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HYBRID POWER SYSTEM FOR PSO TUNED LOAD FREQUENCY CONTROL

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ABSTRACT

This paper deals with the Particle Swarm Optimisation (PSO) tuned Load Frequency Control (LFC) of single area power system, with diversified power sources. The diversified generating units considered for the purpose of LFC study are thermal, hydro and gas power plants. Hybrid power system increases the reliability of the supply and instigates economic/feasible system operation. System frequency gets affected due to real power changes, this is regulated using Load Frequency Control (LFC). The hybrid interconnected power system with various generating units imposes additional complexity in the tuning of controllers. Thus in this paper PSO based tuning is imposed to obtain sophisticated control parameters for LFC of Hybrid power system.

KEYWORDS: Load Frequency Control, Hybrid power system, Particle Swarm Optimisation, Tuning of PI controller.

INTRODUCTION

In the present circumstances power system operation and control has become more intricate due to increase in the inclusion of numerous new electric utilities to meet the increasing demand of electric power. In general, individual power stations cannot generate necessary real power during a faulted condition or when there is a substantial increase in the load. Whereas Hybrid Power Systems with various generation sources like thermal, hydro, gas etc., can meet different desired load scenarios, thereby ensuring consumer demands. Hybrid power system restricts unnecessarily tripping of generators owing to large disturbances, thus enhancing system stability and reliability. Worldwide power grid has witnessed some critical blackouts. In most of these cases, inadequate load frequency control is found to be the major cause. Thereby, Load Frequency Control (LFC) plays a vital role in maintaining synchronism among diversified multi-source generations.[1] LFC helps in adequate control of real power output from generating units in hybrid power systems when there is a change or unanticipated occurrence of load perturbation.[2] LFC consists of two control loops, the primary loop performs pilot adjustment to frequency subsequent to the load disturbances and allows the participating GUs to share loads depending on their individual speed regulation constraints. The secondary loop is the ancillary control loop which does further adjustments in the system to maintain its preset nominal frequency.

Particle Swarm Optimisation (PSO) is an effective optimisation methodology that has been lucratively applied to numerous complex optimisation problems. It has the ability to avoid tendency towards local minima by employing an adaptive memory system.[3-6] PSO is based on swarm intelligence and when compared to other such approaches it has the advantage of uncomplicated implementation and there are few parameters to be preselected. Hence in this paper PSO algorithm is used to tune the PI controllers of the various generating units in the LFC of the Hybrid power system.

The remaining part of this paper is organized as follows: Section 2 describes the modelling of single area LFC of Hybrid power system comprising of thermal, hydro and gas generating units. In Section 3, the mathematical problem formulation for tuning the PI controllers and subsequently the solution methodology using PSO algorithm are presented. In Section 4, simulation results and analysis are presented. In Section 5, conclusions and further discussions are drawn from the analysis and reported.

Modelling Of Single Area Load Frequency Control of Hybrid Power System

A. Thermal generating station

In Thermal generating station the steam turbine converts energy of high pressure and high temperature steam into kinetic energy which is, ultimately, converted into electrical energy by the turbo-alternator. The speed governing mechanism controls the steam input to the turbine thus eventually controlling the real power generation. In general, steam turbine consists of two or more series coupled turbine subsections through reheat chamber. The basic transfer function model of reheat turbine,[7-8] relating changes in turbine output power (ΔP_{mt}) corresponding to change in gate valve position (ΔX_t), is given by (1).

$$\Delta P_{mt} = \frac{1}{1+sT_t}\frac{1+sK_rT_r}{1+sT_t}\Delta X_t(s) \quad (1)$$

where, K_r is the steam turbine reheat gain, T_r is the steam turbine reheat time constant (in s) and T_t is the steam turbine time constant (in s). It may be noted that ΔX_t is the result of speed governor action which is given by (2).

$$\Delta X_t(s) = \frac{1}{1+sT_{sg}}\left(\Delta P_{tref}(s) - \left(\frac{\Delta F(s)}{R_t}\right)\right) \quad (2)$$

where R_t is the speed regulation parameter (in Hz/p.u. MW), T_{sg} is the speed governor time constant (in s), ΔP_{tref} is the reference set power of thermal unit (in p.u. MW) and ΔF is the deviation in nominal frequency (in Hz).

