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# Robust Fuzzy Logic Current and Speed Controllers for Field-Oriented Induction Motor Drive

Fayez F. M El-Sousy and Maged N. F. Nashed*

Electronics Research Institute (ERI), NRC, Dokki, Cairo, Egypt

## ABSTRACT

This paper presents analysis, design and simulation for the indirect field orientation control (IFOC) of induction machine drive system. The dynamic performance of the IFOC under nominal and detuned parameters of the induction machine is established. A conventional proportional plus integral-derivative (PI-D) two-degree-of-freedom controller (2DOFC) is designed and analysed for an ideal IFOC induction machine drive at nominal parameters with the desired dynamic response Varying the induction machine parameters causes a degredation in the dynamic response for disturbance rejection and tracking performance with PI-D 2DOF speed controller. Therefore, conventional controllers can not meet a wide range of speed tracking performance under parameter variations. To achieve high- dynamic performance, a proposed robust fuzzy logic controllers (RFLC) for d-axis rotor flux, d-q axis stator currents and rotor speed have been designed and analysed These controllers provide robust tracking and disturbance rejection performance when detuning occures and improve the dynamic behavior. The proposed RFL controllers provide a fast and accurate dynamic response in tracking and disturbance rejection characteristics under parameter variations. Computer simulation results demonstrate the effectiveness of the proposed RFL controllers and a robust performance is obtained for IFOC induction machine drive system.

**Keywords:** Induction machine, Indirect field orientation control (IFOC), IP, PI-D 2DOF and RFL controllers.

## 1. Introduction

Induction machines have many advantageous characteristics such as high robustness, reliability and low cost. Therefore, induction machine drives are used in high-performance industrial applications such as robotics, rolling mills, machine tools and tracking systems, which require independent torque and speed control Induction machines also possess complex nonlinear, time-varying and tempereature dependency mathimatical model The requirements of high dynamic performance is gained utilizing FOC in which the dynamic model of the induction machine is simplified and decoupled The FOC strategy is being studied in the context developed by Hass and Blashke in Germany some thirty years ago This technique improves the performance of the induction machine drive system to a level comparable to that of the dc machine Therefore, FOC of induction machine drive system has permitted high-performance dynamic response using the decoupled torque and flux control In order to execute the IFOC strategy, current regulated pulse width

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Corresponding Author maged@eri sci eg
Tel +202-3310554, Fax +202-3351631

modulated (CRPWM) inverters are usually employed to satisfy the current control requirement[1][2]. In many industrial drives, the control of field oriented induction machine drive with a conventional controllers have gained the widest acceptance in high-performance ac drive systems. However, the conventional controllers has difficulty in dealing with dynamic speed tracking, parameter variations and load disturbances. So, the dynamic performance of a field-oriented induction motor is affected by the decoupling characteristics. It is known that for the IFOC of induction motor drive, the ideal decoupling between the flux and torque will not be obtained if the rotor parameters used in the FOC can not track their nominal values The most important parameter to be considered is the rotor resistance The adaptation of FOC equation, $\omega_{sl}$, is very important to achieve ideal decoupling To reduce the effects of rotor parameter variations on IFOC, various tuning techniques have been reported[3]-[5] The optimal control rule for adaptaion of rotor time constant requires many motor parameters and it is too complex to be successfully achieved. This difficulty can be overcome by fuzzy control technique instead of using mathematical derivations. Recently, FLC has received much attention in the control applications In contrast with the conventional techniques, FLC formulates the control action of a system in terms of linguistic rules drawn from the behavoir of human operator rather than in terms of an algorithm syntheized from a model of the system[6]. A conventional proportional plus integral-derivative (PI-D) two-degree-of-freedom controller (2DOFC) is designed and analysed for an ideal IFOC induction machine drive at nominal parameters with the desired dynamic response. Varying the induction machine parameters causes a degredation in the dynamic response for disturbance rejection and tracking performance with PI-D 2DOF speed controller To achieve high-dynamic performance, a proposed RFLC for d-q axis stator currents and rotor speed have been designed and analysed. These controllers provide robust tracking and disturbance rejection performance when detuning occures and improve the dynamic behavior

## 2. Dynamics of Induction Machine and IFOC

The nonlinear dynamic d-q model of the induction machine at the synchronous reference frame is given by equations (1, 2 and 3) From this model we can derive the IFOC dynamics for both ideal and detuning cases of FOC strategy as given by equations (4, 5, 6). The block schematic diagram of the proposed control scheme for IFOC induction machine drive system for simulation is shown in Fig 1

