PSO BASED PI CONTROLLER FOR LOAD FREQUENCY CONTROL OF INTERCONNECTED POWER SYSTEMS

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CERTIFICATE

This is to certify that the project entitled "**PSO Based Pi Controller For Load Frequency Control Of Interconnected Power Systems**" submitted by Rashmita Gochhayat (212EE5260) in partial fulfilment of the requirements for the award of Master of Technology degree in Industrial Electronics, Department of Electrical Engineering at National Institute of Technology, Rourkela is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge the matter embodied in this thesis has not been submitted to any other university/Institute for the award of any Degree.

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ABSTRACT

Proportional-plus-integral controller is designed here based on Particle Swarm Optimization (PSO) for controlling the frequency deviation which is a major problem of a two area interconnected power system. In order to improvise the performance of supplying power of a power system, error function is minimised. The objective function taken into consideration over here is Integral Time multiplied with Absolute Error (ITAE). To optimize the gain values of controller, the PSO algorithm is used. The choice of this algorithm over other recent well known algorithms such as Bacteria Foraging Optimisation Algorithm (BFOA) and Genetic Algorithm (GA) is explained for the same interconnected system. Tuning of controllers are done in order to get the gain values or controller parameters such that the desired frequency and power interchange with neighbouring systems is maintained within specific value. Controllers must possess the property of being sensitive against changes in frequency and load. Tuning of controllers based on PSO algorithm is justified by making a comparison with Conventional method and LQR method.

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ABBREVATIONS

LFC	: Load Frequency Control
LQR	: Linear Quadratic Regulator
PI	: Performance Index
ITAE	: Integral of Time multiply Absolute Error
GA	: Genetic Algorithm
BFOA	: Bacteria Foraging Optimization Algorithm
PSO	: Particle Swarm Optimization
ISE	: Integral Square Error
P-I	: Proportional plus Integral
P-D	: Proportional plus Derivative
P-I-D	: Proportional Integral Derivative
ACE	: Area Control Error
Z-N	: Ziegler Nichols

NOMENCLATURE

B_1, B_2	: Frequency Bias Parameters
ACE_1, ACE_2	: Area Control Errors
u_1, u_2	: Control Outputs from the controller
R_1, R_2	: Governor Speed Regulation Parameters
T_{G1}, T_{G2}	: Governor Time Constants
ΔP_{G1}, ΔP_{G2}	: Change in governor valve positions
T_{T1}, T_{T2}	: Turbine time constants
ΔP_{T1}, ΔP_{T2}	: Change in turbine output powers
ΔP_{D1}, ΔP_{D2}	: Load Demand Changes
ΔP_{Tie}	: Incremental change in tie line power
K_{PS1}, K_{PS2}	: Power System Gains
T_{PS1}, T_{PS2}	: Power System time constants
T_{12}	: Synchronizing coefficient
ΔF_1, ΔF_2	: System frequency deviations

CHAPTER-1

THESIS OVERVIEW

1.1 INTRODUCTION

The objectives of the Load Frequency Control (LFC) are to divide the load between generators and to control the tie-line power to pre-specified values and to maintain sensibly uniform frequency. In order to supply reliable electric power with good quality, LFC in power system is very important. Constant frequency is identified as the mark of a normally operating system.

A power plant got to monitor the load conditions and serve consumers entire day. It is therefore irrelevant to consider that uniform power is generated throughout. So depending on load power generation varies. The objective of control strategy is to deliver and generate power in an interconnected system as reliably and economically as possible while maintaining the frequency and voltage within the limits. The system frequency is mainly affected due to change in load, while reactive power depends on changes in voltage magnitude and is less sensitive to frequency. To keep the frequency constant Proportional plus Integral (P-I) controller is used which controls the turbines used for tuning the generators and also the steady state error of system frequency is reduced by tuning the controller gains. There are different algorithms to optimize the controller gains for load frequency control of an interconnected power system like Genetic Algorithm (GA) but this one is difficult to implement because of its complexity in coding and low speed of convergence. Another method Bacteria Forging Optimization Algorithm (BFOA) deals with the problem of reproduction process which gives rise to a population of N individuals. Here in this work Particle Swarm Optimisation (PSO) is used because of its simplicity and is not affected size of problem and effectively solve large-scale non-linear optimization problems. Before these algorithms got attention there were methods like Conventional method, Ziegler-Nicholas and LQR method were used to tune the controller.

1.2 LITERATURE SURVEY

To maintain power with an acceptable quality is the main objective of power system operation and control. The problem of the load frequency control (LFC) is one of the most important areas in the interconnected power systems. Literature shows that C.Concordia and L.K.Kirchmayer et al [1] have done a lot of work on LFC. Appreciate work on LFC of power systems is done by Olle I. Elgerd [2].

Power system is a complex system, nonlinear and is subjected to different kinds of events. Frequency of a power system needs to be kept constant for reliable power supply despite of fluctuations in load. Recently, many different control algorithms have been proposed for LFC. Genetic Algorithm[3], [4] is robust n adaptive method used to solve search and optimisation problem but its complexity in coding makes GA difficult to be implemented as well as its convergence speed.

Bacteria Forging Optimization Algorithm which is another technique to keep the frequency within permissible limit by tuning the gains of controller [5]. Selection procedure in this process tends to eliminate animals with poor foraging schemes and favour the transmission of genes of animals having successful foraging schemes since they are more likely to give success. As it is a process which deals with reproduction process produces a population of N individuals leading to large number of parameters to be set which adds to its drawback. This leads to another algorithm that is Particle Swarm Optimisation (PSO) a population based technique first described by James Kennedy and Russell C. Eberhart (1995) [6] this applies the concept of social interaction to problem solving.

Generally PSO is opted as it is easy to implement, computationally efficient and simple in concept. Hence PSO is successfully applied to tune the parameters of controller which helps in achieving the objective of keeping the frequency constant by minimising the objective function. Here Proportional-Integral controller [7] is used for the application of Load Frequency Control (LFC) of an interconnected power system. Offset can be reduced by increasing proportional gain but that may also increase oscillations. Whereas, with integral control order increases this may cause instability. The Integral of Time multiplied by Absolute Error (ITAE) is a performance index used to design control system. The index was proposed by Graham and Lathrop (1953), who derived a set of normalized transfer function coefficients to minimize the ITAE criterion for a step input [8].

1.3 RESEARCH MOTIVATION

From the literature survey it is clearly understood that Particle Swarm Optimisation (PSO) is an improvised technique. Therefore it is used for load frequency control (LFC) of 2 area interconnected power systems for optimizing the PI controller gains. The main cause behind the fluctuation of frequency is the variation of load. A change in load affects the frequency as well as bus voltages in the systems. As we cannot control variation of load because it is not in our hand and cannot be estimated beforehand so that corrective steps can be taken. To get appreciable performance, error function is derived by using frequency deviation and tie-line power of the control areas and this error is known as the Area Control Error (ACE). To minimise this area control error and optimise the performance index using controller whose gain values are obtained using above algorithm is the main aim of this work.

1.4 THESIS OBJECTIVE

As we know 50 Hertz is normal operating frequency in India and if there is a variation of ± 2.5 hertz then it is going to seriously affect the entire system. For example turbine blades are prone to get damaged in such condition. Also there is a relation between frequency and motor speed which is also going to be affected by frequency variation.

The objective of this work is

- To design a controller based on the optimized parameters obtained from PSO algorithm for restricting the value of frequency to a constant against any variation in load demand.
- The power flow through the tie line of each area must be maintained to its pre-specified value.
- Minimise the error of the system.

1.5 THESIS LAYOUT

Chapter 1 reviews the literature on load frequency control (LFC) of power system and necessity of frequency control. Literatures are also reviewed on different algorithm to tune the controller gains, the performance index considered in this. Motivation and objective along with brief description of the work is presented.

Chapter 2 describes the load frequency control (LFC) of two area interconnected power system, need for maintenance of constant frequency. The major components of power system are described with mathematical modelling. Objective function is described. Also different controllers and the choice of PI among all others are explained.

Chapter 3 discusses recent algorithms on optimization like Genetic Algorithm and Bacterial Foraging Optimization Algorithm and their merits and demerits. Choice of PSO algorithm over other is described. Flow chart and algorithm of PSO are included in this. Process of controller tuning is explained with few methods of tuning. Values of controller gain obtained and are used to get minimised error value.

Chapter 4 comparison of LQR and PSO is done. Shows the simulation results of PSO control algorithm of two area interconnected power system. Simulations were performed using Matlab Simulink. Step load disturbance is applied in areas for PSO based controller and tie-line power flows and frequency oscillations are observed.

Chapter 5 gives conclusion of the thesis and future scope in this work.

CHAPTER-2

LOAD FREQUENCY CONTROL

2.1 INTRODUCTION

Power systems are used to produce electrical power from natural or renewable energy. Load frequency control (LFC) is really important in power systems to supply reliable and better electric power at consumer end. However, the consumers of the electric power vary the loads randomly and frequently. Change in load leads to adjustment of generation so that there is no power imbalance whereas controlling the power generation is a problem. To nullify the effects of the haphazard load changes and to keep the voltage as well as frequency within pre-specified values a control system is essential. The frequency is closely related to the real power balance whereas voltage is related to reactive power. The real power and frequency control is referred to as load frequency control (LFC) [1]. If in a system there are changes in load then those changes will affect both frequency and bus voltages. LFC as the name signifies adjusts the power flow between different areas while holding the frequency constant. LFC is actually a loop that regulates output in the range of megawatt and frequency of the generator [9]. This consists of two loops i.e. primary loop and secondary loop. The problems of frequency control of interconnected areas are more important than those of single area systems.

Reasons to hold frequency constant are:

1. Most types of ac motors run at speeds which are related to the frequency directly.
2. If normal frequency is 50 Hertz and the turbine run at speeds corresponding to ±2.5 Hertz then the blades of the turbine are likely to get damaged.

