

Optimization Techniques Applied to Boiler Turbine Unit

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Abstract

Objectives: Design and implementation of PI/PID controllers with parameter optimization using different techniques for MIMO systems. **Methods:** Biogeography Based Optimization based Proportional Integral Derivative (BBOPID) and investigating the robustness of the BBOPID technique applied to boiler turbine unit. Design of a Coordinated PID (CPID) Controller and tuning the CPID parameters using Particle Swarm Optimization (PSO), Bacteria Foraging (BF) and BBO techniques are discussed. **Findings:** The design of controller is done by using the performance index of Integral Square Error (ISE). Results show that BBO controller gives better performance for both servo and regulatory responses. **Application:** The electric power is generated using steam driven turbo generators, where the steam is produced by drum boilers as as practices base, reuses and stores the best practices.

Keywords: Bacteria Foraging, Biogeography Based Optimization, Boiler Turbine Unit, Particle Swarm Optimization

1. Introduction

According to¹ Genetic Algorithm (GA) gives better performance than the³¹ conventional PI controller for servo and regulatory changes, as evident from the Integral Squared Error (ISE) and Integral Absolute Error (IAE) values.

In² Compared the tuning of the PID controllers using Simulated Annealing (SA) and traditional methods for spherical tank system. SA tuned controllers improve the performance of the process in terms of time domain and frequency domain specifications.

In^{3, 31} Proposed a PID reduction procedure for a centralized controller and showed that the performance of the PI controller for a boiler - turbine unit did not degrade much from the original loop-shaping H_∞ controller. In⁴ discussed a criterion based disturbance rejection and system robustness to assess the performance of PID controllers.

In⁵ presented the new development of the boiler-turbine Coordinated Control Strategy (CCS) using fuzzy

reasoning and auto tuning techniques. CCS is organized into two levels, a basic control level and a high supervision level. PID type controllers are used in the basic level to perform basic control functions while the decoupling between two control loops can be realized in the high level. For the large variation of operating condition, a supervisory control level has been developed by auto tuning technique. Indeed, better control performance and economic benefit have been achieved.

In⁶ deals with the application of a Multivariable Non-linear Controller (MNC) to a multivariable non-linear boiler-turbine unit. The method can asymptotically estimate and compensate the non-linearity, coupling and disturbances owing to its observation ability. A decentralized MNC system is obtained for a non-linear boiler-turbine model, and then evaluated under a wide range of operating conditions and perturbations. Simulation results show that the MNC can achieve decoupling, asymptotic tracking property without steady-state errors, disturbance rejection and better robust performance for boiler-turbine plants. Results are also

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compared with GA/ Linear Quadratic Regulator (LQR) and standard optimal controller LQR.

In⁷ Proposed a frequency domain approach direct Nyquist array method, to the design of PID controllers for multivariable boiler-turbine units based on gain and phase margins. Various PID controller design methods for SISO systems can be easily extended to decoupled or quasi-decoupled MIMO systems. In particular, the proposed method is to specify the robustness and other key performances of the system through the gain and phase margin specifications. Simulation results illustrate the efficacy of the proposed method, showing that the designed controller for a boiler-turbine unit has a reduced number of elements by a half and produces much better dynamic performances.

In⁸ Proposed multivariable PID controllers for a two input two output system. A diagonal PID controller for two input two output system is found using an auto tuning procedure. The critical frequency and gains of the process used in the tuning formulas may be obtained by placing two relay controllers in the system. PID controller parameters can be determined using the generalized ZN method or using characteristic locus. Furthermore, PID tuning using an integral performance optimization procedure for a two input two output system has also been investigated. The results show that the resultant step responses using the generalized ZN method may have a relatively high overshoot but they can be used as an initial setting for further tuning. The characteristic locus method usually results in better step responses than the generalized ZN method.

In⁹ Proposed a new auto tuning method for multivariable PID controllers from decentralized relay feedback for MIMO systems. This method achieved better³¹ performance than the conventional PID controller.

In¹⁰ discussed sequential design method for multivariable decoupling and multiloop PID controllers in a sequential manner. The method is based on a single-loop tuning technique developed for multivariable systems with unknown dynamics. The design algorithms lead to good performance, robust stability, and integrity.