B. Hydro Generating unit

Hydro turbine based prime mover converts the kinetic energy of water flow into mechanical energy and, ultimately, it is converted into electrical energy using generator. Though speed governing mechanism for both thermal and hydro turbine is based on speed droop characteristics, Hydro turbine also requires transient droop compensation for stable speed control performance. Transfer function model,[9-10] describing how the hydraulic turbine power output (ΔP_{mh}) changes in response to a change in gate valve position (ΔX_h) is given by

$$\Delta P_{mh}(s) = \frac{1-sT_W}{1+0.5sT_W}\ \Delta X_h(s) \quad (3)$$

where T_w is the nominal starting time of water (in s). A linear approximation of the speed governor with transient droop in hydraulic turbine is given by (4)

$$\Delta X_h(s) = \frac{1}{1+sT_{gh}}\frac{1+sT_{rs}}{1+sT_{rh}}\left(\Delta P_{href} - \left(\frac{\Delta F(s)}{R_g}\right)\right) \quad (4)$$

Where R_g is the permanent speed droop (in Hz./p.u. MW), T_{gh}, T_{rs} and T_{rh} are the hydro turbine speed governor main servo time constant (in s), reset time constant (in s) and transient droop time constant (in s) respectively. ΔP_{href} is the reference set power for Hydro Generating Unit.

C. Gas Turbine Generating unit

In general, Gas Turbine Generating Unit are multi-fuelled generating system consisting of speed governor, valve positioner, fuel system and combustor in conjunction with associated necessary control mechanism.

Transfer function model,[2] describing how the GT power output changes (ΔP_{mg}) in response to a change in gate valve position (Δx_g) and ΔF is given by (5)

$$\Delta P_{mg}(s) = \frac{1}{1+sT_2}\left(\Delta X_g(s) - D_{tur}\Delta F(s)\right) \quad (5)$$

Where T_2 is the fuel time lag constant (in s) of the fuel system block and D_{tur} is the turbine damping (in p.u.).Expression for the fuel valve gate opening (with the maximum and the minimum opening limit being FOV_{max} and FOV_{min}, respectively) is the function of the minimum of the two signals coming out of low value gate (LVG) and is given by (6)

$$\Delta X_g(s) = \frac{1}{1+sT_1}\left[min\left\{\begin{matrix}\left(\Delta P_{gref} - \left(\frac{\Delta F(s)}{R_g}\right)\right)\\ \left(\left(L_{max} + K_t\left(L_{max} - \left(\frac{\Delta P_{fsb}(s)}{1+sT_3}\right)\right)\right)\right)\end{matrix}\right.\right] \quad (6)$$

where R_g is the speed regulation parameter (in Hz./p.u. MW), T_1 is the fuel time lag constants (in s) of the fuel opening valve block, T_3 is the load limiter time constant (in s) of the exhaust temperature block, ΔP_{fsb} is the output (in p.u.) from fuel system block having time constant T_2 (in s), K_T is temperature control loop gain and L_{max} is the load limit. In this model, ΔP_{gref} is the reference set power for Gas Turbine Generating Unit.

D. Modelling of single area hybrid power system

Transfer function model of the single-area hybrid power system for LFC study is developed by the combination of thermal, Hydro and Gas Turbine Generating Units as presented in Fig.1. In Fig.1., K_t, K_h and K_g represents participation factors from Thermal, Hydro and Gas Turbine Generating Unit, respectively.

Following a small change in load (ΔP_L) in p.u., the total change in net power generation ΔP_G (p.u.) is given by (7), (8) and (9)

$$\Delta P_g(s) = \Delta P_{gt}(S) + \Delta P_{gh}(S) + \Delta P_{gg}(s) \quad (7)$$

$$\Delta P_g(s) = K_t\Delta P_{mt}(S) + K_h\Delta P_{mh}(S) + K_g\Delta P_{mg}(S) \quad (8)$$

where $K_t+K_g+K_h=1$

$$\Delta F(s) = \frac{K_{ps}}{(1+sT_{ps})}\left(\Delta P_g(s) - \Delta P_l(s)\right) \quad (9)$$

where K_{ps} is the power system gain and T_{ps} is the power system time constant (in s).

Mathematical Problem Formulation for Tuning Pi Controller and Pso Based Solution Methodology

Mathematical problem formulation for tuning PI controller

The objective function termed as Figure of Demerit (FOD) is formulated for optimal performance analysis of the single-area power system model. FOD for single-area with multi-source power system model shown in Fig. 1, is defined by, (10)

Objective function: Minimum FOD

$$FOD = \int_0^{t_{sim}} (\Delta f(t))^2\, dt \quad (10)$$

Where, t_{sim} is the time duration of simulation (in s).