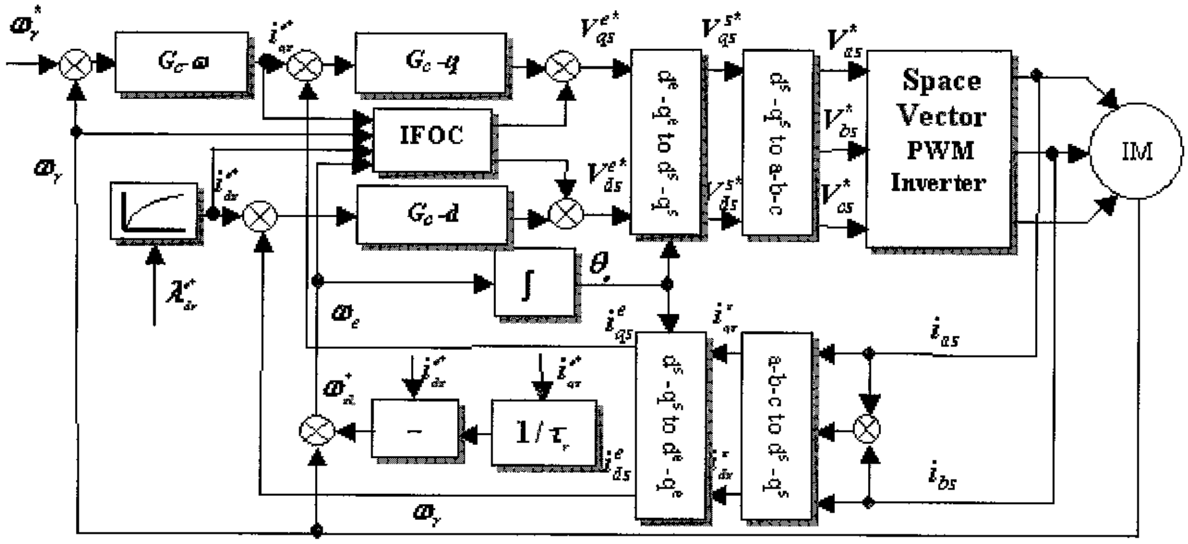


Fig 1 Block diagram of the IFOC induction machine drive system.

## 3. Conventional and FLC

The proportional plus integral plus derivative (PID) controller is one of the most commnly used controllers in industrial applications owing to its tuning flexibility and ease in design[2] However, PID control has difficulty in dealing with dynamic tracking, parameter variations and load disturbances FLC offers a convenient way of designing controllers nonlinearities from experience and expert knowledge about system being controlled. Also, FLC deals with systems that have uncertainty similar to induction machine and uses membership functions with values between 0 and 1 to solve the problem of the induction machine The fuzzy controller has two input signals, the loop error (e) and the error rate of change (e)

The control output is the increment signal (du) which is integrated to generate the command signal required. A rule matrix relates the (e), (e) and (du) variables is established

The input signals (e) and (e) are fuzzified, the corresponding control rules are evaluated from membership functions and rule table and finally defuzzified to derive the control signal (du)[6]

$$T_e = \frac{3}{2}.\frac{P}{2}.\frac{L_m}{L_r}(\lambda^e_{dr} i^e_{qs} - \lambda^e_{qr} i^e_{ds}) \tag{2}$$

$$T_e = T_L + \frac{J}{(P/2)}\frac{d\omega_r}{dt} + \frac{\beta}{(P/2)}\omega_r \tag{3}$$

$$\frac{d}{dt}\begin{bmatrix}\lambda^e_{qr}\\ \lambda^e_{dr}\end{bmatrix} = \begin{bmatrix}-\frac{1}{\tau_r} & -\omega_{sl}\\ \omega_{sl} & -\frac{1}{\tau_r}\end{bmatrix}\begin{bmatrix}\lambda^e_{qr}\\ \lambda^e_{dr}\end{bmatrix} + \frac{L_m}{\tau_r}\begin{bmatrix}i^e_{qs}\\ i^e_{ds}\end{bmatrix} \tag{4}$$

$$T_e = \frac{3}{2}.\frac{P}{2}.\frac{L_m^2}{L_r}.i^e_{ds} i^e_{qs} \tag{5}$$

$$\omega_{sl} = \frac{1}{\tau_r}.\frac{i^e_{qs}}{i^e_{ds}} \tag{6}$$

## 4. Design of the Proposed PI-D 2DOF Controller

### 4.1 PI-D Speed Controller

According to block diagram shown in Fig 2, the closed loop transfer function at $T_L(s) = 0$ is given by

$$\frac{\omega_r(s)}{\omega_r^*(s)} = \frac{K(K_p^\omega s + K_i^\omega)}{s^4 + \tau_{3\omega}s^3 + \tau_{2\omega}s^2 + \tau_{1\omega}s + KK_i^\omega} \tag{7}$$

where, $\tau_1 = (K_i^\wedge / \tau_m + KK_p^\omega)$

$$\tau_{2\omega} = (K_i^\wedge + \tau_i / \tau_m + K_t K_m K_d^\omega)$$

$$\tau_{3\omega} = (\tau_i + 1/\tau_m)$$

Using the fourth order performance index based on the ITAE robust technique which has the following equation, we can determine the controller parameters as follows.

