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Intelligence Method for PID Controller Design in AVR System

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Abstract

Designing of a PID controller is a very common method for industrial process control and due to its very simple and efficient function; it is used in a wide variety of industrial applications. PID controller to reduce the steady state error and dynamic response of the system is used. PID controller design is an inevitable problem in setting the coefficients need to try a lot of trial and error, therefore the optimization of parameters in this controller is attention of many researcher and there are many methods to find optimal parameters of PID controller. Fast and exactly adjustment of the parameters optimized controller is to create high quality answers. In this paper, an optimized tuning method for PID controller is presented. In this method the PSO algorithm is used to design the parameters of an AVR (Automatic Voltage Regulation) system using various fitness functions. Easy implementation, stable convergence characteristic and high computational efficiency are among advantages of presented method.

Keywords: PID controller, PSO algorithm, optimization, AVR system.

1. Introduction

Change in active power, mainly affects system frequency, while reactive power having less sensitivity to frequency change, is related to voltage level. The automatic voltage regulator loop (AVR), regulates reactive power and voltage level. Unfortunately, parameter tuning of controller is extremely difficult due to some hindrances like system high order, time delays and nonlinear behaviour [1,2]. Designing such controller requires determining 3 characteristics: proportional gain K_p, integral gain Ki, and derivative gain K_d. Formerly the common solution to design such controller was trial and error and engineers did it manually which was extremely cost and time consuming. In recent decades various instructions were presented to introduce a regular method to reduce time for parameter optimization process. Zigler-Nicholz method is probably the best well known method [3], in this technique, controller parameters are tuned considering a gain at which, system oscillates, and the oscillation frequency. Overall, determining optimized controller using Ziler-Nicholz method in many industrial processes is difficult. Considering the above mentioned reason, to improve controllers efficiency in a vast variety of industrial processes, many smart techniques are put into practice, such as neural network, fuzzy systems, and neuro-fuzzy logic[4]. Moreover, to reduce the complexity of controller parameters tuning, many random search algorithms like genetic algorithm [1], and gradual cooling [5] are developed. However, there are many reasons to develop better design methods, like improved efficiency and speed of parameter tuning, which are achieved by improved design methods. In [6] bacteria algorithm BFA, is used to design the PID controller. Same algorithm is employed in [7] to design PID controller for LFC system. In this paper, three fitness functions are considered and PSO algorithm is used to design optimized parameters of PID controller for AVR system in synchronous generator connected to vapour turbine. We formulate the design of controller like an optimization problem, and obtain MP, settling time (ts), rise time (tr), and steady state error (Ess). Anarchic Society Optimi-zation (ASO) developed by Ahmadi-Javid [8] is a first introduced human-inspired swarm intelligence optimization method. This novel random method is based on an abnormal human society instead of a swarm of birds or a colony of ants, which are the basis of PSO and ACO, respectively). Gozde and colleagues [9] suggested the ABC based self-tuning PID controller for AVR system and compared the results with that of PSO based methods. In [10] for tuning of PID controller gains with off-line, as well as, nominal input conditions, was represented a CRPSO based search technique. For on-line input conditions, Sugeno Fuzzy Logic (SFL) has been used. It was shown that better quality solution of step response of terminal voltage with less computational effort has been obtained in CRPSO-SFL based PID controller than the binary coded genetic algorithm SFL based PID controller one.

Selection of any of these criteria has been constrained by benchmark problems, though *ITSE* index is calculated and reported independently to make comparison more sensible [11]. A similar problem has been attempted using a multi objective fuzzy adaptive PSO algorithm. However none of these papers consider the inherent design trade-off in the AVR tuning itself, which is one of the main focus in [13]. The fractional order PID (FOPID) controller has been used in the design of AVR systems and has been shown to outperform the PID in many cases [14]. PID controllers have been widely used for speed and position control of various To enhance the capabilities of traditional PID parameter tuning techniques, several intelligent approaches have been suggested to improve the PID tuning, such as those using genetic algorithms (GA) and the particle swarm optimization (PSO) [15].

2. Problem and fitness functions description

PID controller is used to improve system dynamic response and reduce steady state error. Transfer function of PID is presented in (1):

$$G_C(S) = K_p + \frac{K_i}{S} + K_d S \tag{1}$$

K_p, K_i and K_d are proportional, integral and derivative gains respectively.

