International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 7, Number 2 (2014), pp. 353-366
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Design Of Optimum Adaptive Control For DC Motor

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Abstract

This paper deals with the performance evaluation on the comparison of adaptive control and conventional PID control .In this design of adaptive control, Model reference adaptive control (MRAC) scheme is used, in which the adaptation law have been developed by MIT rule. A simulation is carried out using MATLAB and the results were analysed. Hence it shows that the adaptive controller is suitable for this process than the conventional controller. It is very difficult to check each and every value of Adaptation gain in the SIMULINK MODEL. In order to overcome this problem, Genetic Algorithm was implemented.

Keywords- DC motor, Genetic algorithm, PID controller, MRAC.

I. INTRODUCTION

The major disadvantage of non-adaptive control systems that is the control systems cannot work effectively due to the causes of fluctuations in the parameters of the process. The solution to this problem is to increase feedback gain and automatically decrease the sensitivity of the control system. Increasing the feedback gain two major problems occurred. They are signal magnitude and instability of the closed loop system. To overcome this above problem to develop a control system that adapts to changes in the process. The main control objective in this simulation is to maintain the DC Motor at steady state operating point. PID controllers are appropriate for the control of non-linear processes. An adaptive system has maximum application when the plant undergoes transitions or exhibits non-linear behavior and when the structure of the plant is unknown. This permits the controller to maintain a required level of performance in spite of any noise or fluctuation in the process. To get the optimum value of adaptation gain Genetic Algorithm was implemented.

II. MODEL REFERENCE ADAPTIVE CONTROL

The model-reference adaptive system (MRAS) was originally proposed to solve a problem in which the performance of the specifications are given in terms of a reference model. This model tells about how the process output ideally should respond to the command signal. The system has an ordinary feedback loop composed of the process and the controller and another feedback loop that changes the controller parameters. The parameters are changed on the basis of feedback from the error, which is the difference between the output of the system and the output of the reference model.

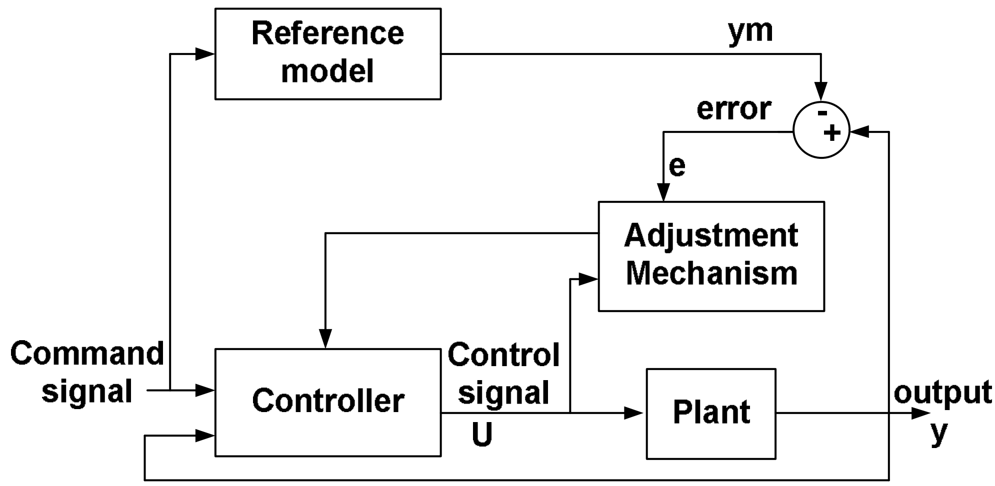


Fig.1. Model Reference Adaptive Controller

The mechanism for adjusting the parameters in a model reference adaptive system. It can be obtained in two ways that is one for gradient method another for applying stability theory. The adaptation law uses the error between the process and the model output, the process output and input signal to vary the parameters of the control system. These are the parameters varied so as to minimize the error between the process and the reference model [8].

III. MODEL OF DC MOTOR

As reference we consider a DC shunt motors as is shown in Fig.2. DC shunt motors consists of field coil in parallel with the armature. The current in the armature and the field coil are independent of one another. As a result, these type of motors have excellent speed and position control. Hence DC shunt motors are used in several applications that require five or more horse power (HPs).

