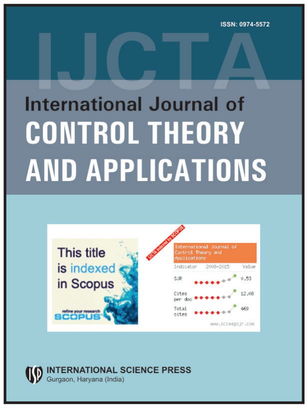

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Genetic Algorithm based Tuning of Controllers for Superheater Steam Temperature Control

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Abstract: Proper control of superheater temperature is vital to assure high efficiency and high load-following capability in the operation of coal-fired thermal power plant. The PID controllers are usually used in cascade control of secondary superheated steam temperature process and the optimal tuning method of PID controller gains is still a hot research area. Here the controller gains are optimally tuned by genetic algorithm for superheated steam temperature regulation in a modern thermal power plant. The dynamical model of the superheater is derived using nonlinear partial differential equations. Using the dynamical model of the superheater, a FOPTD (First order plus dead time model) model is derived using frequency response method. Then optimum gains for PID controller are determined based on the value of ITAE (Integral Time absolute error) using genetic algorithm.

Keywords: Superheated steam temperature system, (SHS), dynamical model, FOPTD, ITAE.

1. INTRODUCTION

Accurate control of temperature at the Superheater outlet is one of the essential and challenging control tasks in a coal fired thermal power plant. The temperature control is done by regulating the spray of water in the Superheater. The difficulty arises at nonlinear characteristics of the SH, the extended time delays caused by the nature of the thermal process, and disturbances from the flue gases [1], [2]. The most popularly used controller in thermal power plant is still the Proportional-Integral-Derivative (PID) controller because of its robustness, acceptable degree of control performance, operation security and technology maturity [4]. It has been reported that more than 95% of the controllers in power plants are of the PID controller. Recent years, more and more PID tuning methods are being developed to deal with various industrial processes. In general, the complex power plant is usually controlled manually by experienced operators based on their knowledge of the plant, when the range of the load change is large. In[10] different conventional tuning methods for superheater steam temperature control system was proposed, but those controllers are tuned without any objective function. The variable adaptive controller has been developed to monitor the steam temperature in a boiler [5]. A predictive control was designed to control superheater steam temperature [5] and pressure. Numerous approaches are presented in the literature for modelling the superheater. The dynamic behaviour of superheater is the main output of these models. In [2] finite difference method based model was proposed which used finite difference method for the solution of the partial differential equations. In [3] predictive adaptive model-based controller is developed for superheater steam temperature control. In [4] advanced control algorithms are developed for steam temperature regulation. The Dynamic modelling of the superheater was explained in[1].

The organization of paper is as follows: The explanation of the steam generation process is given in Sect.2. Superheater steam temperature control circuit is demonstrated in Sect.3. The mathematical model of a superheater is derived in Sect.4. System identification is described in Sect.5. System identification using Transfer function approach is described in Sect.6. System identification using Frequency response approach is described in Sect.7. Zeigler-Nichols tuning method is demonstrated in Sect.8. The Genetic algorithm is given in Sect.9. Finally, conclusion is drawn in Sect.10.

2. STEAM GENERATION PROCESS

Figure 1 shows the simplified diagram of a thermal power plant, which explains about the most important components and their relationship. A coal-fired thermal power plant process is described as follows. Chemical energy released as a result of combustion of coal is converted to thermal energy inside the furnace. Released heat is exchanged between hot flue gases and working fluid through heat exchangers in the boiler, economizer, water wall, primary SH, platen SH, final SH, and reheaters. The SC steam is expanded through turbines. The high pressure developed in the (HP) turbine is energized by the steam supplied by final Superheater, and the reheaters are used to regain energy by reheating the exhaust steam from the HP turbine before it returns to the intermediate pressure (IP) and low pressure (LP) turbine. The mechanical power is thus converted into electrical power by the generator which is coupled to the turbine shaft.

