Tuning Controller for Induction Motor using Model Reference Adaptive Control

Dr. Abdulrahim Thiab Humod* & Nihad Mohammed Ameen *

Received on: 27 /8 /2008
Accepted on: 11/3 /2010

Abstract
This paper is an attempt to design an adaptive controller using model reference adaptive control algorithm involving Indirect Field Oriented Control of an A.C. Induction Machine as a nonlinear plant, without the need for modeling (knowing the plant equations) except the plant order. The objective is to study the controller parameters effect to reflect the performance specification in the control tasks, such as rise time, settling time and overshoot in order to design a controller with an adjustment mechanism so us the closed loop system remains stable. The second plant used is a D.C. Motor as a linear plant to verify the capability of the suggested method for a linear plant. The model is chosen with respect to the order of the plant. The suggested method is to find the initial values of the controller parameters by using a designed table which gives a good response compared with the conventional method (tuned PI controller); in addition the designed controller has an enhancement on the response with the time regarded to the adaptation mechanism.

Introduction
The use of a model reference adaptive control technique seems to be one of the most feasible approaches for the implementation of adaptive control system [1]. The block diagram of the control system is shown in Figure (1). The model is in parallel with the system. The regulator can be thought of as consisting of two loops. An inner loop, which is an ordinary feedback loop, composed of the plant and the regulator. The parameters of the regulator are adjusted by the outer loop in such away that the error
between the plant output and the model output becomes small. Thus the outer loop is also a regulator loop. The problem is to determine the adjustment mechanism which brings the error to zero for all command signals. The plant with large parameter variations is difficult to control and may have some unstable behavior or will not respond. By using the approximation of the controller parameters the performance can be improved. In 1997 de Souza and Jacobina made an investigation of the parameter sensitivity for tuning IFO-Controller by using a cascade parameter estimation technique [2]. In 2003 Al-Olimat and Girman made an adaptive controller with an adjustable reference model parameters, the adjustable MRAC can force the controlled plant to follow as closely as possible a desired reference model, the controller design was applied to a synchronous motor to control its speed [3]. In 2005 Dr. Lei Sun designed an adaptive controller for temperature control in ultrasound hyperthmia, the controller was required to achieve and maintain target temperature for a sustained period with minimal overshoot, valid rising time and small oscillations. Simulations was used to determine the prior initial parameters for the adaptive controller [4]. In this paper, the initial conditions for controller parameters has been found to enable the adaptive control system to follow the reference model without the need for a mathematical model of the induction motor.

Adaptive Controller Design

A single-input single-output system, which may be either a continuous time or a discrete time model, is given by [1].

\[ y(t) = \frac{B_p}{A_p} \ u(t) \]  

(1)

where \( \deg(A_p) \geq \deg(B_p) \)

Where \( u \) is the control signal and \( y \) is the output signal. The symbols \( A_p \) and \( B_p \) denote polynomials in differential operator. The polynomial \( A_p \) is assumed to be monic (the first coefficient is unity). The regulator can be found according to the relation between command signal \( u_c \) and the desired output signal \( y_m \) as

\[ y_m(t) = \frac{B_m}{A_m} \ u_c(t) \]  

(2)

The general linear control law is

\[ R \ u = T \ u_c - G \ y \]  

(3)

\( R \), \( T \) and \( G \) are polynomials. Figure (2) shows the regulator block diagram

\[ A_p \ R + B_p \ G = B^+ \ A_0 \ A_m \]  

(4)

\( A_m \) is the desired model poles, \( A_0 \) is the observer poles and \( B^+ \) is the cancelled zeros.

\[ T = A_0 B_m / b_0 \]  

(5)

\[ P = P_1 P_2 = A_m A_0 \]  

(6)

\( P_2 \) is a stable monic polynomial of the same degree as \( R \)

The filter error can be written as

\[ e_f = \frac{b_0 Q}{A_0 A_m} \left( \frac{1}{P_1} u + \varphi^T \theta^0 \right) \]  

(7)

\( Q \) is a polynomial whose degree is not greater than \( A_0 A_m \) degree, \( \varphi \) is the regression vector and \( \theta^0 \) is the true regulator parameters.

