AUTOMATIC LOAD FREQUENCY CONTROL OF MULTI AREA POWER SYSTEMS

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I ROHIT BHADALA, Roll No – 2k16/PSY/13 student of M.Tech (Power Systems), hereby declare that the project Dissertation titled "AUTOMATIC LOAD FREQUENCY CONTROL OF MULTIAREA POWER SYSTEMS" which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled "AUTOMATIC LOAD FREQUENCY CONTROL ON MULTIAREA POWER SYSTEMS" which is submitted by ROHIT BHADALA, whose Roll No. is 2k16/PSY/13, Electrical Engineering Department, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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Date:	**(SUPERVISOR)**

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ABSTRACT

Variations in load bring about drifts in frequency and voltage which in turn leads to generation loss owing to the line tripping and also blackouts. These drifts might be reduced to the smallest possible value by automatic generation control (AGC) which constitutes of two sections viz load frequency control (LFC) along with automatic voltage regulation (AVR). Here simulation evaluation is done to know the working of LFC by building models in SIMULINK which helps us to comprehend the principle behind LFC including the challenges. The three area system is also being taken into consideration together with single area in addition to two area systems. Several important parameters of ALFC like integral controller gains (KIi), parameters for governor speed regulation (Ri) as well as parameters for frequency bias (Bi) are being optimized by using an optimization technique that is Bacteria Foraging Optimization Algorithm (BFOA) because using the general hit and trial method in the simulation has some demerits which has insisted on using BFOA for obtaining the desired values of the different parameters. Simultaneous optimization of certain parameters like KIi, Ri and Bi has been done which grants not only the best dynamic response for the system but also permits us to use quiet larger values of Ri than put into practice. This will help the industries concerning power for simpler as well as cheaper realization of the governor. The performance of BFOA is also investigated through the convergence characteristics which reveal that that the Bacteria Foraging Algorithm is relatively faster in optimization such that there is drop in the computational load and also minimum use of computer resource utilization

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LIST OF SYMBOLS

ΔP_{ref}= incremental speed reference setting

$\Delta\omega\beta\nu$= drift in frequency for step change in load

ΔP_m= turbine output

P_{12}= power due to tie line

ΔP_{12}= power change in tie line

$\Delta\omega_1$= deviation of frequency in area 1

$\Delta\omega_2$= deviation of frequency in area 2

ΔP_{m1}= “turbine output of area 1”

ΔP_{m2}= turbine output of area 2

ΔP_{01}= Increase of load in area 1

ΔP_{02}= Increase of load in area 2

ΔP_G= Active power generation

ΔP_D= Active power demand

β_1 And β_2 = composite frequency response characteristic of area 1 along with area 2

$\Delta P_v(s)$ = the input to the turbine

$\Delta P_T(s)$ = the output from the turbine

$\Delta P_v(s)$ = the output from the generator

$\Delta P_g(s)$ = the input to the generator

P_g = time constant of generator

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CHAPTER 1

1. INTRODUCTION

Power systems are very large and complex electrical networks consisting of generation networks, transmission networks and distribution networks along with loads which are being distributed throughout the network over a large geographical area [1]. In the power system, the system load keeps changing from time to time according to the needs of the consumers. So properly designed controllers are required for the regulation of the system variations in order to maintain the stability of the power system as well as guarantee its reliable operation.

The rapid growth of the industries has further lead to the increased complexity of the power system. Frequency is greatly depends on active power and the voltage greatly depends on the reactive power. So the control difficulty in the power system may be divided into two parts. One is related to the control of the active power along with the frequency whereas the other is related to the reactive power along with the regulation of voltage [2]. The active power control and the frequency control are generally known as the Automatic Load Frequency Control (ALFC).

Basically the Automatic Load Frequency Control (ALFC) deals with the regulation of the real power output of the generator and its frequency (speed). The primary loop is relatively fast where changes occur in one to several seconds. The primary control loop reacts to frequency changes through the speed governor and the steam (or hydro) flow is managed accordingly to counterpart the real power generation to relatively fast load variations. Thus maintain a megawatt balance and this primary loop performs a course speed or frequency control.

The secondary loop is slower compared to the primary loop. The secondary loop maintain the excellent regulation of the frequency, furthermore maintains appropriate real power exchange among the rest of the pool members. This loop being insensitive to quick changes in load as well as frequency although it focuses on swift changes which occurs over periods of minutes.

Load disturbance due to the occurrence of continuos and frequent variations of loads having smaller values always creates problem for ALFC. Because of the change in the active power demand/load in an area ,tie line power flows from the interconnected areas and the frequency of the system changes and thus the system becomes unstable. So we need Automatic Load Frequency Control to keep up the stability at the time of the load deviations. This is done by minimizing transient deviations of frequency in addition to tie-line power exchange and also making the steady state error to zero [3]. Inequality involving generation with demand causes frequency deviations. If the frequency is not maintained within the scheduled values then it may lead on the way to tripping of the lines, system collapse as well as blackouts.