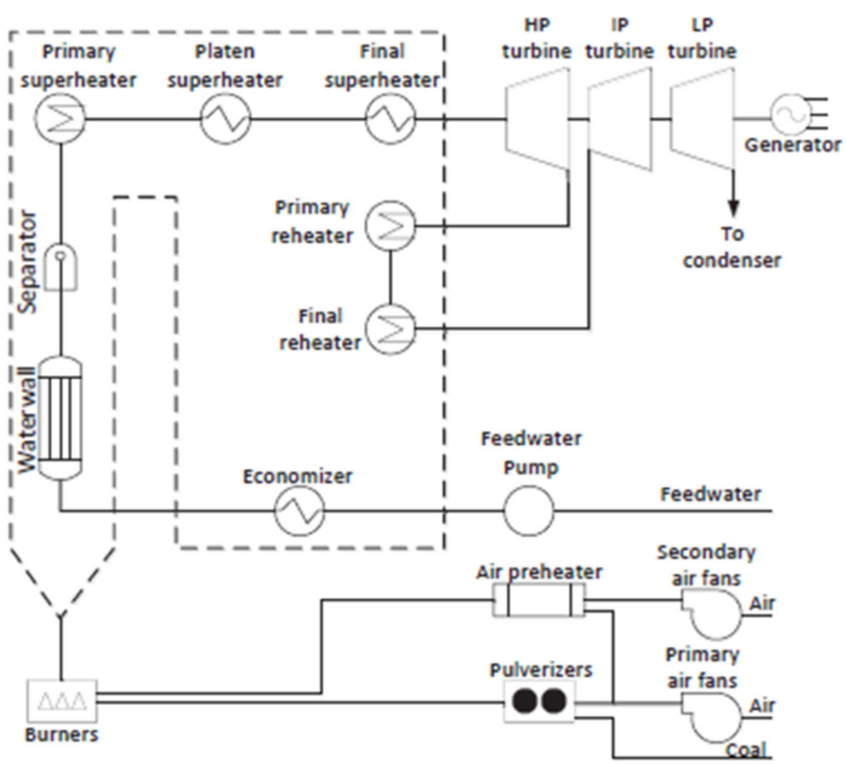

Figure 1: Simplified diagram of a coal-fired power plant

3. SUPERHEATER STEAM TEMPERATURE CONTROL CIRCUIT

The power plant illustrated here is a 200MW subcritical coal-fired boiler-turbine-generator unit [1]. The superheater steam temperature control process is shown in Figure 2. Its main task is to monitor steam temperature constant at 540 °C at the superheater outlet (corresponding to set-point = 540 °C), because hot flue gas 1100 °C is brought near to the superheater, which heats the medium. The temperature regulation is done by injection of certain amount of the water in the mixer, corresponding to manipulated value, using a cascade control.