3. The electrically operated clocks are driven by the synchronous motors. The accuracy of these clocks dependent on the frequency as well as an integral of this frequency error.

Nowadays power systems are connected to neighbouring areas. But interconnection of the power systems leads to high increment in the order of the system. This connection is made possible by tie-lines.

Figure 2.1 Figure showing two areas connected by tie-line

Tie-line allows the flow of electric power between areas. Introduction of tie-line power leads to introduction of an error called tie-line power exchange error. When there is load change in an area, that area will get energy with the help of tie-lines from other areas. The power flow through different tie lines are planned or set i.e. $area_i$ may give a specific amount of power to $area_j$ while taking another specified amount from k^{th} area. Hence LFC also needs to control the tie-line power exchange error. It is said that information regarding local area can be obtained in the tie-line power fluctuations. Therefore the tie-line power is observed and the resulting tie-line power is given back into both areas for a two area system. Also interconnection of the power systems leads to large increase in the order of the system. As a result, when modelling such complex high-order power systems, the model and parameter approximations cannot be avoided [2].

Hence LFC has two main objectives:

1. To keep the frequency constant against any load change.
2. Flow of power in the tie-line must be maintained to its desirable value in each area.

The control objective now is to regulate the frequency of each area and to concurrently regulate the tie line power as per inter area power contracts. In case of frequency control or for bringing deviation in frequency back to desired level, control of turbines is done which turn the generators. For this purpose, the proportional plus integral controller is typically used in order to give zero steady state error in tie line power flow.

2.2 MODELLING OF POWER SYSTEM:

Here each area consists of controller (which is to be tuned) governor, turbine and generator-load model [10]. Each unit is described below with its transfer function. Each unit's output depends on the input it obtains from the previous block or unit.

2.2.1 TURBINE

A turbine is a rotary mechanical device that extracts energy from a steam or water and converts it into mechanical power ΔP_m which is then provided to the generator. Turbine drives the generator. There are 3 kinds turbines generally used, and are: reheat, hydraulic and non-reheat turbines. The simplest turbine among these is the non-reheat turbine and is considered over here which relates the position of the valve to the output of turbine.

The turbine power P_T maintains balance with the electromechanical air-gap power P_G leading to constant frequency. Power difference i.e. $\Delta P_T - \Delta P_G$ if positive the generator unit will accelerate otherwise it will decelerate. Increment of turbine power depends entirely upon increment of valve power and the response characteristics of the turbine.

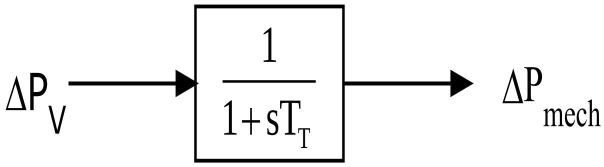


Figure 2. 2 Turbine model

Where, T_T is the time constant

ΔP_v= change in valve position

Normally the time constant T_T range is in between 0.2 to 2.5 sec.

2.2.2 GENERATOR-LOAD

A generator converts the power obtained from the turbine i.e. it converts the mechanical power into electrical power. But here transformation of energy is not taken much into consideration. Rather importance is given to the rotor speed indirectly to frequency of the power systems. As storage of electrical power in large amount is not an easy task, so balance must be maintained within power generated and load demand. Once there is a change in load the power generated by generator will not match with the mechanical power. Loads on power system consist of a variety of electrical devices. Some of them are purely resistive, and some are motor loads which are dominant part of electrical load. Resistive loads are well known as lighting purpose devices.

The generator power increment depends on the changes in the load fed from the generator. The generator power increment ΔP_G depends entirely upon the changes ΔP_D in the load P_D being fed from the generator. The generator always adjusts its output so as to meet the demand changes ΔP_D. We can therefore set

$\Delta P_G = \Delta P_D$

As generator supplies power to a large number of loads the following assumptions are made about interconnected area:

1. The frequency is at normal value f^0 and the system is running in its normal state with power balance.
2. Adding load objects increases the load demand by ΔP_D as a result ΔP_G is increased by the generator to fulfil the load demand i.e. $\Delta P_G = \Delta P_D$
3. As the kinetic energy is directly proportional to the square of speed we can write the area kinetic energy as

$$W_{kin} = W_{kin}^0 \left(\frac{f}{f^0} \right)^2 \quad (2.1)$$

4. As the frequency varies, the motor load also changes cause it is sensitive to speed, the rate of change of load w.r.t frequency, i.e. $\partial P_D / \partial f$ can be considered as constant

$$B = \frac{\partial P_D}{\partial f} \quad (2.2)$$

Writing balance equation of power, we have

$$\Delta P_T = \Delta P_D + \frac{d}{dt}\left(W_{kin} \right) + B\Delta f \quad (2.3)$$

Since, $f = f^0 + \Delta f$

Neglecting Δf kinetic energy can be written as

$$W_{kin} = W_{kin}^0 \left(\frac{f^0 + \Delta f}{f^0} \right)^2$$

$$= W_{kin}^0 \left[1 + \frac{2\Delta f}{f^0} + \left(\frac{\Delta f}{f^0} \right)^2 \right] \approx W_{kin}^0 \left(1 + 2\frac{\Delta f}{f^0} \right) \quad (2.4)$$

by substituting equation (2.4) into equation (2.3)

$$\Delta P_T - \Delta P_D = \frac{2W_{kin}^0}{f^0}\frac{d}{dt}(\Delta f) + B\Delta f \tag{2.5}$$

At specified frequency, the stored kinetic energy is

$$W_{kin}^0 = H \times P_r$$

Now by dividing equation by P_r

$$\Delta P_T - \Delta P_D = \frac{2H}{f^0}\frac{d}{dt}(\Delta f) + B\Delta f \tag{2.6}$$

The advantage of H parameter is that it is independent of system size.

Equation (2.6) can also be written as

$$\Delta P_T - \Delta P_D = 2H\frac{d}{dt}\left(\frac{\Delta f}{f^0}\right) + Bf^0\left(\frac{\Delta f}{f^0}\right) \tag{2.7}$$

Laplace transform of equation (2.6) gives

$$\Delta P_T(s) - \Delta P_D(s) = \frac{2H}{f^0}s\Delta f(s) + B\Delta f(s) \tag{2.8}$$

$$\Rightarrow \Delta f(s) = G_p(s)\left[\Delta P_T(s) - \Delta P_D(s)\right] \tag{2.9}$$

Where

$$G_p(s) = \frac{K_p}{1 + sT_p} \tag{2.10}$$

$$T_p = \frac{2H}{f^0 B} \tag{2.11}$$

$$K_p = \frac{1}{B} \tag{2.12}$$

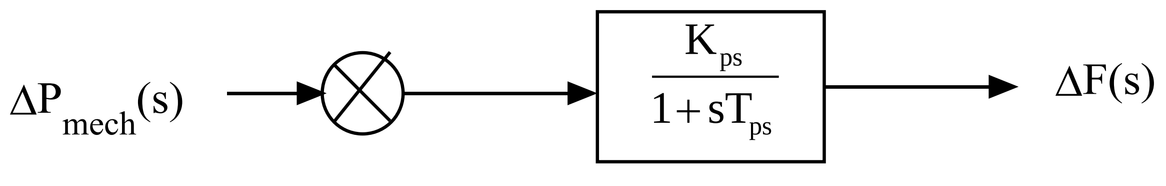


Figure 2.3 Block diagram of generator-load model

2.2.3 GOVERNER

Governor, or speed limiter, is a device used to regulate and measure the speed of a machine. Governor is useful in the power systems as it regulates the speed of the turbine, power and helps in frequency regulation. It also helps in starting the turbine and protecting it from operating conditions causing damages [11].

The load does not remain constant but vary as per the consumer demand. The mismatch between the generation and the demand causes variations in frequency leading to adjustment of generation. When frequency is not constant it results in poor power quality. The governing system provides necessary adjustment by controlling the steam flow to the turbine. The simplest governor, the isochronous governor, adjusts or maintains the input valve to a point that brings frequency back to nominal value.

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta f \tag{2.13}$$

$$\frac{\Delta P_V}{\Delta P_g} = \frac{1}{1+sT_g} \tag{2.14}$$

2.3 TWO AREA INTERCONNECTED POWER SYSTEM

The connection between power systems is made possible via tie-lines [12]. Tie-line allows the flow of electric power between areas. Area will obtain energy with the help of tie-lines from other areas, when load change occurs in that area. Hence LFC also needs to control the tie-line power exchange error. Tie-line power error are the integral of the frequency difference in between two areas.