First fitness function (fitness1) and second (fitness2) and third fitness function (fitness3) are shown in (2) to (4):

$$fit - function1 = W_1 \times ISE + W_2 \times M_p \tag{2}$$

$$fit - function2 = \frac{(1+M_p)\times(t_r+t_s)}{2} \tag{3}$$

$$fit - function3 = [(M_p + E_{SS}) \times (1 - e^{-B}) + ((e^{-B}) \times (t_s - t_r))] \tag{4}$$

$$ISE = \int_0^{\infty} |e^2(t)|\, dt \tag{5}$$

In this criteria, squared error integral ISE, is calculated from squared absolute value of error curve and the goal is to minimize area below this curve. Weight coefficients w1 and w2 are set to 0.5 and B is 1.7. The range of K_p, K_i and K_d parameters is given in table (1).

Table.1.
Algorithm parameters

parameters	Min-value	Max-value
Kp	0	1
Ki	0	1
Kd	0	1

3. System under study

The role of AVR system in a power network is to regulate the output voltage of a synchronous generator connected to vapour turbine, at a certain level. So, stability of AVR system has a large effect on power system safety [7]. The diagrams of AVR system and synchronous generator connected to vapour turbine LFC are illustrated in Fig.1 AVR system block diagram along with PID controller are presented in Fig.2.

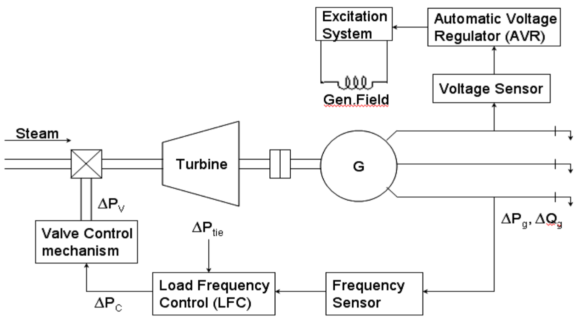

Fig.1. AVR and LFC system diagram

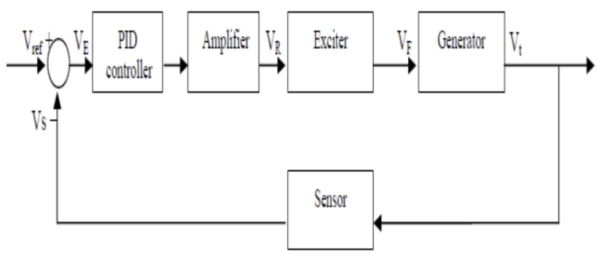

Fig.2. AVR system block diagram along with PID controller

Modelling of various parts of AVR system is given in equations (6) to (9).

Amplifier model:

$$\frac{V_R}{V_E} = \frac{K_A}{1+\tau_A S} \quad 0.02 \le \tau_A \le 0.1 \,,\, 10 \le K_A \le 400 \quad (6)$$

Exciter model:

$$\frac{V_F}{V_R} = \frac{K_E}{1+\tau_E S} \quad 0.5 \le \tau_E \le 1 \,,\, 10 \le K_A \le 400 \quad (7)$$

Generator model:

$$\frac{V_t}{V_F} = \frac{K_G}{1+\tau_G S} \quad 1 \le \tau_G \le 2 \,,\, 0.7 \le K_G \le 1 \quad (8)$$

Sensor model:

$$\frac{V_s}{V_t} = \frac{K_R}{1+\tau_R S} \quad 0.001 \le \tau_R \le 0.06 \quad (9)$$

Fig.3 shows the block diagram of AVR system together with PID controller and various model parameters used in simulation.

