ACADEMIC
World Academic Union

ISSN 1 746-7233, England, UK
World Journal of Modelling and Simulation
Vol. 12 (2016) No. 1, pp. 3-14

Ant colony optimization algorithm based PID controller for LFC of single area power system with non-linearity and boiler dynamics

Jagatheesan Kaliannan[1]*, Anand Baskaran[2], Nilanjan Dey[3], Amira S. Ashour[4]

[1] Dept. of Electrical and Electronics Engineering, Mahendra Institute of Engineering and Technology, Namakkal, Tamilnadu, India
[2] Dept. of Electrical and Electronics Engineering, Hindusthan college of Engineering and Technology Coimbatore, Tamilnadu, India
[3] Department of Information Technology,Techno India College of Technology, Kolkata, India
[4] Department of Electronics & Electrical Communications Engineering, Faculty of Engineering, Tanta University, Egypt

(*Received June 12 2015, Accepted November 17 2015*)

Abstract. Proportional-Integral-Derivative (PID) and Proportional-Integral (PI) controllers are applied into the power system to examine the controller performance. Therefore, this work describes the application of an Artificial Intelligence (AI) optimization technique to design Proportional-Integral-Derivative (PID) controller for Load Frequency Control (LFC) of single area re-heat thermal power system. The PI-/ PID- controllers gain values are optimized using conventional method and AI optimization technique; respectively. In additional, the proposed technique effectiveness is analyzed by adding non-linearity and Boiler dynamics into the same investigated power system. A comparison of the power system with/ without non-linearity is performed. Moreover, robust analysis is carried out via varying the governor's time constants, turbine, re-heater and power system in about $+50\%$ to -50% from its nominal value by the 25% step.

Keywords: artificial intelligence, ant colony optimization, load frequency control, non-linearity, proportional-integral-derivative (PID) controller

1 Introduction

Generally, electric power systems with interconnected areas, Load Frequency Control (LFC) have a significant role. The LFC is endeavoured to preserve the system frequency of each area and the inter-area tie line power with acceptable limits to deal with the variation of the load demands and system disturbances. Consequently, analyzing Load Frequency Control (LFC) crisis in power generating unit is a fascinating topic that has received more attention in literature. Much reliable and economical operation of the power system requires power balance between the total load demand of the power generation and the system associated losses. The goal of LFC in power system is to establish system frequency during sudden load disturbance. Load demand value is not constant or predictable as it varies randomly due to the enormous development in technology and industries[1–26].

The power system is equipped with optimized PI controller and controller gain values using recent Self Adaptive Modified Bat Algorithm (SAMBA) technique. Quasi-Oppositional Harmony Search algorithm (QOHS)[24] is applied to tune the PID controller gain values in the automatic generation control (AGC) of multi-area non re-heat thermal power system. The AGC of multi-area Solar Thermal-Thermal power system with PID controllers is discussed in [23]. As the Grey Wolf Optimizer algorithm (GOW) is used for optimizing the controller gain values with different conditions and parameter variations. Load frequency control issue in the multi-area power system is discussed in [13].

* Corresponding author. *E-mail address*: jaga.ksr@gmail.com

In recent years, several controllers have been developed for regulation of the power system operation and parameters (frequency and tie-line power flow) within the specified or scheduled value [3, 7–11, 14, 15, 26]. To achieve better dynamic response in multi-/ single area power systems, controllers have been proposed such as: Proportional - Integral (PI) controller[11], Integral Double Derivative (IDD)[3], Proportional-Integral-Derivative (PID) controller[10] and Fractional Order PID (FOPID)[19] and 2DOF-PID[4]. The conventional controllers have slow response, lack of efficiency and poor handling when non- linearities are added into the system. The scheme of conventional controller based LFC system is discussed in [8]. Many researchers have applied different control methods such as optimal control and variable Structure control for improving LFC of large scale and small scale power system.

Recently, the difficulties and drawbacks in the classical and conventional tuning methods are effectively eliminated by introducing population based optimization techniques. A promising alternative solution of the LFC problem is to use meta-heuristic algorithms such as: Beta Wavelet Neural Network (BWNN) approach[7], Differential Evolution algorithm (DE)[14], Stochastic Particle Swarm Optimization (SPSO)[10], Imperialist Competitive Algorithm (ICA)[26], Firefly Algorithm (FA)[6, 15, 18], Quasi-Oppositional Harmony Search algorithm (QOHS)[24], Grey Wolf Optimizer algorithm (GOW)[23], Cuckoo Search (CS)[1, 3, 5], Self Adaptive Modified Bat Algorithm (SAMBA)[13], hybrid Firefly Algorithm and Pattern Search (hFA-PS)[21], Multi-Objective Optimization (MOO)[19], Teacher Learning Based Optimization (TLBO)[2, 20], Modified Harmony Search Algorithm (MHSA)[25], Minority Charge carrier Inspire algorithm (MCI)[16], hybrid PSO-PS optimization (hPSO-PS)[22]. From the above literature survey, it is clearly established that the power system performance mainly depends on the proper selection of the controller and the suitable tuning method for the controller parameters' selection. The main contribution of the current wok is the use of an optimization method, namely the Ant Colony Optimization (ACO) technique for optimal tuning of the PID controllers' parameters. The inspiration for this study is to prove and reveal the robustness of ACO based PID controller in the single area reheat thermal power system under different loading conditions in the presence and absent of nonlinearities and boiler dynamics.

