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Stochastic Particle Swarm Optimizaion for Tuning of PID Controller in Load Frequency Control of Single Area Reheat Thermal Power System

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Abstract: This study investigates the stability and optimum gain settings of Load Frequency Control (LFC) for single area reheat thermal power system. The new Particle Swarm Optimization technique (PSO) is used for optimizing Proportional Integral Differential (PID) controller gain values. The proposed technique can be used for the design of the proper PID controller for load frequency control with the help of different objective functions. Furthermore, extension to the uncertainties in the plant model parameters case is also included to illustrate the effectiveness of the proposed controller in damping power system oscillations that follow disturbances. The uncertainties in the plant model parameters case are emulated by changing turbine time constant, generator time constant, reheater time constant and speed regulator parameters by ±25%. Finally, the enhancement in the dynamic response of the system is verified through simulation results of a system under different operating points and exposed to both small and large disturbances. Time domain analysis is used to demonstrate, the necessity of the proposed controller in suppressing power system oscillations that follow disturbances.

Key words: Particle swarm optimization technique, proportional integral differential controller, damping power, load frequency control, synchronous generator, India

INTRODUCTION

In the thermal power generating unit coal is used to convert water into steam. Coal is burnt by combustion in the boiler furnace. Heat is liberated after completion of combustion process which is used for the conversion of water into steam energy. The generated energy is converted into mechanical energy by the use of turbine. The mechanical energy is transmitted through rotating shaft and it is given into the either generator or alternator. Control of real and reactive power of any generating unit is mainly depending on prime mover of the generating unit, this function is commonly known as Load Frequency Control (LFC) or Automatic Generation Control (AGC). The normal operation of power system is affected by continuously varied power surplus. Power surplus in the generating unit causes effects in power flow, frequency of the system and speed of the governor. In order to conquer these types of harms in generating unit design of proper controller is very important for limiting the operating conditions of the system within the permissible limits. Last few years, so many research has been done by many researchers and reported in the decades (Ali and Abd-Elazim, 2011; Anand and Jeyakumar, 2009; Elgerd, 1970; Gopal, 2003; Jagatheesan and Anand, 2012; Kundur, 1994; Saikia *et al*., 2013; Ebrahim *et al*., 2009; Soheilirad *et al*., 2012; Nagrath and Kothari, 1994; Modi *et al*., 2013; Omar *et al*., 2013; Kumar and Ganapathy, 2013; Taher *et al*., 2014). In this study, Proportional Integral Derivative (PID) controller is implemented for the investigation.

In power system LFC, proper design of controller plays major role and also tuning of controller parameter is most essential for enhancing the system dynamic response. In order to achieve better response from the power system, many evolutionary computational techniques are developed and implemented in many research works from the past few years (Ali and Abd-Elazim, 2011; Anand and Jeyakumar, 2009; Elgerd, 1970; Gopal, 2003; Jagatheesan and Anand, 2012;

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Kundur, 1994; Saikia *et al*., 2013; Ebrahim *et al*., 2009; Soheilirad *et al*., 2012; Nagrath and Koyhari, 1994; Modi *et al*., 2013; Omar *et al*., 2013; Kumar and Ganapathy, 2013; Taher *et al*., 2014). Bacterial foraging optimization technique was used for the tuning of fuzzy Integral Double Derivative (IDD) controller in 3 area interconnected hydrothermal power system (Saikia *et al*., 2013) and it is also implemented in load frequency control of 2 area power system with PI controller (Ali and Abd-Elazim, 2011). Imperialist competitive algorithm (Soheilirad *et al*., 2012; Taher *et al*., 2014) is applied for tuning of Fractional Order Proportional Integral Derivative (FOPID) controller in 3 area power system and tuning PID controller in multi area interconnected power system. Ant colony optimization technique (Omar *et al*., 2013) is applied in LFC of 2 area hydrothermal power systems with PID controller parameter tuning, considering different cost functions. Cuckoo search optimization technique (Kumar and Ganapathy, 2013) is implemented in 2 area interconnected power system with proper controller and considering Superconducting Energy Storage (SMES) unit and Governor Dead Band (GDB) non linearity. PID controller parameter in single area power system is optimized by using particle swarm optimization technique (Soheilirad *et al*., 2012; Modi *et al*., 2013) and also, it is used for tuning of PID controller in 2 area decentralized mode interconnected power system.