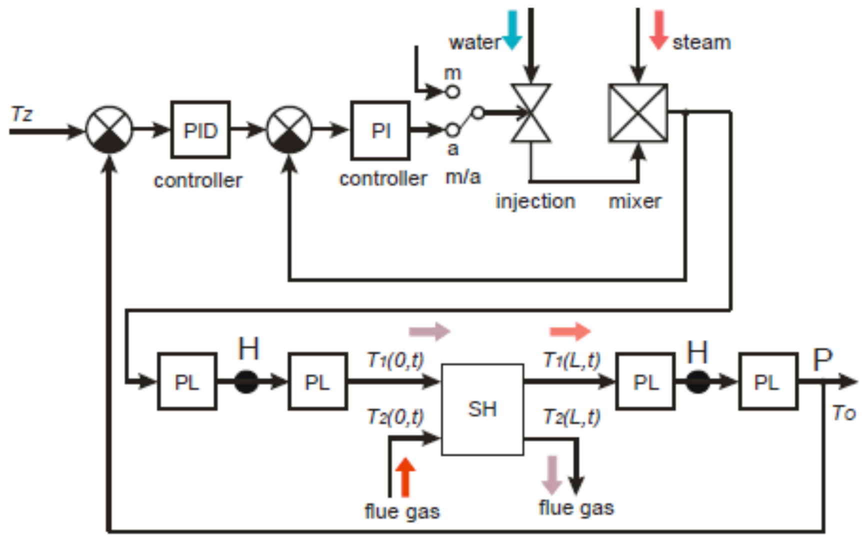

Figure 2: Cascade Superheater steam temperature control system

4. DYNAMIC MODELING OF SUPERHEATER

The five state variables behaviour can be well described by five nonlinear partial differential equations by applying the energy equation, Newton's equation, heat transfer equation, and principle of continuity [1].

Reduced energy equation for flue gas is given by

$$\frac{C_2\rho_2F_2}{\alpha_{S2}O_2}\left[u_2\frac{\partial T_2}{\partial x}+\frac{\partial T_2}{\partial t}\right]+\left(T_2-T_S\right)=0 \tag{1}$$

The Heat transfer equation is given by

$$\frac{\partial T_S}{\partial t}-\frac{T_1-T_S}{\frac{c_S G}{\alpha_{S1}O_1}}-\frac{T_2-T_S}{\frac{c_S G}{\alpha_{S2}O_2}}=0 \tag{2}$$

The Principle of continuity for steam is given by

$$\frac{1}{F\rho_1}\left\{Fu_1\left(\frac{\partial \rho_1}{\partial p_1}\frac{\partial p_1}{\partial x}+\frac{\partial \rho_1}{\partial T_1}\frac{\partial T_1}{\partial x}\right)+u_1\rho_1\left(\frac{\partial F}{\partial p_1}\frac{\partial p_1}{\partial x}+\frac{\partial F}{\partial T_1}\frac{\partial T_1}{\partial x}\right)\right.$$
$$\left.+\,\rho_1\left(\frac{\partial F}{\partial p_1}\frac{\partial p_1}{\partial t}+\frac{\partial F}{\partial T_1}\frac{\partial T_1}{\partial t}+F\left(\frac{\partial \rho_1}{\partial p_1}\frac{\partial p_1}{\partial t}+\frac{\partial \rho_1}{\partial T_1}\frac{\partial T_1}{\partial t}\right)\right)\right\}+\frac{\partial u_1}{\partial x}=0 \tag{3}$$

The Newton's equation for steam is given by[1]

$$\frac{\partial p_1}{\partial x} + \rho_1 u_1 \frac{\partial u_1}{\partial x} + \rho_1 \frac{\partial u_1}{\partial t} + \rho_1 g \sin(\theta) + \frac{\rho_1 \lambda_1 u_1 |u_1|}{2d_n} = 0 \quad (4)$$

Energy equation for steam is given by

$$\frac{\partial}{\partial t}\left\{\rho_1\left(c_1 T_1 + \frac{u_1^2}{2}\right)\right\} + \frac{\partial}{\partial x}\left\{\rho_1 u_1\left(c_1 T_1 + \frac{u_1^2}{2}\right)\right\} + \frac{\partial}{\partial x}\{c_1 u_1\} + \frac{\partial}{\partial x}\{\rho_1 u_1 g \,.\, z\} - \alpha_{1S} O_1 (T_s - T_1)\frac{1}{F} = 0 \quad (5)$$