The remaining structure of the current work is organized as follows: an open loop and closed loop single area thermal power systems are designed in section 2. Section 3 discussed the design of PI/PID controller and Conventional/Ant colony Optimization algorithm tuning procedure. The simulation results are discussed in section 4 and finally the conclusion is described in section 5.

2 Investigated power system and modeling

Thermal power plant converts high temperature and high pressure heat steam energy into constructive mechanical energy with the aid of turbine that feeds the electrical generator. Then, this electrical generator is used to convert the mechanical energy to electrical energy in the power system. As shown Fig. 1, the typical components of the thermal power plants are: governor, re-heater, turbine, generator and load/ speed regulator.

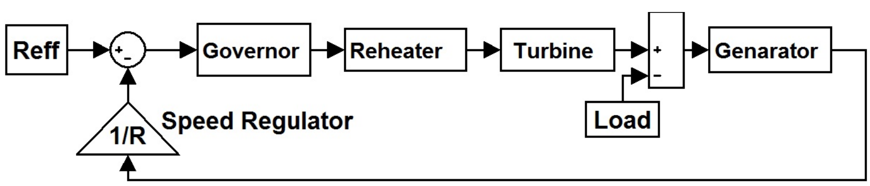

Fig. 1: General block diagram of open loop reheat thermal power system

The water is transformed into steam with high pressure and temperature using steam generator. The essential components of the steam turbine is re-heater, condenser, boiler feed pump, steam generator (Boiler), drum and control valve. The overall efficiency of the turbine is increased by dividing the steam pressure stages into two or more stages using a re-heater unit. Based on the steam stages, turbines are classified into three different types such as: non reheat turbine, single stage reheat turbine and double stage reheat turbine. The steam turbine transfer function is given by:

$$G_T(S) = \frac{1}{(1 + ST_t)} \left(\frac{1 + \alpha ST_r}{1 + ST_r} \right),$$

where, T_t is the re-heat time constant in sec. and T_t is the steam chest time constant in sec., S is Laplace domain function. The governor dead band nonlinearity produces a significant effect on the LFC performance that is defined as "The total magnitude of speed changes within which there is no resulting changes in value position".

In this work, the LFC performance effect is considered to be 0.05%. The permissible rate of generation constraint for thermal power system is 0.0017 pu MW sec^{-1}. The drum type model of boiler dynamics produces steam under pressure. In addition, oil/gas filled boiler dynamics respond quickly during sudden load demand than coal fired boiler dynamics and structure of boiler dynamics given in the Fig. 2. Rating of the investigated thermal power system is 2000 MW.

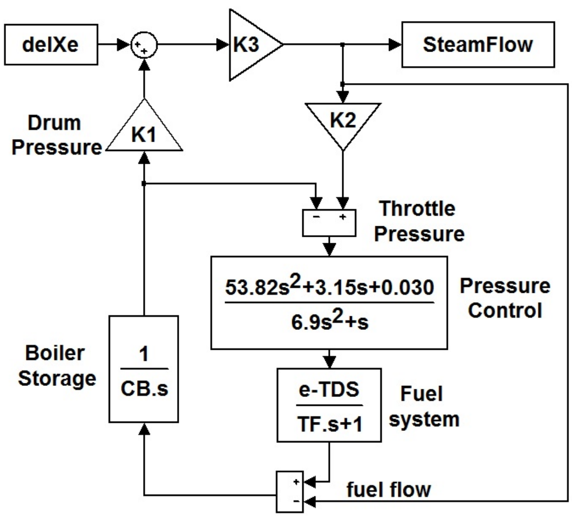

Fig. 2: Structure of boiler dynamics

Figs. 3 and 4 illustrate the block diagram of the transfer function model of both single area open loop and closed loop re-heat thermal power systems; respectively. Here, R refers to the self regulation parameter for the governor in p.u. Hz; T_g represents the speed governor time constant in sec; T_r is the reheat time constant in sec; K_r is the reheat gain; T_p, K_p is the load frequency constant ($T_p = 2H/f * D, K_p = 1/D$. Stability of the open loop system varies depending on the variation of the output response according to the input.