In this study, a new stochastic PSO technique is implemented for tuning of PID controller gain in load frequency control of power system. Due to randomly varied load demand of power system pose great challenge for the design of proper controller. PID controller is applied to meet the desired performance of system during sudden load changes or abnormal conditions. In addition, the proposed technique can be used to design reduced power system model with 3 different cost functions without degrading their performance.

MATERIALS AND METHODS

Thermal power system modeling: The Simulink model of single area reheat thermal power system is shown in Fig. 1 and it is considered for the investigation purpose. The rating of the reheat thermal power system is 2000 MW. The load frequency control system includes reheat turbine with PID controller. In Fig. 1, R represents the self regulation parameter for the governor in p.u. Hz; T_g represents speed governor time constant in sec; T_r is the reheat time constant in sec; K_r is the reheat gain; T_t is the steam chest time constant in sec; T_p, K_p is the load frequency constant (T_p = 2H/f×D, K_p = 1/D); delXE represent incremental governor valve position change; delPg incremental generation change; delF incremental frequency deviation; ACE stands for Area Control Error. The significant parameters are by Anand and Jeyakumar, (2009). The sensitive analysis is done by 1% load disturbance and the system parameters are changed from their nominal value in the range of -25 to +25%.

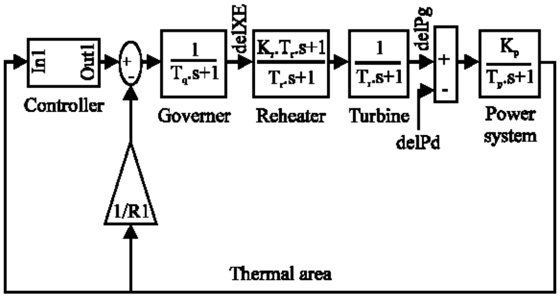

Fig. 1: Simulink model of single area reheat thermal power system

PID controller: The design of controller in LFC system is very essential and performance of the system is mainly dependent on control signal generated by the proposed controller. In this study, industrial PID controller is implemented. The design of PID controller is obtained by using 3 different objective functions and controller gain values are optimized by Stochastic Particle Swarm Optimization technique (SPSO). In this resaerch, Integral Time Absolute Error (ITAE), Integral Absolute Error (IAE) and Integral Square Error (ISE) objective functions are used (Jagatheesan and Anand, 2012). The objective functions are integral absolute error:

$$J_1 = \int_0^\infty | \{\Delta f_i + \Delta P_{tiei-j}\} | \, dt \tag{1}$$

Integral square error:

$$J_2 = \int_0^\infty (\{\Delta f_i + \Delta P_{tiei-j}\})^2 \, dt \tag{2}$$

Integral absolute time error:

$$J_3 = \int_0^\infty t \, | \{\Delta f_i + \Delta P_{tiei-j}\} | \, dt \tag{3}$$

The nature of Proportional (P), Integral (I) and Derivative (D) controller is to reduce maximum over shoot in system response to reduce steady state error and to increase stability of the system, respectively (Elgerd, 1970; Kundur, 1994; Nagrath and Kothari, 1994). The control signal generated by the PID controller is given as:

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \tag{4}$$

The design procedure for SPSO is given in the study.

Particle swarm optimization: The evolutionary computation based particle swarm optimization technique was first introduced by Eberhart and Kennedy in 1995 (Soheilirad *et al.*, 2012; Modi *et al.*, 2013). This technique is inspired by social behavior of natural organisms such as bird flocking and fish schooling. PSO is a population based optimization tool in which individuals are generally called particles. It changes their states (positions) with respect to time. Fitness values of all the particles are evaluated as a fitness function. The direction of a particle is defined by the set of particle neighboring one particle and its past experience. The particles are flow through the problem search space by updating the position of ith particle at time step t. The position and velocity are governed by Omar *et al.* (2013):

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{5}$$

$$\begin{aligned} v_i^{k+1} = wv_i^k + c_1 rand_1 \times (pbest_i - x_i^k) + \\ c_2 rand_2 \times (gbest - x_i^k) \end{aligned} \tag{6}$$

Due to the demerits of basic PSO, a new stochastic PSO technique is introduced. When inertia weighting function equal to zero, the update equation is written as follows (Ebrahim *et al.*, 2009):

$$\begin{aligned} x_i(t+1) = x_i(t) + c_1 rand_1 \times (pbest_i - x_i(t)) + \\ c_2 rand_2 \times (gbest - x_i(t))] \end{aligned} \tag{7}$$

