An 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 Fuzzy logic based speed controller and a method for estimating rotor resistance in an indirect vector-controlled induction motor drive are proposed. The proposed rotor resistance estimator is based on the improvement of control performance when mismatch between estimated rotor resistance and actual one occurs. Analysis, design, and digital simulations are carried out to demonstrate the effectiveness of the proposed estimator. Moreover, Computer simulation results show that the designed Fuzzy Logic based speed controller improves significantly the dynamic behaviour of the motor in presence of load disturbances and parameter variations.*

Key words: *IFOC, FLC, rotor resistance estimator.*

1. Introduction

With the use of field orientation control (FOC) method, and the rapid development of power switches, induction machine drives are becoming a major candidate for most adjustable-speed drives [1]. The most widely used speed control method is perhaps the proportional integral control (PI)[2] . It is easy to design and implement, but it has the difficulty in dealing with parameter variations, and load disturbances. Vector control allows high-performance control of speed and torque to be achieved, however, it is 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 matching between the parameters of the model and those of the actual motor. The estimation of the rotor resistance in an induction motor drive has been investigated by various authors.

The online estimation method proposed by Garces in [3] uses a special adaptation function called the 'Modified Reactive Power Function' to avoid the effects of the stator resistance changes. In [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.

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

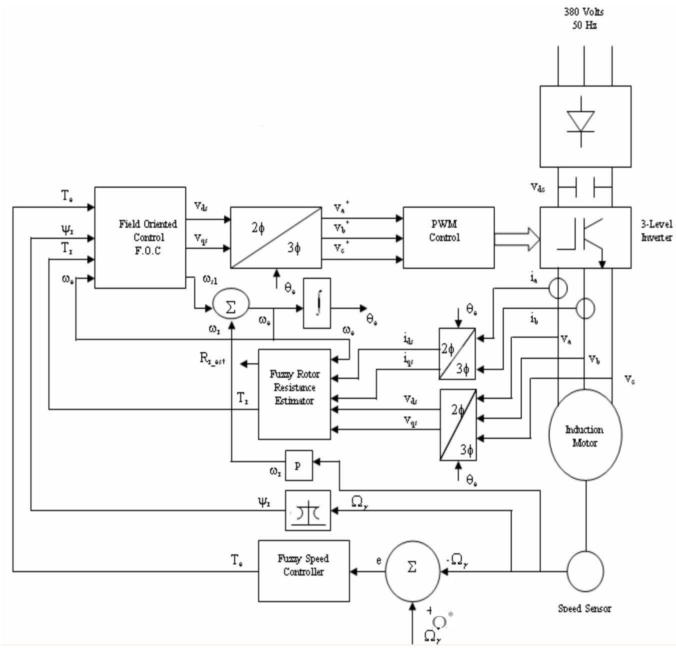

Fig .1. Schematic diagram of the proposed control strategy with rotor resistance identification.

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

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

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

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

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

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)

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

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

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

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:

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

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:

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

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

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

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.

