Model Reference Adaptive Control based on RBFNN for Speed Control of Induction Motors

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ABSTRACT

In speed control of induction motors, generally the performance of induction motor by feedback controllers has been insufficient due to non-linear structure of the system, changing environmental conditions, and undesired disturbance input effects. Recently, researches clearly show that the benefits of using methods based on artificial intelligence to improve the performance of induction motor drive. In this study, an artificial intelligence-based controller is developed to control the speed of induction motor by using radial basis function neural networks (RBFNN) and the structure of model reference adaptive control (MRAC). Indirect vector control technique is widely preferred due to high torque response and accuracy in induction motor drive method. To determine the success of this method, its result is compared with conventional PI type controller in MATLAB/Simulink environment. In addition to that, the performance of controller is analyzed under fan type load used to determine reducing effect of speed. Simulation results show that MRAC controller performance based RBFNN are better than conventional PI type controller performance.

Keywords: Radial Basis Function Neural Network, Model Reference Adaptive Control, Induction Motor.

1 INTRODUCTION

In a developed country, half of the produced electrical energy is consumed by electric motors. More than 90% of these motors are composed of induction motors. Today, induction motors are widely used in the industry due to their simple structure, require little maintenance and high efficiency. A long time, these motors are used in general purpose constant speed applications. The use of motor drives in conjunction with rapid technological development has begun to be used in variable speed applications. In the recent

studies, it has been seen that artificial intelligence is used to increasing the performance of motor drives [1-8].

For successfully speed controlling, motor drives are required to show better dynamic performance. Dynamic performance is a measure of the motor speed or the response to the any change that occurred at torque. Basis to obtain the high performance induction motor drives are based on vector control techniques. Vector control theory, illustrates a more stable dynamic performance of the conventional control method [9-10]. In vector control method, it is provided that perfect performance using mathematical dynamical model of induction motors with controlling motor flux and torque parameters different from each other such as in dc current motors [11-12].

Adaptive control is one of the control strategies commonly used in modern control systems designed to provide better performance and accuracy. The purpose of the adaptive control is to adjust unknown and variable control parameters. MRAC algorithm is a control systems which is directly compatible with an adjustment mechanism to arrange some controller parameters and the controllers [13- 14].

Artificial neural networks (ANN), has gained a great importance in control applications in recent years. ANN can be developed by benefiting from the ability to model nonlinear systems with nonlinear structure controllers [15]. In the drive systems, using ANN effect on the performance and durability of systems against to changing parameters. ANN can be applied successfully a motor whose load parameters are unknown [16]. RBFNN similar to the structure of feed-forward neural network algorithms are a powerful calculation instrument widely used in the identification field, pattern recognition and system modelling [17].

In this study, to control the speed of an Induction motor running under load non-linear type of fan, a controller has been developed MRAC control algorithm based on RBFNN and a simulation study is done in MATLAB / Simulink. In the study, indirect field oriented vector control method is used in the driving method of the induction motors and also space vector pulse width modulation is used to switch the inverter stages. In order to determine the success of the developed controller, simulation results are compared by classical PI type controller.

2 INDUCTION MOTOR DYNAMIC MODEL

To simulate the physical behavior of a system, it is necessary to obtain the system's mathematical model. To obtain the mathematical model of the Induction motors, three phase variables of the motors are transferred to the *d-q* plane. Therefore, induction motor is simulated to DC motor by applying indirect field oriented control to the model in synchronous speed that rotates in *d-q* axis. State-space equations in *d-q* axis are shown in following (1-5).

$$\frac{d\varphi_{rd}}{dt} = \frac{L_m R_r}{L_r} i_{sd} - \frac{R_r}{L_r}\varphi_{rd} + \left(\omega_s - \omega_r\right)\varphi_{rq} \tag{1}$$

$$\frac{d\varphi_{rq}}{dt} = \frac{L_m R_r}{L_r} i_{sq} - \frac{R_r}{L_r}\varphi_{rd} - \left(\omega_s - \omega_r\right)\varphi_{rd} \tag{2}$$

$$\frac{di_{sd}}{dt} = \frac{1}{\sigma L_s}\left[-R_E i_{sd} + \sigma L_s \omega_s i_{sq} + \frac{L_m R_r}{L_r^2}\varphi_{rd} + \omega_r \frac{L_m}{L_r}\varphi_{rq} + V_{sd}\right] \tag{3}$$

$$\frac{di_{sq}}{dt} = \frac{1}{\sigma L_s}\left[-R_E i_{sq} - \sigma L_s \omega_s i_{sd} + \frac{L_m R_r}{L_r^2}\varphi_{rq} - \omega_r \frac{L_m}{L_r}\varphi_{rd} + V_{sq}\right] \tag{4}$$

$$\frac{d\omega_r}{dt} = \frac{3}{2}\frac{pL_m}{JL_r}(i_{sq}\varphi_{rd} - \varphi_{rq}i_{sd}) - \frac{B}{J}\omega_{r-} \frac{T_L}{J} \tag{5}$$