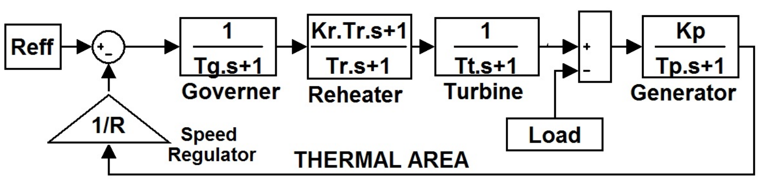

Fig. 3: Transfer function model of open loop reheat thermal power system

In the power generating system, damping oscillations with steady state error in their response occur due to the load demand. The parameters of the open loop response are tabulated in Tab. 1.

In order to mitigate and compensate error in response and load demand, proper assortment of controller is more crucial in the case of LFC problem. In this investigation, industrial Proportional- Integral (PI) and Proportional-Integral-Derivative (PID) controllers are designed and implemented.

Table 1: Time domain specification of the open loop response

Parameters	Load demand $= 0\%$	Load demand $= 1\%$ SLP
Frequency Peak (Hz)	0	-0.05744
Settling time (s)	0	24
Steady state error (Hz)	0	-0.02353

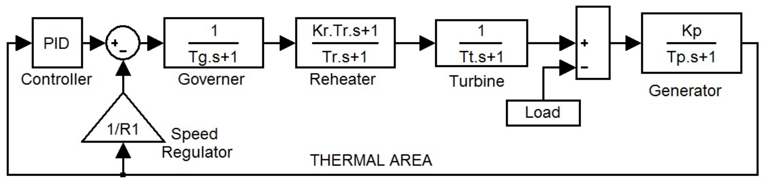

Fig. 4: Transfer function model of the closed loop re-heat thermal power system

2.1 Nominal parameters of power system and boiler dynamics (BD) unit

The nominal parameter values of interconnected two area thermal power system[11] are as follows:

$T_t = 0.3$ s, $T_r = 10$ s, $T_g = 0.2$ s, $R = 2.4$ Hz pu^{-1}MW, $B = 0.425$ p.u MW/Hz, $K = 120$ Hz pu^{-1}MW, $T_p = 20$s, $K_r = 0.333$.

While, the data for Boiler Dynamics (oil fired)[11] is given by:

$K_1 = 0.85$, $K_2 = 0.095$, $K_3 = 0.92$, $C_b = 200$, $T_d = 0$, $T_f = 10$, $K_{ib} == 0.03$, $T_{ib} = 26$, $T_{rb} = 69$.

3 Design of PID controller using ACO with different objective functions

Generally, the controller responsibility in LFC crisis preserves the overall system stability and recovers the system performance, while load demand increases/decreases. The above mentioned problem is solved by generating appropriate control signal using the controller. In this study, industrial PI and PID controller are implemented. The structure of PI and PID controller are shown in Figs. 5 and 6.

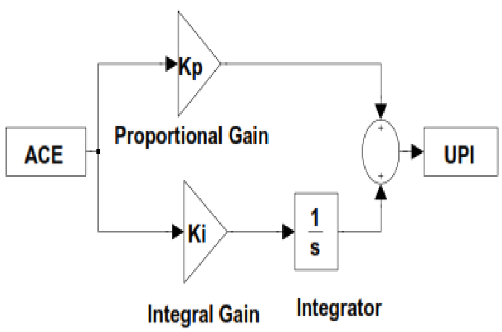

Fig. 5: Structure of PI controller

The control signal (U) generated by the PI and PID controller is given by UPI and UPID ; respectively as:

$$U_{PI} = -K_i.ACE - \frac{K_P}{T_i}\int ACE,$$
$$U_{PID} = -K_i.ACE - \frac{K_P}{T_i}\int ACE - K_d T_d \frac{d}{dt} ACE,$$

where, U_{PI} and U_{PID} are the control signal generated by the PI and PID controllers; respectively, K_i is the integral gain, K_d is the derivative gain, K_p represents the proportional gain, T_i is the integral time constant,

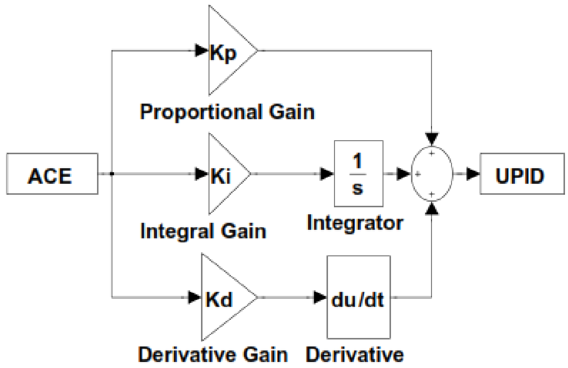

Fig. 6: Structure PID controller

T_d refers to the derivative time constant and ACE is the area control error (ACE). The conventional method tuned PI controller gain value and the performance index curve is shown in Fig. 7. The curve is plot between different values of the gain values with different values of J (performance index).