Table 1
Relevant parameters for superheater dynamic model

Variable	*S.I Unit*	*Description*
$T_1(x, t)$	K	Steam temperature at the superheater inlet
$T_2(x, t)$	K	Flue gas temperature at the superheater inlet
$T_S(x, t)$	K	Superheater wall temperature
$P_1(x, t)$	Pa	Superheater Steam pressure
$u_1(x, t)$	m/sec	Superheater Steam velocity
$P_2(0, t) = P_2(x, t) = P_2(L, t)$	Pa	Flue gas Pressure
$u_2(0, t) = u_2(x, t) = u_2(L, t)$	m/sec	Flue gas velocity
X		The space variable along the active length of the wall of the heat exchanging surface of the superheater
T	Sec	Time
$c_1 = c_1(P, T)$	$J.\ kg^{-1}K^{-1}$	Specific heat capacity of steam at constant pressure
$c_2 = c_2(P, T)$	$J.kg^{-1}K^{-1}$	Specific heat capacity of flue gas at constant pressure
c_S	$J.kg^{-1}K^{-1}$	Specific heat capacity of superheater's wall material
dn	M	Diameter of pipeline
$F_1 = F_1(x)$	m^2	Steam pass cross section
$F_2 = F_2(x)$	m^2	Flue gas channel cross section
g	$m.s^{-2}$	Acceleration of gravity
$G = G(x)$	$kg\ m^{-1}$	Weight of wall per unit of length in *x* direction
L	M	Length of the wall
$O_1 = O_1(x)$	M	Surface of wall per unit of length in *x* direction for steam
$O_2 = O_2(x)$	M	Surface of wall per unit of length in *x* direction for flue gas
$z = z(x)$	M	Ground elevation of the superheater
$\alpha S_1 1K^{-1}$	$J.m^{-2}s^{1}K^{-1}$	Heat transfer coefficient between wall and steam
αS_2	$J.m^{-2}s^{-1}K^{-1}$	Heat transfer coefficient between the wall and flue gas
$\lambda_1(x)$	1	Steam friction coefficient
θ	1	Superheater's constructional gradient
$\rho_1 = \rho_1(P,T)$	$kg.m^{-3}$	Density of Steam
$\rho_2 = \rho_2(P, T)$	$kg.m^{-3}$	Density of flue gas

5. TRANSFER FUNCTION IDENTIFICATION ALGORITHMS

The first order model with delay is given as[10]

$$G_p(s) = \frac{ke^{-Ls}}{Ts+1} \tag{6}$$

The first order derivative of $G_p(s)$ is given by

$$\frac{G'_p(s)}{G_p(s)} = -L - \frac{T}{1+Ts} \tag{7}$$

$$\frac{G''_p(s)}{G_p(s)} - \left(\frac{G'_p(s)}{G_p(s)}\right)^2 = \frac{T^2}{1+Ts^2} \tag{8}$$

Evaluating the values at $s = 0$ results in

$$T^2 = \frac{G''_p(0)}{G_p(0)} - T_{ar}^2 \tag{9}$$

$$T_{ar} = \frac{G'_p(0)}{G_p(0)} = L + T \tag{10}$$

The FOPTD model identified using transfer function approach is given as

$$G_p(s) = \frac{0.8247}{65.7709s+1} e^{-47.8911s} \tag{11}$$

6. FREQUENCY RESPONSE BASED SYSTEM IDENTIFICATION ALGORITHM

The FOPTD model of the system is given by

$$G_p(s) = \frac{K}{Ts+1} e^{-Ls} \tag{12}$$

The frequency response is given by

$$G(j\omega) = \frac{K}{Tj\omega+1} e^{-j\omega L} \tag{13}$$

The ultimate gain K_c is found at the crossover frequency ω_c. The resulting equations are

$$\begin{cases} \dfrac{K(\cos\omega_c L - \omega_c T \sin\omega_c L}{1+\omega_c^2 T^2} = -\dfrac{1}{K_c} \\ \sin\omega_c L + \omega_c T \cos\omega_c L = 0 \end{cases} \tag{14}$$

where, k is gain of the system and it can be calculated directly from the given transfer function. The variables $x_1 = L$ and $x_2 = T$ is given as

$$\begin{cases} f_1(x_1, x_2) = kK_c(\cos\omega_c x_1 - \omega_c x_2 \sin\omega_c x_1) + 1 + \omega_c^2 x_2^2 = 0 \\ f_1(x_1, x_2) = \sin\omega_c x_1 + \omega_c x_2 \sin\omega_c x_1 = 0 \end{cases} \tag{15}$$

