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OPTIMIZATION OF PID CONTROLLER PARAMETERS FOR SO_2 EMISSION CONTROL PROCESS USING PSO ALGORITHM

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ABSTRACT

This paper presents the application of PID controller for SO_2 emission control process using Particle Swam Optimization (PSO) algorithm. To minimize the impacts of SO_2, it must be removed from flue gas. Zeiglar-Nichols based PID (ZN-PID) controller is developed for SO_2 emission control process using MATLAB/SIMULINK platform. Based on the tuning parameters of ZN-PID controller, optimization of PID controller parameters are obtained based on PSO algorithm. Performance of the PSO based PID controller is analysed and compared with Ziegler-Nichols PID controller (ZN-PID) and IMC controller in terms of time domain performance measures such as settling time and rise time (t_s and t_r) and error indices (ISE, IAE, ITAE). The simulation results proved that the PSO-PID controller provides most consistent performance as compared to the conventional controllers.

INTRODUCTION

SO_2 is the major atmospheric pollutant resulted from combustion of coal and oil. The main sources of SO_2 emissions are coal fired boilers, sulphuric acid plants, chemical and metallurgical furnaces. Many techniques have been proposed for SO_2 removal process such as wet flue gas desulphurization, dry flue gas desulphurization and semi dry flue gas desulphurization techniques (Yuegui Zhou *et al.*, 2009). Among all the techniques, wet type flue gas desulphurization produces more removal efficiency (Cofalaa *et al.*, 2004).

While considering the absorbent to the wet FGD process, lime stone based flue gas desulphurization technique is most widely used since it gives more than 90% removal efficiency but it produces CO_2 as a secondary emission to the atmosphere (Edward *et al.*, 2004). Based on the results given in Colle *et al.* (2005), the flow rate and concentration of hydrogen peroxide has the direct influence on outlet SO_2 concentration. For regulating the flow rate of hydrogen peroxide, an appropriate controller is required to improve the removal efficiency by reducing outlet SO_2 concentration.

Zeiglar and Nichols (1949) developed simple and robust tuning rule which is a widely practiced conventional control technique in many industrial applications. Skogestad (2003) developed model based

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tuning algorithm called as Internal model Controller (IMC) proved that it provides better control action since it is designed based on the transfer function model of the process.

PSO is an evolutionary-type global optimization algorithm (Kennedy & Eberhart, 1995) which is different from well-known similar algorithms in that no operators, inspired by evolutionary procedures, are applied to the population to generate new promising solutions. PSO has already been used to determine optimal solution to several power engineering problems such as reactive power and voltage control (Yoshida *et al.*, 2000) and state estimation (Naka *et al.*, 2001).

The present work focussed on tuning the PID controller using PSO algorithm. The PSO-PID controller is simulated within various scenarios and its performance is compared with those of an optimally designed PID controller.

Particle Swarm Optimization (PSO)

PSO is a population based evolutionary algorithm that was developed from research on swarm such as fish schooling and bird flocking (Kennedy & Eberhart, 1995). PSO is a robust stochastic optimization technique based on the movement and intelligence of swarms. PSO applies the concept of social interaction to problem solving. It uses a number of agents (particles) that constitute a swarm moving around in the search space looking for the best solution.

Let the swarm consists of N particles moving around in a search space. Each swarm is initialized with a random position and velocity. Based on its own and companions experience at every iteration each particle modifies its position and velocity. The i^{th} particle is denoted by $X_i = (x_{i1}, x_{i2}, \ldots, x_{in})$ and its individual best previous value (pbest) is represented as $P_i = (p_{i1}, p_{i2}, \ldots, p_{in})$. Current velocity is given by $V_i = (v_{i1}, v_{i2}, \ldots, v_{in})$. Finally, the overall best solution achieved by the whole swarm (gbest) is represented as $P_g = (p_{g1}, p_{g2}, \ldots, p_{gn})$. The fitness function evaluates the performance of particles to determine whether the best fitting solution is achieved. The particles are modified based on the following equations:

$$v_{in}^{new} = w_i v_{in}^{old} + c_1 (p_{in} - x_{in}) + c_2 (p_{gn} - x_{in}) \quad (1)$$

$$x_{in}^{new} = x_{in}^{old} + v_{in}^{new} \quad (2)$$

Where, c_1 and c_2 are two positive constants and w is the inertia factor

w balances the global wide-range exploitation and the local nearby exploration abilities of the swarm and is given by

$$w = w_{max} - \left[\frac{(w_{max} - w_{min})}{iter_{max}} \right] * iter \quad (3)$$

Where, itermax is the maximum number of iterations and iter is the current number of iterations.