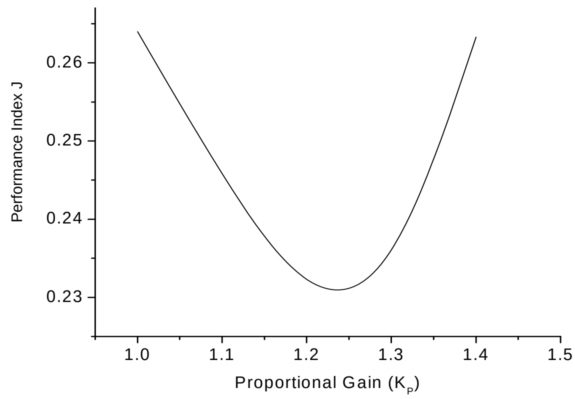

Fig. 7: The PI controller Performance Index Curve

In order to sustain the system stability and to recover system performance, a suitable selection of the objective function is more critical to find controller parameters. In this work, an Integral Time Absolute Error (ITAE) objective function is suggested for both conventional and AI tuning technique. This objective function expression is given by:

$$J = \int_o^T t.\,|\Delta f|\,dt.$$

Thus, the optimization problem is solved using the Ant Colony Optimization (ACO) algorithm to obtain the optimal parameters of the controller gain values.

3.1 Ant colony optimization technique

Ant colony optimization technique was introduced by M. Dorigo in early 1900s as a novel nature inspired metaheuristic for the solution of combinatorial optimization problem[12, 17]. This algorithm is based on the real ant behavior in searching the source of food. It is evident that the shortest path has large pheromone concentrations, so that more ants tend to choose it to travel. There are three major phases in the Ant Colony Algorithm:

- Initialization
- Constructing ant solution

- Updating pheromone

The global updating rule is implemented in the ant system where all ants start their tours and pheromone is deposited and updated on all edges based on:

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \sum_{k \in \substack{\text{colony that} \\ \text{used edge}(i,j)}} \frac{Q}{L_k},$$

where ρ_{ij} is the probability between the town i and j, Q is constant, L_k is the length of the tour performed by K_{th} ant, ρ is the evaporation rate.

In this study, the number of ants $=$ 50, pheromone (τ) $=$ 0.6, evaporation rate (ρ) $=$ 0.95 and the number of iterations $=$ 100. The convergence curve and flow chart of the Ant Colony Optimization (ACO) technique for tuning PID controller were demonstrated in Figs. 8 and 9; respectively.

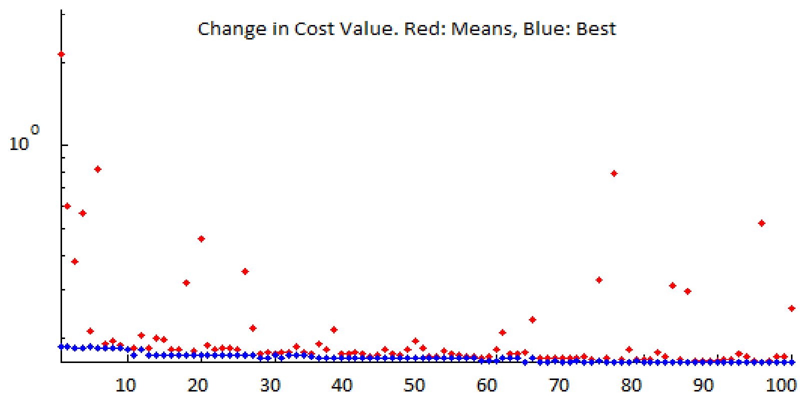

Fig. 8: Convergence curve for ACO technique

Tab. 2 demonstrates the optimal gain values of PID controller using Ant Colony Optimization technique with/without non-linearity and boiler dynamics effect.

Table 2: Optimal gain values of PID controller for different criterions

Criteria	Controller	K_p	K_i	K_d	J
Without non-linearity and Boiler dynamics	Conventional PI controller	1.2	0.17	-	0.2294
	ACO-PID controller	0.98	0.91	0.44	0.1674
With non-linearity and Boiler dynamics	ACO-PID controller	1	1	0.4	0.237

4 Simulation results and discussion

MATLAB/SIMULINK environment is used to model the transfer function of the simulated single area power system discussed in Section 2. The simulation results demonstrate the effectiveness and robustness of the proposed control method. Simulation process of the investigated power system is divided into the following three different cases for performance analysis:

- Power system with conventional PI and ACO PID controller without non-linearity and Boiler dynamics effect.
- Power system with ACO PID controller with/ without non-linearity and Boiler dynamics effect.
- Power system with ACO PID controller and variations (-50% to $+50\%$) in time constants of the investigated power system parameters.

