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Research Manuscript Title

APPLICATION OF ANT COLONY OPTIMIZATION ALGORITHM FOR LOAD FREQUENCY CONTROL OF SINGLE AREA THERMAL POWER SYSTEM

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Application of Ant Colony Optimization Algorithm for Load Frequency Control of Single Area Thermal Power System

Abstract

This paper presents Load Frequency Control (LFC) of single area thermal power system with appropriate turbine unit (Non reheat, Single reheat and double reheat) and suitable secondary Controller. Industrial PID controller is proposed in LFC as secondary controller. Gain values of secondary controller are optimized using a most recent Artificial Intelligence (AI) optimization technique with different objective functions (Integral Square Error (ISE) and Integral Time Absolute Error (ITAE)). The system was simulated for one percent Step Load Perturbation (SLP).Frequency deviation and control input deviations of single area thermal power system with ISE objective function designed PID controller reveals that the ITAE objective function designed PID controller is found to be superior than ISE objective function designed controller.

Keywords-Artificial Inteligince; Ant Colony Optimization; Load Frequency Control;Objective function; Performance Index.

I. Introduction`

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 power system requires power balance between total load demand with 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 a constant or predictable value, because it various randomly due to the enormous development in technology as well as in industries.

In recent years many control strategies have been developed for the regulation of power system frequency within the specified or scheduled value [1-9]. The control strategies like Proportional – Integral (PI) controller [2], Proportional – Integral-Derivative (PID) controller [7], Integral Double Derivative (IDD) [6] controllers have been proposed to achieve better dynamic response. The characteristics of conventional controllers are slow response, efficiency lack and poor handling when non linearities added into the system.

The idea of conventional controller based LFC sy[illegible] Many researchers have applied different control methods like Fuzzy logic control [2], optimal control and variable control for improving LFC of large scale and small scale power system.

Difficulties and drawbacks in classical and conventional methods can be effectively eliminated by introducing population based technique for the past few years. The meta-heuristic algorithms are Artificial Bee colony (ABC) [5], Firefly Algorithm (FA) [9], Stochastic Particle Swarm Optimization (SPSO) [7], Imperialist Competitive Algorithm (ICA) [8] etc are promising alternative solution of LFC problem.

This paper is organized as follows: open loop and closed loop single area thermal power systems are illustrated in section II, Section III discuss the design of PID and Ant colony Optimization algorithm, simulation results are discussed in section IV and conclusion is described in section V.

II. Investigated Power System and Modeling

Normally thermal power plant converts heat steam energy into useful mechanical energy by the use of turbine. High pressure and high temperature steam is converted into mechanical energy and this feed to electrical generator. The role of electrical generator is power system is to convert mechanical energy to electrical energy [10-12]. The components of thermal power plants are: governor, reheater, turbine, generator, load and speed regulator. The arrangement of all power system components in thermal power plant is shown in Fig. 1.

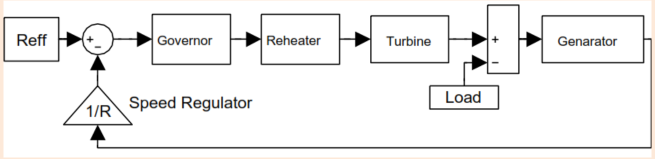

Figure 1. General block diagram of open loop reheat thermal power system

A. Steam Turbine

Water is transformed into steam with high pressure and temperature by using steam generator [10-12]. The basic components of steam turbine is reheater, condenser, boiler feed pump, steam generator (Boiler), drum and control valve. The overall efficiency of the turbine is increased by dividing steam pressure stages into two or more steam stages with help of reheater unit. Based on the steam stages the turbines are classified into three different types. Such as non reheat turbine, single stage reheat turbine and double stage reheat turbine [10-12]. The transfer functions of different steam turbines are given in the equation (1), (2) & (3).