Subject to the constraints on control variables stated by (11) and (12)

$$K_{P_i}^{min} \le K_P \le K_{P_i}^{max} \quad ; i \in (TGU, HGU, GTGU) \quad (11)$$

$$K_{I_i}^{min} \le K_I \le K_{I_i}^{max} \quad (12)$$

PSO based solution Methodology

The problem stated in the above section regarding the tuning of PI controller for LFC of hybrid power system is solved using PSO based methodology. The flowchart shown in Fig.2, represents the general solution methodology.

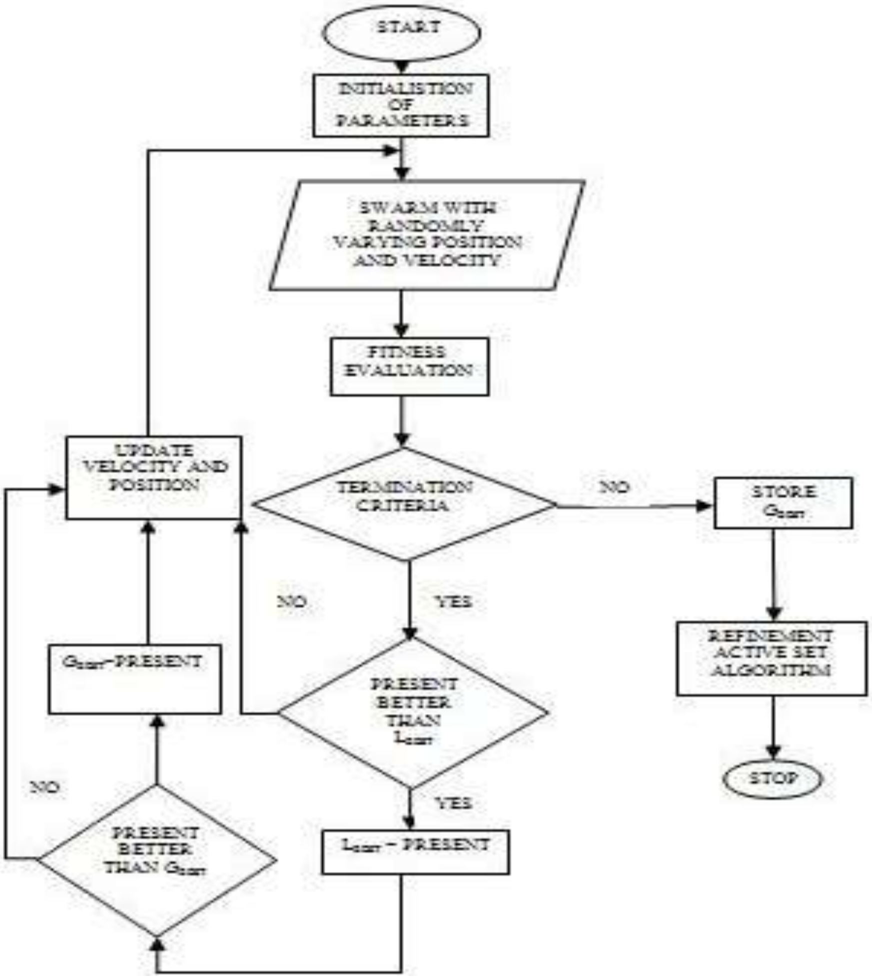

Fig. 2: Flowchart for PSO algorithm.

The sequential steps involved in the PSO based tuning of PI controller in LFC of hybrid power system are as follows

Step1. Random initialization of swarm consisting of initial position with control parameters namely K_P and K_I of thermal, hydro and gas units within their feasible limits.

Step2. Each particles frequency deviation $\Delta f(t)$ is obtained using the transfer function model developed under section II. The control parameters of each position are the input for the controller in the Fig.1.

Step3. Evaluate the fitness of each particle using (10).

Step4. If the termination criterion is satisfied then store G_{BEST} and stop the optimisation process.

Step5. If criteria is not satisfied present value of L_{BEST} is better than the previous value then L_{BEST} = present.

Step6. If the L_{BEST} present value is less than previous value then update position and velocity and proceed with Step 2.

Step7. After Step5 check G_{BEST}, if the present value better than previous value then G_{BEST} = present else update position and velocity and proceed with Step 2.