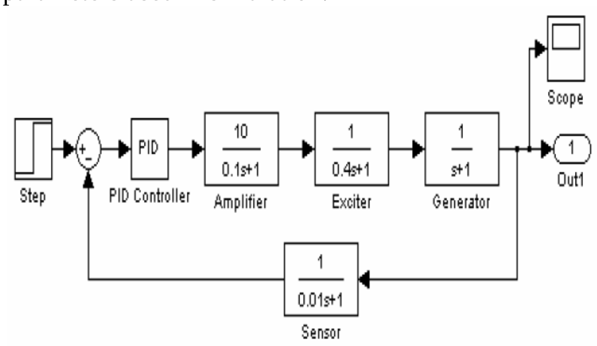

Fig.3.The block diagram of AVR system

4. Particle Swarm Optimization (PSO) algorithm

PSO algorithm is a population-based algorithm in which, a group of particles search the possible space of problem to find the optimized answer. Each particle moves through the search space with an adjustable speed and keep track of its previous best position. Moreover, the best position reached by group, is declared to all members. In this method, there's no member conversion, but the member's behaviour including their speed and their subsequent position is modified through the next iterations to find the best answer. The first value is the best ever answer found by each individual member, we call it ***pbest***. Assuming the search space is n-dimensional, we can define the *i*-th component by two n-dimensional vectors of position (x_i) and velocity (v_i) as shown in (8) and (9):

$$X_i = [x_{i1}, x_{i2}, x_{i3}, \dots, x_{in}]^T \quad (8)$$

$$V_i = [v_{i1}, v_{i2}, v_{i3}, \dots, v_{in}]^T \quad (9)$$

Where, i=1,2,3,…,N and N is total number of members, and superscript $\boldsymbol{T}$ is transpose function. In PSO algorithm, *i*-th component memorizes the best previous position as $P_i = [p_{i1}, p_{i2}, p_{i3}, \dots, p_{in}]^T$ vector and $G = [g_1, g_2, \dots, g_n]^T$ is the best previous position reached by group. Position of *i*th component in *t+1*-th iteration is given by equations (10) and (11):

$$V_i(t+1) = w(t) \times V_i(t) + C_1(t) \times r_1 \times \big(p_i(t) - X_i(t)\big) + C_2(t) \times r_2 \times (G(t) - X_i(t)) \quad (10)$$

$$X_i(t+1) = X_i(t) + \chi \times V_i(t+1) \quad (11)$$

In these equations, $\boldsymbol{\omega}$ is inertia coefficient which indicates the effect of previous velocity vector on actual iteration. $\boldsymbol{\chi}$ is contraction coefficient to limit the effect of velocity vector and here is considered as 0.7. C1 and C2 are recognition parameter (or local acceleration) and social parameter (or global acceleration) respectively, r_1 and r_2 are two real number which are randomly and based on a uniform distribution function, chosen between 0 and 1. The bigger the product of C1 x r1 is, the quicker the *i*-th component moves toward the best previous position. The velocity of component toward the best position, obtained by the group, is also influenced by production of C1 x r1. Larger inertia coefficient makes the group, search a wider space. While smaller inertia coefficient increase the accuracy of group in local searches. Based on the previous experiences, it is suggested to assign a large value to $\boldsymbol{\omega}$ at the beginning of search (here 1) to give a higher priority to global search than local search, then decrease its value to a small number like zero (here 0.1), to reach the best answer [13].

5. Simulation Results

Tuning of PID controller parameters Kp, Ki and Kd, cause the closed loop function to change, so we get different answers.

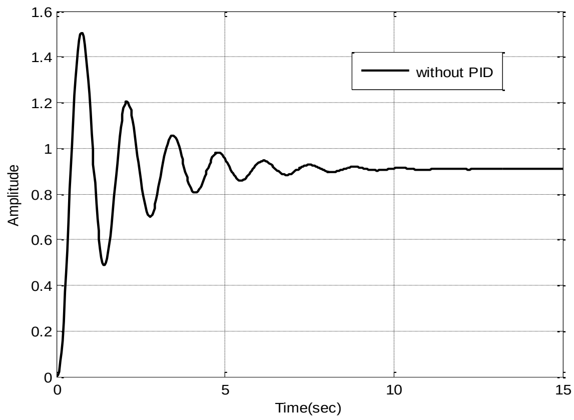

Fig.4. Output voltage step response without PID controller

PID controllers employed in industry are not tuned properly, so their operation is greatly improvable. Here, PSO algorithm is used to design parameters of PID controller to reduce settling time (ts), rise time (tr), maximum overshoot (Mp) and steady state error (Ess).

5.1. Design of PID controller parameters

Fig.4 shows output voltage step response without PID controller. Results of PID controller optimized parameter design, are given in table 2 for 30, 50 and 80 iterations, with first fitness function (Fitness1) and second fitness function (Fitness2) which are described in equations (2) to (4).

