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# Optimal Decentralized Load Frequency Control in a Parallel AC-DC Interconnected Power System Through HVDC Link Using PSO Algorithm

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## Abstract

A new design of decentralized load-frequency controller for interconnected power systems with ac-dc parallel using Particle Swarm Optimization (PSO) algorithm is proposed in this paper. A HVDC link is connected in parallel with an existing ac tie-line to stabilize the frequency oscillations of the ac system. Any optimum controller selected for load frequency control of interconnected power systems should not only stabilize the power system but also reduce the system frequency and tie line power oscillations and settling time of the output responses. In practice Load Frequency Control (LFC) systems use simple Proportional Integral (PI) or Integral (I) controller parameters are usually tuned based on classical or trial-and-error approaches, they are incapable of obtaining good dynamic performance for various load change scenarios in multi-area power system. For this reason, in this paper the PI and I control parameters are tuned based on PSO algorithm method for the LFC control in the two-area power system. A two area interconnected thermal power system is considered to demonstrate the validity of the proposed controller. The simulation results show that the proposed controller provides better dynamic responses with minimal frequency and tie-line power deviations, quick settling time and guarantees closed-loop stability margin.

***Keywords*** *: Load Frequency Control; PSO; ac-dc tie lines; Interconnected Power systems*

## 1. Introduction

The interconnected power system presents a great challenge in power system design and operation. The load-frequency control (LFC) problem has gained much importance because of the size and complexity of modern interconnected power systems. The objective of LFC is to regulate the output powers of

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regulating plants so that the frequency of power system and tie-line powers are kept within prescribed limits. Many control strategies for LFC of power systems have been proposed and investigated by many researchers over the past several years [1-4].

Majority of the works carried out earlier is centered on interconnected power systems considering only the area interconnection with ac tie-lines. However, there has been a tremendous growth of the HVDC transmission system due to economic, environmental and performance advantages over the other alternatives. Hence, it has been applied widely in operating a dc link in parallel with an ac link [5-7] interconnecting control areas to get an improved system dynamic performance with greater stability margins under small disturbances in the system. Therefore, this paper considers LFC of an interconnected power system with a dc tie-line in parallel with an ac tie-line. Incremental dc power flow is considered as an additional state variable in the LFC strategy.

There has been considerable effort devoted to LFC of interconnected power systems in the literature [1-4]. A number of control strategies have been employed in the design of load frequency controllers in order to achieve better dynamic performance.

Hence, a new design of PI controllers using PSO [8] algorithm is proposed in this work, for the decentralized LFC of interconnected power systems with ac-dc parallel tie-lines to achieve a better transient, as well as steady state response and closed loop stability of the system. The proposed controller has been applied to an interconnected two-area thermal power system with ac-dc parallel tie-lines.

## 2. Statement of the problem

The block diagram representation of a two area interconnected thermal power system with ac-dc parallel tie-lines is shown in Fig.1. Each of the area in the interconnected power system consists of two thermal generating units. The dynamic behavior of the LFC system is described by the state space equation:

$$\dot{X} = AX + BU + \Gamma D \qquad (1)$$

$$Y = CX \qquad (2)$$

where the system state vector can be written as $X = [X_{1,}\ X_2]^T$ and sub vector $X_1$ and $X_2$ are the thermal system state vector of area 1 and area 2 respectively. As the two areas are considered to be identical areas the state sub vectors can be written as,

$X_1 = X_2 = X_i, i = 1,2$ ; $U = [\Delta P_{c1}, \Delta P_{c2}]^T$ and $D = [\Delta P_{d1}, \Delta P_{d2}]^T$

where $A, B, \Gamma, X, U, D$ are System matrix, input distribution matrix, disturbance distribution matrix, state vector, control input vector, disturbance vector respectively. The corresponding co-efficient matrices are obtained using the nominal system parameter values given in Appendix. A step load disturbance of 1% in area 1 has been considered as a disturbance in the system. It is known that, by incorporating an integral controller, the steady state requirements can be achieved. In order to introduce integral function in the controller, the system equation (3) is augmented with new state variables defined as the integral of $ACE_i$ ($\int$ vidt), i = 1, 2. The augmented system of the order (2 + n) may be described as

