Optimizing PID Controller for Large-Scale MIMO Systems Using Flower Pollination Algorithm

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***Abstract*—In communications systems, a group of technologies can be linked into one system. Each technology has a function, and each system has stages. Therefore, it can be said that the input stage can have one or multiple inputs. MIMO techniques suffer from a large-scale linear dynamic problem, it will be easy to adjust the (PID) of a continuous system, and any system is considered vulnerable to disturbances during the operation process. Therefore, a state of instability can occur in it, which requires developing solutions to modify the behavior of the it. Systems need control units to handle transient states as a result of changing operating conditions of the system. Expert and intelligent systems can be used to adjust the traditional controllers and make them adapt to the operating conditions of the proposed system. Work must be done to make the proposed approach capable of ensuring stability for the system. Work can be done to reduce the time for the transient state and the speed of response to the stable state. The behavior of the system can be clarified through simulation results and show the difference between the methods. Proposed to test the feasibility and effectiveness of the work and verify it using the MATLAB program to design a highly accurate and efficient model. The current study reviews This work displays the tuning of the PID controller for MIMO systems utilizing a statistical FPA and evaluated by objective function as integral time absolute error (ITAE). A combination of ITAE combined with the FPA reduction method is adopted to reduce the steady-state transient time responses between the higher-order initial scheme and the unit amplitude It also aims to conduct simulation and develop the appropriate and proposed design model with different. It is possible to compare the control of the system using a traditional control unit and another that adjusts using the modern technology of the Flower pollination algorithm FPA-PID. It also showed that the results of the simulation process were clear that the optimization process using FPA-PID was superior to the other traditional case (PID).**

Keywords—Communications Systems LS-MIMO; PID Controller; ITAE Fitness Function; FPA Algorithm.

I. INTRODUCTION

Communications systems depend on two processes: the first is the transmission process and the second is the reception process. There may be one or more communication channels on the sending side, and there may be one or more channels on the receiving side [1].

The name of these systems depends on the fact that they have one or more channels, and they are classified into systems called (SISO), which have a single connection on the input side and a similar connection on the critical side [2]. While the other type (MIMO) is multiple-entry and multiple-exit. It is worth noting that operating conditions vary in all systems and fields, as they change with the change in the crisis and the mechanism of use, and therefore disturbances may occur that require the development of treatments, including the addition of traditional and expert control systems. There is also advanced optimization, which is considered advanced systems to improve the performance of those systems, including communications systems [3].

In writing the current paper, [4] there is a process of developing a study and simulation of a system consisting of a set of relationships between the parts of the system with the aim of identifying them and analyzing the behavior of the system through the function of each part and its impact on the behavior of the system under different and changing operating conditions to suit the real potential of those systems and applications similar to the same proposed system. To learn about the behavior of the system, a first model is built with a working algorithm developed by testing the states of the system. The first is an open-loop linear system, the second is a closed loop [5]. The second model is a non-linear system for the same two previous cases (open loop, the second is a closed loop) [6]. The third model is a model that represents the same system states, but by adding a traditional controller to improve the performance of linear systems, and the fourth model is to improve the non-linear system by adding an intelligent optimal controller Tests were conducted after representing the model mathematically and writing the equation that represents the simulation model using a transfer function [7][8]. The results showed the possibility of verifying the system simulation to know the behavior of the system for all proposed cases, with a clear difference in behavior as a result of changing the proposed operating states. The closed-loop system state was also distinguished from the open-loop according to the proposed measurement criteria to determine the level of performance. The operating state was also distinguished by adding the traditional controller from the previous one. In linear systems and the superiority of the intelligent optimal controller in the operating conditions of nonlinear systems Previous experiments have proven the existence of advanced algorithms to determine the best parameters for the traditional controller (PID)to suit the process of improving the performance of various systems [9][10] including communications systems [11]. Flower pollination algorithms (FPA) are considered one of the most important advanced algorithms that can be added to the system and a suitable, advanced, high-performance mathematical model can be built and designed. To verify the validity and effectiveness of the model's work, tests have been developed in proposals that include operation in different conditions [12][13].

