Gain Tuning PID and IP Controller with an Adaptive Controller Based on the Genetic Algorithm for Improvement Operation of STATCOM

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Abstract: - Static Synchronous Compensator (STATCOM) is a device capable of solving the power quality problems at the power system. These problems happen in milliseconds and because of the time limitation, it requires the STATCOM that has continuous reactive power control with fast response. In this way, optimal exploitation of STATCOM by classical controllers has been a controversial issue in reputable journals. One of the most common controlling devices in the market is the Proportional-Integral-Derivative (PID) and Integral-Proportional (IP) controller's. In this article, the STATCOM is controlled by IP and PID controllers. A new control method that is a Model Reference Adaptive Control method (MRAC) based on the combination of PID and IP control and the Genetic Algorithm (GA) is introduced. Genetic algorithm is employed to find the best values for PID and IP controller's parameters in a very short time. The simulation results show an improvement in current control response. These methods are tested in MATLAB, and their results are obtained.

Key-Words: Adaptive Control , Genetic algorithm , PID controller, IP controller, STATCOM.

1 Introduction

Reactive power control is a critical consideration in improving the power quality of power systems. Reactive power increases transmission losses, degrades power transmission capability and decreases voltage regulation at the load end. In the past, Thyristor-Controlled Reactors (TCR) and Thyristor-Switched Capacitors were applied for reactive power compensation. However, with the increasing power rating achieved by solid-state devices, the Static Synchronous Compensator is taking place as one of the new generation flexible AC transmission systems (FACTS) devices. It has been proven that the STATCOM is a device capable of solving the power quality problems. One of the power quality problems that always occur at the system is the three phase fault caused by short circuit in the system, switching operation, starting large motors and etc. This problem happens in milliseconds and because of the time limitation, it requires the STATCOM that has continuous reactive power control with fast response [1].In order to increase the stability of the system and damping response which makes the inverter in the STATCOM to inject voltage or current to compensate the three phase fault [2].

With only excitation control, the system stability may not be maintained if a large fault occurs close to the generator terminal, or simultaneous transient stability and voltage regulation enhancement may be difficult to achieve. With the development of power electronics technologies, several Flexible AC Transmission System (FACTS) devices [3] at present or in the further can be used to increase the power transfer capability of transmission networks and enhance the stability of the power system. A STATCOM provides better dynamic performance and minimal interaction with the supply grid. The STATCOM is a shunt connected device. The STATCOM consists of voltage source inverter such as Gate Turn Off (GTO) Thyristor, a DC link capacitor and a controller [4]. The STATCOM is normally designed to provide fast voltage control and to enhance damping of inter-area oscillations. A typical method to meet these requirements is to superimpose a supplementary damping controller upon the automatic voltage control loop [5]. Many of the methods focus on decoupling the system variables and designing PI controllers. A STATCOM is a Multiple Input Multiple Output (MIMO) system. It is not possible to totally decouple the system variables. Therefore, the control performance may sometimes be poor. Other control methods apply state feedback control techniques [2], [6], however, very little detail is given in the literature about how to choose the optimal parameters. Some control methods apply state feedback control techniques [1], [7].Two basic controls are implemented in a STATCOM. The first is the AC voltage regulation of the power system, which is realized by controlling the reactive power interchange between the STATCOM and the power system. The other is the control of the DC voltage across the capacitor, through which the active power injection from the STATCOM to the power system is controlled [8]. With the help of robust control theory and the Direct Feedback Linearization (DFL) technique, the nonlinear coordinated control of generator excitation and the STATCOM is investigated in [9]. The modeling and control design are usually carried in the standard synchronous d–q frame [10].

The remainder of the paper is organized as follows. describes modeling of STATCOM detailed in Section 2 and the design of the proposed control algorithm is detailed in Section 3 and 4. Genetic algorithm is shown in Section 5. The computer simulation results are presented and discussed in Section 6. Finally Section 7 concludes this paper.

2 System Configuration and Modeling

In designing the PID and IP controllers, the state space equations from the STATCOM circuit must be introduced. The theory of *d-q* transformation of currents has been applied in the circuit, which makes the *d* and *q* components as independent parameters. Fig. 1 shows the circuit diagram of a typical STATCOM.

The STATCOM is connected in shunt with the power system and the capacitor is used to supply the voltage to the inverter to solve the power quality problems.