Table.2.
PSO algorithm results

Method	iteration	Kp	Ki	Kd	Mp	tr	ts	Ess
PSO_fitness1	It=50	1	0.246	0.2308	2.7539×10^{-4}	0.4099	0.671	2.7825×10^{-4}
PSO_fitness2	It=80	1	0.2442	0.2218	0.0136	0.3706	0.6396	3.4588×10^{-4}
PSO_fitness3	It=30&B=0.7	1	0.3294	0.2341	0.0197	0.4097	0.6388	2.083×10^{-4}
PSO_fitness3	It=50&B=0.7	0.8572	0.2367	0.1901	0.0199	0.4369	0.6789	2.5276×10^{-4}
PSO_fitness3	It=80&B=0.7	0.8516	0.2294	0.1873	0.02	0.437	0.6791	7.8983×10^{-4}
PSO_fitness3	It=30&B=1	1	0.3132	0.2307	0.0199	0.4098	0.6391	2.0444×10^{-4}
PSO_fitness3	It=50&B=1	0.6836	0.2182	0.1538	0.0198	0.5079	0.7794	2.8181×10^{-5}
PSO_fitness3	It=80&B=1	0.8468	0.2195	0.1842	0.02	0.437	0.6793	4.2023×10^{-5}

Fig.5 shows output voltage step response with PID controller designed for various fitness. A comparison of output voltage step response before and after employing PID controller with PSO algorithm for various fitness functions is presented in figure 6.

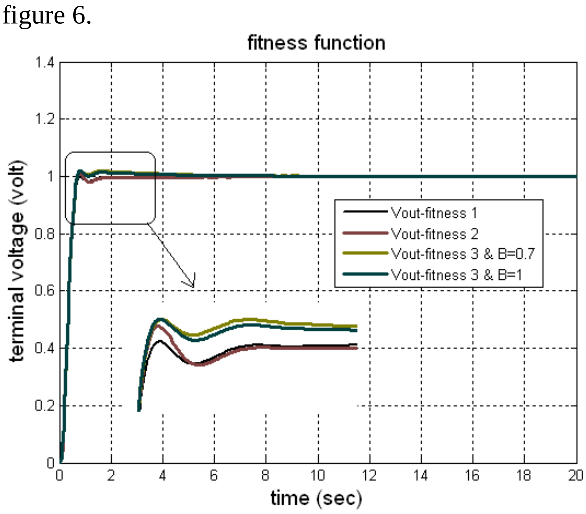

Fig.5. System output voltage step response with PID controller

Convergence of algorithm for fitness functions 1, 2 and 3 is illustrated in figures (7) to (10).

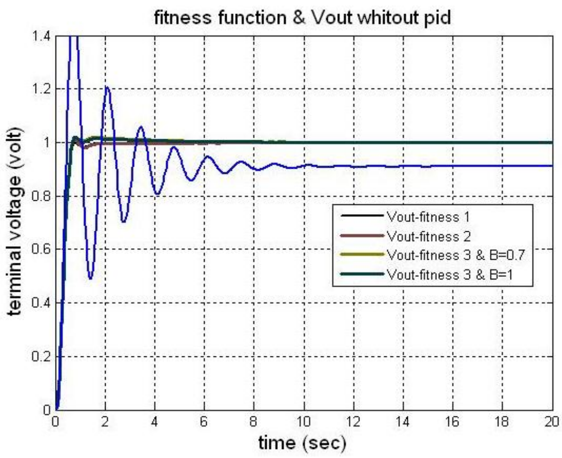

Fig.6. Comparison of output voltage step response before and after employing PID controller