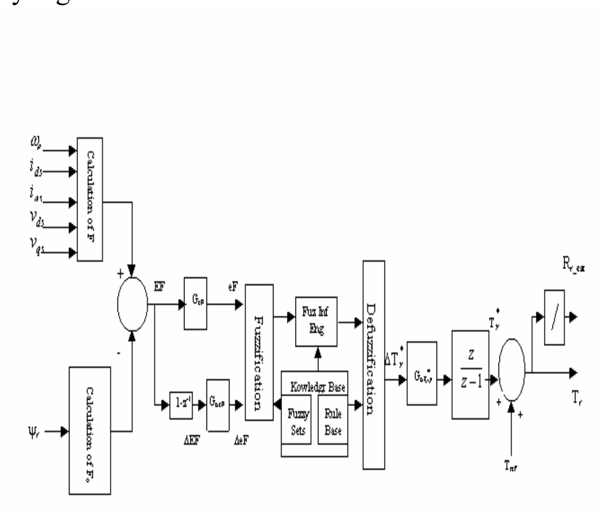

Fig .2 Fuzzy controller block diagram for rotor resistance estimation

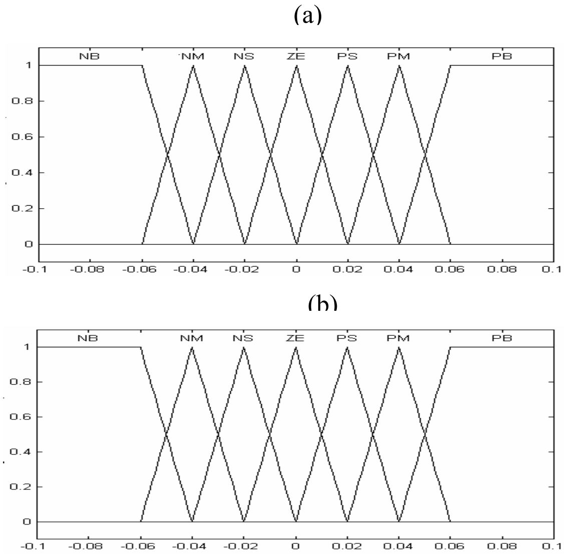

Fig. 3 Input and output membership functions. (a) : eF, ΔeF, (b) : ΔT_r

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 ΔeF 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.

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.

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

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

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 :

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

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

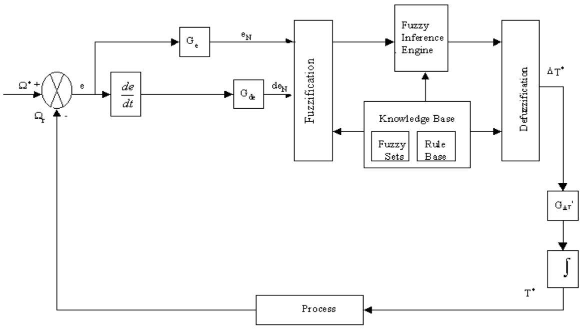

Fig.4. Fuzzy Controller block diagram

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 based speed controller and rotor resistance estimator and to analyze the drive system performance, several simulation tests have been carried out using MATLAB and simulink software. The first set of simulations were carried out to examine the speed performance and disturbance rejection capabilities for both PI and the proposed Fuzzy speed controller.

Fig.6 illustrates the results of the FLC controller under no load with twice inertia. We notice from the graph that the speed response is slow for both controllers, FLC and PI than when driving the induction machine with a rated rotor inertia Fig. 5.
Fig .7 shows the comparison of the two controllers together in presence of load disturbances. The Fuzzy controller returns the speed to the speed command within 0.15 s with a maximum drop of speed of 7.1 rpm. The PI controller takes about 1.5 s to return to the speed command with a maximum drop of 44.7 rpm.

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

Fig. 8 and 9 are included to show the speed tracking performance under no load for both controllers, (Fuzzy and PI). The PI controller tracks the command speed with a delay time of 0.1 s but the FLC controller tracks the command speed with no steady-state error as expected but with a small overshoot at the corners.
Finally, Fig. 10 shows the performance of the induction motor when the rotor resistance is doubled at 2.5 s while the induction motor is under load. The PI controller performs poorly taking about 1.8 s to restore the speed with a drop of 134 rpm, whereas the FLC controller is still perfect with a maximum drop of 22 rpm and a restoring time of 0.25.
Secondly, simulation tests with rotor resistance variation are carried out for the same induction motor.
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 Fig.11 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 converges 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 the motor drive.

Fig. 12 demonstrates the high performance of the fuzzy logic based rotor resistance estimator by applying a trapezoidal change of R_r for a compensated case. We notice from this figure that the rotor resistance tracking is excellent and the field orientation condition is still maintained. However, insensitivity to the drive parameter variations and working conditions can thus be obtained. It is clear that the proposed scheme achieves good performance as it achieves compensation of the rotor resistance changes.

Fig.13 confirms the robustness of the proposed estimated method at low speed for both ramp and trapezoidal changes of R_r at 3 s. The speed tracks perfectly the reference which is fixed at 1000 rpm. The tracking of rotor resistance is achieved and the flux stabilizes at its rated value.

6. Conclusions

A simple fuzzy logic based speed control and rotor resistance estimator of an indirect vector-controlled induction motor drive have been presented. Digital simulation results show that the proposed F.L. controllers can minimize the detuning effects and enhance dramatically the dynamic performance of the motor drive with a rapid settling time, no overshoot, a good rejection of impact load disturbance, a perfect speed tracking.