This equation increases the local search capability but reduces the global search capability (Ebrahim *et al.*, 2009). The new particle j's position can be calculated as follow:

$$\begin{aligned} x_j(t+1) &= G_1(x_j(t)), \text{ if } (\text{random} < P_{select}) \\ x_j(t+1) &= G_2(x_j(t)), \text{ otherwise} \end{aligned} \tag{8}$$

Where:

x_i (t) = The vector of current position
v_i (t+1) = The vector of the current velocity
ω = Inertia weighting function
c = Acceleration constant
rand = Random number of the interval (0,1)
$pbest_i$ = Personal best of particle i
gbest = Global best (best of pbest of the group)
P_{select} = Parameter within (0.01, 0.1) and random is uniform random sequences sampled from U (0, 1)
G_1 (x) = Function which uniformly sample from the domain
G_2 (x) = TS technique

RESULTS AND DISCUSSION

In this investigation, all the simulink model and simulation results are obtained by using MATLAB 2007 software. The proposed optimization technique is designed and implemented in single area reheat thermal system with various objective functions J_1-J_3 with 1% step load perturbation in the system. The effectiveness and performance of the proposed technique is tested with uncertainties in the system parameters T_t, T_g, T_r and R. The system parameters are varied in the range of -25 to +25% from its nominal values. Figure 2-25 show the frequency deviation and area control error with various uncertainties by using IAE, ISE and ITAE objective functions, respectively. It is clearly shown that reduced or increased model power system yield more and less oscillation, respectively compared with unchanged parameter response.

Observe the dynamic responses of the system (frequency deviation and area control error) from Fig. 2-25,