$$\dot{\overline{X}} = \overline{A}\overline{X} + \overline{B}u + \overline{\Gamma}d \qquad (3)$$

$$\overline{x} = \begin{bmatrix} \int vdt \\ x \end{bmatrix} \begin{matrix} \}2 \\ \}n \end{matrix} \quad \text{and} \quad \overline{A} = \begin{bmatrix} 0 & C \\ 0 & A \end{bmatrix} \overline{B} = \begin{bmatrix} 0 \\ B \end{bmatrix} \quad \text{and} \quad \overline{\Gamma} = \begin{bmatrix} 0 \\ \Gamma \end{bmatrix}$$

The decentralized feedback control law may be written in terms of *vi* as:

$$u_i = -k_{i1}\int v_i dt - k_{i2}v_i, \quad i = 1,2 \qquad (4)$$

where $k_i^{\ T} = [k_{i1} \quad k_{i2}]$ is a two dimensional integral and proportional feedback gain vector.

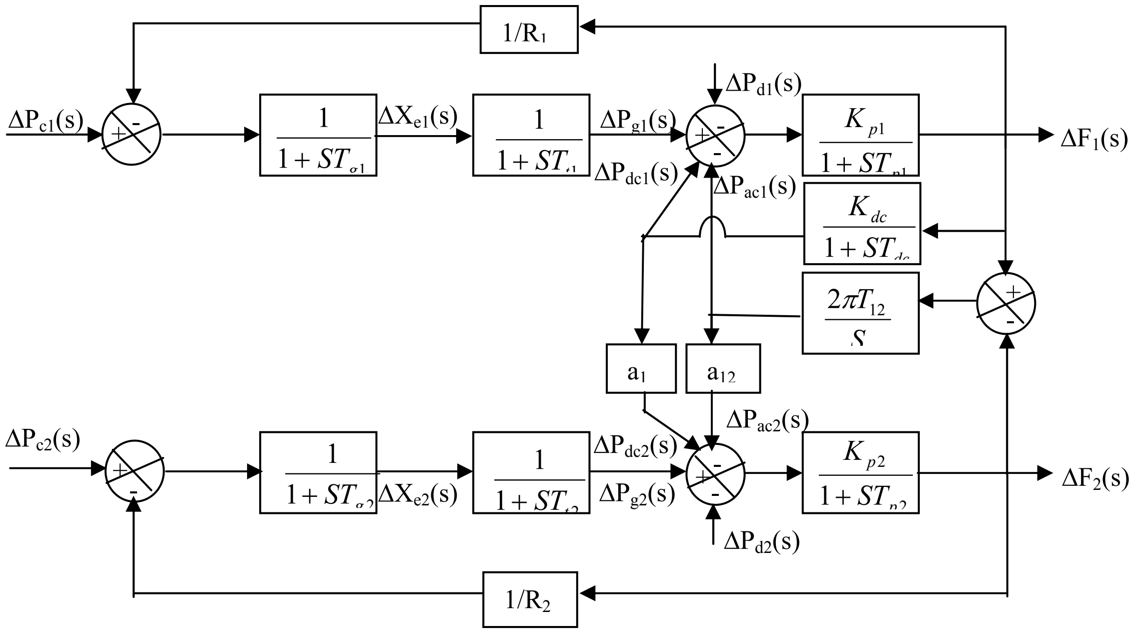


Fig. 1. Block Diagram of a two area interconnected thermal power system with AC/DC tie lines.

This design assumes that, the two area interconnected power system consists of two identical areas. Therefore, the decentralized integral feedback gains $(k_{11} = k_{21} = k_I)$ and the decentralized proportional controller feedback gains $(k_{12} = k_{22} = k_P)$ of the two identical areas are assumed to be equal.

## 3. Design of LFC for an interconnected power system with ac-dc parallel tie-lines

### *3.1. Design of decentralized proportional plus integral controller using ISE criterion*

The objective is to obtain the optimum values of the controller parameters that minimize the performance index,

$$J = \int_0^\infty X_c^T W X_c dt \qquad (5)$$

where $W = \begin{bmatrix} \alpha_1 & 0 \\ 0 & \alpha_2 \end{bmatrix}$ and $X_c = \begin{bmatrix} \Delta P_{tie} \\ \Delta F \end{bmatrix}$

$$J = \int_0^\infty (\alpha_1[\Delta P_{tie}]^2) + (\alpha_2[\beta \Delta F_1]^2) \qquad (6)$$

where $\alpha_1$ and $\alpha_2$ are weighting factors for tie line power deviation and frequency error respectively. Based on the performance index criterion the optimum gain can be easily determined.

