Intelligent 2-DOF PID Control For Thermal Power Plant Using Immune Based Multiobjective

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***Abstract*-In the thermal power plant, the main steam temperature is typically regulated by the fuel flow rate and the spray flow rate, and the reheater steam temperature is regulated by the gas recirculation flow rate. However, Strictly maintaining the steam temperature can be difficult due to heating value variation to the fuel source, time delay changes in the main steam temperature, the change of the dynamic characteristics in the reheater.**

Up to the present time, PID Controller has been used to operate this system. However, it is very difficult to achieve an optimal PID gain with no experience, since the gain of the PID controller has to be manually tuned by trial and error.

This paper focuses on tuning of the 2-DOF PID Controller on the DCS for steam temperature control using immune based multiobjective approach. The stable range of a 2-DOF parameter for only this system could be found for the start-up procedure and this parameter could be used for the tuning problem. Therefore tuning technique of multiobjective based on immune network algorithms in this paper can be used effectively in tuning 2-DOF PID controllers.

***Keywords:* PID control; Steam temperature control; Immune algorithm, Multiobjective control.**

1. INTRODUCTION

Studies on the control of thermal power and combined plant have been popular for many years since these systems have been widely adopted as peak load candidates for electrical power generation [1]. The fully automatic start-up function and the fast run-up characteristics of the control systems have made them particularly suitable for peak-load lopping and standby power supply purposes. In the fossil-fired power plant, high-pressure and high temperature boilers are used for generation of electric power large capacity. Also, steam temperature deviation must be kept within $\pm 5°C$ in order to maintain boiler operating efficiency and equipment life time as well as to ensure safety.

Start-up and shutdown procedures of the steam temperature control in the electric power generation boilers are the most challenging problems when developing new control algorithms. The sequence of operations must be successfully performed to maintain steam temperature at the outlet of the superheater and the reheater regardless of the changes in the plant load, properties of the fuel, the conditions of the furnace through a sequence of safe states. At the same time, many variables must be monitored and controlled to ensure operational safety [3, 4]. Moreover, minimal time and energy losses during start up and run-up procedures would be desirable.

Up to now, a Proportional – Integral – Derivative (PID) controller has been used in the steam temperature control of boiler. However, it cannot effectively control such a complicated or fast running system, since the response of a plant depends on only the gain P, I, and D. The 2-DOF PID controller is well known for its robustness, because it is designed to perform two functions: 1) set point following, 2) disturbance rejection. This paper also addresses whether an intelligent tuning method by multiobjective based on a immune network algorithms can be used effectively in tuning for steam temperature control on DCS.

2. CONTROL CHARACTERISTICS OF THERMAL POWER PLANT FOR CONTROLLER DESIGN

A. Control Characteristic in the Thermal Power Plant

The boiler for a thermal power plant is made by the Hanjoong Co. in Korea, which is a typical 500MW once-through supercritical unit. Steam temperature control, one of many control loops in the thermal power plant considers the most difficult and requires attention [2].

In the coal-fired thermal power plant, there are six manipulated variables: main steam flow, feedwater flow, fuel flow, air flow, spray flow, and gas recirculation flow. In addition, there are five controlled variables; generator output, main steam pressure, main steam temperature, exhaust gas o_2 density, and reheater steam temperature [4]. Therefore, the coal-fired power plant is a multi-input and multi-output system, which must alter the generator output in response to changes in the load demand dictated by the DCS in a central load dispatching office.

Fig. 1 shows a functional diagram of the steam temperature system for the Boryong power plant and is composed of three subsystems such as S/H (Super Heater) tube control subsystem, Platon S/H tube control subsystem, ECO tube control system. The each subsystem has a feedforward loop and a feedback-control system. In the thermal power plant, strict control of the steam temperature is critical to maintain safety and avoid thermal stress, which leads to premature failure of the steam turbines. The main