Transfer function of Non Reheat turbine:

$$G_T(S) = \frac{1}{(1+ST_t)} \qquad \text{-----(1)}$$

Transfer function of Single Stage Reheat turbine:

$$G_T(S) = \frac{1}{(1+ST_t)}\left(\frac{1+\alpha ST_r}{1+ST_r}\right) \qquad \text{-----(2)}$$

Transfer function of double Stage Reheat turbine:

$$G_T(S) = \frac{\left(S^2 T_{r1}T_{r2} + \beta ST_{r2} + \alpha S(T_{r\,[illegible]}) + 1\right)}{(1+ST_{r1})(1+ST_{r2})(1+[illegible])} \qquad \text{-----(3)}$$

B. Open loop single area thermal power system

The rating of the investigated thermal power system is 2000MW.Block diagram shown in fig.2 & 4. Give the transfer function model of single area open loop and closed loop thermal power system respectively. R represents the self regulation parameter for the governor in p.u. Hz; Tg represents the governor time constant in sec; Tr is the reheat time constant in sec; Kr is the reheat gain; Tt is the steam chest time constant in sec; Tp, Kp is the load frequency constant (Tp=2H/f*D, Kp=1/D). In the open loop system output response is varied with respect to input, so stability of the system is varied.

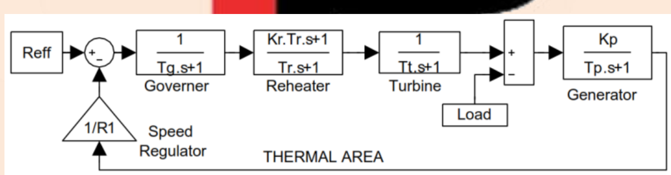

Figure 2. Transfer function model of open loop reheat thermal power system

Open loop response of thermal power system with one percent Step Load Perturbation (SLP) is shown in fig.3. When load demand occurs in any power generating system, it yields damping oscillations with steady state error in their response. The parameters of open loop response are tabulated in tale 1.

TABLE I. PARAMETERS OF 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

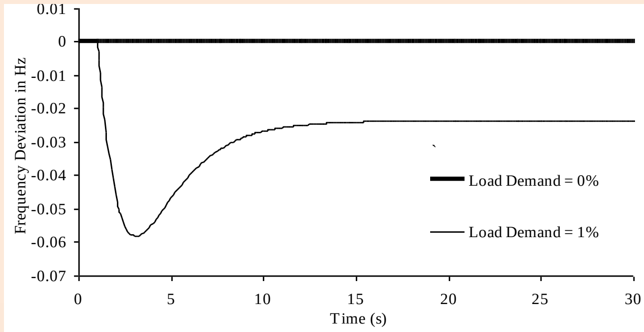

Figure 3. Frequency deviations of the test system under open loop after 1% SLP

C. *Closed loop single area thermal power system*

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 – Derivative (PID) controller is designed and implemented.

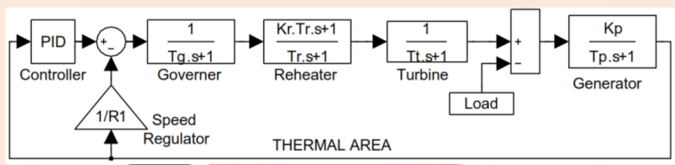

Figure 4. Transfer function model of closed loop reheat thermal power system

III. Design of PID controller using ACO with different objective functions

The role of controller in LFC problem is to maintain the overall system stability and improve system performance while load demand increase/decrease. Above mentioned is achieved by generating proper control signal by the controller. In this investigation industrial PID controller is implemented. The control signal (U) generated by the PID controller is given by:

$$U = -K_i.ACE - \frac{K_P}{T_i}\int ACE - K_d T_d \frac{d}{dt} ACE \quad \text{------(4)}$$

Where U- control signal generated by the controller, K_i – Integral gain, K_d- Derivative gain, K_p-Proportional gain, T_i – Integral time constant, T_d-Derivative time constant, ACE- Area Control Error (ACE)

In order to maintain system stability and improve system performance suitable selection of objective function is more crucial to find controller parameters. In this paper, Integral Time Absolute Error (ITAE) and Integral Square Error (ISE) performance indices are considered as objective function as following:

Integral Square Error (ISE)

$$J = \int_{o}^{T} (\Delta f)^2 \, dt \quad \text{------(5)}$$

Integral Time Absolute Error

$$J = \int_{o}^{T} t.|\Delta f| \, dt \quad \text{------(6)}$$

An optimization problem is solved an ACO algorithm to obtain the optimal parameters of the controller gain values.

A. *Ant Colony Optimization technique*

Ant colony optimization technique was introduced by M.Dorigo and colleagues in early 1900s as a novel nature inspired metaheuristic for the solution of combinatorial optimization problem [13]. The behavior of real ant in searching the source of food, it evident that shortest path having large pheromone concentrations, so more ants tends to choose and travel in the path. There are there major phase in Ant Colony Algorithm namely

- Initialization
- Constructing ant solution
- Updating pheromone

The optimal gain values of PID controller using Ant Colony Optimization technique with Integral Time Absolute Error (ITAE) and Integral Square Error (ISE) objective function is given in table 1.

