TUNING MODEL REFERENCE ADAPTIVE CONTROLLER FOR AVR OF SYNCHRONOUS GENERATOR[1]

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Abstract

A Tuning Model Reference Adaptive Controller (TMRAC) for a synchronous generator is presented in this paper. The controller performs the function of terminal voltage of the machine. The proposed controller is used to overcome the problems of nonlinearities and parametric uncertainties for Synchronous Generator (SG). The results verify improved performance of TMRAC compared to conventional Automatic Voltage Regulator (AVR) under various operating conditions.

Keyword: Mode Reference Adaptive Controller, synchronous generator, Automatic Voltage Regulator (AVR)

الخلاصة

في هذا البحث تم تقديم مسيطر النموذج المرجعي التكيفي المُنغم (TMRAC) لمولد متزامن. . يُؤدّي المسيطرة وظيفةَ تنظيم الفولطيةِ الطرفيةِ للماكنةِ. يُستَعملُ جهازالسيطرة المُقتَرَحللتَغَلُّب على مشاكل ألاخطية وعدم وثوقية المتغيرات للمولد المتزامن. أثبتت النَتائِجُ أداء مُحسَّن لمسيطر النموذج المرجعي التكيفي المُنغم بالمقارنة مع منظم الفولطيةِالآلي الاعتيادي تحت ظروف الاشتغال المُخْتَلِفةِ.

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1. Introduction

Synchronous generators are responsible for the bulk of the electrical power generated in the world today. The voltage stability and power quality of the electrical system depend on proper operation of AVR. Synchronous generator excitation control is one of the most important measures to enhance power system stability and to guarantee the quality of electrical power it provides. The main control function of the excitation system is to regulate the generator terminal voltage which is accomplished by adjusting the field voltage with respect to the variation of the terminal voltage [1]. Synchronous Generator in a power system is non-linear and fast acting which is continuously subjected to load variations [2,3]. Nowadays, Design technology of AVR is being broadly improved. Nonlinearities and parametric uncertainties are unavoidable problems faced in controlling the output voltage of SG when working alone or with others. Fig (1) shows a block diagram of SG and AVR system [4].

Conventional linear controllers for the synchronous generator consist of the AVR to maintain constant terminal voltage and the turbine governor to maintain constant speed and power at some set point. They are designed to control, in some optimal fashion, the generator around one particular operating point; and at any other point the generator's damping performance is degraded [5].

A number of new control theories and methods have been introduced to design high performance excitation controllers to deal with the problem of transient stability for nonlinear synchronous generator models. Among them are the Lyapunov method, singular perturbation methods, feedback linearization and sliding mode control, linear optimal control, the adaptive control method associated with neuro technique, the fuzzy logic control theory [2,6].

The proposed controller in this paper is TMRAC [7]. It is used to design an AVR for a non-linear and fast acting synchronous generator which is subjected to continuously load variations. The controller parameters are tuned according to their effect on the rise time, peak over shoot and steady state response where each parameter is examined separately and adjusted to overcome their drift. The voltage stability is obtained even though the plant mathematical model is unknown.

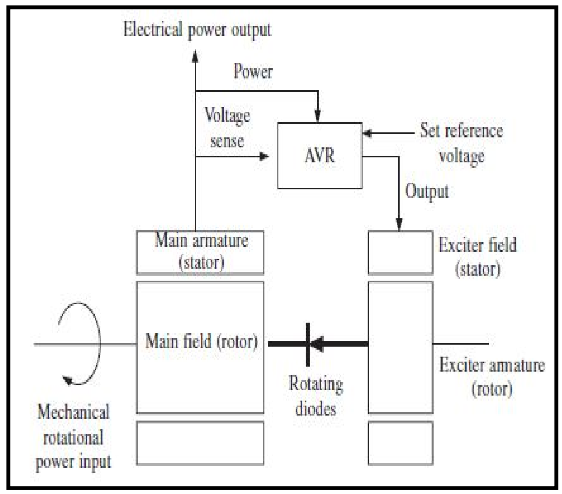


Fig (1) Block diagram of a synchronous generator and AVR

2. Model Reference Adaptive Controller (MRAC)

The MRAS is one of the main approaches to adaptive control. The desired performance can be expressed in term of a reference model. The system consists 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 a way that the error between the plant output and the model output becomes small. The outer loop is thus also a regulator loop. The problem is to determine the adjustment mechanism which brings the error to zero for all command signals. The block diagram of the MRAC is shown in Figure (2).