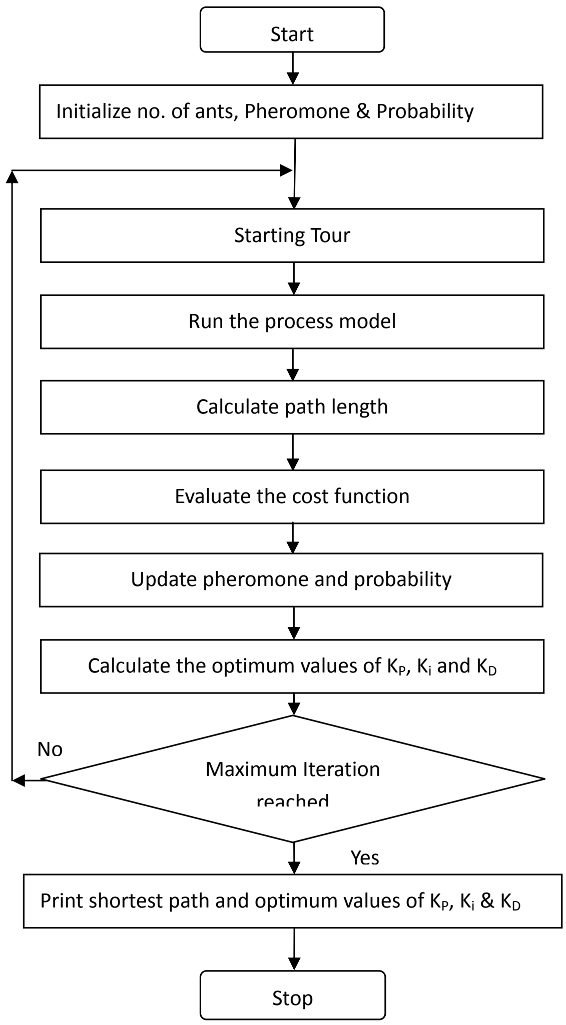

Fig. 9: Flow chart for PID controller tuning using ACO

In case A: simulations are performed for 1% SLP in the system applying the conventional PI and ACO-PID controllers. The frequency deviations in investigated power system were shown in Fig. 10. It is clear from Fig. 10 that the damping oscillations and the settling time of the conventional PI controller are more than ACO-PID based controller response. This proves that the ACO-PID controller gives superior and enhanced controlled performance during sudden load demand.

Fig. 11 demonstrates the comparisons of ISE and ITAE cost functions tuned ACO-PID controller performance in the investigated power system. It is established from the figure that the ITAE cost function provided less damping oscillation with less settling time. Tab. 3 illustrates a time domain specification comparison of the PI and ACO-PID control parameters with respect to their respective settling time and maximum overshoot to clarify the performance of the tuning technique.

Table 3: Time domain specification comparison of conventional PI and ACO-PID controller

Time domain Specification	Conventional PI controller	ACO PID controller
Settling Time (s)	14.56	12.19
Peak Undershoot (Hz)	0.0296	0.0204
Peak Overshoot (Hz)	0	0.00357

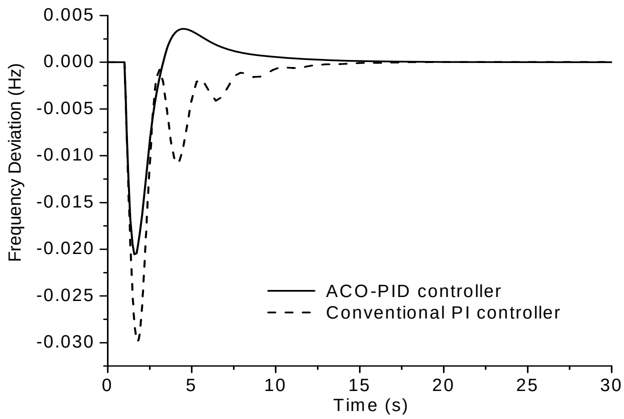

Fig. 10: Comparisons of frequency deviations considering Conventional PI and ACO-PID controller without considering non-linearity and boiler dynamics