One convenient way for studying balanced three-phase system (especially in synchronous machine problems) is to convert the three phase voltages and currents into synchronous rotating frame by *abc/dq* transformation.

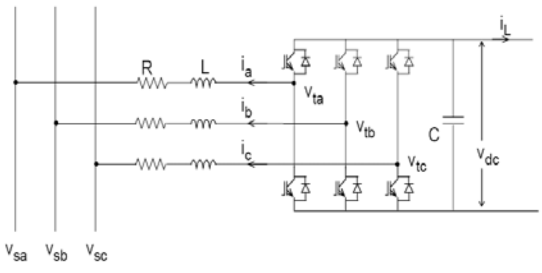

Fig. 1 STATCOM system configuration

The benefits of such arrangement are:

The control problem is greatly simplified because the system variables become DC values under balanced condition; Multiple control variables are decoupled so that the use of classic control method is possible, and even more physical meaning for each control variable can be acquired.

Equations (1) to (4) give the mathematical expression of the STATCOM shown in Fig. 1, [4], [11]. The variable ω is the angular power frequency, and subscripts d, q represent variables in rotating dq− coordinate system.

$$\frac{di_d}{dt} = -\frac{R}{L} i_d + \omega i_q + \frac{1}{L}(V_{td} - V_{sd}) \quad , \qquad (1)$$

$$\frac{di_q}{dt} = -\omega i_d - \frac{R}{L} i_q + \frac{1}{L}(V_{tq} - V_{sq}) \quad , \qquad (2)$$

$$\frac{dV_{dc}}{dt} = -\frac{3(V_{td} i_d + V_{tq} i_q)}{2CV_{dc}} - \frac{i_L}{C} \quad , \qquad (3)$$

$$Q = \frac{3}{2}(V_{sq} i_{sd} - V_{sd} i_{sq}) \quad , \qquad (4)$$

Given a linear system,

$$\dot{x} = Ax + Bu \quad ,$$

$$y = Cx \quad , \qquad (5)$$

Writing equations (1) and (2) in the state space format as (5), the corresponding matrix can be found as,

$$A = \begin{bmatrix} -\frac{R}{L} & \omega \\ -\omega & -\frac{R}{L} \end{bmatrix} \quad , \quad B = \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & \frac{1}{L} \end{bmatrix} \quad , \quad C = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \quad , \qquad (6)$$

Where the states x, the inputs u, and the output y,

$$x = \begin{bmatrix} i_d \\ i_q \end{bmatrix} \quad , \quad u = \begin{bmatrix} V_{td} - V_{sd} \\ V_{tq} - V_{sq} \end{bmatrix} \quad ,$$

$$y = \begin{bmatrix} i_d \\ i_q \end{bmatrix} \quad , \qquad (7)$$

3 Adaptive Control

The adaptive control is used for the automatic adjustment in real time of the process parameters. We employ it when the parameters of a process to control are difficult to determine or when the time is varying [12, 13].

The synthesis of an adaptive controller imposes nearly all the time the following phases :

A. specification of the required performances. We search, when it is possible, to characterizes them by an indication of performances,

B. definition of the control structure or the regulator type which will be used in a view to achieve the required performances,

C. conception of the mechanism of adaptation which will set optimal values to the parameters of the used regulator.

The interest of the adaptive control appears essentially in the level of the parametric disruptions, that is, acting on the characteristics of the process to control. We have noticed that for the realization of the PID and IP control, the regulator parameters vary with the operation of the STATCOM.

4 Controller Design of IP and PID

4.1 Controller Design of IP

One of the most common controlling devices in the market is the IP controller. The order of types of controller positioning is depicted in Fig. 2.

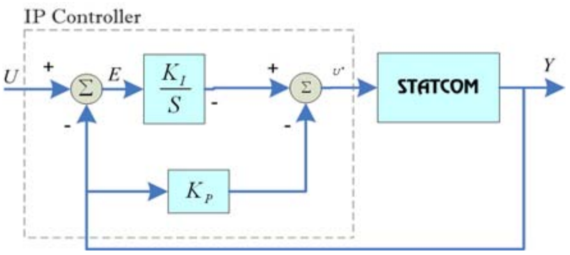

Fig. 2. Block diagram with I - P controller

The closed loop transfer function between the output C(s) and the input R(s) is given in (8).

$$\frac{C(s)}{R(s)} = \frac{K_I G(s)}{s(1 + K_P G(s)) + K_I G(s)} \quad , \qquad (8)$$

Such as:
G(s)= Transfer Function of plant
K_I= Integral *Gain*
K_P= Proportional *Gain*

4.2 PID Controller Designing

One of the most common controlling devices in the market is the PID controller. The order of types of controller positioning is depicted in Fig. 3.