1.1. CHARACTERISTICS OF A PROPERLY DESIGNED POWER SYSTEM

i) It should supply power everywhere the customer demand practically.
ii) It should always supply power.
iii) It should always supply ever changing load demand.
iv) The supplied power should be economical.
v) The necessary safety requirements should be satisfied.

The power delivered must satisfy certain minimal necessities with regards to the supply quality. The superiority of the power supply can be decided as follows:

a) The system frequency must be kept around the specified value i.e. 50 Hz.
b) The magnitude of the bus voltage is maintained within prescribed limits around the normal value.

Voltage and frequency controls are the necessary requirements for the effective operation of the power systems.

1.2. REASONS FOR LIMITING FREQUENCY DEVIATIONS

There are few reasons as to why there should be strict limitations on frequency deviations and keeping the system frequency constant. They are as follows:

a) The three phase a.c. motors running speed are directly proportional to the frequency. So the variation of system frequency will directly affect the motor performance."

b) The blades of the steam turbine and the water turbines are designed to operate at a particular speed and the frequency variations will cause change in the speed. This will lead to excessive vibration and cause damage to the turbine blades.The frequency error may produce havoc in the digital storage and retrieval process.

1.3. CONCEPT OF CONTROL AREA

A control is interpreted as a system where we can apply the common generation control or the load frequency control scheme. Usually a self-governing area is made reference to as a control area. Electrical interconnection is very strong in every control area when compared to the ties in the midst of the adjoining areas. Within a control area all the generators move back and forth in logical and consistent manner which is depicted by a particular frequency. Automatic Load frequency Control difficulty of a bulky interrelated power system have been investigated by dividing the whole system into number of control areas and termed as multi-area [4].

In the common steady state process, power systems every control area must try to counterbalance for the demand in power by the flow of tie-line power through the interconnected lines. Generally the control areas encompass only restricted right to use to the information of the total grid: they are able to manage their own respective buses however they cannot alter the parameters at the unknown buses directly. But an area is alert of the dominance of its nearby areas by determining the flow in and flow out of power by the side of its boundaries which is commonly known as the tie-line power. In every area the power equilibrium equations are computed at the boundaries, taking into consideration the extra load ensuing from the power that is being exported. Later on, the areas work out the optimization problem in accordance to their objective function which is local.

1.4. OBJECTIVES RELATING TO CONTROL AREAS

The major objectives relating to control areas are as follows:-

a) Each control area should accomplish its individual load demand in addition to the power transfer all the way through tie lines on the basis of communal agreement.

b) Every control area must have adjustable frequency according to the control.

1.5. MAJOR OBJECTIVES OF ALFC IN A POWER SYSTEM

a) To take care of the required megawatt power output of a generator matching with the changing load.

b) To take care of the appropriate value of exchange of power linking control areas . To facilitate control of the frequency for larger interconnection.

1.6. ADVANTAGES OF ALFC IN MULTI AREA SYSTEM

a) The ALFC helps to diminish the transient deviations in addition to making the steady state error to zero.

b) It also holds system frequency at a specified value

c) ALFC also collaborate in keeping the net power interchange between the pool members at the predetermined values.

1.7. TYPES OF CONTROL

a)**Primary Control**: This type of control is endeavored locally to keep the balance involving generation along with demand within the network. It is apprehended by speed of turbine governors that adjusts the generators output as a response to the frequency divergence in the area. If there is a major disturbance then the primary control permits the balance of generated as well as utilized power at a frequency distinguishable from the set-point quantity in order to make the network stable.

b)**Secondary Control**: This type of control is exerted by means of an automatic centralized procedure in the control building block. It has two purposes:

a) It keeps the interchange power connecting the control block and its adjoining blocks according to the planned value.

b) In case of major frequency drop, it brings back the set point value of the frequency.

1.8. NEED FOR THE INTER-CONNECTION OF AREAS

Earlier electric power systems were usually operated as individual units. But a need for the inter-connection was realized due to the following reasons:

a) There was demand for larger bulk power with increased reliability so there was interconnection of neighboring plants.

b) It is also beneficial economically since fever machines are necessary as reserve for action at peak loads (reserve capacity) and also less machines are needed to be run without load to take care of sudden rise and fall in load(spinning reserve).

C . For that reason, several generating units are connected with each other forming state, regional and national grids respectively. Also for the control of power flow in these grids the Load dispatch centers are needed.

1.8.1. ADVANTAGES OF HAVING INTERCONNECTED SYSTEM

Reserve capacity is reduced and thus there is reduction in the installed capacity.

