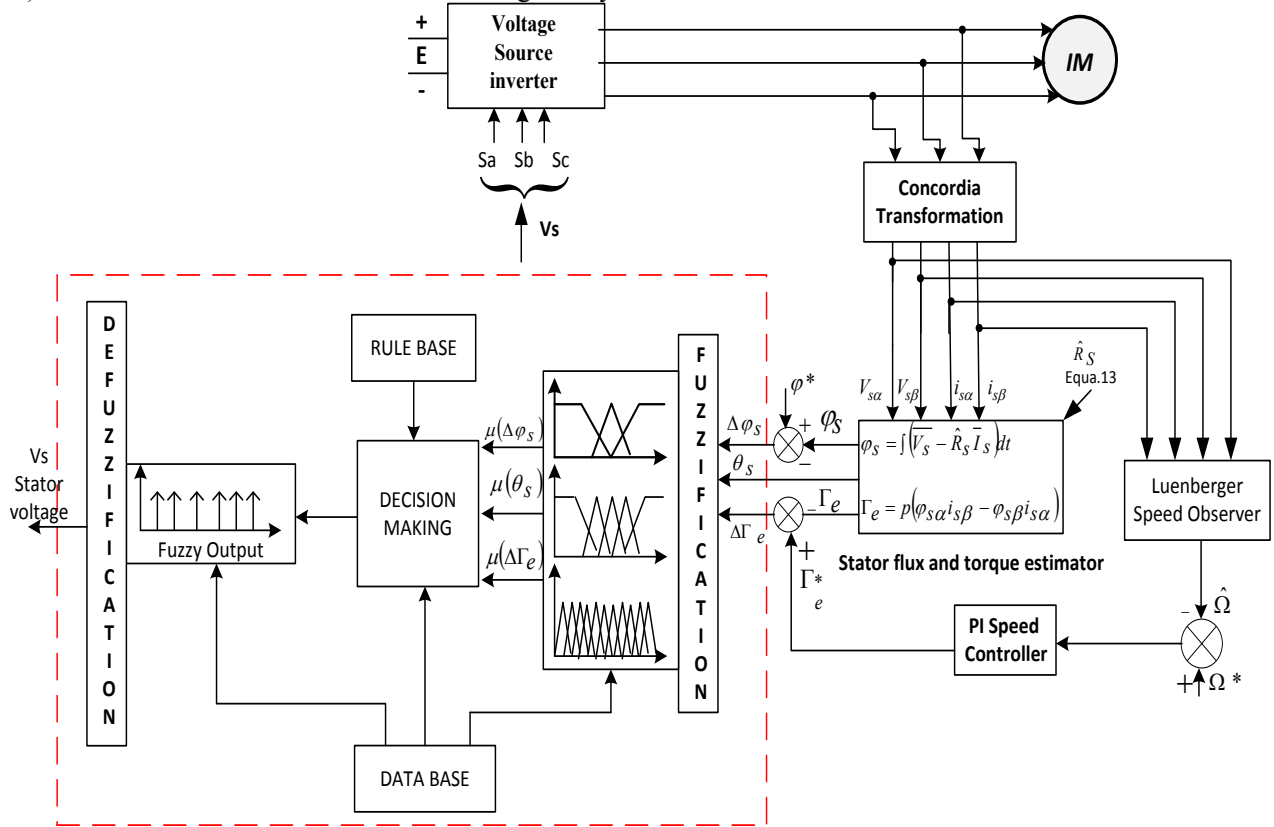


Fig. 7. Block diagram of sensorless control proposed

6. Modeling results

The parameters motor are illustrate in table1:

Table 1
Induction Motor Parameters

Stator resistance	$R_s [\Omega]$	4.850	$P_n [kw]$	1,5	$f_c [Nms/rd]$	0.00114
Rotor resistance	$R_r [\Omega]$	3.805	$I_n [A]$	6.5	p	2
Stator inductance	$L_s [H]$	0.274	$V_n [V]$	220	$F_n [Hz]$	50
Stator inductance	$L_r [H]$	0.274	$\omega_n [rd/s]$	149	n denotes nominal value	
Mutuel inductance	$L_m [H]$	0.258	$J_n [kg/m^2]$	0.031		

The parameters motor estimator scheme was simulated with a Matlab/Simulink model showed on Figure 8.

Where, rotor resistance estimator is given by equation

(11), the stator resistance estimator is given by equation (13), the, and the load torque estimator is given by equation (16).

