Speed Estimation for Induction Motor using Model Reference Adaptive System and Fuzzy Logic Controller

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Abstract

*Three-phase induction motors have been widely used in industry. In addition, sensorless speed electric drive systems are more and more popular as they have small sizes, low-costs, high reliability and suitable with novel robust control algorithms. In these drive systems, the speed measuring devices with tachometers or photoelectric encoders have been replaced by sensorless estimation algorithms. This paper describes a method of sensorless speed estimation of three-phase induction motor based on MRAS and Fuzzy logic controller. The simulation results obtained show that the estimated motor speed tracks the actual motor speed with very small error.***

Keywords - *Induction motor, Model reference adaptive systems- MRAS, Speed estimation, Fuzzy logic controller, Sensorless estimation, Kalman filter, Sliding mode observer, Luenberger observer.*

I. INTRODUCTION

In the recent years, theory on vector control drew much attention because this method of control has proper stability and efficiency [1]. Close loop motor speed control (with speed feedback) is necessary for drive system requiring high performance. Normally, speed sensor can be speed generator or photoelectric encoder is used to control close loop speed. However, in some cases that the speed sensor cannot be attached because of the hot environment and requirement on high speed of motor [1],[2]. On the other hand, speed measurers are expensive, bulky which increase price and size of asynchronous motor drive. For the reasons above, currently sensorless speed electric drive systems are more and more popular as they have small sizes, low-costs, high reliability and suitable with novel robust control algorithms [1],[3]. Estimation techniques have become a very important issue in the advanced control theory and its application. This problem is especially important in uncertain systems where the dynamics and/or parameters of the plant change during the work. There are many estimation observer, such as the sliding mode observer for rotor flux observation was presented in [3],[9],[10],[11]. The motor voltage equations and current equation were used to build up the full order sliding mode observer. The observer does not include the rotation speed variable, so the observer is not affected by the estimated speed error with strong robustness. The Kalman filter observer, firstly, a flux observer and a robust coefficient are designed to optimize the Kalman filter, which makes the system more immune to the variation of motor parameters. Then, a speed estimation adaptive law is designed according to the least square principle. Kalman filter-based speed and flux observation have strong robustness to motor parameters because the error of the motor parameters was considered at the beginning [1],[9],[12]. The Luenberger observer is a classical system for reconstruction of state variable vector. This system is characterized by simple parameter selection and is easy for practical implementation. This makes the Luenberger observer popular in industrial applications. However, it is not sufficiently robust against measurement noises and parameter changes [1],[7],[8]. Speed estimation by using MRAS and PI controller [4], [5], [6]. In this paper, the author introduced speed estimation method by using Model reference adaptive systems with Fuzzy logic controller/ MRAS-FLC.

II. GENERAL AERODYNAMICS MODEL OF INDUCTION MOTOR

General aerodynamics model of three-phase induction motor includes sub-models as follows [11]:

- Electric model used to transform three phases to two coordinate axes of stator voltage.
- Torque model for calculating electromagnetic moment.
- Mechanical model for calculating speed of rotor.
- Model for calculating the stator current with resistance of the connecting wire.

A. Electrical model

The three-phase power supply voltage is converted to voltage at static coordinate system attached with stator and executed by following matrix equation:

$$\begin{bmatrix} U_{ds} \\ U_{qs} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix} \quad (1)$$

Where:
U_a, U_b, and U_c are stator voltage.
U_{ds} và U_{qs} are voltage elements of voltage vector V_s according to static coordinate system attached to stator.

In the two-axis reference system, the current equation is as follows:

$$\begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} = \int_0^{\tau} \left\{ \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix}^{-1} x \left(\begin{bmatrix} U_{ds} \\ U_{qs} \\ U_{dr} \\ U_{qr} \end{bmatrix} - \begin{bmatrix} R_s & 0 & 0 & 0 \\ 0 & R_s & 0 & 0 \\ 0 & \frac{P}{2}\omega_r L_m & R_r & \frac{P}{2}\omega_r L_r \\ -\frac{P}{2}\omega_r L_m & 0 & -\frac{P}{2}\omega_r L_r & R_r \end{bmatrix} x \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} \right) \right\} d\tau \quad (2)$$

Where:
R_s, R_r are stator and rotor resistance.
L_s, L_r and L_m are stator, rotor inductor and inductance, P is number of poles.
ω_r is rotor speed.
In the electrical model, three-phase voltage [U_a, U_b, U_c] are the input and current vector [i_{ds}, i_{qs}, i_{dr}, i_{qr}] are output. Rotor voltage vector is normal zero because rotor has a squirrel cage shape, it means $U_{dr} = U_{qr} = 0$.