Tie-line power can be written mathematically as

$$P_{12}^0 = \frac{\left|V_1^0\right|\left|V_2^0\right|}{X}\sin\left(\delta_1^0 - \delta_2^0\right) \tag{2.15}$$

Where

$\delta_1^0 \delta_2^0$ =power angles of equivalent machines

For small deviations in the angles the tie-line power changes to

$$\Delta P_{12} = T_{12}\left(\Delta\delta_1 - \Delta\delta_2\right) \quad (2.16)$$

Where

$$T_{12} = \frac{\left|V_1^0\right|\left|V_2^0\right|}{X}\cos\left(\delta_1^0 - \delta_2^0\right) \text{ is the synchronizing coefficient} \quad (2.17)$$

Frequency deviation Δf is related to reference angle by

$$\Delta f = \frac{1}{2\pi}\frac{d}{dt}\left(\delta^0 + \Delta\delta\right)$$

$$= \frac{1}{2\pi}\frac{d}{dt}\left(\Delta\delta\right) \quad (2.18)$$

$$\Delta\delta = 2\pi\int \Delta f dt \quad (2.19)$$

$$\Delta P_{12} = 2\pi T_{12}\left(\int \Delta f_1 dt - \int \Delta f_2 dt\right) \quad (2.20)$$

Taking Laplace transformation of above formula gives

$$\Delta P_{12}(s) = \frac{2\pi T_{12}}{s}\left(\Delta f_1(s) - \Delta f_2(s)\right) \quad (2.21)$$

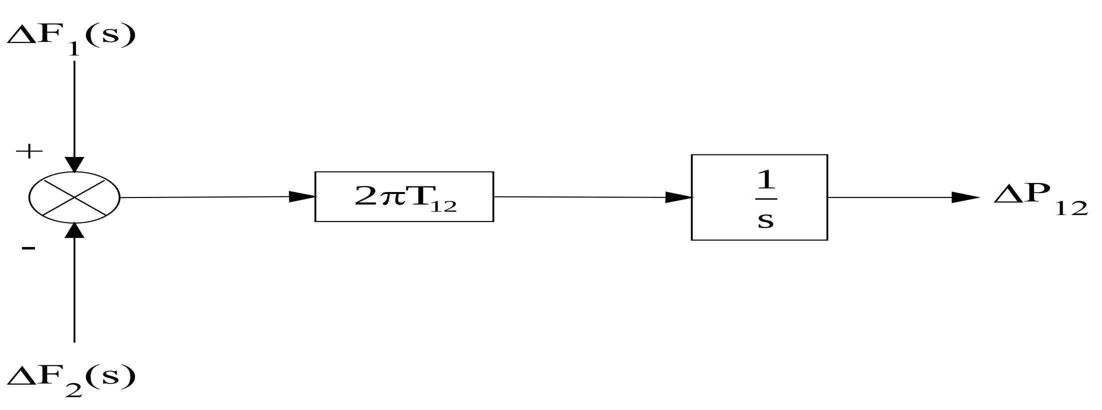


Figure 2.4 Linear representation of tie-line

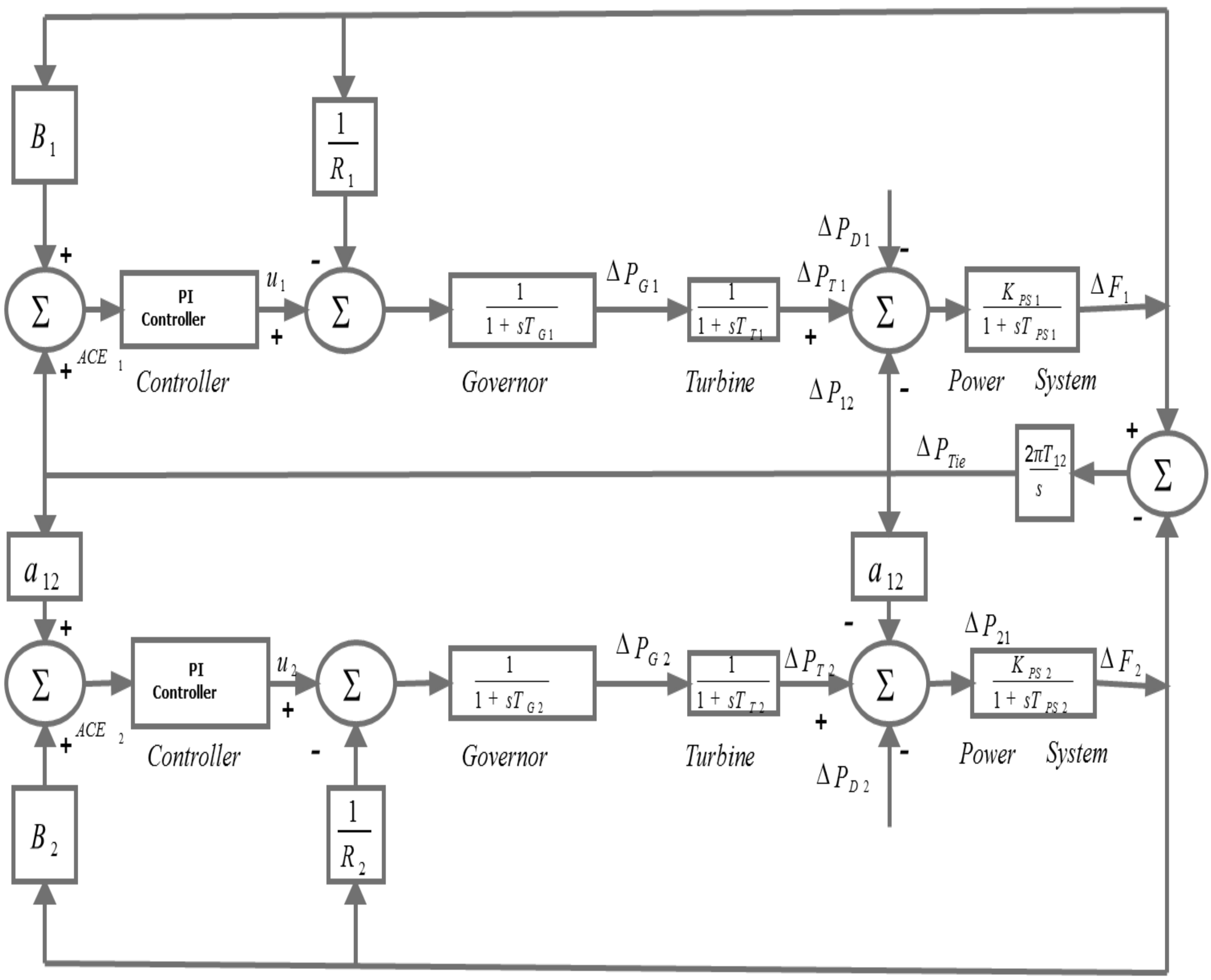
Similarly T_{21} can be written in terms of T_{12} as

$$T_{21} = a_{12} T_{12}$$

So, for control area 2

$$\Delta P_{21}(s) = \frac{-2\pi a_{12} T_{12}}{s}\left(\Delta f_1(s) - \Delta f_2(s)\right) \qquad (2.22)$$

BLOCK DIAGRAM OF TWO AREA INTERCONNECTED SYSTEM



2.3.1 AREA CONTROL ERROR

Control error of each area consists of linear combination of tie line flows and frequency. ACE represents a mismatch between area generation and load (AGC) [13]. The objective of LFC is to minimize the error in frequency of each area as well as to keep the tie-line error to scheduled value [14] which is quite difficult in presence of fluctuating load. If we control the error in frequency back to zero, any steady state errors in the frequency of the system would result in tie-line power errors because the error in tie-line power is the integrel of the frequency change between each pair of areas. Therefore it is needed to consider the information of the tie-line power deviation in control input. As a result, an error called ACE is defined as

$$ACE_i = \sum_{j=1}^{n} \Delta P_{tie,ij} + B_i \Delta f_i \qquad (2.23)$$

Where,

ACE_i is the i^{th} area control error

Δf_i = i^{th} area frequency error

$\Delta P_{tie,ij}$ =power flow error in tie line between i^{th} and j^{th} area

B_i= i^{th} area frequency bias coefficient.

The input to controller is area control error having objective of controlling the ACE and the frequency deviation.

Now which controller is to be taken into consideration depends on performance of controller and the requirement of process.

2.4 CONTROLLERS

The fundamental control loop can be simplified for a SISO (single-input-single-output) system as in Fig. 2.5 Here we are ignoring the disturbances in the system.

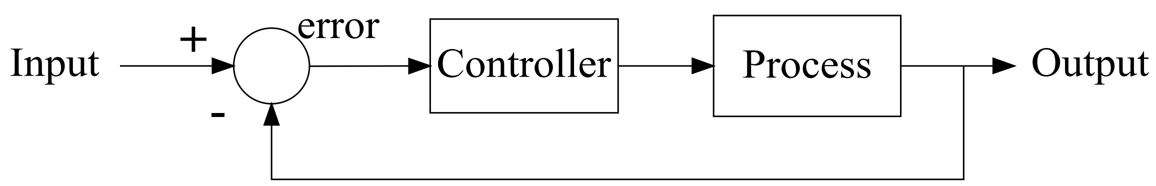


Figure 2.5 Basic control loop

The controller may have different structures. But the one of most popular controller in all is Proportional-Integral-derivative (PID) type controller. In fact more than 95% of the industrial controllers are of PID type.

The transfer function of the controller is given by:

$$C(s) = K_p\left(1 + \tau_d s + \frac{1}{\tau_i s}\right) \qquad (2.24)$$

Where K_p=Proportional gain

τ_d =Derivative time, and

τ_i =Integral time

In this the effects of the individual components- proportional, derivative and integral on the closed loop response of this system are explained.

1. In case of proportional controller the time response improves (i.e. the time constant decreases) and there is offset between the output response and desired response. By increasing the proportional gain, this offset can be reduced; but that may also cause increase oscillations for higher order systems.
2. When only integral action of controller is considered with integral controller, the order of the closed loop system increases by one. This increase in order may cause

instability of the closed loop system, if the process is of higher order dynamics. The major advantage of this integral control action is that it reduces steady state error to zero due to step input. But simultaneously, the system response is in general oscillatory, slow as well as even sometimes unstable.

3. PI gives the double advantages of fast response due to P-action and the zero steady state error because of I-action. By using P-I controller, the steady state error can be carried down to zero, and simultaneously, the transient response can be improved.
4. P-D controller apparently is not very useful, since it cannot reduce the steady state error to zero. But for higher order processes, it can be shown that the stability of the closed loop system can be improved using P-D controller.
5. Suitable combination of proportional, integral and derivative actions can provide all the desired performances: fast response, zero steady state error and less offset. In this order is low, but is universally applicable as it can be used in any type of system. PID controllers have also been found to be robust, and that is the reason, it finds wide acceptability for industrial processes.

