Application of Soft Computing in Automatic Generation Control

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Abstract— The objective of this paper is to study the load frequency control problem associated in two-area electrical power systems. In the present work some attention is given to single area power system, but the main emphasis is on the two area interconnected electrical power system. At first uncontrolled system is studied and then improvement of its response is learnt on the application of integral controller and PSO. All the study is done using MATLAB software both in SIMULINK and Workspace windows. By comparing the simulation of PSO based controller and workspace controller results obtained. By using matlab Software, a good agreement between these results is obtained. Thus the response of PSO controller is suitable than response of other controllers available

Keywords— PSO (based) Controller, Parameter calculations, Load frequency control, Integral Controller, SIMULINK and Workspace, MATLAB

1. INTRODUCTION

In actual power system operations, the load is changing continuously and randomly. As a result the real and reactive power demands on the power system are never steady, but continuously vary with the rising or falling trend. The real and reactive power generations must change accordingly to match the load perturbations. Load frequency control is essential for successful operation of power systems, especially interconnected power systems [13]. Without it the frequency of power supply may not be able to be controlled within the required limit band. To accomplish this, it becomes necessary to automatically regulate the operations of main steam valves or hydro gates in accordance with a suitable control strategy, which in turn controls the real power output of electric generators. The problem of controlling the output of electric generators in this way is termed as Automatic Generation Control (AGC) [14]. Automatic generation control is the regulation of power output of controllable generators within a prescribed area in response to change in system frequency, tie-line loading, or a relation of these to each other, so as to maintain the schedule system frequency and/or the established interchange with other areas within predetermined limits [13].Automatic Generation Control can be sub divided into fast (primary) and slow (secondary) control modes. The loop dynamics following immediately upon the onset of the load disturbance is decided by fast primary mode of AGC. This fast primary mode of AGC is also known as “Uncontrolled mode” since the speed changer position is unchanged. The secondary control acting through speed changer and initiated by suitable controller constitutes the slow secondary or the “Controlled modes” of AGC. The overall performance of AGC in any power system depends on the proper design of both primary and secondary control loops. So the overall performance of AGC in any power system depends on the proper design of both primary control loop (selection of R) and secondary control loops (selection of gain for supplementary controller).

Among the various types of load frequency controllers, the most widely employed are integral (I), proportional plus integral (PI), integral plus derivative (ID) and proportional plus integral plus derivative (PID) controllers. Their use is not only for their simplicity, but also due their success in large industrial applications

2. Block Diagram Representation of Load Frequency Control of an Isolated Area

A block diagram representation of an isolated power system by combining the block diagrams of turbine, generator, governor and load with feedback loop as shown in Fig. 2.1

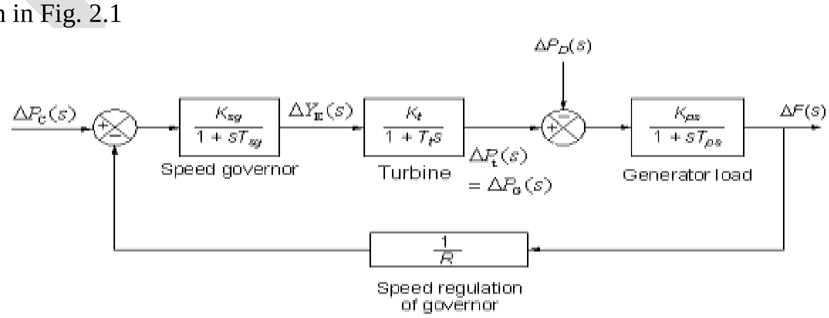


Fig. 2.1 Block Diagram Model of Load Frequency Control (isolated power system)