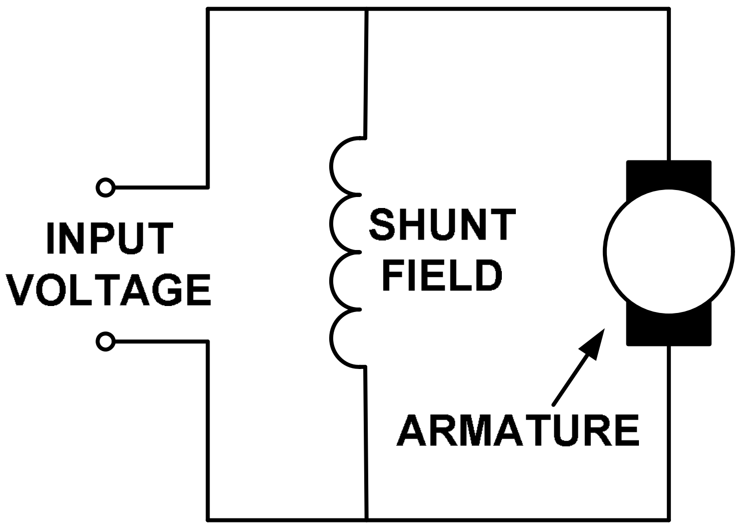


Fig.2. Diagram of DC shunt motor

The dynamic behavior of the DC shunt motor are described by the following equations

$$V = RI + L\frac{di}{dt} + e_b \tag{1}$$

$$T_m = K_t \, \mathrm{I} \tag{2}$$

$$T_m = J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} \tag{3}$$

$$e_b = K_b \frac{d\theta}{dt} \tag{4}$$

$$\omega = \frac{d\theta}{dt} \tag{5}$$

We will get the transfer function after simplification and taking the ratio of ω(s)/v(s) and is given as follows

$$\frac{\omega(s)}{v(s)} = \frac{K_b}{((Js+B)(Ls+R))+K_b^2+RB} \tag{6}$$

- R- Armature resistance in ohms,
- *L*- Armature inductance in Henry,
- I-Armature current in ampere,
- V-Armature voltage in volts,
- E_b- Back emf voltage in volts,
- K_b-Back emf constant in volt/(rad per sec),
- K_T-Torque constant in N.m/Ampere,
- T_m-Torque developed by the dc motor in N.m,
- θ (t)- Angular displacement of shaft in radians,
- J-Moment of inertia of motor and load in Kg.m^2/rad,
- B -Frictional constant of motor and load in N.m/(rad per sec),

A. Numerical Values

The DC motor has the following specifications and parameters under study.

1) Specifications

2hp, 230 volts, 8.5 amperes, 1500rpm

2) Parameters:

Ra=0.45 ohm, La=0.035 H, Kb=0.5 volt/(rad per sec), J=0.022Kg-m^2/rad, B=0.2*10^-3N-m/(rad/sec).

IV .CONVENTIONAL PID CONTROLLER

Fundamentals of PID controller:

PID controllers are the most widely-used type of controller for industrial applications. They are structurally simple and exhibit robust performance over a wide range of operating conditions. In the absence of the complete knowledge of the process these types of controllers are the most efficient of choices. The three main parameters involved are Proportional (P), Integral (I) and Derivative (D). The proportional part is responsible for following the desired set-point, while the integral and derivative part account for the accumulation of past errors and the rate of change of error in the process respectively.