2.4.1 SELECTION OF CONTROLLER

Guidelines for selection of controller:

1. In case of Proportional Controller easy to tune but usually introduces steady state error. It is recommended where transfer functions having a single dominating pole or a pole at origin.
2. Integral Controller is effective for high order systems with all the time constants of same magnitude. It does not exhibit steady state error, but is relatively slow responding.

3. Proportional plus Integral (P-I) Controller having much faster response than alone integral action also does not cause offset.
4. Proportional plus Derivative (P-D) Controller is effective for systems whose time constants are large. It results in a minimum offset and much rapid response in comparison to only proportional one.
5. Tuning of P-I-D Controller is difficult. It is mostly used in controlling slow variables, like pH, temperature, etc.

Here PI controller is taken into consideration. The working of PI controller is that it monitors the error between a desired set point and a process variable. P-I controller is weighted sum of two time functions

K_p: Effect of present error value on the control mechanism

K_i: reaction based on the area under error-time curve

Adjusting or controlling the process is the foremost issue that is considered in the process industry. In order to make the controllers work suitably, they need be tuned properly. Tuning of controllers can be done in several ways. In order to get the optimal solution, conventional objective function is taken.

2.5 OBJECTIVE FUNCTION

In this adjustment of parameters is done using optimization and objective function which is a function of error and time and the function used is integral of time-multiplied absolute error criterion (ITAE) [8].

Another objective function which is also a function of error and time is there known as integral of the square of the error criterion (ISE) but this performance index is not taken into consideration because this one is computationally not comfortable and is less sensitive in comparison to ITAE. Whereas ITAE has the benefits of producing less oscillations and smaller overshoots, maintain robustness and in addition to that it is most sensitive i.e. best selectivity this makes the ITAE index the desirable criterion used for design of control system. Focus is on minimizing the ITAE criterion.

ITAE is composed of tie line power and frequency deviation of both areas. The objective function is

$$j = \int_0^\infty t\left(\left|\Delta f_1\right| + \left|\Delta f_2\right| + \left|\Delta p_{tie}\right|\right)dt \quad (2.25)$$

Where, Δf_1 and Δf_2 are frequency deviations;

ΔP_{tie} is the change in tie line power

Since integrating up to infinity is not practicable a large value of T should be chosen such that error is negligible. Here T=10 seconds is taken.

CHAPTER-3

TUNING OF CONTROLLERS BASED ON PSO

3.1 TUNING OF CONTROLLER

The selection procedure of controller parameters such that it fulfills desired performance demands is known as tuning of controller. The need to tune controller is for fast response and to have good stability. Ziegler-Nichols (Z-N) first proposed tuning rules of controller.What leads to development of other tuning methods after Z-N method is that it involves trial and error procedure which is not desirable, not applicable to open loop unstable processes. After that a lot of new techniques were developed analytical tuning; amigo tuning; optimization methods etc. Nowadays optimization based methods are getting fame.

3.1.1 CONVENTIONAL METHOD OF TUNING

Conventional method of controller tuning is a trial and error based method. This makes it difficult to be implemented in all kind of problems. Because this requires continuous tuning of parameters values and observing the response which consumes a lot of time and requires effort, which is tedious method. Here no certainty is there that the result obtained after so much variation will be the optimum one. That means all the time given to particular problem and effort will all go in vain. These all demerits encourage us to go for other developed techniques to get optimum values.

3.1.2 LINEAR QUADRATIC REGULATOR

LQR is an optimal controller. Optimal means providing least possible error to its input, i.e. one or more of the outputs of the plant combined with minimizing the control output. This control mechanism is based on model of plant taken under consideration or control. Controller is said to be optimal, if the model replicates plant exactly. The LQR is a state feedback controller where the states of a system may have some physical meaning, or may not have at all. Accordingly there may be trouble in finding out the states to use for feedback. For this another function, called an observer is required, which estimates the values of the state. But the complexity of the system increases due to involvement of observer. This is based on state space model [12].

Where, the state space equation is

$$\dot{x} = Ax + Bu \quad (3.1)$$

And x= state vector

u=control vector

Control vector 'u' is obtained by linearly combining all the states i.e. here in this there are 9 state vectors.

$$u = -Kx \quad (3.2)$$

Where K is the feedback matrix which is to be determined such that the performance index is minimised to fulfil our objective. K is obtained from solution of a set of linear algebraic equation given by Riccati equation given below

$$A^T S + SA - SBR^{-1}B^T S + Q = 0 \quad (3.3)$$

$$K = R^{-1}B^T S \quad (3.4)$$

The value of K for which the system remains stable is acceptable one.

$$R = kI \quad (3.5)$$

k is the weighing factor.

Where,

A, B, R, Q and S are matrices whose dimensions depend on the number of states, R and Q are symmetric matrices.

$$A = \begin{bmatrix} \frac{-1}{T_{ps1}} & \frac{K_{ps1}}{T_{ps1}} & 0 & 0 & 0 & 0 & \frac{-K_{ps1}}{T_{ps1}} & 0 & 0 \\ 0 & \frac{-1}{T_{T1}} & \frac{1}{T_{T1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{-1}{R_1 T_{G1}} & 0 & \frac{-1}{T_{G1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{T_{ps2}} & \frac{K_{ps2}}{T_{ps2}} & 0 & \frac{a_{12}K_{ps2}}{T_{ps2}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{-1}{T_{T2}} & \frac{1}{T_{T2}} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{R_2 T_{G2}} & 0 & \frac{-1}{T_{G2}} & 0 & 0 & 0 \\ 2\pi T_{12} & 0 & 0 & -2\pi T_{12} & 0 & 0 & 0 & 0 & 0 \\ b_1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & b_2 & 0 & 0 & -a_{12} & 0 & 0 \end{bmatrix}$$

$$B^T = \begin{bmatrix} 0 & 0 & \frac{1}{T_{G1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{G2}} & 0 & 0 & 0 \end{bmatrix}$$

Disadvantages of LQR method is that for minimizing function a weighing factor needed to be supplied by the user. This is a tedious work for the user in optimizing controller because user needs to specify weight factor and compare results. Another demerit is that it is difficult to find the right weighing factor.

3.2 OPTIMIZATION ALGORITHMS

Keeping in view the effort required and time consumed to get optimum values of the controller by the above methods motivates us to go for an advanced method which includes optimization algorithm based on natural processes. There are many optimization algorithm proposed or developed till date like genetic algorithms, heuristic method, evolutionary programming etc. Study and comparison is done mainly with recently published technique i.e. Genetic Algorithm (GA), Bacteria Forging Optimization Algorithm (BFOA) and Particle Swarm Optimization (PSO) algorithm.

3.2.1 GENETIC ALGORITHM

Genetic Algorithms (GAs) were introduced by John Holland and his students. This algorithm is basically adaptive method used in searching and solving optimization problems. This is based on genetic processes of biological organism. In a population individuals compete with each other for food, shelter also to attract mate. Individuals who are most successful in surviving as well as in attracting mates are going to have large number of offspring. Which means genes of fit individuals will be there in each successive generation. In this every individual is allotted with a fitness score depending on how suitable solution it provides to a particular problem. This can be used in task like pattern recognition, machine learning and image processing. This is a robust technique and can handle extensive range of problem areas which are tough for other techniques successfully. This is efficient in finding acceptable good solution to a problem and that to in less time. The performance of this algorithm is affected by parameters such as size of population, no. of generations, mutation and rate of crossover. Large population size and generation raise the possibility of finding a global optimum solution, but significantly increase processing time.

Advantages:

- Using this many kind of problems can be solved like non-continuous, multi-dimensional and non-differential.

- This algorithm can be simply moved to prevailing simulations and models.
- Every problem described with chromosome encoding can be solved using this algorithm.

Disadvantages:

- No such guarantee is provided that it will provide a global optimum.
- Demands complete knowledge of fitness function. If the fitness function is not well known then the problem cannot be solved.
- Difficult to implementation coz of coding complexity and convergence speed is low.
- Premature convergence and slow finishing are few of its disadvantages.

3.2.2 BACTERIA FORAGING OPTIMIZATION ALGORITHM

Bacteria Foraging Optimization Algorithm (BFOA), is suggested by Passino. Generally in order to maximize their energy bacteria search for nutrients. The four main processes of BFOA are: Chemotaxis, swarming, reproduction, and elimination-dispersal.

The method, of movement of a bacterium in search of nutrients, is known as chemotaxis and the main idea of BFOA is imitating chemotactic movement of bacteria in the search space. Flagella helps bacteria in movement i.e. tumble or swim performed at the time of foraging. Clockwise rotation of flagella pulls the cell resulting in independent movement of flagella and then the bacterium tumbles it increases its tumbling rate in an unsafe place to find a nutrient gradient. In case of counter-clockwise movement of flagella the bacterium swims fast. When they find sufficient food, they increase in length and get split into two in presence of appropriate temperature. Changes may occur in the environment which may ruin the process leading to movement of bacteria to some different place or introduction of new ones. This establishes the occurrence last process and that is elimination-dispersal.

As BFOA has dispersal and elimination method which helps in finding suitable sections when involved population is of small size, this overcomes the problem of premature convergence in genetic algorithms. The main disadvantage of this BFO algorithm is that it involves reproduction scheme which results in generation of a population of N number of individuals as a results large number of parameters needed to set.

3.2.3 PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO), originated by James Kennedy and R.C. Eberhart in 1995. It is a stochastic (connection of random variable) evolutionary computation method used to explore search space. This technique is based on swarm's intelligence and movement. As this is based on swarm behavior, is a population based technique. The bird generally follows the shortest path for food searching. Based on this behavior, this algorithm is developed. It uses a number of particles where every particle is considered as a point in N-dimensional space. Each particle keeps on accelerating in the search space depending on the knowledge it has about the appreciable solution comparing its own best value and the best value of swarm obtained so far. It is well described by the concept of social interaction because each particle search in a particular direction and by interaction the bird with best location so far and then tries to reach that location by adjusting their velocity this require intelligence.