2.1 Steady State Analysis

The model of Fig. 2.1 shows that there are two important incremental inputs to the load frequency control system i.e. $-\Delta P_C$, the change in speed changer setting; and ΔP_D, the change in load demand. Let us consider the speed changer has a fixed setting (i.e. $\Delta P_C = 0$) and load demand changes. This is known as free governor operation. For such an operation the steady change in system frequency for a sudden change in load demand by an amount ΔP_D (i.e $\Delta P_D(s) = \Delta P_D/s$) is obtained as follows:

$$\Delta F(s)|_{\Delta P_C(s)=0} = -\frac{K_{ps}}{(1+T_{ps}s)+\dfrac{K_{sg}K_tK_{ps}/R}{(1+T_{sg}s)(1+T_ts)}} \times \frac{\Delta P_D(s)}{s} \tag{2.1}$$

$$\Delta f \text{ } \mathbf{steady} \text{ state} = s\Delta F(s) \Big|_{\substack{\Delta P_C = 0 \\ \Delta P_C(s) = 0}} = -\left(\frac{K_{ps}}{1+(K_{sg}K_tK_{ps}/R)}\right)\Delta P_D \tag{2.2}$$

Let it be assumed for simplicity that K_{sg} is so adjusted that $K_{sg}K_t \approx 1$

It also recognized that $K_{ps} = 1/B$, where $B = (\partial P_D/\partial f) / P_r$ (in pu MW/unit change in frequency). Now

$$\Delta f = -\left(\frac{1}{B+\dfrac{1}{R}}\right)\Delta P_D \tag{2.3}$$

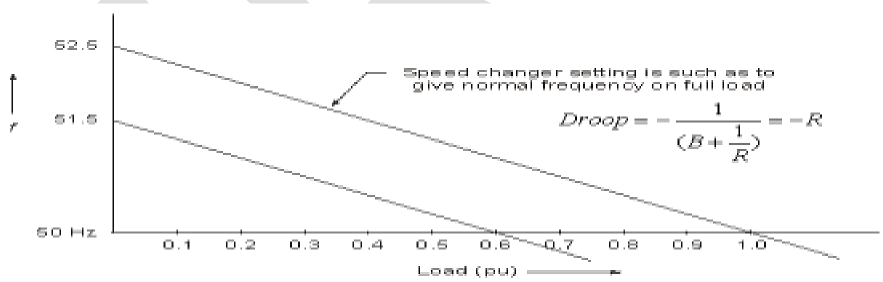


Fig. 2.2 Steady State LFC characteristics of a speed governor system

Fig. 2.2 shows the linear relationship between frequency and load for free governor operation with speed changer set to give a scheduled frequency of 100% at full load. It depicts two load frequency plots – one to give scheduled frequency at 100% rated load and the other to give the same frequency at 60% rated load.

The 'droop' or slope of this relationship is. $-\left(\dfrac{1}{B+\dfrac{1}{R}}\right)$

Consider now the steady effect of changing speed changer setting with load demand remaining fixed (i.e. $\Delta P_D = 0$). The steady state change in frequency is obtained as follows.

$$\Delta F(s)\Big|_{\Delta P_D(s)=0} = \frac{K_{sg}K_tK_{ps}}{(1+T_{sg}s)(1+T_ts)(1+T_{ps}s)+\dfrac{K_{sg}K_tK_{ps}}{R}} \times \frac{\Delta P_C}{s} \tag{2.4}$$

$$\Delta f \Big|_{\substack{steady\ state \\ \Delta P_D = 0}} = \left(\frac{K_{sg} K_t K_{ps}}{1 + \frac{K_{sg} K_t K_{ps}}{R}} \right) \Delta P_C$$

If, $K_{sg} K_t \approx 1$

$$\Delta f = \left(\frac{1}{B + \frac{1}{R}} \right) \Delta P_C \qquad (2.5)$$

If the speed changer setting is changed by ΔP_C while the load demand changes by ΔP_D the steady frequency change is obtained by superposition, i.e.

$$\Delta f = \left(\frac{1}{B + \frac{1}{R}} \right) (\Delta P_C - \Delta P_D) \qquad (2.6)$$

From Eq. (2.6) the frequency change caused by load demand can be compensated by changing the setting of the speed changer, i.e. $\Delta P_C = \Delta P_D$, for $\Delta f = 0$

2.2 Dynamic Response

To obtain the dynamic response giving the change in frequency as function of the time for a step change in load, we must obtain the Laplace inverse of Eq. (2.1). The characteristic equation can be approximated as first order by examining the relative magnitudes of the time constants involved. Typical values of the time constants of load frequency control system are related as

$T_{sg} << T_t << T_{ps}$

Consider T_{sg}=0.08 sec, T_t=0.3 sec., and T_{ps}=20 sec.