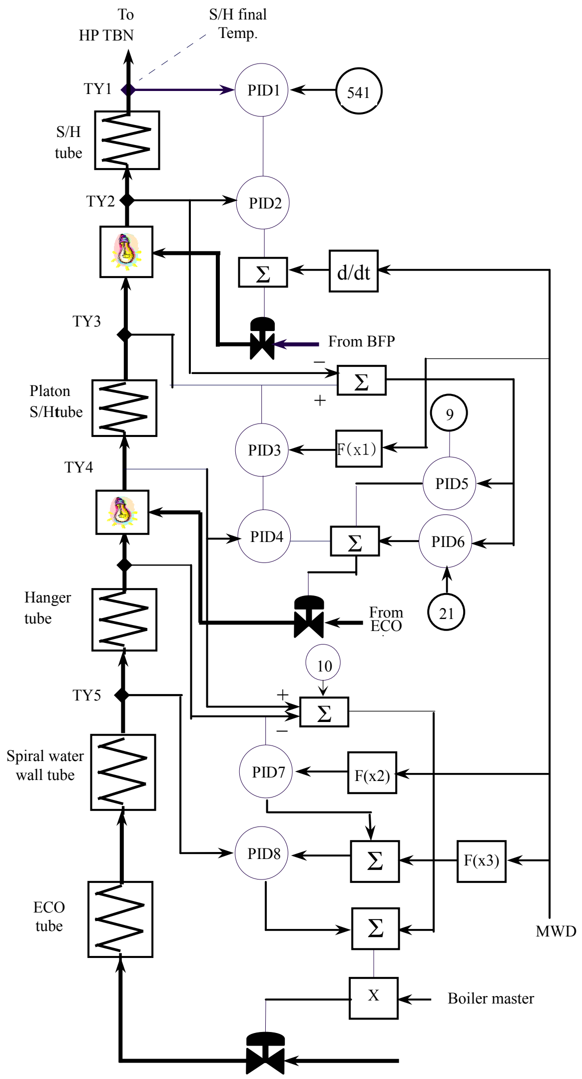

Fig. 1. Shematic diagram of S/H heater steam temperature control system in the power plant.

steam temperature typically is regulated by the fuel flow rate and the spray flow rate, and the reheater steam temperature is regulated by the gas recirculation flow rate. However, the following problems have been identified in steam temperature control [1, 13].

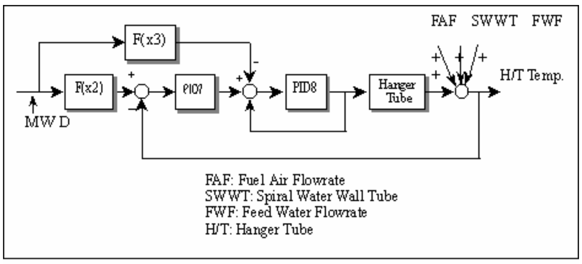

Fig.2 Block diagram of Hanger Tube temperature control system.

1) The heating value of coal, which cannot be measured on-line, varies according to the coal source. The coal source changes within a period ranging from a week to a month and the heating value of the coal can vary from approximately 90% to 110% of a typical value during the course of a day. Furthermore, process characteristics change slowly during a long operation. These factors make it difficult to provide accurate control of the heat input to the boiler.

(2) Since the coal pulverizing process proceeds slowly and since the heat capacity of coal-fired plants is larger than that of oil or gas burning plants, the time delay of changes in main steam temperature versus the changes in fuel flow rate greatly exceeds the delay experienced in oil or gas burning plants. That is, accurate steam temperature control is very difficult to attain during rapid load changes. If the load changes rapidly, the conventional PID controller adjusts the input variables to values corresponding to the boiler load, causing steam temperatures deviation from its set point (more than $\pm 5°C$). Therefore, it is not easy to compensate for steam temperature deviation during start up and rapid load changes.

(3) The main steam temperature control system and the reheater steam temperature control system may interfere with each other. This means that overall temperature control comprises a multi-input and output interference system. Hence, it is difficult to control well both the main steam temperature and the reheater steam temperature.

(4) Flow rates in water and steam fluctuate widely during load-following operation. For example, both the time constant and the gain vary by more than a factor of two during a load-following operation.

B. Steam Temperature Control Approaches in Power Plant Boiler

In the power plant, the strategy used for the control of steam temperature for power plant boilers is normally recommended by the boiler manufacturer. The normal steam temperature control requirement has to sustain the temperature within $\pm 5°C$. Fig. 2 shows two methods of controlling the superheater temperature using a water spray in the power plant. That is, in typical steam temperature control approaches, some form of feedforward control, cascade control, or a F($x1$) has a feedforward function.

C. Superheated Steam Temperature Control

Fundamentally, the temperature of the final superheated steam is a function of the boilers firing rate and the steam flow, and of the design of the heating surfaces and the plant generally.

The control systems for the final superheated steam temperature in boilers rely almost exclusively on attemperators-usually of the spray type. A cascade control system is used to overcome the long time constants of the secondary superheater in steam temperature control.