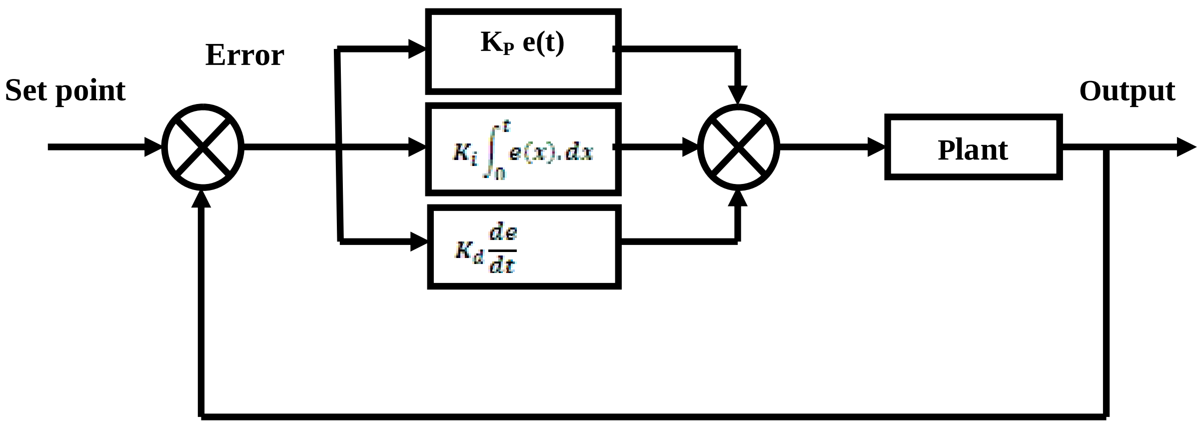


Fig.3. Block diagram of a conventional PID controller

The PID controller presented in Fig3. Output of the PID controller,

$$u(t)=K_p e(t) + K_i \int_0^t e(x).dx + K_d \frac{de(t)}{dt} \quad (7)$$

Where, Error, e (t) =Set point- Plant output

Kp=proportional gain

Ki= integral gain

Kd= derivative gain

V. ADAPTATION LAW

The adaptation law gives to find a set of parameters that minimize the error between the plant and the model outputs. Hence the parameters of the controller are adjusted until the error becomes zero. A number of adaptation laws have been developed. The two main types are the Gradient and the Lyapunov approach. Here the Gradient approach (MIT Rule) was used to develop the adaptation law.

A. MIT Rule

The MIT rule is the original approach to model reference adaptive control. The name is derived from the fact that it was developed at the Instrumentation Laboratory (now the Draper Laboratory) at Massachusetts Institute of Technology (MIT), U.S.A.

To present the MIT rule, we will consider a closed loop system in which the controller has one adjustable parameter. The desired closed loop response is specified by a model output Y_M. The error (e) is difference between the output of the system (Y) and the output of the reference model (Y_M). The Modeling error e is given by equation

$$e = Y - Y_M \tag{8}$$

One possibility is to adjust parameters in such a way that the loss function J (θ) is minimized.

$$J(\theta)=\frac{1}{2}e^2 \tag{9}$$

To make J small, it is reasonable to change the parameters in the direction of negative gradient of J. That is,

$$\frac{d\theta}{dt} = -\gamma\frac{\delta j}{\delta\theta} = -\gamma e\frac{\delta e}{\delta\theta} \tag{10}$$

This is the celebrated MIT rule. The partial derivative $\frac{\delta e}{\delta\theta}$ is called the sensitivity derivative of the system, tells how the error is influenced by the adjustable parameter. γ is called adaptation gain.

B. Adaptive MIT (AMIT) Algorithm

For designing the control systems, many of the advanced control techniques are based on the understanding of the system. If the process is not known then we call that as a "black-box" model. In most of the situations, we know something about the process but which is not sure whether it is correct or not. This is called as a "grey-box" model. If we know the process information, then it is called as a "white box" model. Based on a priori knowledge, the process is modeled as second order [8]. The transfer function of the process is represented as given below

$$\frac{Y}{U} = \frac{K}{S^2 + a_1 S + a_2} \tag{11}$$

Where K, a1 and a2 are positive and are the process parameters The control law is given by

$$U = \theta_1 U_c - \theta_2 Y \quad (12)$$

The closed-loop transfer function related to the output and input with the controller in the loop is given by equation

$$\frac{Y}{U_c} = \frac{K\theta_1}{S^2 + a_1 s + (a_2 + K\theta_2)} \quad (13)$$

Where Uc is the command signal (reference input). The controller parameters are updated by the adaptation mechanism such that the process output follows the model output equation.

$$\frac{Y_M}{U_C} = \frac{K_M}{S^2 + A_1 S + A_2} \quad (14)$$

Where K_M, A_1 and A_2 are the reference model parameters.

To apply the control law, the sensitivity derivatives are obtained by calculating the partial derivatives of modeling error with respect to the controller parameters. The process parameters K, a1 & a2 are not known. These formulas cannot be used directly because the process parameters are not known. One possible approximation is based on the observation when the parameters give perfect model following. We will use the approximation.

$$s^2 + a_2 s + (a_2 + k\theta_2) = s^2 + A_1 s + A_2 \quad (15)$$

Which will be reasonable when parameters are close to their correct values? With this approximation we get the following equations for updating the controller parameters:\

$$\frac{\partial e}{\partial \theta_1} = \frac{K}{S^2 + A_1 S + A_2} U_c \text{ and } \frac{\partial e}{\partial \theta_2} = -Y \frac{K}{S^2 + A_1 S + A_2} \quad (16)$$

