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# Genetic Algorithm based Compensator Design for Higher Order Systems

Ganesh C[1], Shanmugasundaram R[2] and Mohamed Iqbal M[3]
[1]Rajalakshmi Institute of Technology, Chennai 600124, India
[2]Sri Ramakrishna Engineering College, Vattamalaipalayam, Coimbatore 641022, India
[3]PSG Institute of Technology and Applied Research, Coimbatore 641062, India
Email: c.ganesh.srit@ gmail.com

***Abstract*— This research article highlights the optimization of the performance of higher order feedback systems by employing GA (Genetic Algorithm) based proposed compensator and existing controller / compensator. The results of GA based PID controlled / compensated system are compared with that of GA based proposed compensated system by using reduced order models for few higher order systems. Superiority of GA based compensator structure over GA based PID controller / compensator is validated and illustrated numerically by evaluating the time domain specifications of the higher order systems.**

***Index Terms*— Genetic algorithm, compensator, controller, reduced, higher order.**

## I. INTRODUCTION

Design of an appropriate control algorithm to optimize the performance of higher order systems is quite challenging task. Number of reduction techniques [1–8] were employed to reduce a higher order system and controller was designed on the equivalent reduced order system. These methods had drawbacks such instability problems, non-uniqueness, pole clustering, and gain adjustment. These techniques had limitations such as stability issues, non-uniqueness, pole clustering and gain adjustment. Reduced order models [9–13] obtained by Mihailov stability, Enhanced Pade approximation and truncation, improved generalized pole clustering, moment matching and Salp swarm optimization approach overcome these limitations. This research article employs these reduced order models for design of the proposed compensator.

Artificial Neural Network based PID controller was proposed [14–15] for a third order system. This control algorithm was more complex and time consuming. An online neural network tuning based on genetic algorithm was suggested [16] to control the position of a third order BLDC drive system. It suffered from appreciable steady state error in its step response that cannot be tolerated in precise position control applications. PID controller was optimized [17–18] by PSO (Particle Swarm Optimization) technique. Fuzzy, neural network and adaptive neuro-fuzzy inference system was used [19–21] for speed control of a BLDC drive. From these research works, it can be inferred that optimization-based techniques can be effectively employed for the control of higher order systems. A simple first order compensator [22–24] was designed for the position control using a BLDC drive. The result was found to be better than that of a PID controller. The design procedure was non-iterative, simple and could overcome the drawbacks of classical compensating approaches. This compensator design [25-26] could yield excellent results for type-1 higher order systems. However, this compensator could not reduce the steady state

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error appreciably in a type-0 system. Therefore, this compensator could not be effectively used for the higher order systems by using the reduced order models. A compensator whose Transfer function is identical to that of a PID controller [9–13] was utilized on the reduced order system to improve the response of higher order systems. The compensator could assure stability and improve the transient response for higher order systems. But the design methodology is complex and not easily realizable.

This paper suggests a simple, computationally efficient, and easily realizable generalized compensator structure [27] for the continuous time higher order LTI systems. GA is used to optimize the parameters of this compensator and existing compensator / PID controller for various higher order systems by using reduced order models. This research article is organized as follows: Section I Introduction highlights the research gap in the existing work and underlines the need for GA based proposed compensator for higher order systems; section II deals with GA based proposed compensator design to few standard reduced order models and compares the performance of GA based proposed compensator design with the existing compensator/controller; section 3 deals with the conclusion and scope for further work.

## II. GENETIC ALGORITHM BASED COMPENSATOR DESIGN

Let G(s) be the transfer function of the reduced order model [9–13] for the higher order system to be regulated and $G_c(s)$ be the transfer function of the proposed compensator [27] provided by

$$G_c(s) = \frac{K(1+T_a s)(1+T_b s)}{s(1+T_c s)} \qquad (1)$$

Parameters $K$, $T_a$, $T_b$ and $T_c$ are optimized using GA. GA based tuning of compensator is employed [9–13] to few higher order systems by employing their reduced order models. Block diagram of a typical unit feedback system is shown in Fig. 1. The variable which is optimized using GA is the actuating signal or error $e$(t). The objective of the proposed work is to tune the parameters $K$, $T_a$, $T_b$ and $T_c$ of the compensator with minimum error between the input and output. ISE (Integral Square Error) is one of the most frequently employed error criteria to achieve optimized tuned values of compensator / PID controller. The objective function $J$ used in GA is expressed by $J(K, T_a, T_b, T_c)$ = ISE where ISE = $\int_0^\infty [e(t)]^2 dt$. Table I shows the particulars of GA parameters used in the simulation.