II. Dynamic System Representation

The system can be represented mathematically taking into account all the different and changing operating conditions. The linear system can be described to build the prototype of a multi-entry, multi-exit open loop system. Input can be coded with the letter U, while output can be coded with Y, and the number of inputs or outputs can be coded with the letter N.

The simulation process is usually experimental to verify and know the effectiveness of the system using mathematical representation of the system through numerical methods. Specifications for the system are developed, [14][15] the relationships between the components of the system are written, and the values are substituted to write the appropriate simulation model with the requirements of the proposed cases. Therefore, a table of values for the system parameters is created and a diagram is drawn up. An explanation shows the parts and components of the system, and the mathematical equations for the system are written.

The simulation process is usually experimental to verify and know the effectiveness of the system using mathematical representation of the system through numerical methods. [16][17]. Specifications for the system are developed, the relationships between the components of the system are written, and the values are substituted to write the appropriate simulation model with the requirements of the proposed cases. Therefore, a table of values for the system parameters is created and a diagram is drawn up. An explanation shows the parts and components of the system, and the mathematical equations for the system are written. An approximate algorithm is also developed to enable the model order reduction to be implemented [18][19].

Develop an approximation to the model and formulate the problem:

We can begin by establishing a single state of a linear system that can change with time, and thus the mathematical equation for the transfer function of the system can be written:

$$G_n(s) = \frac{N_n(s)}{D_n(s)} = \frac{a_0 + a_1 s + a_1 s^2 + \cdots . a_{n-1} s^{n-1}}{b_0 + b_1 s + b_1 s^2 + \cdots . b_{n-1} s^n} \tag{1}$$

$$G_r(s) = \frac{N_r(s)}{D_r(s)} = \frac{e_0 + e_1 s + e_1 s^2 + \cdots . e_{n-1} s^{r-1}}{f_0 + f_1 s + f_1 s^2 + \cdots . f_{r-1} s^r} \tag{2}$$

The special mathematical equation for any multiple-entry, multiple-exit system can also be written to represent the following transfer function: 1st: HOS (original high-order system).

$$G_n(s) = \frac{1}{D_n(s)} = \begin{bmatrix} a11(s) & a12(s) & \dots a1p(s) \\ a21(s) & a22(s) & \dots a2p(s) \\ \dots & \dots & \dots \\ am1(s) & am2(s) & \dots amp(s) \end{bmatrix} \tag{3}$$

2nd: ROM (reduced order model) [20].

$$G_r(s) = \frac{1}{D_r(s)} = \begin{bmatrix} e11(s) & e12(s) & \dots e1p(s) \\ e21(s) & e22(s) & \dots e2p(s) \\ \dots & \dots & \dots \\ em1(s) & em2(s) & ..emp(s) \end{bmatrix} \tag{4}$$

It is suggested to include realistic examples to verify the effectiveness of the dynamic system and build a model to test the proposed cases to simulate the system. The simulation process is conducted to carry out tests of the proposed dynamic systems to simulate the large-scale equilibrium truncation approximation. It is based on the exploration mechanism for equilibrium truncation with the case of large-scale reduction. The system algorithm is used for each case depending on the type of system and different operating conditions that are similar to real systems [21].

As a result of the development taking place in all fields, this development also included communications systems. The simulation process occupies a wide space in many fields and for various systems, including communication (dynamic systems). The mathematical representation of systems is to build an appropriate simulation model according to the specifications of those systems. To learn about the behavior of the system, a prototype is built to conduct tests, and then the appropriate design is determined [22].

III. Integral Time Absolute Error ITAE

The performance indication techniques are commonly employed to describe the outcomes of a PID controller aiming to design a model efficiently with the expected conditions. There multiple techniques that tune PID controllers and are mainly categorized as the Classical Methods and the Optimization Methods. The goal is to determine which algorithm performs the tuning process faster and with a better system response. Some of these methods are using Genetic Algorithm, PFA, Particle Swarm Optimization and another metaheuristic algorithm These methods are mainly formulated to minimize an error objective function and there four types of objective functions which are: IAE, ISE, $ITAE$, $ITSE$. In this work, the method called ITAE is adopted as an indication approach to the system's performance as well as its robustness. The features of such an approach are that it has acceptable damped oscillation with a fairly low overshoot value. In (5) defined such an approach while Fig. (10) exhibits the block diagram of ITAE with a PID controller [23].