In¹¹ Proposed the PSO algorithm and¹² discussed the design of frequency selective surface using PSO and it is used for electromagnetic optimization problems. This combined and synergic use of information yields a promising tool for solving design problems that require the optimization of a relatively large number of parameters. The performance of the PSO is compared with GA.

In¹³ Proposed the PSO algorithm which can be used to solve the minimization problem and a detailed overview of the basic concepts of PSO and its variants. It also provides the power system applications that have benefited from the powerful nature of PSO as an optimization technique. For each application, technical details that are required for applying PSO, such as its type, particle formulation (solution representation), and the most efficient fitness functions are also discussed.

In¹⁴ Presented the optimal design of high speed axial flux generator. GA and PSO are used for optimizing the efficiency of machine and PSO shows better efficiency.

In¹⁵ Focused on the development and real time implementation of an intelligent optimization method based on PSO for the control of liquid level in a spherical tank. Proportional integral (PI) controller based on ZN setting is designed and the results are compared with Internal Model Control (IMC) based on Skogestad's settings and PSO based PI (PSOPI) controller. The robustness of all the controllers is validated by imposing both servo and regulatory disturbances.

In¹⁶ Discussed the control system on the E.coli that dictates how foraging should proceed. A computer program that emulates the distributed optimization process represented by the activity of social BF is presented.

In^{17,31} Presented Dynamic Bacterial Foraging Algorithm (DBFA), to solve the problem of Optimal Power Flow (OPF) with load variations. The simulation results, obtained by evaluating DBFA are compared with BF Algorithm (BFA) and PSO.

In¹⁸ Introduced a modified BFA for solving the Economic Dispatch (ED) problem. The proposed algorithm is a dynamic BF technique which applies a dynamic non-linear function to update the solution vector and enhance the algorithm convergence.

In¹⁹ Introduced a Micro-Bacterial Foraging Optimization Algorithm (μ -BFOA), which evolves with a very small population compared to its classical version. In this technique, the best bacterium is kept unaltered, whereas the other population members are reinitialized. This new small population μ -BFOA is tested over a number of numerical benchmark problems for high dimensions and found this to outperform the normal bacterial foraging with a larger population as well as with a smaller population.

In²⁰ Proposed a novel BFA for solving OPF problems with considering transmission security. The objective of OPF is to minimize total generation cost, enhance

transmission security, reduce transmission loss and improve the bus voltage profile under normal or contingent states. The effectiveness of the proposed method is demonstrated for a 26-bus and the IEEE 30-bus systems, in terms of solution quality and evolutionary computing efficiency.

In²¹ Present the use of Battery Energy Storage (BES) system for the grid-connected Doubly Fed Induction Generator (DFIG). The control scheme is modified and the co-ordinated tuning of the associated controllers to enhance the damping of the oscillatory modes is presented using BF technique. The results from Eigen value analysis and the time domain simulation studies are presented to elucidate the effectiveness of the BES systems in maintaining the grid stability under normal operation.

In²² Discussed the natural biogeography and its mathematics, and it can be used to solve optimization problems. It demonstrates the performance of Biogeography Based Optimization (BBO) on a set of 14 standard benchmarks and compares it with seven other biology-based optimization algorithms. A real-world sensor selection problem for aircraft engine health estimation is also demonstrated.

In²³ Presented BBO technique for solving constrained ED problems in power system. Many non-linear characteristics of generators, like valve point loading, ramp rate limits, prohibited zone, and multiple fuels cost functions are considered. Two Economic Load Dispatch (ELD) problems with different characteristics are applied to investigate the effectiveness of the proposed algorithm.

In²⁴ Presented a BBO algorithm to solve both convex and non-convex ELD problems of thermal plants.

In²⁵ Derived a dynamic system model for BBO that is asymptotically exact as the population size approaches infinity. The states of the dynamic system are equal to the proportion of each individual in the population. The dynamic system model allows us to derive the proportion of each individual in the population for a given optimization problem.