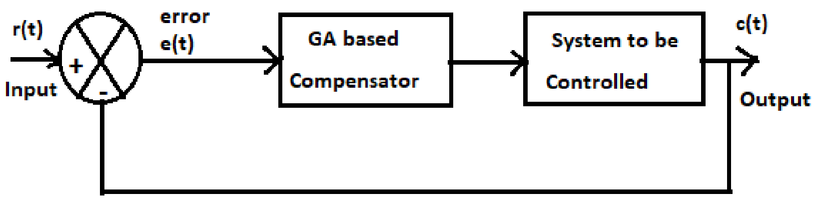


Figure 1. Block diagram of GA based Compensated system

TABLE I. PARAMETERS USED IN GENETIC ALGORITHM

| Parameter | Type/Values |
|---|---|
| Population size | 50 |
| Number of generations | 100 |
| Mutation | Uniform |
| Crossover | Single point cross over |
| Selection | Stochastic Uniform |
| Encoding | Binary |

An example is shown below to illustrate the GA based tuning of the proposed compensator.
Consider a sixth order helicopter engine [10] whose transfer function is expressed by

$$G_p(s) = \frac{248.05s^4+1483.3s^3+91931s^2+468370s+634950}{s^6+26.24s^5+1363.1s^4+26803s^3+326900s^2+859170s+528050} \qquad (2)$$

Reduced order model [10] transfer function of the sixth order system is expressed as

$$G(s) = \frac{0.6357s+1.48}{s^2+3.042s+2.056} \qquad (3)$$

Parameters $K$, $T_a$, $T_b$ and $T_c$ of the proposed compensator are optimized by GA and shown in Fig. 2. Range of compensator parameters used for the simulation is shown in Table II.

TABLE II PROPOSED COMPENSATOR PARAMETERS USED IN GENETIC ALGORITHM

| Compensator Parameters | *K* | $T_a$ | $T_b$ | $T_c$ |
|---|---|---|---|---|
| Minimum value | 0 | 0 | 0 | 0 |
| Maximum value | 40 | 2000 | 20000 | 100000 |

From Fig. 2, Transfer function of the proposed compensator becomes

$$G_c(s) = \frac{13.087(1+1999.739s)(1+17735.21s)}{s(1+0.566s)} \qquad (4)$$

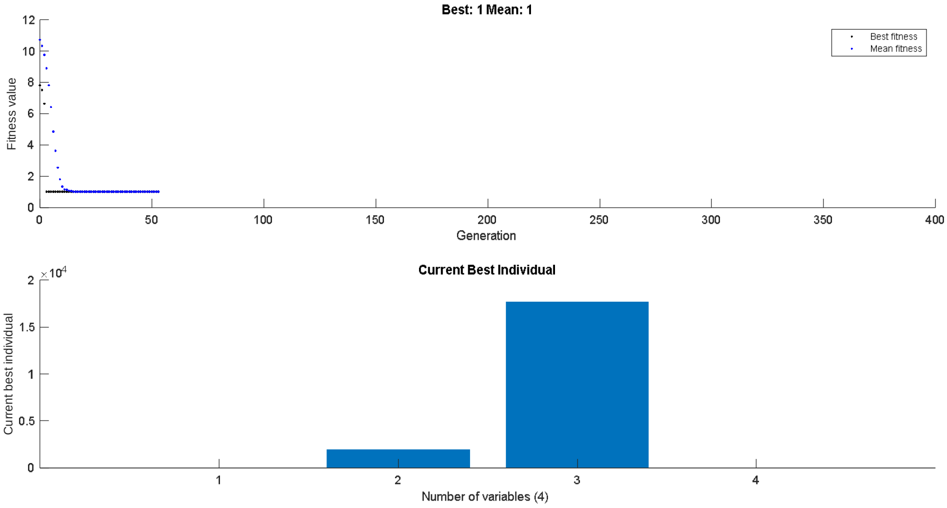


Figure 2. Optimized parameters of the GA based Compensated sixth order system

Step response of the compensated system with this reduced order model transfer function G(s) is simulated and shown in Fig. 3. From the response it can be deduced that system has a rise time of 4.21 ns, settling time of 7.5 ns, zero peak overshoot and zero steady state error.

Parameters $K_c$, $T_{z1}$ and $T_p$ of the existing compensator are optimized by GA and shown in Fig. 4. Range of compensator parameters used for the simulation is shown in Table III.

