IMPACT OF ROTOR TIME CONSTANT PARAMETER VARIATION ON THE ACTIVE DISTURBANCE REJECTION CONTROL BASED SENSORLESS INDUCTION MOTOR COMPARED WITH A FUZZY LOGIC CONTROL

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Abstract: This article aims at providing a novel control of the Active Disturbance Rejection Control (ADRC) applied to the sensorless speed control of the induction motor that has been a primary concern of researchers in recent years and compared with fuzzy logic control. Active disturbance rejection control (ADRC) has gained an important traction with its simple tuning method and robustness against process parameter variations, an advanced-MRAS observer is developed and employed in order to estimate the rotor speed that uses a strategy of novel technique of fuzzy logic control applied in adaptation mechanism. The simulation results conclude that the efficiency and reliability of the proposed active disturbance rejection controller is excellent under a variety of operating conditions of the induction motor drive.

Key words: Fuzzy Logic Control (FLC), Advanced-MRAS observer, Active Disturbance Rejection Control (ADRC), Induction Motor, Rotor Time Constant.

1. Introduction

Out of various industrial applications require high dynamic performances and robustness to different perturbations. Thus, the robust control algorithm is desirable in stabilization and tracking trajectories. The variable structure control can offer a good insensitivity to parameter variation, external disturbances rejection and fast dynamics.

The Active Disturbance Rejection Control (ADRC) was proposed by Han in 1998 and has recently gained popularity for induction motor drives, The ADRC is a nonlinear controller for an uncertain system, it estimates and compensates the external disturbances and parameter variations, and accordingly the specific model of the plant is not required. It means that the concept of ADRC is intrinsically independent of the controlled system model and its parameters. The essential element of ADRC is the extended state observer (ESO), which is based on the concept of generalized derivatives and generalized functions. Using the extended state observer, the ADRC can achieve an exact decoupling of induction motors. Afterwards, the impact of external disturbances and parameter variations could evenly be estimated and compensated by the ADRC.

In several years, great efforts have been performed to increase the mechanical robustness and reliability of the induction motor [13], and to reduce costs and hardware complexity. Thereby, it is necessary to eliminate the speed sensor. MRAS-based speed sensorless estimation has been popularly used in AC speed regulation systems due to its good performance and facility of implementation. It is able to adduce both rotor flux and speed without problems of closed-loop integration. In this regard, the fuzzy logic controller (FLC) replaces the PI controller in the speed adaptation mechanism of the MRAS estimator. The main advantage of the FLC established by Zadeh [1] that it does not require specific mathematical model of the system studied. Fuzzy logic is based on the linguistic rules by means of IF-THEN rules with the human language.

Fuzzy control has appeared over the years to become one of the most productive areas of research in the application of fuzzy set theory [14]. In recent years, fuzzy logic has been successfully implemented in several control applications including the control of induction motors [10]. Besides, fuzzy logic controller has been presented to be less sensitive to external disturbance.

In order to perform MRAS for sensorless speed estimation, we have to model the induction machine. In induction motor, motor's inputs are stator currents and voltages, rotor's output is speed. In this regard, it is necessary while choosing reference model for MRAS to make rotor flux equation in the form of stator side parameters. In adaptive model, speed is the adaptive parameter [9].

2. Influence Of Rotor Time Constant On the Dynamic Performance of IRFOC

The rotor flux FOC is recognized as the most interesting scheme for practical implementation due to its simplicity. Therefore, the analysis of the rotor time constant variations that will be shown in this section are based on the principles of this method of orientation. Rotor time constant changes are principally due to temperature changes which affect the rotor resistance, and to the saturation of the motor inductances [11].

To analyze the influence of rotor time constant variation on the steady state response of electromagnetic torque and on the rotor flux, we consider the dq model of an induction motor in the synchronously rotating frame. This model is designed as follows [1]:

$$\frac{d}{dt}\begin{bmatrix}\psi_{ds}\\\psi_{qs}\\\psi_{dr}\\\psi_{qr}\end{bmatrix}=\begin{bmatrix}v_{sd}-R_si_{sd}+\omega\psi_{qs}\\v_{sq}-R_si_{sq}-\omega\psi_{ds}\\-R_ri_{rd}+\omega_{sl}\psi_{qr}\\-R_ri_{rd}-\omega_{sl}\psi_{dr}\end{bmatrix} \tag{1}$$

The electromagnetic torque is presented as:

$$T_{em}=\frac{p.M}{L_r}(i_{qs}\psi_{dr}-i_{ds}\psi_{qr}) \tag{2}$$

Where ψ_{dr} and ψ_{qr} represent the direct and quadrature components of the rotor flux:

$$\begin{aligned}\psi_{dr}&=L_ri_{dr}+Mi_{ds}\\\psi_{qr}&=L_ri_{qr}+Mi_{qs}\end{aligned} \tag{3}$$

