Genetic Algorithm Based PID Controller for Attitude Control of Geostationary Satellite

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Abstract

The main objective of this paper is to design a PID controller for a geostationary satellite system by selecting the optimal values of the PID controller parameters using genetic algorithms. The model of a geostationary satellite system is considered as a second order system. In addition, this paper compares two kinds of tuning methods for PID controller parameters. The first method is the controller design, which incorporates the genetic algorithms as tuning tool and the second is the conventional controller designed by Ziegler and Nichols experimental method. It was concluded from simulation results that the PID parameters adjusted by the genetic algorithm gives better closed-loop performance than the Ziegler & Nichols'.

Keywords: Ggeostationary Satellite, Genetic Algorithms, PID Controller, Ziegler Nichols Method.

1. Introduction

In general, Proportional-Integral-Derivative (PID) controllers have been widely used for process control [1, 2]. It well established fact that PID controllers are considered as the dominant controllers in the process. The main reason for this domination is due to the robustness of these controllers to control a wide range of processes and also the simplicity of their structures. However, the tuning parameters of the conventional PID controllers must be estimated by tuning techniques either in frequency response or time response to attain the desired performance [3].

Many conventional PID tuning methods are introduced. Some of these tuning methods are based on mathematical criteria Cohen –Con method, Trial and Error methods and Experimental method such as the Ziegler-Nichols method and Relay feed-back method. Conventionally, the experimental Ziegler-Nichols method of [4] is widely used despite the requirement of a step input application with stopped process. One of disadvantage of this method is a time consuming and it may not provide the good values of the PID parameters (K_p, K_I and K_d) [5].

Therefore, in order to overcome these limitations, it is highly desirable to increase the capabilities of PID controllers by adding new artificial intelligent features such as Fuzzy Logic, Neural Networks and genetic algorithms. The Genetic Algorithms (GAs) have recently much interest for achieving high efficiency and solving global optimization problems [2, 6, 7]. Therefore, this research endeavours to combine the advantages of PID controllers with those of Genetic Algorithms.

GAs is a search algorithm based on principles of natural selection and genetics which mimics the process of natural evolution. It has been recognized as an effective technique for process control optimization compared with classical tuning methods [6, 7]. For this reason the main objective of this paper is to demonstrate the effect of GAs tuning method in the performance of closed-loop system. This can be investigated by comparing the simulation results of GAs tuning method against those of the classical Ziegler-Nichols experimental method.

The paper is organised as follows: Section 2 formulates the system model of a geostationary satellite. Section 3 focuses on the conventional PID controller tuning by Ziegler Nichols method with application to a geostationary satellite. A brief review of GAs presented in section 4. Section 5 presents the simulation results to demonstrate the performance of the closed loop system using both conventionally tuned and GAs based PID control. The concluded remarks and recommendations for future work are given in section 6.

2. Satellite Model

Satellites can be polar orbiting, covering the entire Earth asynchronously, or geostationary which is hovering over the same spot on the equator [9]. Geostationary or geosynchronous satellites are orbits at a distance of 35,900 km above an almost fixed spot above the equator on the earth surface in order to cover meteorological applications such as monitoring the weather and climate of the Earth and other changes in the Earth vegetation, and to perform the TV broadcasting and most other types of global communications. The geostationary meteorological satellite is primarily used to monitor clouds, fires, effects of pollution, sand and dust storms, snow cover, ice mapping, boundaries of ocean currents, and energy flows [9, 10].

The problem of designing an attitude control system for a rigid satellite body in geostationary orbit operating in a friction less environment, having no disturbance is considered. Geostationary satellite usually requires attitude control so that antennas, sensors, and solar panels are properly oriented. For example, antennas are usually pointed towards a perpendicular location on the earth while solar panels need to be oriented towards the sun for maximum power generation [8].

