

Comparison of meta heuristic optimization methods in load frequency control

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Abstract

In this paper an optimal load frequency controller for two area interconnected power system is presented to quench the deviations in frequency and tie line power due to different load disturbances. Here, a PI type controller is considered for LFC problem. The parameters of the proposed PI controller are tuned using Particle Swarm Optimization (PSO) method. A two-area electric power system with a wide range of parametric uncertainties is given to illustrate proposed method. To show effectiveness of the proposed method, a PI type controller optimized by Genetic Algorithms (GA) is designed in order to comparison with the proposed PI controller. The simulation results visibly show the validity of PSO-PI controller in comparison with the GA-PI controller.

Keywords: Load Frequency Control, Two Area Electric Power System, Particle Swarm Optimization, Genetic Algorithms, PI Controller

Introduction

For large scale electric power systems with interconnected areas, Load Frequency Control (LFC) is important to keep the system frequency and the inter-area tie power as near to the scheduled values as possible. The input mechanical power to the generators is used to control the frequency of output electrical power and to maintain the power exchange between the areas as scheduled. A well designed and operated power system must cope with changes in the load and with system disturbances, and it should provide acceptable high level of power quality while maintaining both voltage and frequency within tolerable limits.

Many control strategies for Load Frequency Control in electric power systems have been proposed by researchers over the past decades. This extensive research is due to the fact that LFC constitutes an important function of power system operation where the main objective is to regulate the output power of each generator at prescribed levels while keeping the frequency fluctuations within pre-specified limits. A unified tuning of PID load frequency controller for power systems via internal mode control has been proposed by Tan (2010).

In this paper the tuning method is based on the two-degree-of-freedom (TDF) internal model control (IMC) design method and a PID approximation procedure. A new discrete-time sliding mode controller for load-frequency control in areas control of a power system has been

presented by Vrdoljak *et al.* (2010). A full-state feedback is applied for LFC not only in control areas with thermal power plants but also in control areas with hydro power plants, in spite of their non minimum phase behaviors. To enable full-state feedback, a state estimation method based on fast sampling of measured output variables has been applied. The applications of artificial neural network, genetic algorithms and optimal control to LFC have already been reported (Kocaarslan & Cam, 2005; Liu *et al.*, 2003; Rerkpreedapong *et al.*, 2003). An adaptive decentralized load frequency control of multi-area power systems has been presented by Zribi *et al.* (2005). Also the application of robust control methods for load frequency control problem has been presented by Shayeghi *et al.* (2007) and Taher *et al.* (2008).

Here we design method for LFC in a multi area electric power system using a PI type controller whose parameters are tuned using PSO. In order to show effectiveness of the proposed method, this PSO-PI is

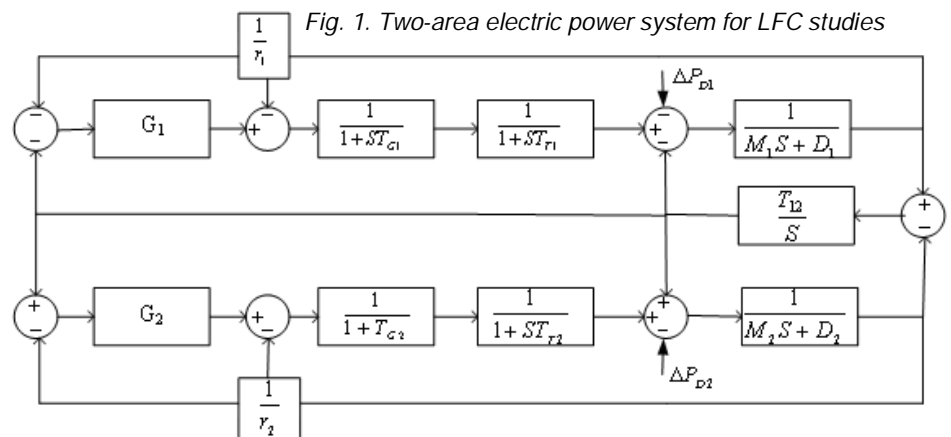


Fig. 1. Two-area electric power system for LFC studies

compared with a PI type controller whose parameters are tuned using GA (GA-PI). Simulation results show that the PSO-PI guarantees robust performance under a wide range of operating conditions and system uncertainties.

