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Tuning Controller for Induction Motor using Model Reference Adaptive Control

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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.

تنغيم المسيطر التكيفي باستعمال خوارزمية مسطرة النموذج المرجعي التكيفية

الخلاصة

هذا البحث هومحاولةٌ جادة لتَصميم المسيطرالتكيفي باستعمال خوارزمية سيطرة النموذج المرجعي التكيفيةِ تَتضمّنُ محرك حثٍّ تيار متناوبِ، بدون الحاجةِ إلى النموذج الرياضي للنظام (معرفة معادلاتَ النظام) ماعدا طلبِ درجة النظام. إنّ الهدفَ هو دراسة تاثيرمتغيرات النظام المطلوبَ السيطرة عليه لعَكْس مواصفاتِ الأداءَ في مهامِ السيطرةَ، لكي يُصممّ مسيطر تكيفي بآليةِ التعديلِ بحيث يكون نظام سيطرة ألتغذيه ألخلفيه مستقرّا.ً النظام الثاني المستخدم هو محرك تيار مستمرً لغرض التّحقق من قابليةِ الطريقةِ المُقترحةِ في السيطرة على أداء الانظمه الخطيّة. النموذج يَختَارُ بناءا على درجة النظام. إنّ الطريقة المُقترحة لإيجاد القِيَمَ الأوليـة لمتغيرات النظام باستعمال جداول صمّمتْ لهذا الغرض تَعطي استجابة جيده مقَارنَة بالطريقةِ التقليديةِ (تنغيم المسيطر النسبي التكامليَ)؛ بالإضافة لذلك فان نظام السيطرة المُصَمَّم لَهُ قابلية تحسينُ الاستجابة بمرور الزمن عائد لآليةِ التكيّفَ.

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

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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].

$$y(t) = \frac{B_p}{A_p}\; u(t) \qquad (1)$$

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

$$y_m(t) = \frac{B_m}{A_m}\; u_c(t) \qquad .....(2)$$

The general linear control law is

$$R\ u = T\ u_c - G\ y \qquad ......(3)$$

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

$$A_P\ R + B_P\ G = B^+\ A_0\ A_m \qquad (4)$$

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

$$T = A_0 B_m / b_0 \qquad ...(5)$$

$$P = P_1 P_2 = A_m A_0 \qquad (6)$$

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

The filter error can be written as

$$e_f = \frac{b_0 Q}{A_0 A_m}\left(\frac{1}{P_1}u + j^{\ T} q^{\,0}\right) \qquad (7)$$

Q is a polynomial whose degree is not greater than $A_0 A_m$ degree, j is the regression vector and $q^{\,0}$ is the true regulator parameters.

The feedback law is

$$u = -q^{T}(P_1 j) \qquad (8)$$

Where q is the actual regulator parameter. Introduce the signals ς and μ, defined by

$$V = -\left(\frac{1}{P_1}u + j^T q\right) \qquad (9)$$

$$m = e_f + \frac{b_0 Q}{A_0 A_m} V \qquad (10)$$

m is the augmented error and ς is the error augmentation. The Gradient Rule used for updating parameters is

$$\frac{dq}{dt} = g \;\; j \;\; m \qquad (11)$$

Where γ 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 quadrate direction (d-q frame) that is rotating synchronously with the magnetic field is shown in Figure (5), Where vs is the stator voltage, wk =ws is the stator frequency, wm is the speed range, Te is the electromagnetic torque, Bm 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 (γ) 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

$$T_{(s)} = t_0 s + t_1 \;,\;\; R_{(s)} = s + r_1$$

$$g_{(s)} = g_0 s + g_1$$

can be written as

t1: enables the plant to reach the final value, the value should be chosen carefully to obtain zero steady state error.

to: enables the plant to follow the model response increasing the value will decrease the rise time and peak time.

r1: high effect on overshoot value where increasing r1 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.

g1: effect on settling time, peak time and steady state error where decreasing the value of g1 will increase the settling time, peak time and steady state error.

go: decreasing the value will reduce the oscillation.

The parameters effect is illustrated in table (1), where x=negligible effect, Low=low effect, High=high effect,–ve =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 tuning the initial values of the controller parameters separately. The new strategy used in this thesis can improve the transient performance such as maximum overshoot and rise time in the tuning phase.