B. Torque model

In two-axis stator frame, electromagnetic torque T_e is calculated as follows:

$$T_e = \frac{3PL_m}{4}\left(i_{dr} i_{qs} - i_{qr} i_{ds}\right) \quad (3)$$

C. Mechanical model

From equilibrium torque equation and viscous friction, the rotor speed is calculated as follows:

$$\omega_r = \int_0^{\tau} \frac{T_e - T_L}{J} d\tau \quad (4)$$

Wherein J is inertia moment of rotor and T_L is load moment.

D. Stator current model

Stator current model is used to calculate stator current amplitude by following equation:

$$\left| i_s \right| = \frac{2}{3}\sqrt{i_{ds}^2 + i_{qs}^2} \quad (5)$$

E. Power supply model

Power supply model for motor is sinusoidal three-phase source as follows:

$$\begin{aligned} U_a &= \left| U \right| \cos\left(\omega_s t + \theta\right) \\ U_b &= \left| U \right| \cos\left(\omega_s t - 2\pi/3 + \theta\right) \\ U_c &= \left| U \right| \cos\left(\omega_s t + 2\pi/3 + \theta\right) \end{aligned} \quad (6)$$

Wherein $\left| U \right|$ terminal voltage amplitude, ω_s the angular speed of the power supply and θ initial phase angle.

III.SPEED ESTIMATION OF MOTOR WITH MRAS-FUZZY

In a MRAS system, status variables ($\hat{\psi}_{dr}, \hat{\psi}_{qr}$) are is estimated from Adaptive Model. The difference ξ_ω between the state variables of these two models is put in adaptive mechanical fuzzy model to calculate estimated speed ($\hat{\omega}$).

Inheriting [1], Reference Model is written as follows:

$$\begin{cases} \psi_{dr} = \dfrac{L_r}{L_m}\left[\int\left(U_{ds} - R_s i_{ds}\right)dt - L_s^{'} i_{ds}\right] \\ \psi_{qr} = \dfrac{L_r}{L_m}\left[\int\left(U_{qs} - R_s i_{qs}\right)dt - L_s^{'} i_{qs}\right] \end{cases} \quad (7)$$

Where:

$L_s^{'} = \sigma L_s$ with $\sigma = 1 - \dfrac{L_m^2}{L_r L_s}$ is called leakage flux coefficient. It is easy to see that equation (7) excludes rotor speed.
Besides, equation of adaptive model has following shape:

$$\begin{cases} \hat{\psi}_{dr} = \dfrac{1}{T_r}\int\left(L_m i_{ds} - \hat{\psi}_{dr} - \hat{\omega}_r T_r \hat{\psi}_{qr}\right)dt \\ \hat{\psi}_{qr} = \dfrac{1}{T_r}\int\left(L_m i_{qs} - \hat{\psi}_{qr} + \hat{\omega}_r T_r \hat{\psi}_{dr}\right)dt \end{cases} \quad (8)$$

**. Mechanical adaptive model for calculating estimated speed:*
In this section, proposing a fuzzy logic controller using Mamdani fuzzy model with the inputs are signals ξ_ω và $\Delta\xi_\omega$; output is values of differences of speed $\Delta\hat{\omega}(k)$.
Where:

$$\xi_\omega(k) = I_m(\overline{\psi}_r \; x \; \overline{\hat{\psi}}_r) = \psi_{qr}.\hat{\psi}_{dr} - \psi_{dr}.\hat{\psi}_{dq} \quad (9)$$