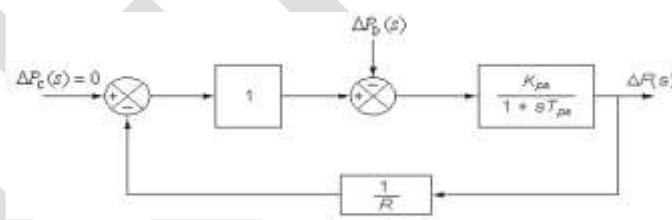


Fig. 2.3 first order approximate block diagram of load frequency control of an isolated area

Letting $T_{sg} = T_t = 0$, (and $K_{sg} K_t \approx 1$), the block diagram of Fig. 2.1 is reduced to that of Fig.2.3, from which we can write

$$\Delta F(s) \Big|_{\Delta P_C(s) = 0} = -\left(\frac{K_{ps}}{1 + \frac{K_{ps}}{R} + T_{ps} s} \right) \times \frac{\Delta P_D}{s}$$

$$= -\frac{K_{ps} / T_{ps}}{s \left[s + \frac{R + K_{ps}}{R T_{ps}} \right]} \times \Delta P_D$$

$$\Delta f(t) = -\frac{R K_{ps}}{R + K_{ps}} \left\{ 1 - \exp\left[-\frac{t}{T_{ps}} \left(\frac{R + K_{ps}}{R} \right) \right] \right\} \Delta P_D \qquad (2.7)$$

Taking R=2.4, K_{ps}=120, T_{ps}=20 sec., ΔP_d =0.01 pu,

$$\Delta f\,(t) = -0.0235(1- e^{-2.55t}) \qquad (2.8)$$

$\Delta st_{eady\ state}$ = - 0.0235 Hz

3. SIMULINK Model

3.1 Introduction

The large-scale power systems are normally composed of control areas (*i.e. multi-area*) or regions representing coherent groups of generators. The various areas are interconnected through tie-lines. The tie-lines are utilized for contractual energy exchange between areas and provide inter-area support in case of abnormal conditions. Without loss of generality we shall consider a two-area case connected by a single line as illustrated in Fig. 3.1. The concepts and theory of two-area power system is also applicable to other multi-area power systems i.e. three-area, four-area, five-area etc.

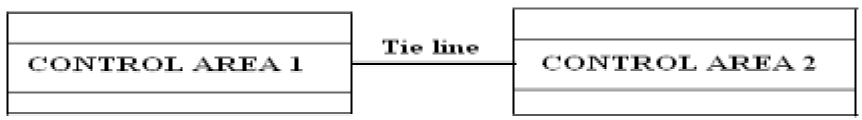


Fig. 3.1 Two interconnected control areas (single tie line)

Power transported out of area 1 is given by

$$P_{tie,\ 1} = \frac{|V_1||V_2|}{X_{12}} \sin(\delta^0{}_1 - \delta^0{}_2) \qquad (3.1)$$

Where

$\delta°_1$, $\delta°_2$ = power angles (angle between rotating magnetic flux & rotor) of equivalent machines of the two areas.

For incremental changes in δ_1 and δ_2, the incremental tie line power can be expressed as

$$\Delta\ P_{tie,\ 1}(pu) = T_{12}\ (\Delta\delta_1 - \Delta\delta_2) \qquad (3.2)$$

Where

$$T_{12} = \frac{|V_1||V_2|}{P_{r1}X_{12}} \cos(\delta^0{}_1 - \delta^0{}_2) \quad = \textit{synchronizing coefficient}$$

Since incremental power angles are integrals of incremental frequencies, we can write above Eq. (3.2) as

$$\Delta P_{tie,\ 1} = 2\pi T_{12}\left(\int \Delta f_1 dt - \int \Delta f_2 dt\right) \qquad (3.3)$$

Where, Δf_1 and Δf_2 are incremental frequency change of areas 1 and 2 respectively.