D.C. Motor Simulation Results

The second plant used is a D.C. Motor as a linear plant. The Matlab/Simulink model is shown in figure (11). Where va is the armature voltage, La is the armature inductance, k is the coupling coefficient, Te is the electromagnetic torque, J is the moment of inertia, wm is the speed range and Bm is the damping coefficient [5]. The controller parameters effect on plant response is illustrated in table (2).

Tuning Phase

For tuning the controller parameters set the adaptation gain to zero, and obtain the initial values of the controller parameters t1, r1, go and g1 separately. The tuning steps for are shown in figures (12-A, B, C, D). The model is a second order and the plant is a D.C. Motor.

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.

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

Controller parameter	Rise time	Peak time	Settling time	Over-shoot	Ess	Damping ratio	Natural freq.
t1	High	High	x	x	High	High -ve	x
to	High	x	Low	x	x	Low -ve	x
r1	x	High	High -ve	High	x	High	x
g1	x	x	x	Low -ve	x	High	Low -ve
go	Low	x	Low	High -ve	x	High	High -ve

Table (2) Controller Parameters Effect with D.C. Motor

Controller parameter	Rise time	Peak time	Settling time	Over-shoot	Ess	Damping ratio	Natural freq.
t1	High	High	x	x	x	High -ve	x
to	High	x	Low	x	x	High -ve	x
r1	x	x	High -ve	High	x	High	x
g1	x	x	x	Low -ve	x	x	Low -ve
go	High	x	Low	High -ve	x	High	High