For larger units the capital cost/kW is reduced. (in India a particular unit can hold up >500MW due to interconnection) Generators are used effectively.Generation is optimized so there is reduction in the installed capacity. The reliability of the system is increased.

1.8.2. DISADVANTAGES OF HAVING INTERCONNECTED SYSTEM

- Faults gets propagated which is responsible for faster switchgear operation
- Circuit breaker rating increases
- Proper management is required.

1.9. LITERATURE REVIEW

A lot of work has been done related to automatic load frequency control in power systems. Load variations give rise to drifts in frequency along with voltage consequential in reduction of generation because of line tripping as well as blackouts. These variations are reduced by AGC that constitutes of two sections namely LFC and AVR. In the paper [5] simulation analysis is dispensed to comprehend operation of LFC by rising models in SIMULINK that helps to know the principles and various challenges relating to LFC.

The PI controller parameters derived from conventional or trial-and-error methods can’t have sensible dynamical act for a large variety of operating circumstances and changes in load in multi-area power system. To solve this difficulty, decentralized LFC combination is developed as an H-∞ control problem plus worked out by means of iterative linear matrix inequalities algorithmic rule to style sturdy PI controllers in multi-area power systems as shown in [6].

In the paper [7] a unified PID tuning technique dependent on two-degree-of-freedom for LFC of power system is discussed. Also time domain act in addition to robustness of consequential PID controller is associated to two regulation constraints as well as its robustness is discussed. Simulation results shows improvement in damping of power systems. The additional degree-of-freedom cancels the impact of unwanted poles of the disturbance, improving the disturbance reduction performance of system having closed-loop.

FA is used in control of the frequency in CCGT plant for controller gain optimization in the paper [8]. Also Performance of traditional controllers I, PI, PID as well as ID are also compared.

Investigation of differential evolution algorithmic program based on PI controller designed for AGC of interrelated power system is shown in the paper [9] by U.K.Rout and the outcomes are made a comparison by means of BFOA and GA on the basis of PI controller.

In the paper [10] tuning method is used to model PID load frequency controller meant for power systems along with relay based recognition technique is considered for estimation of dynamics of the power system. Robustness investigations on stability as well as performance are given in relation to uncertainties in parameters of the plant and it is seen that on the whole the system remains asymptotically steady for all enclosed uncertainties in addition to oscillations in the system.

1.10. MOTIVATION

There are numerous works pertaining to ALFC of interconnected areas of the power system by using various control methods like classical, optimal, suboptimal and adaptive control etc. to obtain better dynamic response characteristics but there are a very small number of work concerned to primary control/governor control characteristic i.e. suitable choice of speed regulation constraint 'R'.

Also the works are concerned with the selection of the speed regulation constraint 'R' more willingly than the optimized value. Also few works has been presented about the study of the significance of the tie line power alterations and its impact on the systems dynamic response. The changes in the system response due to imbalanced ties which are present in actual operation in a multi area system have not been investigated properly.

Through simulations, the objective is to maintain constant frequency and fulfill the load demand and also minimize the overall generated steady state error but it poses some demerits.

The general hit and trial method seems very tiresome for finding the suitable parameters so we are using an optimization tool i.e. BFOA for tuning of the parameters such as KIi, Ri and Bi. Along with the optimized parameters the steady state error is to be minimized. Convergence characteristics can ensure reduction in computational burden as it is faster.

1.11. PROBLEM STATEMENT

1.11.1. LOAD FREQUENCY PROBLEM

In a system as the load changes, the frequency of the system also changes. No regulation control would be required if it was not important to keep the frequency of the system constant. Normally the frequency would vary by 5% approx. from light load to full load conditions.

1.11.2. TIE LINE POWER PROBLEM

In case of a two machine system having two loads, the change in load is to be taken care of by both the machines such that there is equal participation by both the machines in sharing the tie-line power and also maintaining the system stability by reducing the error to zero value.

1.12. HOW ESTIMATION PROBLEM BECOMES OPTIMIZATION PROBLEM

Estimation problem is based on the empirical or measured data that's why to approximate the values of the unknown parameters used from among the group of measured data.

Optimization problem is based on the process of finding the best solution from among the feasible solutions with respect to a particular goal, obtained through the process of several steps. The best solution is known as the optimal value.

Here the optimization technique is being utilized to find the values of the controllable factors that determine the system behavior and minimize the objective function constituting the errors which occur due to variation in load.

1.13. WHY TO GO FOR BFOA

An effort has been done to initiate a new-fangled optimization method called as Bacteria Foraging Optimization Technique (BFOA) intended for optimization of the parameters of the Automatic Load Frequency Control (ALFC) which would otherwise have been very difficult. BFOA technique gives us a chance to optimize several parameters simultaneously. Simultaneous optimization of the parameters controls the relative effects of the variation of the parameters. The most vital achievement of using this method is the optimization of 'R' together with the controller gain parameters.