Similarly the incremental tie line power out of area 2 is given by

$$\Delta P_{tie,\ 2} = 2\pi T_{21}\left(\int \Delta f_2 dt - \int \Delta f_1 dt\right) \qquad (3.4)$$

Where

$$T_{21} = \frac{|V_2||V_1|}{P_{r2}X_{21}}\cos(\delta^0{}_2 - \delta^0{}_1) = \left(\frac{P_{r1}}{P_{r2}}\right)T_{12} = a_{12}T_{12} \qquad (3.5)$$

With ref. to Eq. (1.9), the incremental power balance equation for area1 can be written as

$$\Delta P_{G1} - \Delta P_{D1} = \frac{2H_1}{f_1^0}\frac{d}{dt}(\Delta f_1) + B_1\Delta f_1 + \Delta Ptie,{}_1 \qquad (3.6)$$

It may be noted that all quantities other than frequency are in per unit in Eq. (3.6).

Taking the Laplace transform of Eq. (3.6) and reorganizing, we get and show the block diagram in fig 3.2

$$\Delta F_1(s) = [\Delta P_{G1}(s) - \Delta P_{D1}(s) - \Delta Ptie,{}_1(s)] \times \frac{Kps_1}{1 + Tps_1 S} \qquad (3.7)$$

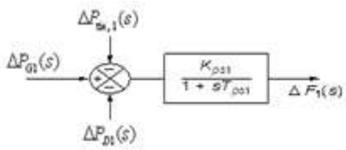


Fig. 3.2 Turbine-Load Model for Two-Area LFC

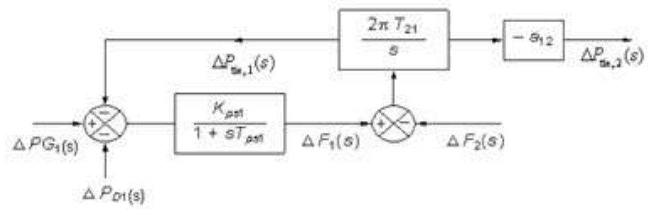


Fig. 3.3 Model Corresponding to Tie line Power Change

Taking the Laplace transform of Eq. (3.3), the signal $\Delta P_{tie,\,1}(s)$ is obtained as

$$\Delta P_{tie,\,1}(s) = \frac{2\pi T_{12}}{s}[\Delta F_1(s) - \Delta F_2(s)] \qquad (3.8)$$

The corresponding block diagram is shown in Fig. 3.3.

For the control area 2, $\Delta P_{tie,\,2}(s)$ is given as

$$\Delta P_{tie,\,2}(s) = \frac{-2\pi a_{12}T_{12}}{s}[\Delta F_1(s) - \Delta F_2(s)] \qquad (3.9)$$

This is also indicated by the block diagram of Fig. 3.3.

In the case of an isolated control area, ACE is the change in area frequency which when used in integral control loop forced the steady state frequency error to zero. In order that the steady state tie line power error in a two-area control be made zero another control loop (one for each area) must be introduced to integrate the incremental tie line power signal and feed it back to speed changer. This is accomplished by a single line-integrating block by redefining ACE as linear combination of incremental frequency and tie line power.

Thus, for control area 1

$$ACE_1 = \Delta P_{tie,\,1} + b_1\Delta f_1 \qquad (3.10)$$

Where,

constant b_1 is called *area frequency bias.*

Eq. (3.10) can be expressed in the Laplace transform as

$ACE_1(s) = \Delta P_{tie,\,1}(s) + b_1 \Delta F_1(s)$

Similarly, for the control area 2, ACE_2 is expressed as

$ACE_2(s) = \Delta P_{tie,\,2}(s) + b_2\, \Delta F_2(s)$ (3.11)

3.2 Block Diagram of Uncontrolled Two-Area LFC

Block diagram of uncontrolled two-area power system is given in Fig. 3.4.

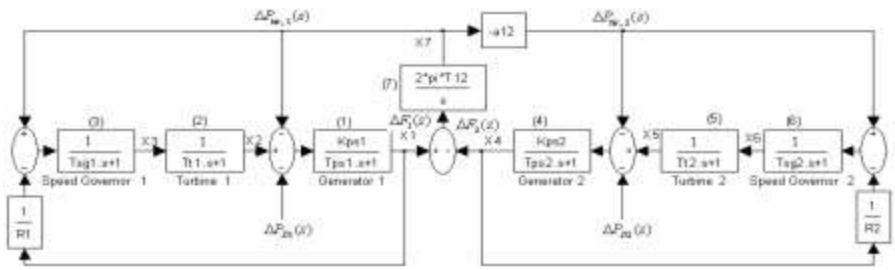


Fig. 3.4.Block diagram of two-area load frequency control without controller

3.2.1 SIMULINK Model for Uncontrolled Two-Area LFC

A SIMULINK model named **sm_A2_wc** is constructed as shown in Fig. 3.5.