TABLE II. OPTIMAL GAIN VALUES OF PID CONTROLLER BY USING ANT COLONY OPTIMIZATION TECHNIQUE

Objective function	Turbine	Proportional Gain (K_p)	Integral Gain (K_i)	Derivative Gain (K_d)
ISE	Non Reheat	8.1	4.2	3.3
	Single Stage Reheat	2.9	5.2	6.5
	Double Stage Reheat	1.4	5.6	7.3
ITAE	Non Reheat	7.5	8.5	1.7
	Single Stage Reheat	8.3	9.8	1
	Double Stage Reheat	4.2	9.2	0.5

IV. Simulation results and Discusses

The simulation results are helpful to demonstrate the effectiveness of proposed method. Simulation process of the investigated power system divided into following subsection:

- Performance analysis of the proposed system is modeled under following criteria:
  a) Power system with non reheat turbine
  b) Power system with single stage reheat turbine
  c) Power system with double stage reheat turbine
- Further performance analysis for different objective functions:
  a) Integral Square Error (ISE)
  b) Integral Time Absolute Error (ITAE)
- Comparison between ITAE and ISE objective functions for designing of PID controller.

The simulation results are obtained by Matlab software and investigated power system has been modeled in Matlab Simulink environment.

A. *Simulation of non reheat thermal power system for 1% SLP with different objective functions*

In this case, simulations are performed for one percent SLP in system considering with different objective functions. The proposed AI based ACO algorithm is implemented to tune the PID controller gain values.

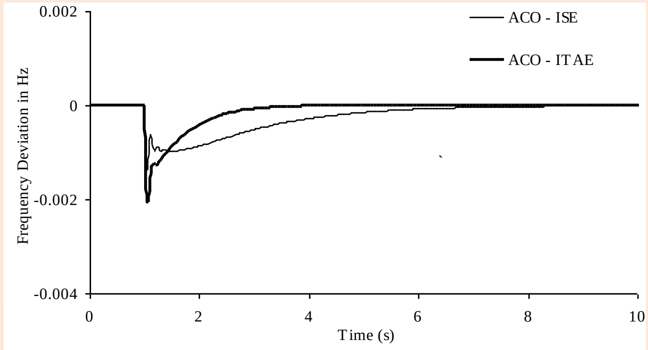

Figure 5. Comparisons of frequency deviations considering ISE and ITAE objection functions with non reheat turbine

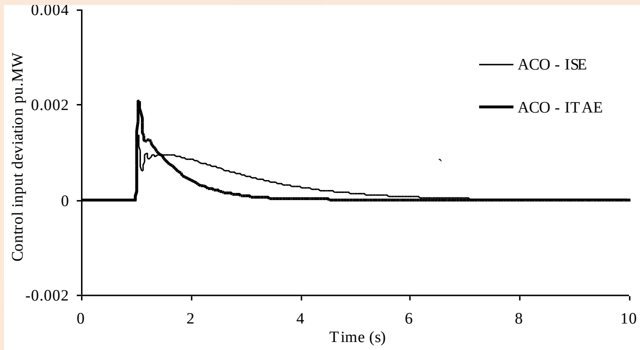

Figure 6. Comparisons of control input deviations considering ISE and ITAE objection functions with non reheat turbine

It is clear from figures 5&6 that, the damping oscil[illegible]e ISE function is more than ITAE function based controller response, which shows ITAE function give greater and [illegible] controlled performance, during sudden load demand.

B. *Simulation of single stage reheat thermal power system for 1% SLP with different objective functions*

The SLP is applied to the system to evaluate the effectiveness of objective function in PID controller gain optimization process.

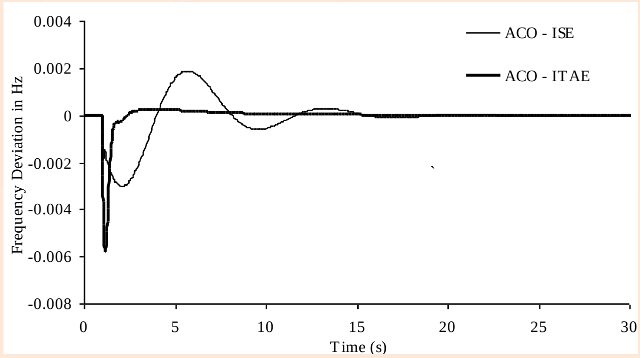

Figure 7. Comparisons of frequency deviations considering ISE and ITAE objection functions with single stage reheat turbine