When the motor is current fed i_{sd} and i_{sq} are impressed by the IRFOC regulator, the expression of the flux can be expressed using these currents and the rotor resistance and inductance:

$$\psi_{dr}=\frac{Mi_{ds}+T_r.\omega_{sl}.Mi_{qs}}{(1+T_r.\omega_{sl})^2}$$
$$\psi_{qr}=\frac{Mi_{qs}-T_r.\omega_{sl}.Mi_{ds}}{(1+T_r.\omega_{sl})^2}$$

Rotor flux is hence becomes:

$$\psi_r=\sqrt{\psi_{dr}{}^2+\psi_{qr}{}^2}=M.\sqrt{\frac{i_{ds}{}^2+i_{qs}{}^2}{1+T_r{}^2.\omega_{sl}{}^2}} \tag{4}$$

Substituting (4) in (2), the electromagnetic torque deduced as:

$$T_{em}=\frac{p.M^2\omega_{sl}}{L_r}.\left[\frac{T_r(i_{ds}{}^2+i_{qs}{}^2)}{(1+T_r{}^2.\omega_{sl}{}^2)}\right] \tag{5}$$

As it can be deduced, The IRFOC drive is sensitive to the variation of the magnetizing inductance for low values of (R_r/R_{r0})[11].
As the motor heats up, the effect of this inductance becomes less significant and the performance is mainly affected by the rotor resistance variation. Afterwards, for the case were $T_r=T_{r0}$ and $R_r<R_{r0}$, which correspond to the ideal condition of decoupling. Also, for $R_r>R_{r0}$, the flux variation decreases while the torque variation increases with increasing R_r[15][11].

Fig. 1. Block diagram of indirect rotor FOC
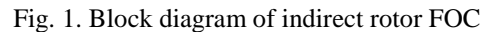
3. Control Strategies

3.1. Fuzzy Logic Control

Fuzzy logic is mainly advantageous for problems that cannot be easily represented by mathematical modeling because data is either incomplete, unavailable or the process is too complex. Such systems can be easily upgraded by adding new rules to enhance performance or add new features [6].

In many cases, fuzzy control can be used to enhance existing traditional controller systems by adding an extra layer of intelligence to the current control method. Many types of fuzzy controllers that are presented in literature are basically multi input single output (MISO) type controllers [6].
The main preference of the fuzzy logic is that is easy to implement control and it has the ability of generalization [18]. In the conventional methods of MRAS speed observer PI controller was commonly used in the adaptation mechanism which is generating estimated speed which in turn is reducing the speed tuning signal e_x or error between the reference and adaptive models. In the proposed method the PI controller that used in the adaptation mechanism is replaced by a fuzzy logic controller. The general block diagram of fuzzy controller is represented as shown in Figure-2[19].
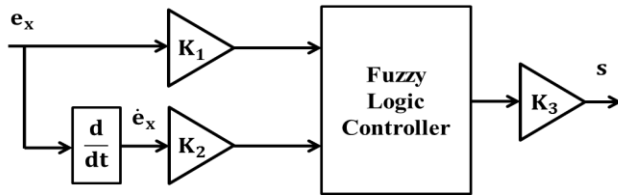
Fig. 2. Shows the block diagram of fuzzy logic controller system where the variables K_1, K_2 and K_3 are used to tune the controller.

Speed tuning signal e_x and its rate of change are the inputs to the proposed FLC that are multiplied by two scaling factors K_1 and K_2 respectively. Then the output of the controller is multiplied by a third scaling factor K_3 and we obtain the estimation speed. The error technique and the trial are used to find the values of scaling factors for the best performance [6].

The values hence obtained for K_1, K_2 and K_3 are 2.2, 3.1 and 0.89 respectively.
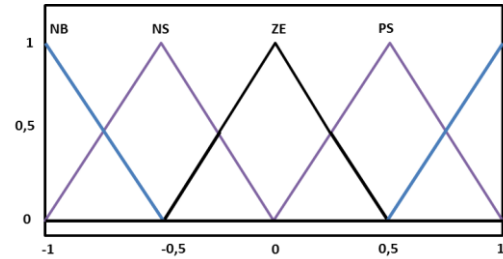
(a)
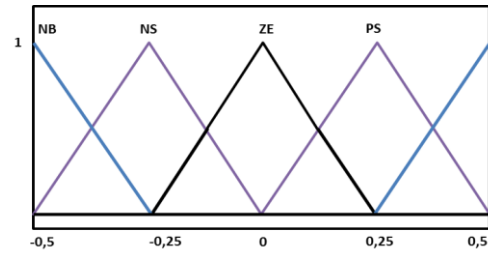
(b)