Plant model

Fig. 1 shows a two-control area power system which is considered as a test system. The state-space model of foregoing system is as (1) (Wood *et al.*, 2003).

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx \end{cases} \quad (1)$$

Where:

$$\begin{aligned} u &= [\Delta P_{D1}, \Delta P_{D2}, U_1, U_2] \\ y &= [y_1, y_2] = [\Delta f_1, \Delta f_2, \Delta P_{tie}] \\ x &= [\Delta P_{G1} \quad \Delta P_{T1} \quad \Delta f_1 \quad \Delta P_{tie} \quad \Delta P_{G2} \quad \Delta P_{T2} \quad \Delta f_2] \end{aligned}$$

The parameters of model, defined as follow:

$$A = \begin{bmatrix} -\frac{1}{T_{G1}} & 0 & -\frac{1}{r_1 T_{G1}} & 0 & 0 & 0 & 0 \\ \frac{1}{T_{T1}} & -\frac{1}{T_{T1}} & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{M_1} & -\frac{D_1}{M_1} & -\frac{1}{M_1} & 0 & 0 & 0 \\ 0 & 0 & T_{12} & 0 & 0 & 0 & -T_{12} \\ 0 & 0 & 0 & 0 & -\frac{1}{T_{G2}} & 0 & \frac{-1}{r_2 T_{G2}} \\ 0 & 0 & 0 & 0 & \frac{1}{T_{T2}} & -\frac{1}{T_{T2}} & \\ 0 & 0 & 0 & \frac{1}{M_2} & 0 & \frac{1}{M_2} & -\frac{D_2}{M_2} \end{bmatrix} \quad B = \begin{bmatrix} 0 & 0 & \frac{1}{M_1} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{M_2} \\ \frac{1}{T_{G1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{T_{G2}} & 0 & 0 \end{bmatrix}$$

- Δ: Deviation from nominal value
- M=2H: Constant of inertia
- D: Damping constant
- R: Gain of speed droop feedback loop
- T_i: Turbine Time constant
- T_G: Governor Time constant
- G₁: First area controller
- G₂: Second area controller

The typical values of system parameters for nominal operation condition are as follow:

$$\begin{aligned} T_{T1} = T_{T2} &= 0.03 & T_{G1} = T_{G2} &= 0.08 \\ T_{P1} = T_{P2} &= 20 & R_1 = R_2 &= 2.4 \\ K_{P1} = K_{P2} &= 120 & B_1 = B_2 &= 0.425 \\ K_1 = K_2 &= 1; a_{12} &= -1 & T_{12} = 0.545 \end{aligned}$$

The values of the first and second area parameters given above are considered to be equal.

The objectives are Design G₁ and G₂ in Load Frequency Control (LFC). Meta heuristic optimization methods such as PSO and GA have been applied to design the foregoing controllers. The goals are to study

the ability of these methods in Load Frequency Control (LFC) problem and also comparing the performances of these methods. In the next sections the process of controllers design using these methods is developed. In the controller design for multi-area electric power systems, some areas have more importance than the others for tie-power and also frequency control. But the importance of areas is considered as equal.

Design methodology

PI controller is considered for LFC problem. The parameters of this PI controller are obtained using PSO.

Particle swarm optimization

PSO was formulated by Edward and Kennedy in 1995. The thought process behind the algorithm was inspired by the social behavior of animals, such as bird flocking or fish schooling. PSO is similar to the continuous GA in that it begins with a random population matrix. Unlike the GA, PSO has no evolution operators such as crossover and mutation. The rows in the matrix are called particles (same as the GA chromosome). They contain the variable values and are not binary encoded. Each particle moves about the cost surface with a velocity. The particles update their velocities and positions based on the local and global best solutions as shown in (2) and (3) (Randy & Sue, 2004):

$$V_{m,n}^{new} = W \times V_{m,n}^{old} + \Gamma_1 \times r_1 \times (P_{m,n}^{local\ best} - P_{m,n}^{old}) + \Gamma_2 \times r_2 \times (P_{m,n}^{global\ best} - P_{m,n}^{old}) \quad (2)$$

$$P_{m,n}^{new} = P_{m,n}^{old} + \Gamma V_{m,n}^{new} \quad (3)$$

Where:

- V_{m,n} = particle velocity
- P_{m,n} = particle variables
- W = inertia weight
- r₁, r₂ = independent uniform random numbers
- Γ₁ = Γ₂ = learning factors

P_{m,n}^{local best} = best local solution

P_{m,n}^{global best} = best global solution

The PSO algorithm updates the velocity vector for each particle then adds that velocity to the particle position or values. Velocity updates are influenced by both the best global solution associated with the lowest cost ever found by a particle and the best local solution associated with the lowest cost in the present population. If the best local solution has a cost less than the cost of the current global solution, then the best local solution replaces the best global solution. The particle velocity is reminiscent of

local minimizes that use derivative information, because velocity is the derivative of position. The advantages of PSO are that it is easy to implement and there are few parameters to adjust. The PSO is able to tackle tough cost functions with many local minima (Randy & Sue, 2004).

PI controller adjustment using PSO

The parameters of the proposed PI controllers are tuned using PSO. In optimization methods, the first step is to define a performance index for optimal search. The performance index is considered as (4). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (ITAE).

$$ITAE = \int_0^t t|\Delta\omega_1|dt + \int_0^t t|\Delta\omega_2|dt \quad (4)$$

The parameter "t" in ITAE is the simulation time and is considered from zero to 100 seconds. It is clear to understand that the controller with lower ITAE is better than the other controllers. To compute the optimum parameter values, a 10 % step change in ΔP_{D1} is assumed and the performance index is minimized using PSO. In order to acquire better performance, number of particle, particle size, number of iteration, Γ_1 , Γ_2 , and Γ are chosen as 24, 4, 40, 2, 2 and 1, respectively. Also, the inertia weight, w , is linearly decreasing from 0.9 to 0.4. It should be noted that PSO algorithm is run several times and then optimal set of parameters is selected. The optimum values of the PI parameters are obtained using PSO and summarized in the Table 1. The boundaries of parameters for optimal search are as follows: $1 \leq K_P$ and $K_I \leq 100$

Table 1. Optimum values of K_P and K_I for PSO-PI controllers

	K_P	K_I
First area PI parameters	14.2391	49.8127
Second area PI parameters	2.7772	65.1124

In order to comparison and show effectiveness of the proposed method, another PI type controller optimized by GA is designed for LFC. The optimum value of the GA-PI controllers Parameters have been obtained using GA and summarized in the Table 2.

Table 2. Optimum values of K_P and K_I for GA-PI controllers

	K_P	K_I
First area PI parameters	11.7321	43.1291
Second area PI parameters	5.5099	66.7739

The GA parameters are as follows:

- Number of Chromosomes: 4; Population size: 24
- Crossover rate: 0.5; Mutation rate: 0.1

Results and discussions

The proposed controller is applied to the system for LFC. In order to study and analysis system performance under system uncertainties, three operating conditions

are considered as follows:

- Nominal operating condition
- Heavy operating condition (20% changing parameters from their typical values)
- Very heavy operating condition (40% changing parameters from their typical values)

In order to demonstrate the robustness performance of the proposed method, the ITAE is calculated following step change in the demand of first area (ΔP_{D1}) at all operating conditions (Nominal, Heavy and Very heavy) and results are presented (Table 3) Following step change, the PSO-PI controller has better performance than the GA-PI controller at all operating conditions.

Table 3. 10% step increase in demand of first area (ΔP_{D1})

	The calculated ITAE	
	PSO-PI	GA-PI
Nominal operating condition	0.0028	0.0055
Heavy operating condition	0.0042	0.068
Very heavy operating condition	0.0065	0.010

Fig. 2 shows $\Delta\omega_1$ at nominal, heavy and very heavy operating conditions following 10 % step change in the demand of first area (ΔP_{D1}). It is seen that the PSO-PI controller has better performance than the other method at all operating conditions.