$$ITAE = \int_0^\infty t|e(t)|dt \tag{5}$$

IV. Flower Pollination Algorithm (FPA)

Flower pollination algorithm is a nature motivated algorithm based on the phenomenon of FP, and solves the multi objective optimization problem with multiple criteria [24]. When using any optimization technique, performance indicators are adopted that can be tested to find out the best response by comparing them the comparison depends on the response speed, rise time, and the above and below the level required to complete the process of analyzing the response for different system cases.

The first stage in FPA aims to determine the highest and lowest value that can be among the best expected values from previous experiences.

After determining the highest and lowest value that enables us to achieve the desired goal, we work with the step. The second is to choose a group of n flowers that undergo pollination within the rules of the proposed algorithm. Using random solutions to search for the best among the proposed group. Find the potential permutation and motion for each i = 1 flower of a group of n flowers, plotting the directions of motion within a Levy.

There is also a third rule, the possibility of reproduction on the basis of considerations in the regularity of flowers, and there is a possibility of reproduction by the similarity of the two pollinating flowers participating in that process.

Finally, or the last and fourth rule, the possibility of self- or mutual pollination, on the assumption that each flower works on a solution and has the possibility of improvement in the procedures for the reproduction of offspring. Also, the possibility depends on conversions between global and local vaccination and the so-called mass vaccination and includes two bases at the same time.

A. *Analysis of FPA Varlant*

The FPA can be idealized by the following rules [20][25].

- Rule1. Pollens transferred by pollinators by the biotic and cross-pollination process. Pollinators contribute in the global pollination where they perform lévy flights.
- Rule2. Abiotic and self-pollination are included in local pollination.
- Rule3. Reproduction probability is proportional to the similarity of two flowers of same species. This depends on the constancy of a pollinator.
- Rule4. The number of iterations of the global and local pollination can be control by the switch probability. The factors have a significant fraction_ in local pollination. factors have a significant fraction_ in local pollination.

B. *Mathematical Modeling*

In FPA there are global pollination and local pollination are the two important points in consideration as key points. Rule (1) and (3) are considers in global pollination process. Pollen carrying pollinators (i.e., insects) can travel and move to over long distance, which increases the probability to reproduce fittest [20]. This characteristic represented by mathematically as in Eq. (5).

$$I_i^{\tau+1} = I_i^{\tau} + \gamma L(v)(\vartheta^* - I_i^{\tau}) \tag{6}$$

Where, $I_i^{\tau+1}$is the generated solution vector at iteration $\tau + 1$, I_i^{τ} is the pollen i or the solution vector Ii at iteration τ, where ϑ^* denotes the optimal global solution obtained under the current generation according to the fitness function, γ is a scaling factor used to control the step size, L(v) is the Lévy flights-based step size, it corresponds to the strength of the pollination. In reality, pollinators can fly long distances with different lengths (step size), this can be modeled using a Lévy distribution according to the equation (7).

Lévy flight distribution is used to define the step size $s >$ 0valid for by Eq. (7).

$$L \sim \frac{v\Gamma(v)\sin(\pi v/2)}{\pi} . \frac{1}{s^{1+v}} \;(s >> s_0 > 0) \tag{7}$$

where $\Gamma(v)$ is the tandard gamma function and this distribution is valid for large steps s>0.

Local pollination (Rule 2), and flower constancy (Rule 3) can be represented as eq. (8).

$$I_i^{\tau+1} = I_i^{\tau} + \cup\,(I_j^{\tau} - I_k^{\tau}) \tag{8}$$

where,I_j^{τ} and I_k^{τ} are the different flower pollens of same population and ∈ defined by uniform distribution in range [0,1]. $I_j^{\tau}$is the neighbor flower pollen of the I_k^{τ} flower pollen,

Note: Randomly choose j and k among all the solutions.