Fig. 3. The inputs membership functions of FLC, (a) the error ,(b) the change of error
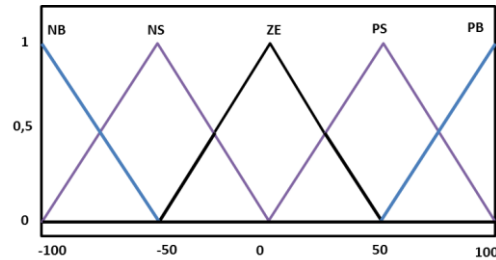
Fig. 4. The output membership functions of FLC

The first step to elaborate the fuzzy controller is to generate the fuzzy rules based on the knowledge of the expert. According to the expert, three situations can be designed for the motor speed, namely, above, around and below the desired reference speed. By defining the system error between the measured speed and the desired speed, the propositions, higher, around and beneath the desired reference speeds are otherwise expressed as Positive, Zero and Negative errors. For 2 inputs and N number of linguistic variables the numbers of rules are given as N^2. In this proposed method linguistic value of 5 is determined which gives

25 rules. For fuzzyfication triangular fuzzyfication is used and for deffuzzyfication the centroid deffuzzyfication method is used in the proposed method. The fuzzy sets used in the proposed method are NB: Negative Big, NS: Negative Small, ZE: Zero Equal, PS: Positive Small, PB: Positive Big. The look-up table for the proposed method is shown in Table.1

Table 1. Fuzzy rules for proposed system

e_x / Δe_x	PB	PS	ZE	NS	NB
PB	PB	PB	PB	PS	ZE
PS	PB	PB	PB	ZE	NS
ZE	PB	PS	ZE	NS	NB
NS	PS	ZE	NS	NB	NB
NB	ZE	NS	NB	NB	NB

3.2. Active Disturbance Rejection Control

ADRC Active Disturbance Rejection Controller (ADRC) is a robust control scheme highly employ in adaptive controlling of the system based on the extension of the model system by a state observer to estimate what the user cannot master in the mathematical model of the system to control [7]. This extended state observer in the feedback state eliminates the error generated by the induction motor and the reference point. It makes the controller to pursue the output system response with minimum peak overshoot and absence of the offset error in both transient state and steady state analysis.

We consider the case of a first order system to illustrate the principle of the ADRC[2].

$$\frac{dy(t)}{dt} = -\frac{1}{T}y(t) + Bu(t) \qquad (6)$$

Where $b = \frac{K}{T}$ is the known part of b, and Δb is the modeling error and/or variations in system parameters. External disturbances are added, (6) of the system becomes:

$$\frac{dy(t)}{dt} = -\frac{1}{T}y(t) + \frac{1}{T}d(t) + \Delta bu(t) + b_0 u(t)$$

$$\frac{dy(t)}{dt} = f(y,d,t) + b_0 u(t) \qquad (7)$$

Where $f(y,d,t) = -\frac{1}{T}y(t) + \frac{1}{T}d(t) + \Delta bu(t)$ represents the total disturbance (internal and external).

The fundamental idea of the ADRC is to implement the extended state observer (ESO), which provides an estimate $\tilde{f}(t)$ such that it can compensate for the effects of $f(t)$ on the system [2], [3], [4], [7].

The description of the state space of the process described by (7) is given in following form:

$$\begin{aligned} \dot{x}_1 &= x_2 + b_0 u \\ \dot{x}_2 &= \dot{f} \\ y &= x_1 \end{aligned} \qquad (8)$$

In matrix form:

$$\begin{aligned} \dot{x} &= Ax + Bu + D\dot{f} \\ y &= Cx \end{aligned} \qquad (9)$$

Where:

$$A = \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}; B = \begin{pmatrix} b_0 \\ 0 \end{pmatrix}; C = \begin{pmatrix} 1 \\ 0 \end{pmatrix} and\ D = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

We cannot measure overall disturbance $f(t)$, we can only make an estimation using the extended state observer (ESO) built using the input $u(t)$ and the output $y(t)$ [2]-[3]. The equations of ESO are shown as follows:

$$\begin{aligned} \dot{x} &= Ax + Bu + D(y - \tilde{y}) \\ \tilde{y} &= Cx \end{aligned} \qquad (10)$$

Or $D = \begin{pmatrix} \beta_1 \\ \beta_2 \end{pmatrix}$, β_1 and β_2 are the observer parameters.