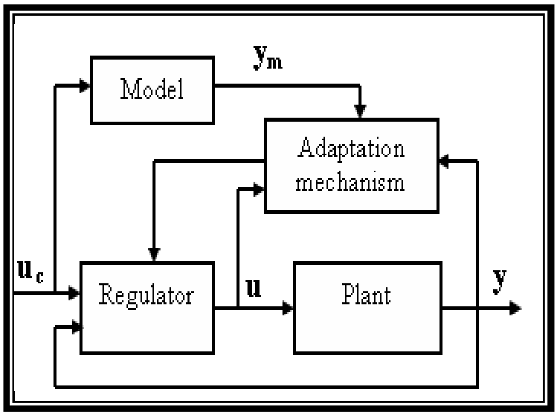


Figure (2) Block Diagram of MRAC [8]

A single-input single-output system, which may be either a continuous time or a discrete time model, is given by [8]

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

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

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 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

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

A general linear control law is

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

where R , T and G are polynomials. Figure (3) shows the regulator block diagram.

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

where A_m is the desired model poles, A_0 is the observer poles (they are fast response than desired poles) and B^{+} is the cancelled zeros (it is used to cancel the effect of plant zeros). Observer poles are added to become possible to obtain R and G from equation (4), and must be have fast response compared

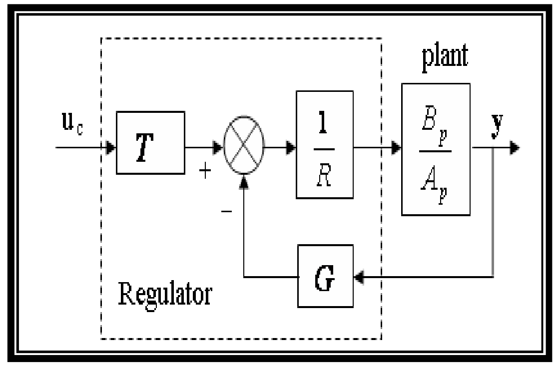


Figure (3): Regulator Block Diagram

with desired poles. The polynomial T can be found from the following equation

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

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

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

The filter error can be introduced as

$$e_f = \frac{Q}{p}(y - y_m) \qquad (7)$$

Filtered error in term of regression vector can be written as

$$e_f = \frac{b_0 Q}{A_0 A_m}\left(\frac{1}{P_1}u + \varphi^{T}\theta^{0}\right) \qquad (8)$$

where Q is a polynomial whose degree is not greater than $A_0 A_m$ degree, φ is the regression vector and θ^0 is the true regulator parameters.

The feedback control law is

$$u = -\theta^{T}(P_1\varphi) \qquad (9)$$

where θ is the actual regulator parameter. Using this control law, it follows from eq. (8) that that the

Introduce the signals ς and μ, defined by

$$\varsigma = -\left(\frac{1}{P_1}u + \varphi^{T}\theta\right) \qquad (10)$$

$$\mu = e_f + \frac{b_0 Q}{A_0 A_m}\varsigma \qquad (11)$$

where μ is the augmented error and ς is the error augmentation. The Gradient Rule that used for updating parameters is

$$\frac{d\theta}{dt} = \gamma\ \varphi\ \mu \qquad (12)$$

where γ is the adaptation gain. Figure (4) shows a block diagram of a model reference adaptive controller. The controller is designed using Matlab/Simulink, the reference model is a second order and the input signal is a unit step signal. The plant of synchronous generator model with saturation non-linearty is taken from Matlab toolbox.