Advantages of PSO over above two algorithms:

Few parameters need adjustment so easy to perform unlike BFO algorithm. Only algorithm that does not implement the survival of the fittest hence entire population is member throughout the process. PSO unlike GA is not affected by size of the problem. The shortcoming of GA i.e. premature convergence is overcome by PSO. This is quite easy and simple to implement as it consist of two equations only. Even for large problems less than hundred iterations are required.

Given below are the two main equations of PSO algorithm:

Velocity modification equation:

$$v_i^{k+1} = wv_i^k + c_1 rand_1 \times \left(pbest_i - s_i^k\right) + c_2 rand_2 \times \left(gbest_i - s_i^k\right) \quad (3.6)$$

Where, v_i^k = velocity of agent i at iteration k

w =weighing function

c_i =weighing factor

$rand_i$ =random number between 0-1

$pbest_i$ =p-best of agent i

s_i^k =current position of agent i at iteration k

$gbest_i$ =g-best of the group

In equation 3.1, the first term wv_i^k is inertia component responsible for movement of particle in the direction it was previously heading. 'w' has a vital impact on speed if its value is less then it speed up the convergence otherwise encourage exploration.

Second term: $c_1 rand_1 \times \left(pbest_i - s_i^k\right)$ is the cognitive component acts as particle's memory.

Third term: $c_2 rand_2 \times \left(gbest_i - s_i^k\right)$ the social component which is the reason why the particle move to best region found so far by the swarm.

Once the calculation for velocity of each particle is done then position can be updated using equation of position modification.

Position modification equation:

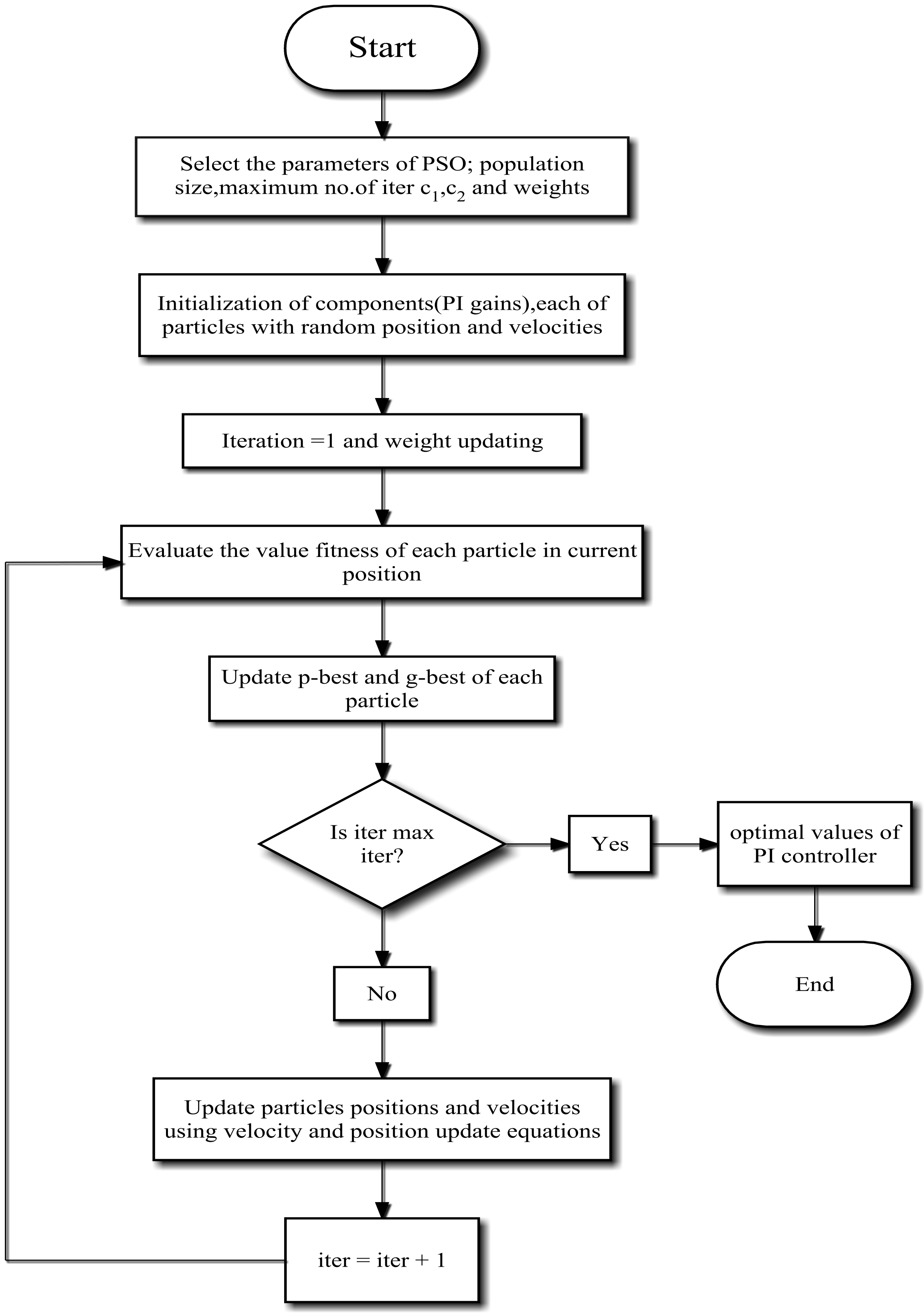
$$s_i^{k+1} = s_i^k + v_i^{k+1} \quad (3.7)$$

Where, s_i^{k+1}, s_i^k are modified and current search points respectively

v_i^{k+1} = modified velocity

This process is repeated unless and until some stopping criteria is fulfilled.

FLOW CHART OF PSO ALGORITHM:



3.3 PSO BASED CONTROLLER DESIGN

Step1: The initial particles are set to some linear position in the range of K_p and K_i.

Step2: Their velocities are set to zero.

Step3: Initial ITAE is set to some values.

Step4: Evaluate the ITAE for the particles at their corresponding positions.

Step5: Initialize p_{best} for each particle.

Step6: Find g_{best} based on minimum ITAE.

Step7: Start iteration 1.

Step8: Update the positions.

Step9: Then calculate ITAE at their corresponding position.

Step10: Accordingly update p_{best} and g_{best} based on ITAE.

Step11: Update velocity.

Step12: Iteration=iteration+1.

Step13: If iteration<=maximum iteration, go to step 8 otherwise continue.

Step14: The obtained g_{best} is the optimum set of parameters of PI controller.

CHAPTER-4

RESULTS AND DISCUSSION

At first PSO algorithm is written taking a general mathematical equation as the objective function to check whether it gives minimum value for the considered equation or not. The equation considered is given below:

$$x^2 + y^2$$

Then the result obtained is as shown in fig.4.1.

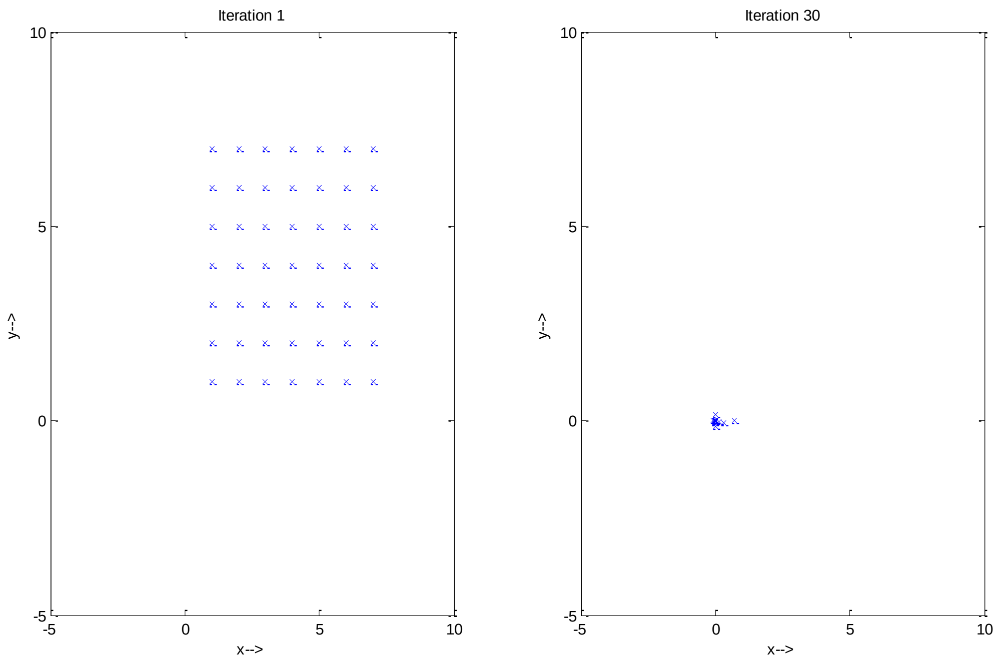


Figure 4. 1Implementation of PSO taking objective function as x^2+y^2

And as it is observed it gives zero as the minimum value for the equation under consideration. This shows that the basic algorithm gave desirable result.

Then simulation work is done for two area interconnected power system according to its block diagram and considering transfer function of each block simulation is done. The parameter values taken in the simulation are tabulated in the table.4.1.