In²⁶ Presented BBO algorithm to tune a PID controller of non-linear systems. Simulations of the proposed algorithm are carried out over an inverted pendulum and mass-spring damper system. Performances of the BBO are compared to those of GA in PID tuning problem and the BBO gives acceptable results than GA.

In²⁷ Developed BBO algorithm for the prediction of the optimal sizing coefficient of Small Autonomous Hybrid Power System (SAHPS) in remote areas. BBO algorithm is used to evaluate optimal component sizing and operational strategy by minimizing the total cost of SAHPS, while guaranteeing the availability of energy. The proposed BBO method has excellent convergence property, requires less computational time and also it can avoid the shortcoming of premature convergence of other optimization techniques to obtain a better solution.

In²⁸ Proposed Swarm Intelligence Algorithm improves the system stability, efficiency, dynamism and reliability. In²⁹ PID controller with antcolony optimization for the conical tank process was Developed. Results provided improvement in tracking the set point. In³⁰ Designing and constructing concrete gravity dams must be in a way that not only realize sustained conditions, but also impose the minimum production costs. The major imposed cost in such dams is expenses of excessive use of concrete. Optimizing this cost requires cross-section optimization.

Need is to design the controller using various optimization techniques to reduce the Integral Square Error.

2. Physical Model

The³¹ boiler-turbine unit can be modeled as a 2X2 system. The two inputs are boiler firing rate or fuel flow rate assuming air flow rate is regulated well by air control subsystem) and the governor valve position and the two outputs are electric power and throttle pressure by Tan et al (2004).

The underlying idea is that this simple model can capture the essential dynamics of the system which is under consideration. Tuning of controller for a boiler-turbine unit is important because it helps to find a simple model that can capture the essential dynamics, especially the coupling effect between the generated electricity and the throttle pressure. A non-linear dynamic system with a simple structure is able to capture the essential dynamics of the boiler-turbine unit. A simple diagram of a boiler turbine unit is given in Figure 1 and it shows the energy balance relation and the essential non-linear characteristics of the boiler-turbine system.

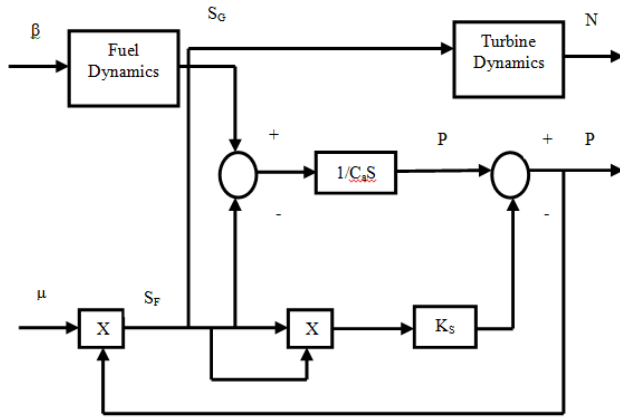


Figure 1. Simple diagram of a boiler turbine unit.

3. Controller Design

The Coordinated PID (CPID) controller for two input two output system⁴, is designed. These CPID controller parameters are tuned using Particle Swarm Optimization (PSO), Bacteria Foraging (BF) and Biogeography Based Optimization (BBO) algorithms.

The transfer function $G(S)$ of the boiler-turbine unit obtained by⁴ is given by

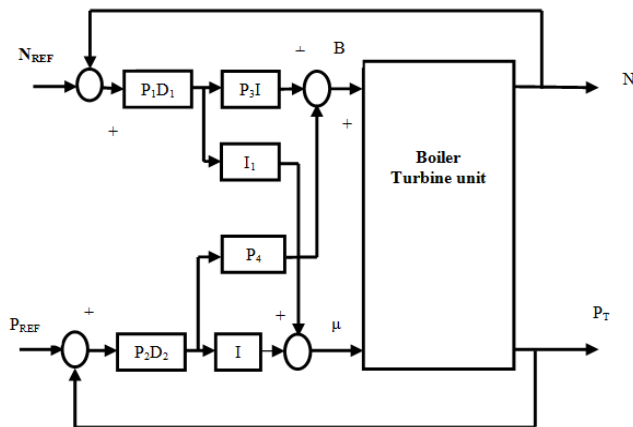


Figure 2. CPID controller structure for boiler turbine unit.