The Jacobian matrix J is denoted as

$$J = \begin{bmatrix} \partial f_1/\partial x_1 & \partial f_1/\partial x_2 \\ \partial f_2/\partial x_1 & \partial f_2/\partial x_2 \end{bmatrix} \tag{16}$$

The Jacobian matrix is calculated as

$$= \begin{bmatrix} -kK_c\omega_c \sin\omega_c x_1 - kK_c\omega_c^2 x_2 \cos\omega_c x_1 & 2\omega_c^2 x_2 - kK_c\omega_c \sin\omega_c x_1 \\ \omega_c \sin\omega_c x_1 - \omega_c^2 x_2 \sin\omega_c x_1 & \omega_c \cos\omega_c x_1 \end{bmatrix} \tag{17}$$

The two variables x_1 and x_2 is solved using quasi-Newton algorithm and it is given as. The first order plus dead time model thus identified using frequency response method [9] and the transfer function is given by

$$G_p(s) = \frac{0.8247}{174s+1} e^{-37s} \tag{18}$$

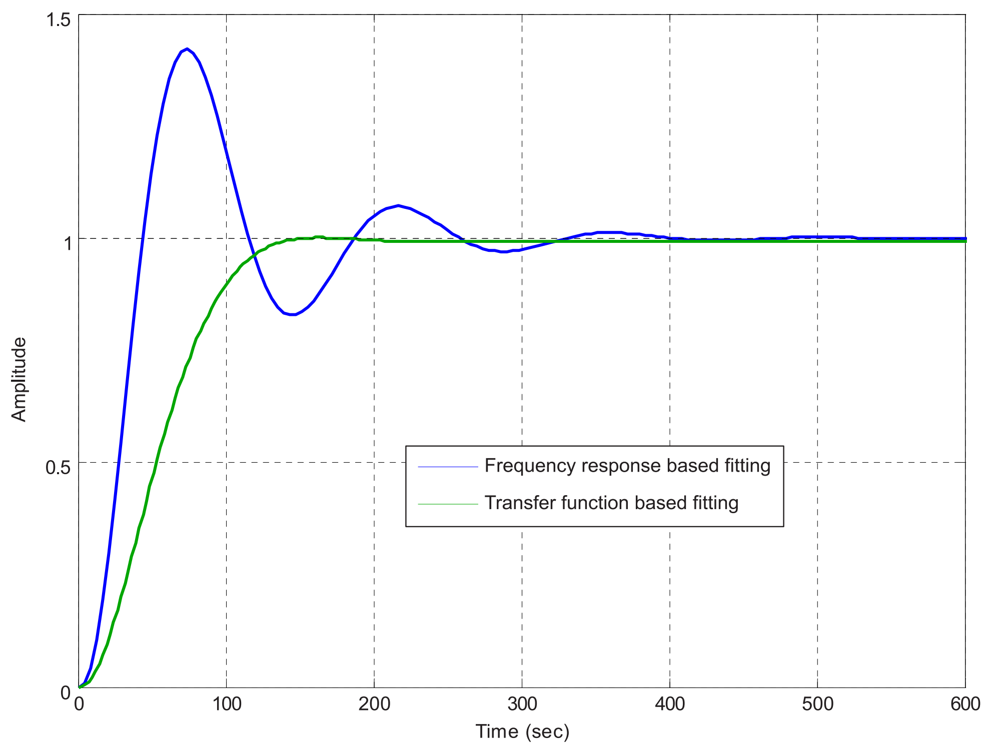

Figure 3: Closed Loop step responses

The simulation results are shown in Figure 3. From Figure 3 the PID controller tuned with the transfer function identification algorithm looks better, it does not exhibit the overshoot characteristics of Ziegler–Nichol's tuning, because of inaccurate identified parameters of an First order plus dead time model. Hence FOPTD parameters such as K, L and T determined using frequency response based method is used for optimal tuning of controller of supeheater steam temperature control.