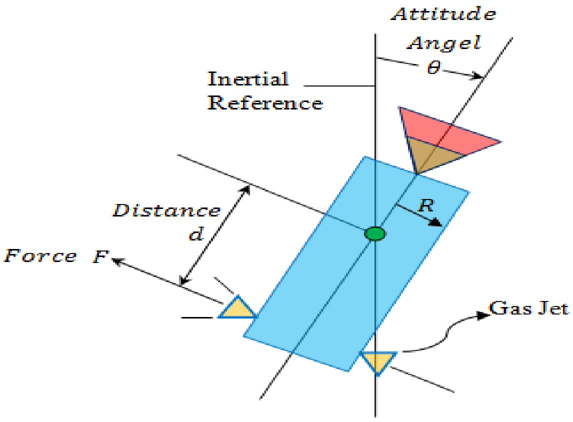

Fig.1: Rigid satellite body Schematic.

The equations of motion of the satellite system can be expressed by [8]:

$$J\ddot{\theta} = M_C + M_D \tag{1a}$$
$$M_C = Fd \tag{1b}$$
$$J = \frac{1}{2}MR^2 \tag{1c}$$

Where, F is the force coming from the reaction jet, d is the distance of the body from its mass centre, J is the moment of inertia of the satellite about its mass centre, M_C is defined as the control torque applied by the thrusters which comes from the reaction jet, M_D is the disturbance torque, M is the mass of satellite, R satellite radius and θ (rad) is the angle of the satellite axis with respect to an "inertial" reference.

If we assume that:

$$u(t) = M\ \frac{C}{J} \tag{2}$$

and $\xi'(t) = \frac{M_D}{J}$

(3)

then the dynamic equation (1a) becomes:

$$\ddot{\theta}(t) = \left(u(t) + \xi(t)\right) \tag{4}$$

Where $u(t)$ is the control input signal and $\xi(t)$ is the process noise.

Taking Laplace Transform of equation (4) yields:

$$\theta(s) = \frac{1}{s^2}[U(s) + \xi(s)] \tag{5}$$

The discrete model of the satellite system can be written as [8]:

$$\theta(z) = \frac{T_s^2}{2} \frac{(z+1)}{(z-1)^2} [U(z) + \xi(z)] \tag{6}$$

A discrete state-space of Single-Axis Geostationary Satellite attitude control model at $T_s = 1sec$ is:

$$\begin{bmatrix} X_1(t+1) \\ X_2(t+1) \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -1 & 2 \end{bmatrix} \begin{bmatrix} X_1(t) \\ X_2(t) \end{bmatrix} + \begin{bmatrix} 0.5 \\ 1.5 \end{bmatrix} u(t) + \begin{bmatrix} 0.5 \\ 1.5 \end{bmatrix} \xi(t) \tag{7a}$$

$$y(t) = [1 \quad 0] \begin{bmatrix} X_1(t) \\ X_2(t) \end{bmatrix} + v'(t) \tag{7b}$$

where, the state $X_1(t)$ is the position state (rad) of satellite, and the state $X_2(t)$ is the velocity state of satellite (rad/sec). However, in this work the proposed controller is used to control the position of one axis of the satellite model (i.e. Pitch, Yaw or Role) [8].

3 Tuning of PID Controller Using Convention Approach

Considering only Ziegler-Nichols method of conventional PID controller tuning method, which is widely accepted method for tuning the PID controller, the control system may give poor performance and even it becomes unstable, if improper values of the controller tuning parameters are used. Therefore, it is important to tune the controller parameters to achieve satisfactory closed loop system performance. The PID controller tuning method involves the selection of the optimal values of K_c, T_i and T_D , which is often a subjective procedure and is certainly process dependent. The method is straightforward. First, set the controller to P mode only. Second, set the gain of the controller (K_c) to a small value. After that make a small set point (or load) change and observe the response of the controlled variable. If K_c is low the response should be sluggish. Increase K_c by a factor of two and make another small change in the set point or the load. Keep increasing K_c (by a factor of two) until the response becomes oscillatory. Finally, adjust K_c until an oscillatory response is obtained. Where the oscillatory gain is known as ultimate gain (K_u) and the period of this oscillation is known as oscillation period (P_u). From these oscillatory gains K_u and P_u as shown in table 1, the PID controller tuned parameters can be obtained.

