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Neuro-Fuzzy Based Model Reference Adaptive Control for Induction Motor Drive

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Abstract

An adaptive neuro-fuzzy inference system (ANFIS) based model reference adaptive control (MRAC) approach for vector controlled induction motor drive system is proposed in this paper. Due to the complex and nonlinear construction of induction motors, speed and torque controls are very difficult compared to direct current motors. To improve the speed control system of induction motors, a controller was developed by combining the ANFIS and MRAC structures. The use of the MRAC in the control

scheme facilitates the analysis of the adaptive system and provides stability. The ANFIS is used to adaptively compensate for the plant nonlinearities. The adjustable parameters of the controller are updated online. A simulation model for indirect field-oriented control (IFOC) of the induction motor drive is developed using MATLAB/Simulink. The results of the developed controller are compared with the results of the conventional PI type controller to prove the success of the control method. The simulation environment, it is clearly shown that the proposed control structure is considerably successful from the results obtained by operating the induction motor under different conditions.

Keywords: Induction Motor, ANFIS, MRAC, IFOC.

1. Introduction

Three phase induction motors have been widely used in industrial applications, due to its high reliability, high efficiency, relatively simple robustness, and low cost (Bohari, 2014; Sit, 2016). Because of the complex and nonlinear construction of induction motors, speed and torque controls are very difficult compared to direct current motors, and it requires complex control algorithm to control.

Fuzzy logic control (FLC) is defined as a mathematical sequence for describing fuzzy states and for working under fuzzy conditions (Gani, 2016). The artificial neural networks (ANN) have capability for tolerance, to fault, learning ability, to miss data, and to carry out in noise environment (Bohari, 2014). Expression of the fuzzy logic system using the artificial neural networks provides the advantage of automatic adjustment of the fuzzy FLC parameters through the learning ability of the ANN. Many applications have been made taking advantage of the complementary properties of FLC and ANN (Wang, 1993; Chen, 1994; Buja, 1994; Canberi, 2005; Gani, 2015; Sit, 2016; Acikgoz, 2017; Altun, 2017). Adaptive network based fuzzy inference system (ANFIS) is a neuro-fuzzy method where the fusion is made between the ANN and the FLC system (Buragohain, 2008). The model reference adaptive control (MRAC) structure is based on the principle of observing the behavior of a system in which the mathematical model is not fully established due to its non-linear properties, a system of which the mathematical model is known (Canberi, 2005). The paper take into account control structure based on combination of MRAC and ANFIS for vector controlled induction motor drive system to use advantages of both structures simultaneously.

The performance requirements for induction motor drive units are to monitor the desired value changes quickly with minor errors. Researchers are constantly studying and recommending many new control strategies, in order to achieve better performance than induction motor drivers (Halbaoui, 2008).

In this study; to improve the speed control system of induction motors, a controller was developed by combining the ANFIS and MRAC structures. The use of the MRAC in the control scheme facilitates the analysis of the adaptive system and provides stability. The ANFIS is used to adaptively compensate for the plant nonlinearities. The adjustable parameters of the controller are updated online.

2. Model reference adaptive control (MRAC)

The MRAC structure is based on the principle of observing the behavior of a system in which the mathematical model is not fully established due to its non-linear properties, a system of which the mathematical model is known (Canberi, 2005). The purpose in MRAC system is asymptotically to converge unknown system output to the reference model output as given a part of the control system. In MRAC system, a mathematical model (reference model) is used as based on comparison with the actual system. Reference model is a fairly stable linear filter which produces the desired set points to be approached by the system. An error is formed with comparing between the system output and reference model output. Controller parameters are adjusted with feedback taken from the error signal in setting mechanism. Figure 1 shows block diagram of model reference adaptive control.