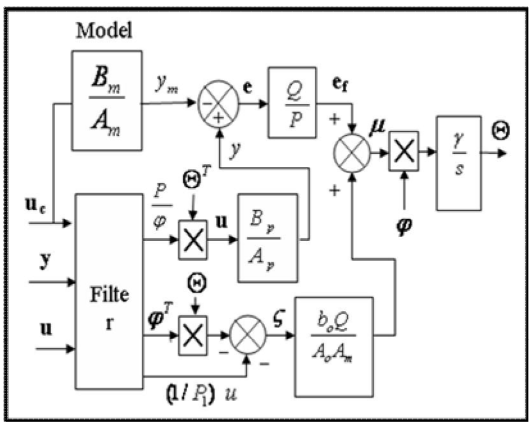


Figure (4): the block diagram of a MRAS for SISO system

3. The Synchronous Generator Model (Plant)

The synchronous generator terminal voltage under faulted condition has been shown that the dynamic response of SG in a practical power system when a fault occurs is very complicated including many nonlinearities such as the magnetic saturation. However, the classical third order dynamic generator model has been commonly used for designing the excitation controller. This third order model can be shown in [3]. The MATLAB/SIMULINK toolbox synchronous generator model takes into account the dynamics of the stator, field, and damper windings. The equivalent circuit of the model is represented in the rotor reference frame (qd frame). All rotor parameters and electrical quantities are viewed from the stator. They are identified by primed variables. The subscripts used are defined as follows:

- *d,q*: d and q axis quantity
- *R,s*: Rotor and stator quantity
- *l,m*: Leakage and magnetizing inductance
- *f,k*: Field and damper winding quantity

The electrical model of the machine is

$$V_d = R_s i_d + \frac{d}{dt}\varphi_d - \omega_R \varphi_q \qquad (13)$$

Where $\varphi_d = L_d i_d + L_{md}(i'_{fd} + i'_{kd})$ and

$\varphi_q = L_q i_q + L_{mq} i'_{kq}$

$$V_q = R_s i_q + \frac{d}{dt}\varphi_q + \omega_R \varphi_d \qquad (14)$$

$$V'_{fd} = R'_{fd} i_{fd} + \frac{d}{dt}\varphi'_{fd} \qquad (15)$$

Where $\varphi'_{fd} = L'_{fd} i'_{fd} + L_{md}(i_d + i'_{kd})$

$$V'_{kd} = R'_{kd} i_{kd} + \frac{d}{dt}\varphi'_{kd} \qquad (16)$$

Where $\varphi'_{kd} = L'_{kd} i'_{kd} + L_{md}(i_d + i'_{fd})$

$$V'_{kq1} = R'_{kq1} i'_{kq1} + \frac{d}{dt}\varphi'_{kq1} \qquad (17)$$

Where $\varphi'_{kq1} = L'_{kq1} i'_{kq1} + L_{mq} i_q$

$$V'_{kq2} = R'_{kq2} i'_{kq2} + \frac{d}{dt}\varphi'_{kq2} \qquad (18)$$

Where $\varphi'_{kq2} = L'_{kq2} i'_{kq2} + L_{mq} i_q$

The saturation non linearity can be added to the synchronous generator model by activate the saturation of field current in MATLAB / SIMULINK program.

4. Determination of Controller Parameters

For the plant has exact mathematical model the controller parameters can be obtained directly by applying equations 4 and 5. But the controller parameters for Synchronous Generator which has nonlinearities and parametric uncertainties can not found directly from equations 4 and 5. The parameters of regulator can be determined as follows

(1) Set all parameters of the regulator 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 last coefficient for polynomial T(s) of the regulator parameters then record its effect on the response, change its value until good results obtained.
(4) Repeat step 3 for other coefficients of polynomial T(s) consequently until the first coefficient.
(5) Repeat step 3 and 4 for polynomial R(s) and G(s) consequently.

5. Simulation and Results

The AVR for SG with saturation effect of exciter is designed and implemented using the conventional PID and TMRAC which are shown in figures (5 and 6) respectively, and the parameter for SG used in the simulation are shown in table (1).

The study of the regulator parameters

$$T(s) = t_0 s^2 + t_1 s + t_2 \ ,$$

$$R(s) = s + r_1 \qquad and$$

$$G(s) = g_0 s^2 + g_1 s + g_2$$

effect on the transient and steady state response of SG with zero adaptation gain can be done by applying simulink program shown in figure(6).

t_2: Increase the value of this parameter will tend to decrease the rise time and increase the steady state level as shown in figure (7). Figure (7) shows the responses of different values of parameter t_2 with the present of exciter saturation (upper limit=2 & lower limit=0) and all the other parameters of regulator are set to zero value.

g_2: Increase the value of this parameter will tend to decrease the steady state level as shown in figure (8). Figure (8) shows the responses of different values of parameter g_2 with the present of exciter saturation (upper limit=2 & lower limit=0), parameter t_2=1000 and all other the parameters of regulator are set to zero value.

g_1: Increase the value of this parameter will tend to decrease the over shoot as shown in figure (9). Figure (9) shows the responses of different values of parameter g_1 with the present of exciter saturation (upper limit=2 & lower limit=0), parameter t_2=1000, parameter g_2=900, and all the other parameter of regulator are set to zero value.