Table1: Control law settings.

Controller	K_p	T_i	T_d
P	$\frac{K_u}{2}$		
PI	$\frac{K_u}{2.2}$	$\frac{P_u}{1.2}$	
PID	$\frac{K_u}{1.7}$	$\frac{P_u}{2}$	$\frac{P_u}{8}$

4 Overview of Genetic Algorithm

Genetic Algorithms is a stochastic global optimization method based on the mechanisms of natural selection, which is inspired by Darwinian Theory. It has been recognized as an effective and efficient technique to solve optimization problems compared with other optimization techniques. The Genetic Algorithms Architecture is shown in Fig.2 it can be seen from Fig.2 that GAs starts with an initial population containing a number of encoded strings known as chromosomes; each string represents a solution of the problem. Crossover operator is employed on these strings to obtain possible solutions, which inherit the good and bad properties of their parents' solutions. Each solution has a fitness value. The solutions that are having higher fitness value are the most likely survived for the next generation. Mutation operator applied to produce new characteristics, which are not found in the present solution. This algorithm is repeated for many generations and finally stops when reaching individuals that represent the optimum solution to the problem [6, 7].

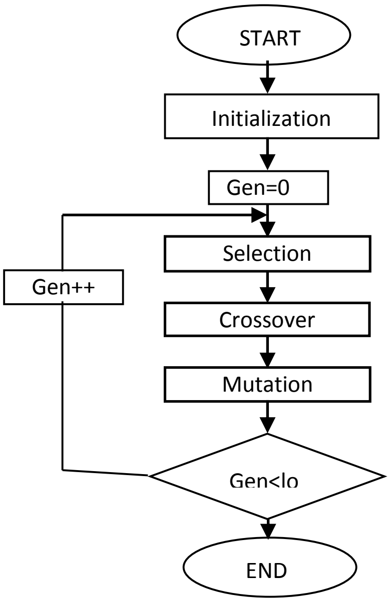

Fig.2: Genetic Algorithm Architecture.

5 Simulation Results

In order to see the performance of both the PID conventionally tuned and GA based PID controller, these controllers are used to control the altitude of geostationary satellite. In section 5.1, the conventional PID controller is used to control the attitude of geostationary satellite and using the genetic algorithms based PID controller to control geostationary satellite attitude is presented in section 5.2. The simulation results is analysed in section 5.3.

5.1 Geostationary satellite position Control using conventionally tuned PID Control

In this simulation experiment a unit step signal is introduced as a reference input. The conventional PID controller which is tuned using Z-N method and discussed in section 3 was applied to the geostationary satellite simulated model of equations (7a) and (7b) using Matlab simulation environment. The conventional PID controller parameters using Z-N method are shown in table2.

Table2: PID controller setting.

Gain Coefficients	K_p	K_i	K_d
Values	40	50	20

The output and control input signals are shown in Fig.3a and Fig. 3b, respectively. Whereas, bode plot is shown in Fig.3c.

Table.3 shows the performance criteria in the situation where the Conventional PID controller is used.

Table3: Conventional PID Performance criteria.

System specifications	**Maximum overshoot**	**Rise time(sec)** t_r	**Settling time(sec)** t_s	**GM**	**PM deg.**
Values	8.67	0.875	1.08	Inf.	154