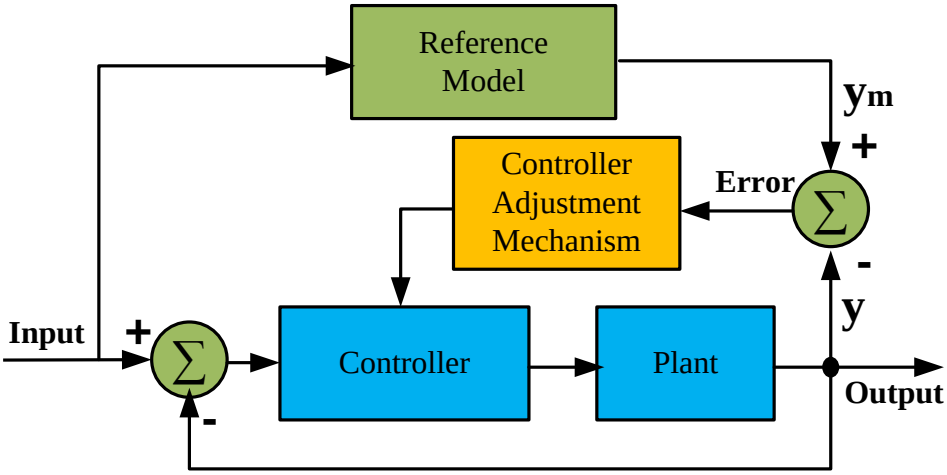


Figure 1. Block diagram of MRAC

3. Adaptive neuro-fuzzy inference system (ANFIS)

The hybrid structure, in which adaptive neural networks are functionally equivalent to fuzzy inference systems, is called ANFIS (Gedik, 2011). It was first developed by Jang in 1992 for neuro-fuzzy modeling, architecture, analysis and applications (Jang, 1992). Later, in 1993 and 1995, he worked on "ANFIS: Adaptive Network based Fuzzy Inference System" and "Neuro-Fuzzy Modeling and Control". Thus, for the first time in 1993, the term ANFIS was mentioned (Jang, 1993; Jang, 1995). ANFIS is an adaptable method and proven to be effective in problems such as modeling, control and classification of complex systems (Sit, 2016). Adaptive neuro-fuzzy inference system is realized by a convenient combination both ANN and FLC. The backpropagation algorithm is one of the most important parts of learning at online ANFIS. The premise and consequent parameters are set using the backpropagation algorithm (Sit, 2016). ANFIS architecture is also an artificial intelligence modeling technique applied by the hybrid learning algorithm (Jang, 1995). Figure 2 shows ANFIS structure with two input variables and a five-layer.

