A simple and Efficient Method for a Based Fuzzy Logic Speed Controller and Rotor Resistance Estimation of an Indirect Vector Controlled Induction Motor Drive

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Abstract: In this paper, a simple method for estimating rotor resistance in an indirect vector-controlled induction motor drive is proposed. The proposed rotor resistance estimator which uses fuzzy logic principle is based on the improvement of control performance when mismatch between estimated rotor resistance and actual one occurs. The major advantages of the method is its simplicity, accuracy and good response at low speed and at the transient instants. A series of computer simulations have been performed with satisfactory results.

Key words: IFOC, FLC, rotor resistance estimator.

1. Introduction

With the rapid development of microelectronics and power switches, most adjustable-speed drives are now realized with ac machines [1]. Vector control allows high-performance control of speed and torque to be achieved from an induction motor. In typical indirect vector controlled induction motor drive, the flux, torque and slip commands are calculated from the motor variables (voltage, current and speed) based on a model. The control performance is thus sensitive to the system parameters in particular the rotor resistance which changes significantly with temperature and often causes field orientation detuning and degrades system performance. Therefore, an important requirement to obtain good performance is to guarantee the coincidence between the parameters of model and those of the actual motor. Various methods are proposed to estimate the rotor resistance, as it is not possible to measure its value directly in a squirrel-cage motor. The online estimation method for static AC drives proposed by Garces in [2] uses a special adaptation function called the 'Modified Reactive Power Function' to avoid the effects of the stator resistance change.In [3,4,5], the proposed rotor parameter estimation uses the thermal model of the induction motor to estimate at each operating point the values of stator and rotor resistances. Lorenz in [6] developed an algorithm to correct the adverse effects of rotor resistance variations on torque and speed characteristics of motor. In [7,8,10], rotor time constant measurement schemes for an indirect vector controlled drives run by a voltage source inverter (VSI) were proposed. In [9,11], the system is directly tuned on line for the rotor resistance variation for Direct Self-Control (DSC). In [15], a new sliding mode current observer for an induction motor is developped in which the speed and rotor resistance are assumed to be unknown constant parameters. In [16], a method using a programmable cascaded low pass filter for the estimation of rotor flux with a view to estimate the rotor time constant of an IFOC induction motor drive is investigated. Despite all these efforts, rotor resistance estimation remains a difficult problem.

This paper presents a relatively simple fuzzy controller that is robust in terms of disturbance rejection, tracking performance and parameter variations [14] which is used to regulate the speed. Moreover, it details a method of estimation of the rotor resistance identification[12,13] based on the reactive power using fuzzy logic controller to correct detuning of field orientation. The estimator uses available system signals. The main and control system have been designed and simulated using MATLAB/SIMULINK software. Furthermore, the machine and control equations are derived, effects of the rotor resistance variations in the fuzzy controllers are presented. Simulation results show the high performance of the method used by using a simple structure of F.O.C. block with d -q axis currents as outputs.

2. Induction Motor Drive

The system presently considered, shown in Figure.1, is an indirect field oriented control (IFOC)-based induction motor drive. It consists mainly of a squirrel-cage induction motor, a voltage-regulated pulse width modulated inverter, fuzzy speed controller and rotor resistance estimator. The induction motor