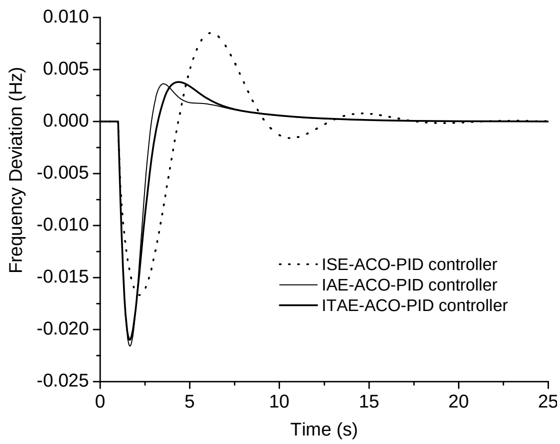

Fig. 11: Comparisons of frequency deviations considering ISE ACO-PID, IAE ACO-PID and ITAE ACO-PID controller

In case B: The ACO tuned PID controller is equipped in the examined power system. The performance is analyzed by adding non-linearities and boiler dynamics into the power system with 1% SLP to evaluate the effectiveness. The system response, frequency deviation is shown in Fig. 12.

Fig. 8 demonstrates that the power system response yields more damping oscillations and consumes more time when the non-linearity and Boiler Dynamics is taken into the account. Thus, it is concluded that, tuning the PID controller using ACO provides better controlled performance with and without non-linearity and boiler dynamics.

In case C: The robustness of the ACO-PID controller is examined via varying the power system time constants from its nominal value i.e. from -50% to $+50\%$ with 25% step. The system response is demonstrated in Fig. 13, as the governor time constant is varied from -50% to $+50\%$ using 1% SLP. The PID controller gain value of different criteria is given in the Tab. 2.

Fig. 14 illustrates the comparisons of frequency deviations for changes in re-heater time constant in the same tested power system.

Fig. 15 shows the response of frequency deviation with variations in the turbine time constant. While, Fig. 16 demonstrates the variations in the frequency deviations with changes in the power system time constant.

The parameter variation test is effectively done into the tested power system and the responses are shown in Figs. 13–16. From the above discussions of all three cases, it is established that ACO tuned PID controllers always give better controlled response in single area thermal power system with different cases.

As a future work, the ACO optimization techniques can be employed with different constant parameters such as number of ants, pheromone (τ), evaporation rate (ρ) and the number of iterations. This will allow

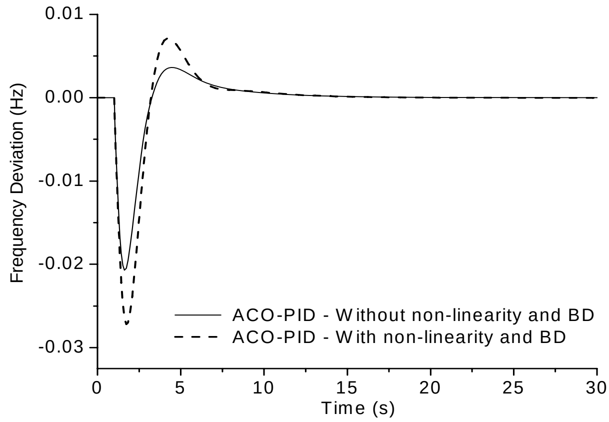

Fig. 12: Comparisons of frequency deviations with and without out considering non-linearity and boiler dynamics

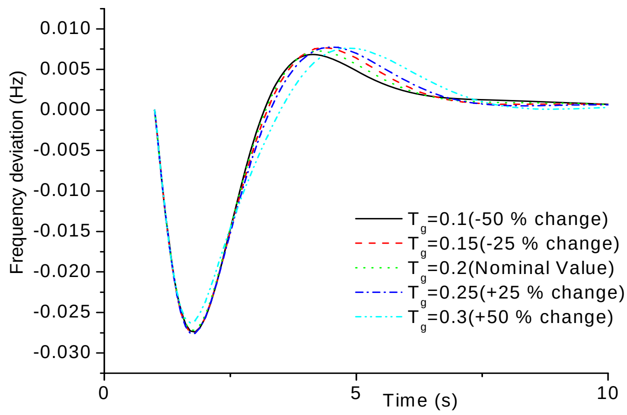

Fig. 13: Comparisons of frequency deviations for changes in T_g

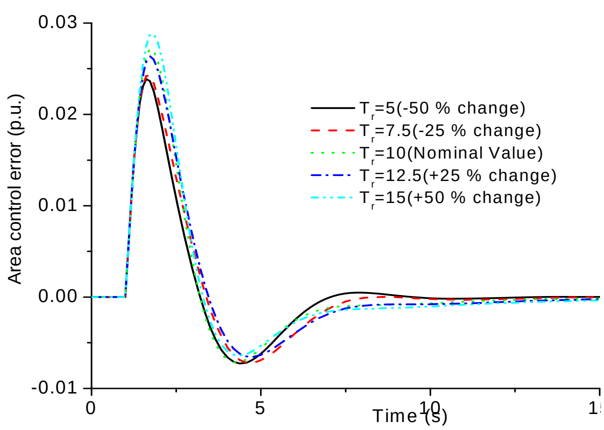

Fig. 14: Comparisons of frequency deviations for changes in T_r

discriminating the system performance based on different choice of values used for the constant parameters. In addition, for further future work, the size of the power system model can be extended with different sizes to contain multiple interconnected generators. Additionally, the ability of the proposed tuning technique can be tested by varying loading conditions (2% SLP and 3% SLP).