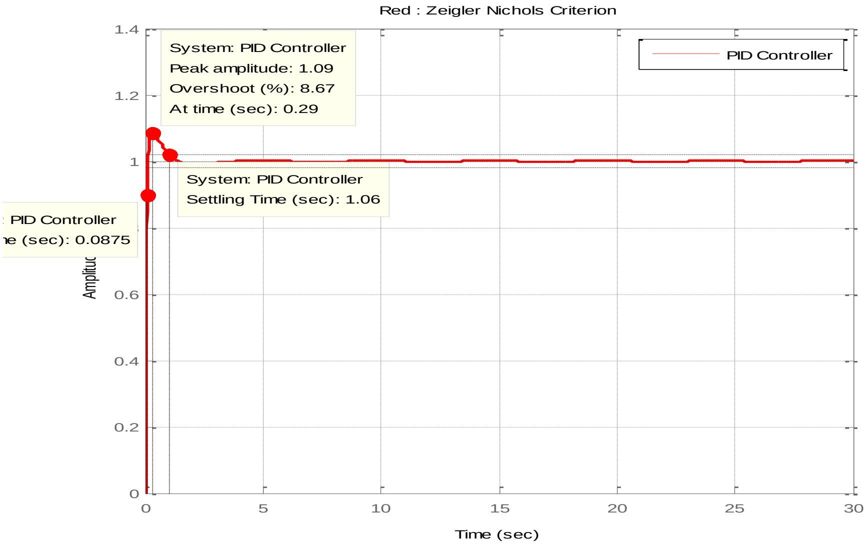

Fig.3a: The output response using PID controller based Z-N Tuning method.

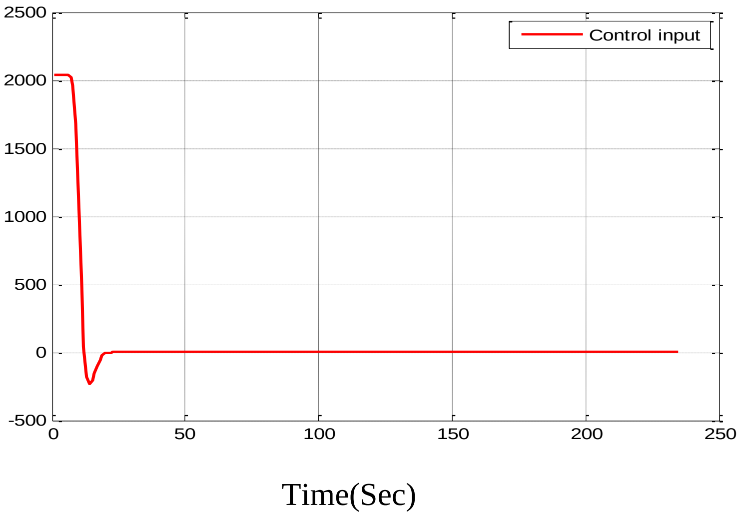

Fig.3b: The System control input signal.

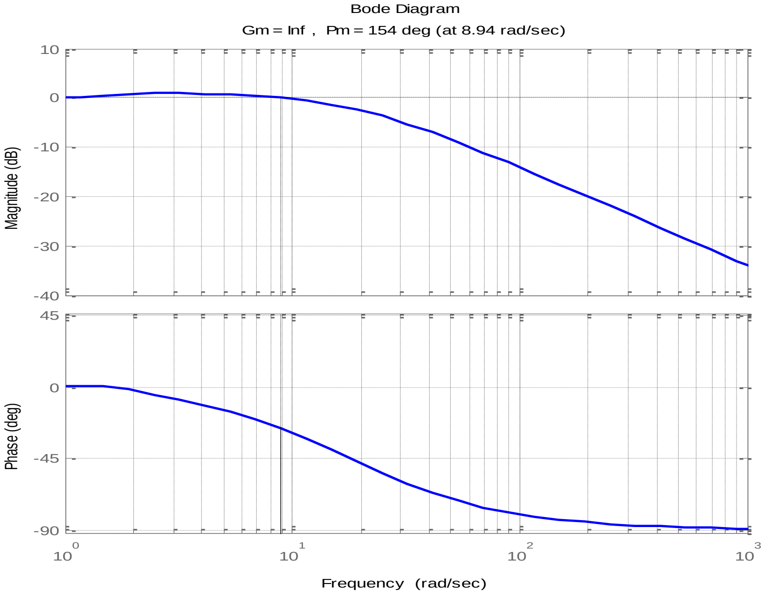

Fig.3c: Bode plot of the system when the conventional PID Controller is used.