From this study we observed the rest controller parameters (t_1,t_0,r_1, and g_0) have no a valuable effect on the response. So they are not tuned and set to zero.

When the TMRAC examined with unit step input, second order reference model (0.7 damping ratio and 4 rad/second natural frequency), and exciter saturation (upper limit =2 &lower limit=0). The obtained results for different loads (heavy=1.9MVA, medium=1MVA, light=.1MVA) are according to the following cases:-

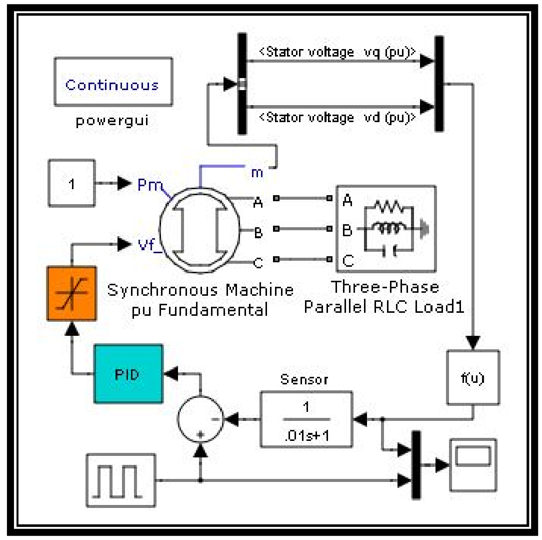
Case one with regulator parameters (t_2=1000, g_2=900, g_1=250, and t_1=t_0=r_1=g_0=0) and no adaptation (adaptation gain equal to zero) the obtained responses are depicted in figure (10), which shows good response only with medium load.

Case two with the same setting of regulator parameters as in case one and adaptation for dominant parameter g_2 (adaptation gain (γ) for parameter g_2=120 and the other parameters adaptation gain sated to zero). The obtained responses are shown in figure (11), which shows good responses for different loads. The adaptations of parameter g_2 for different loads are depicted in figure (12). It is clear from figure (12) the adaptation time approximately four second.

The conventional PID controller responses with same exciter saturation and loads are shown in figure (13). The used gains for PID controller are (proportional =5, integral =4, derivative =0). Figure (13) shows high over shoot and large settling time compared with TMRAC for different loads.

Table (1) parameter of SG from Matlab R2008a

Rated Power KVA	2000
Rated voltage V(L-L)	400
Rated frequency HZ	50
stator resistance pu	.0095
Stator inductance pu	0.05
Quadrature mutual ind.pu	1.51
direct mutual ind. pu	2.06
Field resistance pu	.001971
Field inductance pu	.3418
Damper resistance pu	.2013
Damper inductance pu	2.139



