Disturbance Rejection PID controller optimized using Genetic Algorithm for Time Delay systems

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***Abstract*— This paper presents a optimal solution of disturbance rejection PID controller using Genetic Algorithm method for time delay systems. Disturbance rejection PID controller has two goals first goal is to optimize a PID controller to reject the disturbance and second goal is for set point tracking. Therefore two separate controllers need to design one goal is for disturbance rejection and second goal is for set point tracking. Genetic Algorithm is used to find the optimum values of these two controllers. Optimum values are obtained by evaluating the individual controller separately. MATLAB/Simulink software is used to find the optimum values of PID controller.**

Keywords— Disturbance Rejection, Set point Tracking, PID Controller, Genetic Algorithm.

I. INTRODUCTION

In Recent years PID controller has been widely used in industrial fields. There are many methods to find the parameters of PID controller such as Ziegler-Nichols method, IMC method, kappa tau method, cohan-coon method etc. But most commonly used method to tune the PID controller is Ziegler-Nichols method [1]. But one disadvantage of this method is that it depends on user experience. Therefore this method is used to find the approximate results. Recently many optimization techniques are developed for tuning of PID controller such as Particle swarm optimization, artificial bee colony algorithm, Taguchi method, Genetic Algorithm etc. These methods find the optimum values of Kp, Ki, Kd based on performance indices.

Addition of delay in the system will become too much difficult to tune [1]. Therefore tuning a PID controller for a time delay system will be a difficult task [2]. For a long time there are many results about how to tune the Time Delay system consists of transfer functions with Dead time. Typically, Dahlin algorithm and smith predictor are commonly used. Increase in dead time will increase the delay in the system, addition of time delay in the system tends to reduce the stability [3]. Therefore tuning of such controller becomes very difficult task. In real time applications there are many disturbances present in the system. Therefore transfer function of the model and transfer function f the actual system is different. This results change in the parameters of the system transfer function [7]. This results in improper tuning of PID controllers. Improper tuning of PID controller may lead to instability of whole system [8]. Therefore if there is any disturbance in the system, it is very difficult to tune PID controller for such systems [9]. System may become unstable due to unwanted disturbances.

Therefore to obtain the better results, controller has to reject the disturbance as well as to track the set point. This needs to design two controllers. First controller is to reject the disturbance and second controller is for set point tracking. This means that designing of PID controller must be robust. But there can be two reasons behind PID controller bad robustness. Firstly, plant model is different than actual plant. Then designed controller will not give the optimum results as required. Secondly, change in controller plant parameter due to disturbances and delays. Therefore two controllers need to be designed first for rejection of disturbance and second is for set point tracking [10].

This paper uses Genetic algorithm optimization technique for finding the values of PID controller. Genetic Algorithm is optimization technique based on natural evaluation [10]. Genetic Algorithm is a robust and powerful search technique to find the optimum values of Kp, Ki, Kd. Genetic Algorithm depends on natural selection [11]. Genetic Algorithm has three operators as: Selection, Crossover, and Mutation. Genetic Algorithm uses Objective function and this objective function is to be maximized or minimized.

II. PROBLEM FORMULATION

The design problem is to find the values of two Controllers such that first controller rejects the disturbance and second controller is to track the set point using Genetic Algorithm optimization technique. The objective function for Genetic Algorithm is to minimize the Integral Time Absolute Error (ITAE).

$$\mathrm{ITAE}=\int t\,|e(t)|\,dt \tag{1}$$

III. DISTURBANCE REJECTION PID CONTROLLER

This paper uses first order system with time delay. Therefore transfer function of the plant is given by,

$$G(s) = \frac{K\, e^{-ds}}{(Ts+1)} \qquad (2)$$

Apply a PID Controller to given system with time delay. The main objective of PID controller is to reject the disturbance as well as track the set point. Single degree of freedom PID controller can't perform these two tasks simultaneously; therefore two degree of freedom PID controller is used to perform these two tasks simultaneously. Disturbance Rejection PID controller is shown in figure below:

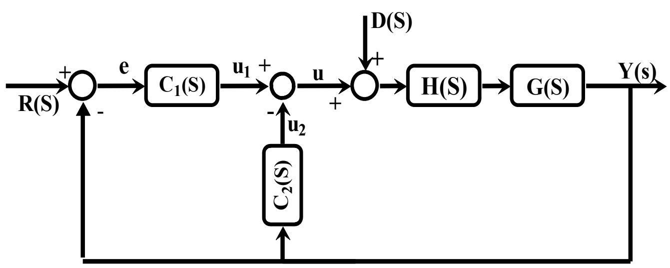


Figure Control System with Disturbance

Where, $G(s)$ = Plant to be controlled.