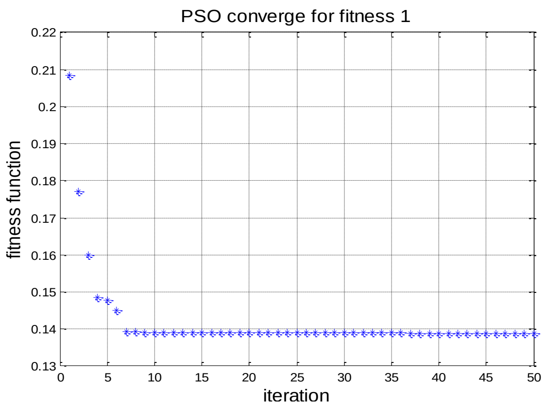

Fig.7. Algorithm convergence for first fitness function

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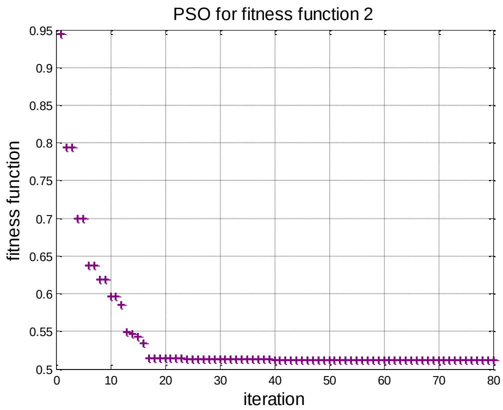

Fig.8. Algorithm convergence for second fitness function

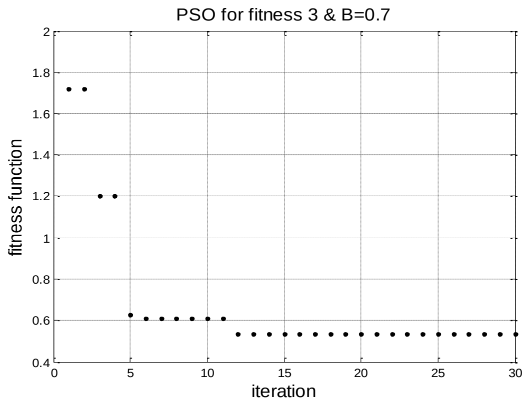

Fig.9. Algorithm convergence for third fitness function with B=1

Error signals of before and after employing PID controller are shown in figures (10) to (13). As it can be seen, after employing PID controller, error signal goes faster to zero. Convergence of PID controller parameters is given in figures (14) to (17).