CHAPTER 2

2. DYNAMICS OF THE POWER SYSTEM

The automatic load frequency control loop is mainly associated with the large size generators. The main aim of the automatic load frequency control (ALFC) can be to maintain the desired unvarying frequency, so as to divide loads among generators in addition to managing the exchange of tie line power in accordance to the scheduled values. Various components of the automatic load frequency control loop are as given away in the Fig. 2.1 .

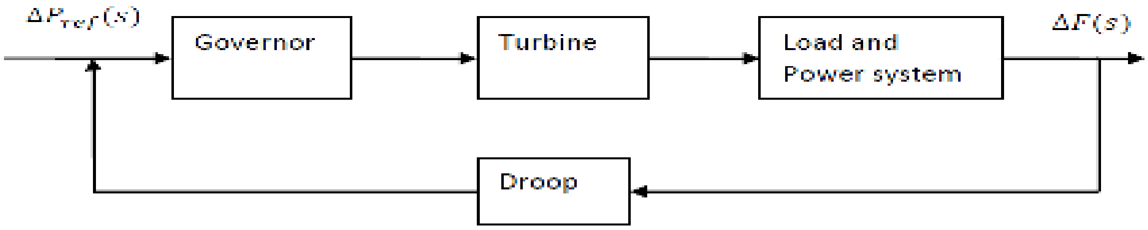


Fig.2.1: Block diagram of Automatic load frequency control

2.1. TURBINES

Turbines are used in power systems for the conversion of the natural energy, like the energy obtained from the steam or water, into mechanical power (P_m) which can be conveniently supplied to the generator. There are three categories of turbines usually used in power systems: non-reheat, reheat in addition to hydraulic turbines, each and every one of which may be modeled and designed by transfer functions. We have non-reheat turbines which are represented as first-order units where the delay in time known as time delay (T_{ch}) takes place between the interval during switching of the valve and producing the torque in the turbine. Design of reheat turbines is done by using second-order units as there are different stage because of soaring and low down of the pressure of the steam. Because of the inertia of the water hydraulic turbines are treated as non-minimum phase units.

The turbine model represents changes in the steam turbines power output to variation in the opening of the steam valve. Here we have considered a non-reheat turbine with a single gain factor and single time constant. In the model the representation of the turbine is,

$$\frac{\Delta P_T(s)}{\Delta P_v(s)} = \frac{K_T}{1 + sT_T} \qquad (1)$$

Where $\Delta P_v(s)$ = the input to the turbine

$\Delta P_T(s)$ =the output from the turbine

2.2. GENERATORS

Generators receive mechanical power from the turbines and then convert it to electrical power. However our interest concerns the speed of the rotor rather than the power transformation. The speed of the rotor is proportional to the frequency of the power system. We need to maintain the balance amid the power generated and the power demands of the load because the electrical power cannot be stored in bulk amounts. When there is a variation in load, the mechanical power given out by the turbine does not counterpart the electrical power generated by the generator which results in an error which is being integrated into the rotor speed deviation ( ). Frequency bias . The loads of the power can be divided into resistive loads (P_L), which may be fixed when there is a change in the rotor speed due to the motor loads which change with the speed of the load. If the mechanical power does not change then the motor loads shall compensate the change in the load at a rotor speed which is completely dissimilar from the planned value.

Mathematically,

$$\frac{\Delta P_v(s)}{\Delta P_g(s)} = \frac{1}{1 + sT_g} \qquad (2)$$

Where $\Delta P_v(s)$ = the output from the generator

$\Delta P_g(s)$ = the input to the generator

T_g = time constant of the generator

2.3. GOVERNORS

Governors are employed in power systems for sensing the bias in frequency which is the result of the modification in load and eliminate it by changing the turbine inputs such as the characteristic

for speed regulation (*R*) and the governor time constant (T_g). If the change in load occurs without the load reference, then some part of the alteration can be compensated by adjusting the valve/gate and the remaining portion of the alteration can be depicted in the form of deviation in frequency. LFC aims to limit the deviation in frequency in the presence of changing active power load. Consequently, the load reference set point can be utilized for adjusting the valve/gate positions so as to cancel all the variations in load by controlling the generation of power rather than ensuing deviation in frequency.

