Controller Optimization for Boiler Turbine Using Simulated Annealing and Genetic Algorithm

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Abstract— The present work takes up the boiler turbine process for control system design and its optimization. The control system is designed and optimized, to exhibit the best control performance, using two different optimization techniques, called simulated annealing (SA) and genetic algorithm (GA). Their control performance is also compared with that of controller designed, for the same process, using Ziegler Nichol (ZN) technique. All the simulations have been done on MATLAB software.

Keywords— Boiler turbine; simulated annealing; genetic algorithm; optimization

1 Introduction

Simulated annealing is basically an imitation of a physical process, called annealing, in which first of all a solid material is heated and then its temperature is gradually decreased, by which it starts melting and its defects are mitigated and its internal energy is minimized. In the same manner the SA algorithm decreases the temperature with every iteration until the minimum value is reached. The rate of lowering of temperature should be chosen to be small to increase the possibility of achieving the best solution.

At the start of algorithm, a test solution is generated randomly. The value of objective function is calculated at this current solution. Now, the current state is little perturbed, based on some probability distribution, to obtain a new state. If the value of objective function is better for this new state than the last current state then it is considered as the current state and next iteration of algorithm is run. This is done for preventing the algorithm from being stuck at a local minima point [1]. The worse point may also be accepted as the current state, after this comparison, with some acceptance probability given by equation (1) [2].

$$P_A = e^{\frac{(U_1 - U_2)}{K\theta}} \tag{1}$$

Where U1 and U2 represent objective function value in current and next state respectively such that U2 > U1, K is Boltzmann constant, and θ represents temperature. S.B.Gelfand and S. K. Mitter proposed a modified annealing algorithm for a noise corrupted inaccurate objective function [3].

Pawel Drag and Krystyn Styczen presented a solution to nonlinear optimization problem using simulated annealing for a two reactors system [4]. Young-Jae Jeon et al. minimized losses in electric power distribution system using SA [5]. Yogendra Kumar Soni and Rajesh Bhatt designed PID control system for a process with known transfer function model and optimized its performance using SA [6]. Alexander Hošovský optimized control system for temperature control of boiler water using SA [7]. J.S. Higginson et al. optimized performance of biomechanical system using SPAN [8]. Stanisław Mikulski performed optimization of parameters of PID controller using SA with integral squared error as the objective function, and compared three different approaches of cooling [9].

Genetic algorithm (GA) is an imitation of how the progression of birth and reproduction takes place in human beings. This is very efficient and effective technique to solve an optimization problem which finds the most optimal solution in a very small amount of time. To initiate this algorithm, initial population of possible solutions, called chromosomes, is selected. Now, fitness of all the chromosomes is determined using a predefined fitness function. Finally, the two fittest chromosomes are selected, and crossover and mutation operations are performed on them to produce new pool of solutions (chromosomes). This sequence of steps represents one iteration, also called one generation of GA. This way a large number of generations are executed following the same sequence of steps on newly generated population until the global optimum solution is obtained [12].

2 Process Model and Controller Design

In the boiler turbine system, the high pressure steam, injected through a control valve, runs the turbine to produce electricity in large scale [10]. Here, a single input-single output (SISO) model of boiler turbine process is considered. The corresponding state space representation of this process is presented in equation (2) and (3) with a time delay of 2 sec. Here, the manipulated variable (mv) is control valve opening for steam flow. The control variable (cv) is electric power generated [11]. The state vector is represented by s.

$$\frac{ds}{dt} = As + B(mv) \tag{2}$$

$$(cv) = Cs + D(mv) \tag{3}$$

Where the matrices A, B, C, D are defined as under,

$$[A] = \begin{bmatrix} 0.4611 & 0.047 & 0.0015 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \quad (4)$$

$$[B] = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (5)$$

$$[C] = [0.0268 \quad 0.0757 \quad 0.0260 \quad 0.0008 \quad 0 \quad 0] \quad (6)$$

$$[D] = 0 \quad (7)$$

Now, the formulated objective function, for the PI controller based control system with the considered plant model, is the mean square error (MSE) as expressed in equation (4). Here K_P and K_I are proportional constant and integral constant respectively of the PI controller. The corresponding objective function plot is displayed in Fig.1.

$$MSE = 0.9959 - 1.063K_P + 3.602K_I + 0.8492{K_p}^2 - 55.95K_PK_I \quad (8)$$

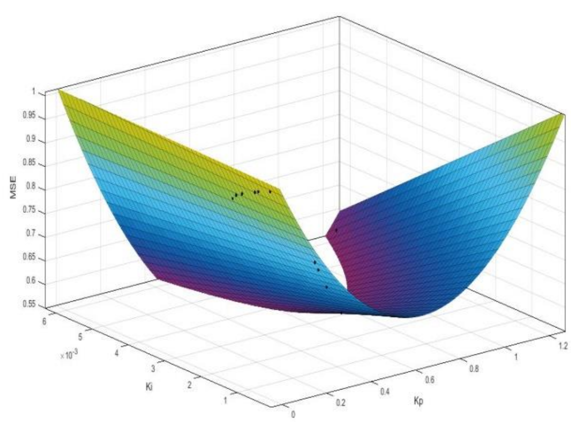

Fig. 1. Objective function

Table 1. SA Parameters

Parameter	Value/Type
Initial Temperature	50
Re-annealing Interval	50
Annealing Function	Boltzmann
Temperature Update Function	Logarithmic
Iterations	100

The SA optimization algorithm is run to minimize this objective function with the parameters specified in Table 1. After running 100 iterations of SA algorithm, the objective function fitness (MSE) comes out to be 0.72 as depicted in Fig.2. The optimized values are KP = 0.3 and KI = 0.0018.