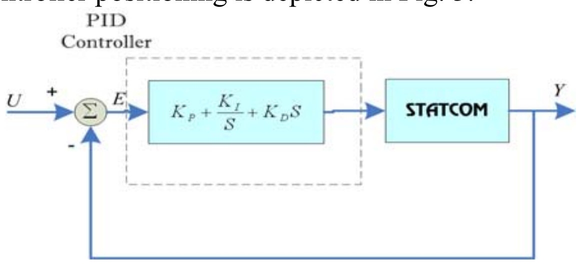

Fig. 3. STATCOM with controllers

There are different processes for different composition of proportional, integral and differential. The duty of control engineering is to adjust the coefficients of gain to attain the error reduction and dynamic responses simultaneously. The PID controlling coefficients are the same as (11).

$$G_{PID}(s) = K_p + \frac{K_I}{s} + K_D s = \frac{K_D s^2 + K_P + K_I}{s}, \qquad (9)$$

5 Genetic Algorithm

GA as a powerful and broadly applicable stochastic search and optimization techniques is perhaps the most widely known types of evolutionary computation method today. In this paper, the GA is employed to find the best K_P, K_I, and K_D parameters. Genetic Algorithms are heuristic search algorithms based on the mechanics of natural selection, genetics and evolution [14].

5.1 Genetic Algorithm Procedure

The main procedure of applying GA's to search the optimum parameters of the controller's include:

Encoding: The first step in applying GA's to the selection of STATCOM controller parameters is Encoding, which maps the parameters of the controller's into a fixed-length string.

Fitness Computation: According to the comprehensive design objectives as mentioned above.

New Population Production: New populations are created using three operators: Reproduction, Crossover and Mutation. Reproduction is a process in which individual strings are copied according to their fitness value. reproductions directs the search toward the best existing individuals but does not create any new individuals. The main operator working on the parents is Crossover, which happens for a selected pair with a crossover probability. Multi-point crossover has been applied to solve combinations of features encoded on chromosomes. Although Reproduction and Crossover produce many new strings, they do not introduce any new information into the population. As a source of new bits, mutation is introduced and is applied with a low probability.

Stopping Criterion: If all of the objectives are met, the generation cycles will terminate. Otherwise, go to step (2), and compute the fitness for each population (see in Fig.4.).

Decoding: This process converts binary alphabets into digital numbers, which gives meaning to the strings, after which the controller parameters are finally determined.

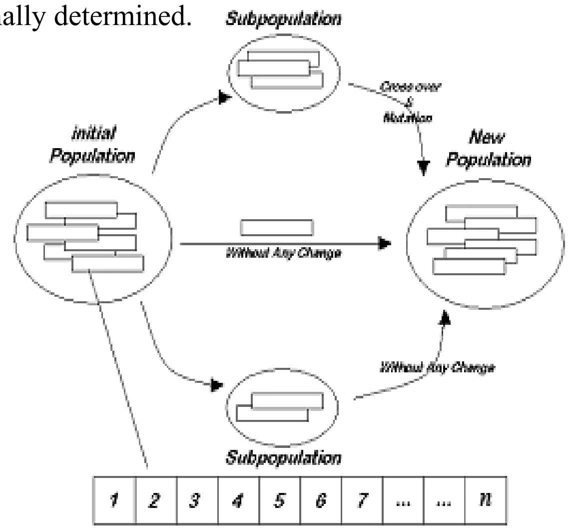

Fig. 4. Schematic of GA operation

5.2 Genetic Algorithm Based On The Model Reference Adaptive Control For PID Controller

Therefore we have decided to realize an adaptive PID control. The parameters of the regulating PID are laboriously obtained through trial and error, although time consuming. Genetic algorithm is employed to find the best values for PID controller's parameters in a very short time [12].