### 3.2. PSO Algorithm

A novel population based optimization approach, has been introduced. In a PSO [8] system, multiple candidate solutions coexist and collaborate simultaneously. Each solution candidate, called a "particle", flies in the problem space (similar to the search process for food of a bird swarm) looking for the optimal position. A particle with time adjusts its position to its own experience, while adjusting to the experience of neighboring particles. If a particle discovers a promising new solution, all the other particles will move closer to it, exploring the region more thoroughly in the process.

#### 3.2.1 Steps of PSO

Steps of PSO as implemented for optimization are:

Step 1: Initialize an array of particles with random positions and their associated velocities to satisfy the inequality constraints.
Step 2: Check for the satisfaction of the equality constraints and modify the solution if required.
Step 3: Evaluate the fitness function of each particle.
Step4: Compare the current value of the fitness function with the particles previous best value (pbest). If the current fitness value is less, then assign the current fitness value to pbest and assign the current coordinates (positions) to pbestx.
Step 5: Determine the current global minimum fitness value among the current positions.
Step 6: Compare the current global minimum with the previous global minimum (gbest). If the current global minimum is better than gbest, then assign the current global minimum to gbest and assign the current coordinates (positions) to gbestx.
Step 7: Change the velocities.
Step 8: Move each particle to the new position and return to step 2.
Step 9: Repeat step 2-8 until a stop criterion is satisfied or the maximum number of iterations is reached.

#### 3.2.2 PSO algorithm definition:

The PSO definition is presented as follows

- Each individual particle i has the following properties:
  $x_i$ = A current position in search space.
  $v_i$ = A current velocity in search space.
  $y_i$ = A personal best position in search space.
- The personal best position $p_i$ corresponds to the position in search space, where particle i presents the smallest error as determined by the objective function f, assuming a minimization task.
- . The global best position denoted by g represents the position yielding the lowest error among all the $p_i$'s. Equation 7 and 8 define how the personal and global best values are updated at time k, respectively. In below, it is assumed that the swarm consists of s particles. Thus, $i \in \mathbf{1,\ldots,}s$

$$p_i^{k+1} = \begin{cases} p_i^k & \text{if } f(p_i^k) \le (X_i^{k+1}) \\ X_i^{k+1} & \text{if } f(p_i^k) > (X_i^{k+1}) \end{cases} \quad (7)$$

$$g^k \in \{p_1^k, p_2^k, \ldots, p_s^k\} \; \Big| f(g^k) = \min \{f(p_1^k), f(p_2^k), \ldots, f(p_s^k)\} \quad (8)$$

During the each iteration, every particle in the swarm is updated using 4 and 5. Two pseudorandom sequences r1 ~ U(0,1) and r2 ~ U(0,1) are used to affect the stochastic nature of the algorithm.

$$v_i^{k+1} = w \times v_i^k + c_1 \times rand()_1 \times (p_i^k - X_i^k) + c_2 \times rand()_2 \times (g^k - X_i^k) \quad (9)$$

$$X_i^{k+1} = X_i^k + v_i^{k+1} \tag{10}$$

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \tag{11}$$

$$v_{max} = k \times x_{max} \qquad 0.1 \le k \le 1 \tag{12}$$

Where,

$v_i^k$ = Velocity of $i^{th}$ particle at $k^{th}$ iteration

$v_i^{k+1}$ = Velocity of $i^{th}$ particle at $(k+1)^{th}$ iteration

$w$ = Inertia weight

$X_i^k$ = Position of the $i^{th}$ particle in the $k^{th}$ iteration

$X_i^{k+1}$ = Position of the $i^{th}$ particle in the k+1th iteration

$c_1, c_2$ =Positive constants both equal to 2

Iter, itermax =Iteration number and maximum iteration number

rand () 1, 2 = random number selected between 0 and 1

### *3.3 Design of LFC Controller*

Optimum gain setting for LFC controller for the two area interconnected thermal power system with ac-dc parallel tie-lines are obtained and they are given below.