The estimated variables $\tilde{x}_1(t) = \tilde{y}$ and $\tilde{x}_2(t) = \tilde{f}(t)$, are used to perform the disturbance rejection and control laws.

$$\dot{\tilde{x}} = (A - DC)\tilde{x}(t) + Bu(t) + Dy(t) \qquad (11)$$

Or:

$$u(t) = \frac{u_0(t) - \tilde{f}(t)}{b_0}$$

Where:

$$u_0(t) = k_p(r(t) - \tilde{y}(t)) \qquad (12)$$

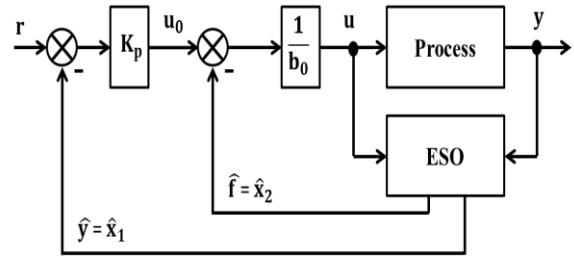$r(t)$ is the reference input signal to pursue.
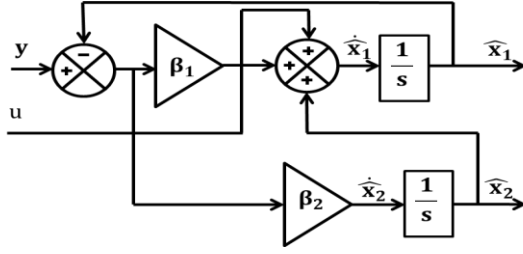

Fig. 5. ADRC topology

Fig. 6. ESO topology

Fig. 5 shows the structure of the control loop by ADRC for a first order process [2], [3], and Fig.6 presents the ESO design that is the core of ADRC.

The gain K_p acts on the $\tilde{y}(t)$ rather than on the actual output $y(t).u_0(t)$ represents the output of linear proportional controller.
By substituting (12) into (7), we demonstrate, that the system behaves as a simple integrator if $f(t) = \tilde{f}(t)$.

$$\frac{dy(t)}{dt} = f(t) + b_0 \frac{u(t) - \tilde{f}(t)}{b_0} \simeq u_0(t)$$
$$= k_p\big(r(t) - \tilde{y}(t)\big) \qquad (13)$$

If $y(t) = \tilde{y}(t)$, behavior of order 1 is got in closed loop with the pole $S_{CL} = -K_p$:

$$\frac{1}{K_p}\frac{dy(t)}{dt} + y(t) \simeq r(t) \qquad (14)$$

If the state observer and disturbance rejection work properly, a proportional controller must be chosen to realize the same behavior as that of closed loop indifferent of the parameters of the actual process [4], [7].
Generally, the gain K_p is designed as a function on the desired response time of the system t_r.

$$K_p = \frac{4}{t_r} \qquad (15)$$

To run correctly, the observation parameters β_1 and β_2 , established in (10), must also be defined. The dynamics of the observer must be speedy, the observer poles must be placed to the left of the pole of the closed loop S_{CL} . A simple rule suggests [4]:

$$S_{ESO1} = S_{ESO2} \simeq (3 \dots 10)S_{CL} \qquad (16)$$

for the two concerned poles where $S_{CL} = -K_p \simeq \frac{4}{t_r}$
From the matrix $(A - DC)$ in (11), we define the parameters of the observer in order to have a common pole S_{ESO} of its characteristic polynomial:

$$det\big(sI - (A - DC)\big) = s^2 + \beta_1.s + \beta_2$$
$$= (s - S_{ESO})^2 \qquad (17)$$

From this equation, we determine:

$$\beta_1 = -2.S_{ESO} \text{ and } \beta_2 = (S_{ESO})^2 \qquad (18)$$

Where $S_{ESO} \simeq (3 \dots 10)S_{CL}$
In this regard, the stator currents are written to be controlled by ADRC in the form as follows:

$$\frac{di_{sd}}{dt} = -\left(\frac{R_s}{\sigma L_s}\right)i_{sd} - \left(\frac{M}{\sigma L_r L_s}\right)\frac{d\psi_r}{dt} + \left(\frac{1}{\sigma L_s}\right)U_{sd} \quad (19)$$

$$\frac{di_{sq}}{dt} = -\left(\frac{R_s}{\sigma L_s}\right)i_{sq} - \left(\frac{\omega_s M}{\sigma L_r L_s}\right)\psi_r + \left(\frac{1}{\sigma L_s}\right)U_{sq} \quad (20)$$

In the canonical model of ADRC:

$$\left.\begin{array}{l} \frac{di_{sd}}{dt} = f_d(i_{sd}, d, t) + b_0 u(t) \\[2mm] \frac{di_{sq}}{dt} = f_q(i_{sq}, d, t) + b_0 u(t) \end{array}\right\} \qquad (21)$$