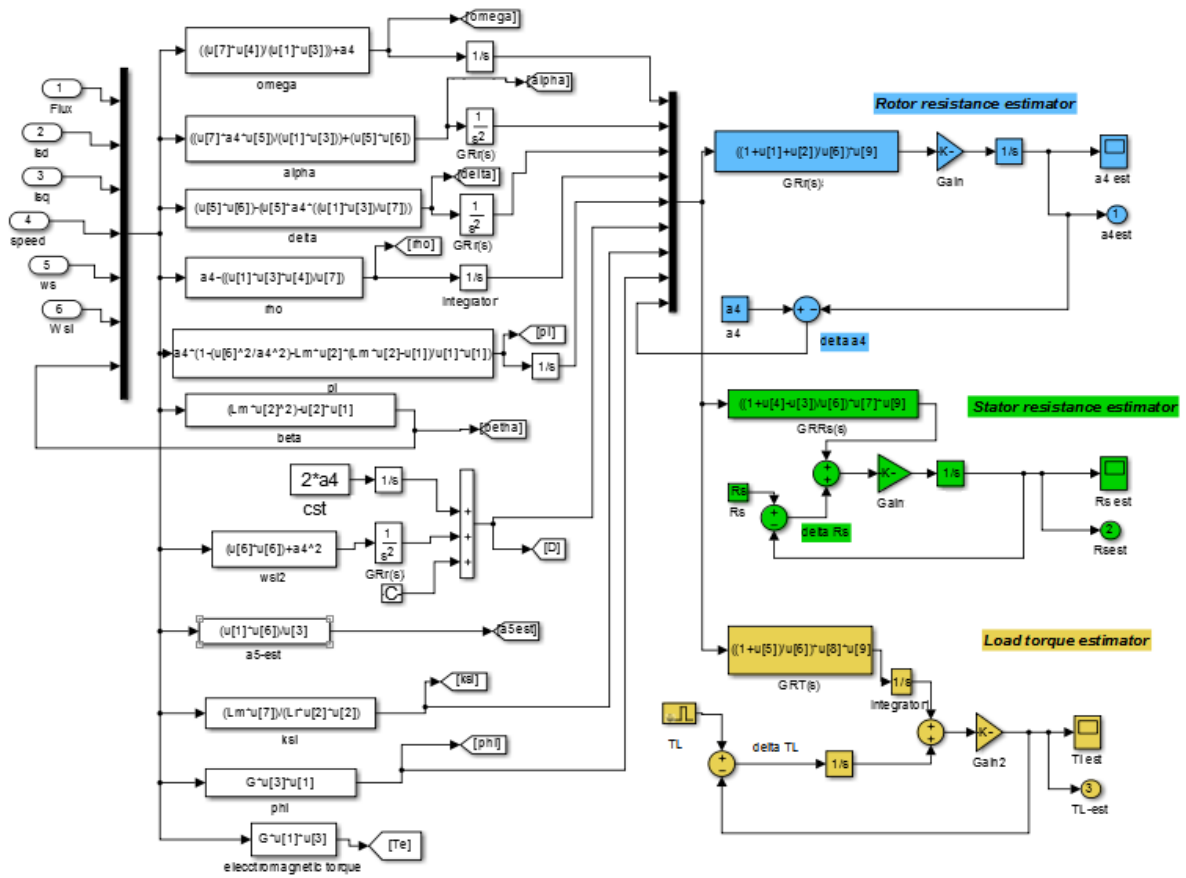


Fig. 8. Simulink block of parameters motor estimator

On the left of the figure 9, one represented Electromagnetic torque with basic DTC control.

On the right of the figure 9, one represented Electromagnetic torque with Fuzzy DTC control.