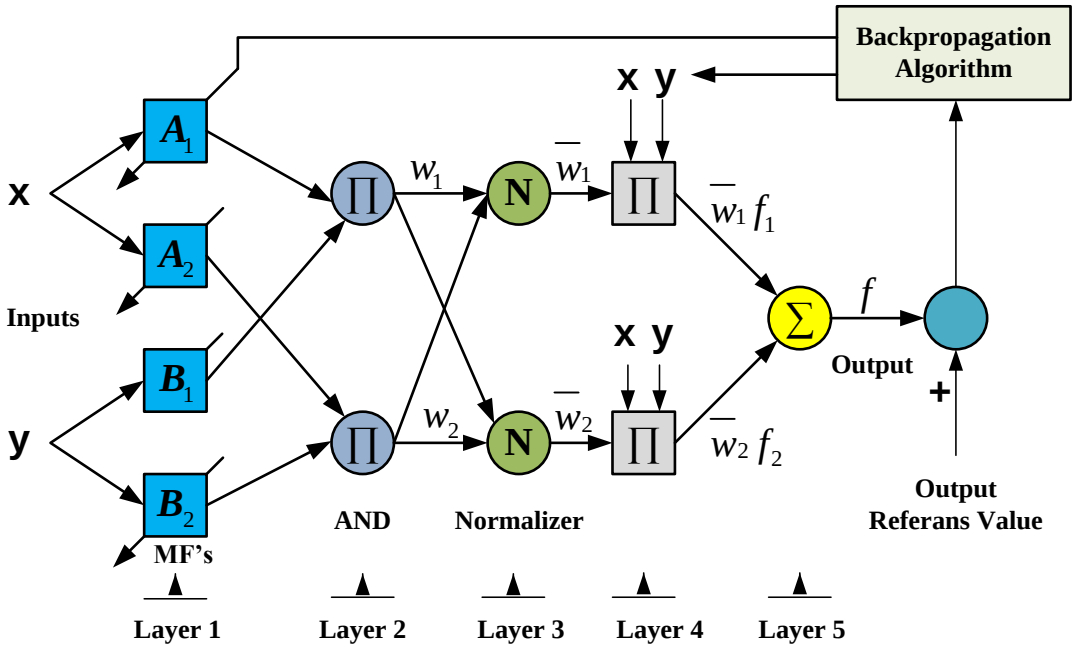


Figure 2. ANFIS controller structure with two-input and five-layer

Layer 1: This layer is called the fuzzification layer. Fuzzy clustering of input values at the fuzzification layer also uses a generalized Bell-shaped activation function as a membership function. Here, the output of each node consists of membership values that depend on the input values and the membership function used. The input variables of ANFIS are selected as error (e) and change of error (Δe) given by equations (1) and (2). Every node *i* in this layer is an adaptive node with node function (Sit, 2016):

$$x = e(t) \tag{1}$$

$$y = \Delta e(t) \tag{2}$$

$$O_i^1 = \mu_{A_i}(x) = \frac{1}{1+\left[\frac{x-c_i}{a_i}\right]^{b_i}} \qquad i=1,2,3 \tag{3}$$

$$O_{i+2}^1 = \mu_{B_i}(y) = \frac{1}{1+\left[\frac{y-c_{i+2}}{a_{i+2}}\right]^{b_{i+2}}} \qquad i=1,2,3 \tag{4}$$

where, {ai, bi, ci} is premise the parameter. While the system is trained by the hybrid method, these parameters will be updated to shape membership functions (Gedik, 2011).

Layer 2: This layer is called rule (∏) layer. Each node in this layer expresses the number and rules generated by the Takagi-Sugeno fuzzy inference system. The output of each rule node, is the product of the degrees of membership from the first layer (Gedik, 2011).

$$O_i^2 = w_i = \mu_{A_i}(x)\mu_{B_i}(y) \qquad i=1,2,3 \tag{5}$$

Layer 3: This layer is called normalization (N) layer. Each node here considers all nodes coming from the second layer as input values and calculates the normalized firing strength of each rule (Gedik, 2011).

$$O_i^3 = \overline{w_i} = \frac{w_i}{\sum_i w_i} \qquad i=1,2,3 \tag{6}$$

Layer 4: This layer is called consequent layer. All nodes are an adaptive mode with node function (Sit, 2016):

$$O_i^4 = \overline{w_i} f_i = \overline{w_i}(p_i x + q_i y + r_i) \qquad i=1,2,3 \tag{7}$$

where, $\{p_i, q_i, r_i\}$ is consequent the parameter.

Layer 5: This layer is called output layer and there is one node. The actual output value of the ANFIS system is obtained by summation ($\sum$) the output values of the nodes from the previous layer (Gedik, 2011).

$$O_i^5 = \sum_i \overline{w_i} f_i \qquad i=1,2,3 \tag{8}$$

4. Proposed control scheme

A simulation model for indirect field-oriented control (IFOC) of the induction motor drive is developed using MATLAB/Simulink. The ANFIS controller has two inputs and one output, error and its derivative are inputs where modified error is output of ANFIS controller.