$$\frac{C(s)}{R(s)} = \frac{\omega_n^4}{s^4 + 2.1\omega_n s^3 + 3.4\omega_n^2 s^2 + 2.7\omega_n^3 s + \omega_n^4} \tag{8}$$

Where, C(s) is the system output and R(s) is the system input

From equations (7 and 8), we can determine the controller parameters as follows.

$$K_p^\omega = \frac{2.7\omega_n^3 - K_{qe}K_i'(1/\tau_m)}{K} \tag{9}$$

$$K_i^\omega = \frac{\omega_n^4}{K} \tag{10}$$

$$K_d^\omega = \frac{\left(3.4\omega_n^2 - K_{qe}K_i' - (\tau_{iq}/\tau_m)\right)}{K_t K_m} \tag{11}$$

$$\frac{d}{dt}\begin{bmatrix}i^e_{qs}\\ i^e_{ds}\\ \lambda^e_{qr}\\ \lambda^e_{dr}\end{bmatrix} = \begin{bmatrix}-(\frac{1}{\sigma\tau_s}+\frac{1-\sigma}{\sigma\tau_r}) & -\omega_e & \frac{L_m}{\sigma L_s L_r \tau_r} & -\omega_r\frac{L_m}{\sigma L_s L_r}\\ \omega_e & -(\frac{1}{\sigma\tau_s}+\frac{1-\sigma}{\sigma\tau_r}) & \omega_r\frac{L_m}{\sigma L_s L_r} & \frac{L_m}{\sigma L_s L_r \tau_r}\\ \frac{L_m}{\tau_r} & 0 & -\frac{1}{\tau_r} & -(\omega_e - \omega_r)\\ 0 & \frac{L_m}{\tau_r} & (\omega_e - \omega_r) & -\frac{1}{\tau_r}\end{bmatrix}\begin{bmatrix}i^e_{qs}\\ i^e_{ds}\\ \lambda^e_{qr}\\ \lambda^e_{dr}\end{bmatrix} + \frac{1}{\sigma L_s}\begin{bmatrix}V^e_{qs}\\ V^e_{ds}\\ 0\\ 0\end{bmatrix} \tag{1}$$

### 4.2 PI-D 2DOF Speed Controller

#### 4.2.1 Feedback-Controller

The type of feedback controller is proposed as a PI-D controller which is designed in the preceding section while the feedforward controller is designed based on the desired closed loop response.

#### 4.2.2 Feedforward Controller

According to block diagram shown in Fig. 3 with PI-D 2DOF controller, the closed loop transfer function with pre-filter and at $T_L(s)=0$ is given by :

$$\frac{\omega_r(s)}{\omega_r^*(s)}=\frac{K(K_p^\omega s+K_i^\omega)}{s^4+\tau_{3\omega}s^3+\tau_{2\omega}s^2+\tau_{1\omega}s+KK_i^\omega}.G_{ff}(s) \tag{12}$$

Accordingly, we can obtain the feedforward controller transfer function that has the following relation from equations (8 and 12)

$$G_{ff}(s)=\frac{\omega_n^4}{K(K_p^\omega s+K_i^\omega)} \tag{13}$$

Equation (13) is a lag compensator but to speed up the response we add a lead compemsator to obtain a lead-lag compensator. Therefore, the feedforward compensator transfer function is given by:

$$G_{ff}(s)=K^\wedge.\frac{(1+\tau_1)}{(1+\tau_2)} \tag{14}$$

where, $\tau_1>\tau_2$, $\tau_2=(K_p^\omega/K_i^\omega)$

## 5. Design of the Proposed RFL Controllers

In this section, the analysis and design procedures of diferent RFL controllers, which includes current and speed controllers are carried out The RFL controllers proceed as follows to evaluate the desired output signals. Firstly, input variables are normalized Then, the membership functions of the RFL controllers output signals are determined by linguistic codes Finally, the numerical values of the RFL controllers output signals corresponding to a specific linguistic codes are determined.