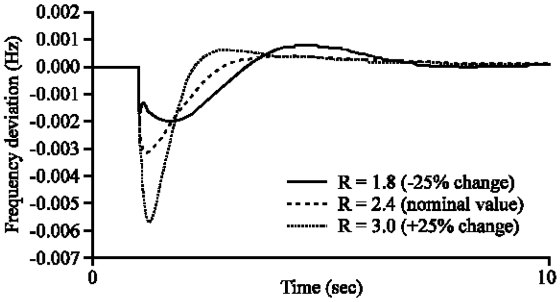

Fig. 2: Frequency deviation for 1% load change with varying R by using IAE

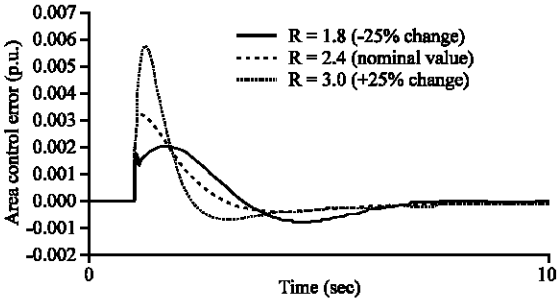

Fig. 3: Area control error for 1% load change with varying R by using IAE

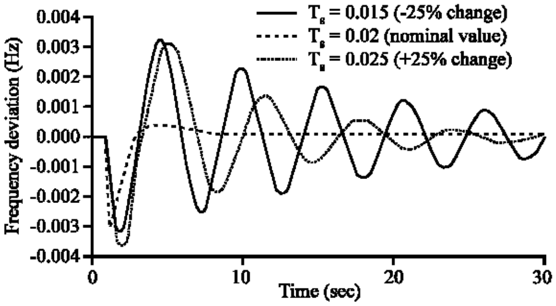

Fig. 4: Frequency deviation for 1% load change with varying T_g by using IAE

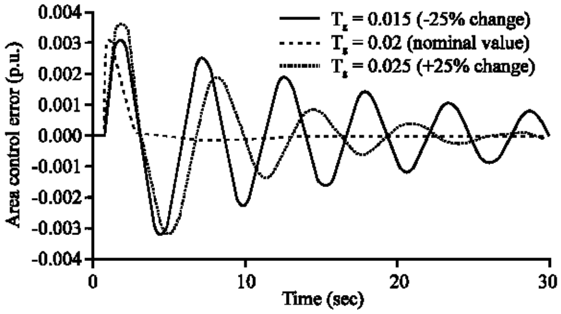

Fig. 5: Area control error for 1% load change with varying T_g by using IAE

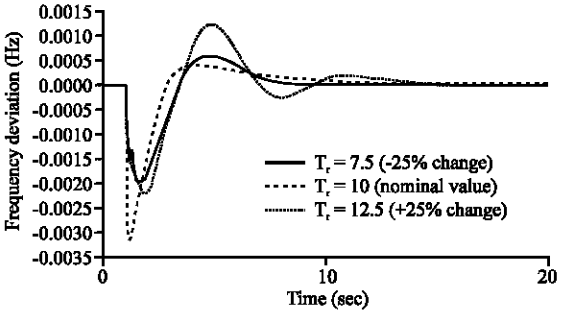

Fig. 6: Frequency deviation for 1% load change with varying T_r by using IAE

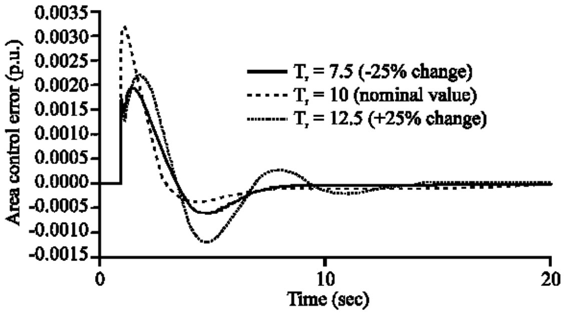

Fig. 7: Area control error for 1% load change with varying T_r by using IAE

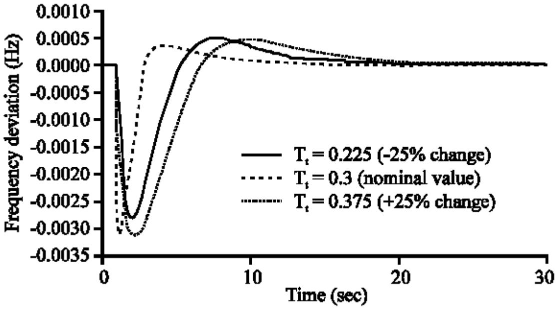

Fig. 8: Frequency deviation for 1% load change with varying T_t by using IAE

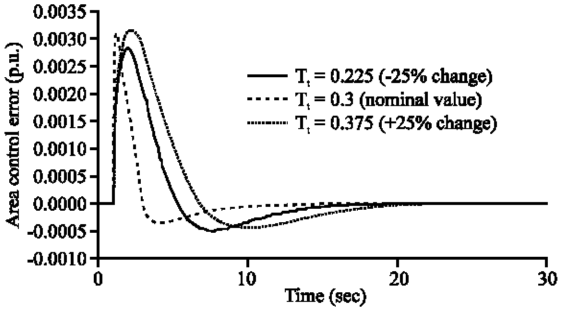

Fig. 9: Area control error for 1% load change with varying T_t by using IAE

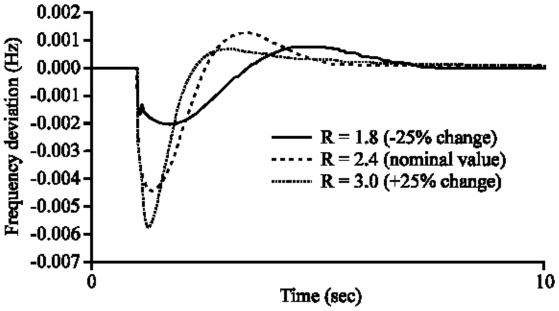

Fig. 10: Frequency deviation for 1% load change with varying R by using ISE

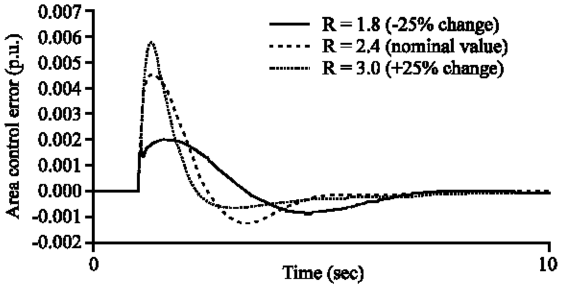

Fig. 11: Area control error for 1% load change with varying R by using ISE

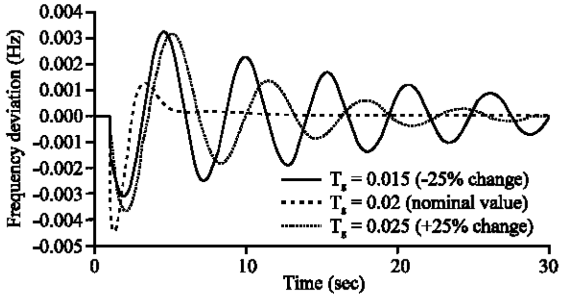

Fig. 12: Frequency deviation for 1% load change with varying T_g by using ISE

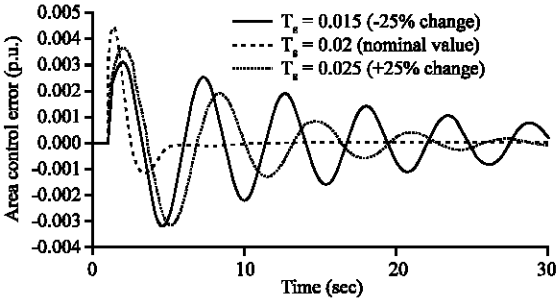

Fig. 13: Area control error for 1% load change with varying T_g by using ISE

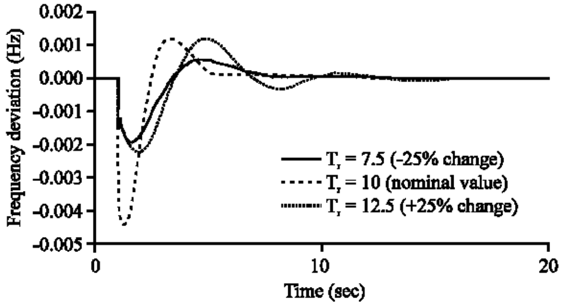

Fig. 14: Frequency deviation for 1% load change with varying T_r by using ISE

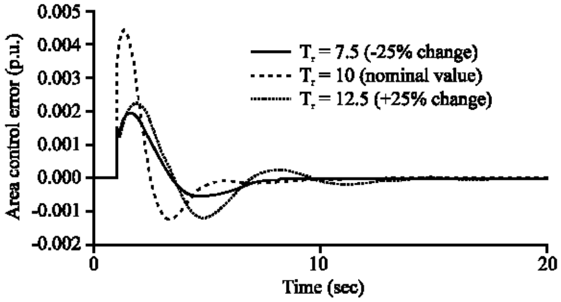

Fig. 15: Area control error for 1% load change with varying T_r by using ISE

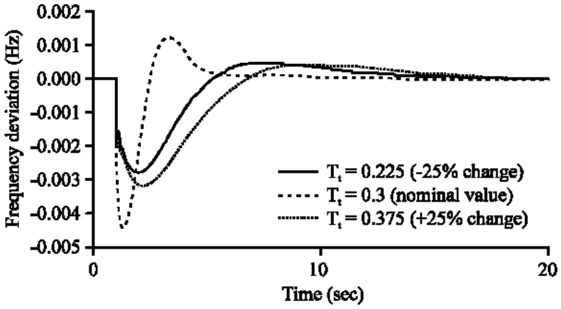