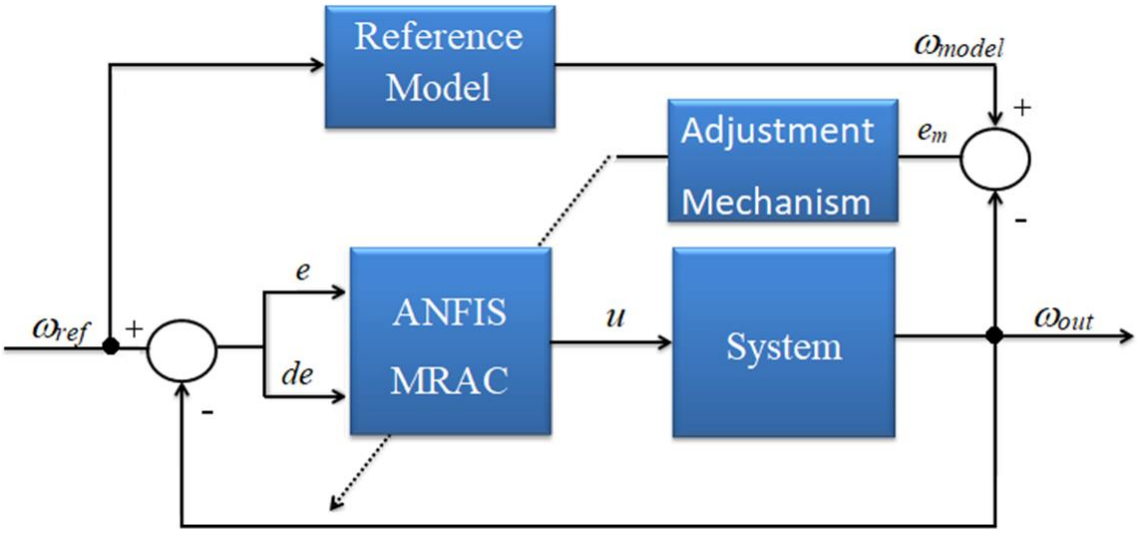


Figure 3. Proposed control structure

The generated vector controlled induction motor drive system shown in Figure 4. Indirect field oriented control system has three control cycles that control speed, flux and torque. In the work done with the classical controller, all of the controllers were used as PI type controllers. In the artificial intelligence based study, ANFIS based MRAC type controller which is recommended as speed controller, PI type controller as flux and torque controller is used.

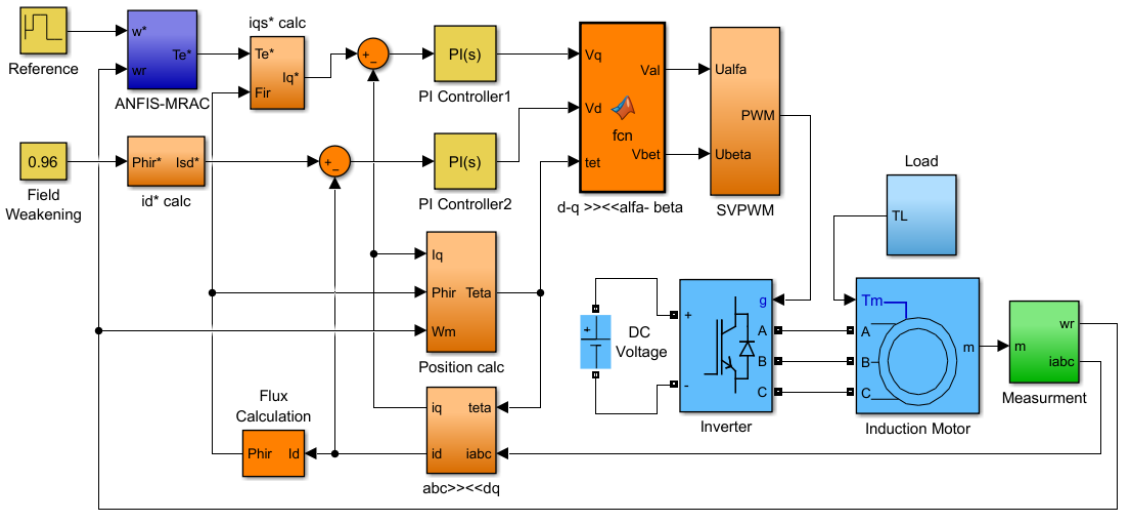


Figure 4. Motor drive system developed for simulation studies

The output of the controllers is limited by the capacity of the system. The performance of the induction motor drive for both control types has been examined for constant speed-variable load and variable speed-constant load cases. The results of the proposed controller are compared with the results of the classical PI-type controller. In this study, the inverter DC link voltage is 540 V, the switching frequency is fs = 5 kHz and the simulation sampling time is Ts = 0,02 ms. The parameters of the three-phase induction motor used in the simulation studies are given in Table 1.