Where ω_s synchronous angular speed, ω_r rotor angular speed ω_m mechanical angular speed, V_{sd} and V_{sq} *d-q* axis stator voltages, i_{sd} and i_{sq} *d-q* axis stator currents, ψ_{rd} and ψ_{rq} *d-q* axis rotor flux, R_s and R_r stator and rotor resistances, R_E equivalent resistance and σ leakage factor, L_s and L_r inductance of the stator and rotor, L_m represents the mutual inductance [3, 18-21].

3 RBFNN STRUCTURE

RBFNN is widely used as a powerful computational technique for pattern recognition, system modeling and identification field because of its simple structure and rapid learning algorithm [17]. As shown in the Fig. 1, RBFNN consist of input layer that is similar to the forward pass multilayer ANN, hidden layer and output layer. Input layer consists of the source node in the input vector size.

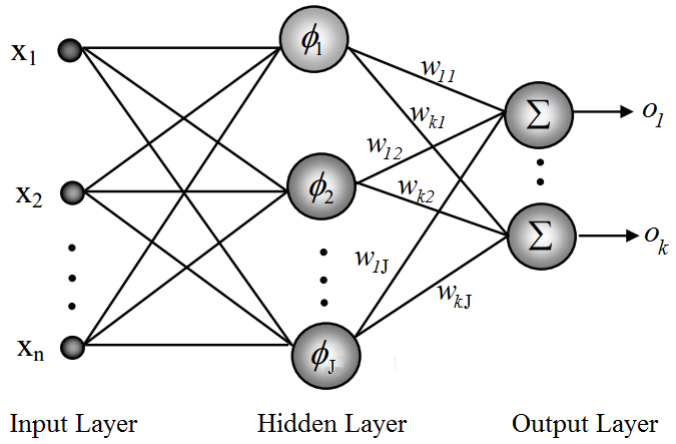


Figure 1: RBF neural network structure

Second layer consisting of nonlinear units is called hidden layers and is directly connected to each node in the input layer. It is performed a linear transformation from hidden layer to output layer.

$$\varnothing_j(x) = exp\left[\frac{-\|x - c_j\|^2}{\sigma_j^2}\right] \tag{6}$$

In RBFNN c_j center vectors, σ_j width of radial function and output layer weights w_{kj} are the parameters that can be adapted [22-23]. In here, x is an input vector. $\| x\text{-}c_j \|$ refers to Euclidean distance between x and c_j vectors. *j*, activation level of the intermediate node, is equal to $\varnothing_j$. Output is given in equation (7). Updating the parameters in the structure RBFNN are given expressions equation (8-10).

$$O_k = \sum_{j=1}^{J} \omega_{kj}\varnothing_j(x) \tag{7}$$

$$w_{kj}(t+1) = w_{kj}(t) + \eta e(t)\varnothing_j \tag{8}$$

$$c_j(t+1) = c_j(t) + \eta e(t)\varnothing_j w_j(x - c_j)/\sigma^2 \tag{9}$$

$$\sigma_j(t+1) = \sigma_j(t) + \eta e(t) \varnothing_j w_j \left\| x - c_j \right\| / \sigma^3 \tag{10}$$

4 MODEL REFERENCE ADAPTIVE CONTROL (MRAC) STRUCTURE

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 produce 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. The performance of controller system depends on how close the model represents the actual system [5-6, 24-26].

RBFNN based controller used in structure of developed controller by study produces controller signal to compensate nonlinear dynamics and to follow reference model outputs [26]. Block diagram of control system, obtained using this structure, is given in Fig. 2 [27]. The expressions created for the d-axis is similar to the expressions given for *q* axis. The differential equation related to structure of the system can be derived as follow.