Fig. 16: Frequency deviation for 1% load change with varying T_t by using ISE

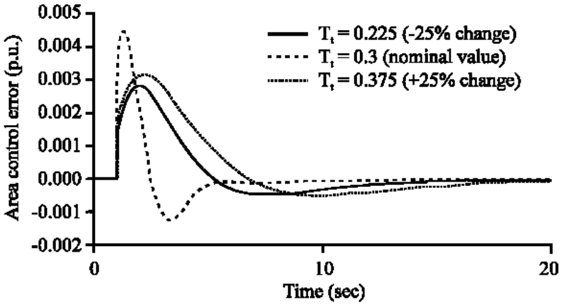

Fig. 17: Area control error for 1% load change with varying T_t by using ISE

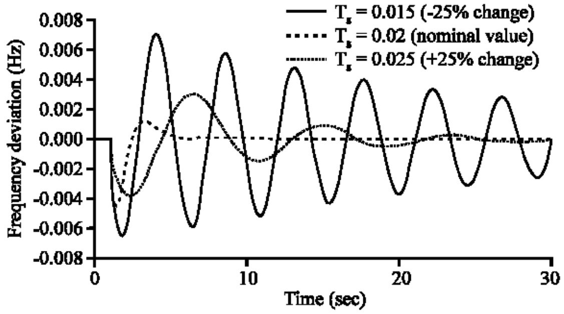

Fig. 18: Frequency deviation for 1% load change with varying T_g by using ITAE

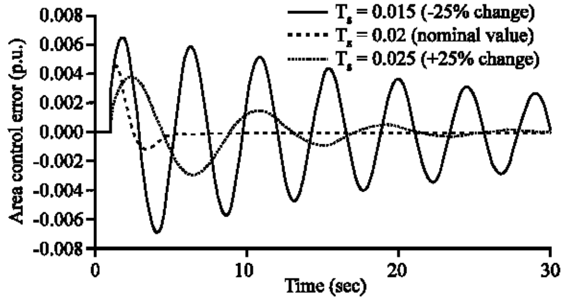

Fig. 19: Area control error for 1% load change with varying T_g by using ITAE

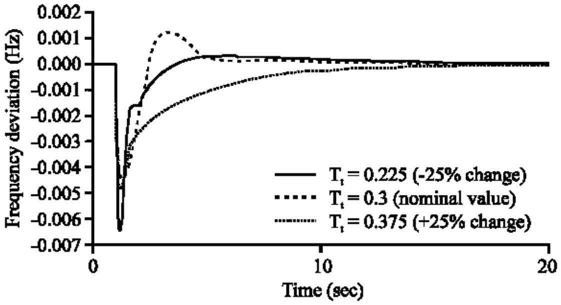

Fig. 20: Frequency deviation for 1% load change with varying T_t by using ITAE

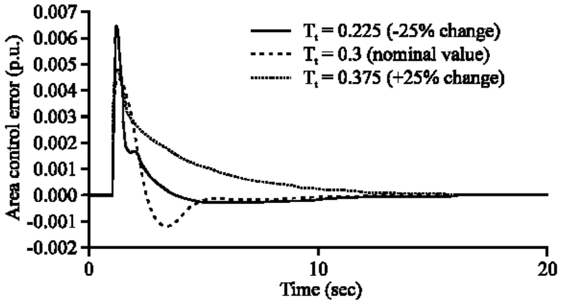

Fig. 21: Area control error for 1% load change with varying T_t by using ITAE

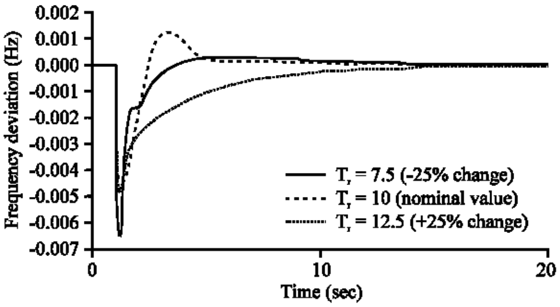

Fig. 22: Frequency deviation for 1% load change with varying T_r by using ITAE

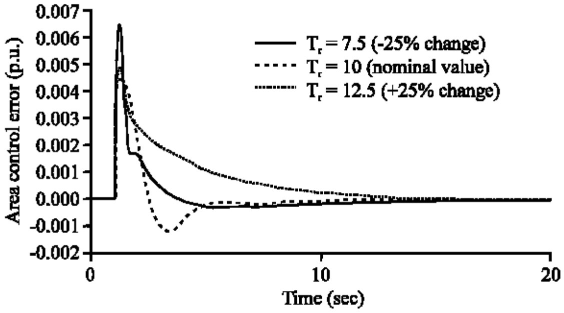

Fig. 23: Area control error for 1% load change with varying T_r by using ITAE

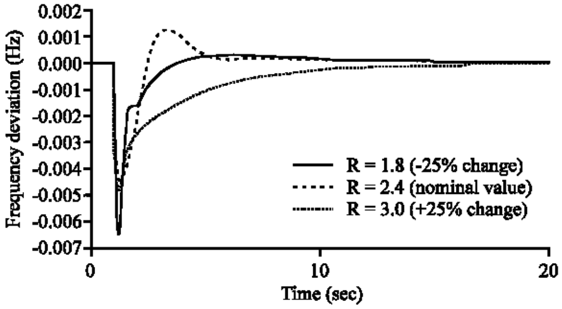

Fig. 24: Frequency deviation for 1% load change with varying R by using ITAE

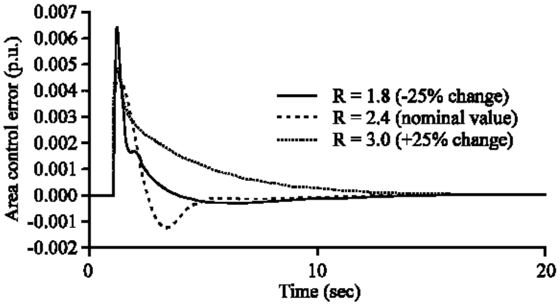

Fig. 25: Area control error for 1% load change with varying R by using ITAE

Table 1: Optimal gain values of PID controller parameters and performance index J to the variation in T_g

T_g	K_p	K_i	K_d	J_{min}
0.15	0.1361	5.8766	2.6031	9.0115
0.2 (nominal value)	4.2354	7.1567	2.0436	0.5376
0.25	1.5063	3.9084	6.3878	6.1769

Table 2: Optimal gain values of PID controller parameters and performance index J to the variation in R

R	K_p	K_i	K_d	J_{min}
1.8	1.3791	5.6108	4.4830	3.7842
2.4 (nominal value)	4.2354	7.1567	2.0436	0.5376
3	2.4721	4.7659	8.5098	4.6985