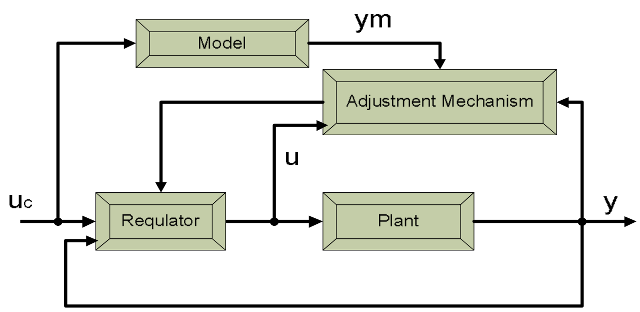


Figure (1) Block Diagram of MRAC

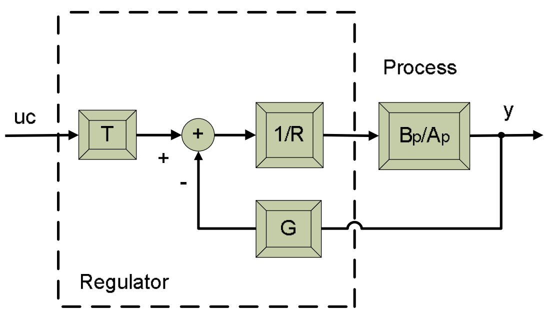


Figure (2) Regulator Block Diagram

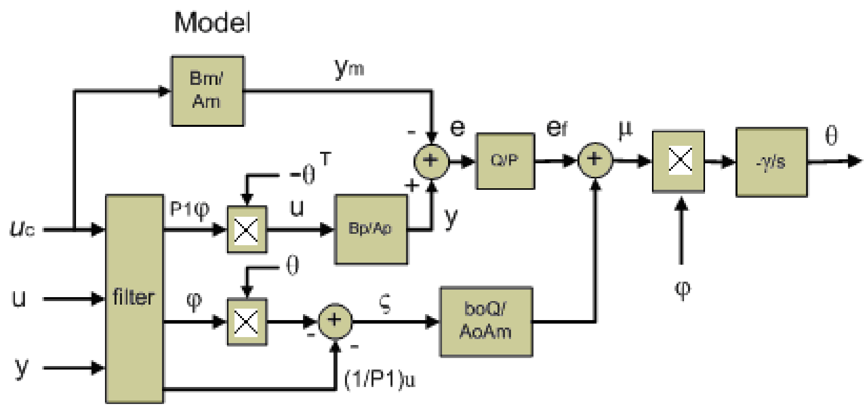


Figure (3) Model Reference Adaptive System block diagram

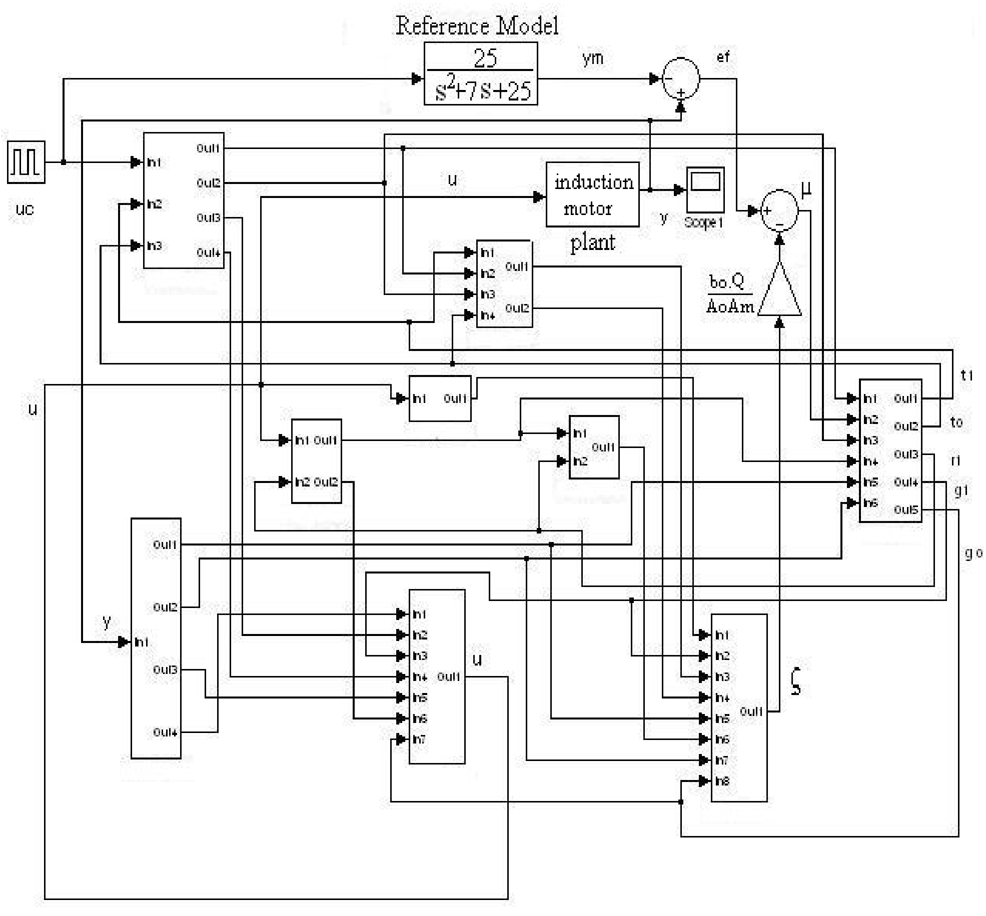


Figure (4) Simulink Program for MRAC system

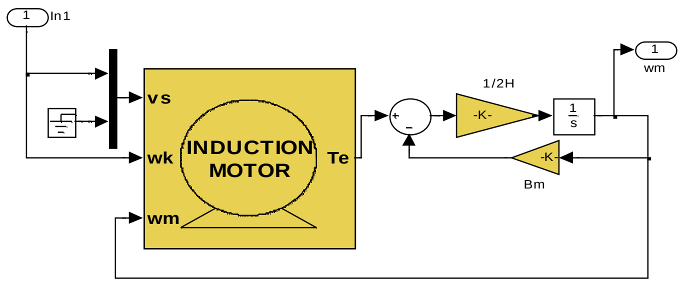


Figure (5) A.C. Induction Motor Matlab/Simulink

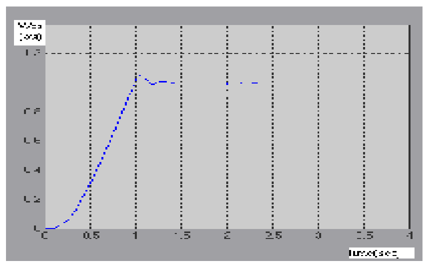


Figure (6) Conventional tuned PI controller response of an A.C. induction motor

Figure (7-A) t1 tuning effect.