5.2 Geostationary Satellite Altitude Control Using GA Based PID Control

GAs can be used to tune the parameters of PID parameters in order to ensure optimal control performance at nominal operating conditions. The genetic algorithms parameters chosen for the tuning purpose are shown in table 4.

Table4: Tuning parameters of Gas.

GA property	Value/Method
Population Size	80
Maximum Number of Generations	20
Performance index/fitness function	Mean square error
Selection Method	Normalized Geometric Selection
Probability of Selection	0.05
Number of crossover Points	3
Mutation Method	Uniform Mutation
Mutation Probability	0.1

A unit step signal is introduced in this case as a reference input. The output and control input signals are respectively shown in Fig. 4a and Fig.4b. Whereas, the frequency response and the values of the GA based PID controller parameters K_p, K_i and K_d are shown in Fig.4c and Fig.4d respectively and are situated in table 5.

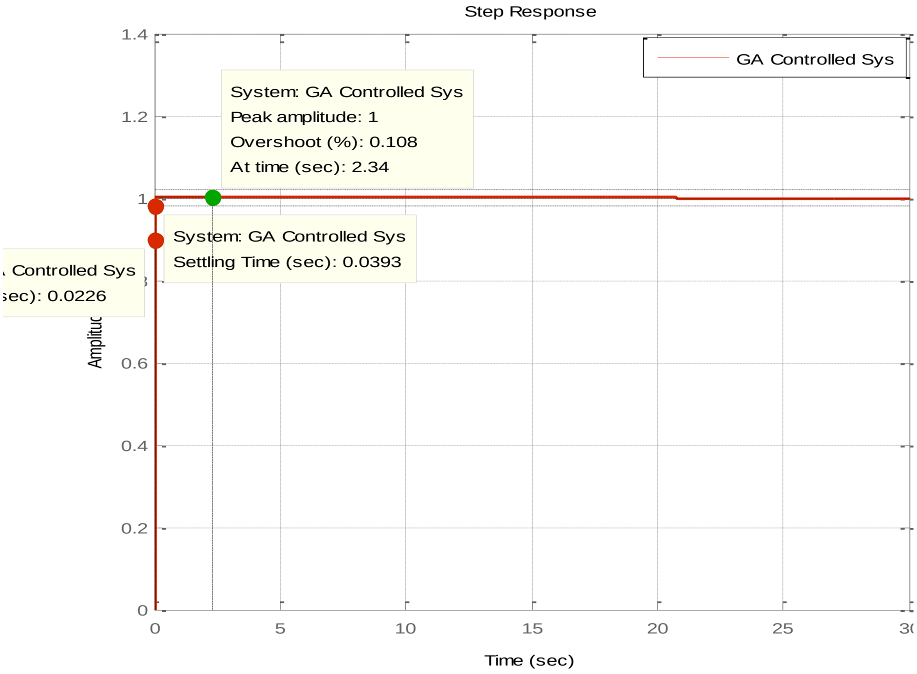

Fig.4a: The output signal when GA based PID controller is used.

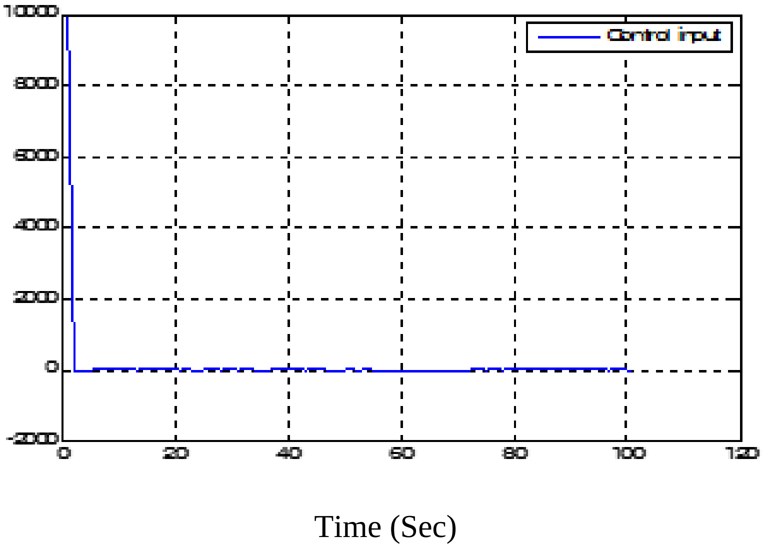

Fig.4b: The control input signal using GA based PID controller.