Table4. 1: Nominal parameters of Two-Area System

Parameter	**Value**
B_1, B_2	0.425 p.u. MW/Hz
R_1,R_2	2.4 Hz/p.u.
T_{G1},T_{G2}	0.08 s.
T_{T1}, T_{T2}	0.2 s.
T_{PS1},T_{PS2}	20 s.
T_{12}	0.0707 p.u.
K_{PS1},K_{PS2}	120 Hz/p.u.
a_{12}	-1

At first conventional method is applied to get the k_p and k_i value and correponding error value. Similarly LQR is also applied and an optimal K value is obtained and error corresponding to that. Then PSO algorithm is applied to get the value of parameters of controller where ITAE value is minimum. For this the values in the table 4.2 are used in tuning. The table 4.3 gives the values of parameters and error for each method applied.

Table4. 2Parameter values tuned for PSO Algorithm

Parameters	**Values**
Population Size	11
Numbers of iterations	50
Inertia Weight (w)	0.8
Cognitive Coefficient (C_1)	2
Social Coefficient (C_2)	2

Table4. 3Error values for corresponding methods

Method	Kp	Ki	Error
Conventional	0.60	-0.75	7.6
LQR	Optimal K is given below		2.8
PSO	0.0563	-0.7302	0.7

Where, the optimal K is given in the matrix below:

$$K = \begin{bmatrix} 0.5604 & 0.5724 & 0.2057 & 0.2271 & -0.1919 & -0.0644 & 1.0027 & 0.9986 & -0.3376 \\ -0.2450 & -0.1972 & -0.0644 & 0.6029 & 0.5917 & 0.2121 & -1.9131 & 0.3376 & 0.9986 \end{bmatrix}$$

In the below figure error of the three methods are compared and shown in the plot.

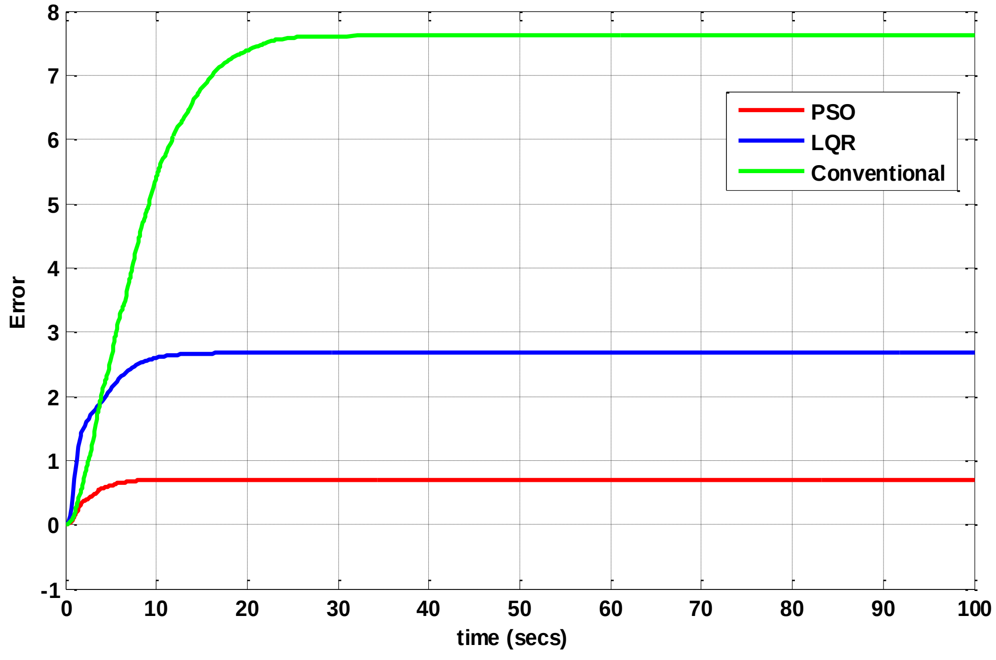


Figure 4. 2Error obtained by three used method

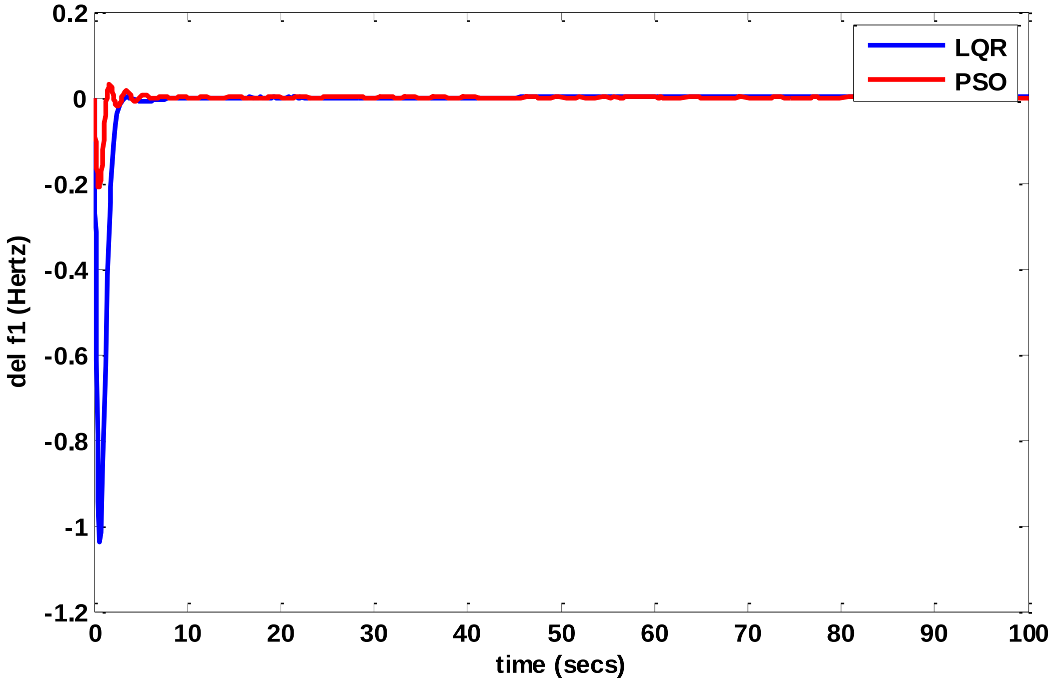


Figure 4. 3Frequency deviation of area-1 by LQR and PSO method

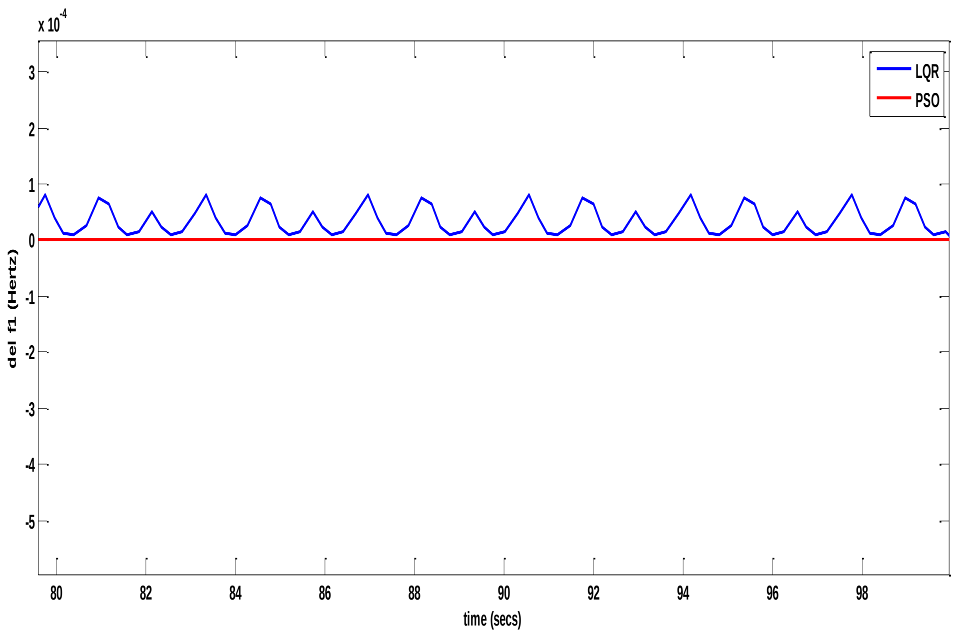


Figure 4. 4Plot showing ripples present in the frequency by LQR method

To indicate the robustness of the mentioned controller simulations are done on time domain for step load change at various areas and with parameter variations. The responses with PI controller optimized employing PSO using objective function ITAE.

The following cases are considered:

Case1: A step load change in area-1 only

A step load 10% rise in area-1 (ΔP_{D1}) is given & the deviation in frequency of area1 Δf_1, the deviation in frequency of area-2 Δf_2 and the tie line power signal of the system are shown in Figs. (4.5-4.7).