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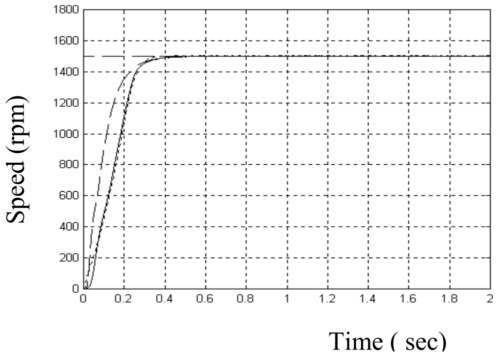

Fig. 5 Speed Drive Response $J = J_0$

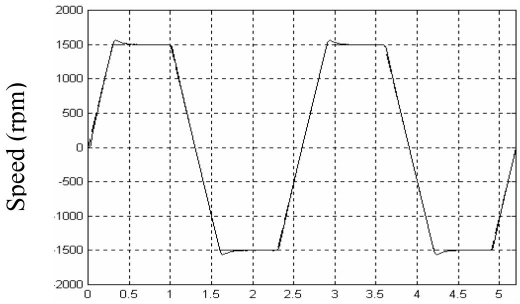

Fig . 8 FLC : Speed Tracking Performance
---- Command Speed , —— Actual Speed

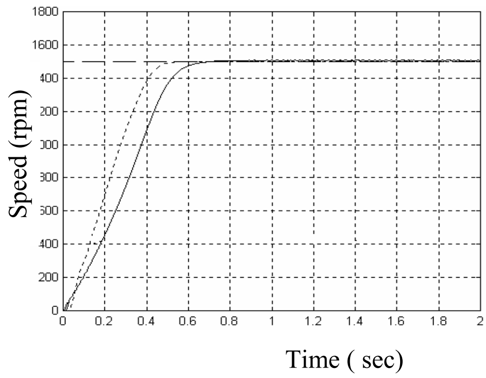

Fig. 6 Speed Drive Response $J = 2*J_0$

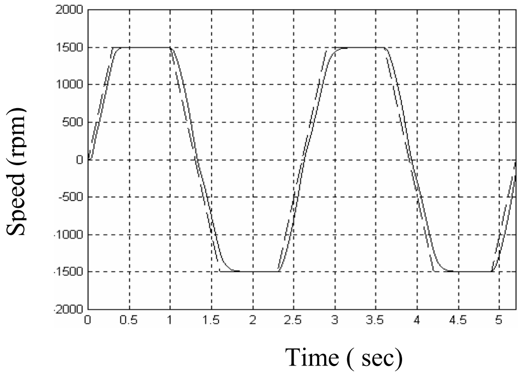