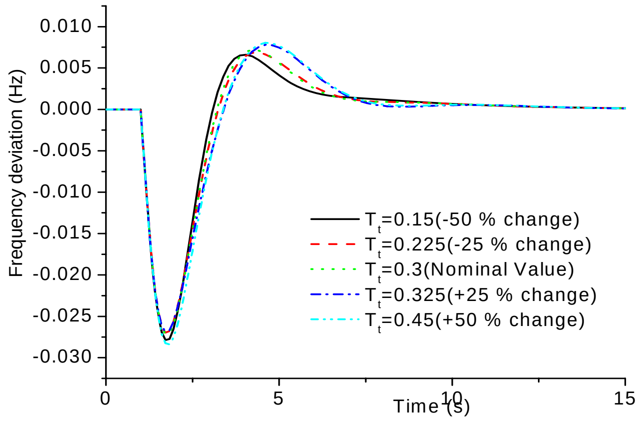

Fig. 15: Comparisons of frequency deviations for changes in T_t

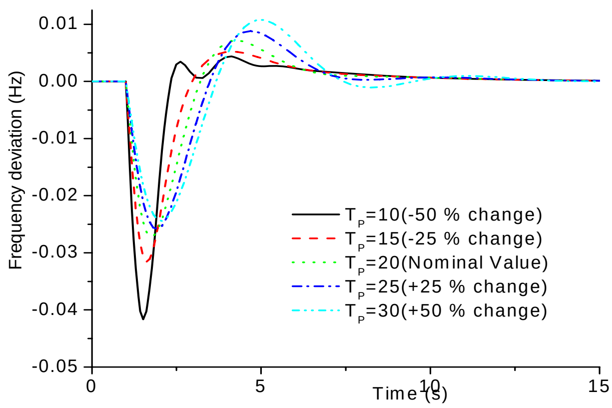

Fig. 16: Comparisons of frequency deviations for changes in T_p

5 Conclusion

Through this study, the Load Frequency Control (LFC) of single area re-heat thermal power system is performed using conventional and Artificial Intelligence technique tuned controllers. The conventional tuning method is used to tune PI controller parameters and its performance is compared to the ACO tuned PID controller. The experimental simulation results reveal that the ACO-PID controller provided superior controller response with/ without considering non-linearity in the system with 1% Step Load Perturbation (1% SLP) over conventional method based PI controller. Moreover, the performance variation test is performed by varying the time constants (Governor, Turbine, re-heater and power system time constant) of the examined power system from its nominal value (i. e. -0% to $+50\%$ by the step of 25%). Finally, simulation result exposed that, the performance of the ACO technique based PID controller is unaffected by changing the system parameters from the nominal values.

References

[1] A. Abdelaziz, E. Ali. Cuckoo search algorithm based load frequency controller design for nonlinear interconnected power system. *International Journal of Electrical Power & Energy Systems*, 2015, **73**: 632–643.

[2] A. Barisal. Comparative performance analysis of teaching learning based optimization for automatic load frequency control of multi-source power systems. *International Journal of Electrical Power & Energy Systems*, 2015, **66**: 67–77.

[3] S. Chaine, M. Tripathy. Design of an optimal smes for automatic generation control of two-area thermal power system using cuckoo search algorithm. *Journal of Electrical Systems and Information Technology*, 2015.

[4] P. Dash, L. C. Saikia, N. Sinha. Comparison of performances of several facts devices using cuckoo search algorithm optimized 2dof controllers in multi-area agc. *International Journal of Electrical Power & Energy Systems*, 2015, **65**: 316–324.

[5] N. Dey, S. Samanta, et al. Optimisation of scaling factors in electrocardiogram signal watermarking using cuckoo search. *International Journal of Bio-Inspired Computation*, 2013, **5**(5): 315–326.

[6] N. Dey, S. Samanta, et al. Firefly algorithm for optimization of scaling factors during embedding of manifold medical information: An application in ophthalmology imaging. *Journal of Medical Imaging and Health Informatics*, 2014, **4**(3): 384–394.

[7] R. Francis, I. Chidambaram. Optimized pi+ load–frequency controller using bwnn approach for an interconnected reheat power system with rfb and hydrogen electrolyser units. *International Journal of Electrical Power & Energy Systems*, 2015, **67**: 381–392.