The controller parameters θ1and θ2 are

$$\theta_1 = -\frac{\gamma'}{s} e \frac{K}{S^2 + A_1 S + A_2} U_c \quad (17)$$

$$\theta_2 = \frac{\gamma'}{s} e \frac{K}{S^2 + A_1 S + A_2} Y \quad (18)$$

Where $\gamma' = \gamma K$

C. Model Reference Adaptive Controller Using Genetic Algorithm

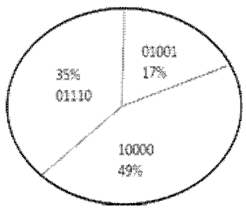
Genetic algorithm is an optimization technique based on evolution of species and individual selection. The origin of this parameter iterative search technique is based on DARWIN'S "SURVIVAL OF THE FITTEST" principle. GA technique is inspired by two biological principles namely the process of natural selection and the mechanics of natural genetics. It manipulates collection of potential solutions which is known as population. The size of population is based on trial and error. Generally, the safe size of population is form 30 to 100. The potential solution of population is called Chromosomes. These are encoded representations of all the parameters of the solution. Each chromosome is compared to other chromosomes in the population and awarded fitness rating that indicates how successful this chromosomes to later. How an individual performs a task is measured and assessed by the objective function. The objective function assign a corresponding number to each individual called its fitness. There are three stages of a genetic algorithm. They are Reproduction, crossover and mutation.

Reproduction:
The fitness value is used on the selection process to provide bias towards fitter individuals. Like In natural evolution, a fit chromosome has a higher probability of being selected for reproduction. There are four methods for selection, they are

1 Roulette Wheel selection
2 Stochastic Universal sampling
3 Normalized geometric selection
4 Tournament selections

Among all, we prefer Roulette Wheel method. In this method, each individual is allocated a section of a roulette wheel. The size of the section is proportional to the fitness of the individual. A pointer is placed in wheel and the individual to whom it points is selected. This continues until the selection of higher probability of individual. This probability is related to its fitness', ensuring that fitter individual is more likely to leave offspring.

During this selection for reproduction, we may get multiple copies of same string. But the fitter string should begin to dominate the weaker string (01001)



Roulette Wheel selection

Crossover:
After selection, this crossover algorithm is initiated. The crossover operations swap certain parts of the two selected strings in a bid to capture the good parts of old chromosomes and create better new ones. A probability of 0% means that the 'offspring' will be exact replicas of their 'parents' and a probability of 100% means that each generation will be composed of entirely new offspring. There are three types of crossover. They are single point crossover, multi point crossover, and uniform crossover. Out of all, single point crossover is the simplest crossover technique.

$$\begin{array}{c|c} 100 & 00 \\ 011 & 10 \end{array} \longrightarrow \begin{array}{c} 100 \\ 011 \end{array}$$

Single point crossover

Mutation:
Mutation is the process in which alteration of bits to 1 or 0 taking place depending on the bit value. Using selection and crossover on their own will generate a large amount of different strings. However there are two main problems with this:

1 Depending on the initial population chosen, there may not be enough diversity in the initial strings to ensure the Genetic Algorithm searches the entire problem space.

2 The Genetic Algorithm may converge on sub-optimum strings due to a bad choice of initial population.

It is considered a background operator in the genetic algorithm. Mutation probability values of around 0.1% or 0.01% are common.

$$10000 \longrightarrow 10010$$

Mutation

GENERAL ALGORITHM OF GENETIC ALGORITHM:
The algorithm consists of the following steps:
Begin
Initialize
Chromosomes in the population
Evaluate fitness of all chromosomes
do until
Number of generation is large enough
do until
The new population if formed
Select parents from the old population
Produce offspring's via reproduction, crossover or mutation process
Evaluate fitness of offspring's
End

VI. ADAPTIVE CONTROL DESIGN AND SIMULATION
From the DC motor, we found the transfer function:

$$G_p(s) = \frac{0.5}{0.0077s^2 + 0.09007s + 0.25018} \tag{19}$$

The next step is to define the model transfer function. The standard form of second order system is given by the equation:

$$G_m(s) = \frac{\omega_n^2}{s^2 + 2\omega_n \xi s + \omega_n^2} \tag{20}$$

The required specifications for the temperature control are a maximum Overshoot (Mp) of 2% and a settling time (Ts) of less than 3 seconds. Now, to determine the damping ratio and natural frequency of the system using the equation below.