$H(s)$ = Zero order hold.

$C_1(s)$ = PID Controller.

$C_2(s)$ = PID Controller.

$R(s)$ = Reference input.

$D(s)$ = Disturbance input.

Therefore Two controllers are implemented first controller is used to rejects the disturbance and second controller is used for set point tracking [7].

PID controller is of the form given by equation,

$$\text{PID controller} = (K_p + K_i/s + K_d\, s)\, e(s) \qquad (3)$$

Where, K_p = Proportional Gain

K_i = Integral Gain

K_d = Derivative Gain

$e(s)$ = Error Signal

Addition of delay and disturbance in the system in the system decreases the stability. Therefore tuning of PID controller is always a difficult task. Genetic Algorithm is an optimization technique used to find the optimal values of PID controllers.

IV. DESIGN METHOD FOR DISTURBANCE REJECTION PID CONTROLLER

Designing of Disturbance Rejection PID controller has two goals first goal is to reject the disturbance and second goal is to track the set point. Therefore this need to implement two controllers, first for disturbance rejection and second is for set point tracking.

For Disturbance rejection reference input is taken as zero and for Set point tracking Disturbance input is taken as zero. Then Find the values of two PID controllers.

A. Disturbance Rejection PID Controller

The designing of PID controller should be such that any disturbance in the system will not affect the performance of the system. If Reference input is set to zero, then there is only one input to the system and this input is nothing but disturbance input [7].

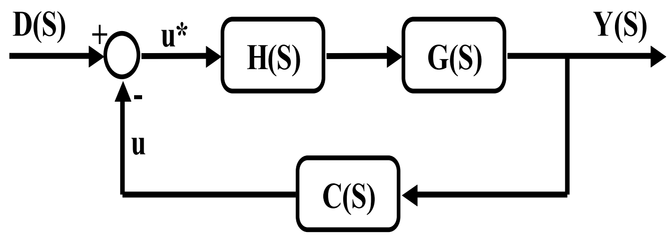


Figure Equivalent Disturbance Rejection Diagram

Where, $C(s) = C_1(s) + C_2(s)$

Running for first GA, the optimal values of PID controller are given by K_p, K_i, K_d.

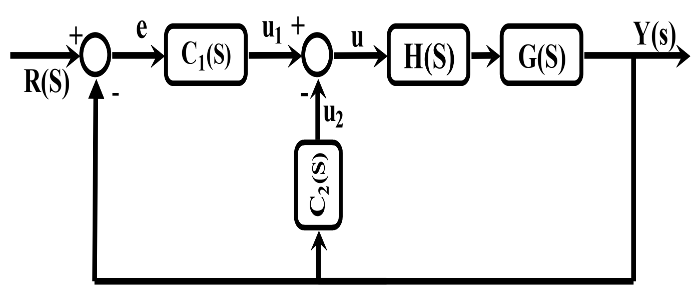
From above figure:

$$K_p = K_{p1} + K_{p2}$$
$$K_i = K_{i1} + K_{i2}$$
$$K_d = K_{d1} + K_{d2} \qquad (4)$$

For Disturbance rejection the output must set to zero finally when reference input is set to zero.

B. Set Point Tracking PID Controller

For set point tracking, system output must follow the reference input. In that case the disturbance input to the system is assumed to be zero. Therefore block diagram for set point tracking is shown in below:



Running second GA, the optimal values of PID controller are K_{p1}, K_{i1}, K_{d1}. From equation 4 we can optimal values for second controller K_{p2}, K_{i2}, K_{d2} [7].

V. GENETIC ALGORITHM

Genetic Algorithm is an optimization technique that depends on survival of fittest. Genetic Algorithm is a powerful search technique to find the optimal values of PID controller. Fitness function or objective function is required to find the optimal values of PID controllers. These objective function or fitness function can be found by minimizing the performance indices. Performance indices of the systems are Integral time absolute error (ITAE), Integral absolute error (IAE), Integral square error (ISE), Integral Time Absolute Error (ITSE). This paper uses Integral Time Absolute Error (ITAE) as a performance Index [8] Therefore fitness function is given by the equation given below:

$$\text{Fitness function} = \frac{1}{\text{Performance Index}} \qquad (5)$$

Genetic Algorithm starts with random generation of populations Single population consists of a set of chromosomes and single chromosome consists of arrays of Genes. Each gene has particular value.