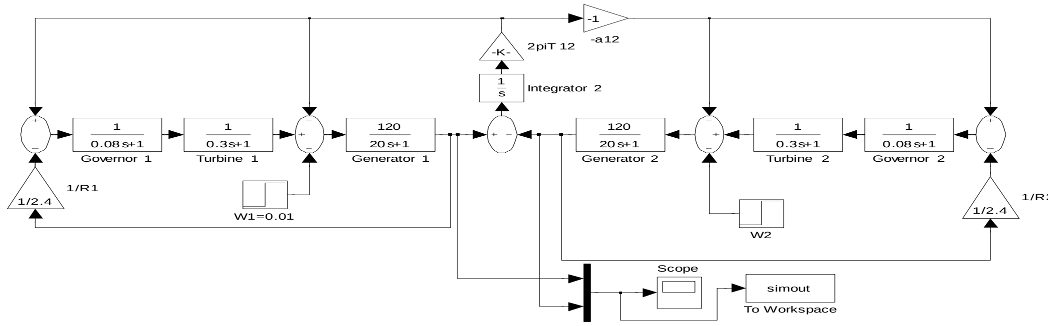
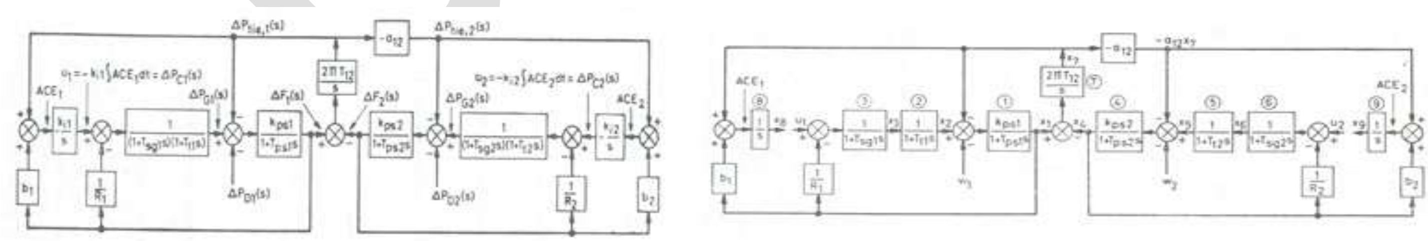


Fig. 3.5 SIMULINK model for two-area LFC without using controller

3.3 Block Diagram of Two-Area LFC with Integral Controller

Block diagram model and its corresponding diagram to derive state space model of two-area LFC with integral controller are given in Fig. 3.8 (a) and (b) respectively.



(a) (b)

Fig. 3.6 (a) Block diagram of two-area LFC with Integral controller (b) state space model of two-area LFC with integral controller

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3.3.1 SIMULINK Model for Two-Area LFC with Integral Controller

A SIMULINK model named **sm_A2_I** is constructed as shown in Fig. 3.7

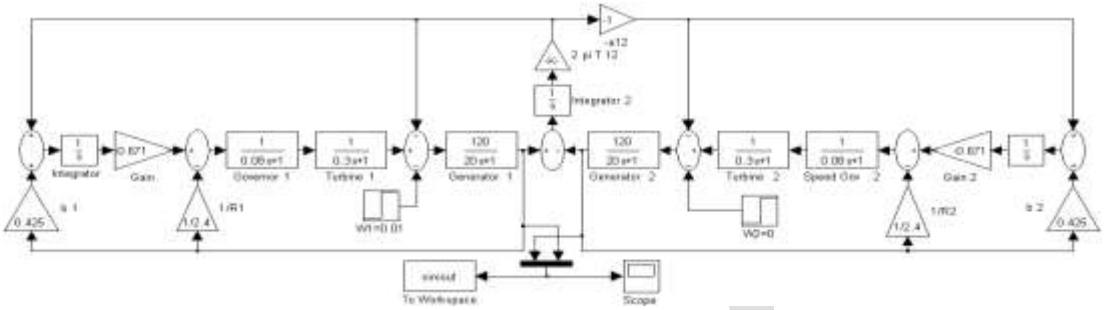

Fig. 3.7 SIMULINK model of two-area LFC with Integral controller

3.4 SIMULINK Model OF Two Area Power System with PSO

Two-Area Power System is controlled with using Particle Swarm Optimization Technique. PSO controller is applied to the Power System of Two area. PSO controller based. Two area Power System has good results than other controller. It has good dynamic response than other controllers.