$$G(s) = \begin{pmatrix} \frac{4.247(3.4s+1)}{(100s+1)(20s+1)(10s+1)} & \frac{3.224s(3.4s+1)}{(100s+1)(10s+1)} \\ \frac{0.224}{(100s+1)(20s+1)} & \frac{0.19(20s+1)}{100s+1} \end{pmatrix} \quad (1)$$

The controller performance is evaluated in terms of Integral Square Error (ISE) as follows,

$$ISE = ISE1 + ISE2$$

$$ISE1 = \sum_0^{t_f} (N_{REF} - N)^2$$

$$ISE2 = \sum_0^{t_f} (P_{REF} - P)^2$$

and IAE is given below

$$IAE = IAE1 + IAE2$$

$$IAE1 = \sum_0^{t_f} |N_{REF} - N|$$

$$IAE2 = \sum_0^{t_f} |P_{REF} - P|$$

where	N	-	Electrical Power output
	N_{REF}	-	Set point of Electrical Power output
	P	-	Throttle Pressure
	P_{REF}	-	Set point of Throttle Pressure

3.1 Coordinated PID (CPID) Controller

Figure 2 shows the CPID controller structure of a boiler turbine unit designed by⁴. The CPID controller for the boiler-turbine unit is

$$[K_c(s)] = \begin{bmatrix} \frac{(T_1 + T_b)s + 1}{m_{11}s} & \frac{m_{12}}{m_{11}m_{22}} \\ \frac{m_{21}}{m_{11}m_{22}s} & \frac{1}{m_{22}s} \end{bmatrix} X \begin{bmatrix} PD_1 & 0 \\ 0 & PD_2 \end{bmatrix} \quad (2)$$

3.2 Particle Swarm Optimization Based PID (PSOPID) Controller

The following PSO parameters are selected for the training cycle for³¹ boiler turbine unit

Size of the swarm "no of birds"	$n_b = 50$;
Maximum number of "birds steps"	$= 100$;
Velocity constant	$c_1 = 0.4$;
Velocity constant	$c_2 = 0.4$;
PSO momentum of inertia	$w = 0.9$;

3.3 Bacteria Foraging Based PID (BFPID) Controller

The following BF parameters are selected for the training cycle for boiler turbine unit.

Number of bacteria s_b	$= 100$
Number of chemotactic steps N_c	$= 4$
Limits the length of a swim N_s	$= 4$

Number of reproduction steps $N_{re} = 4$

Number of elimination-dispersal events $N_{ed} = 2$

Number of bacteria reproductions (splits)/Generation $S_r = s/2$

The probability that each bacteria will be eliminated/dispersed $P_{ed} = 0.25$

3.4 Biogeography Based Optimization Based PID (BBOPID) Controller

The following BBO parameters are selected for the training cycle for ³¹ boiler turbine unit.

Population size	=10
Maximum generation	=100
Number of Variables	=9
Mutation Probability	=0.05

4. Result and Discussions

Simulations are carried out to evaluate the proposed PID controller for the transfer function of the boiler turbine unit given in Equation (1). The PID controller parameters are tuned with different optimization techniques by utilizing the Matlab/Simulink software. The performance of the different control strategies are compared based on the performance criteria (ISE and IAE) for the two controlled outputs electrical power and throttle pressure. The output disturbance is also shown for characterizing the performance of the four different control strategies.

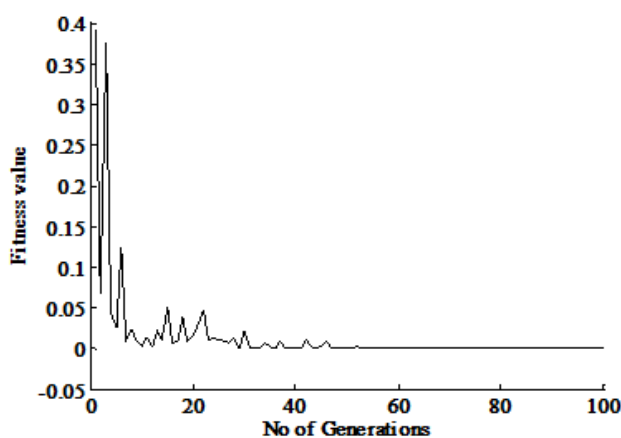


Figure 3. Performance illustrating objective function and number of generations for boiler turbine unit using PSO.