Figure(5) PID simulink program for SG with exciter saturation

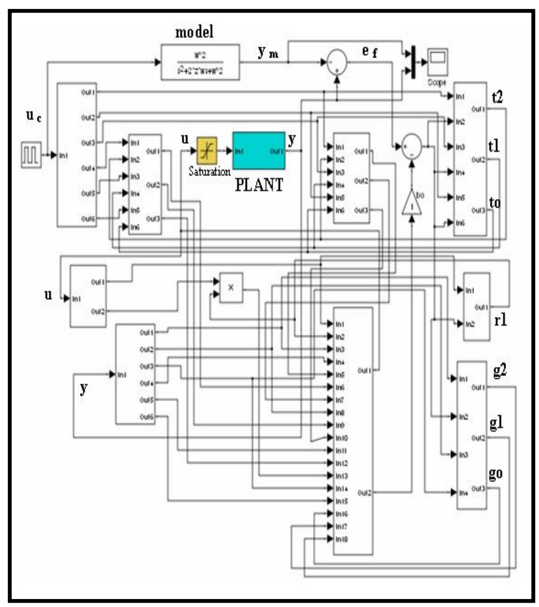


Figure (6): Simulink program of TMRAC for SG & saturation

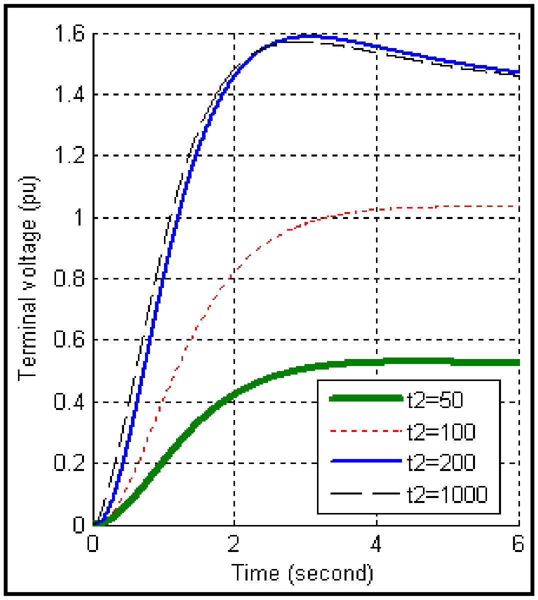


Figure (7): TMRAC response for t2 parameter when other parameters are zero

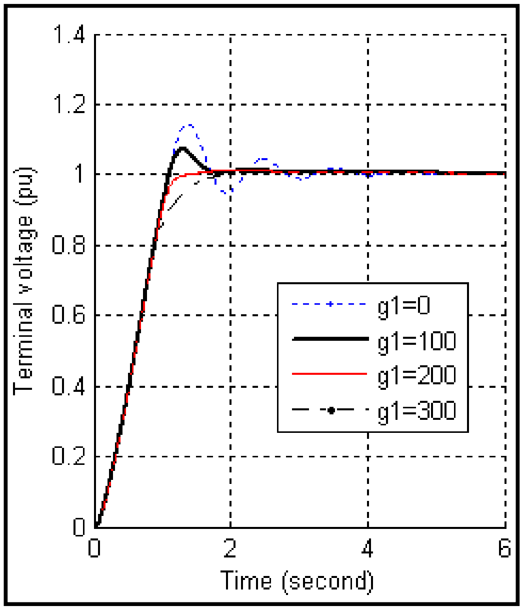


Figure (9): TMRAC responses for parameter g1, g2=900 and t2=1000

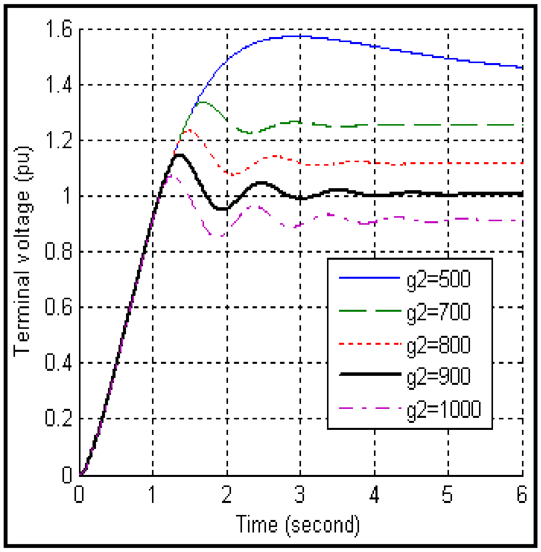


Figure (8): TMRAC response for parameters g2 and t2=1000

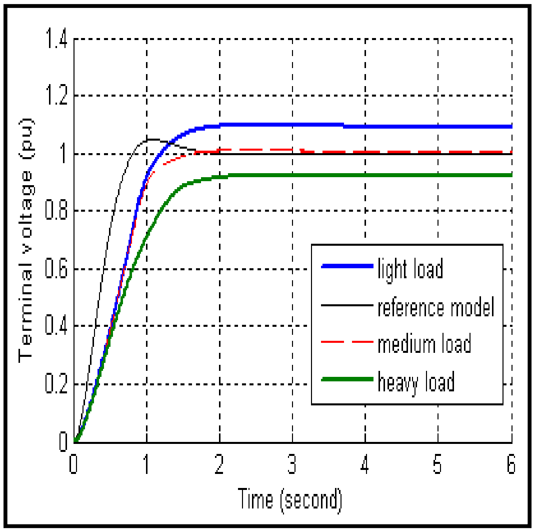


Figure (10): TMRAC response for different loads and adaptation gain=0 (no adaptation)