MATERIALS AND METHODS

Modelling of SO_2 Emission Control Process

Absorption is the process of converting a gaseous pollutant from gas phase to a liquid phase. It involves the removal of gaseous pollutants by making them to dissolve in a liquid (Sinnott 1991). For this process, packed column is designed based on the principle of gas-liquid interface to obtain proper liquid to gas mixing. It leads to the efficient removal of soluble SO_2 from gas stream.

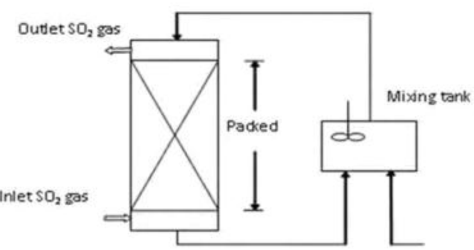

Fig. 1 Schematic of control setup

Figure 1 illustrates the schematic of control set up used for SO_2 emission control process. Packed column (or) liquid-gas absorption column is used for analysis. Flue gas with maximum of 5000 ppm SO_2 concentration is entered at the inlet of the packed column. The mixing tank containing fresh hydrogen peroxide is flowing towards the top of the column. The flow rate of hydrogen peroxide has the direct influence on the SO_2 absorption rate. Hence based on the concentration of SO_2 leaving out of the column, flow rate of SO_2 is manipulated to get better SO_2 removal efficiency.

Mathematical modelling is developed by considering material balance equations and reaction of kinetics of SO_2 removal process. Detailed mass balance study is carried out based on the material balance and kinetic chemical equations for Figure 1.

MATLAB/SIMULINK model is developed based on Figure 1. Open loop response is identified for flow rate of hydrogen peroxide Vs SO_2 removal efficiency. From the open loop response, the process is approximated to first order plus time delay (FOPTD) transfer function shown in equation 1.

$$G(s) = \frac{K_p}{\tau_p s+1} e^{-t_d s} \quad (4)$$

Based on open loop response graph, the model parameters Kp, and tp are identified by step test method. The worst case model is selected and the identified transfer function is given by,

$$G(s) = \frac{27}{244s+1} e^{-1s} \quad (5)$$

A PID controller has proportional, integral and derivative terms that can be represented in transfer function form as

$$K(S) = K_P + \frac{K_i}{S} + K_d \quad (6)$$

Performances Criteria

Different tuning rules are used to calculate the parameters of PID controller. Probing the optimal parameters of PID controller is an optimum problem in essence. PSO technique is used to determine the optimal values of the PID controller in this paper. There are several performance criterions for design of controllers. Integral of absolute error (IAE), integral of squared error (ISE) and integral of time-weighted-squared-error (ITSE) are often used in literatures to design controllers. Gaing (2004), illustrated that the performance criterion w(z) is defined for PID controller design, is defined as

$$W(z) = (1-e^{\beta}) * (Mp + E_{ss}) + e^{-\beta} * (t_s - t_r) \quad (7)$$

where β is a weighting factor, M_p, E_{ss}, tr and ts are respectively the overshoot, steady-state error, raising time and settling time.

Design process of PSO-PID

The design process of PSO based PID controller for SO_2 emission controller process is summarized as follow:

i. Initialize the parameters like number of iteration and particle size

ii. Randomly initializing swarm velocities and position

iii. For each initial particle of the population, calculate the values of the performance criterion

iv. Compare each particles evaluation values and calculate personal best position $P_i(t)$ and global best position $P_g(t)$

v. Update swarm position and velocity based on the eqn

vi. If the number of iteration reaches the maximum value evaluate Pg which is the optimal controller parameter else goto step (iii)

The optimized parameters of the PID controller based on PSO algorithm are K_p =0.05776, K_i =0.00038 and K_d =0.29905.

RESULTS AND DISCUSSION

The MATLAB/SIMULINK platform is developed for the SO_2 emission control process. Tuning values that are optimized using PSO algorithm is used to control the process. Response of the PSO-PID, IMC-PID and ZN-PID for 500 ppm operating point is shown in Figure 2. The figure clearly shows that PSO-PID gives better performances than ZN-PID and IMC-PID controller and it is ensured with the performance measures in terms of error indices Integral Squared Error (ISE), Integral Absolute Error (IAE), Integral Time Absolute Error (ITAE), and Quality indices (rise time tr, settling time ts) of the controller. the performance measures tabulated in Table 1 shows that PSO-PID controller provides less error indices and good quality indices.