Damping ratio

$$(\xi) = \frac{\ln\left(\frac{M_p}{100}\right)}{-\pi}\sqrt{\frac{1}{1+\left\{\ln\left(\frac{M_p/100}{-\pi}\right)\right\}^2}} \tag{21}$$

Natural frequency

$$(\omega_n) = \frac{4}{\xi T_s}$$

Now, the damping ratio (ξ) = 0.71 and natural frequency (ω_n) = 1.88 rad / sec. Hence the transfer function of the model is given:

$$G_m(s) = \frac{3.56}{s^2 + 2.67s + 3.56} \tag{22}$$

Note that we have defined the plant we need to develop a standard controller to compare with the adaptive controller. Controller setting is done using Ziegler-Nichols technique and the best controller parameters are found to be Kp= 1, K_I= 1, K_d =0.1.

VII. SIMULATION AND RESULTS

The conventional PID controller simulink model is shown in fig4.This model has the step input signal, PID controller and transfer function of dc motor. The controller output is the combination of step signal and process output signal.

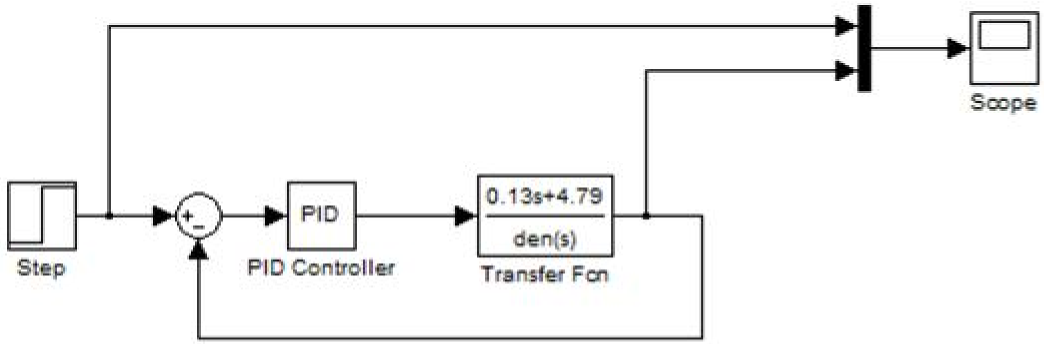


Fig.4. Simulink model of conventional PID

The model reference Adaptive controller simulink model shown in fig 5.It has the input signal, reference model transfer function, and process transfer function and adaptation gain value. The error signal is produced from the difference between process output and reference model output values($e=Y-Y_M$).The controller parameters ($\theta 1$ & $\theta 2$) values are depend on the reference input signal(Uc),transfer function of the reference model, error signal(e) and adaptation gain values.

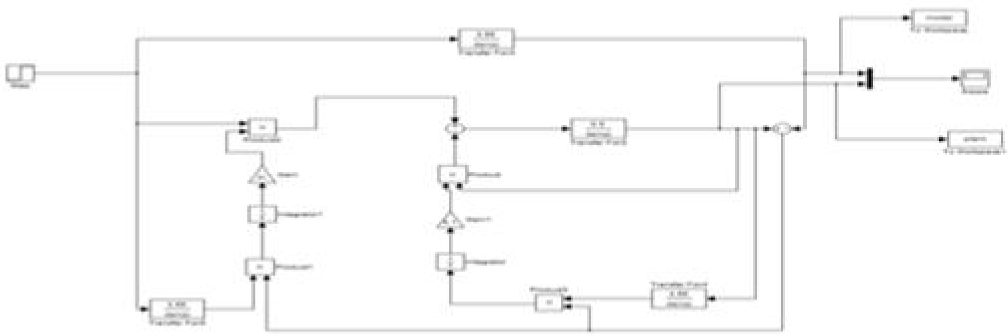


Fig. 5. Simulink Model of MRAC with MIT rule

Comparison of Adaptive controller and conventional controller with a step input.