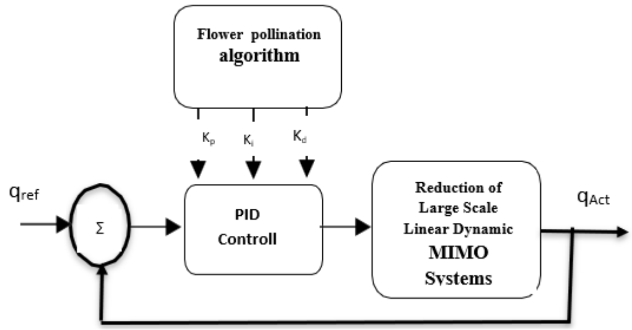


Fig. 1. Optimal design of PID controller for Reduction of Large Scale Linear Dynamic MIMO systems using FPA

V. Simulation Model and Simulation Results

A. *Open Loop System*

In this section there are two parts include, first part that include the simulation model of open loop system in section and result below.

- Simulation model of open loop

In this part include the simulation model of linear system by using T.F for Reduction of Large Scale Linear Dynamic MIMO Systems that show in Fig. 2 below:

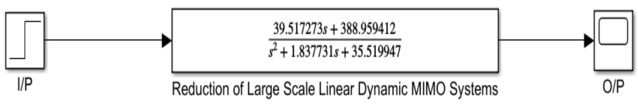
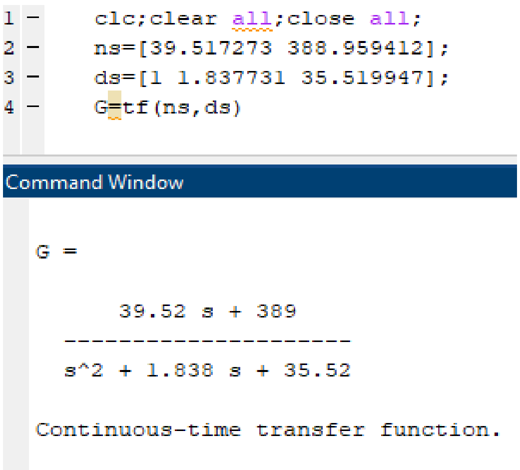


Fig. 2. Simulation model of open loop linear system by using T.F for Reduction of Large Scale Linear Dynamic MIMO systems

- Simulation result of open loop

In this part include the simulation result of open loop linear system by using T.F for Reduction of Large Scale Linear Dynamic MIMO Systems that show in Fig. 3 and Fig. 4.



```
clc;clear all;close all;
ns=[39.517273 388.959412];
ds=[1 1.837731 35.519947];
G=tf(ns,ds)
```

```
Command Window

G =

     39.52 s + 389
  ---------------------
  s^2 + 1.838 s + 35.52

Continuous-time transfer function.
```

Fig. 3. Simulation m. file using T.F for open loop Dynamic MIMO Systems

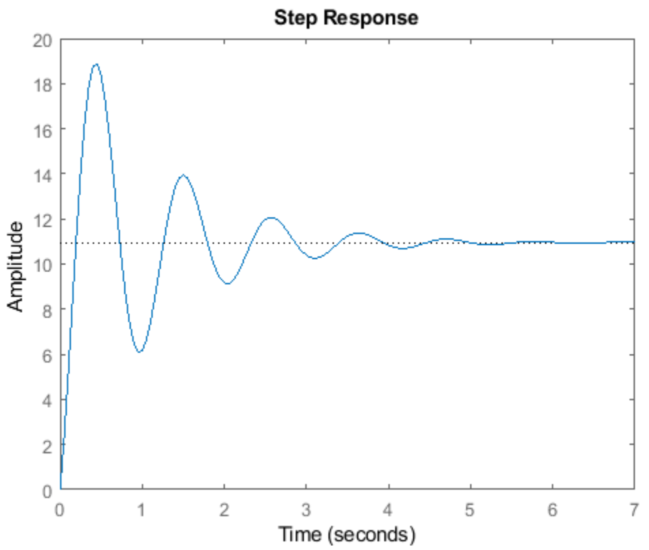


Fig. 4. Simulation result of open loop linear system by using T.F for Reduction of Large Scale Linear Dynamic MIMO Systems

B. *Close Loop without Controller*

In this section there are two parts include, first part that include the simulation model of close loop system in section and result below:

- Simulation model of Close loop without controller

In this section there are two part include, first part that include the simulation model of close loop system as show in Fig. 5 bellow:

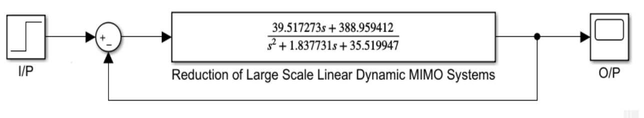
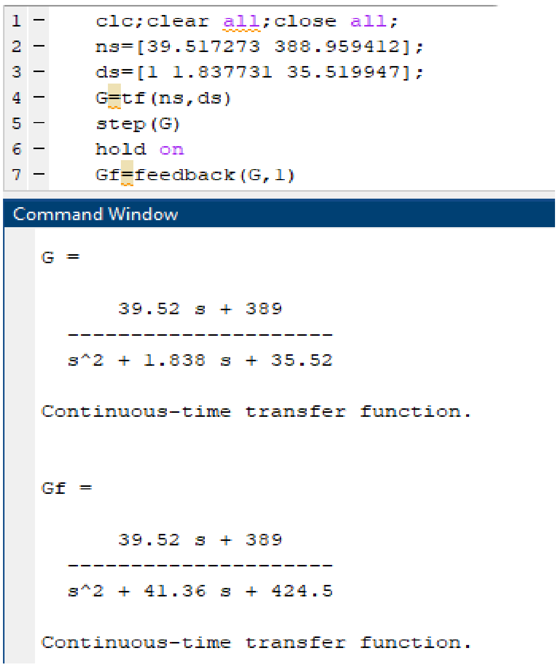


Fig. 5. simulation model of close loop linear system by using T.F for Reduction of Large Scale Linear Dynamic MIMO Systems

- Simulation result of close loop

In this part include the simulation result of close loop linear system by using T.F for Reduction of Large Scale Linear Dynamic MIMO Systems that show in Fig. 6 and Fig. 7.



```
clc;clear all;close all;
ns=[39.517273 388.959412];
ds=[1 1.837731 35.519947];
G=tf(ns,ds)
step(G)
hold on
Gf=feedback(G,1)
```

```
Command Window
G =

     39.52 s + 389
  ---------------------
  s^2 + 1.838 s + 35.52

Continuous-time transfer function.

Gf =

     39.52 s + 389
  ---------------------
  s^2 + 41.36 s + 424.5

Continuous-time transfer function.
```

Fig. 6. simulation m. file using T.F for close loop Dynamic MIMO Systems

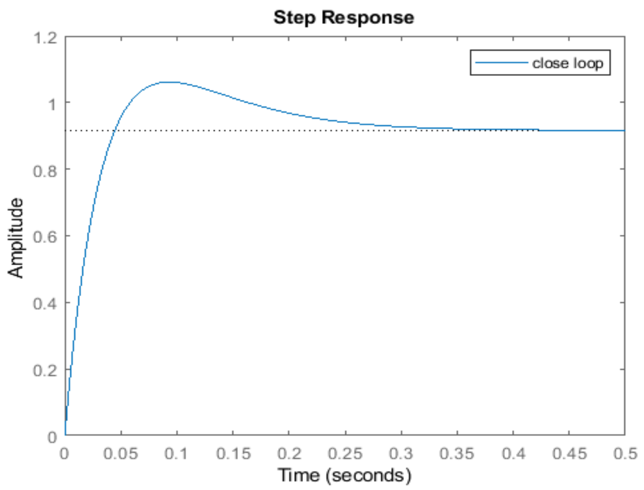


Fig. 7. simulation result of close loop linear system by using T.F for Reduction of Large Scale Linear Dynamic MIMO Systems

C. *Close Loop with PID Controller*

- Simulation model of close loop linear system with PID controller

In this section there are two parts include, first part that include the simulation model of close loop system with PID controller as show in Fig. 8 bellow:

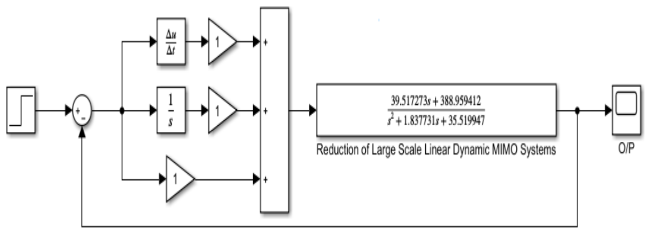


Fig. 8. simulation model of close loop linear system with PID controller by using T.F for Reduction of Large Scale Linear Dynamic MIMO Systems

- Simulation result with PID Controller

In this part include the simulation result of close loop linear system by using T.F for Reduction of Large Scale Linear Dynamic MIMO Systems that show in Fig. 9 and Fig. 10 below:

```
clc;clear all;close all;
ns=[39.517273 388.959412];
ds=[1 1.837731 35.519947];
G=tf(ns,ds);
step(G)
hold on
Gf=feedback(G,1);
  step(Gf)
  hold on
  kp=7;
 ki=0.05
 kd=0.001;
Gc=pid(kp,ki,kd);
        Gcf=feedback(Gc*G,1)
        step(Gcf)
```

```
Command Window

Gcf =

  0.03952 s^3 + 277 s^2 + 2725 s + 19.45
  --------------------------------------
  1.04 s^3 + 278.8 s^2 + 2760 s + 19.45

Continuous-time transfer function.
```

Fig. 9. Simulation m. file using T.F for close loop with PID controller Dynamic MIMO Systems

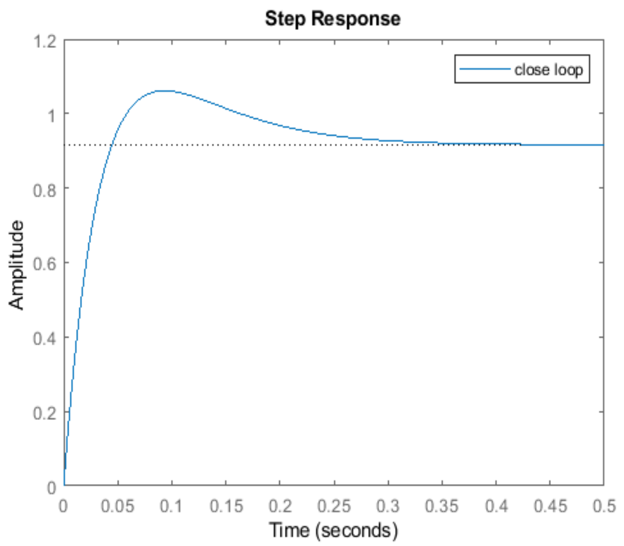


Fig. 10. simulation result of close loop linear system with PID Controller by using T.F for Reduction of Large Scale Linear Dynamic MIMO Systems

D. *Close Loop with FPA-PID Controller*

In this section there are two parts include, first part that include the simulation model of close loop system with FPA-PID controller in section 5.4.1, and result in 5.4.2 below:

- Simulation model of close loop linear system with FPA-PID controller

In this section there are two part include, first part that include the simulation model of close loop system with FPA-PID controller as show in Fig. 11.

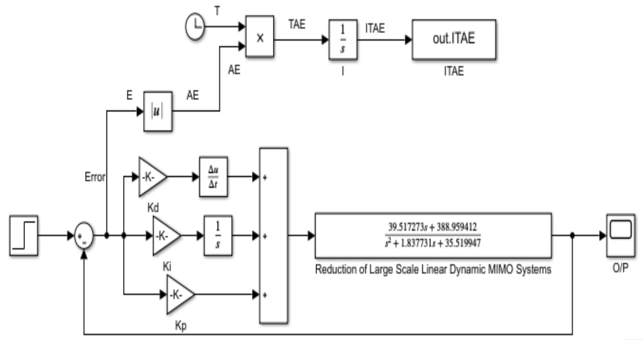


Fig. 11. simulation model of close loop linear system with FPA-PID controller by using T.F for Reduction of Large Scale Linear Dynamic MIMO Systems