Variation of the fitness function with the number of generations using PSOPID is shown in Figure 3. For

getting optimum PID values of 100 iterations, 20 trials, the minimum value of PSOPID is 0, the maximum value is 0.3920 and the average value is 0.0076 which had given the minimum fitness value.

Performance illustrating the fitness function with the number of generations using BFPID is shown in Figure 4. Maximum number of generation is 100 and 20 trials used to the best solutions are selected for the set of PID parameters, which had the least error.

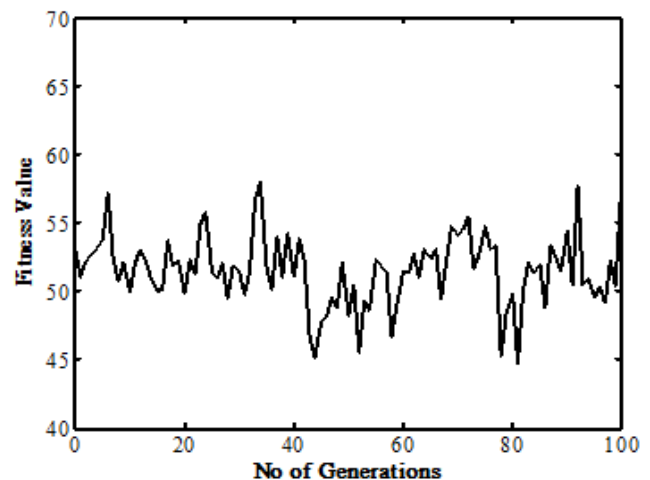


Figure 4. Performance illustrating objective function and number of generations for boiler turbine unit using BF.

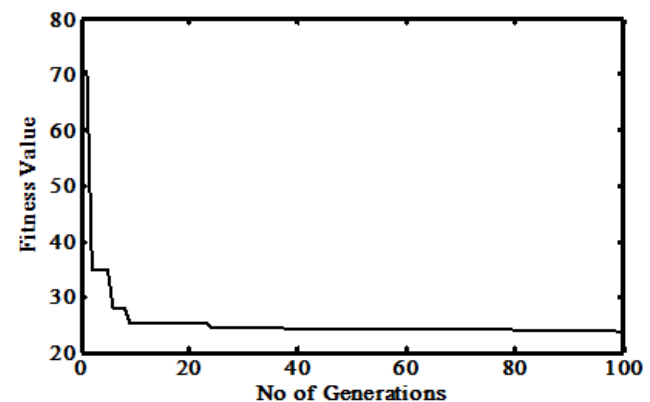


Figure 5. Performance illustrating objective function and number of generations for boiler turbine unit using BBO.

The best solutions are selected for the set of PID parameters, which had the minimum error for 20 trials, minimum value is 25.063, maximum value is 60.276 and the mean value is 50.356. Variation of the fitness function with the number of generation is 100 for 20 trials using BBOPID is shown in Figure 5.

Controller parameters for boiler turbine unit are given in Table 1 using CPID, PSOPID, BFPID and BBOPID.

Table 1. Controller parameters of boiler turbine unit (2X2 System)

Controller parameters		Type of Controller			
		CPID (Tan et al (2004))	PSOPID	BFPID	BBOPID
P_1D_1	P_1	0.01	0.107	0.104	00.102
	D_1	2.05	5.648	3.102	03.100
P_2D_2	P_2	0.01	0.107	0.104	00.102
	D_2	2.05	5.648	4.512	05.135
P_3I_3	P_3	9.04	2.164	9.402	09.223
	I_3	0.24	0.035	0.261	00.234
	I_1	0.28	0.031	1.842	00.452
	I_2	5.03	4.192	3.004	10.023
P_4		3.09	4.194	2.041	02.044

4.1 Servo Response of Electrical Power and Throttle Pressure

Figure 6 and 7 show the servo response characteristics of the CPID, PSOPID, BFPID and BBOPID controllers for boiler turbine unit of Electrical power output and Throttle pressure. From Figure 6, the Electrical power output is initially maintained at 1MW from 0 to 500 sec. At 500 sec Electrical power is increased from 1MW to 5MW and then decreased from 5MW to 2MW at 1000sec.