7. ZEIGLER-NICHOLS METHOD

Zeigler and Nichols developed a tuning formula in 1942.

$$G(s) = \exp(-sL) \times \frac{K}{Ts+1} \tag{19}$$

Table 2
Controller parameters using Zeigler-Nichol's tuning formula

Controller type	*From step response*		
	K_p	T_i	T_d
PI	0.9/a	3L	
PID	1.2/a	2L	L/2

where, a = KL/T

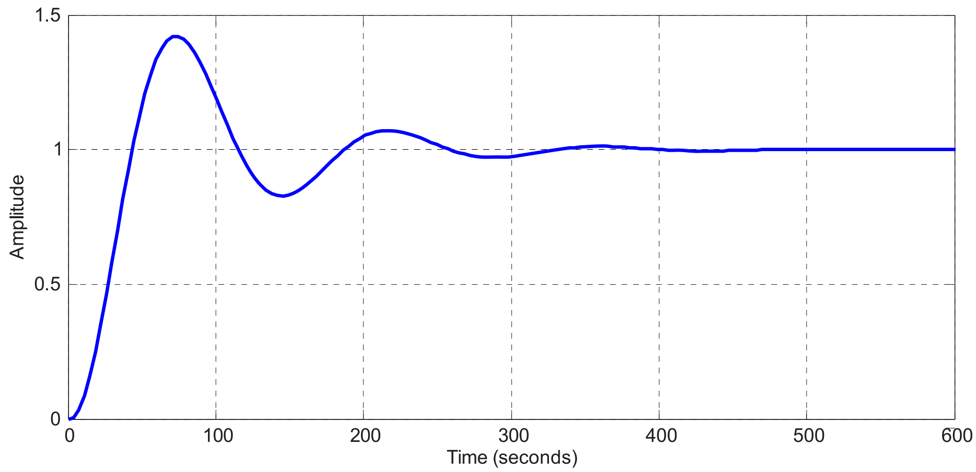

Figure 4: Response of PID controller tuned using Zeigler-Nichol's algorithm.

8. GENETIC ALGORITHM

Initial population production is the first step of GA. The population consist of the chromosomes that are binary bit stream or real codes. The evaluation of a population is called the "fitness function". Here the fitness function is defined as:

$$\text{ITAE} = \int_0^\infty t\left|e(t)\right|dt \qquad (20)$$

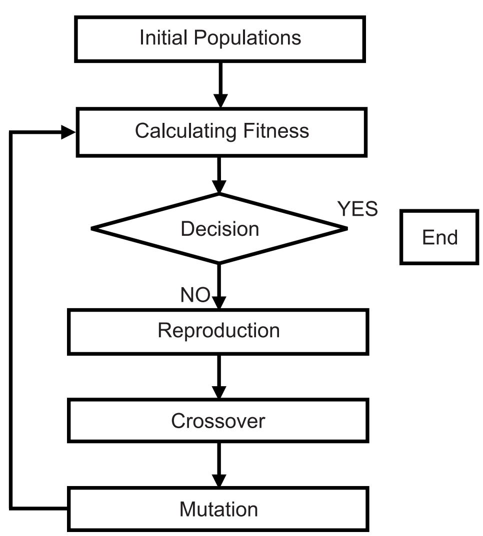

Figure 5: Flow chart of Genetic Algorithm

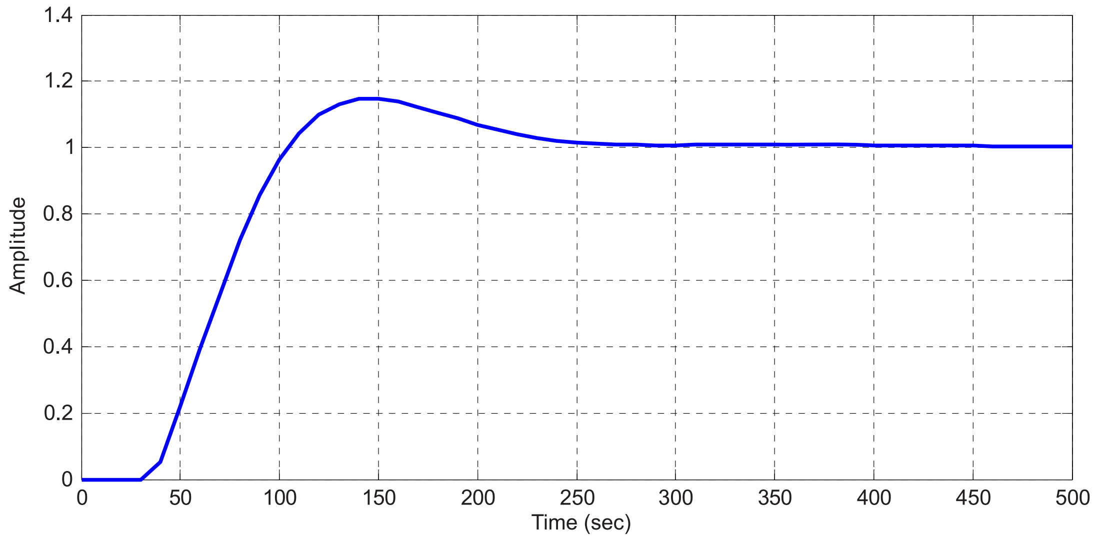

Figure 5: PID controller response tuned using Genetic algorithm

The simulation results shown in Figure 5 clearly shows that GA based tuning of controllers for superheater steam temperature control has less overshoot and good set point tracking.