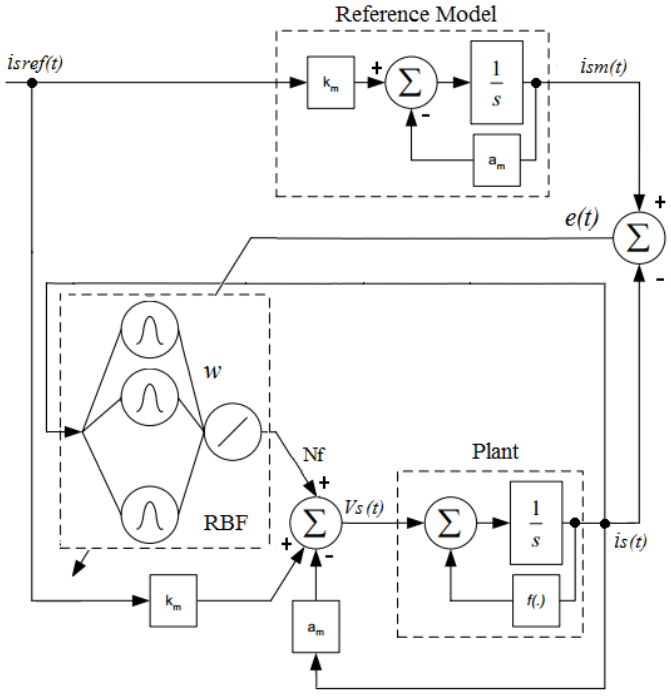


Figure 2: MRAC Controller based on RBF neural network

Differential equality related to system structure can be given in the following;

$$\dot{i}_{sq}(t) + f\left[i_{sq}(t)\right] = V_{sq}(t) \qquad t \geq 0 \tag{11}$$

where $V_{sq}(t)$ control signal of system, $i_{sq}(t)$ output signal of system and $f(.)$ is a continuous changing nonlinear static function in the set of real numbers. Reference model is stable and linear in continuous time interval. Differential of reference model can be given as below.

$$\dot{i}_{sqm}(t) + a_m i_{sqm}(t) = k_m i_{sqref}(t) \qquad t \geq 0 \tag{12}$$

where, $i_{sqm}(t)$ output signal, $i_{sqref}(t)$ reference input signal and $a_m > 0$, $k_m > 0$. Controller rule proposed for controller signal in equation (13), RBFNN is network output value N_f is given in equation (14). If the Equation (11) and (12) are combined each other, the equation (13) is obtained [26-29].

$$V_{sq}(t) = -a_m i_{sq}(t) + k_m i_{sqref}(t) + N_f\left[i_{sq}(t), w(t)\right] \tag{13}$$

$$N_f\left[i_{sq}(t), w(t)\right] = \sum_{j=1}^{J} w_j(t) \exp\left[\frac{\left\|i_{sq}(t) - c_j\right\|^2}{2\sigma^2}\right] \tag{14}$$

$$\left[\dot{i}_{sq}(t) - \dot{i}_{sqm}(t)\right] + a_m\left[i_{sq}(t) - i_{sqm}(t)\right] = N_f\left[i_{sq}(t), w(t)\right] - f\left[i_{sq}(t)\right] \tag{15}$$

$w(t)$ weighting vector of RBFNN controller are parameters that adapted with $e(t)$ error signal.

$$e(t) = i_{sq}(t) - i_{sqm}(t) \tag{16}$$

When the N_f is close to $f(.)$ value the equation (15) can be written as equation (17).

$$\dot{e}(t) + a_m e(t) \approx 0 \tag{17}$$

6. SIMULATION STUDY

Parameters of induction motor used in study are given Table 1.

Table 1. Motor Parameters

Parameter	Value
Nominal Power [P]	3 kW
Nominal Revolution [n]	1430 rpm
Nominal Voltage [U]	380 V
Nominal Current [I]	6.7 A
Nominal Load Torque [M]	19 Nm
Poles Number [p]	2
Frequency [f]	50 Hz
Rotor Phase Winding Resistance [R_r]	1.93Ω
Stator Phase Winding Resistance [R_s]	1.45Ω
Magnetization Inductance [L_m]	187.8 mH
Stator Winding Inductance [L_s]	200 mH
Rotor Winding Inductance [L_r]	197 mH
Rotor Inertia Torque [J]	0.03 kg.m^2
Friction Torque Coefficient [B]	0.003 Nm.s/rad

For controlling indirect field oriented vector, system model of induction motor is developed in MATLAB/Simulink software according to Fig. 3. In this study, RBFNN based MRAC controller is placed instead of PI type controller which produces V_{sq} and V_{sd} control signals.