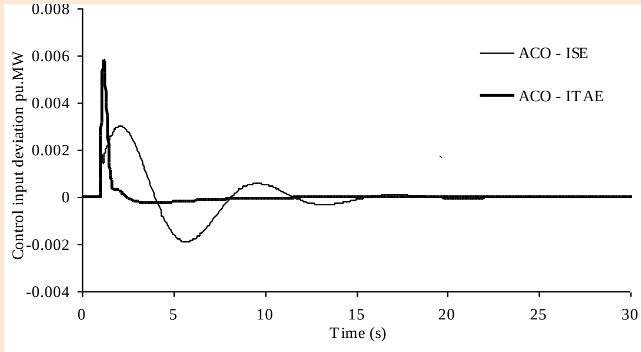

Figure 8. Comparisons of control input deviations considering ISE and ITAE objection functions with single stage reheat turbine

Fig. 7 & 8 illustrates the frequency and control input response demand of system. Simulation results are shows that the responses are limited effectively by using ITAE objective function based PID controller.

C. Simulation of double stage reheat thermal power system for 1% SLP with different objective functions

In order to investigate the robustness [illegible]jective function functions in the LFC problem for tuning of controller gain is obtained with one percent SLP in syst[illegible]he dynamic response comparisons with aforementioned objective functions are depicted in Fig. 9 & 10.

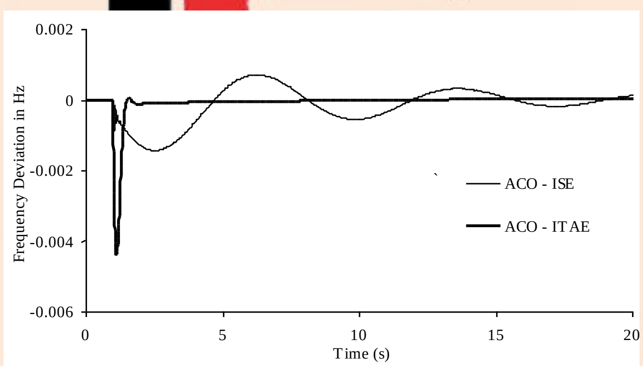

Figure 9. Comparisons of frequency deviations considering ISE and ITAE objection functions with double stage reheat turbine

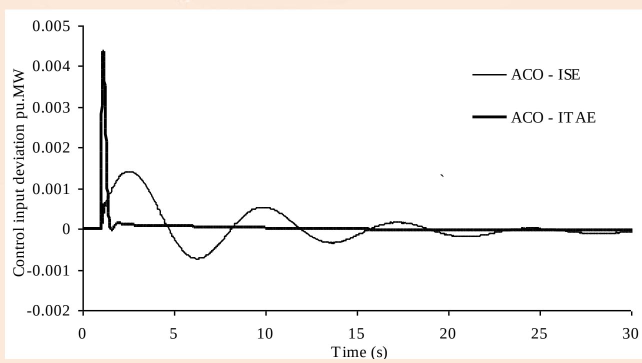

Figure 10. Comparisons of control input deviations considering ISE and ITAE objection functions with double stage reheat turbine

It can be observed from simulation response ITAE objective function based optimized controller effectively reduces the damping ossifications and it improve the overall stability of the system compared to ISE based controller.

The comparative performance of different steam turbine and cost functions of single area thermal power system values are tabulated in table II. The result shown on table III indicates that, settling time of the system is improved by the use of ITAE objective function optimized PID controller.

TABLE III. COMPARISONS OF SETTLING IN FREQUENCY DEVIATIONS WITH DIFFERENT OBJECTIVE AND STEAM TURBINE

Turbine	Objective function	Settling time (s)
Non Reheat Turbine	ISE	8.9
	ITAE	3.7
Single stage reheat turbine	ISE	26.9
	ITAE	10.26
Double stage reheat turbine	ISE	45.2
	ITAE	2.47

V. Conclusion

PID controller is designed and implemented by using ACO algorithm with two different objective functions in single area thermal power system. The response of the system using ITAE based controller is compared with the response of ISE based controller with one percent step load perturbation. Power system is equipped with three different turbines and performance are analyze afore mentioned objective functions. Comparison proves that ITAE objective function optimized controller effectively damps [illegible]ations in frequency and controller input response compared to ISE based controller.

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