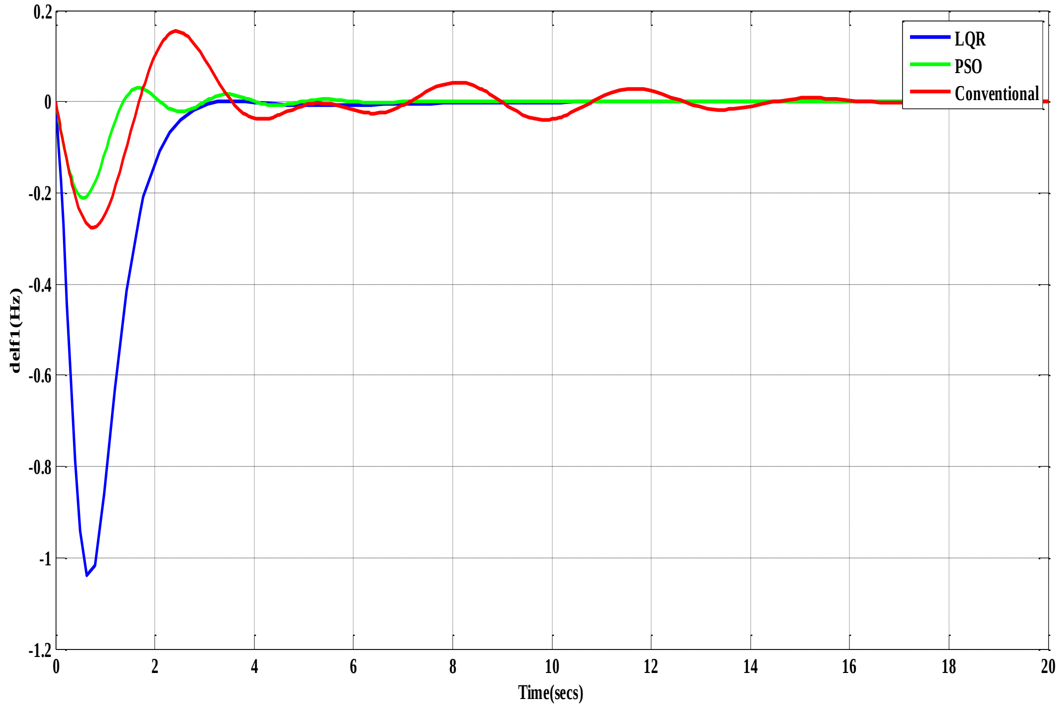


Figure 4. 5Change in frequency of area-1 for 0.1 p.u change in area-1

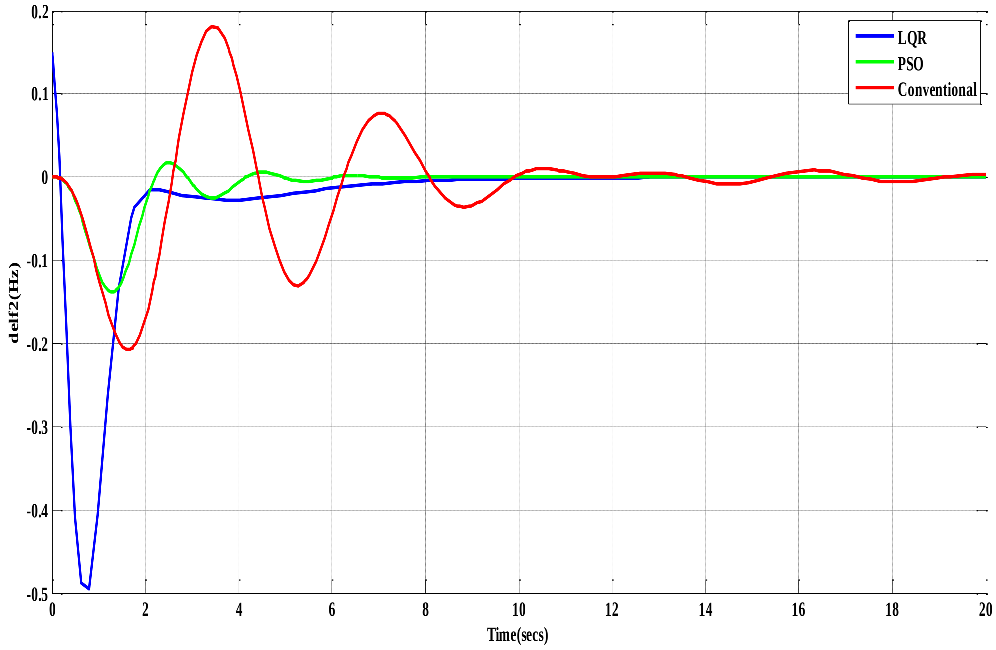


Figure 4. 6Change in frequency of area-2 for 0.1 p.u change in area-1

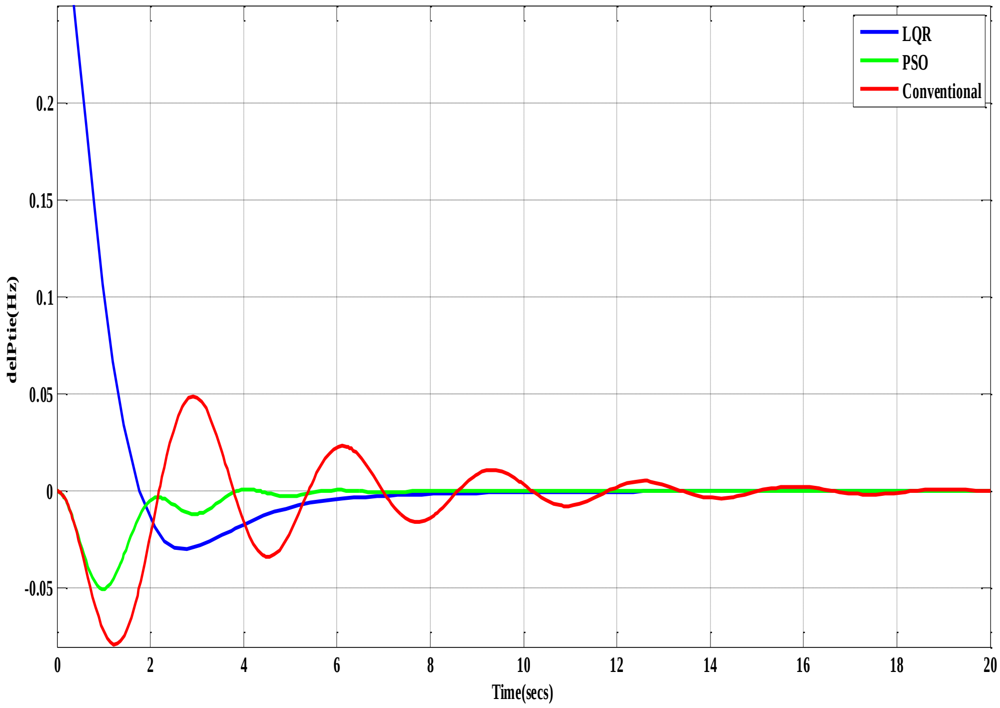


Figure 4. 7Change in tie line power for 0.1 p.u change in area-1

Case2: Step load change in area-1 and area-2 simultaneously

In this case, 10% step load rise in demand of first area and 15% step load rise in demand of second area respectively are applied. The response of the system is shown in Figs. (4.8-4.10)

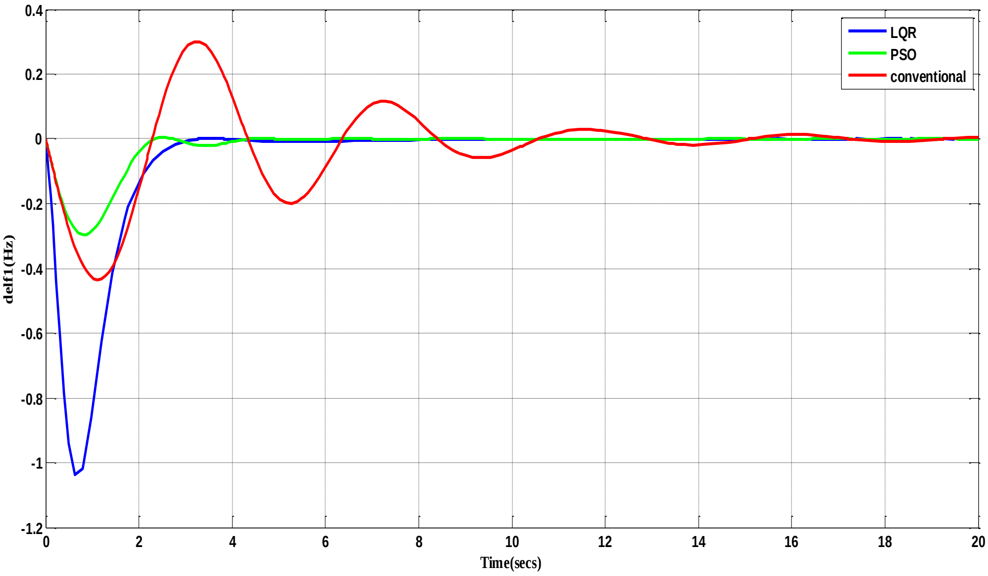


Figure 4. 8Change in frequency of first area for 0.1 p.u change in area-1 & 0.15 p.u for area-2

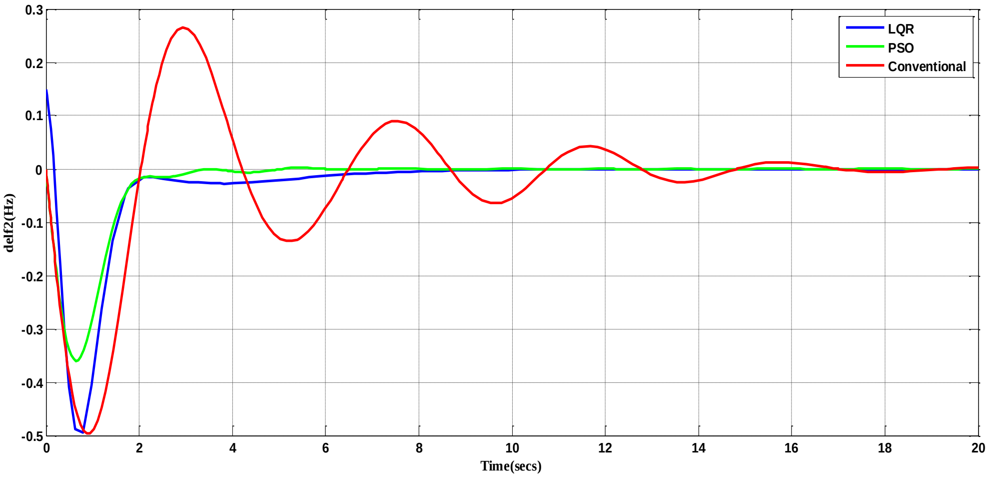


Figure 4. 9Change in frequency of second area for 0.1 p.u change in area-1 & 0.15 p.u for area2