Mathematically,

$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta F(s) \qquad (3)$$

Where $\Delta P_g(s)$ = governor output

$\Delta P_{ref}(s)$ = the reference signal

R = regulation constant or droop

$\Delta F(s)$ = frequency deviation due to speed

2.4. LOAD

The power systems load constitutes of a diversity of electrical devices. The loads that are resistive, for example lighting and also heating loads are not dependent on frequency, but the motor loads are responsive to frequency depending on the speed-load characteristics as shown below.

$$\Delta P_e = \Delta P_L + D\Delta\omega \qquad (5)$$

Where ΔP_L = non frequency responsive load change

$D\Delta\omega$ = frequency responsive load change

$\mathrm{D} = {}^{\text{\%change in load}}/_{\text{\%change in frequency}}$

2.5. TIE-LINES

Various areas can be connected with one another by one or more transmission lines in an interconnected power grid through the tie-lines. When two areas are having totally different frequencies, then there’s an exchange of power between the two areas that are linked by the tie lines. The power due to tie-line trades in area *i* and area *j* (ΔPij) and the tie-line synchronizing torque coefficient (Tij). Thus we can also say that the integral of the divergence in frequency among the two areas is an error in the power due to tie-line.

The objective of tie-lines is to trade power with the systems or areas in the neighborhood whose costs for operation create such transactions cost-effective. Moreover, even though no power is being transmitted through the tie-lines to the neighborhood systems/areas and it so happens that suddenly there is a loss of a generating unit in one of the systems. During such type of situations all the units in the interconnection experience a alteration in frequency and because of which the desired frequency is regained.

Let there be two control areas and power is to be exchanged from area 1 to area 2. Mathematically,

$$P_{12} = \frac{|V_1||V_2|}{X_{12}} \sin(\delta 1 - \delta 2) \qquad (6)$$

Where 1 stands for control area 1 and 2 stands for control area 2

X_{12} = series reactance involving area 1 and 2

$|V_1|$ and $|V_2|$ = magnitude of voltages of area 1 plus area 2

2.6. AREA CONTROL ERROR

The aim of LFC is not just to terminate frequency error in all areas, but as well to enable the exchange of the power due to tie-line as scheduled. In view of the fact that the error due to tie-line power will be the integral of the dissimilarity in frequency among every pair of areas, but when we direct frequency error back to zero, all steady state errors present in the system frequency will give rise to in tie-line power errors. For this reason it is necessary to consider the control input in the variation in the tie-line power. Consequently, an area control error (ACE) is stated. Each of the power generating area considers ACE signal to be used as the output of the plant. By making the ACEs zero in all areas makes all the frequency along with errors in the tie-line power in the system as zero.

In order to take care of the total interchange of power among its areas within the neighborhood, ALFC utilizes real power flow determinations of all tie lines as emanating through the area and there after subtracts the predetermined interchange to compute an error value. The total power exchange, jointly with a gain, B (MW/0.1Hz), known as the bias in frequency, as a multiplier with the divergence in frequency is known as the Area Control Error (ACE) specified by,

$$ACE = \sum_{k=1}^{k} P_k - P_s + B(f_{act} - f_0) \text{ MW} \quad (7)$$

Where,

P_k = power in the tie line (if out of the area then +ve)

P_s = planned power exchange

f_0 = base frequency

f_{act} = actual frequency

Positive (+ve) ACE shows that the flow is out of the area.

2.7. PARALLEL OPERATION OF GENERATORS

If there are a number of units for power generation to be operational in parallel in that particular area, a counterpart generator may be created for ease. The corresponding generator inertia constant (M_{eq}), damping constant of load (D_{eq}) and characteristics for frequency response (B_{eq}) may be shown. Tie line flows as well as frequency droop represented for interconnecting power areas may be combined characteristics derived from parallel action of generators. Each one of the areas could retain its speed, then a load general to both areas; by superposition include the voltage at the terminal. Two generators paralleled include completely diverse governor-speed-droop characteristics. Since they may be in parallel, power exchange linking them insists them to synchronize at a general frequency.

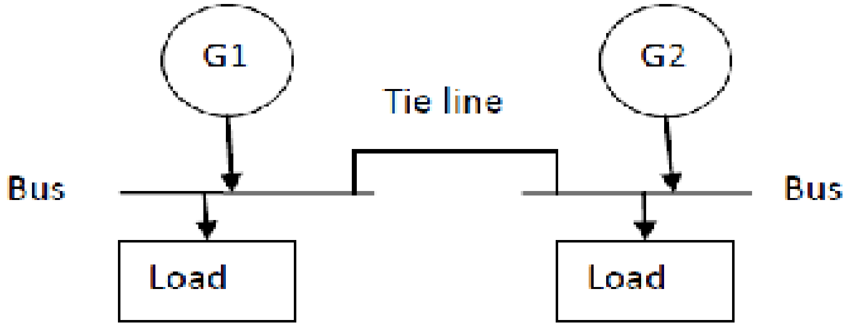


Fig.2.2: Block diagram for parallel operation of generators

2.8. MODELING OF ALFC

A. Modeling for the change in frequency

Let us consider an automatic load frequency control loop of a system which is isolated intended for the examination of the steady state and dynamic responses. The figure is as shown below in the Fig. 2.1.