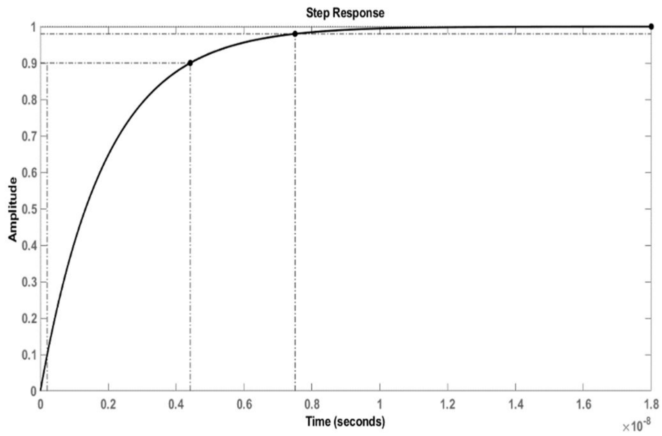


Figure 3. Step response of GA based proposed compensated sixth order system

TABLE III. EXISTING PID CONTROLLER PARAMETERS USED IN GENETIC ALGORITHM

| Compensator Parameters | $K_c$ | $T_{z1}$ | $T_p$ |
|---|---|---|---|
| Minimum value | 0 | 0 | 0 |
| Maximum value | 40 | 4 | 0.08 |

From Fig. 4, Transfer function of the existing compensator becomes

$$G_c(s) = \frac{19.999(1+3s)}{s} \qquad (4)$$

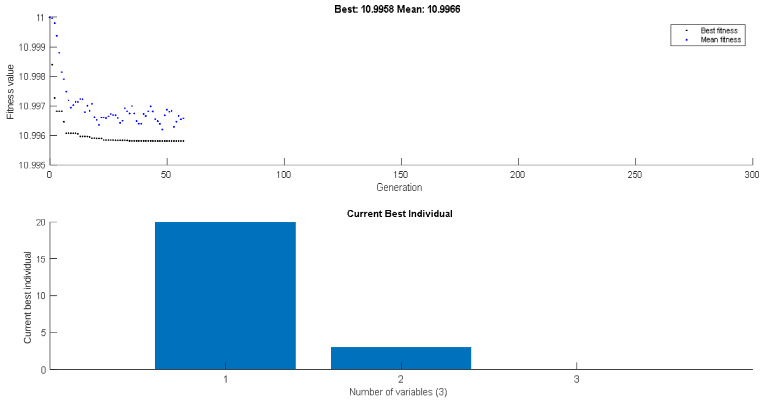


Figure 4. Optimized parameters of the GA based existing compensated sixth order system

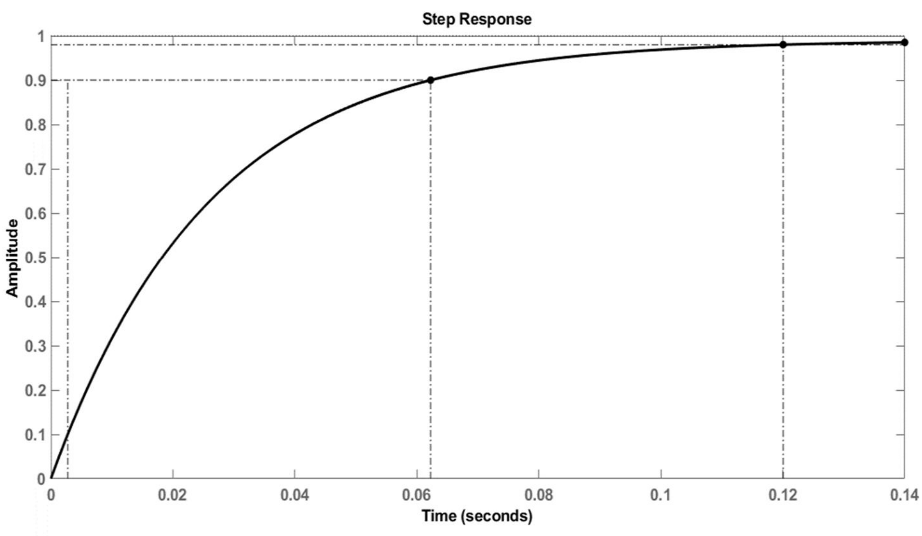


Figure 5. Step response of GA based existing compensated sixth order system

Step response of the existing compensated system [13] is shown in Fig. 5. It can be found from the figure that the transient response has a rise time of 0.0595 sec, settling time of 0.12 sec, zero peak overshoot and zero steady state error. From Fig. 4 and Fig. 5, it can be observed that GA based proposed compensating technique could yield better transient response compared to the GA based existing compensating technique.
Few numerical examples employed for model reduction and compensator/controller design of higher order systems are employed for the validating GA based proposed compensator design. Table IV shows the comparison of the structure of GA based proposed compensator with GA based existing compensator / controller.
The performance specifications of the GA based proposed compensated system are obtained for various systems shown in Table IV, compared with the existing / control techniques and tabulated in Table V.
From the Table IV and Table V, following inferences can be deduced about the application of GA based proposed compensator to the higher order system.