Because our controlled system is a very complex nonlinear system . As a linear control methods , PID control method can not get a good control effect when it is used in controlling a nonlinear system [15]. But PID control method is a simple control method that is wildly used in various controlled systems , Considering GA is a global optimization search algorithm and can be applied in linear and nonlinear problems, we wonder whether PID control method can control a nonlinear system and obtain a good control result ,when PID control method combines with GA [13] . In this control method reference model supplies the expected performance of system, GA optimizes PID.PID control can be expressed as following Equation (9).

In this system, optimized parameters are K_P, K_I and K_D of the PID control. They are encoded to binary bit string. If every parameter is encoded to 6 bits, then a chromosome that is represents a group of parameters is expressed is shown as Fig. 5.

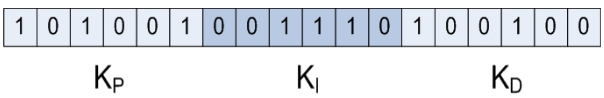

Fig. 5. Chromosomal representation of K_P, K_I and K_D

The indexes of the active current characteristics are required as: Mp<1%, tr<0.001, ts<0.002,where Mp is overshoot ,ts is settling time, tr is rise time. The reference model takes the form as below:

$$G(s) = \frac{1}{s^2 + 2s + 1} , \qquad (10)$$

The members of every individual are K_P ,K_I and K_D,
Population size M=18,
Crossover rate Pc=0.9,
Mute rate Pm=0.01,
The numbers of generation is 1000.

The fitness of PID parameters is applied to the controlled system , and a good control result is obtained. In this control method. The system control block diagram is shown as Fig. 6. and Fig. 7.

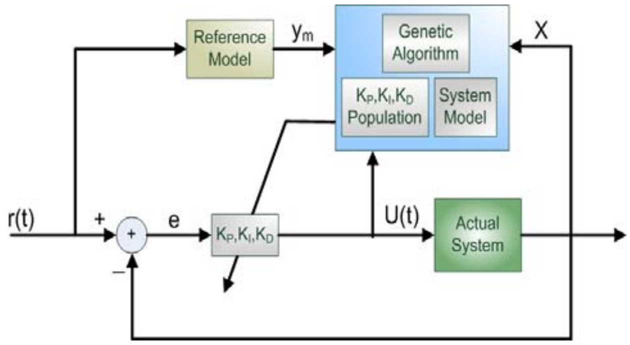

Fig. 6. Genetic Model Reference Adaptive Control

The genetic algorithm flowchart for adaptive controller is shown in Fig. 7.

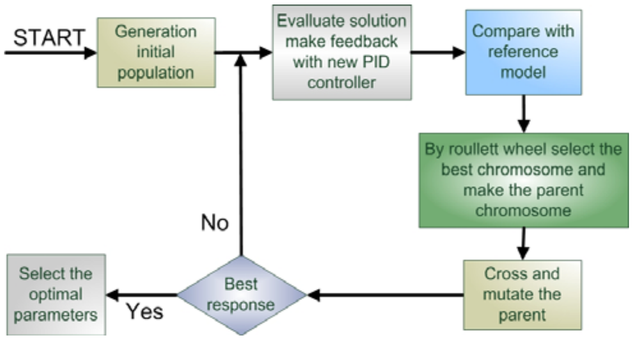

Fig. 7. Genetic algorithm flowchart for adaptive controller

5.3 IP Controller Design by Genetic Algorithm

The configuration of the proposed gain-tuning control system for the STATCOM is depicted in Fig. 8, in which the reference model is chosen according to the prescribed time-domain control specifications.

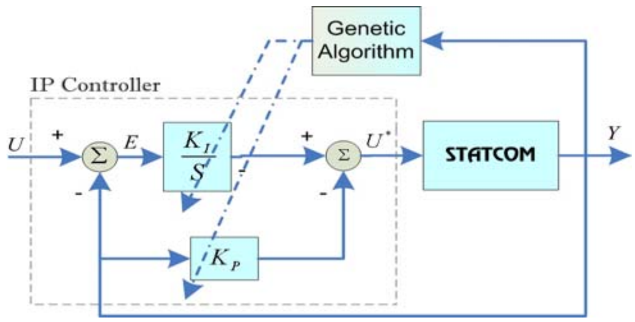

Fig. 8. Block diagram of gain-tuning IP control system using GA

Additionally, the set of the number of generations is dependent on the problem. Usually, some simulation has to be done in advance to decide the best number of generations. The target function is as follows,

$$F_{obj} = \left\{(100Ess^{0.5} + 5Mp^2) + (10ts + tr)\right\} . \qquad (13)$$

That *tr* is rise time, *ts* is settling time, *Mp* is overshoot and *Ess* is steady state error.