Fig . 9 PI : Speed Tracking Performance
---- Command Speed , —— Actual Speed

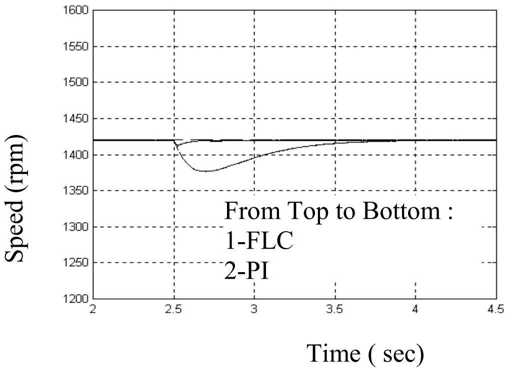

Fig . 7 2 Nm Load Torque Disturbance

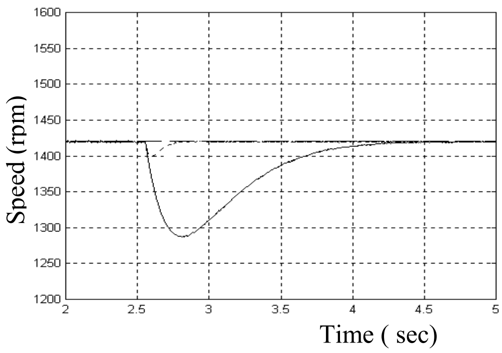

Fig . 10 IFOC disturbance rejection : $2*R_r$

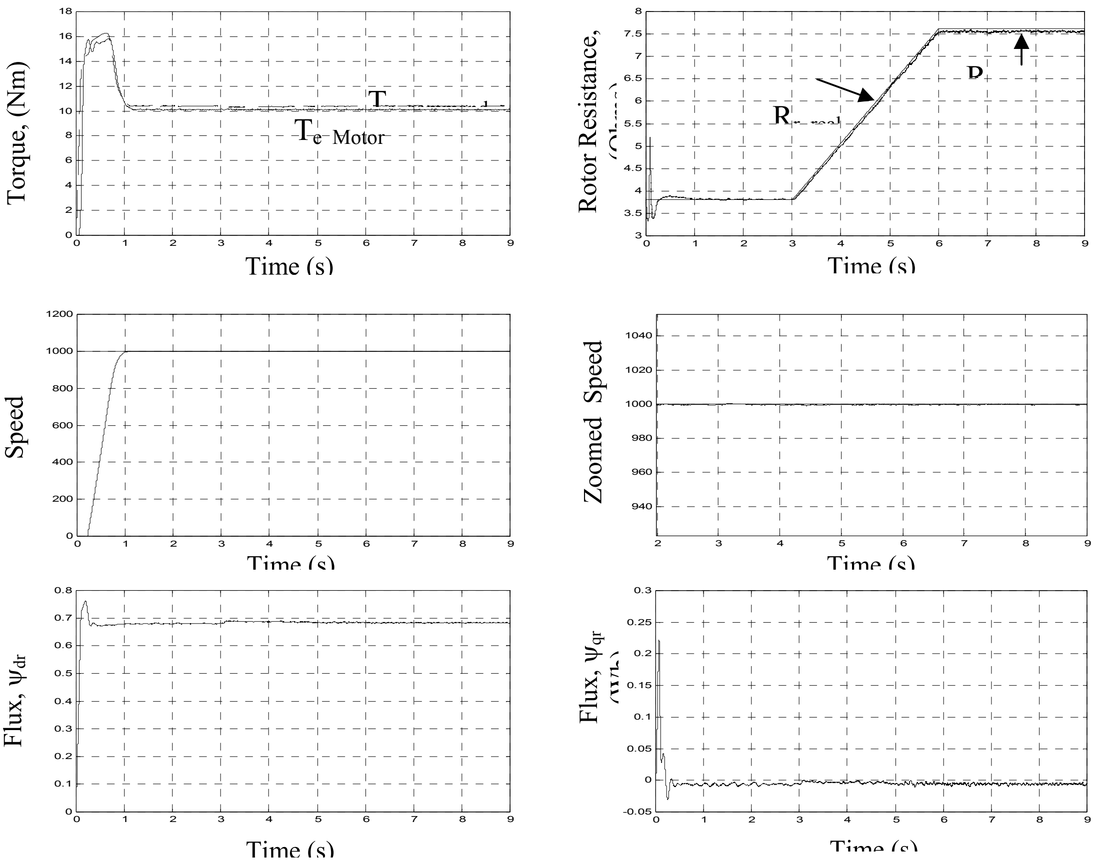

Fig. 11 Effect of rotor resistance variation with fuzzy estimator for compensated ramp change of R_r