Table 1. Induction motor parameters used in the study

Parameter	**Value**
Power [P]	3 kW
Rated Speed [n]	1400 rpm
Stator Voltage [V]	380 V
Stator Current [I]	6.7 A
Load Torque [M]	19 Nm
The number of pole pairs [2p]	4
Frequency [f]	50 Hz
Rotor Resistance [R_r]	2,68 Ω
Stator Resistance [R_s]	1,7 Ω
Mutual Inductance [L_m]	217 mH
Stator Inductance [L_s]	229 mH
Rotor Endüktansı [L_r]	229 mH
Moment of Inertia of Rotor [J]	0.046 kg.m^2
Coefficient of Friction [B]	0.001 Nm.s/rad

5. Simulation results

Case 1: The induction motor was started without load at 1400 rpm reference speed. At t=1 s, the motor is loaded with a sudden load of 19 Nm. At t=2 s, this load has been removed. The loading and unloading of the load caused disruptive effects on the system. The graph obtained in this study is shown in Figure 5. The performance values of the asynchronous motor during the development are shown in Table 2. Table 3 is given the performance values indicated by the controllers in the case of the load applied and removed.

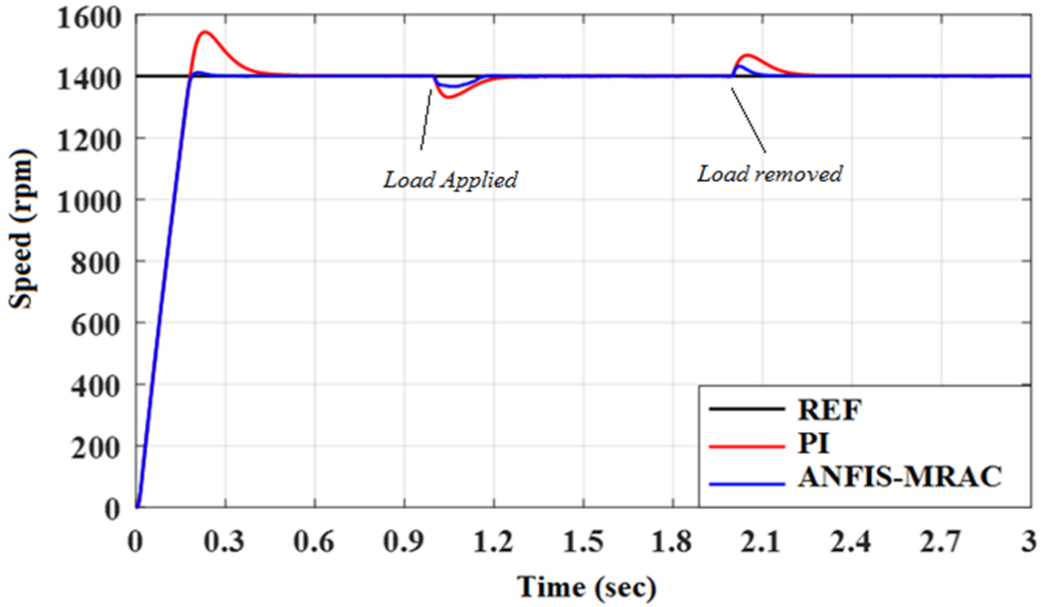


Figure 5. Constant reference speed response under load

Table 2. Start Response

Controller	Rise Time(s)	Settling Time(s)	Overshoot(%)
PI	0,13	0,35	10
ANFIS-MRAC	0,13	0,18	1

Table 3. Load Response

Controller	Speed Dip(%)	Recovery Time(s)	Overshoot(%)	Settling Time(s)
PI	4,3	0,3	5	0,3
ANFIS-MRAC	2,5	0,18	2,3	0,14

Although there was no difference in rise time between both controllers, the ANFIS based MRAC control performed very well in terms of maximum overshoot and settling times compared to PI control.