SIMULATION RESULTS AND ANALYSIS

All The hybrid power system considered for the LFC

Analysis consist of thermal, hydro and gas generating units of rated capacity of 1000 MW, 600 MW and 400 MW respectively. The MVA based of the power system is considered as 100. All the parameter of the studied single-area power system configuration are included in appendix. The range of the control parameters is chosen as 0.01 to 10. The simulation time (t_{sim}) is taken as 100s .The PSO parameters are as follows: Number of particles = 20; Max. iteration = 200: Acceleration factors = 1.1:Inertia weigh constant = 1.6. The simulation of the LFC model is done using MATLAB/SIMULINK and the code for the proposed PSO is realized using MATLAB software. The convergence characteristics of PSO algorithm for PI controller tuning of LFC is shown in Fig.3.

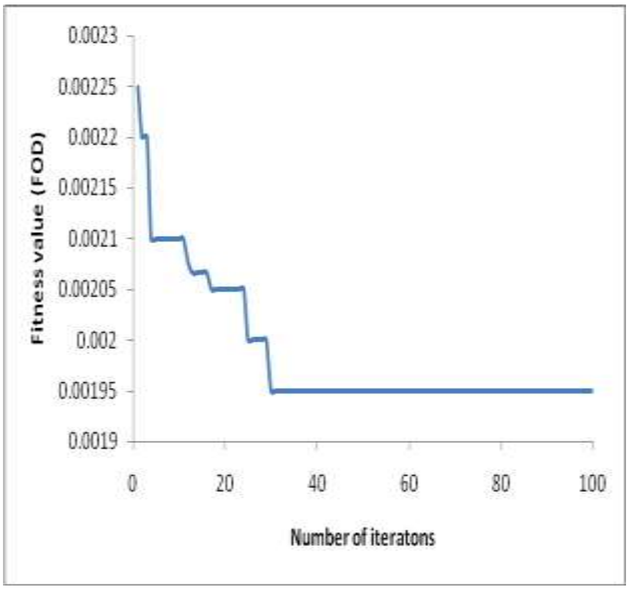

Fig. 3: Convergence characteristics of PSO algorithm for PI controller tuning of LFC.

From Fig. 3, it is inferred that the PSO algorithm converges without any abrupt oscillations thus the applicability of the proposed algorithm is ascertained. Under the action of PI controller with 0.1 p.u.MW increase in load, PSO optimized controller gains for each controller located at TGU, HGU and GTGU are presented in Table 1.

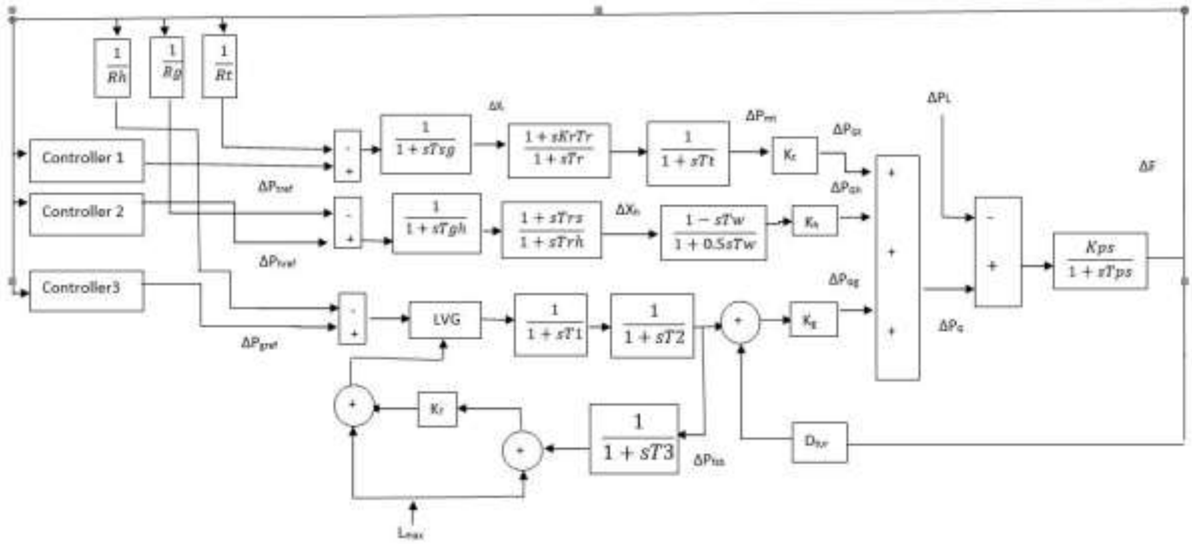

Fig. 4: Single area LFC model of Hybrid Power system.