### 5.1 RFL Current Controllers

#### 5.1.1 q-axis RFL Current Controller

The proposed RFL controller has two inputs, the current error $e_q(k)$ and error change of current $\Delta e_q(k)$ in q-axis. This RFL controller uses the sampled values of the

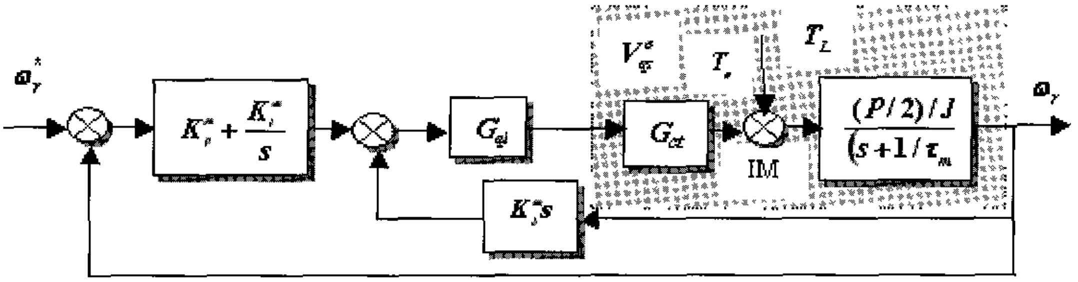


Fig 2 Block diagram of induction machine speed control with PI-D controller

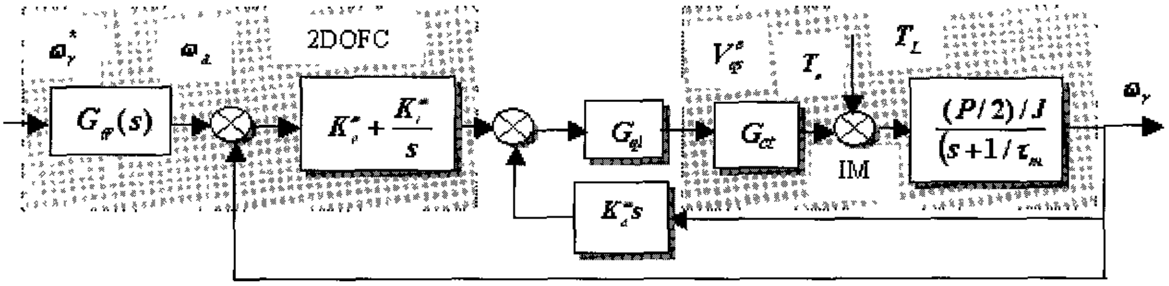


Fig. 3 The block diagram of the speed control with PI-D 2DOF controller

induction machine current in q-axis to compute the error and error change of current

- Dynamic Signal Analysis :

We consider a discrete-time controller where the error $e_q(k)$ at a step k is the difference between the command current $i_q^{e}(k)$ and the feedback current $i_{qs}^{e}(k)$ The RFL-q controller error and error change are given by the following equations·

$$e_q(k) = i_{qs}^{e*}(k) - i_{qs}^{e}(k) \tag{15}$$

$$\Delta e_q(k) = e_q(k) - e_q(k-1) \tag{16}$$

Where $i_{qs}^{e*}(k)$ is the current command in the kth sampling interval, $i_{qs}^{e}(k)$ is the feedback current in the kth sampling interval, $e_q(k)$ is the current error and error change of current $\Delta e_q(k)$ in the kth sampling interval and $\Delta e_q(k)$ is the error change of current in the kth sampling interval

- Linguistic Control Rules :

Based on the experience, knowledge of the IFOC dynamics and the dynamic signal analysis, the linguistic control rules are proposed depend on the following conditions·

- The RFL controller maintains its output when the output signal is a set value and the current error change is zero.
- Based on the magnitudes and signs of the current error and current error change, the change of the output signal is obtained such that the output of the controller will go back to the set value whenever a deviation between them occur.

Using the above conditions, the linguistic rule table is constructed as shown in Table 1

Table 1

| e / Δe | HN | MN | LN | ZE | LP | MP | HP |
|---|---|---|---|---|---|---|---|
| HN | HN | HN | MN | MN | LN | LN | ZE |
| MN | HN | LN | LN | LN | LN | ZE | LP |
| LN | HN | ZE | LN | LN | ZE | ZE | LP |
| ZE | MN | ZE | LN | ZE | LP | ZE | LP |
| LP | LN | ZE | ZE | LP | LP | LP | MP |
| MP | ZE | LP | LP | MP | MP | MP | HP |
| HP | LP | LP | LP | HP | HP | HP | HP |