- Simulation result of with FPA-PID Controller

In this part include the simulation result of close loop linear system by using T.F for Reduction of Large Scale Linear Dynamic MIMO Systems that show in Fig. 12 to Fig. 14 below:

```
FPA.m
clc;
clear all;
close all;
ns = [39.517273 388.959412];
ds = [1 1.837731 35.519947];
t_sim=20;
G=tf(ns,ds);
Gf=feedback(G,1);
N=50;
T=30;
c=0.4;
p=0.7;
var=3;
lb=0;
ub=10;
```

Fig. 12. simulation m. file using T.F for close loop with FPA-PID controller Dynamic MIMO Systems

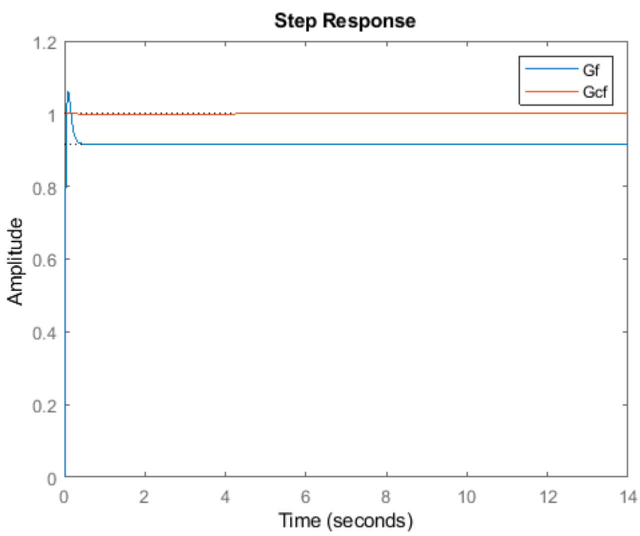


Fig. 13. simulation result of close loop linear system with FPA-PID Controller by using T.F for Reduction of Large Scale Linear Dynamic MIMO Systems

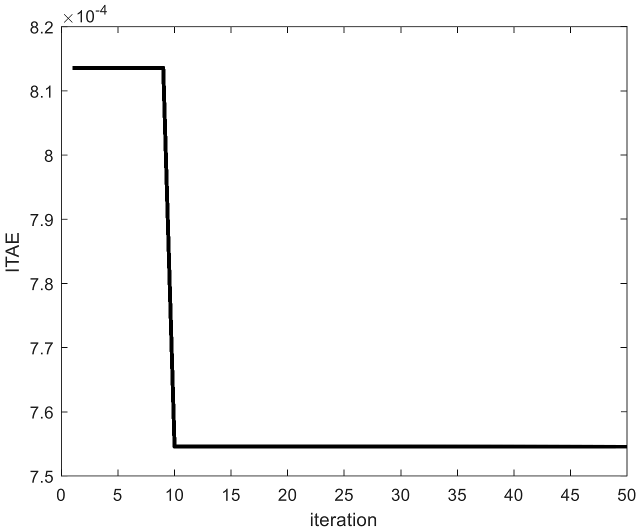


Fig. 14. Performance index trajectory of FPA-PID by using ITAE with 50 Iteration

VI. CONCLUSIONS

This work proposes a control method based on the combination of ITAE as a fitness function and FPA as an optimization algorithm with a PID controller for reducing the order of linear dynamic MIMO systems based on minimizing the Integral square error (ISE) between the transient responses of original and reduced order models pertaining to unit step input. Using MATLAB 2018b, the m. file was dedicated to the transfer function (TF), the FPA algorithm, and the ITAE. Simulink was used to construct the PID controller.

The desired response model was obtained by changing the three PID parameters (Kp, Ki, and Kd values). The method was validated by measuring time domain parameters such as rising time, settling time, and overshoot/undershoot. It was concluded that improvements of response speed and relative stability, respectively.

The open-loop system is a system that is not sensitive to the changes that occur during its work. A closed-loop system automatically regulates the system to a state that is intended to be stable with feedback to maintain a stable system. By comparing the results of FPA-PID with ITAE with linear and nonlinear systems give better results than the conventional control systems through the results in those in the literature, it can be observed that our proposed approach can provide a remarkable and superior dynamic response. Therefore, it is inferred that this enhanced ratio can reduce the time response of large-scale MIMO systems.

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