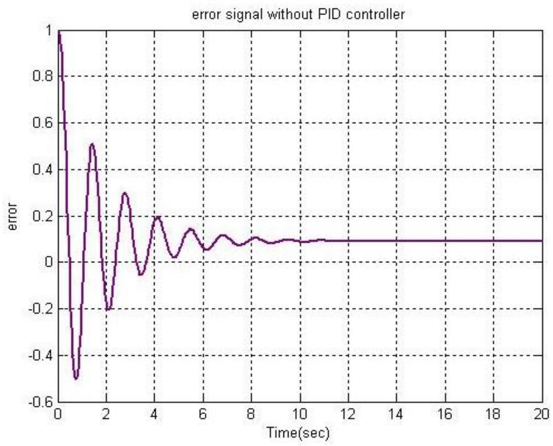

Fig.10. Error signal before controller design

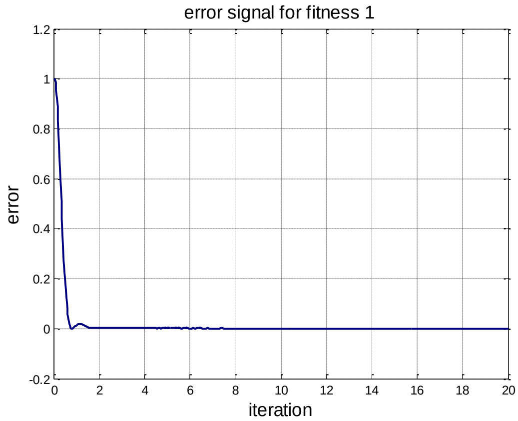

Fig.11. Error signal after controller design with first fitness function

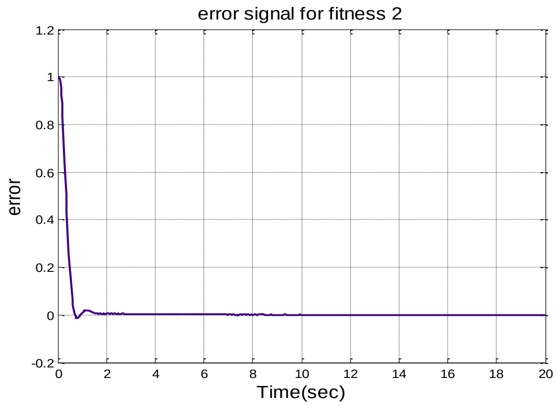

Fig.12. Error signal after controller design with second fitness function

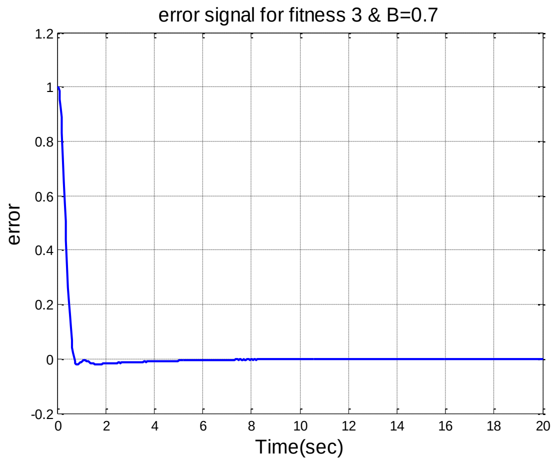

Fig.13. Error signal after controller design with third fitness function, B=0.7

PID controller parameters convergence is presented in figures (14) to (17).

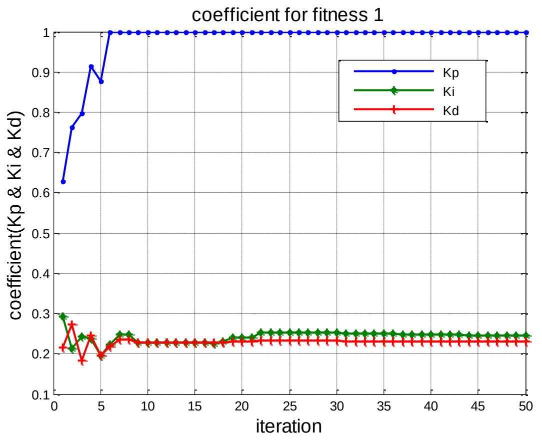

Fig.14. PID controller parameters convergence with first fitness function

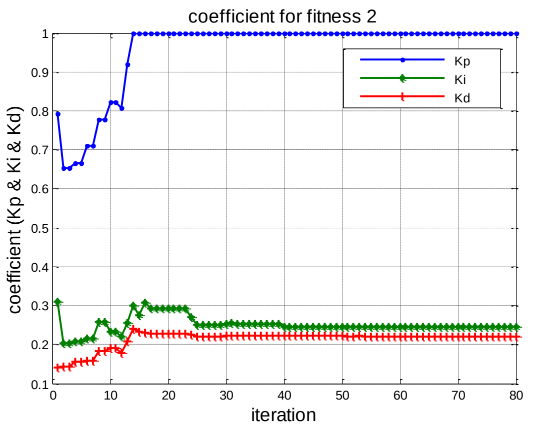

Fig.15. PID controller parameters convergence with second fitness function

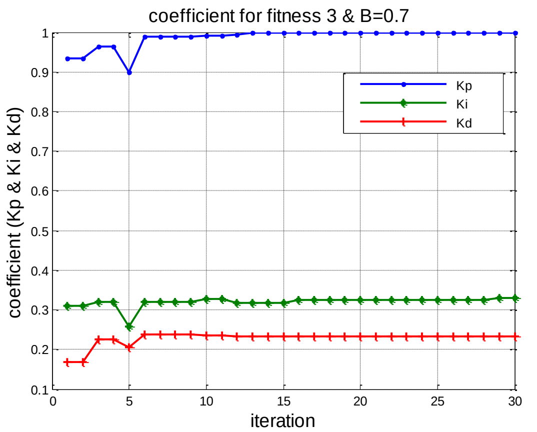

Fig.16. PID controller parameters convergence with third fitness function, B=0.7

6. Conclusion

Parameter tuning is significant in two respect: first, change of controller parameters changes system close loop operation. Second, these parameters are weights or coefficients that indicate which percent of these commands should be add up to each other and apply to process input. In this paper PSO algorithm is used to design PID controller parameters for various fitness function. Results show that third fitness function converges faster than others and parameters can be designed for various fitness. For example, if the aim is minimizing settling time, third fitness function with 30 iteration and B=1, and if rise time is important, second fitness function, and if minimum MP is to be obtained, first fitness function are suggested.

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