[1] Steady state analysis

Let be the setting for the speed changer and be the alteration in demand of the load. Considering a simple situation where the speed changer might have constant setting i.e. as well as there is change in the load demand. This may be known to be free governor operation.

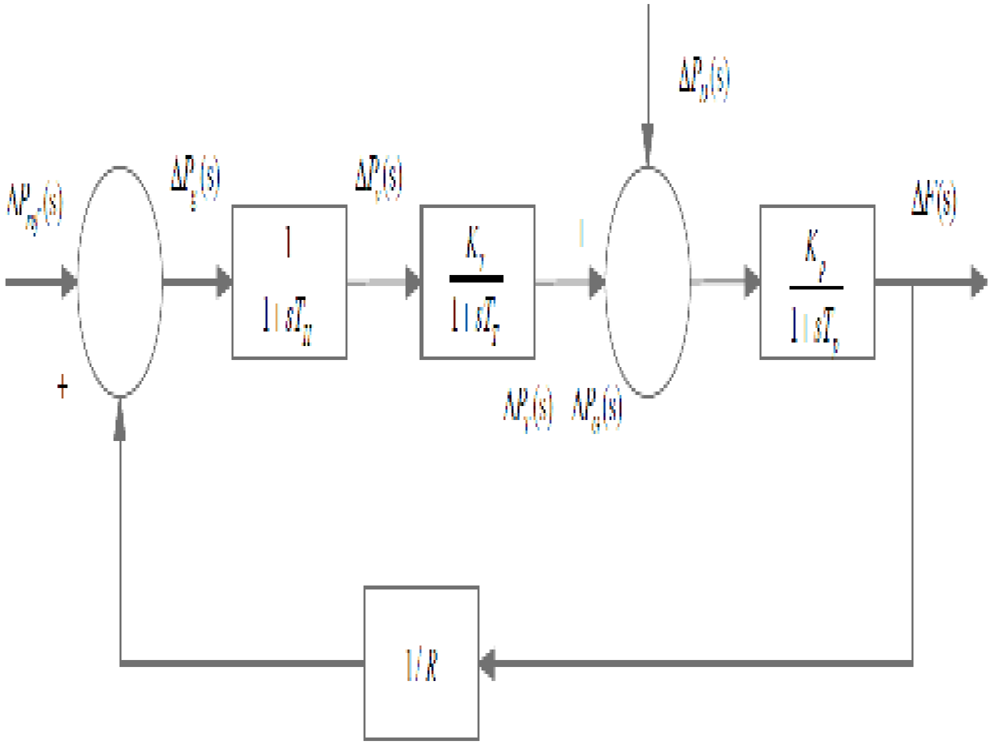


Fig.2.3: Automatic load frequency control loop

For such a process the steady modification in the system frequency for a step change in load i.e. is obtained as follows

$$[\left\{\Delta P_{ref}(s) - \frac{1}{R}\Delta F(s)\right\}\frac{K_T}{(1+sT_H)(1+sT_T)} - \Delta P_D(s)]\frac{K_p}{(1+sT_p)} = \Delta F(s) \qquad (8)$$

This implies that,

$$\Delta F(s) = \frac{-K_p\Delta P_D(s)/s(1+sT_p)}{(K_T K_p/R)/(1+sT_H)(1+sT_T)(1+sT_p)} \qquad (9)$$

After simplification we get,

$$\Delta F(s) = -\frac{\Delta P_D}{\beta} \qquad (10)$$

Where β is the area frequency response characteristics

2] Dynamic analysis

For a step change in load,

$$\Delta F(s) = \frac{-K_p\Delta P_D(s)/s(1+sT_p)}{(K_T K_p/R)/(1+sT_H)(1+sT_T)(1+sT_p)} \qquad (11)$$

Assuming amplifier and turbine response to be instantaneous i.e. T_T=T_H=0 and K_T=1, we have

$$\Delta F(s) = \frac{-K_p}{(1+sT_p)+K_p/R}\frac{\Delta P_D}{s} \qquad (12)$$

After simplification we get,

$$\Delta F(s) = \frac{-RsK_p(1+sT_H)(1+sT_T)}{Rs(1+sT_H)(1+sT_T)(1+sT_p)+(s+RK_i)K_p}\frac{\Delta P_D}{s} \qquad (13)$$

B. Modeling of the Tie-Line

Let us consider that area 1 is having surplus power and it transfers power to the area 2 by the tie-line.