Or:

$$\left.\begin{array}{l} f_d = -\left(\frac{R_s}{\sigma L_s}\right)i_{sd} - \left(\frac{M}{\sigma L_r L_s}\right)\frac{d\psi_r}{dt} \\[2mm] \qquad + \left(\frac{1}{\sigma L_s} - b_0\right)U_{sd} \\[2mm] u = U_{sd} \quad b_0 = \frac{1}{\sigma L_s} \end{array}\right\} \qquad (22)$$

$$\left.\begin{array}{l} f_q = -\left(\frac{R_s}{\sigma L_s}\right)i_{sq} - \left(\frac{\omega_s M}{\sigma L_r L_s}\right)\psi_r \\[2mm] \qquad + \left(\frac{1}{\sigma L_s} - b_0\right)U_{sq} \\[2mm] u = U_{sq} \quad b_0 = \frac{1}{\sigma L_s} \end{array}\right\} \qquad (23)$$

f_d and f_q are the total disturbance respectively influencing the stator currents i_{sd} and i_{sq}.
$u = U_{sd}$ and $u = U_{sq}$ are respectively the control inputs of the currents loops i_{sd} and i_{sq}. b_0 is the known part of the system parameters. By choosing an acceptable response time, we can easily define the parameters k_p, β_1 and β_2 of the ADRC controllers, in

order that the stator currents follow respectively their reference i_{sd_ref} and i_{sq_ref} .
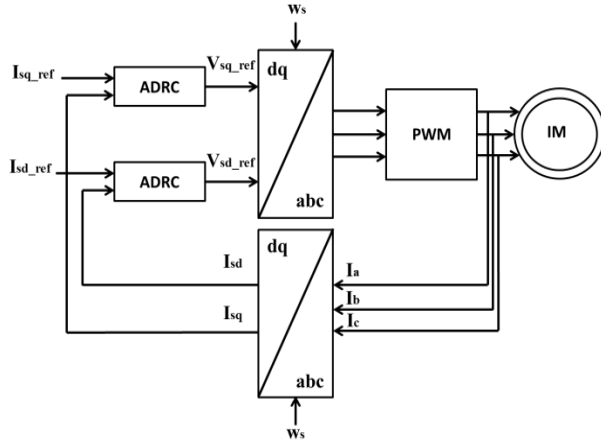

Fig. 7. Control system of stator currents using ADRC

4. Rotor Speed Estimation

4.1. Advanced-MRAS observer

Depending on the principle of sensorless vector controlling of induction motor, getting the angle and amplitude of the rotor flux is one of the most influential factors affecting the performance of the system control, and the accuracy of speed detection is instantly affected by the accuracy of the magnetic field orientation. And speed sensorless AC speed regulation, it equally avoids the errors that it may happen. In this work, the model reference adaptive method (MRAS) is presented, which has an excellent impact on the speed sensorless control field. Furthermore, It is only the proportional-integral factor of the adaptive law to be regulated, which makes the design and debugging of the system more simple[12], the simulation results show efficiency of these design, and the method are constantly being improved Therefore, in this paper, the indirect vector control technology of the rotor field orientation (irfoc) is introduced. The basic scheme of the Advanced-MRAS configuration is presented in figure 8. The scheme consists of reference ,adjustable and adaptation mechanism models. The block "reference model" represents voltage model that is independent of speed.

The block "adjustable model" is the current model that uses the speed as a parameter[17].

4.1.1 Reference Model

Consider the voltage model stator equation that is determined as a reference model. It generates the reference value of the rotor flux components in the stationary reference frame (α, β).

The reference rotor flux components obtained from the reference model are given by:

$$\frac{d}{dt}\Phi_{\alpha r} = \frac{L_r}{M}(V_{\alpha s} - R_s i_{\alpha s} - \sigma L_s \frac{d}{dt} i_{\alpha s}) \quad (24)$$

$$\frac{d}{dt}\Phi_{\beta r} = \frac{L_r}{M}(V_{\beta s} - R_s i_{\beta s} - \sigma L_s \frac{d}{dt} i_{\beta s}) \quad (25)$$

4.1.2 Adaptive Model

In this regard, if the speed signal ω_r is known, the fluxes are calculated from the input stator current. The rotor flux components are obtained with the help of speed and current signals [6].

The adaptive model represents the rotor voltage equation of the IM in the stator reference frame [5] which can be defined as in equations (26) and (27):

$$\frac{d}{dt}\widehat{\Phi}_{\alpha r} = -\frac{1}{T_r}\Phi_{\alpha r} - \omega_r \Phi_{\beta r} + \frac{M}{T_r} i_{\alpha s} \quad (26)$$

$$\frac{d}{dt}\widehat{\Phi}_{\beta r} = -\frac{1}{T_r}\Phi_{\beta r} + \omega_r \Phi_{\alpha r} + \frac{M}{T_r} i_{\beta s} \quad (27)$$