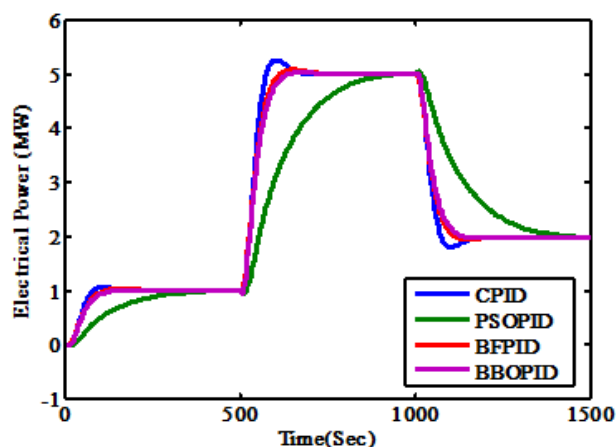


Figure 6. Servo responses of CPID, PSOPID, BFPID and BBOPID controllers for boiler turbine unit of electrical power.

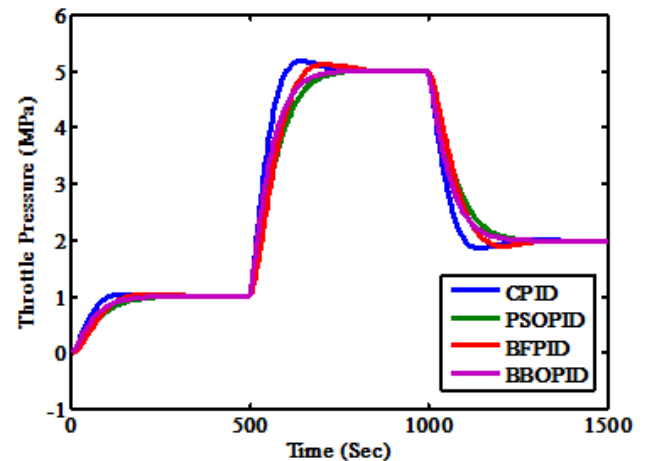


Figure 7. Servo responses of CPID, PSOPID, BFPID and BBOPID controllers for boiler turbine unit of throttle pressure.

Table 2. Simulation results on servo response performance comparison of electrical power for boiler turbine unit (2X2 System)

Performance Index	Set Point	Type of controller			
		CPID	PSOPID	BFPID	BBOPID
ISE	1MW	0.123	0.196	0.120	0.118
	5MW	0.746	1.291	0.724	0.706
	2MW	0.241	0.438	0.234	0.227
IAE	1MW	0.151	0.258	0.146	0.141
	5MW	0.241	0.429	0.233	0.222
	2MW	0.106	0.197	0.103	0.097

Table 3. Simulation results on servo response performance comparison of throttle pressure for boiler turbine unit (2X2 System)

Performance Index	Set Point	Type of controller			
		CPID	PSOPID	BFPID	BBOPID
ISE	1MPa	0.140	0.137	0.205	0.121
	5MPa	0.879	0.846	0.719	0.636
	2MPa	0.289	0.279	0.235	0.111
IAE	1MPa	0.182	0.186	0.164	0.097
	5MPa	0.296	0.301	0.259	0.220
	2MPa	0.133	0.135	0.115	0.141

Similarly in Figure 7 shows the throttle pressure is initially maintained at 1MPa from 0 to 500 sec and

increased from 1MPa to 5MPa from 500sec. At 1000 sec the throttle pressure is decreased from 5MPa to 2MPa. The responses are plotted. From the above responses the ISE and IAE values of BBOPID is less when compared to the CPID, PSOPID and BFPID controllers.

Table 2 and 3 gives the servo response performance comparison of boiler turbine unit of electrical power and throttle pressure respectively. In the above tables the ISE and IAE values of BBOPID of electrical power and throttle pressure are less compared to other controllers.