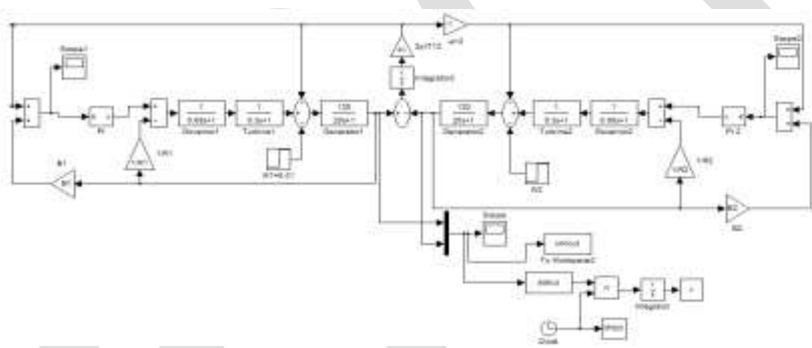

Fig.3.8. SIMULINK Model of Two area Power System with PSO

4. Results and Discussion

4. Two-Area Power System

Simulations Models were performed with no controller, with integral controller. PSO based controller is applied to two-area electrical power system by applying 0.01 p.u. MW step load disturbance to area 1. The Simulations were also performed with PSO based controller applied to two-area power system with Generation Rate Constraint as given in Fig. 3.8.

4.1 Two-Area Power System without Controller

From the Fig.3.4 and Fig. 3.5, we observe that both responses match with each other, also the steady-state frequency deviation, Δf (steady state) is -0.0178 Hz and frequency returns to its steady state value in 4.7 seconds. Results are shown in Table-1.

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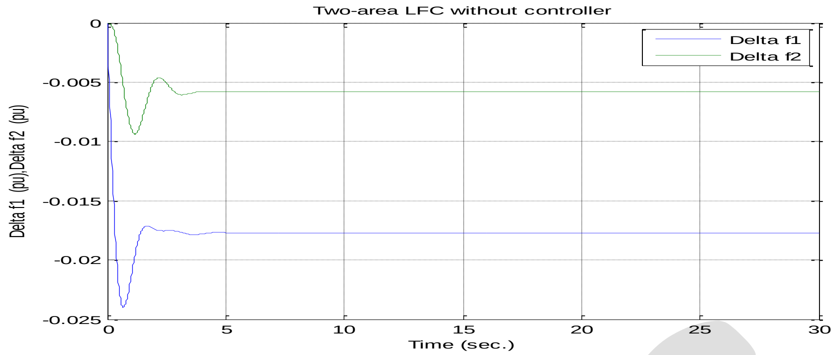

Fig.4.3.Result of Two Area LFC without Integral controller

This fig. shows Controlled Two Area power system without Integral controller, It shows the relationship between power unit and frequency(1/time) for two power system .The Power Unit is high at time zero second, oscillation will produce till time five second after that it damped out i.e. become study state, It mean frequency of load controlled

4.2 Two-Area Power System with Integral Controller

From the responses of the Figs. 3.6 and 3.7 we observe that both responses match with each other and steady state frequency deviation is zero, and the frequency returns to its nominal value in approximately 15 seconds. Results are shown in Table-1.