The linguistic set HP, MP, LP, ZE, LN, MN, HN is choosen where P, N, H, M, L and ZE denote positive, negative, high, medium, low, and zero respectively These linguistic codes are close to the logic of human, so RFLC is easiely designed

- Membership Functions ·

Using the fuzzy linguistic control rules, the member ship functions corresponding to each element in the linguistic set must be defined In this paper, the triangular-shaped functions shown in Fig 4 are choosen owing to simplicity

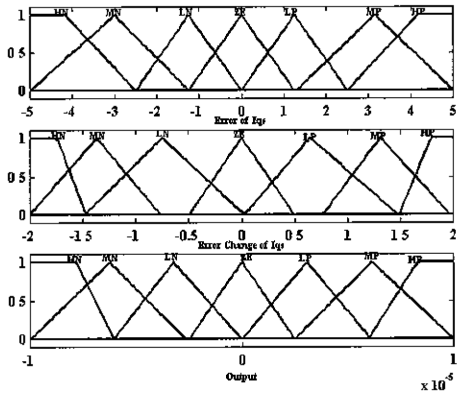


Fig 4 Member ship function of q-axis current controller

- Lookup Table

With the linguistic control rules shown in Table 1 and the membership functions shown in Fig. 4, the RFLC output must be converted back to numerical values The conversion table for the induction motor under consideration is constructed.

### 5.1 2 d-axis RFL Current Controller

Similar to the design of the q-axis current controller, the proposed RFL controller has two inputs, the current error $e_d(k)$ and error change of current $\Delta e_d(k)$ in d-axis

- Dynamic Signal Analysis :

The RFL-d controller error and error change are given by the following equations :

$$\begin{aligned} e_d(k) &= i_{ds}^{e*}(k) - i_{ds}^{e}(k) \\ \Delta e_d(k) &= e_d(k) - e_d(k-1) \end{aligned} \tag{17}$$

- Linguistic Control Rules ·

Similar to the design procedure of the q-axis current controller, the linguistic rule table is constructed as shown in Table 2

- Membership Functions ·

Similar to q-axis RFL current controller, the membership functions corresponding is constructed as shown in Fig 5.

- Lookup Table

The conversion table for the induction motor under consideration is constructed Table 2 and the membership functions shown in Fig. 5

### 5.2 RFL Speed Controller

The proposed RFL controller has two inputs, the speed error $e_\omega(k)$ and error change of speed $\Delta e_\omega(k)$ in q-axis. This RFL controller uses the sampled values of the rotor speed to compute the error and error change of speed

Table 2

| e \ Δe | HN | MN | LN | ZE | LP | MP | HP |
|---|---|---|---|---|---|---|---|
| HN | HN | HN | MN | MN | LN | LN | ZE |
| MN | HN | LN | LN | LN | LN | ZE | LP |
| LN | HN | ZE | LN | LN | ZE | ZE | LP |
| ZE | MN | ZE | LN | ZE | LP | ZE | LP |
| LP | LN | ZE | ZE | LP | LP | LP | MP |
| MP | ZE | LP | LP | MP | MP | MP | HP |
| HP | LP | LP | LP | HP | HP | HP | HP |

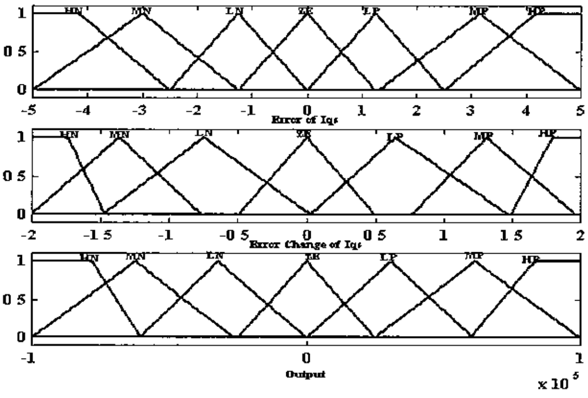


Fig 5 Member ship function of d-axis current control

- Dynamic Signal Analysis

The RFL-ω controller error and error change are given by the following equations

$$e_\omega(k) = \omega_r^*(k) - \omega_r(k) \tag{19}$$

$$\Delta e_\omega(k) = e_\omega(k) - e_\omega(k-1) \tag{20}$$

- Linguistic Control Rules .

Similarly, to the design procedure of the current controllers, the linguistic rule table of the speed loop is constructed as shown in Table 3.