4.2 Regulatory Response of Electrical Power and Throttle Pressure

Figures 8 and 9 shows the regulatory responses of CPID, PSOPID, BFPID and BBOPID controllers for boiler turbine unit of electrical power and throttle pressure. Initially the Electrical power and Throttle pressure are maintained at 1MW and 1MPa respectively. At 750sec, an external disturbance of 0.5MW and 0.5MPa of electrical power and throttle pressure are applied

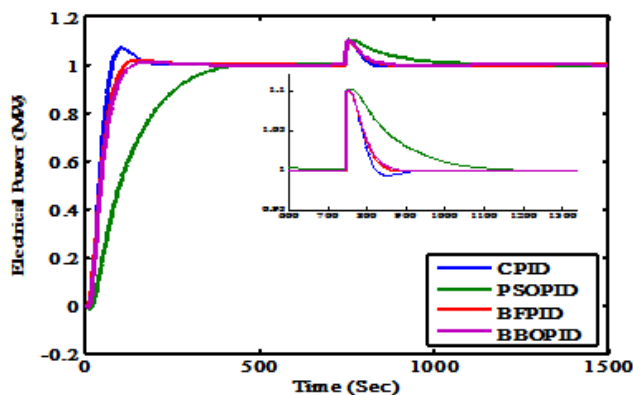


Figure 8. Regulatory responses of CPID, PSOPID, BFPID and BBOPID controllers for boiler turbine unit of electrical power.

Table 4. Simulation results on regulatory response performance comparison of boiler turbine unit (2X2 System)

Type of controller	Electrical Power		Throttle Pressure	
	ISE	IAE	ISE	IAE
CPID	0.041	0.053	0.047	0.064
PSOPID	0.066	0.091	0.046	0.065
BFPID	0.040	0.051	0.041	0.057
BBOPID	0.039	0.049	0.037	0.049

The corresponding readings are noted and these responses are plotted. From the responses it is observed that the BBOPID gives better results than the other PID controllers. Performance comparisons of regulatory response of controllers are given in Table 4.

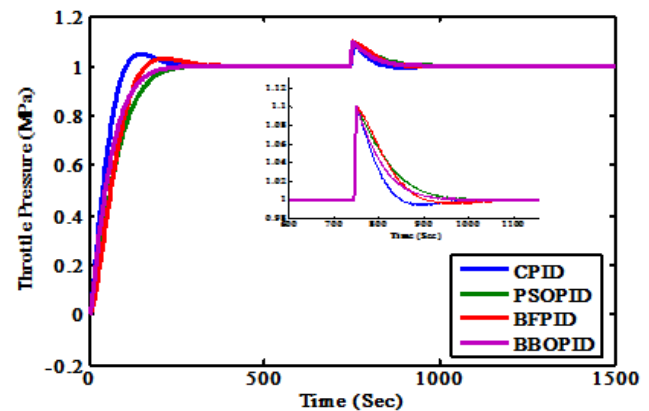


Figure 9. Regulatory responses of CPID, PSOPID, BFPID and BBOPID controllers for boiler turbine unit of throttle pressure.

From Table 4, four electrical power output is observed that the BBOPID minimizes ISE by 4.9% and IAE by 7.5% compared with CPID controller. BBOPID minimizes ISE by 40.9% and IAE by 46.15% compared to PSOPID controller. BBOPID minimizes ISE by 2.5% and IAE by 3.9% when compared with BFPID controller. Similarly for Throttle pressure, BBOPID minimizes ISE by 21.3% and IAE by 23.4% compared with the CPID controller. BBOPID minimizes ISE by 19.6% and IAE by 24.6% compared to PSOPID controller. BBOPID minimizes ISE by 9.75% and IAE by 14% when compared with BFPID controller.

5. Conclusion

Four different controllers (CPID, PSOPID, BFPID and BBOPID) are addressed for two input two output system. The controllers have been designed to control electrical power and throttle pressure for boiler turbine unit and the performances of these controllers are compared with that of CPID. From these responses it is observed that the ISE and IAE values are low with BBOPID. The results show that BBOPID performance is better and effective for both servo and regulatory responses.

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