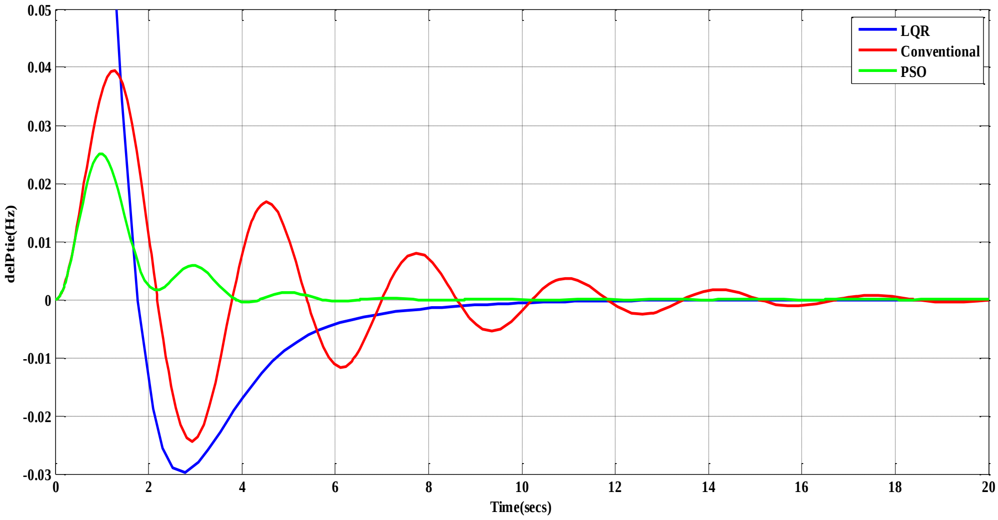


Figure 4. 10Change in Ptie for 0.1 p.u change in area-1 & 0.15 p.u change for area-2

Case3: Robustness of system parameter

To find the robustness of the system T_G , T_T & T_{12} are changed by ±30% with frequency deviation of 0.1 p.u in area-1 and 0.15 p.u in area-2 is shown in Figs. (4.11-4.13). These below plots shows the performance of the controller irrespective of the variation of the time constants of the systems included in this.

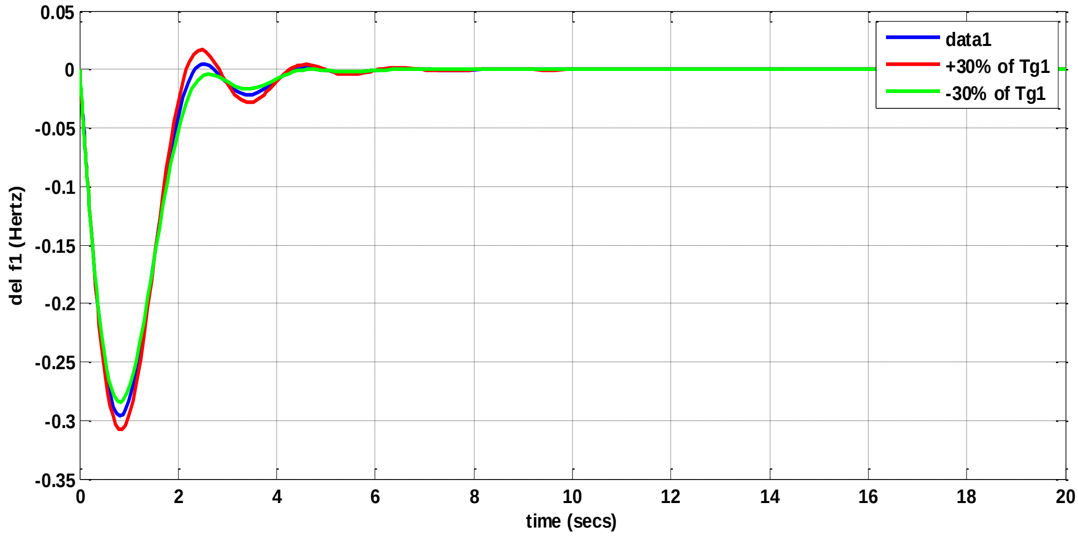


Figure 4. 11Change in frequency for change in T_G of PI controller

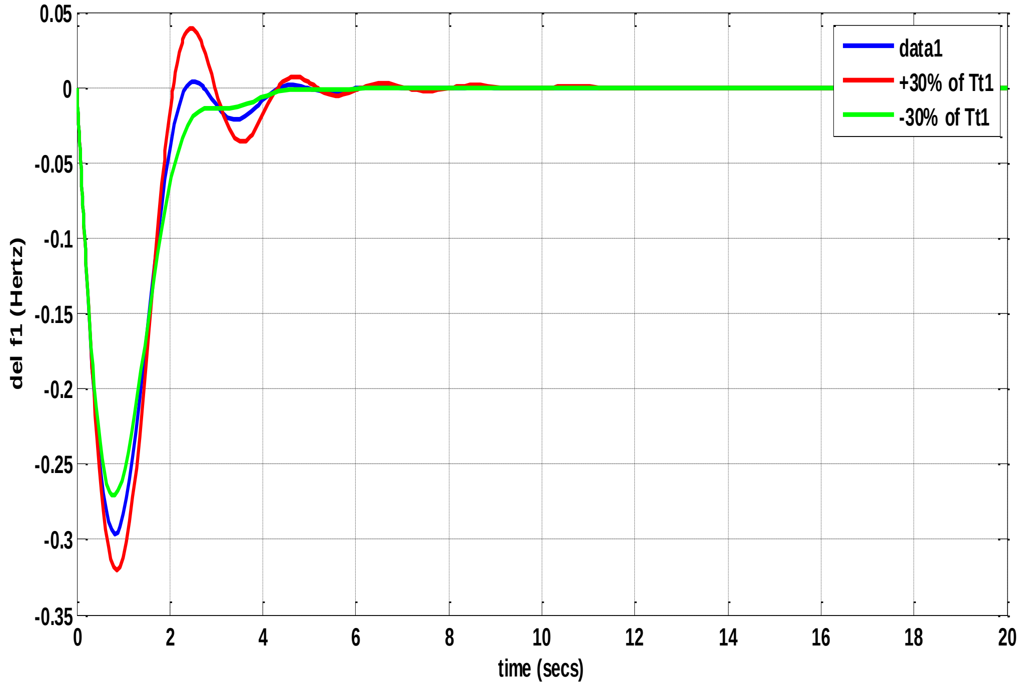


Figure 4. 12Change in frequency for change in T_T of PI controller

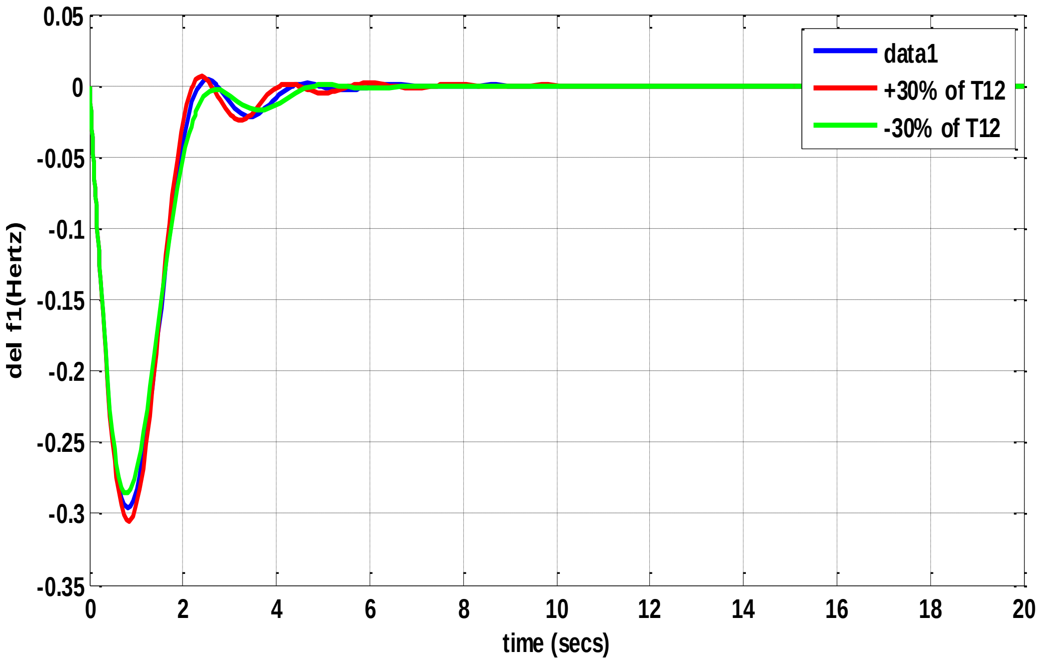


Figure 4. 13Change in frequency for change in T_{12} of PI controller

CHAPTER-5

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

Controlling of power systems in order to meet the demands of consumers is a challenging task that motivates to design optimum controllers. They should have the capability of monitoring the power system like maintenance of frequency and voltage in no time. Many optimization techniques are used in the design of controllers. In this thesis, PSO is used to tune parameters of proportional-plus-integral controller . A two-area system is taken into consideration to show the method. The integral of time multiplied absolute error was used as objective function. Different plots of frequency deviation were obtained by varying the load demand of areas. Effects of parameter variation on system response were also plotted and observed. Its superiority over other methods used to tune the controller is justified by comparing the error values.

5.2 FUTURE SCOPE

In this work only PSO algorithm is used to obtain the gain values of controllers for two-area interconnected systems. So it can be implemented for multi area power system. Other algorithms can also be considered to get the controller values and comparison can be made among the algorithms.

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