The genetic algorithm flowchart for IP controller is shown in Fig. 9,The members of every individual are K_P ,K_I,

Population size M=20,
Crossover rate Pc=0.9,
Mute rate Pm=0.01,
The numbers of generation is 1000.

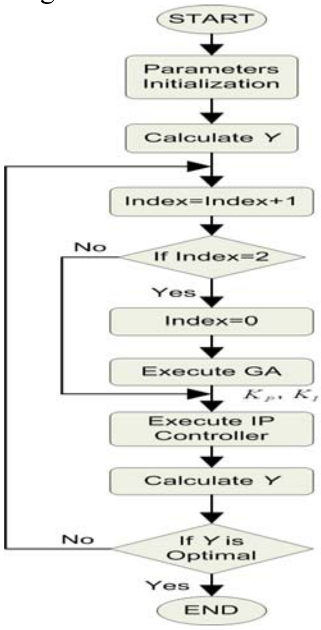

Fig. 9. Genetic algorithm flowchart for IP controller.

6 The Result of Simulation

The system parameters chosen are listed below [11].

TABLE 1
STATCOM PARAMETERS

Source line-line voltage	*460 V*	*DC linkage voltage dc*	*800 V*
Rated power	*140 KVA*	*Frequence*	*50 Hz*
Line resistance	*2 mΩ*	*Line inductance*	*400 μH*
DC linkage capacitance	*7.8 mF*		

The STATCOM open loop response will be in the form of Fig. 10.

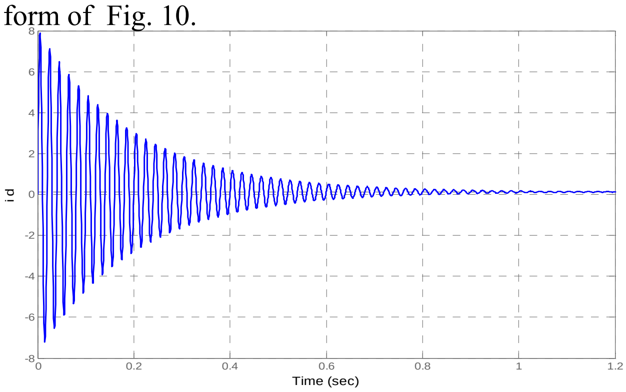

Fig. 10. STATCOM open loop response

As it is evident from the study of outputs, the open loop system has not a good dynamic response, and ideal conditions, for example Mp is higher than 200%. Of course, the outputs will eventually approximate ideal rate with regard to the stability of the system.

6.1 The Result of Simulation With PID Controller

With various K_P, K_I, and K_D designs, the following results the current response of STATCOM are obtained, The K_P, K_I, and K_D in PID control method in the form of manual and genetic algorithm are presented in Table 2, and their outcomes are illustrated in Fig. 11.

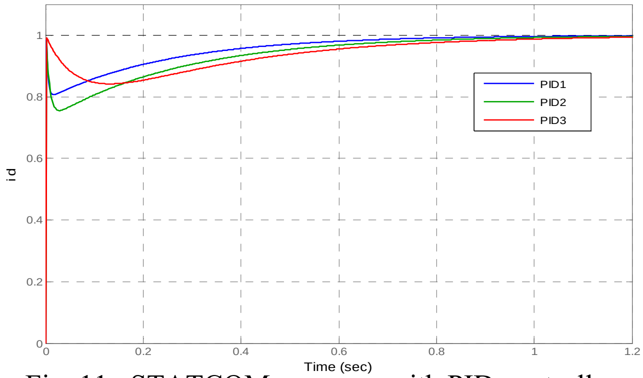

Fig. 11. STATCOM response with PID controllers (PID1, PID2, PID3)

TABLE 2
PID CONTROLLER'S PARAMETERS

	KP	*KI*	*KD*
PID Controller 1	*0.728*	*151.64*	*0*
PID Controller 2	*1.1*	*105*	*0*
PID Controller 3	*11*	*105*	*0*
PID Controller -GA	*782.189*	*1.65*	*0*

6.2 The Result of Simulation PID Controller with Adaptive Method

By applying genetic algorithm based on the model Reference adaptive control optimization of the PID controller for the improvement of STATCOM response, we obtain the conclusions in Fig. 12.