Or: $\qquad\qquad T_r = L_r/R_r$

4.1.3 Adaptation mechanism

Finally, the adaptation mechanism scheme produces the value of the estimated speed to be used in such a way as to reduce the error between the estimated and reference fluxes [6]. The rotor flux MRAS scheme is executed by defining a speed tuning signal ε_ω to be reduced by Fuzzy controller which produces the estimated speed that is fed back to the adaptive model. The expressions for the speed tuning signal and the estimated speed can be presented as[16]:

$$\varepsilon_\omega = \Phi_{\beta r}\widehat{\Phi}_{\alpha r} - \Phi_{\alpha r}\widehat{\Phi}_{\beta r} \qquad (28)$$

The rotor speed is given by:

$$\omega_r = \left(K_p + \frac{K_i}{s}\right) * \varepsilon_\omega \qquad (29)$$

In this work, the conventional PI is replaced by a fuzzy logic controller in Advanced-MRAS estimator in the adaptation mechanism.
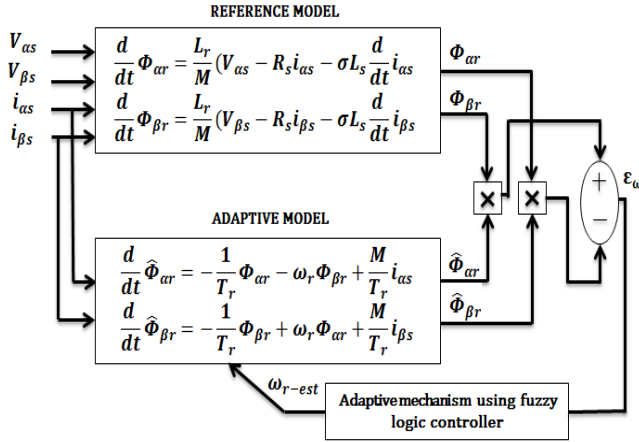

Fig. 8. Block diagram of MRAS using Fuzzy logic controller

Fuzzy logic based MRAS speed observer is presented in Figure-8. Conventionally PI controllers used in adaptation mechanism are replaced by a fuzzy logic controller in order that the performance of the drive can be improved and also during load variations the speed can be kept constant.

5. Simulation Results and Discussion

To study the performance of the proposed control scheme, a MATLAB/Simulink model has been established for an induction machine driven by a voltage source inverter (VSI) using the proposed scheme. The parameters of the squirrel-cage induction motor are shown in the table 2.

The proposed method of ADRC is compared with the vector control based on the FLC regulators. We have studied the robustness of the proposed schemes under the cases of motor parameter variations, the model uncertainty and the load disturbance.

To evaluate the rapidity and the precision of control algorithms. For induction motor drive systems the rotor resistance may abruptly increase or decrease due to the variation in temperature during the operation of the machine as the machine losses change. The step variation of the rotor resistance is still selected here in order to establish the comparative simulation, so as to evaluate the proposed ADRC scheme under the worst operation condition. A simulation motor model with a varying rotor resistance that instantly influences on the rotor time constant is used to simulate the performance of the proposed control.

The speed reference steps up from 0 to 150 rad/s at 1s, still constant at 150 rad/s until 2s and steps down to -150 rad/s at 3s. The motor parameters, including the iron loss equivalent resistance, are set as the parameters listed aforementioned.When the torque control and the flux control of the induction motor are completely decoupled, the q-axis component rotor flux should be zero at the steady state. Even though both of the ADRC and the FLC controls do not make the q-axis component rotor flux to be zero, the steady-state error of the q-axis rotor flux of the ADRC is evidently less than that of the FLC command. It means that the decoupling degree of the proposed control is better than that of FLC.

In the steady-state performance side, the ADRC system can always become steady to the speed reference value without steady-state error, while the steady-state error of the FLC system increases slightly when the load is heavier, and up to 1.2% under rated load.
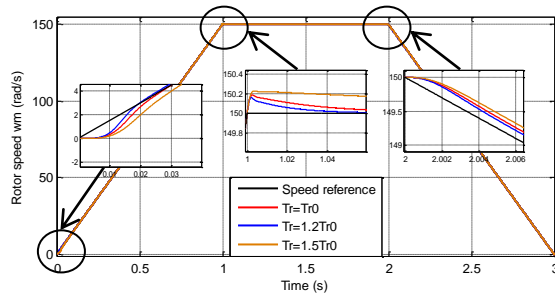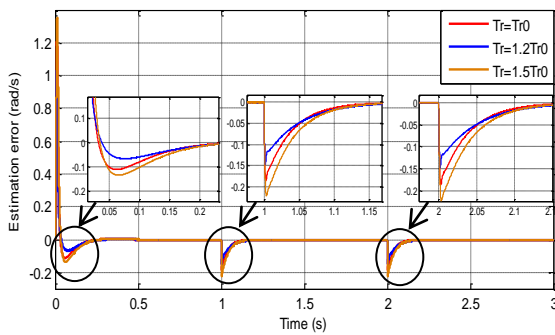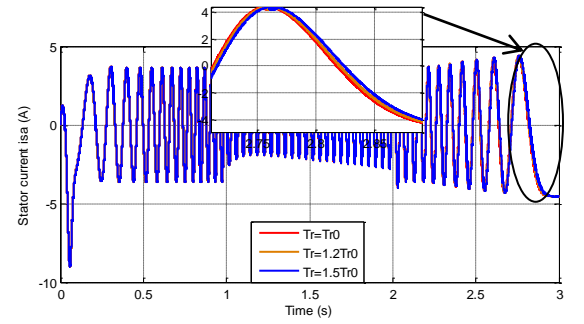