Conclusions

In this paper a new PSO based PI controller has been successfully proposed for Load Frequency Control problem. The proposed method was applied to a typical two-area electric power system containing system parametric uncertainties and various loads conditions. Simulation results demonstrated that the PI controllers capable to guarantee the robust stability and robust performance under a wide range of uncertainties and load conditions. Also, the simulation results showed that the PSO-PI controller is robust to change in the system parameters and it has better performance than the GA-PI type controller at all operating conditions. The PI controller is the most used controller in the industry and practical systems, therefore the paper's results can be used for the practical LFC systems.

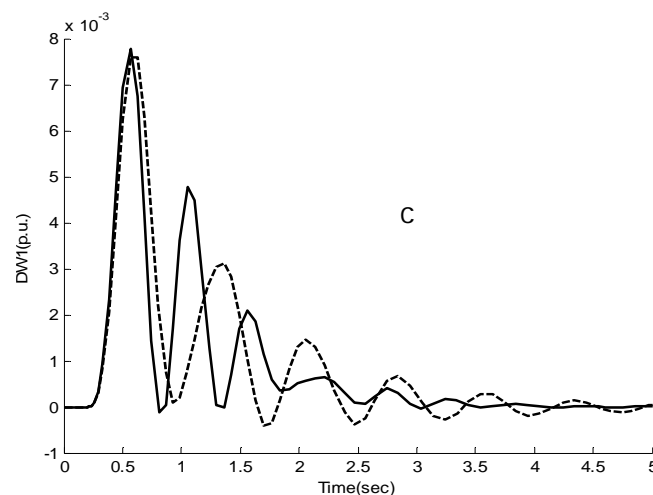
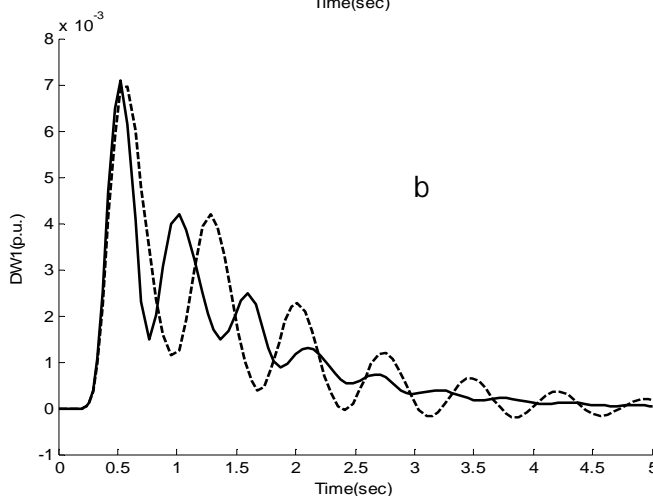
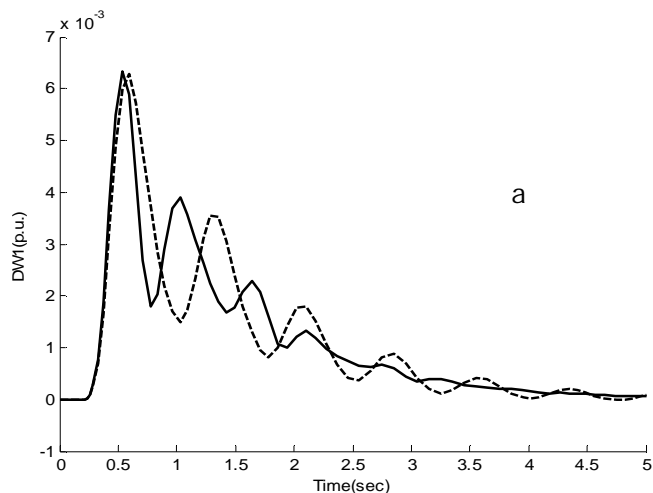
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Fig. 2. Dynamic response $\Delta\omega_1$ following step change in demand of first area (ΔP_{D1}) a: Nominal b: Heavy c: Very heavy



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