The feedback law is

\[ u = -\theta^T (P \varphi) \]  

(8)
Where $\theta$ is the actual regulator parameter. Introduce the signals $\varsigma$ and $\mu$, defined by

$$
\varsigma = -\left(\frac{1}{P} u + \phi^T \theta\right)
$$

(9)

$$
\mu = e_j + \frac{b_0 Q}{A_0 A_m} \varsigma
$$

(10)

$\mu$ is the augmented error and $\varsigma$ is the error augmentation. The Gradient Rule used for updating parameters is

$$
d\theta = \gamma \phi \mu
$$

(11)

Where $\gamma$ is the adaptation gain.

Figure (3) shows a block diagram of a model reference adaptive system. The Block Diagram of a Model Reference Adaptive Control system is shown in figure (4), the controller is designed using Matlab/Simulink. In the block diagram it is noticed that the reference model is a second order and the input signal is a square wave signal. The plant is an A.C. Induction Motor and the output is shown in the scope is both the plant and model response.

**A.C. Induction Motor**

An A.C. induction motor model on the basis of direct and quadrant direction (d-q frame) that is rotating synchronously with the magnetic field is shown in Figure (5). Where $v_s$ is the stator voltage, $w_k = w_s$ is the stator frequency, $w_m$ is the speed range, $T_e$ is the electromagnetic torque, $B_m$ is the damping coefficient and $H$ is the inertia constant. The a.c.induction motor response with PI speed controller is shown in figure(6);the result is carried out using matlab simulation package [5].

**Determination of Controller Parameters**

For the plant has insufficient information about its dynamics the controller parameters which is designed according to the plant order, can be determined as follows

1-Set all parameters of the controller and adaptation gain ($\gamma$) to zero.
2-Applying test signal to the system (plant and the controller) and observe the response.
3-Set an arbitrary value for one of the controller parameters then record its effect on the response, change its value until good results obtained.
4-Repeat step 3 for other parameters. The study of the controller parameter effect on the transient and steady state response for

$$
T_{ss} = t_0s + t_1, \quad R_{ss} = s + r_1
$$

$g_{ss}(s) = g_0s + g_1$

can be written as

$\mathbf{t}_1$: enables the plant to reach the final value, the value should be chosen carefully to obtain zero steady state error.

$\mathbf{r}_1$: high effect on overshoot value where increasing $r_1$ value will decrease the overshoot value but in the same time the number of input changes to reach the model response (adaptation time) will increase.

$\mathbf{g}_1$: effect on settling time, peak time and steady state error where decreasing the value of $g_1$ will increase the settling time, peak time and steady state error.

$\mathbf{g}_0$: decreasing the value will reduce the oscillation.

The parameters effect is illustrated in table (1), where $x=$negligible effect, $\text{Low}=\text{low effect}$, $\text{High}=\text{high effect},–\text{ve}=\text{reverse effect}$.

**Tuning Phase**

The period of the parameter changes in MRAC is equal to 10 seconds.
with 0.3 amplitude, the reference model is a second order model. With no adaptation (adaptation gain equal to zero), the initial condition for each parameter is tuned separately and continuously, as shown in figure (7-A), the first tuned parameter is t1 because it has a high effect on the transient response of the controlled system which makes the response of the plant reach 1 Per unit value. The second effective parameter is r1 which enables the controller to follow the model response, figure (7-B). The other controller parameter is tuned to make a precision to the controller response figure (8-A) and figure (8-B).

**Simulation Results**

Plant and model response without tuning of the controller parameters and the initial condition is set to zero for all parameters is shown in figure (9). The response where the initial condition for each tuned parameter is set to the value obtained from the tuning phase is shown in Figure (10). From the results obtained in figures (9) and (10), it is noticed that the plant can follow the model response by setting the adaptation gain to zero (gama = 0) and tuning the initial values of controller parameters separately. The Simulation Result which represents the responses for the D.C. motor and the model without tuning the controller parameters and setting the initial conditions of all parameters to zero is shown in figure (13). The responses for a D.C. motor and the model with tuned parameters values and adaptation gain equal to 0.05 is shown in figure (14). The Simulation Results for a D.C. Motor in Figure (14) shows the fast and stable transient response. Disturbance rejection and a very fast parameter adaptation are performed for the systems with frequent parameter variations.