$$\Delta\xi_\omega(k) = \xi_\omega(k) - \xi_\omega(k-1) \quad (10)$$

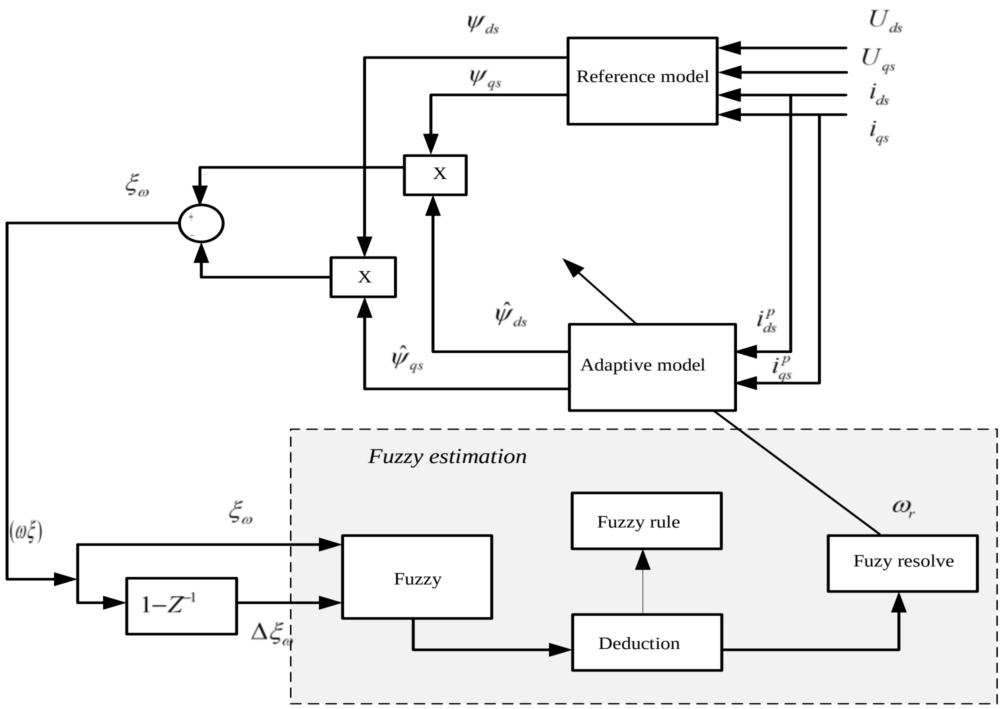

Fig. 1: Model on estimation of induction motor based on MRAS and Fuzzy

Dependent function of the input variable is shown in Fig. 2.

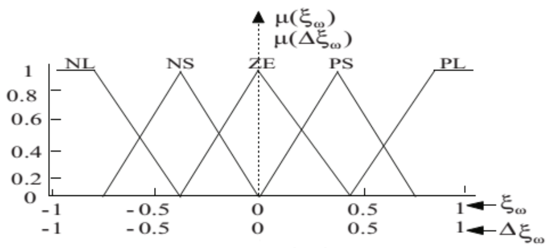

Fig. 2: *Dependent function of the input variable* ξ_ω, $\Delta\xi_\omega$

Dependent function of the output is shown on Fig. 3.

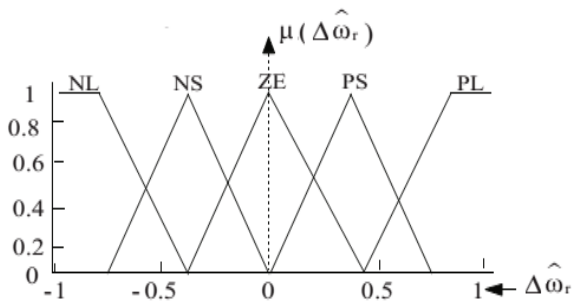

Fig. 3: *Dependent function of the output variable*

Rule on control of fuzzy model is shown in table 1 bellows:

Table 1: Rule of FLC:

$\xi_\omega(k)$ \ $\Delta\xi_\omega(k)$	NL	NS	ZE	PS	PL
NL	NL	NB	NB	NS	ZE
NS	NL	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PS
PS	NS	ZE	PS	PS	PL
PL	ZE	PS	PL	PL	PL

We determine the speed value in the k sample extraction cycle:

$$\hat{\omega}(k) = \hat{\omega}(k-1) + \Delta\omega(k) \qquad (11)$$

IV. SIMULATION RESULT

Matlab/Simulink software is used to simulate MRAS-FUZZY method to estimate motor speed. Specifications of motor used for simulation are shown in table 2 with load moment is constant 10 Nm during the time of simulation.

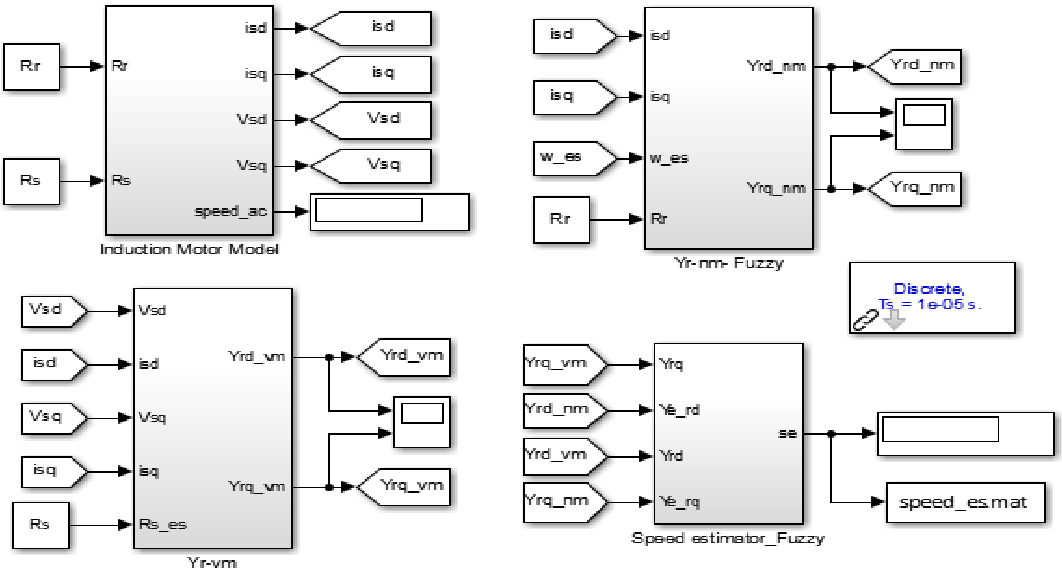

Fig. 4: Overall model of motor speed estimation system using MRAS-FUZZY in Matlab/ Simulink