Further, the performance of the controller is verified with the disturbance test. It is obtained by changing set point form 500 ppm SO_2 outlet concen-

Table 1. Performance measures of PSO-PID, ZN-PID and IMC-PID controller

Controller	ISE	IAE	ITAE	Rise Time (t_r) (Sec)	Settling Time(t_s) (Sec)
ZN-PID	$54.84*10^7$	$27.29*10^4$	$23.42*10^6$	58	1025
IMC-PID	$42.04*10^7$	$16.98*10^4$	$68.01*10^5$	76	813
PSO-PID	$25.69*10^7$	$94.63*10^3$	$17.19*10^5$	53	500

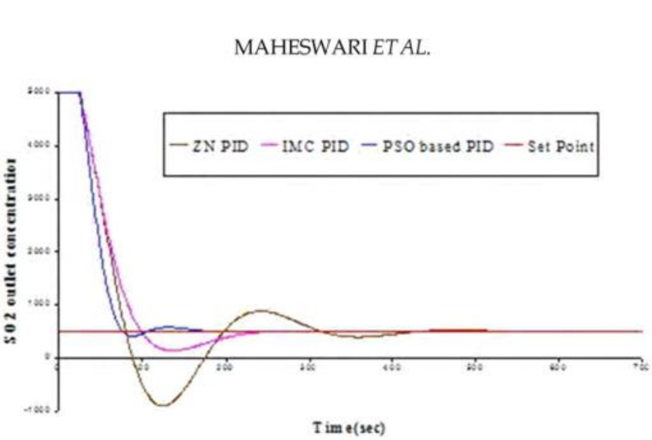

Fig. 2 Performance of PSO-PID, ZN-PID and IMC-PID controller

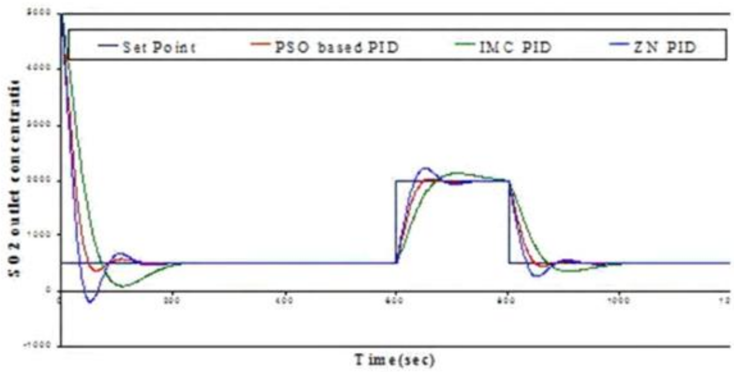

Fig. 3 Disturbance rejection test on ZN-PID, IMC-PID and PSO-PID

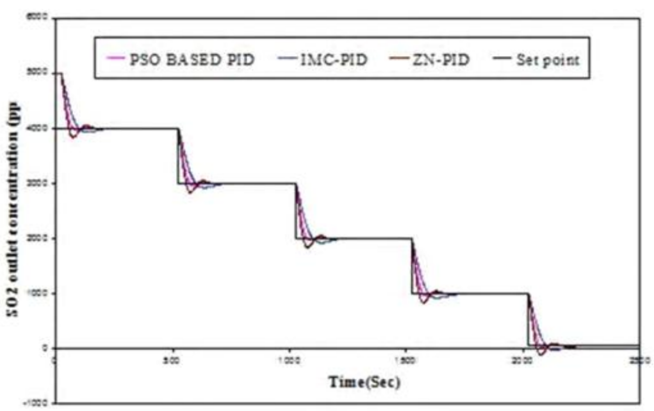

Fig. 4 Closed loop transient responses at different operating points

tration into 2000 ppm at 600 seconds, and it is maintained up to 800 sec as shown in Figure 3. The performance graph shows that the PSO-PID controller reaches the set point at the earliest than the conventional controllers.

The performance of the controllers are tested for different continuous tracking cases at 4000 ppm, 3000 ppm, 2000 ppm, 1000 ppm and 50 ppm SO_2 outlet concentrations as shown in Figure 4. The figure ensure that the better performance achieved by PSO-PID controller at all operating points.

CONCLUSION

SO_2 emission control process is modelled using mathematical equations and based on the open loop response transfer function is determined. In order to implement a better control action over the SO_2 emission control process, PID controller parameters are optimized based on performance measures. The PSO based PID controller parameters are calculated (K_p = 0.05776, K_i = 0.00038 and K_d = 0.29905) and its performance is compared with the conventional controllers such as ZN-PID and IMC-PID controllers. The simulation results developed in MATLAB/SIMULINK platform ensured that the optimized tuning parameters provide better control action over the conventional controllers.

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