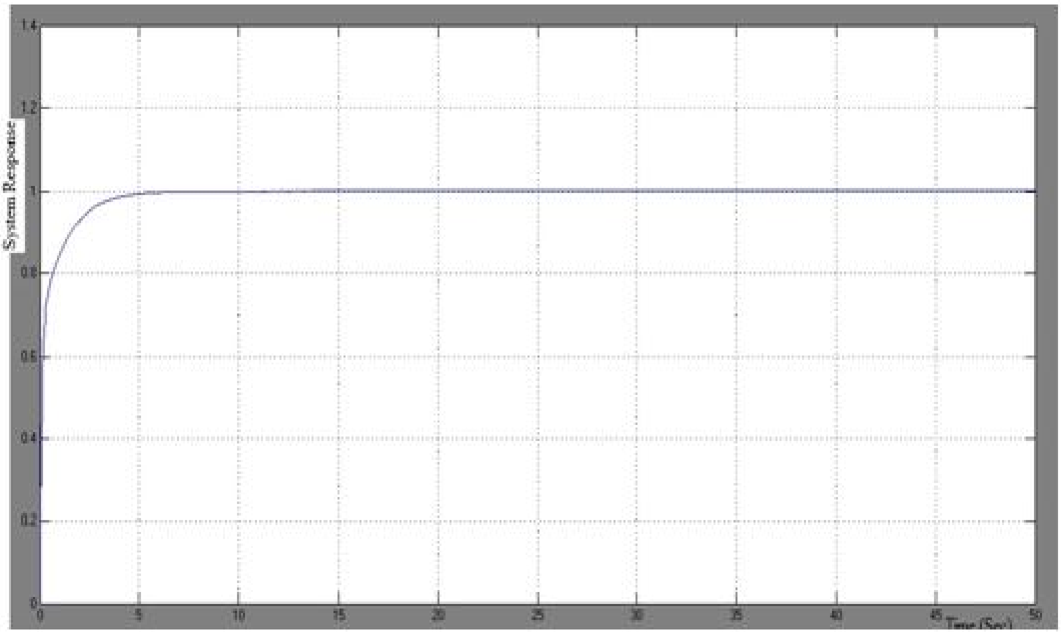


Fig.6. Plant output with conventional PID controller

By using the conventional PID controller, the time taken to reach the set value was 35 seconds.

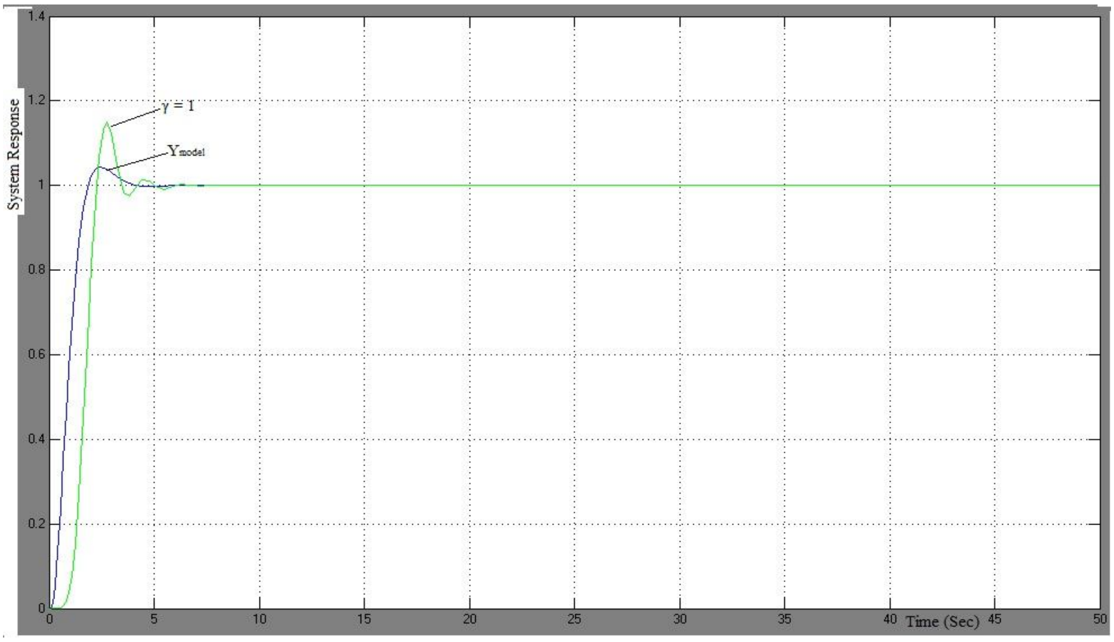


Fig.7. Plant output with Adaptation gain Gamma=1

By using Adaptive control, the time taken to reach the set value was 6 seconds with the adaptation gain of 1. Therefore the settling time in adaptive control method is less than conventional control method. Hence the Adaptive control is suitable for process control applications than conventional PID controller.