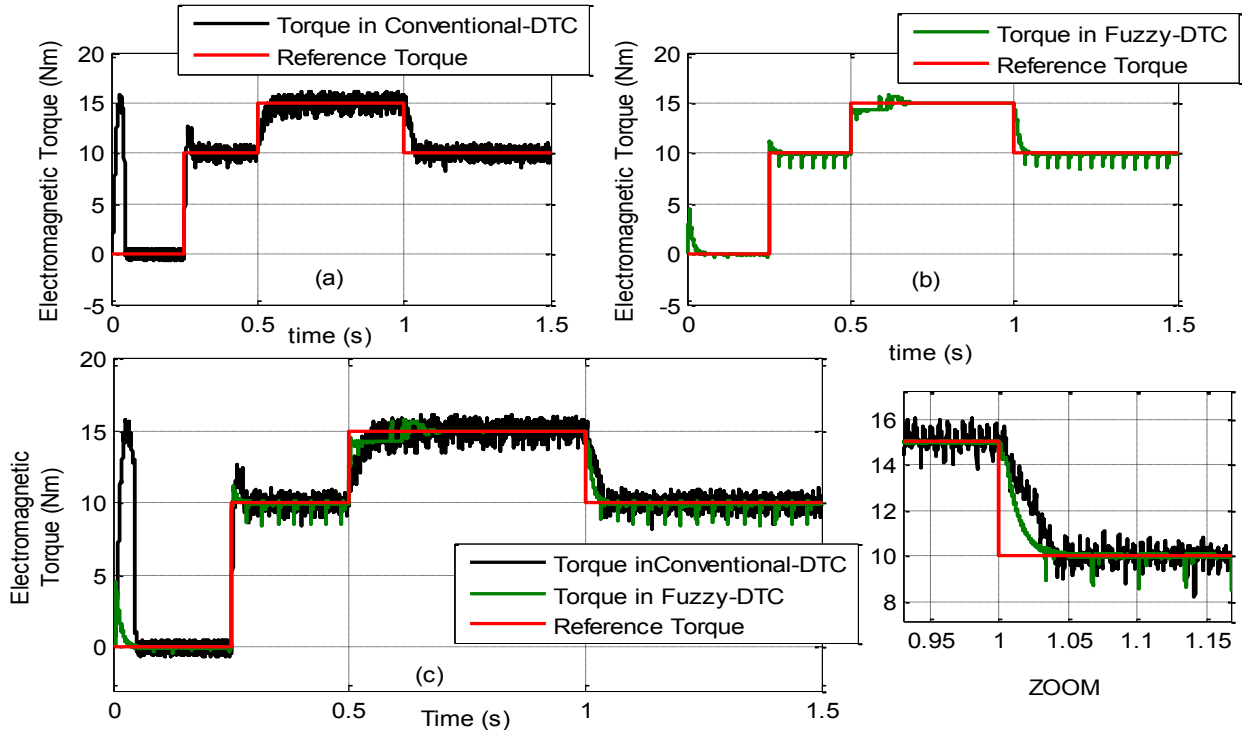


Fig. 9. Electromagnetic torque, (a) conventional DTC (C-DTC) in left and (b) FLDTC in the right (c) Comparison between (C-DTC) and FLDTC

On the left of the figure 10, one represented stator flux in conventional DTC control.

On the right of the figure 10, one represented stator flux in Fuzzy DTC control.