- Membership Functions

Using the fuzzy linguistic control rules, the member ship functions corresponding to each element in the linguistic set must be defined. In this paper, the triangular-shaped functions shown in Fig. 6 are choosen owing to simplicity

- Lookup Table

Similarly, the conversion table for the induction motor under consideration is constructed Table 3 and the membership functions shown in Fig 6

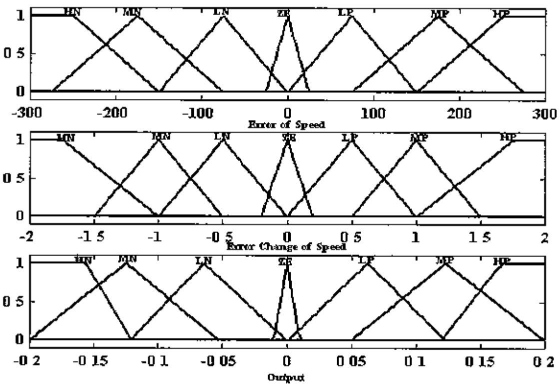


Fig 6 Member ship function of the rotor speed controller

Table 3

| e \ Δe | HN | MN | LN | ZE | LP | MP | HP |
|---|---|---|---|---|---|---|---|
| HN | HN | HN | MN | MN | LP | LN | ZE |
| MN | HN | HN | LN | LN | LN | ZE | LP |
| LN | HN | ZE | LN | ZE | ZE | ZE | LP |
| ZE | MN | ZE | LN | ZE | LP | LP | LP |
| LP | LN | ZE | ZE | LP | LP | MP | MP |
| MP | ZE | LP | LP | MP | MP | MP | HP |
| HP | LP | MP | MP | HP | HP | HP | HP |

## 6. Simulation Results of the Drive System

The proposed control scheme for IFOC induction machine drive system simulation is carried out using PCMATLAB package. To demonstrate the proposed RFL controllers for IFOC of induction machine drive system performance, simulation of the proposed control scheme with RFLC are compared with those of a conventional IP and PI-D 2DOF controllers in currents and speed loops respectively. The dynamic performance of the drive system for different operating conditions is studied with the application of RFL controllers in the current and speed loops. Taking into consideration the parameter variations of the induction machine, the drive system performance has been studied under load changes and set-point variations. Also the results of simulation for such disturbances are given. The dynamic response of the drive system uder the disturbances of step change in the load, step change in the reference speed and speed reversal. have been studied.

The performance of the drive system with the proposed RFL controller and conventional PI-D 2DOF controller are shown in Fig. 7-9. Fig. 7 illustrates the dynamic response of the IFOC induction machine drive system with RFL controllers in the current and speed loops under the conditions of external load of 10 N.m and the machine parameters are fixed at the nominal values. The dynamic response of the IFOC induction machine drive system with a conventional PI-D 2DOF controller at the same conditions is illustrated in Fig. 8. The speed response and the load regulation performance of a conventional PI-D 2DOF controller and the proposed RFL controllers are shown in Fig. 9 (X-Y), respectively under the same conditions where the rotor time constant changes from 0.5 $\tau_r$ to 1.5 $\tau_r$ and the mechnical time constant changes from $\tau_m$ to 5 $\tau_m$. At t = 1.5 sec, external load of 10 N.m is applied to the drive system in the cases of conventional PI-D 2DOF controller and the proposed RFL controllers and removed at t=4 sec.

Fig. 9 shows the speed tracking and load regulation performance under nominal and detuned parameters for both PI-D 2DOF and RFL controllers. The proposed RFL controllers provide a rapid and accurate response for the reference, regardless of whether a load disturbance is imposed and the induction machine parameters vary as illustrated in Fig. 9-X (a-b). The RFL controllers quickly return the speed to the command speed within 0.15 sec with a maximum dip of 6 rad/sec. Also, the RFL controllers can compensate the induction machine drive system at nominal values and is insignificantly affected by variations in the induction machine's parameters. The speed response of the RFL control scheme was influenced slightly by the load disturbance, whether the system parameters varied or not as shown in Fig. 9 (X). However, the speed response of the conventional control scheme with IP and PI-D 2DOF did have a long recovery time of 1 sec and large dipping in speed of about 30 rad/sec under load changes as shown in Fig. 9-Y (a-b). The simulated torque and torque current responses of the designed RFL and PI-D 2DOF controllers due to step command and load torque changes are shown in Fig. 9-X (c-d) and 9-Y (c-d) respectively. When the variations of the rotor and mechanical parameters occur, the response of the PI-D 2DOF controller deviate significantly from the desired