(a)
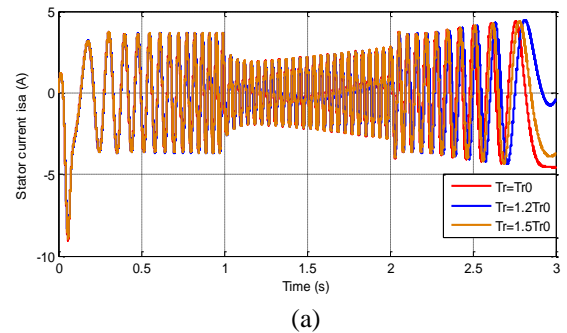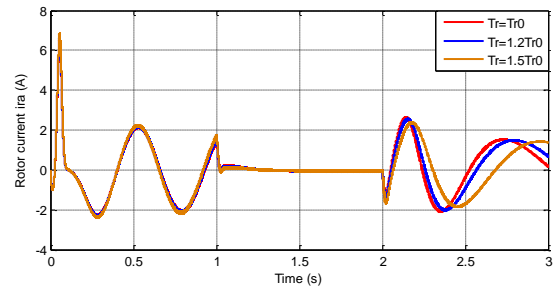
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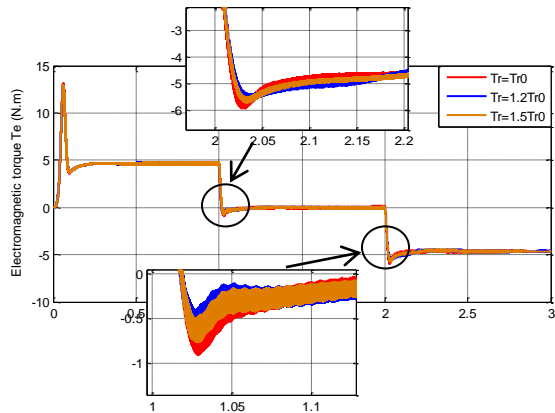
(c)

(d)
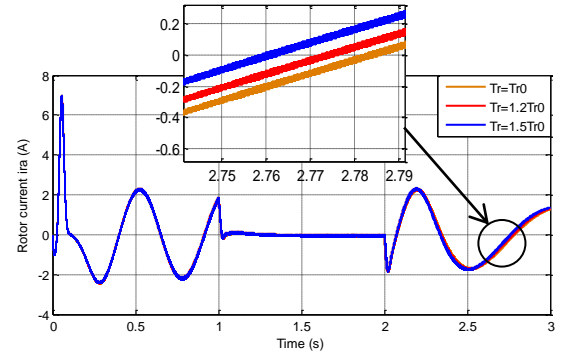

(e)
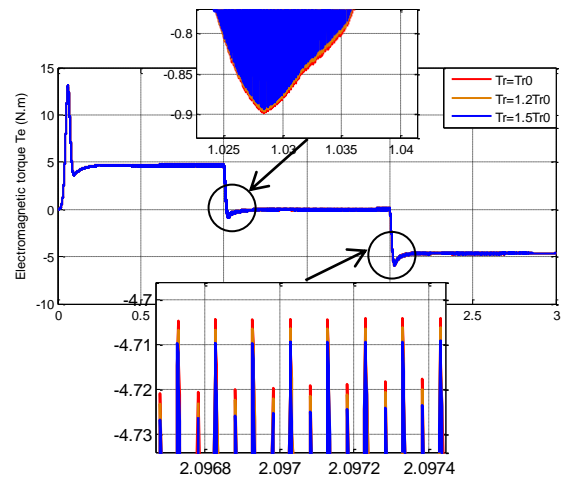
Fig. 9. Simulation results of FLC under rotor time constant variation, (a)Stator current isa, (b)Rotor current ira, (c)Electromagnetic torque, (d)Rotor speed, (e)Estimation error of speed
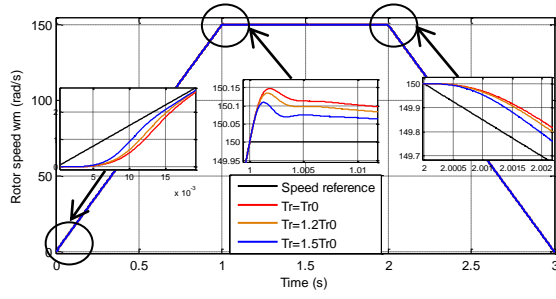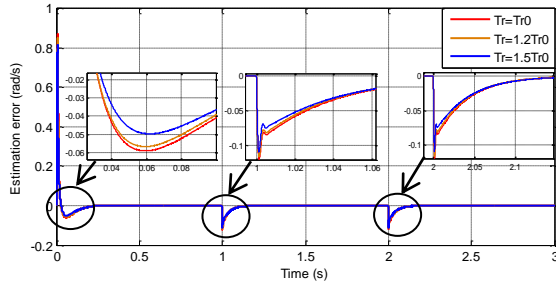