Table 2: Specifications of motor as follows

No.	Motor specifications	Value
1	Rated capacity (P_n)	1,5 kW
2	Rated voltage (U_n)	220V
3	Rated current (I_n)	5,25 A
4	Rated frequency (f)	50 Hz
5	Stator resistance (R_s)	4,85 Ω
6	Rotor resistance (R_r)	3,805 Ω
7	Stator inductance (L_s)	0,274 H
8	Rotor inductance (L_r)	0,274 H
9	Inductance (L_m)	0,258 H
10	Inertia moment (J)	0,031 kgm^2
11	Number of poles (P)	2
12	Rated speed	1420 rpm

After finishing simulation process, we obtain the results as shown in figures 5, 6, 7, 8. Sinusoidal voltage has an effective value of 220 V (Fig. 5), after finishing starting process, rated current of motor is stable at ≈ 5,3 A (Fig. 6), electromagnetic moment is equal to load moment (Fig. 7). Fig. 8 is real speed, estimated speed and estimation difference. Estimated speed is closed to the real speed of motor in both transition mode and in setting mode.

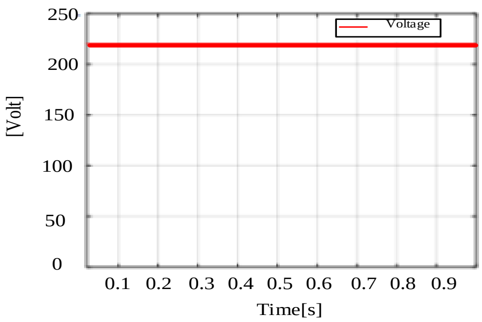

Fig. 5: Effective value of power supply

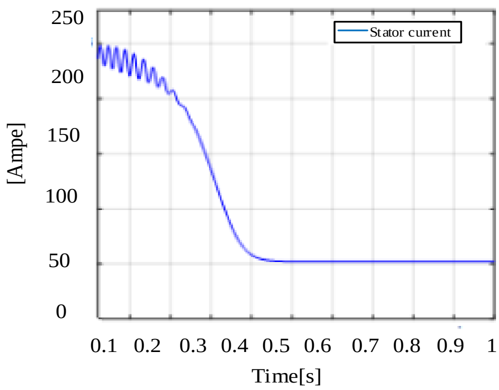

Fig. 6: Effective value of stator current

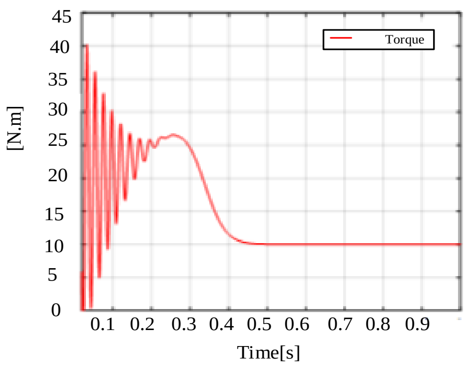

Fig. 7: Electromagnetic moment

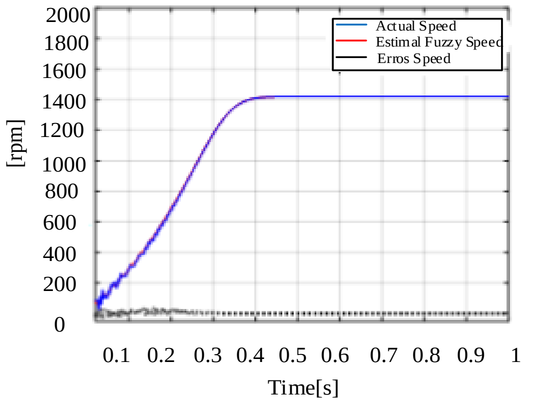

Fig. 8: Motor speed includes real speed, estimated speed and estimation difference

V. CONCLUSIONS

The paper presented motor speed estimation method by using fuzzy controller with sinusoidal three-phase power supply model. Estimated speed is closed to the real speed of motor in both transition mode and in setting mode. Following research direction of the group of authors is to use proposed speed estimation method for speed sensorless vector control of induction motor to assess the performance of the research method.

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