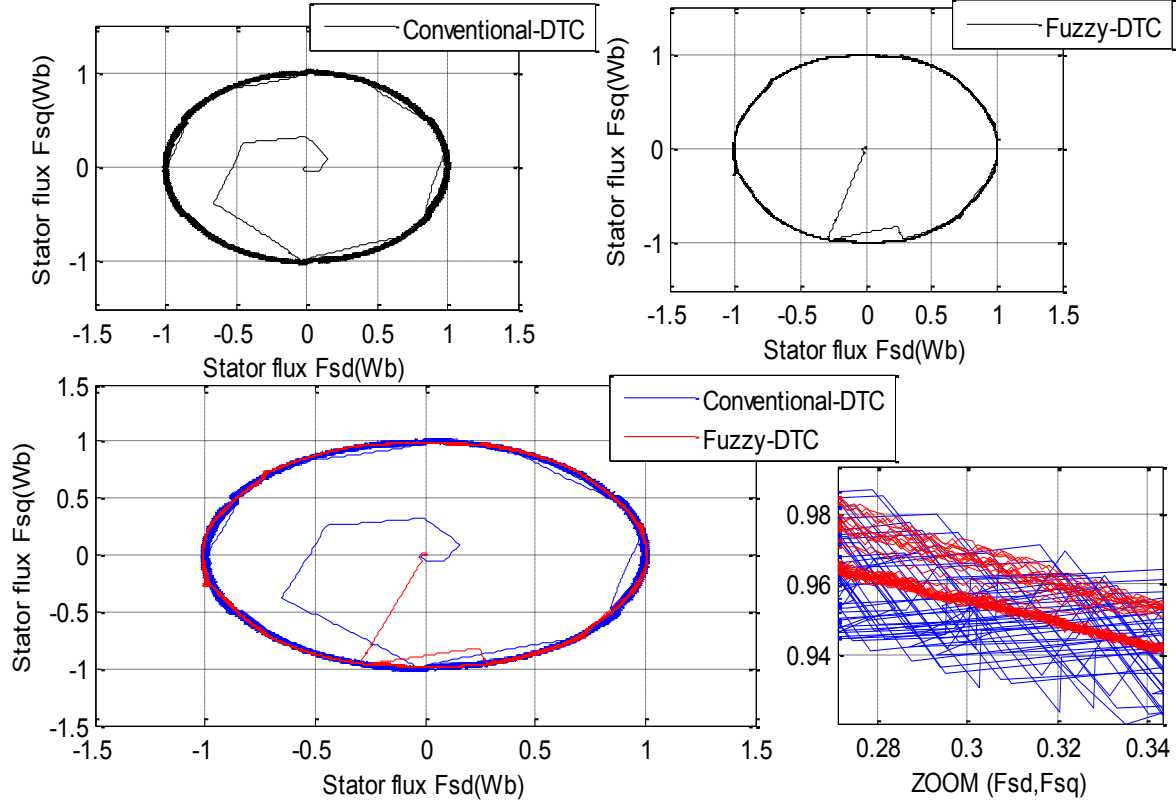


Fig. 10. Stator flux, Conventional DTC in left and FLDTC in the right

The simulation results on fig 9 and fig 10 show that the torque has very good dynamic response for the mentioned DTC methods response

The torque ripple is significantly reduced by introducing fuzzy logic; the stator flux trajectory is a circle.

The benchmark proposed for sensorless speed IM is operating under three conditions: (1) low speed with nominal load; (2) high speed with nominal load; (3) case where the motor state is unobservable (at low frequencies).

Figure.11.shows, the simulation responses with Luenberger speed observer, obtained by considering the nominal case with identified parameters are shown on

Where, Motor Speed, ω -observ, and ω_s mean respectively, the rotor speed at the output of the machine, the rotor speed at the output of the luenberger observer, and the stator speed.

T_e^* , T_e -motor mean the desired torque, and the electromagnetic torque at the output of the machine

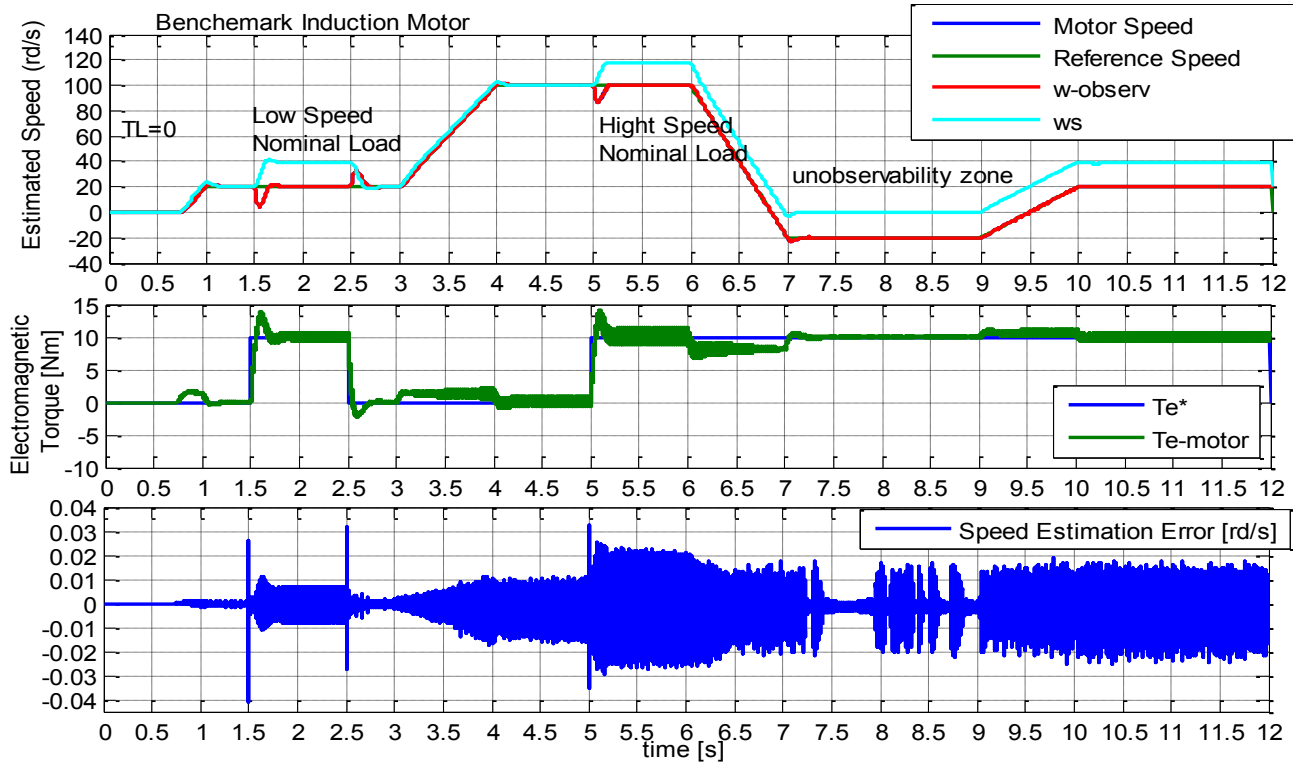


Fig. 11. Performance of the sensorless FLDTC Control at low speed

Notice the good performance of the proposed scheme that maintains the speed close to the desired reference even though the presence of disturbance (load torque).