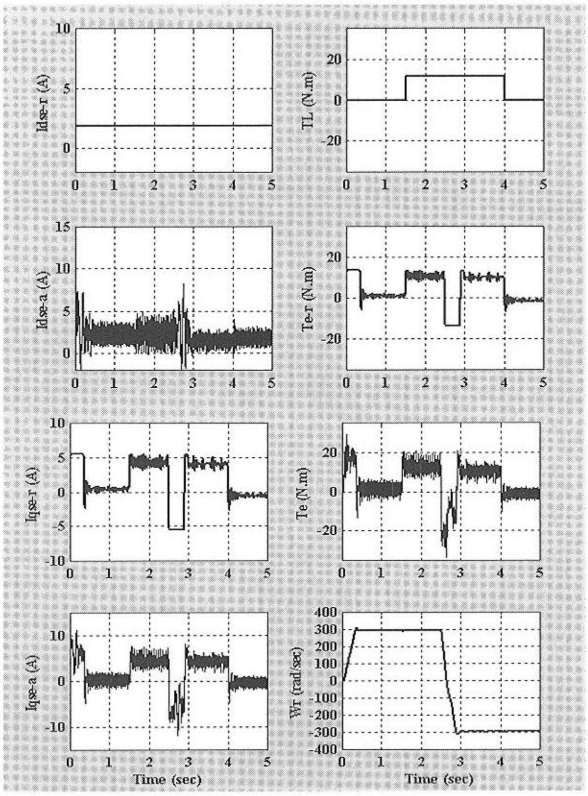


Fig. 7. Step responses in speed reference reversal and load disturbance with the proposed RFL controllers.

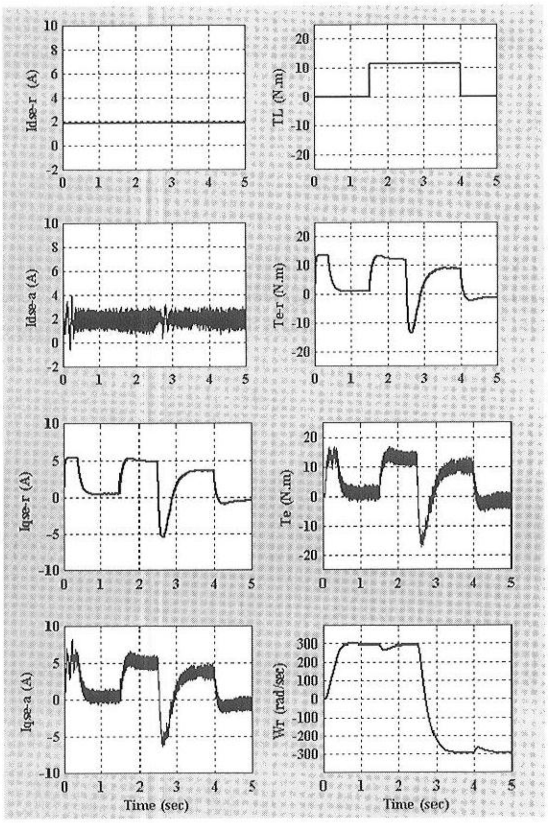
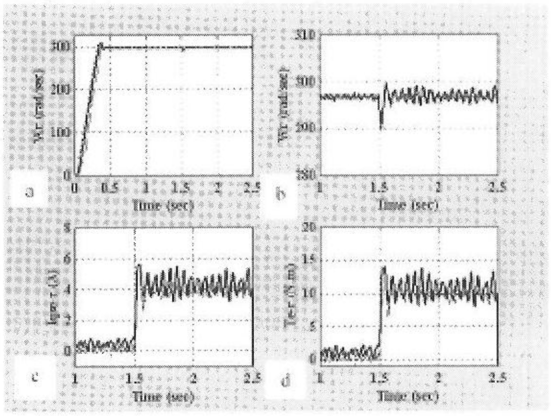


Fig. 8. Step responses in speed reference reversal and load disturbance with the proposed PI-D 2DOF controller.

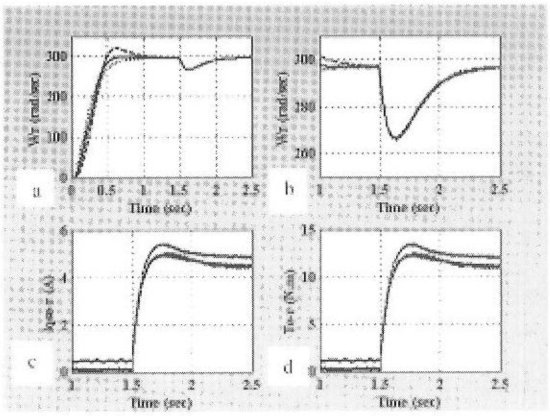
ones while in case of RFL controllers, the response is improved and there is no deviation from the desired ones. Computer simulation results demonstrate that the proposed RFLC can obtain a robust response for the drive system. The results of the simulation confirm the effectiveness of the proposed RFL controllers and their superiority compared with the IP and PI-D 2DOF controllers for IFOC induction machine drive system.