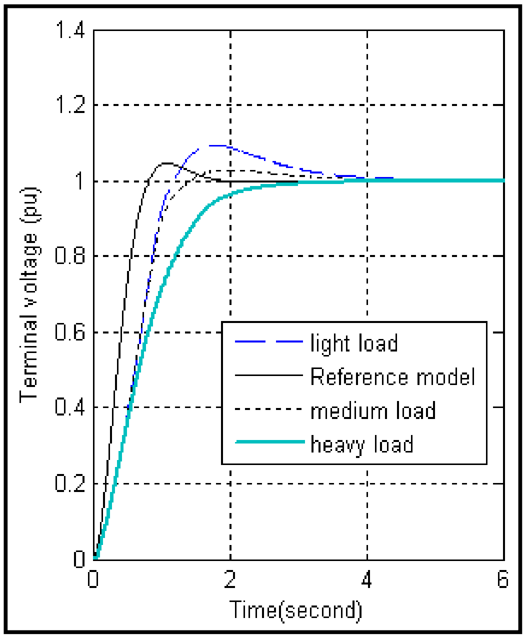


Figure (11): TMRAC response for different loads with adaptation gain of g2=120

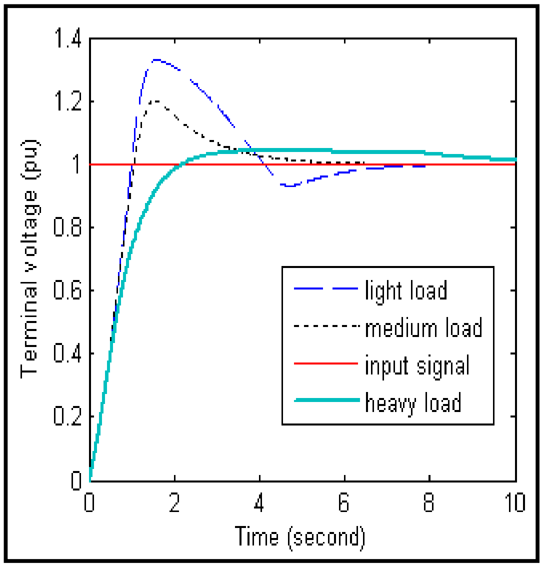


Figure (13): PID response for different loads

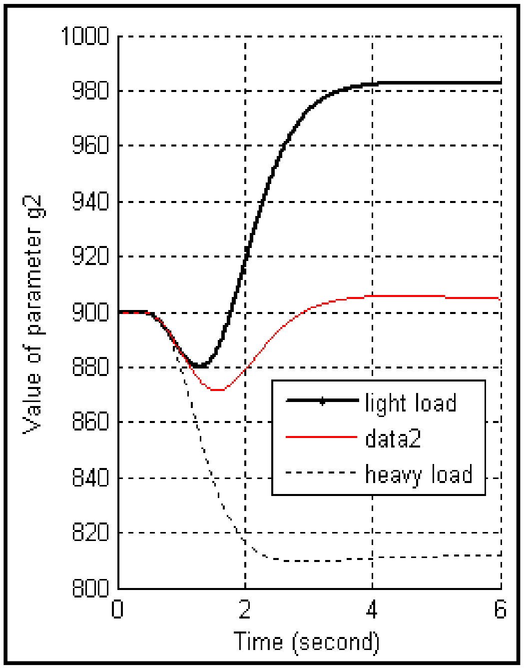


Figure (12): the adaptation of parameter g2 for different loads

6. Conclusions

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

1-With the novel approach, asymptotically stable response is achieved even though the plant is with unknown dynamic equations of physical system.

2-the regulator parameters can be tuned without adaptation (adaptation gain =0) until the response approximately reachs the reference model.

3-After the adaptation mechanism works, the response will be very close to the reference model.

4-Only the dominant regulator parameters can be used.

5-The adaptation mechanism can be used for only one parameter.

6-The implementation of TMRAC used in this work is simple because of the reduction

in regulator parameters and the number of dominant parameters having adaptation.
7- The TMRAC has a better response than the conventional PID controller for the different loads.
8-The contributions obtained from this work are the adaptation mechanism for only one parameter and only the dominant regulator parameters can be used in the TMRAC.

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