The estimated load torque converges to the measured load torque, under conditions of observability and at very low frequency (conditions of unobservability between 7 and 9 s).

Nevertheless, it appears a small static error when the motor speed increases (between 4 and 6 s).

Finally, by introducing an error of +50% on stator resistance we can see in Fig. 12 that the controller performs is less robust under R_s variations. In unobservable zone, we note divergency on speed motor.

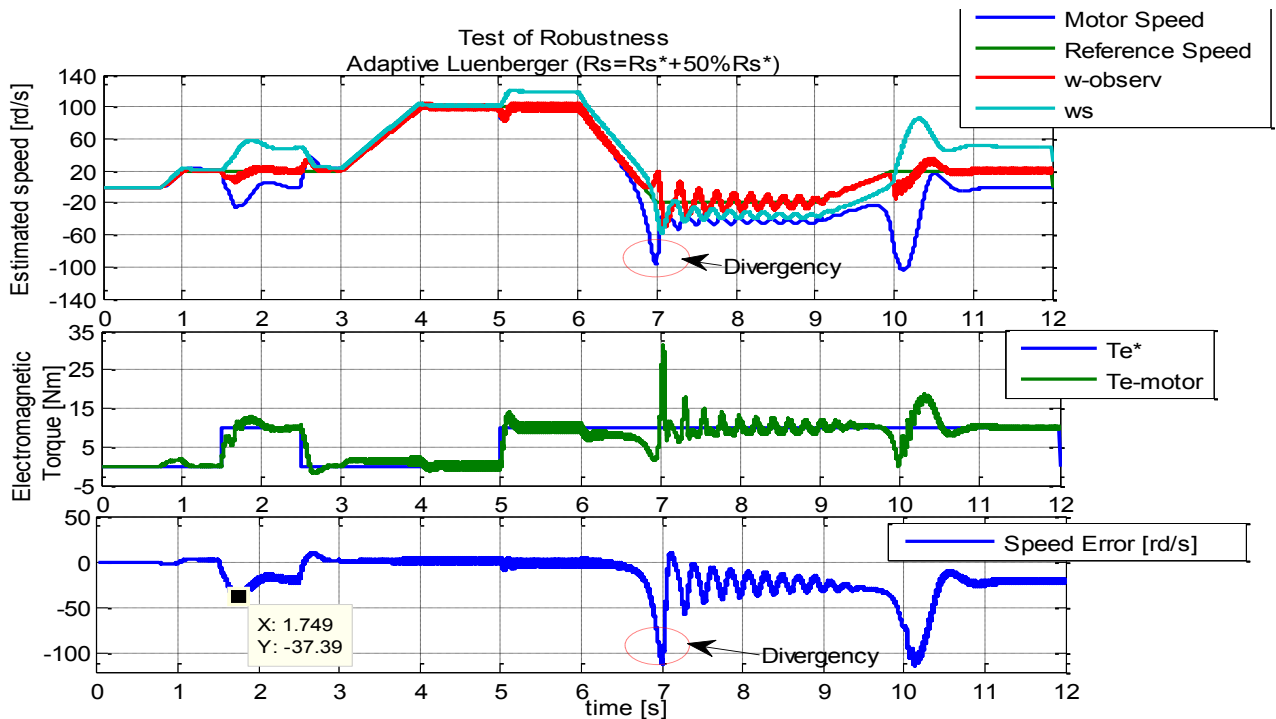


Fig. 12. Test of robustness of the proposed scheme

7. Conclusion

This paper proposes improvement of DTC using FLC as switching state selector based on modified classical DTC

This controller determinates the desired amplitude of torque hysteresis band. It is shown that the proposed scheme results in improved stator flux and torque responses under steady state condition. The main advantage is the improvement of torque and flux ripple characteristics at low speed region; this provides an opportunity for motor operation under minimum switching loss and noise.

It is seen that the steady state performances of the FLDTC- controller is much better than of the DTC- without fuzzy controller [6].

For dynamic performance, the modified DTC is almost as good as the basic DTC.

Therefore using the proposed method results in improving the motor performance

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