Case 2: The induction motor is operated at a reference speed of 1000 rpm and a constant load of 19 Nm. The reference speed is increased from 1000 rpm to 1400 rpm at t=1 s, and decreased from 1400 rpm to 800 rpm at t=3 s. The graph obtained in this study is shown in Figure 5. Step input is applied as the induction motor reference speed value. The results obtained in this study are given in Tables 3, 4 and 5.

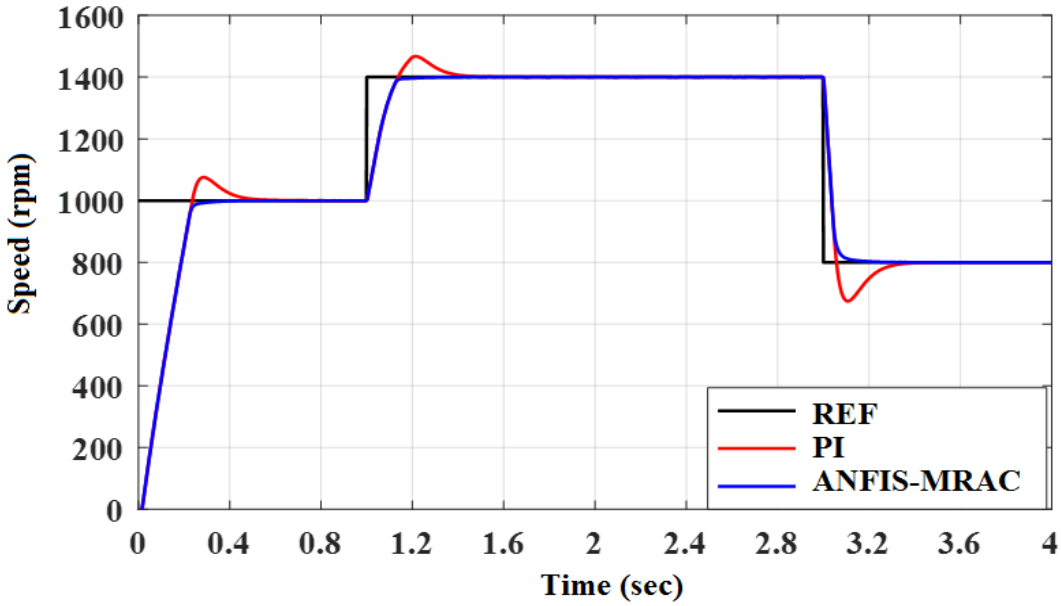


Figure 6. Step reference input speed response under load

Table 4. The reference speed is 1000 rpm

Controller	Rise Time(s)	Settling Time(s)	Overshoot(%)
PI	0,21	0,55	7,5
ANFIS-MRAC	0,21	0,15	0

Table 5. The reference speed is increased from 1000 rpm to 1400 rpm

Controller	Rise Time(s)	Settling Time(s)	Overshoot(%)
PI	0,10	0,37	5
ANFIS-MRAC	0,10	0,12	0

Table 6. The reference speed is decreased from 1400 rpm to 800 rpm

Controller	Down Time(s)	Settling Time(s)	Overshoot(%)
PI	0,06	0,28	16
ANFIS-MRAC	0,08	0,10	0

There was no significant difference in rise time in all cases of reference speed changes. However, the ANFIS based MRAC controller is located in a shorter time than the PI type controller. Despite the occurrence of the overshoot in PI type control work, there is no overshoot in the work done with the proposed controller.

4. Conclusions and future work

The induction motor drive system is simulated using both traditional PI and the proposed control algorithm. The results of the developed controller are compared with the results of the conventional PI type controller to prove the success of the control method. The proposed control algorithm offers better performance than the conventional PI controller when overshoot and response times are taken into consideration. The simulation environment, it is clearly shown that the proposed control structure is considerably successful from the results obtained by operating the induction motor under different conditions.

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