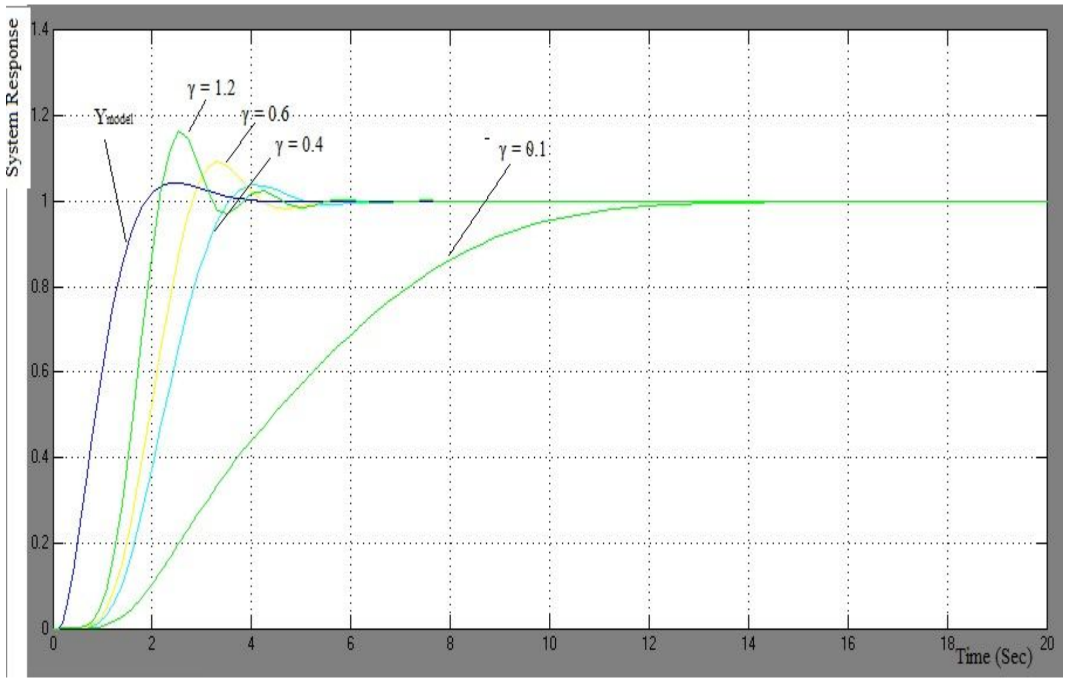


Fig.8. Plant output with Adaptation gain Gamma=0.1, 0.4, 0.6 1.0 and 1.2 .

Comparison of Adaptive controller by varying the Adaptation gain. From this fig.7. it is observed that if the value of Adaptation gain is increased then the settling time, peak time and rise time is reduced.

Genetic Algorithm:

The GA is a stochastic global search method that mimics the metaphor of natural biological evolution. GAs operate on a population of potential solutions applying the principle of survival of the fittest to produce (hopefully) better and better approximations to a solution.