The temperature of the steam leaving the secondary superheater is controlled by a three-term controller as shown in Figs. 1, 2. Since boiler-plant measured variables tend to be very noisy, much of the noise will be fed to the controller. Therefore, excessive filtering would degrade the quality of control and any derivative action will cause the output to become unstable.

D. Multistage Superheaters for Steam Temperature Control

In boilers with several stages of superheating and employing cascade systems for each section as shown in Fig. 2, spray attemperators are normally provided between the major superheating banks. The operation of each individual cascade system is broadly similar to the simple loop. However, the secondary superheater system includes some notable provisions.

The first key condition in this system is to generate the desired value for the secondary superheater outlet temperature controller from the outlet of the final steam temperature controller, PID8. This is because the final temperature controller output signal can determine the optimum temperature conditions throughout the superheater string.

The second point is the maximum selector block, A, interposed between the first-stage main controller, PID7 and its slave, PID8. This block also receives a signal derived from the drum pressure via a function block, which translates the measured pressure into the equivalent saturation temperature and adds the required safety margin to the result. This arrangement prevents the slave from receiving a desired-temperature signal that is too close to the saturation temperature, and therefore prevents the chilling effect referred to earlier [13]. Finally, the system incorporates an air flow feedforward signal an attempt to optimize response to load changes.

3. 2-DOF PID CONTROLLER DESIGN FOR THE THERMAL POWER PLANT

A. Problem of the PID controller on the Steam Temperature Control System of the Thermal Power Plant

The PID controller has been widely used due to its simplicity and robustness in chemical process, power plant, and electrical systems. Its popularity is also due to easy implementation of hardware and software.

Table 1. P, I, D gain PID1 and PID2 controller for operation of the power plant.

PID1					PID2				
MW (%)	P (Multiple)	MW (%)	I (Multiple)	D	MW (%)	P (time)	MW (%)	I (%)	D
30	0.7	30	0.2	0	30	1.0	30	1.0	0
50-100	0.2	50	0.2	0	65	2.2	65	2.2	0
		75	0.3	0	75	2.5	75	2.5	0
		100	0.3	0	100	3.0	100	3.0	0

However, using only the P, I, D parameters, it is very difficult to control a plant with complex dynamics, such as large dead time, inverse response, and highly nonlinear characteristics. Since the PID controller is usually poorly tuned, a higher of degree of experience and technology is required for tuning in the actual plant [5]. Up to this time, many sophisticated tuning algorithms have been tried an attempt to improve the PID controller performance under such difficult conditions since the control performance of the system depends on the P, I, D parameter gains.

B. Design Principle and Advantage of the Modified 2-DOF PID Controller for the Thermal Power Plant

This type of the 2-DOF PID controller has a combined parameter for a 2-DOF function as shown in Fig. 3 The transfer functions between process value *PV(s)* and settling value *SV(s)*, and between process value *PV(s)* and disturbance *DV(s)* are given in the following equations, respectively:

$$G_{PVDV}(s) = \frac{PV(s)}{DV(s)} = \frac{G_d(s)}{1+K_p\left(1+\frac{1}{T_i s}\right)\gamma} \qquad (1)$$

$$G_{PVSV}(s) = \frac{PV(s)}{SV(s)} = \frac{\alpha K_p\left(1+\frac{1}{T_i s}\right)\left(\frac{1}{1+\beta T_i s}\right)+\left(\frac{\beta K_p K_d s}{1+\eta T_d s}\right)}{1+K_p\left(1+\frac{1}{T_i s}\right)\gamma} SV \qquad (2)$$

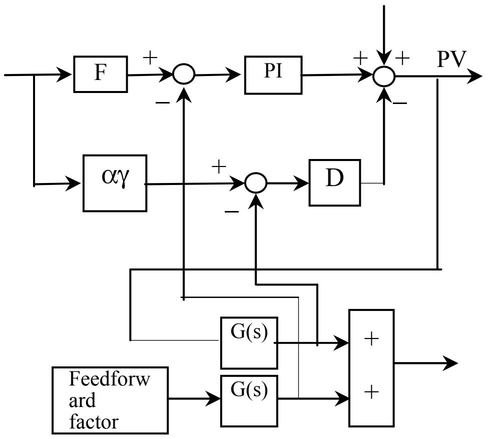

Fig. 3. Block diagram of the design principle of the 2-DOF PID controller with a combined 2-DOF parameter for the thermal power plant.