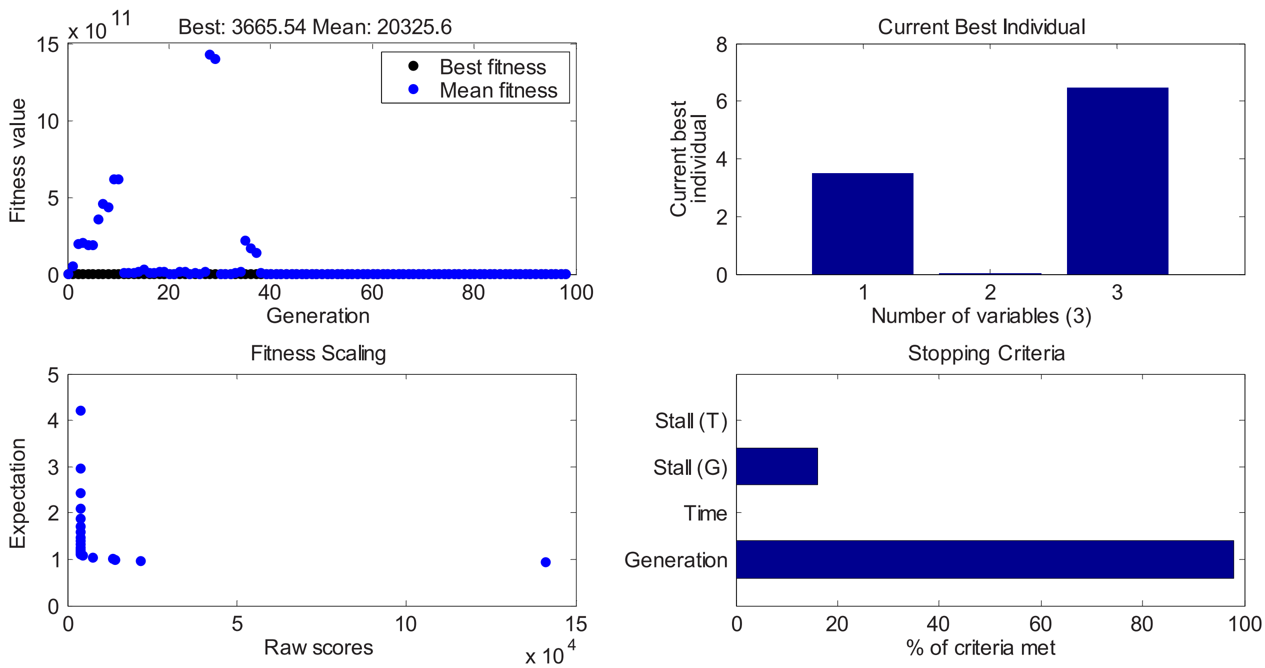

Figure 6: PID Controller tuned using GA

Table 3
Comparison of performance indices

Performance Indices	*Zeigler-Nichols Algorithm*	*Genetic Algorithm*
Rise time (sec)	28.1922	51.4802
Settling Time (sec)	307.5812	237.7118
Settling Min	0.8279	0.9632
Settling Max	1.4200	1.1470

Performance Indices	*Zeigler-Nichols Algorithm*	*Genetic Algorithm*
Overshoot	42.0017	14.3428
Undershoot	0	0
Peak	1.4200	1.1470
Peak Time (sec)	74.5434	150
ITAE	4142	3665.54

9. CONCLUSION

Finally it can be concluded that Genetic algorithm based tuning of PID controller gains is optimum for temperature control of superheated steam temperature system. Using the dynamical model of superheater, FOPTD model identification using Frequency response method and transfer function method is presented. Based on the FOPTD model derived using frequency response approach, it was shown that controller tuned using Genetic algorithm method for superheated steam temperature control has least value of ITAE. Compared with conventional tuning techniques, the PID controller tuned using GA for superheated steam temperature control system has obtained good set point tracking with very less overshoot.

REFERENCES

[1] Nevriva,Ozana P, Pies S and Vilimec M, 2010, Dynamical Model of a Power Plant Superheater, Trans.WSEAS,vol.9, 774-783.

[2] Sung S. W., Lee J and Lee I. B., 2009, Process Identification and PID Control, New York: Wiley.

[3] Gough B, 2000, Advanced control of steam temperature on a utility boiler, Universal Dynamics Technologies Inc., Richmond, Canada.

[4] Sanchez Lopez A, Arroyo Figueroa G, and Villavicencio Ramirez A,2004, Advanced control algorithms for steam temperature regulation of thermal power plants, International Journal of Electrical Power & Energy Systems, Vol. 26, No. 10, 779–785.

[5] Moelbak T, 1999, Advanced control of superheater steam temperatures-an evaluation based on practical applications, Control Engineering Practise, Vol. 7, 210-215.

[6] Zhang J and Hou G, 2006,Adaptive neuro-control system for superheated steam temperature of power plant over wide range operation, Sixth International Conference on Intelligent Systems Design and Applications (ISDA’06), pp. 138-141.

[7] Lee K.Y, Ma L, Boo C.J, Jung W.H, and. Kim S.H,2009,Inverse dynamic neuro-controller for superheater steam temperature control of a large-scale ultra supercritical (USC) boiler unit, Proc. of the IFAC Symposium on Power Plants and Power Systems Control, in Tampere, Finland, July 5-8.

[8] Heo J. S. and Lee K. Y,2006, Multi-objective control of power plants using particle swarm optimization techniques, IEEE Trans. Energy Convers., Vol. 21, No. 2, 552-561.

[9] Liu X.J and Zhou X, 1999, Identification of boiler models and its fuzzy logic strategy, in Proc. the 14 th IFAC World Congress, Beijing China, June, Vol. 10, 149-154.

[10] Sreenivasulu G, and Reddy S. N,1999, Performance Evaluation of Superheated Steam Temperature Control System based on tuning methods of analog controllers, IETE Journal of research, Vol. 49, 399-404.