While finding the values using GA, actual solution space (Phenotype space) is encoded into computational space (Genotype space). After termination of genetic algorithm, the computational space (Genotype space) is decoded into a actual solution space (Phenotype space).

Basically Genetic Algorithm consists of three operators given by:

A) Selection

B) Crossover

C) Mutation

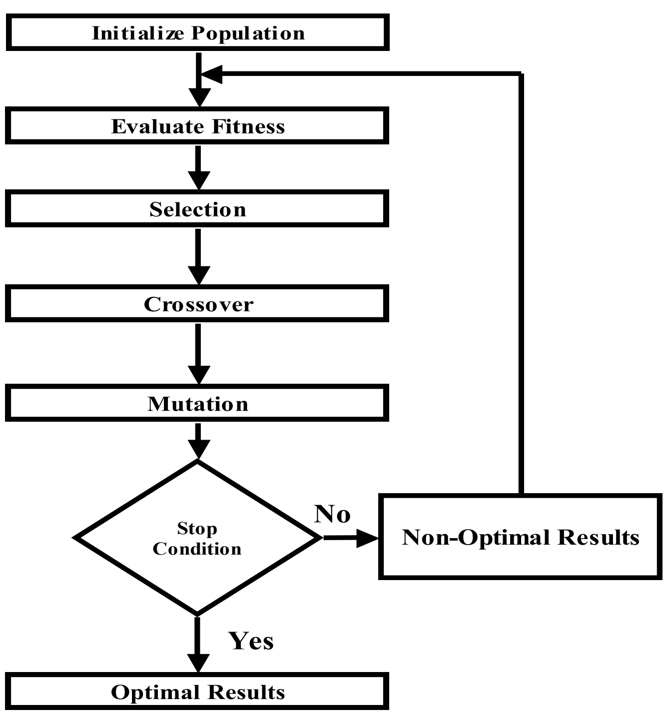


Figure Block Diagram of Genetic Algorithm

A. Selection

Genetic Algorithm starts with random generation of population. The selection criteria for genetic algorithm towards it's optimal values is based on fitness function or objective function. In selection criteria, solution which goes near to the optimal value are selected and other solutions are rejected [9]. There are different types of selection such as roulette wheel selection, Tournament selection, rank selection, random selection.

Furthermore in reproduction two parent solutions are selected to form a new solution and this newer solution is closer towards optimal solution.

B. Crossover

From selection two parents solutions are selected to form a new one in crossover. In crossover operator, it exchanges the genes of two chromosomes to form a third one. This chromosome is closer to the optimal solution. Use of crossover operator moves one step ahead towards the optimality of the solution.

Crossover exchanges the gene of two solutions. Therefore this chromosome has combined characteristics of two parent solutions. There are different types of crossovers namely one point crossover, multi point crossover, uniform crossover, whole arithmetic recombination and davis order crossover.

C. Mutation

Mutation operator is defined as small random tweak in the chromosome to get a new solution. It is used to maintain diversity in the population. Normally mutation operator is usually applied with the low probability. If mutation probability is high then search will be random [10].

Mutation alters one or more gene values in the chromosome in the set of population. There are different types of mutation operators as bit flip mutation, random resetting, swap mutation, Scramble mutation, and Inversion mutation.

The fitness function required for genetic algorithm is Integral Time absolute Error (ITAE). our main objective is to minimize the response, track the set point and reject the disturbance.

VI. STEPS TO DESIGN CONTROLLERS

For a given transfer function with time delay systems, the designing of PID controllers using MATLAB/Simulink is given below:

For Disturbance Rejection PID controller

To find the values of disturbance rejection PID controller reference input is taken as zero.

Step 1: To form a program using MATLAB/Simulink for Disturbance rejection PID controller with the fitness function.

Step 2: Open the optimization toolbox and select genetic algorithm from solver (GA), write @name of the file, number of variables are three finally write the bound on the system.

Step 3: Click on start button, genetic algorithm will starts to find the optimal values of PID controller.

We get the values of PID controller K_p, K_i, K_d and this is the value of addition of two controllers.

For Set point Tracking PID controller

Same procedure is applied for set point tracking but the difference is that disturbance input should be zero.