$$G_{PVG1}(s) = \frac{\left(\frac{\beta K_p K_d s}{1+\eta T_d s}\right)}{1+K_p\left(1+\frac{1}{T_i s}\right)\gamma} G_1(s) \qquad (3)$$

where, the filter transfer function is $F(s) = 1/(1+\beta T_i s)$, the PI controller transfer function is $PI(s) = K_p\left(1+1/T_i s\right)$, and the D controller transfer function is $D(s) = K_p T_d s/(1+\eta T_d s)$. In equation (1), the numerator has a similar function to that of the conventional PID controller. That is, if the proportional gain K_p goes to a greater value, the efficiency of disturbance G_d is smaller. However, equations (2) and (3), the process value *PV(s)* and the plant $G_1(s)$ depend on the two degrees parameter α, β, γ . The proportional gain could also be affected by the parameter α, β, and γ given for the two degrees function. Since the disturbance can be reduced by gains K_p, T_i, and γ the process value PV and the plant $G_1(s)$ are effectively controlled by the two degrees parameter α, β, γ . Then, a 2 - DOF PID controller can perform the two-degrees of function, completely. The result of this arrangement distinguishes it from the conventional arrangement method. A detailed description is given in the simulation section.

4. 2-DOF PID CONTROLLER TUNING BY IMMUNE ALGORITHMS BASED ADAPTIVE MULTIOBJECTIVE

A. Immune Algorithm

The coding of an antibody in an immune network is very important because a well designed antibody coding can increase the efficiency of the controller. As shown in Fig. 4, there are three types antibodies in this paper: 1) antibody type 1 is encoded to represent only α gain in the 2-DOF PID controller; 2) antibody type 2 is encoded to represent I gain; 3) antibody is encoded to represent β gains. The value of the k locus of antibody type 1 shows α gain allocated to route 1. That is, the value of the first locus of antibody type 1 means that α gain allocated to route 1 is obtained by 2 [11, 12].

α	2	1	0.5	• • •	0.2	0.1
β	2	1	0.5	• • •	0.2	0.12
χ	2	1	0.5	• • •	0.2	0.1

Fig. 4. Allocation structure of α , β , χ gain in locus in antibody.

On the other hand, the k locus of antibody 2 represents β gain for tuning of the 2-DOF PID controller. Here, the objective function can be written as follows.

$$\delta_i = \sum_{n=1}^{z} \left\{ \left(L_n - L_n^{object} \right) \right\}^2 + \zeta f_n \quad (4)$$

$$L_n = \sum_{i=1}^{P} \left(R_i I_{i,n} \right)$$

$$f_n = \begin{cases} 0 : L_n \le L_n^{\lim it} \\ 1 : Otherwise \end{cases}$$

where, δ_i : objective function

z: the number of processes for obtaining an optimal PID gain

L_n : optimal level in process for selection of an optimal gain

L_n^{object} : target optimal value in process for selection of an optimal gain

ζ : penalty constant

f_n : penalty function

P: the number of route for selection of an optimal gain

R_i : gain level in route i

$I_{i,n}$: subsidiary function

$L_n^{\lim}$: limit speed in PID gain

This algorithm is implemented by the following procedures.

[step 1] Initialization and recognition of antigen: The immune system recognizes the invasion of an antigen, which corresponds to input data or disturbances in the optimization problem.

[step 2] Product of antibody from memory cell: The immune system produces the antibodies that were effective to kill the antigen in the past. This is implemented by recalling a past successful solution from memory cell.

[step 3] Calculation for searching a optimal solution.

[step 4] Differentiation of lymphocyte: The B - lymphocyte cell, the antibody that matched the antigen, is dispersed to the memory cells in order to respond to the next invasion quickly.

[step 5] Stimulation and suppression of antibody: The expected value η_k of the stimulation of the antibody is given by

$$\eta_k = \frac{m_{\varphi k}}{\sigma_k} \quad (5)$$

where σ_k is the concentration of the antibodies. The concentration is calculated by affinity based on phenotype but not genotype because of the reduction of computing time. So, σ_k is represented by

$$\sigma_k = \frac{sum\ of\ antibodies\ with\ same\ affinity\ as\ m_{\varphi k}}{sum\ of\ \ antibodies}. \quad (6)$$

Using equation (6), a immune system can control the concentration and the variety of antibodies in the lymphocyte population. If antibody obtains a higher affinity against an antigen, the antibody stimulates. However, an excessive higher concentration of an antibody is suppressed. Through this function, an immune system can maintain the diversity of searching directions and a local minimum.