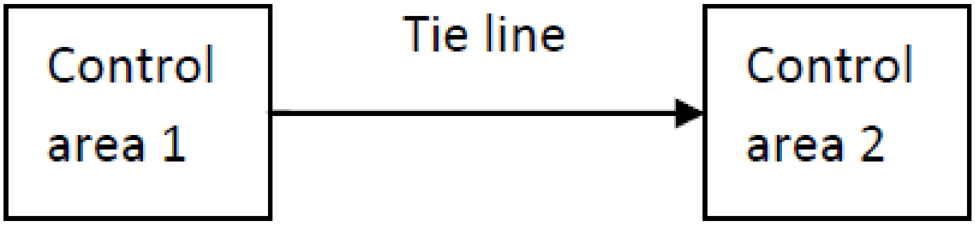


Fig.2.4: Power transfer through tie line

P_{12} = power exchanged from area 1 towards area 2 via tie lines. Then the power transfer equation the tie-line is specified as follows:

$$P_{12} = \frac{|V_1||V_2|}{X_{12}} \sin(\delta 1 - \delta 2)$$

$$\Delta P_{12} = \frac{|V_1||V_2|}{X_{12}} \cos(\delta 1 - \delta 2)\,(\Delta\delta_1 - \Delta\delta_2) \qquad (14)$$

Where $\delta 1$ and $\delta 2$ = power angles of end voltages V_1 and V_2 of corresponding machine of the two areas.

X_{12} = reactance of the tie line.

$|V_1|$ and $|V_2|$ = magnitude of voltages of area 1 and area 2

The sequence of the subscripts depicts that the flow of power due to the tie lines is positive in the direction from 1 to 2.

For little deviation in the angles $\delta 1$ and $\delta 2$ changes by $\Delta\delta 1$ and $\Delta\delta 2$, the tie line power changes as follows:

i.e.

$$\Delta P_{12} = \frac{|V_1||V_2|}{X_{12}}\cos(\delta 1 - \delta 2)\,(\Delta\delta_1 - \Delta\delta_2) \tag{15}$$

$$\Delta P_{12} = T^0(\Delta\delta_1 - \Delta\delta_2) \tag{16}$$

i.e.

$$\Delta P_{12}(s) = \frac{2\Pi T^0}{s}\,(\Delta F_1(s) - \Delta F_2(s)) \tag{17}$$

Where, $T^0 = \frac{|V_1||V_2|}{X_{12}}\cos(\delta 1 - \delta 2)$ = Torque produced

In a control area which is isolated, the incremental power (ΔP_G – ΔP_D) is the rate of rise of preserved kinetic energy due to rise in the load followed by a rise in the frequency. The power due to the tie-lines for each area is as below

$$\Delta P_1(s) = \Delta P_{12}(s) + a_{31}\Delta P_{31}(s) \tag{18}$$

$$\Delta P_2(s) = \Delta P_{23}(s) + a_{12}\Delta P_{12}(s) \tag{19}$$

$$\Delta P_3(s) = \Delta P_{31}(s) + a_{23}\Delta P_{23}(s) \tag{20}$$

Control of tie line bias is utilized to get rid of the steady state error because of frequency plus the exchange of the power due to tie-lines. This shows that all of the control areas should put in their share in frequency control, besides dealing with their own particular total interchange of power

Let,

ACE_1 = area control error of area 1

ACE_2 = area control error of area 2

ACE_3 = area control error of area 3

$ACE_{1,}$ ACE_2 and ACE_3 are given as linear arrangement of frequency along with tie-line power error as follows:

$$ACE_1 = \Delta P_{12} + b_1 \Delta f_1 \quad (21)$$

$$ACE_2 = \Delta P_{23} + b_2 \Delta f_2 \quad (22)$$

$$ACE_3 = \Delta P_{31} + b_3 \Delta f_3 \quad (23)$$

Where are known as bias in area frequency of area 1, area 2 and area 3 respectively.

Area control error (ACE) is negative when the net power flow output from an area is very small or else when the frequency has dropped or both. During such situations we need to increase the generation.

CHAPTER 3

3. DESIGN MODEL FOR VARIOUS SYSTEMS

3.1. SINGLE AREA SYSTEM

Fig.3.1 shows the Automatic Load Frequency Control (ALFC) loop. The frequency which changes with load is contrasted with reference speed setting. The frequency can be set to the desired value by making generation and demand equal with the help of steam valve controller which regulate steam valve and increases power output from generators. It serves theprimary/basic purpose of balancing the real power by regulating turbine output according to the variation in load demand .