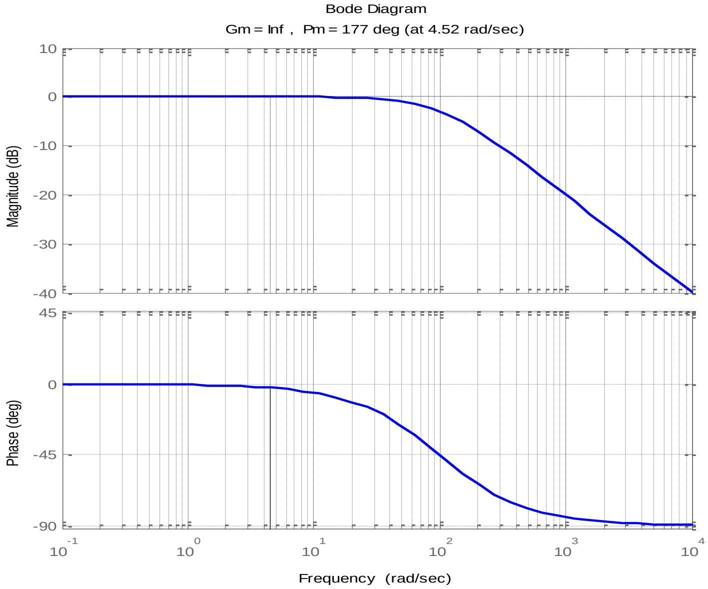

Fig.4c: Bode plot of the system when the GA based PID Controller is used.

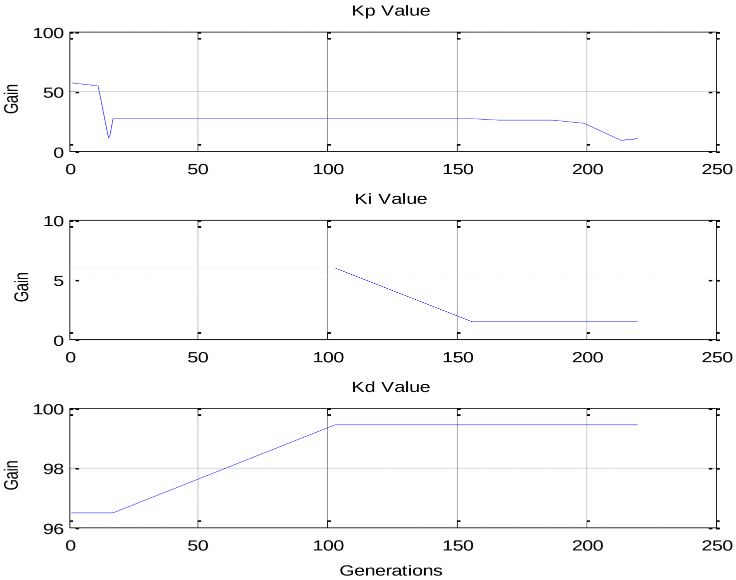

Fig.4d: Illustration of the Genetic Algorithms Converging through Generations.

Table5: Results of GA based PID controller.

Tuning Method	**K_p**	**K_i**	**K_d**	**Maximum overshoot**	**Rise time(sec)**	**Settling time(sec)**	**G_m**	**P_m**
GA	10.1949	1.4440	99.4437	0.108	0.0226	0.0393	Inf.	177

5.2.1 Investigating the effect of set point change and load disturbance on the performance using GA base PID controller

In order to see the influence of set-point change and the load disturbance on the closed loop system performance a set-point change from one to two was made at (t = 20 sec) and a step disturbance (20% of set-point) was artificially added to the system at (t = 10 sec). The output and control output signals are shown in Fig.5a and Fig. 5b. It can be seen from Fig. 5a and Fig. 5b that the GAs based PID control can cope with set point change and can easily regulate load disturbance to zero.