[step 6] Stimulation of Antibody: To capture the unknown antigen, new lymphocytes are produced in the bone marrow in place of the antibody eliminated in step 5. This procedure can generate a diversity of antibodies by a genetic reproduction operator such as mutation or crossover. These genetic operators are expected to be more efficient than the generation of antibodies.

B. Adaptive Multiobjective Optimization by Immune Algorithm

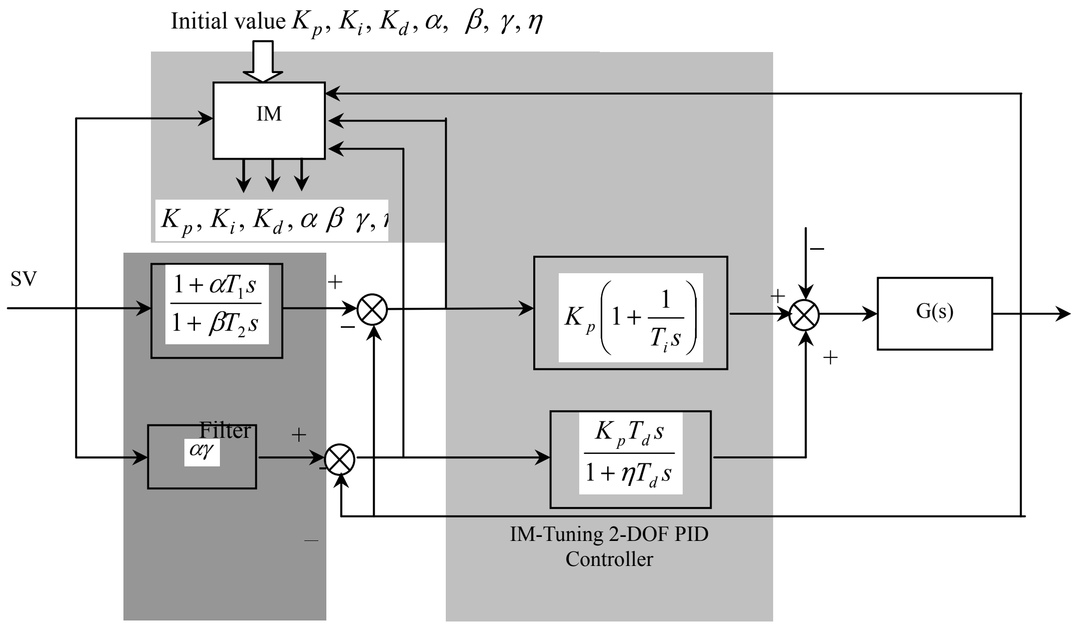

Fig. 5. Immune based tuning of the 2-DOF PID controller with a combined 2-DOF parameter.

Conventional optimization techniques, such as gradient-based and simplex-based methods, were not designed to cope with multiple-objectives search problems, which have to be transformed into single objective problems prior to optimization.

On the other hand. evolutionary algorithms are considered to be better tailored to multiple-objectives optimization problems. This is mainly due to the fact that multiple individuals are sampled in parallel, and the search for multiple solutions can be more effective. This section Stats by reviewing some basic approaches utilized in conjunction with evolutionary computation for multiple-objective optimization. Later, we propose a novel technique to handle this problem.

Evolutionary algorithms typically work with a scalar number to reward individuals' performance, the fitness value. In the case of a single-objective optimization problem, we call this scalar $f(x)$ where x is a particular individual. Considering a multiple-objective problem, we can now define the fitness vector $f(x)$:

$$f(x) = (f_1(x), f_2(x), \ldots, f_n(x)) \quad (7)$$

where $f_i(x)$ represent the scalar components of $f(x)$. The search problem is now restated to the me of seeking for optimal values for all the functions $f_i(x)$. This is the most straightforward approach, to transform the objective vector in a scalar. It is simply accomplished by the traditional weighted sum, i.e.,

$$f(x) = \sum_{i=1}^{n} w_i f_i(x) \quad (8)$$

Chromosome representation: there are six control parameters $[K_p, K_i, K_d, \alpha, \beta, \eta]$ to be determined for an adaptive optimal control. Now, the chromosome H is given as

$$f = [K_p, K_i, K_d, \alpha, \beta, \chi, T_1, T_2] \quad (9)$$

$$f = w_1 f_t + w_2 f_t, \quad f_t = f_1 + f_2 + f_3$$

$$w_1 = [\alpha, \beta, T_1, T_2], \; w_2 = [K_p, K_i, K_d, \eta]$$

with real-number representation.