1. Conventional proportional plus integral controller was found to be $K_p$ = 0.4 and $K_i$ = 0.2709.
2. PSO tuned proportional plus integral controller was found to be $K_p$ = 0.0302 and $K_i$ = 0.3755.

### *3.4. Simulation, Observations and Discussions*

The simulation results are shown in Fig.2, Fig.3 and Fig.4. From the figures it is observed that the controller applied PSO algorithm provides good transient and steady state responses.

The results obtained with the application of the PSO tuned proportional plus integral controller in the two area interconnected thermal power system with ac-dc parallel tie-lines are found to satisfy the control performance criteria. Simulation results show that with the PSO tuned proportional plus integral controller, the ACE approaches to zero quickly for 1% step load change in area 1.

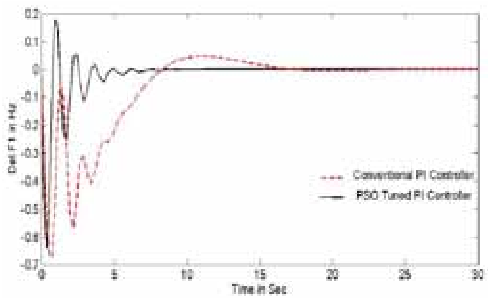


Fig. 2 Frequency deviation in area 1 for 0.01 p.u. MW step load change in area 1

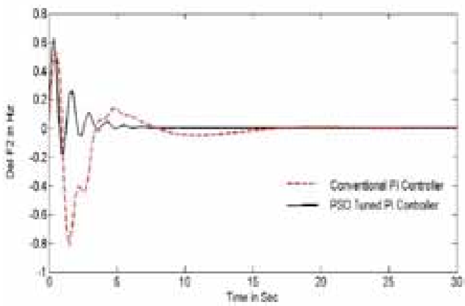


Fig. 3 Frequency deviation in area 2 for 0.01 p.u. MW step load change in area 1

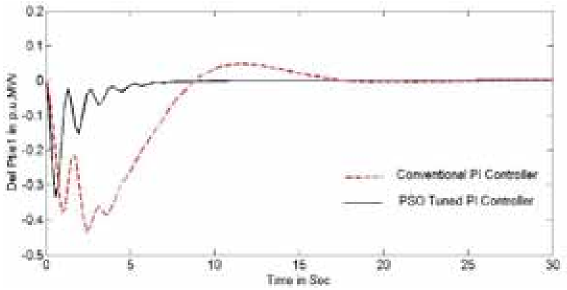


Fig. 4 Tie-line power deviation in area 1 for 0.01 p.u. MW step load change in area 1

## 4. Conclusion

Due to economical and reliability reasons the neighboring power systems are interconnected to form a power pool. The net power flow on the tie lines, connecting a system to the internal system is frequently scheduled by on a priori contract basis. System disturbances caused by load fluctuations results in changes in tie-lines power and system frequency which give rise to a load frequency control problem. This paper deals an application of PSO tuned proportional plus integral Controller for an interconnected two area thermal power systems with ac-dc parallel tie-lines. Simulation study reveals that the PSO tuned proportional plus integral controller is improving both the transient and steady state responses and therefore is superior to the conventional controller. The application of PSO tuned proportional plus integral concept can be extended to more than two areas of interconnected power systems and also considering system non linearity such as Generation Rate Constraints and Governor Dead Band.

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## Appendix

Two area interconnected thermal systems with AC/DC tie lines System Parameters

$R_1 = R_2 = 2.4 Hz/pu.MW$, $T_{g1} = T_{g2} = 0.08$ Sec., $T_{t1} = T_{t2} = 0.3$ Sec., $K_{p1} = K_{p2} = 120 Hz/pu.MW$, $T_{p1} = T_{p2} = 20$ Sec.;
$\beta_1 = \beta_2 = 0.425$ pu.MW/Hz, $a12 = -1$, $2\pi T_{12} = 0.545$ pu.MW/Hz, $K_{dc} = 1.0$, $T_{dc} = 0.5$ Sec.