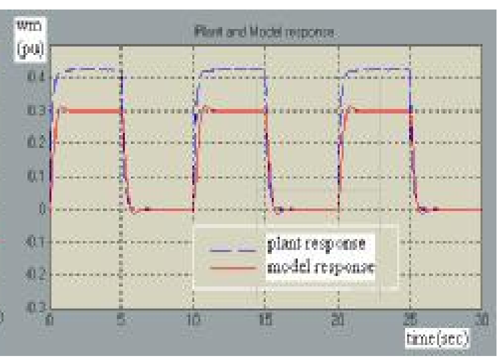


Figure (7-B) r1 tuning effect.

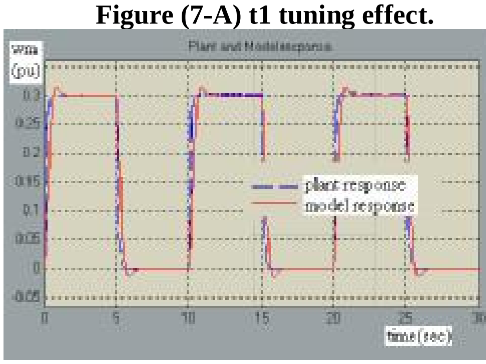


Figure (8-A) g1 tuning effect.

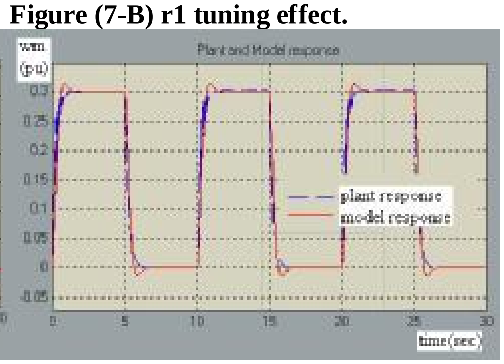


Figure (8-B) go tuning effect.