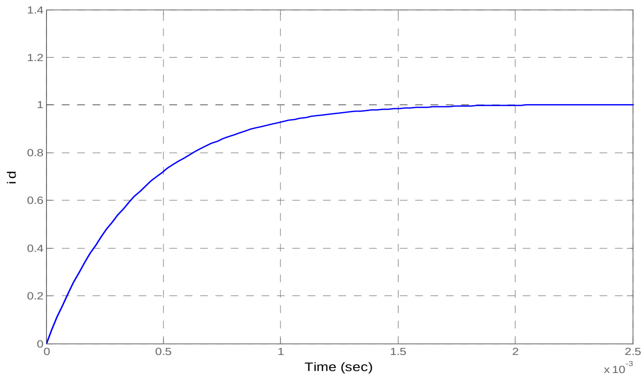

Fig. 12. STATCOM response of PID control methods with adaptive controller

6.3 The Result of Simulation with IP Controller

The K_I ,K_P in IP control method in the form of manual and genetic algorithm are presented in Table 3, and their outcomes are illustrated in Fig. 13.

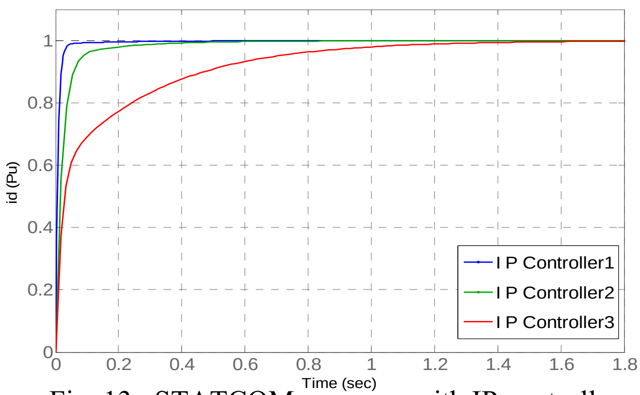

Fig. 13. STATCOM response with IP controllers (IP1, IP2, IP3)

6.4 The Result of Simulation IP Controller with Adaptive Method

By applying genetic algorithm based on the model Reference adaptive control optimization of the IP controller for the improvement of STATCOM response, we obtain the conclusions in Fig. 14.

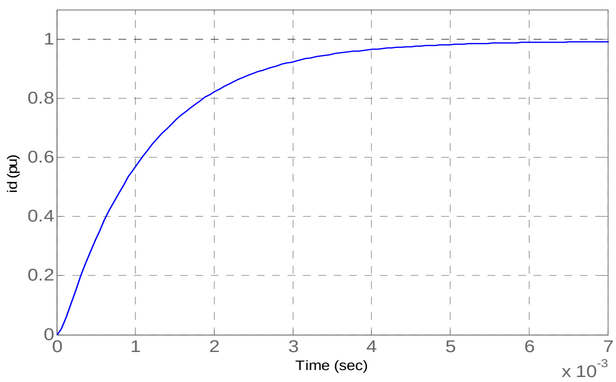

Fig. 14. STATCOM response of IP control methods with adaptive controller

TABLE 3
IP CONTROLLER'S PARAMETERS

	KI	*KP*
IP Controller 1	*900.6596*	*19.498*
IP Controller 2	*66.906*	*1.9498*
IP Controller 3	*1282*	*7.873*
IP Controller -GA	*5965.96*	*6.98*

7 Conclusion

The reduction of output current ripple of the STATCOM is very important. One of the most common controlling devices in the market are IP and PID controller and is able to control the dynamic behavior of the STATCOM. In this paper , GA combines with IP and PID controller's. So a new control method the Model Reference Adaptive Control method based on the combination of them is presented. The results can show that the proposed GA method can obtain high quality solution with good computation efficiency. Therefore, the proposed method has robust stability and efficiency, and can solve the searching and tuning problems of IP and PID controller's parameters more easily and quickly. The use of genetic algorithm for the calculation of optimum coefficients of IP and PID in the designing of controllers can bring about optimum dynamic response, in a very short time. The results of simulation prove the improvement of the performance of this method.

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