1. The proposed compensator has an additional open loop zero apart from the structure of existing compensator / controller.
2. GA based proposed compensated system does not have any overshoot in step response and is always stable, irrespective of the nature of higher order system.

3. The proposed compensating structure is more effective and does not depend on nature of the higher order system and model reduction technique employed.

TABLE IV. COMPARISON OF THE STRUCTURE OF GA BASED PROPOSED COMPENSATOR WITH EXISTING COMPENSATOR / CONTROLLER

| Reduction Technique with system order | Transfer Function of the Reduced order model | **Proposed Compensator** $G_c(s) = \frac{K(1+T_a s)(1+T_b s)}{s(1+T_c s)}$ GA based Tuned Parameters | | | | Transfer Function of Existing Compensator /Controller with Tuned Parameters |
|---|---|---|---|---|---|---|
| | | **K** | $T_a$ | $T_b$ | $T_c$ | |
| Moment matching 4th order [9] | $\frac{0.6357s + 1.48}{s^2 + 3.042s + 2.056}$ | 13.087 | 1999.739 | 17735.21 | 0.566 | $\frac{K_c(1+T_{z1}s)}{s(1+T_p s)}$ $K_c$ =19.999; $T_{z1}$= 3; $T_p$= 0 |
| Mihailov and Improved Pade 6th order [13] | $\frac{5.934s + 1}{101s^2 + 16.23s + 1}$ | 13.955 | 28736 | 304575 | 2431 | $\frac{K_i + K_p s + K_d s^2}{s(1+T_p s)}$ $K_p$ = 40; $K_d$ = 180; $K_i$ = 3.998 |
| Mihailov and Truncation 3rd order [11] | $\frac{0.601s + 0.1069}{0.7024s^2 + 0.8498s + 0.110}$ | 0.6 | 3892.227 | 260793 | 0.005 | $\frac{K_c(1+T_{z1}s)}{s(1+T_p s)}$ $K_c$ = 0.6; $T_{z1}$=24.999; $T_p$=0.004 |
| Salp Swarm Optimization 84th order [28] | $\frac{476.7s + 0..5026}{0.1838s^2 + 54.02s + 0.0569}$ | 14931 | 6.983 | 69.957 | 498.771 | $\frac{1.431 \times 10^4 s^2 + 4.206 \times 10^6 s + 4434}{s^3 + 2.282 \times 10^4 s^2 + 4724s + 4.956}$ (Salp Swarm Optimized Controller) |

TABLE V. COMPARISON OF CLOSED LOOP SPECIFICATIONS OF THE PROPOSED GA BASED COMPENSATED SYSTEM WITH GA BASED EXISTING COMPENSATED / CONTROLLED SYSTEM

| Reduction Technique with system order | Rise Time | | Settling time | | Peak overshoot (%) | |
|---|---|---|---|---|---|---|
| | proposed | existing | proposed | existing | proposed | existin g |
| Moment matching 4th order [9] | **4.21ns** | 0.0595s | **7.5ns** | 0.12s | **0** | 0 |
| Mihailov and Improved Pade 6th order [13] | **0.744µs** | 7.17s | **1.33µs** | 26.5s | **0** | 0.542 |
| Mihailov and Truncation 3rd order [11] | **0.0211ns** | 0.216s | **0.0375ns** | 50s | **0** | 0 |
| Salp Swarm Optimization 84th order [28] | **0.579ns** | 1.25ms | **0.0103ns** | 2.27ms | **0** | 0 |

## III. CONCLUSIONS

GA based compensator is designed for higher order systems by using the proposed compensator structure. Its effectiveness and superiority is validated through some standard examples and simulation. From the simulation results, it can be concluded that the proposed compensator yields a better transient response over the existing compensator / controller irrespective of the nature and order of the higher order system. GA can be used to optimize the parameters of the proposed compensator. GA based tuning is suitable for the SISO LTI higher order continuous time systems but can also be extended for the MIMO (Multi Input Multi Output) and discrete time LTI systems.

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