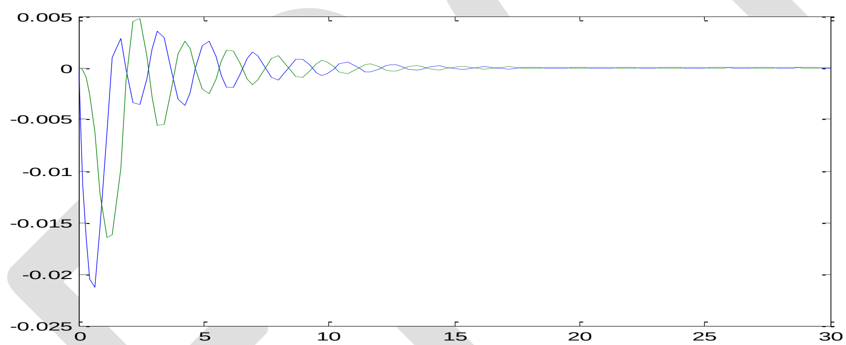

Fig.4.4.Result of Two area LFC with Integral controller

4.3 Two-Area Power System with Controller Based PSO

A MATLAB program is written in M-file for PSO based controller is run and the results so obtained are given in Fig. 4.5.

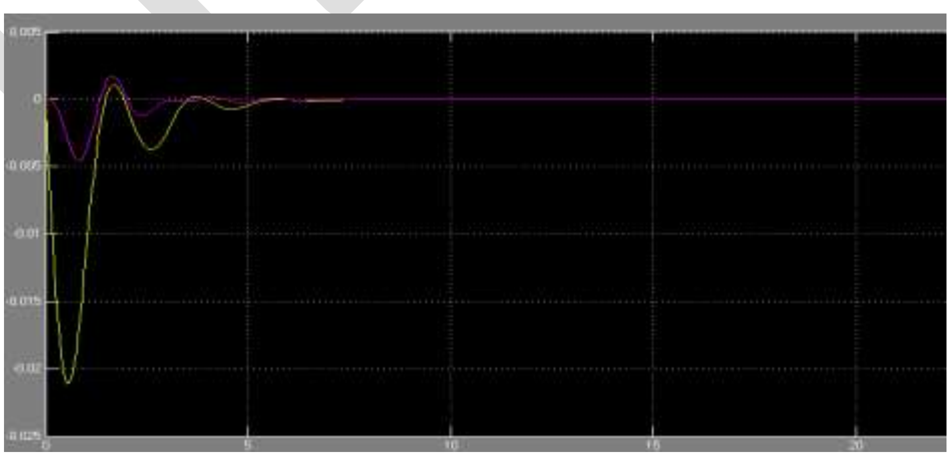

Fig. 4.5.Dynamic response of Two-Area PS with PSO based controller

The overall results without controller, with integral and with PSO based controllers applied to two-area power system are summarized in Table-1. Table-1 shows that the peak overshoot and settling time in case of optimal integral controller is better/less than the integral controller.

Table-1 Comparisons of settling time, peak overshoot & Frequency error of controller of two area Power System

For Δf_1 ↓	Without Controller		With Integral Controller		With PSO based Controller	
	Simulink	Workspace	Simulink	Workspace	Simulink	Workspace
Settling Time (s)	4.7	4.7	15.0	15.0	6.0	6.0
Peak overshoots (pu)	-0.0236	-0.0236	-0.0216	-0.0216	-0.020	-0.020
Freq. Error Δf_{ss} (pu)	-0.0178	-0.0178	0	0	0	0

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CONCLUSION

In this paper LFC problem related to two-area power systems is studied for uncontrolled case and then with the application of the integral controller, PSO based controller using MATLAB SIMULINK/Workspace software.

In two-area power system, integral controller is used in both the areas to overcome system's steady state frequency errors and thereby enhancing system's dynamic performance. The integral controller is optimized using PSO based controller and is shown that the PSO based integral controller provides better dynamic performance than integral controller in terms of lesser settling time and peak overshoots. Then a PSO based PI controller is developed to control two-area power systems. In the case of PSO based controller applied to two Area power system, three (i.e. settling times, overshoots and integral absolute errors (IAE) of frequency deviation) performance criteria are utilized for the comparison. The simulation results given in Table-1 shows that proposed PSO based controller for load frequency control of two-area power system Power System is giving reduction in settling time and peak overshoots when compared with other controllers.

Table-1 shows that the PSO based controller developed better than the integral, optimal integral and other existing controllers with respect to the settling time, peak overshoots, integral absolute error and integral of time multiplied absolute error of the frequency deviation (Δf_1). The simulation results also show that proposed controller for load frequency control of Two-area system provide a reduction in settling time and peak overshoots when compared with other controllers.

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