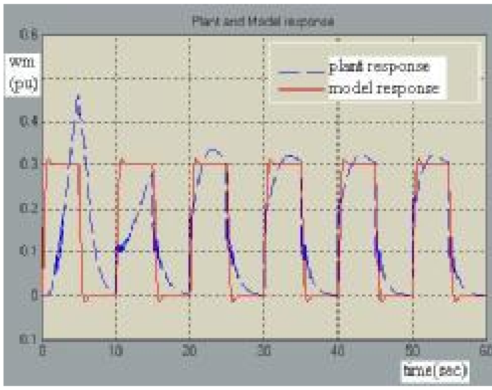


Figure (9) Response without tuning

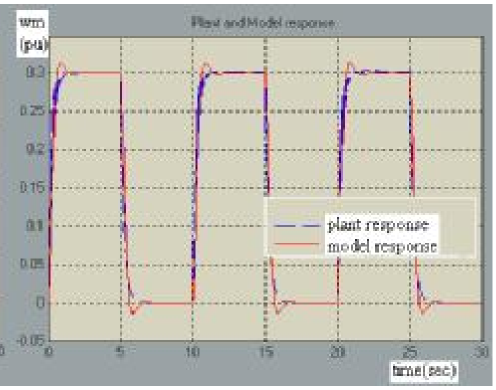


Figure (10) Tuned system response

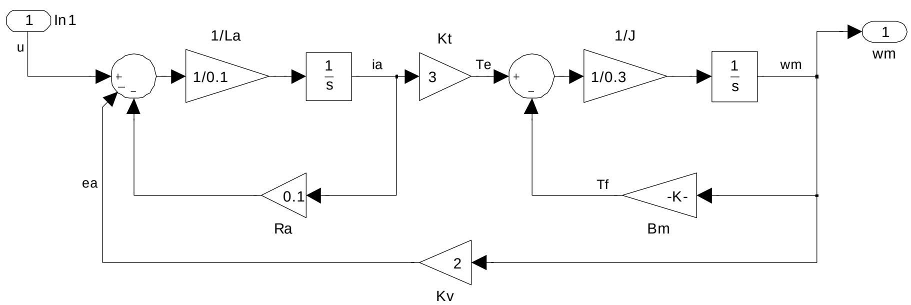
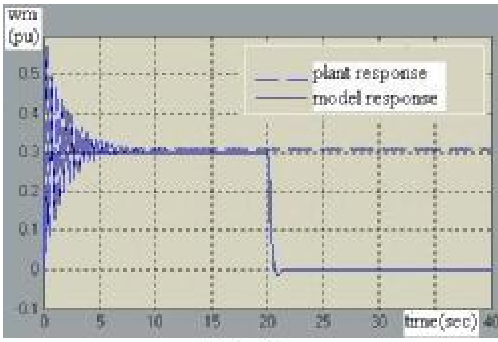
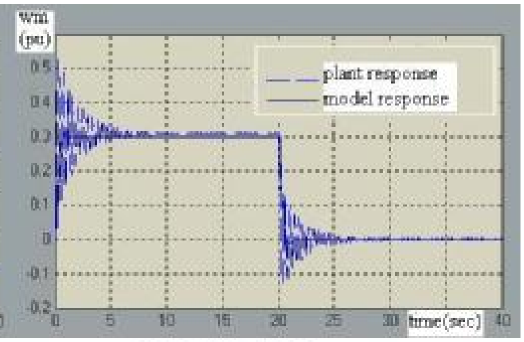


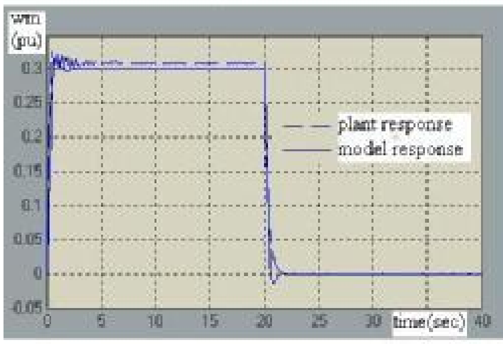
Figure (11) D.C. Motor Matlab/Simulink



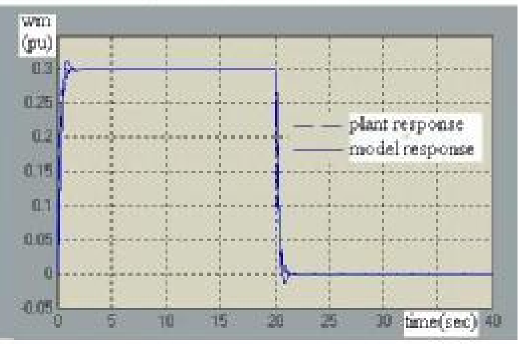
A) t1=24



B) t1=24 ; r1=8.9



C) t1=24 ; r1=8.9 ; go=6.4



D) t1=24 ; r1=8.9 ; go=6.4 ; g1=3.9

Figure (12) D.C. Motor Response at Tuning Phase

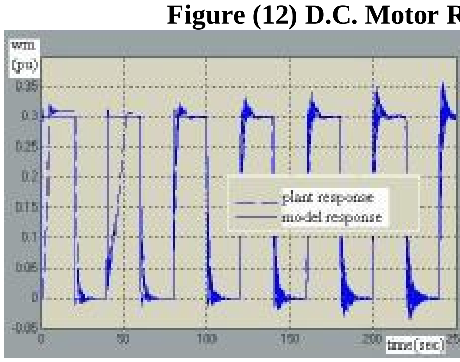


Figure (13) Response without tuning

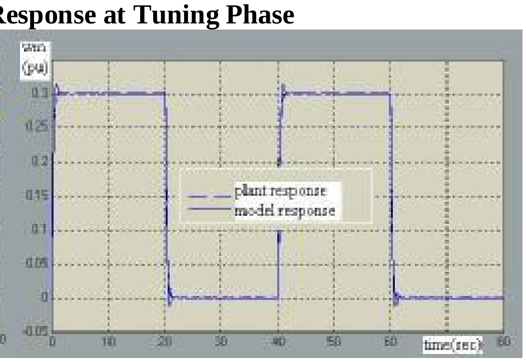


Figure (14) Tuned system response