Step 1: To form a program using MATLAB/Simulink for Set point tracking PID controller with the fitness function.

Step 2: Open the optimization toolbox and select genetic algorithm from solver (GA), write @name of the file, number of variables are three finally write the bound on the system.
Step 3: Click on start button, genetic algorithm will starts to find the optimal values of PID controller.

We get the values of PID controller K_{p1}, K_{i1}, K_{d1} and this is the value of addition of two controllers.

Therefore from equation 4 we can find the values of K_{p2}, K_{i2}, K_{d2}.

VII. DESIGN EXAMPLE

The transfer function of the system with delay is given by,

$$G(s) = \frac{10\ e^{-0.1s}}{s+10} \quad (6)$$

Therefore we have to design disturbance rejection PID controller. Problem formulation is that optimize PID controllers which will rejects the disturbance as well as to track the set point. Genetic Algorithm is used to find the optimal values of PID controllers [12]. we have to run the genetic algorithm two times first for disturbance rejection and second is for set point tracking.

While designing for disturbance rejection, system reference input is taken as zero. Consider disturbance is in the form of step signal. If reference input is taken as zero for unit step disturbance, find the values of PID controller as shown in above figure such that output must goes to zero. Running the first GA will finds the values of two PID controllers K_p, K_i, K_d from figure 2

For set point tracking input disturbance is taken as zero and input is only a reference signal. Run it for second GA will find the optimal values first controller ie- K_{p1}, K_{i1}, K_{d1}. Therefore from equation 4 we can find the values of K_{p2}, K_{i2}, K_{d2}.

Table Optimal Values of Parameters of PID controller with unit step disturbance

K_{p1}	K_{i1}	K_{d1}
0.5333	4.7870	0.0054
K_{p2}	K_{i2}	K_{d2}
0.167	0	0.0259

Table 2 Optimal Values of Parameters of PID controller with Sinusoidal disturbance

K_{p1}	K_{i1}	K_{d1}
0.784	6	0
K_{p2}	K_{i2}	K_{d2}
0.051	0	0

VIII. SIMULATION AND RESULTS

For a system with time delay as given in the design example, two simulations need to be performed. First simulation is for disturbance rejection PID controller in which K_p, K_i, K_d need to be find out using GA. And second simulation is for Set point tracking in which K_{p1}, K_{i1}, K_{d1} need to be find out. From equation 4 K_{p2}, K_{i2}, K_{d2} are calculated.