[8] K. Jagatheesan, B. Anand. Load frequency control of an interconnected three area reheat thermal power systems considering non linearity and boiler dynamics with conventional controller. *Advances in Natural and Applied Science, ISSN*, 2014, **8**(20): 16–24.

[9] K. Jagatheesan, B. Anand. Automatic generation control of three area hydro-thermal power systems with electric and mechanical governor. **in:** *Computational Intelligence and Computing Research (ICCIC), 2014 IEEE International Conference on*, IEEE, 2014, 1–6.

[10] K. Jagatheesan, B. Anand, M. Ebrahim. Stochastic particle swarm optimizaion for tuning of PID controller in load frequency control of single area reheat thermal power system. *International Journal of Electrical and Power Engineering*, 2014, **8**(2): 33–40.

[11] K. Jagatheesan, B. Anand, N. Dey. Automatic generation control of thermal-thermal-hydro power systems with PID controller using ant colony optimization. *International Journal of Service Science, Management, Engineering, and Technology (IJSSMET)*, 2015, **6**(2): 18–34.

[12] K. Jagatheesan, B. Anand. Performance analysis of double reheat turbine in multi -area AGC system using conventional and ant colony optimization technique. *Journal of Electrical and Electronics Engineering*, 2015, **15**(1): 1849–1854.

[13] M. H. Khooban, T. Niknam. A new intelligent online fuzzy tuning approach for multi-area load frequency control: Self adaptive modified bat algorithm. *International Journal of Electrical Power & Energy Systems*, 2015, **71**: 254–261.

[14] B. Mohanty, S. Panda, P. Hota. Controller parameters tuning of differential evolution algorithm and its application to load frequency control of multi-source power system. *International Journal of Electrical Power & Energy Systems*, 2014, **54**: 77–85.

[15] K. Naidu, H. Mokhlis, et al. Application of firefly algorithm (fa) based optimization in load frequency control for interconnected reheat thermal power system. **in:** *Applied Electrical Engineering and Computing Technologies (AEECT), 2013 IEEE Jordan Conference on*, IEEE, 2013, 1–5.

[16] J. Nanda, M. Sreedhar, A. Dasgupta. A new technique in hydro thermal interconnected automatic generation control system by using minority charge carrier inspired algorithm. *International Journal of Electrical Power & Energy Systems*, 2015, **68**: 259–268.

[17] M. Omar, M. Soliman, et al. Optimal tuning of PID controllers for hydrothermal load frequency control using ant colony optimization. *International Journal on Electrical Engineering and Informatics*, 2013, **5**(3): 348–360.

[18] S. Padhan, R. K. Sahu, S. Panda. Application of firefly algorithm for load frequency control of multi-area interconnected power system. *Electric Power Components and Systems*, 2014, **42**(13): 1419–1430.

[19] I. Pan, S. Das. Fractional-order load-frequency control of interconnected power systems using chaotic multi-objective optimization. *Applied Soft Computing*, 2015, **29**: 328–344.

[20] B. K. Sahu, S. Pati, et al. Teaching–learning based optimization algorithm based fuzzy-PID controller for automatic generation control of multi-area power system. *Applied Soft Computing*, 2015, **27**: 240–249.

[21] R. K. Sahu, S. Panda, S. Padhan. A hybrid firefly algorithm and pattern search technique for automatic generation control of multi area power systems. *International Journal of Electrical Power & Energy Systems*, 2015, **64**: 9–23.

[22] R. K. Sahu, S. Panda, G. C. Sekhar. A novel hybrid pso-ps optimized fuzzy pi controller for agc in multi area interconnected power systems. *International Journal of Electrical Power & Energy Systems*, 2015, **64**: 880–893.

[23] Y. Sharma, L. C. Saikia. Automatic generation control of a multi-area st–thermal power system using grey wolf optimizer algorithm based classical controllers. *International Journal of Electrical Power & Energy Systems*, 2015, **73**: 853–862.

[24] C. K. Shiva, G. Shankar, V. Mukherjee. Automatic generation control of power system using a novel quasi-oppositional harmony search algorithm. *International Journal of Electrical Power & Energy Systems*, 2015, **73**: 787–804.

[25] M. Shivaie, M. G. Kazemi, M. T. Ameli. A modified harmony search algorithm for solving load-frequency control of non-linear interconnected hydrothermal power systems. *Sustainable Energy Technologies and Assessments*,

2015, **10**: 53–62.

[26] S. A. Taher, M. H. Fini, S. F. Aliabadi. Fractional order PID controller design for lfc in electric power systems using imperialist competitive algorithm. *Ain Shams Engineering Journal*, 2014, **5**(1): 121–135.