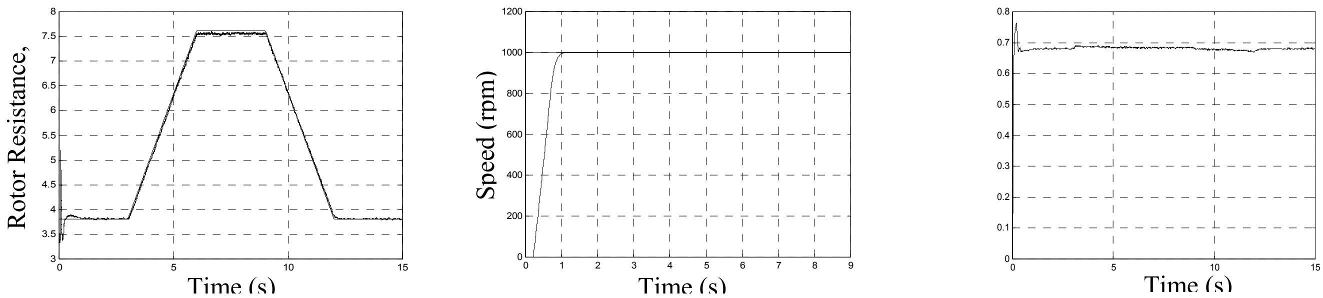

Fig. 12 Effect of rotor resistance variation with fuzzy estimator for compensated trapezoidal change of R_r.

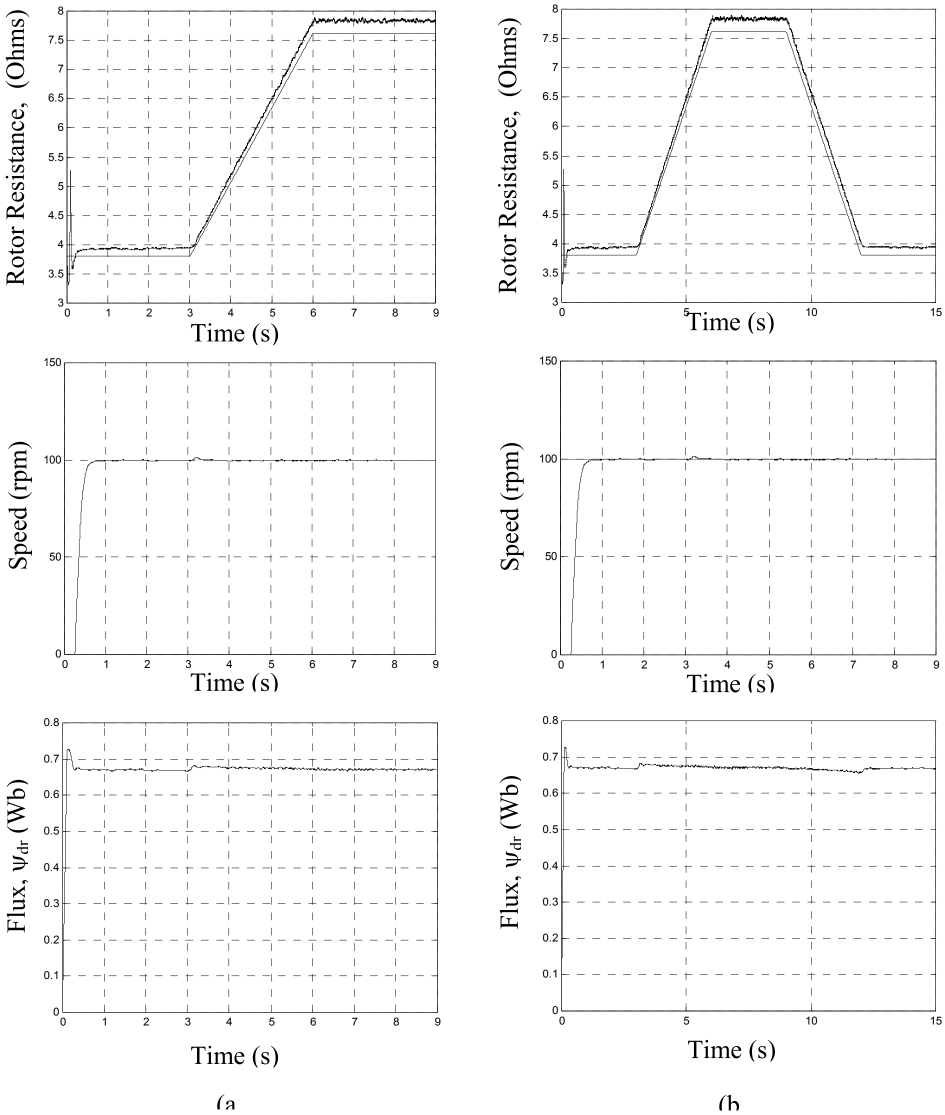

Fig. 13 Proposed estimated method at low speed :
(a) Ramp ; (b) Trapezoidal.