(a)

(b)

(c)

(d)

(e)

Fig. 10. Simulation results of ADRC under rotor time constant variation, (a)Stator current isa, (b)Rotor current ira, (c)Electromagnetic torque, (d)Rotor speed, (e)Estimation error of speed

This test demonstrates that the ADRC system has good robustness compared with the FLC System from the side of load disturbances. In the dynamic performance aspect, the FLC system always has larger overshoot than the ADRC system in the simulation results, the reason is that their linearization mechanisms are basically different. Indirect vector control depends on the field oriented to achieve the decoupling of the torque and the flux control, when the rotor flux direction coincides with the d-axis, under this circumstance, the induction motor can be considered as a "linear" system. Even so, in ADRC control scheme, the ESO, a core element of ADRC, estimate the external and the internal disturbances as the "total disturbance" in real time, then compensate it. Accordingly, the system is dynamically linearized.

The following figure show the performance of ADR control of the side the stator currents that operate the induction machine, it is clearly these currents are quasi sinusoidals.
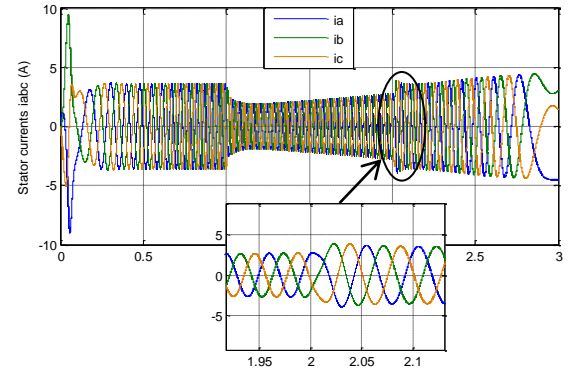

Fig. 11. Stator currents isabc of ADRC

Finally, the simulation results show the comparison between the two commands of FLC and ADRC, Highlighting the performances of each control.
By concluding, the ADRC is not badly affected under rotor resistance variation contrariwise when we implement the FLC.

6. Conclusion

In this work, the active disturbance rejection controller (ADRC) has been executed to the induction motor control compared with Fuzzy Logic control using an advanced-MRAS observer for rotor speed estimation. The extended state observer is The basis of ADRC, estimates and compensates the variety of motor parameters, the complete decoupling of the induction motor is gained. The generalized derivatives of obtained signals are achieved precisely. In other hand, the main advantage of both commands is that the closed loop characteristics of the motor drive system do not rely on the accurate mathematical model of the induction motor. Comparisons were realized in detail between ADRC and FLC under rotor time constant variation. As verified with simulation results, it is obviously concluded under rotor resistance disturbance that the proposed control of ADRC has a perfect dynamic performance than the command of FLC.

7. Appendix

ADRC controller parameters:
Stator currents controller gain $k_{p-s}= 130$
Stator currents parameter $b_{so}= 50$
Observation parameters of the loop currents stator:

The direct current gains of stator
$$\beta_{1d} = 900 \; ; \; \beta_{2d} = 100$$
The quadrature current gains of stator
$$\beta_{1q} = 180 \; ; \; \beta_{2q} = 10^{-3}$$

Table 2. Induction motor parameters

Symbol	Quantity	Numerical application
U	Power supply voltage	380 V
Tl	Load torque	7N.m
Nn	rated speed	1430 tr/mn
f	Current stator frequency	50 Hz
p	Number of pole pairs	2
Rs	Stator resistance	4.85 Ω
Rr	Rotor resistance	3.805 Ω
Ls	Stator inductance	0.274 H
Lr	Rotor inductance	0.274 H
M	Mutual inductance	0.258 H
J	Moment of inertia	0.031 Kg.m²

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