## 7. Conclusions

This paper has presented a control system design for IFOC of induction motor drive system. Quantitative design procedures for a conventional PI-D 2DOF speed controller and RFL controllers for currents and speed have been developed. The conventional PI-D 2DOF controller is designed based on the nominal machine parameters to match the tracking and regulation performance. The rbust FLC are designed to improve the performance of the IFOC induction motor drive. The proposed RFL controller can compensate the induction machine drive system at nominal valuses and is insignificantly affected by variations in the induction machine's parameters. The speed response of the proposed RFL control scheme was influenced slightly by the load disturbance, whether the system parameters varied or not. However, the speed response of the conventional PI-D 2DOF control scheme did have a long recovery time of one second. Computer simulation results demonstrate that the proposed RFLC can obtain a robust response for the drive system. The results of the simulation confirm the effectiveness of the



X- RFL controllers



Y- PI-D 2DOF controllers

solid lines $\tau_r = \tau_r^*$ and $\tau_m = \tau_m^*$,

dotted lines $\tau_r = 1.5\tau_r^*$, $\tau_r = 0.5\tau_r^*$ and $\tau_m = 5\tau_m^*$

Fig. 9. Speed tracking response and load regulation performance with parameter variations.

proposed RFL controllers and their superiority compared with the PI-D 2DOF controller for IFOC induction machine drive system. Also, the results demonstrate that the proposed RFL control scheme has a robust speed response and can rapidly cancel a load disturbance.

## References

[1] Fayez F. M. El-Sousy, Faeka M.H. Khater and Farouk I. Ahmed, "Analysis and Design of Indirect Field Orientation Control for Induction Machine Drive System", Proceeding of the 38th SICE annual conference, SICE99, Iwate, Japan, pp. 901~908, July 28~30 1999.

[2] Fayez F. M. El-Sousy, "Design and Implementation of 2DOF I-PD Controller for Indirect Field Orientation Control Induction Machine Drive System," ISIE 2001 IEEE International Symposium on Industrial Electronics, Pusan, Korea, pp. 1112~1118, June 12~16 2001.

[3] K.B. Nordin, D.W. Novotny and D. S. Zinger, "The influence of motor parameter deviations in feedforward field orientation drive systems", IEEE Trans. Ind. Appl., Vol. IA-21, No. 4, July/Aug. 1985.

[4] L. J. Garces, "Parameter adaption for the speed controlled static ac drive with a squirrel cage induction motor", IEEE Trans. Ind. Appl., Vol.IA-16, No. 2, pp. 173~178, Mar./Apr. 1980.

[5] T. Matsuo and T.A Lipo, "Rotor resistance identification in the field oriented control of a squirrel cage induction motor", IEEE Trans. Ind. Appl., Vol. IA-21, No. 3, pp. 624~632, May/July 1985.

[6] F. Cheng and S. Yeh, "Application of fuzzy logic in the speed control of ac servo systems and an intellgent inverter", IEEE Trans. Energy Conversion, Vol. 8, pp. 312~318, June 1993.

**Fayez Fahim Mohamed El-Sousy** received B. S. degrees in Electrical Engineering, from the univ. of Menoufia University, Egypt, in May 1988, the M.Sc degree in Electrical Engineering, from Cairo univ., Cairo, Egypt, in March 1994 and the Ph. D.of degree in Electrical Engineering, from Cairo univ., Cairo, Egypt, in April 2000. Since 1990, he has been with the Dept. of Electronic and Energy conversion, Electronic Research Institute, where he is currently a Researcher. He is engaged in research on Power Electronic, Drive circuit, control of drives, Electrical Machines and Microprocesors and Interfacing.

**Maged Naguib Fahmy Nashed** received B. S. degrees in Electrical Engineering, from the univ. of Menoufia University, Egypt, in May 1983, the Diploma of Higher, from Cairo Univ., May 1990, the M.Sc degree in Electrical Engineering, from Ain shams univ., Cairo, Egypt, in April 1995 and the Ph. D. of degree in Electrical Engineering, from Ain shams univ., Cairo, Egypt, in January 2001. Since 1989, he has been with the Dept. of Electronic and Energy conversion., Electronic Research Institute,.where he is currently a Researcher. He is engaged in research on Power Electronic, Drive circuit, control of drives and Renewable Energy.