MATLAB Simulation

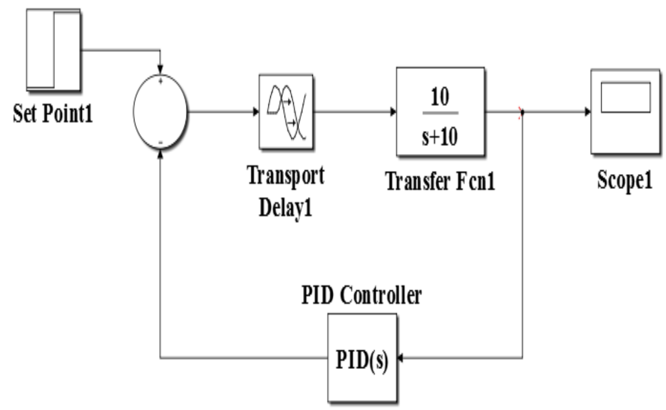


Figure Disturbance Rejection PID Controller

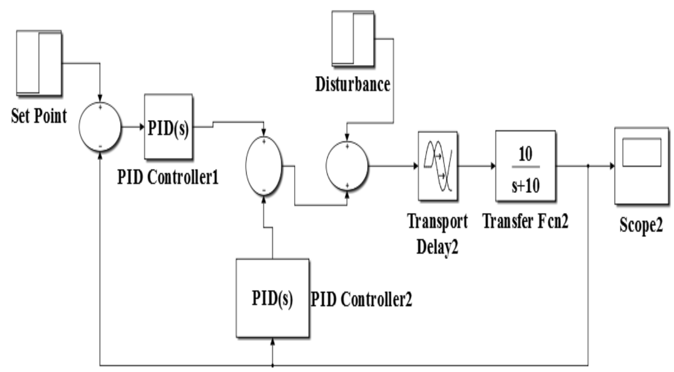


Figure Set point tracking and disturbance rejection PID Controller

Results:-

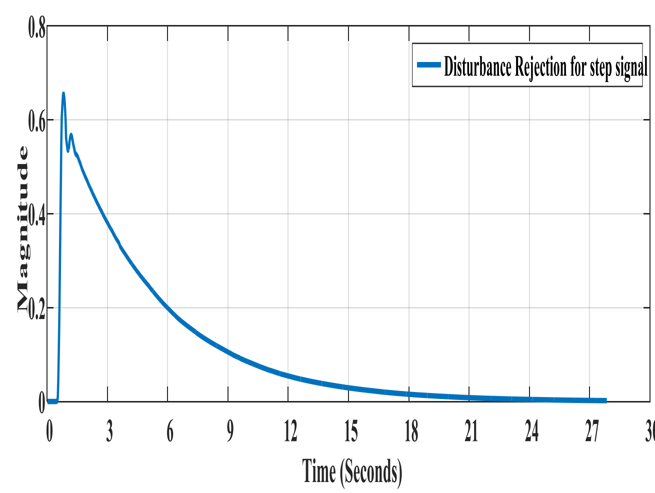


Figure Disturbance Rejection PID controller for Step Disturbance

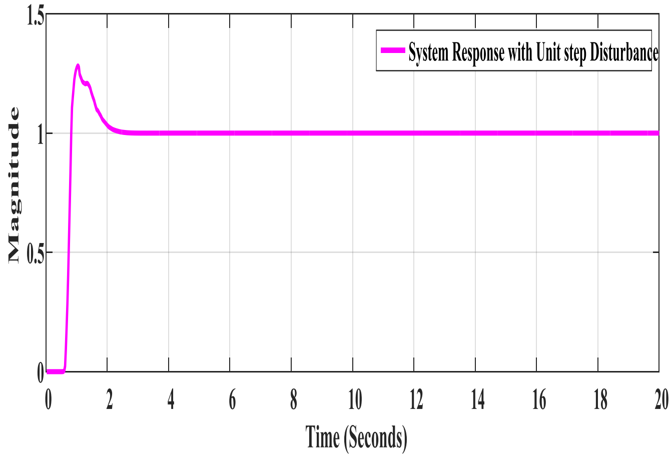


Figure System Response with Unit Sep Disturbance

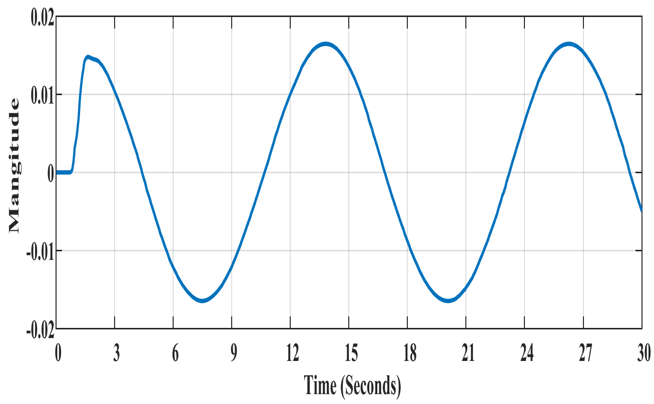


Figure Disturbance Rejection PID controller for Sinusoidal Disturbance

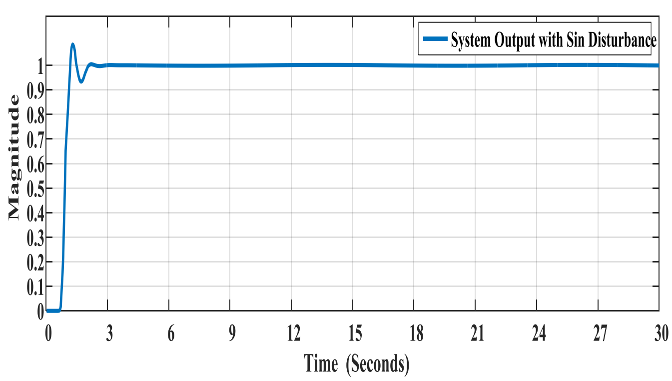


Figure System Output With Sinusoidal Disturbance

IX. Conclusion

This paper proposes proposes Genetic Algorithm based disturbance rejection PID controller for time delay systems. Two PID controllers are used in this work. Run GA for two different disturbances that is step and sinusoidal disturbances. The simulation results are found that output waveform rejects the disturbance as well as it tracks the set point for two different disturbances.

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