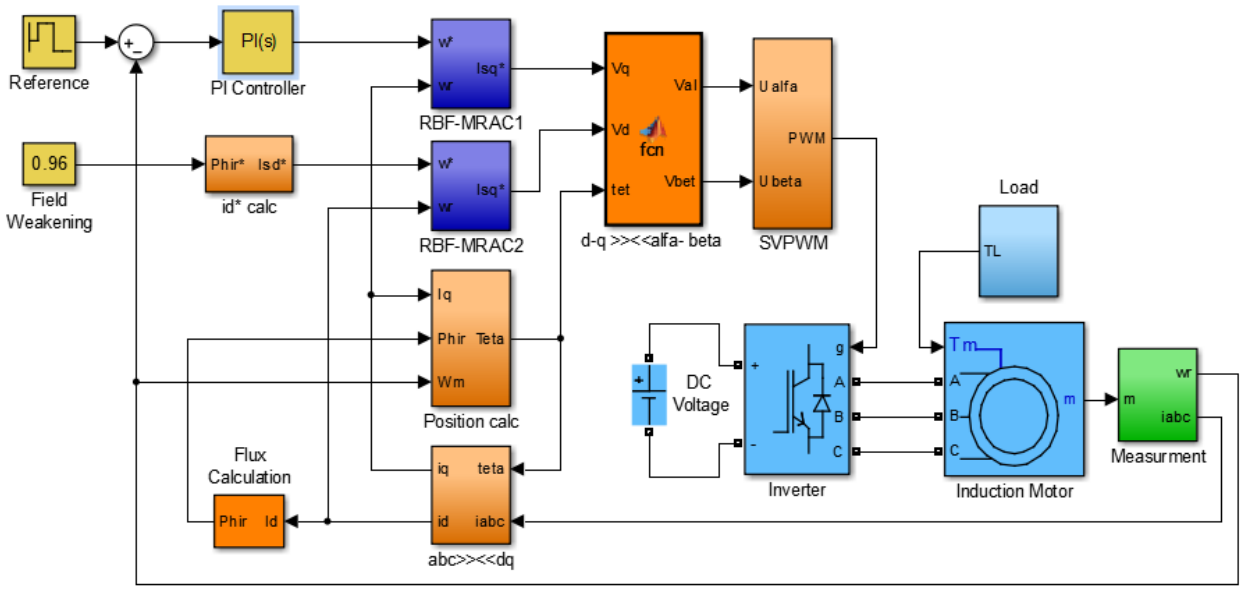


Figure 3: Simulation block diagram

PI controller parameters are determined for speed controller K_p=80, K_i=5, torque controller K_p = 30, K_i= 10, for the flux controller K_p = 50, K_i = 20. In system, motor reference speed is adjusted as 1400 rpm. The following reference speed performance is analyzed with applying to motors nonlinear fan type variable load ($T_L = k.\omega_m^2$). Motor synchronous speed is 1500 rpm or 157 rad/s and its power is 3 kW.

Accordingly, nominal torque of induction motors and *k* constant in load expression are calculated as:

$T_n = \frac{3000\ kW}{157\ rad/s} = 19\ Nm$ and $k = \frac{19Nm}{157^2 rad/s} = 7{,}71.10^{-4}$, respectively [30].

Speed response of controller system is shown in Fig. 4. As shown in the figure, there is no exceed in both controller. In addition to that, steady state error stay in rather low values.

In RBFNN based MRAC controller study, it is seen that given the better results for settling and rise time criteria according to PI type study.

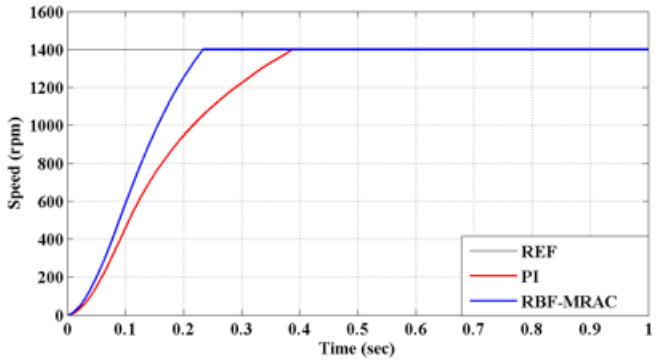


Figure 4: Speed response

The change of nonlinear load torque by time that applied to motor depending on speed variation is given Fig. 5.