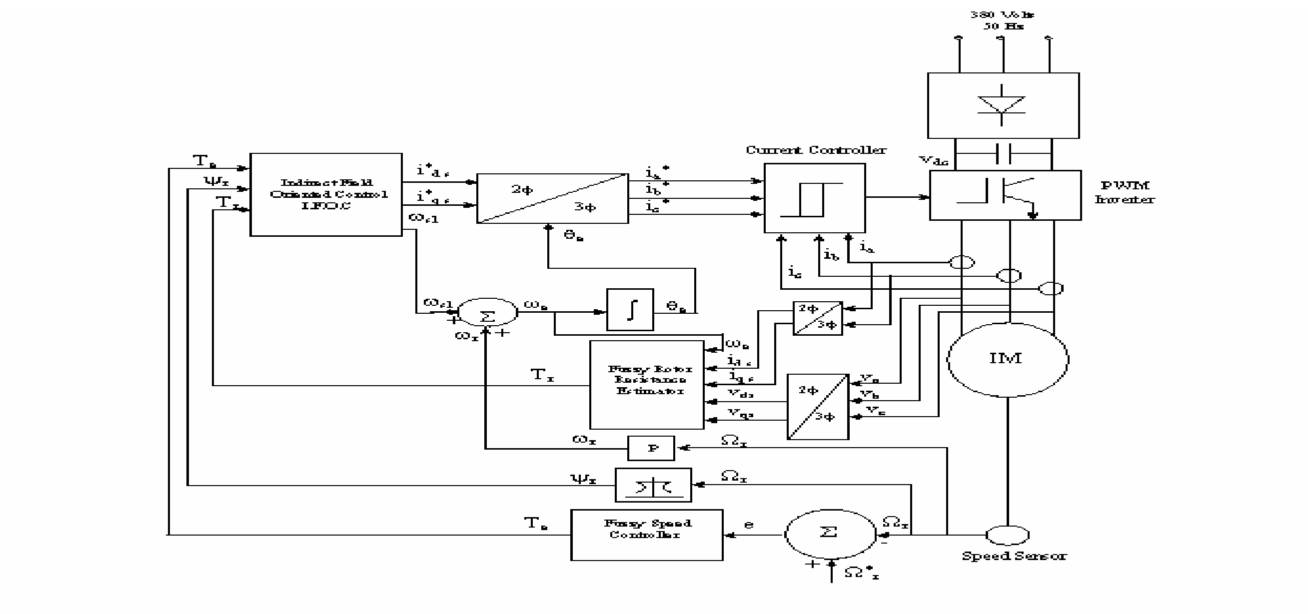

Fig .1. Schematic diagram of the proposed control strategy with rotor resistance identification.

is a three phase, Y connected, four pole, 1.5 Kw, 1420tr/mn 220/380V,50Hz and 6.4/3.7A.

Under field orientation condition, the d-q equations of the motor in the synchronous reference frame are:

$$R_r i_{qr} + \omega_{sl}\psi_{dr} = 0 \qquad (1)$$

$$R_r i_{dr} + \frac{d}{dt}\psi_{dr} = 0 \qquad (2)$$

$$L_m i_{qs} + L_r i_{qr} = 0 \qquad (3)$$

$$L_m i_{ds} + L_r i_{dr} = \psi_{dr} \qquad (4)$$

where R_r, L_r, L_m are motor parameters, i_{dr}, i_{qr}, i_{ds}, i_{qs} ψ_{dr}, ψ_{ds} are motor currents and fluxes, and ω_{sl} is slip frequency. The equations describing the motor operation in decoupling mode are deduced from (1-4)

$$\omega_{sl} = \frac{L_m}{\psi_r}\left(\frac{R_r}{L_r}\right) i_{qs} \qquad (5)$$

$$T_e = \frac{3}{2} p \frac{L_m}{L_r}\psi_r i_{qs} \qquad (6)$$

$$\left(\frac{L_r}{R_r}\right)\frac{d\psi_r}{dt} + \psi_r = L_m i_{ds} \qquad (7)$$

Because of the variation of R_r and L_r, the desired field orientation condition can not always be maintained and the drive performance can be significantly affected.

3. Proposed Identification Approach

For the normal operation of the drive and without considering the effects derived from the saturation (L_r constant), the rotor resistance can vary up to 100 percent as a function of the temperature. In order to study the influence of this parameter, a characteristic function F can be defined as:

$$F = \frac{1}{\omega_e}\left[\left(v_{ds} - \sigma L_s \frac{di_{ds}}{dt}\right) i_{qs} - \left(v_{qs} - \sigma L_s \frac{di_{qs}}{dt}\right) i_{ds}\right] + \sigma L_s \left(i_{ds}^2 + i_{qs}^2\right) \qquad (8)$$

where ω_e is the electrical synchronous speed.

This function can also be defined from a modified expression of field orientation conditions $(\psi_{qr} = 0, \psi_{dr} = \psi_r)$ as follows:

$$F = \frac{L_m}{L_r}\left(\frac{d\psi_r}{dt} i_{qs} - \psi_r i_{ds}\right) \qquad (9)$$

In permanent mode $\left(\frac{d\psi_r}{dt} = 0\right)$, equation (9) becomes:

$$F_0 = -\frac{L_m}{L_r}\psi_r i_{ds} = -\frac{1}{L_r}(\psi_r)^2 \qquad (10)$$

The error function ($EF = F - F_0$) as will be shown later by simulation reflects the rotor resistance variation and can be used as a correction function for the adaptation of the rotor time constant $T_r = \frac{L_r}{R_r}$ in the fuzzy controller.