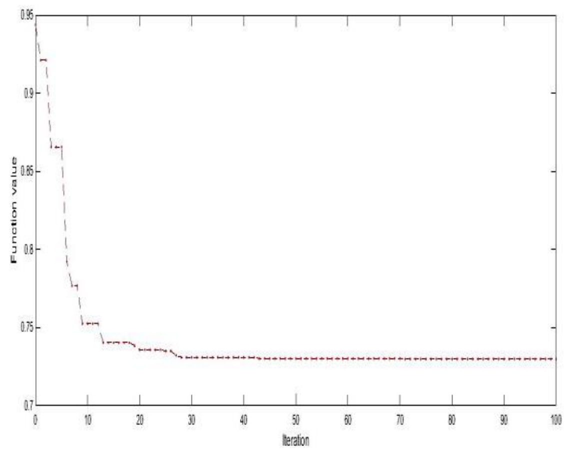

Fig. 2. Fitness value plot in SA optimization

Table 2. GA parameters

Parameter	Value/Type
Population size	100
Selection function	Roulette
Crossover probability	0.6
Mutation function	Gaussian
Crossover function	Single point

Now the GA optimization algorithm is executed to minimize this objective function with the parameters specified in Table2. After running 100 iterations of GA algorithm, the objective function fitness (MSE) comes out to be 0.44 as depicted in Fig.3. The optimized values are KP = 0.82 and KI = 0.006.

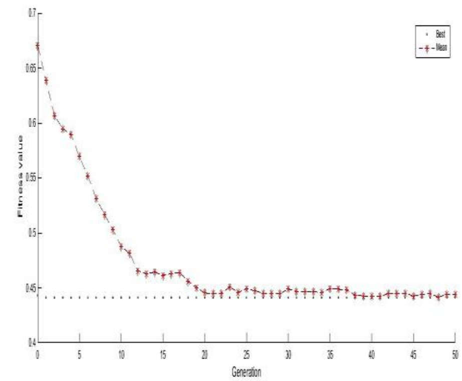

Fig. 3 Fitness value plot in GA optimization

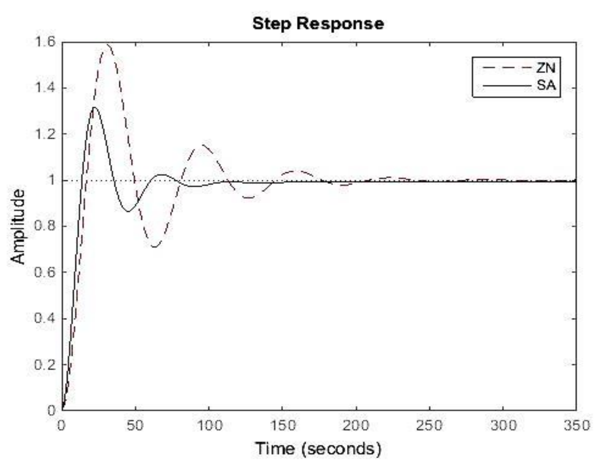

Fig. 4 Comparison of ZN and SA based set-point tracking responses

Table 3. Comparison of Performance

Controller	K_P	K_I	Settling Time (sec)	Peak Overshoot (%)
ZN	0.16	0.008	193	58.9
SA	0.3	0.0018	98.7	31.6
GA	0.82	0.006	81.3	48.8

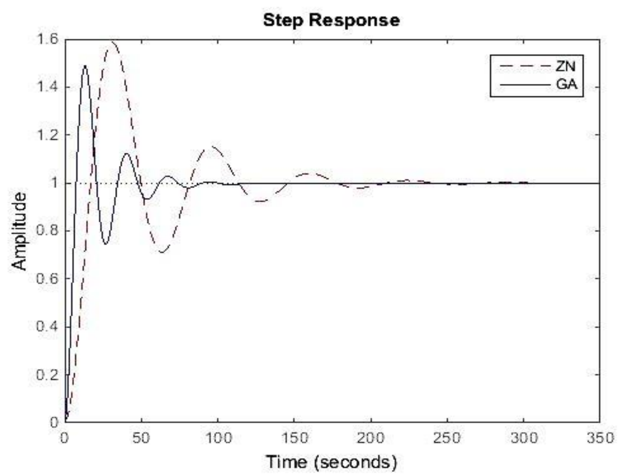

Fig. 5. Comparison of ZN and GA based set-point tracking responses

A clear performance comparison of ZN , SA and GA based controllers is presented in Table 3,which is clearly showing that the SA and GA optimized controllers exhibit control performance much superior to that of ZN based controller with smaller settling time and less peak overshoot. The corresponding set-point tracking responses are showcased in Fig.4 and Fig.5.

3 Conclusion

The present work highlights the optimization of PI controller parameters using simulated annealing and genetic algorithm optimization algorithm using MATLAB software. The controller is designed for the boiler turbine process with one input and one output variable. It has been observed that the SA and GA based controllers exhibit much better control performance than conventional ZN tuning based controller. Mutual comparison of SA and GA reveals that the transient response of SA based controller is better than that of GA based controller with smaller peak overshoot. However, the steady state response of GA based controller is better than that of SA based controller with smaller settling time.

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