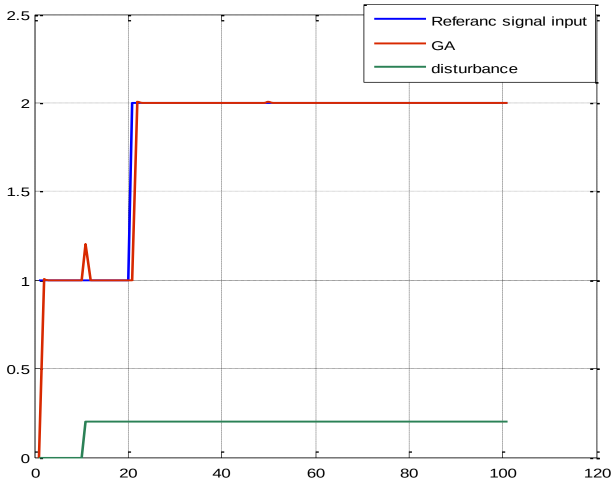

Fig.5a: The output signal in the presence of load disturbance and set point change.

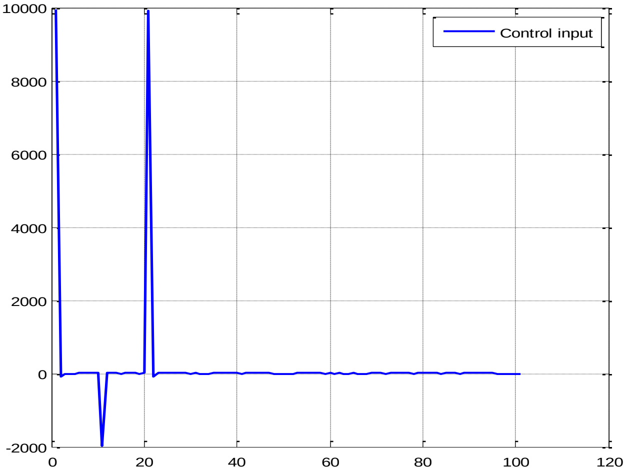

Fig.5b: The control input signal using GA based PID controller.

5.3 Analysis of the simulation results

It can be seen from Fig.3a and Fig.4a that, the implementation of conventionally tuned PID controller could not give accurate results. However, more satisfactory response can be achieved by the proper optimized gain values of the controller which are obtained with the implementation of GA based PID controller. Also it can clearly be seen from figures Fig.5a and Fig.5b and table5 that the GA based PID controller has the ability to eliminate steady state error to zero and can handle set point change with better Phase Margin value.

6 Conclusions

Geostationary satellites play key role in weather, navigation, communication, military intelligence and in scientific studies. They must be controlled to remain pointed in a specific direction, or orientation to accomplish their mission. For example, environmental satellites designed to detect changes in the Earth's vegetation, sea state, ocean colour, and ice fields.

In this paper, an attitude controller for geostationary satellite by selecting the optimal values of the PID controller parameters using genetic algorithm has been presented. It can be seen from simulation results shown in section 5, that the designed PID based GA has better response than response of the Ziegler-Nichols classically tuned method. The classical methods good for giving us the pre-starting indication of what are the PID initial values. It is obvious from section 5 that, the GA based PID is much better in terms of the overshoot, the settling time and phase margin than the conventional method. It is clearly can be seen from fig.5a and fig.5b that can cope with set-point change and has the ability to suppress the step load disturbances to zero. In order to further assess this design, the idea of implementing it in real time should be progressed. Since Global Positioning System (GPS) is effectively used for determination of a vehicle position and velocity with high accuracy [11], it is desirable to extend this work to cover GPS to perform attitude control.

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