**Conclusions**

The design parameters of adaptive control have been investigated via several simulations. The results of this study can be summarized as follows:

1- Random or zero initial condition values for controller parameters didn’t lead to a close response to a perfect model.

2- With a novel approach we can use a plant with unknown dynamic equations of physical system, just the order of the plant must be known.

3- We can tune initial values of the controller parameters without adaptation (adaptation gain =0) until
the response approximately reaches a perfect model.
4-After adaptation mechanism works, the response will be very close to a perfect model.
5-The procedure can be applied on the linear and non linear plants.
6-The tuning controller has a good response compared with conventional PI controller.

References
[5] M. Riaz, "Simulation of Electric Motor and Drive Systems", University of Minnesota, Department of Electrical and Computer Engineering, E-mail: riaz@ece.umn.edu http://www.ece.umn.edu/users/ri az.

Table (1) Controller Parameters Effect with the A.C. Induction Motor

<table>
<thead>
<tr>
<th>Controller parameter</th>
<th>Rise time</th>
<th>Peak time</th>
<th>Settling time</th>
<th>Over- shoot</th>
<th>Ess</th>
<th>Damping ratio</th>
<th>Natural freq.</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1</td>
<td>High</td>
<td>High</td>
<td>x</td>
<td>x</td>
<td>High</td>
<td>High -ve</td>
<td>x</td>
</tr>
<tr>
<td>to</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>x</td>
<td>High</td>
<td>Low -ve</td>
<td>x</td>
</tr>
<tr>
<td>rl</td>
<td>x</td>
<td>High</td>
<td>High -ve</td>
<td>High</td>
<td>x</td>
<td>High</td>
<td>x</td>
</tr>
<tr>
<td>g1</td>
<td>x</td>
<td>x</td>
<td>Low -ve</td>
<td>x</td>
<td>High</td>
<td>Low -ve</td>
<td>x</td>
</tr>
<tr>
<td>go</td>
<td>Low</td>
<td>Low</td>
<td>High -ve</td>
<td>x</td>
<td>High</td>
<td>High</td>
<td>High -ve</td>
</tr>
</tbody>
</table>
Table (2) Controller Parameters Effect with D.C. Motor

<table>
<thead>
<tr>
<th>Controller parameter</th>
<th>Rise time</th>
<th>Peak time</th>
<th>Settling time</th>
<th>Overshoot</th>
<th>Ess</th>
<th>Damping ratio</th>
<th>Natural freq.</th>
</tr>
</thead>
<tbody>
<tr>
<td>t₁</td>
<td>High</td>
<td>High</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>High -ve</td>
<td>x</td>
</tr>
<tr>
<td>t₂</td>
<td>High</td>
<td>x</td>
<td>Low</td>
<td>x</td>
<td>x</td>
<td>High -ve</td>
<td>x</td>
</tr>
<tr>
<td>r₁</td>
<td>x</td>
<td>x</td>
<td>High -ve</td>
<td>High</td>
<td>x</td>
<td>High</td>
<td>x</td>
</tr>
<tr>
<td>g₁</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Low -ve</td>
<td>x</td>
<td>x</td>
<td>Low -ve</td>
</tr>
<tr>
<td>g₂</td>
<td>High</td>
<td>x</td>
<td>Low</td>
<td>High -ve</td>
<td>x</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

Figure (1) Block Diagram of MRAC

Figure (2) Regulator Block Diagram
Figure (3) Model Reference Adaptive System block diagram

Figure (4) Simulink Program for MRAC system
Tuning Controller for Induction Motor using Model Reference Adaptive Control

Figure (5) A.C. Induction Motor Matlab/Simulink

Figure (6) Conventional tuned PI controller response of an A.C. induction motor

Figure (7-A) $t_1$ tuning effect.  Figure (7-B) $r_1$ tuning effect.

Figure (8-A) $g_1$ tuning effect.  Figure (8-B) $g_0$ tuning effect.
Tuning Controller for Induction Motor using Model Reference Adaptive Control

Figure (9) Response without tuning Figure (10) Tuned system response

Figure (11) D.C. Motor Matlab/Simulink
Figure (12) D.C. Motor Response at Tuning Phase

Figure (13) Response without tuning

Figure (14) Tuned system response