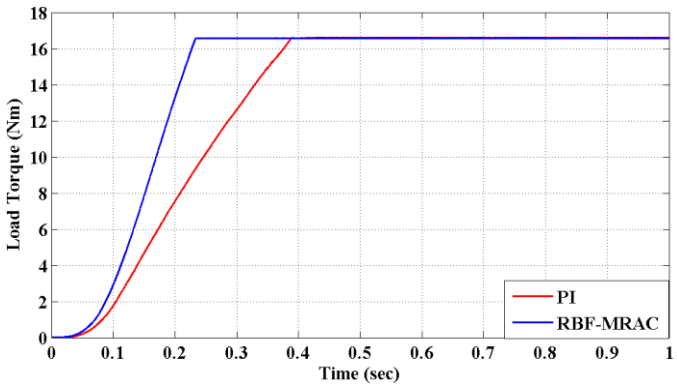


Figure 5: Load torque

It is seen that, load torque is changed non-linearly until it reaches the reference speed, then stayed in 16.6 Nm. Because it is lately reached to the reference speed in PI controller, the change of load moment is also slow.

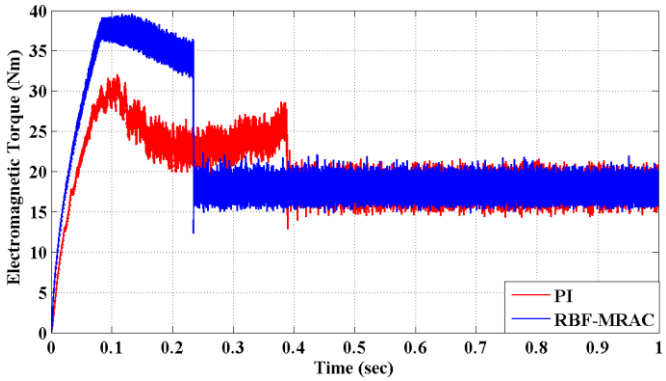


Figure 6: The electromagnetic torque response

When the graphical of induced induction motor (Fig. 6) is analyzed, in RBFNN-MRAC controller has less torque ripple than PI type controller. The performance of both torque controller is shown in Fig 7-8.

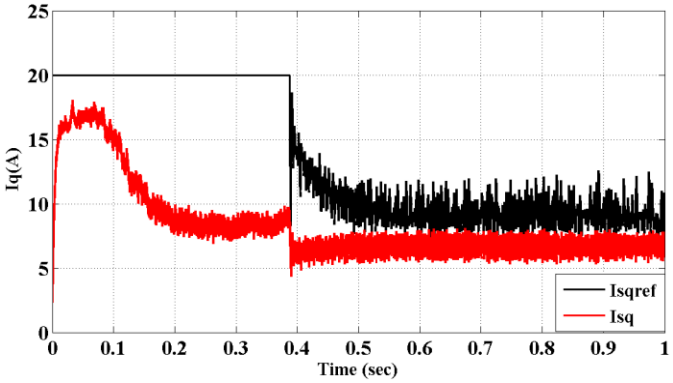


Figure 7: I_q current in PI control

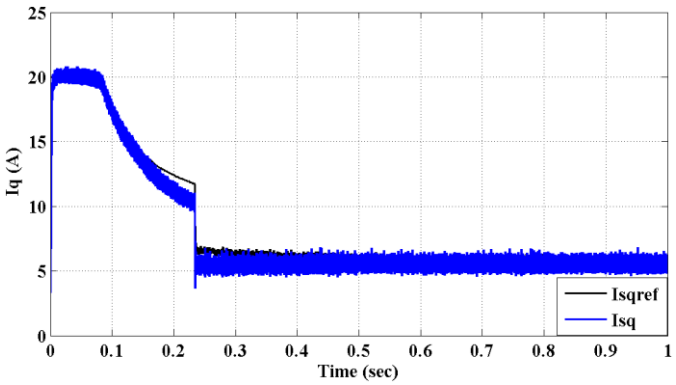


Figure 8: I_q current in RBF-MRAC control

It is clearly shown that success of following the reference current in RBFNN-MRAC controlled study is greater than PI type controller as seen in figure 7 and 8.

7 CONCLUSION

Induction motors have been widely used in the industry and therefore it is important to control them. In this study, in order to improve the control performance of the induction motor, MRAC type controller based on RBFNN is developed, and the analysis of speed control of a three-phase squirrel cage induction motor under non-linear fan type load is performed in MATLAB/Simulink environment. When the graphical analysis of system is carried out, it is found that MRAC type controller based RBFNN provided better response compared to PI type controller in terms of rise time, settling time, and torque ripple. By simulation results, in real-time applications for the vector control of induction motors running under the fan type variable load, it is considered that more successful results are obtained in MRAC type controller based on RBFNN compared to PI type current controller.

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