Table I: PSO optimized controller gains of PI controller in LFC for hybrid power system

Generating unit	K_P	K_I	FOD
TGU	5.999	1.1918	0.00195
HGU	0.0010	1.4290	
GTGU	5.7516	1.9869	

The change in frequency profile for the PSO tuned (Table 1) LFC of hybrid power system is shown in Fig.4. From Fig. 4, it is inferred that due to PI controllers action the frequency deviation settles to zero under steady state. Moreover it can be observed that the maximum frequency deviation due to 0.1 p.u. MW increase in load is 0.59 Hz

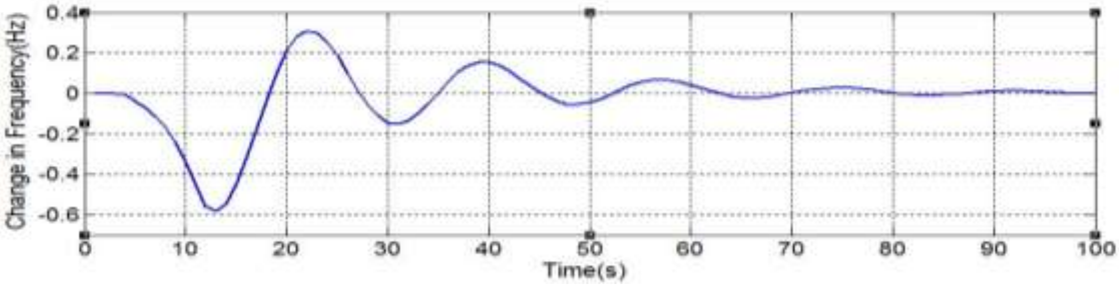

Fig. 5: Change in frequency profile for the PSO tuned LFC of hybrid power system (multi-source system).

The change in frequency profile for the PSO tuned LFC of Thermal power system (excluding hydro and gas units) is shown in Fig.5. From Fig. 5, it can be observed that the maximum frequency deviation due to 0.1 p.u. MW increase in load is 0.62 Hz.

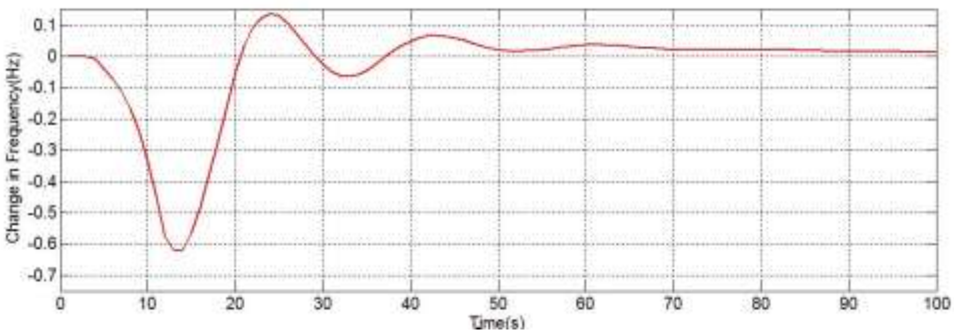

Fig 6: Change in frequency profile for the PSO tuned LFC of Thermal power system (single source system)

On comparing Fig.4 and Fig.5. it is evident that the maximum frequency deviation is minimal for hybrid power system.

CONCLUSIONS

The In this paper, LFC of single-area hybrid power system incorporating thermal ,hydro and gas generating units has been presented. The LFC is comparatively analysed for the hybrid system and isolated thermal system for an increase in load with PI controllers. The gain(s) of these PI controllers are tuned using PSO based methodology. Results obtained shows that performance of the PSO tuned PI controller is found to be suitable for stable power system operation. In addition the comparative analysis of hybrid and isolated power system reveals the superiority in the frequency control of hybrid power system.

Appendix

Parameters of single-area power system model

Rt = Rh = Rg = 2:4 Hz/p.u. MW, Tsg = 0:08 s, Tt = 0:3 s, Tr = 10 s, Kr = 0:3; Tw = 1 s, Trs = 5 s, Trh = 28:75 s, Tgh = 0:2 s, T1 = 1:5 s, T2 = 1:5 s, T3 = 3 s, Lmax = 1, KT = 1, FOVmin = _0:02, FOVmax = 1, Dtur = 0, Kps = 68:9566, Tps = 11:49 s, Kt = 0:543478, Kh = 0:326084, Kg = 0:130438.

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