4. Principle and Design of the Fuzzy Controllers

4.1 Rotor Resistance Estimator Using F.L [17]

Figure.2 shows the configuration of the proposed fuzzy logic rotor resistance estimation.

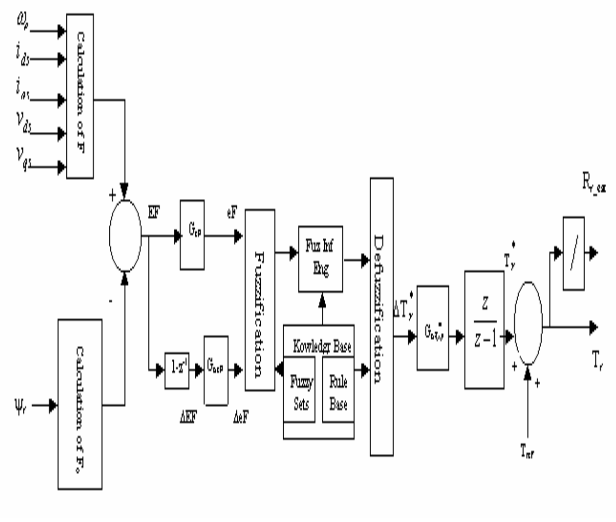

Fig .2 Fuzzy controller block diagram for rotor resistance estimation

The functions F and F_0 are first calculated respectively from the measured variables $i_{ds}, i_{qs}, v_{ds}, v_{qs}, \omega_e$ and the reference value Ψ^*. The error EF and its time variation ΔEF are then calculated:

$$EF(k) = F(k) - F_0(k) \qquad (11)$$

$$\Delta EF(k) = EF(k) - EF(k-1) \qquad (12)$$

For the successful design of FLC's, proper selection of these gains is a crucial job which in many cases is done through trial and error to achieve the best possible control performance.
The crisp variables are converted into fuzzy variables eF and Δ eF using triangular membership functions as in Figure 3. These input membership functions are used to transfer crisp inputs into fuzzy sets.
In the defuzzification stage, the implied fuzzy set is transformed to a crisp output by the centre of gravity defuzzification technique as given by equation (13) , z_i is the numerical output at the ith number of rules and $\mu(z_i)$ corresponds to the value of fuzzy membership function at the ith number of rules.

$$z = \frac{\sum_{i=1}^{n} z_i.\mu(z_i)}{\sum_{i=1}^{n} \mu(z_i)} \qquad (13)$$

The summation is from one to n, where n is the number of rules that apply for the given fuzzy inputs.
The crisp output ΔT_r^* is multiplied by the gain factor $G_{\Delta T_r^*}$ and then integrated to give:

$$T_r^*(k) = T_r^*(k-1) + G_{\Delta T_r^*}\Delta T_r^*(k) \qquad (14)$$

This value added to the reference rotor time constant (T_{ref}) gives the estimated time constant (T_r) which is used as an input to the F.O.C block of Figure1 to ensure correct field orientation operation of the drive.