it is clearly shown that better controlled performance can be obtained by using proposed optimization technique and performance is insensitive to the system parameter changes.

Performance analysis

Effects in governor time constant (T_g): Table 1 shows the optimal gain values of PID controller parameters and performance index of Integral Time Absolute Error (ITAE) objective function J_{min} for T_g = 0.15, 0.02 (nominal) and 0.025 sec. The dynamic performance of the system, however practically insensitive when T_g is changed by ±25% from its nominal value.

Effects in regulation parameter (R): Table 2 shows the optimal gain values of PID controller parameters and

Table 3: Optimal gain values of PID controller parameters and performance index J to the variation in T_r

T_r	K_p	K_i	K_d	J_{min}
7.5	6.5181	5.3854	5.0472	0.93949
10 (nominal value)	4.2354	7.1567	2.0436	0.53760
12.5	6.0074	2.8414	4.3981	1.37750

Table 4: Optimal gain values of PID controller parameters and performance index J to the variation in T_t

T_t	K_p	K_i	K_d	J_{min}
0.225	6.8724	4.2433	0.5366	0.51155
0.3 (nominal value)	4.2354	7.1567	2.0436	0.53760
0.375	8.0548	0.8034	1.8852	2.41130

performance index of Integral Time Absolute Error (ITAE) objective function J_{min} for R = 1.8, 2.4 (nominal) and 3 Hz p.u. MW. The dynamic performance of the power system, however practically insensitive. When the value of R is changed by ±25% from its nominal value.

Effects in reheat time constant (T_r): Table 3 shows the optimal gain values of PID controller parameters and performance index of Integral Time Absolute Error (ITAE) objective function J_{min} for T_r = 7.5, 10 (nominal) and 12.5 sec. The dynamic performance of the system, however practically insensitive when T_r is changed by ±25% from its nominal value.

Effects in turbine time constant (T_t): Table 4 shows the optimal gain values of PID controller parameters and performance index of Integral Time Absolute Error (ITAE) objective function J_{min} for T_t = 0.225, 0.3 (nominal) and 0.375 sec. The dynamic performance of the system, however practically insensitive when T_t is changed by ±25% from its nominal value.

Analysis revels that the stability, optimum gain settings of proportional gain (K_p), integral gain (K_i) and derivative gain (K_d) and objective index are varied with changes in system parameters. But, practically performance of system is insensitive to changes in nominal system parameters of the system.

CONCLUSION

The proposed controller is designed to be a modular way for outlining artificial intelligence based controller that is applicable to LFC issues. During this research, it is evident that the SPSO-PID controller performance will improve the power system performance. The controller supersedes a conventional AGC, since it will benefit from artificial intelligence domain to achieve better performance. It is proved that a conventional AGC would have required additional tuning effort whereas the proposed PID has utilized less effort to achieve a comparable performance. The SPSO-PID is one among the recently proposed load frequency controllers that utilize the artificial intelligence. SPSO-PID provides a simply understood artificial intelligence based design for a load frequency control. The effectiveness of the proposed SPSO-PID is evident through simulations studies and comparison with conventional AGC.

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