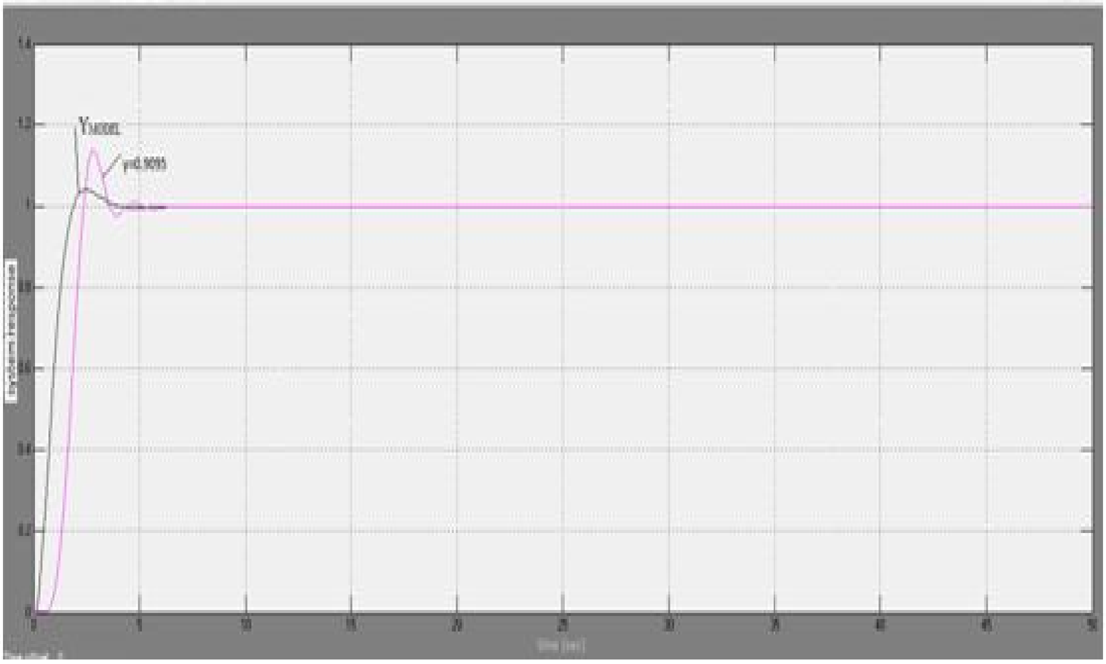


Fig.9 .Plant output with adaptive control, Gamma=0.9095

Table I. Effect of Adaptation Gain on Time Response Curve

Time domain response	PID	MRAC (Adaptation gain value)					MRAC GA
		0.1	0.4	0.6	1	1.2	0.9095
Settling time(sec)	8.5	14	5.2	5.5	6	7	5.4
Peak time(sec)	-	-	4.1	3.2	2.8	2.5	2.6
Rise time(sec)	3.5	9	3.1	2.6	2.2	2	2.2

VI. CONCLUSION

As compared to conventional fixed gain controllers (PID Controllers) Adaptive Controllers are very effective to handle the situations where the parameter variations and environmental changes are frequent have been demonstrated clearly in results. The adaptive controller maintains constant dynamic performance in the presence of unpredictable and immeasurable variations. This paper describes the behavior of a system controlled by model reference adaptive control scheme using MIT rule. Also the effect of adaptation gain is checked on the time response characteristic of the second order system. It has been seen that response is very slow with the smaller value of adaptation gain. The adaptation gain is increased then the settling time is reduced and the peak time and rise time is decreased. If adaptation gain is increased further the time response specifications are almost become constant on time response curve.

In order to avoid the computational complexity GA was used for further implementation. Here by using the GA we got the the best result, means plant output is perfectly matched with the model output at an Adaptive gain value of 0.9095.

REFERENCES

[1] Pankaj Swarnkar,Shailendra Jain and R.K.Nema, ―Effect of Adaptation Gain on System Performance for Model Reference Adaptive Control Scheme using MIT Rule, World Academy of Science, Engineering and Technology.pp.621-626,2010.

[2] Megha Jaiswal , Mohna Phadnis -Speed Control of DC Motor Using Genetic Algorithm Based PID Controller , International Journal of Advanced Research in Computer Science and Software Engineering , Volume 3, Issue 7, July 2013.

[3] MahboobehDelbari,KarimSalahshoor and BehzadMoshiri, ―Adaptive Generalized Predictive Control and Model Reference Adaptive Control for CSTR Reactor, International Conference on Intelligent Control and Information Processing.pp.165-169,2010.

[4] Rahul Upadhyay and Rajesh Singla, ―Application of adaptive control in a process control, International Conference on Education Technology and Computer.pp.323-327, 2010.

[5] B.Wayne Bequette, process dynamic modeling, analysis and simulation; Precentice Hall: NJ, 1998.

[6] W. J. Astrom and B. Wittenmark, ―Adaptive Control, Pearson Education, Singapore, 1995.

[7] Vinodha.R, Abraham Lincoln.S and Prakash.J, ―Multiple Model and Neural based Adaptive Multi- loop PID Controller for a CSTR Process, International Journal of Electrical and Computer Engineering.pp.251-256, 2010.

[8] George Stephanopoulis, ―Chemical Process control, Prentice-Hall of India Private Ltd., India, 2008.

[9] The Mathworks, MATLAB Model Reference Guide, Conchitutate place, 24 prime park, Natick 01760MA,USA, 1992

[10] K.Prabhu, Dr, Murali Bhaskaran-Optimization of control loop using Adaptive method.