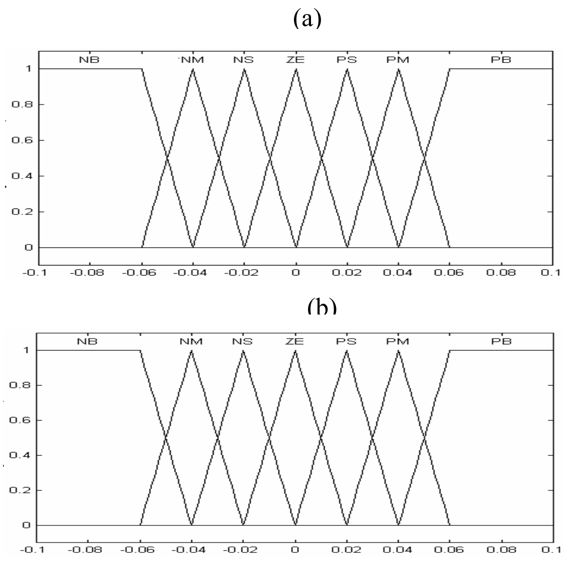

Fig. 3 Input and output membership functions. (a) : eF, ΔeF, (b) : ΔT_r

4.2 Fuzzy Logic Speed Controller [14]

The block diagram showing the implementation of the Fuzzy speed controller is illustrated in Figure 4.
It includes four major blocks: knowledge base, fuzzification, inference mechanism, and defuzzification. The knowledge base is composed of a data and a rule base. The data base, consisting of input and output membership functions. The rule base is made of a set of linguistic rules relating the fuzzy input variables into the desired fuzzy control actions.
The same type of membership functions used in fuzzy logic rotor resistance estimation is applied in fuzzy sets for speed fuzzy logic controller.
The inputs are e_1 and e_2 as defined in (15) and (16), where G_1 and G_2 are adjustable input gains.

$$e_1 = G_1\left(\Omega_r^*(k) - \Omega_r(k)\right) \qquad (15)$$

$$e_2 = G_2\left(e_1(k) - e_1(k-1)\right) \qquad (16)$$

A knowledge base of 7 x 7 rules, as shown in Table 2, is applied to tune T_e to reduce the speed error to zero. The final output of speed fuzzy logic controller is expressed in :

$$T_e(k) = T_e(k-1) + G_{T_e^*}.T_e^*(k) \qquad (17)$$

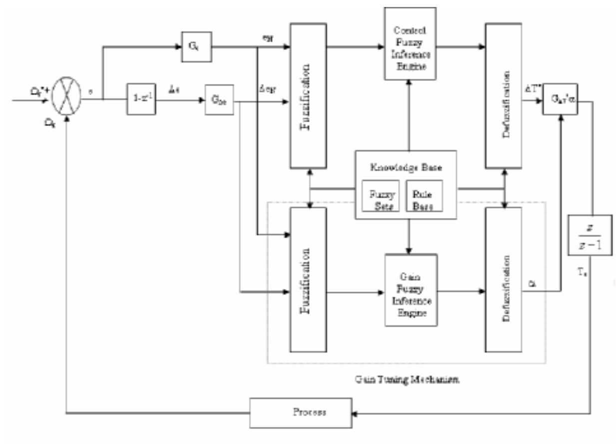

Fig .4. Block diagram of the proposed self-tuning fuzzy

These fuzzy rules can be understood easily and can be explained intuitively.

Table2. Rule base for speed control

e_2 \ e_1	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NS	NS	ZE
NM	NB	NM	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PM	PB
PB	ZE	PS	PS	PM	PB	PB	PB

For example, IF error of speed is negative big (e_1 = NB) and change of error is negative small (e_2 = NS) then it is quite natural that the fuzzified torque command should be negative big (ΔT_e^* = NB). The other rules can be understood in a similar way [12].

5. Simulation Results

In order to verify the validity of the proposed fuzzy estimator and to analyze the drive system performance for their flux and torque responses with rotor resistance variation, several simulations are carried out using MATLAB and simulink software. The configuration of the overal control system is shown in Figure.1. A squirrel cage induction motor with a rated power of 1.5 Kw has been used. The specifications and parameters of the induction motor are listed in Appendix. The sampling time of the controller is 50 μs.The motor is allowed to rotate at a constant speed of 1000rpm and a load of 10N.m is applied to the rotor shaft.

In the actual operating conditions, the rate of change of temperature is very slow and so the resistance variation. Figure. 5 covers this situation, where at 3 s a ramp change of rotor resistance for an uncompensated case is applied linearly from 100% of its rated value to 200% till 6 s, after that, this value is maintained constant during 3 s.

We notice from this figure, that the torque command deviates from the motor torque and therefore the quadratic rotor flux is no longer zero. The direct rotor flux has increased from its rated value giving a detuning problem. However, the performance of the control system is affected when the rotor estimated resistance value used in the control algorithm does not match properly the real value.

Therefore, in order to maintain a high performance of the induction motor drive, it is required that the rotor resistance value used in the control model should be updated regularly to track its real value. In this case, the field orientation condition can be maintained as it is required and is illustrated in Figure.6 by applying a ramp change of rotor resistance for a compensated case. In this figure, ψ_{qr} stabilizes to almost zero and ψ_{dr} to its rated value 0.69 wb. The drop in speed is negligible and the estimated value of the rotor resistance coverges to the real value and decoupling IFOC is respected.