Objective functions: for the general control problem, it is desirable to optimize a number of different system performances. Consider a step input R(t) and the output response Y(t). The following objectives are stated for design.

- Minimizing the maximum overshoot of the output

$$f_1 = OV = \max_t Y(t) \quad (10)$$

- Minimizing the settling time of the output

$$f_2 = ST = t_s \quad (11)$$

such that $0.98R \le Y(t) \le 1.02R, \forall t \ge t_s$.

- Minimizing the rise time of the output

$$f_3 = RT = t_1 - t_2 \quad (12)$$

such that $Y(t_1) = 0.1R$ and $Y(t_2) = 0.9R$.

C. Tuning of the 2-DOF PID Controller By Adaptive Multiobjective Based on Immune Algorithms

In this paper, the immune network algorithm is used to tune the modified 2 - DOF PID controller. Figs. 5 - 6 show the proposed control system in this paper, as some overshooting in the response of the PID controller tuned by Zielgler-Nichols shown in the same Figs. On the other hand, Figs. 5 and 6 are the minimum and average response when P is varied and I, D are fixed as 10 and 20.

5. SIMULATIONS AND DISCUSSIONS

A. The Characteristic of the PID Controller on the Thermal Power Plant

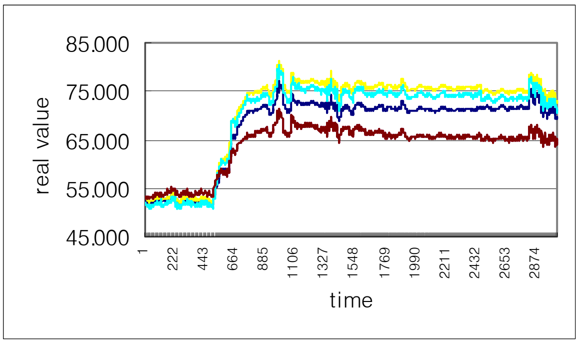

Fig. 6. Response to average values on parameter learning of immune network.

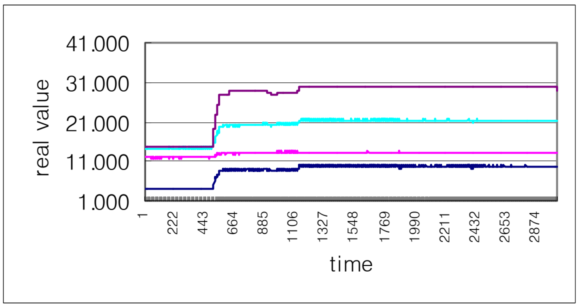

Fig. 7. Comparison of the conventional tuning methods and the proposed tuning method.

Table 2. Comparison of tuning methods.

Item	Tuning methods			Response		
	K_p	T_i	T_d	t_r	t_s	OV
Z-N-PID	36.30	0.21	0.05	0.0674	1.0636	73.2
PI	27.23	0.35	-	0.1099	1.418	81.2
ISTE - PID	30.86	7.55	0.05	0.1111	2.6953	6.8
PI	21.90	8.035	-	0.1405	1.4818	20.6
IM	35.85	21.97	0.06	0.0863	1.4402	8.3

6. Conclusions

Up to now, the PID controller has been used to operate the power plants. However, achieving an optimal PID gain is very difficult for the steam temperature control loop with disturbances and without any control experience since the gain of the PID controller has to be tuned manually by trial and error the design of the PID controller may not cover a plant with complex dynamics, such as large dead time, inverse response, and a highly nonlinear characteristic.

To design an optimal controller that can actually be operated on a generating system in Seoul, Korea, this paper focuses on comparing the characteristics of the PID controller and the modified 2 - DOF PID controller for developing tuning technology on the DCS. The modified 2 - DOF PID controller is designed by rearranging the 2 - degrees parameter to enable parameters of controller to fit into the power plant when it has a disturbance.

For this purpose, we suggest an immune algorithm based multiobjective tuning method for the 2 – DOF PID controller. Parameters P, I and D encoded in antibody are randomly allocated during selection processes to obtain an optimal gain for plant. The object function can be minimized by gain selection for control, and the variety gain is obtained as shown in Table 2. The suggested controller can also be used effectively in the power plant since the controller needs no feedforward or cascade loop.

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