However, by comparing the results for uncompensated and compensated cases of a ramp change variation of rotor resistance, one can say that the association of rotor resistance estimator using fuzzy logic controller provides excellent dynamic performance to an induction motor drive.

Figure.7 confirms the robustness of the proposed estimated method at low speed for a ramp change of R_r at 3 s.The speed tracks perfectly the reference which is fixed at 100 rpm. The tracking of rotor resistance is achieved and the flux stabilizes at its rated value.

Finally, a comparison between fuzzy estimator for compensated ramp change of R_r and PI rotor resistance variation is carried out, Figure.8. The PI controller presents an overshoot at transient time of 33 rpm (3.3%) whereas the proposed controller has no overshoot. When a ramp change of rotor resistance is applied at 3 s, the fuzzy controller reacts perfectly with no change in speed but the PI controller has an overshoot of speed of 1.8 rpm . Some oscillations of the direct flux at transient instants have appeared with PI estimator figure. 8(b), but the fuzzy estimator has no oscillations Figure.8(a).

6. Conclusions

The variation of rotor resistance has a most important effect on the performance of indirect vector control systems. The analysis in this paper has shown that the two major effects include:

- Destroying the decoupled conditon of flux and torque, hence, deteriorating the dynamic performance of the system.
- Deviation of the flux from the desired value for an incompensated ramp change of R_r.

Therefore, the on-line estimation of the rotor resistance is important to high performance vector control system. An on-line technique for establishing the exact value of the rotor resistance of an induction motor has been described in this paper. Digital simulation results show that this technique can minimize the detuning effects and efficiently enhance the performance of an indirect field oriented induction motor drive. An excellent tracking performance was obtained and at low speed, the proposed estimated method showed its robustness by tracking the real rotor resistance value.The low speed at transient instant and in the steady state is perfect which is one of the great advantages of this proposed estimated method.

The proposed fuzzy rotor resistance estimator can be implemented on any existing digital control system for indirect vector controlled induction motor drive with minimum add-on hardware and software.

7. References

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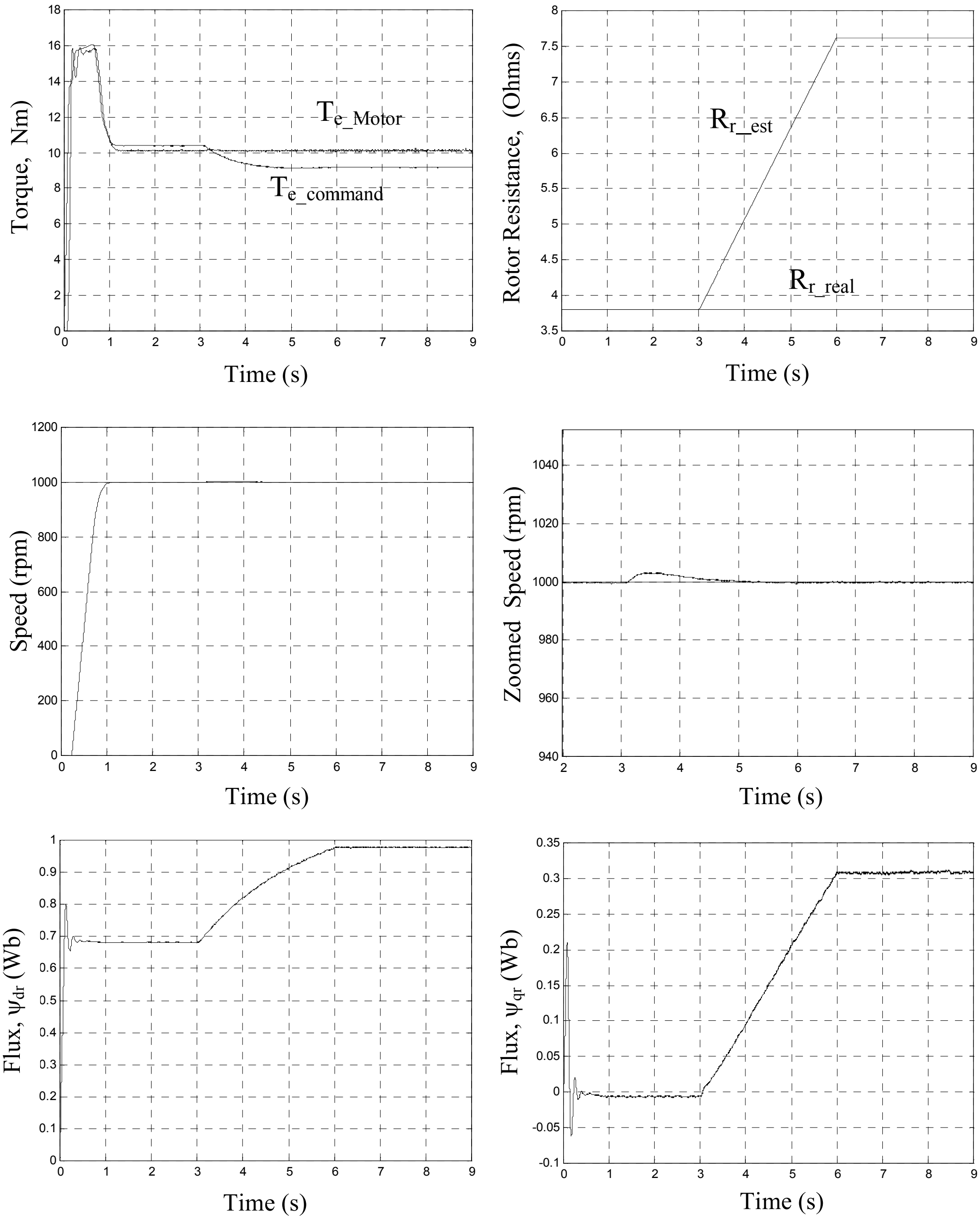


Fig. 5 Effect of rotor resistance variation with fuzzy estimator
for uncompensated ramp change of $R_{r.}$

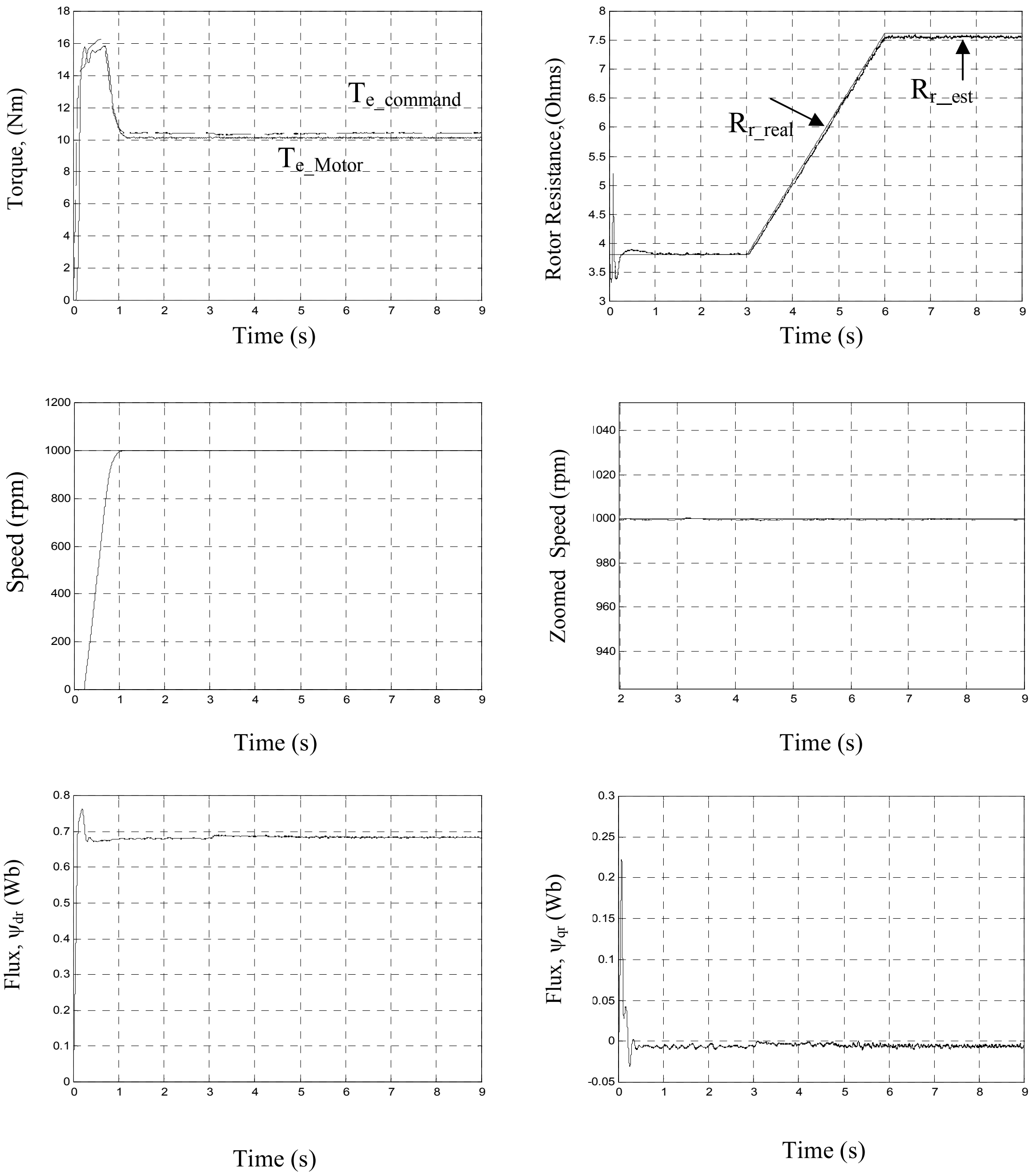


Fig. 6 Effect of rotor resistance variation with fuzzy estimator
for compensated ramp change of R_r.

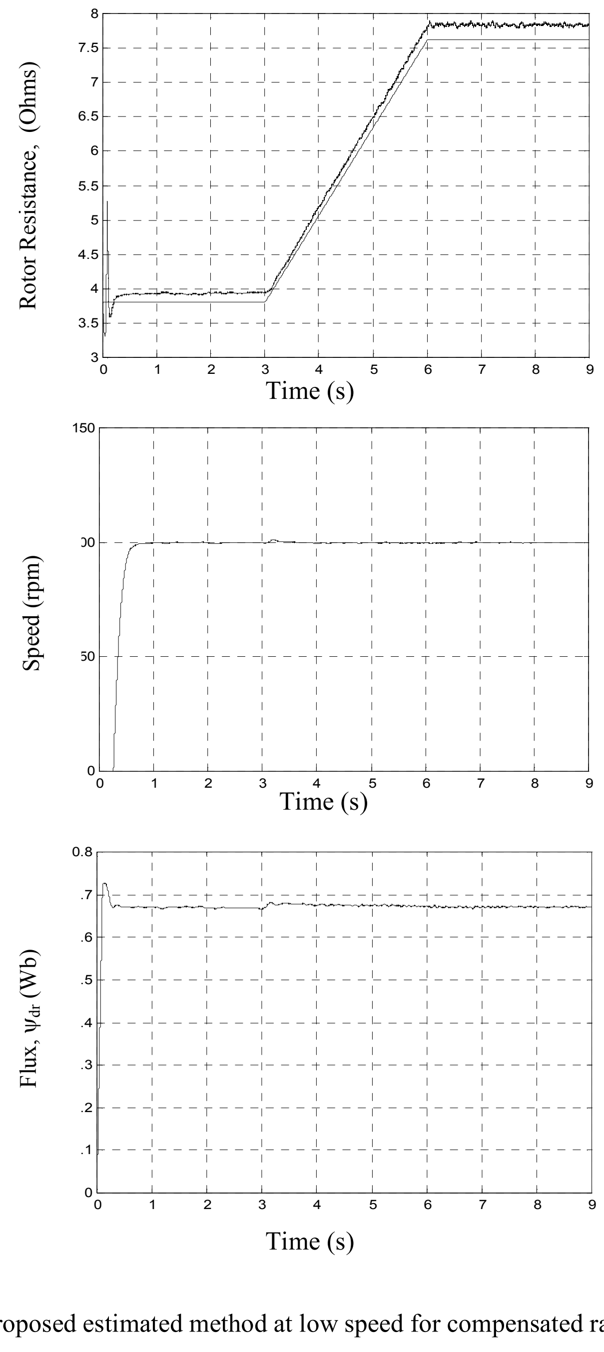
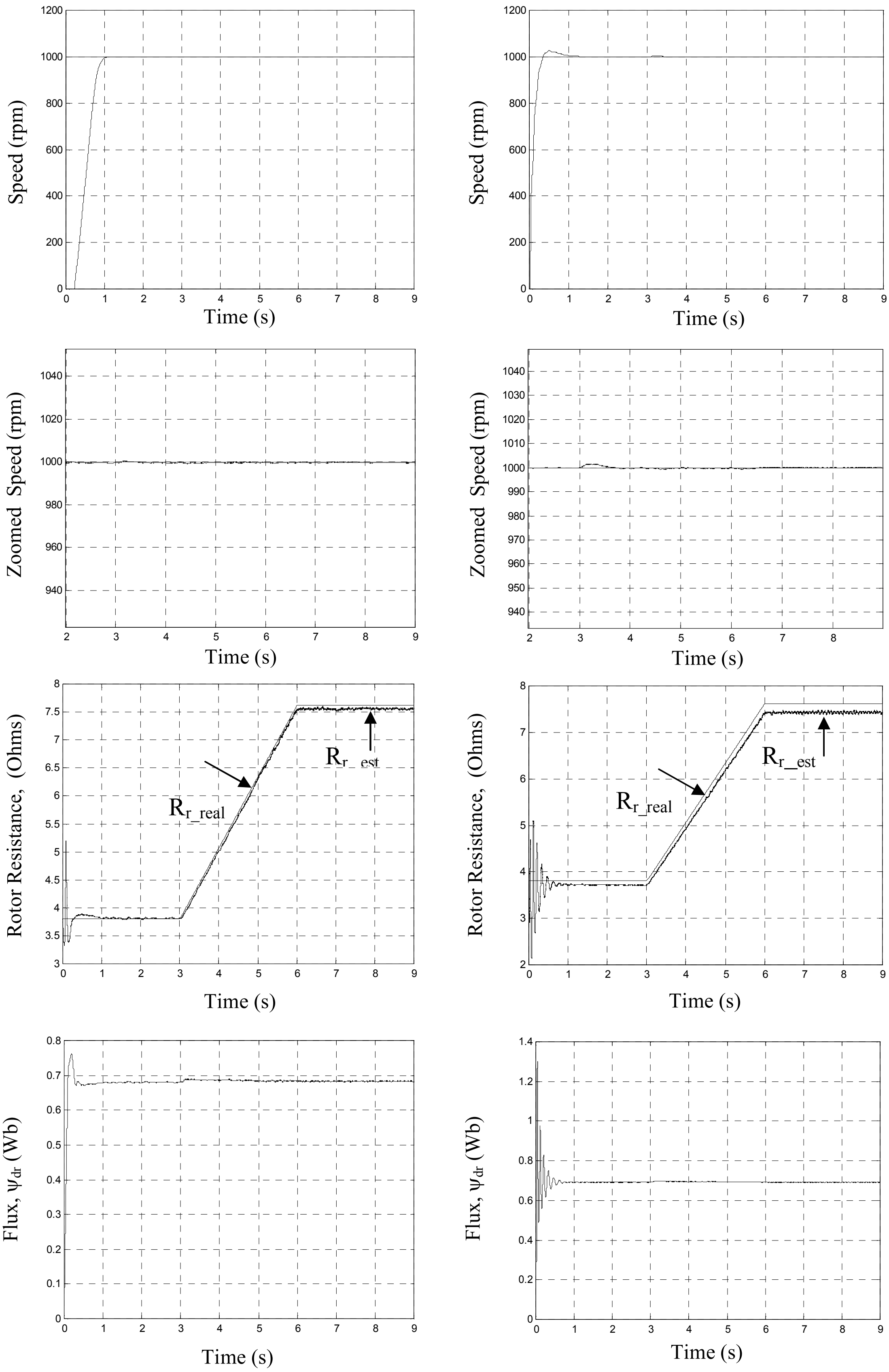


Fig. 7 Proposed estimated method at low speed for compensated ramp change of R_r.



(a) (b)

Fig. 8 Effect of rotor resistance variation for compensated ramp change of R_r with (a): fuzzy estimator, (b): PI estimator.