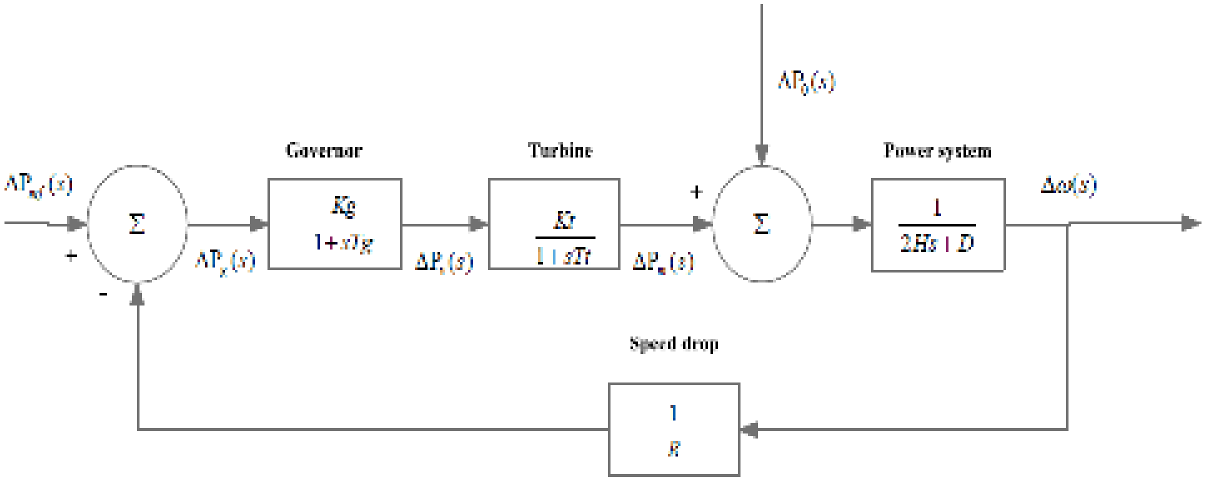


Fig. 3.1: Model of single area ALFC without using secondary control

The transfer function of the model of the single area system as shown in Fig. 3.1 is as below:

$$KG(s)H(s) = \frac{1}{R}\frac{1}{(2Hs+D)\left(1+\tau_g s\right)(1+\tau_T s)} \tag{24}$$

$$\frac{\Delta\omega(s)}{-\Delta P_L(s)} = \frac{\left(1+\tau_g s\right)(1+\tau_T s)}{(2Hs+D)\left(1+\tau_g s\right)(1+\tau_T s)+1/R} \tag{25}$$

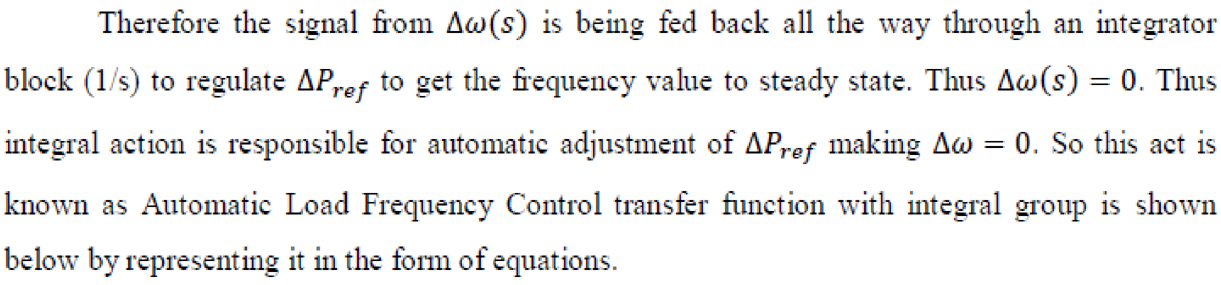
$$\Delta\omega(s) = -\Delta P_0(s)T(s) \tag{26}$$

For the case with load which is not sensitive to frequency load (D=0):

$$\Delta\omega_{ss} = (-\Delta P_0)R \tag{27}$$

From the above equations we can get the steady state value of new system frequency which is less than the initial value. But we have to make the frequency drift to zero or to an acceptable value with the help of secondary loop for stable operation. This is shown above in Fig.3.1.

Due to change in load there is change in the steady state frequency so we need another loop apart from primary loop to convey the frequency to the initial value, before the load disturbance occurs. The integral controller which is responsible in making the frequency deviation zero is put in the secondary loop as shown in Fig.3.2. known as Automatic Load Frequency Control transfer function with integral group is shown below by representing it in the form of equations.



Therefore the signal from $\Delta\omega(s)$ is being fed back all the way through an integrator block (1/s) to regulate ΔP_{ref} to get the frequency value to steady state. Thus $\Delta\omega(s) = 0$. Thus integral action is responsible for automatic adjustment of ΔP_{ref} making $\Delta\omega = 0$. So this act is known as Automatic Load Frequency Control transfer function with integral group is shown below by representing it in the form of equations.

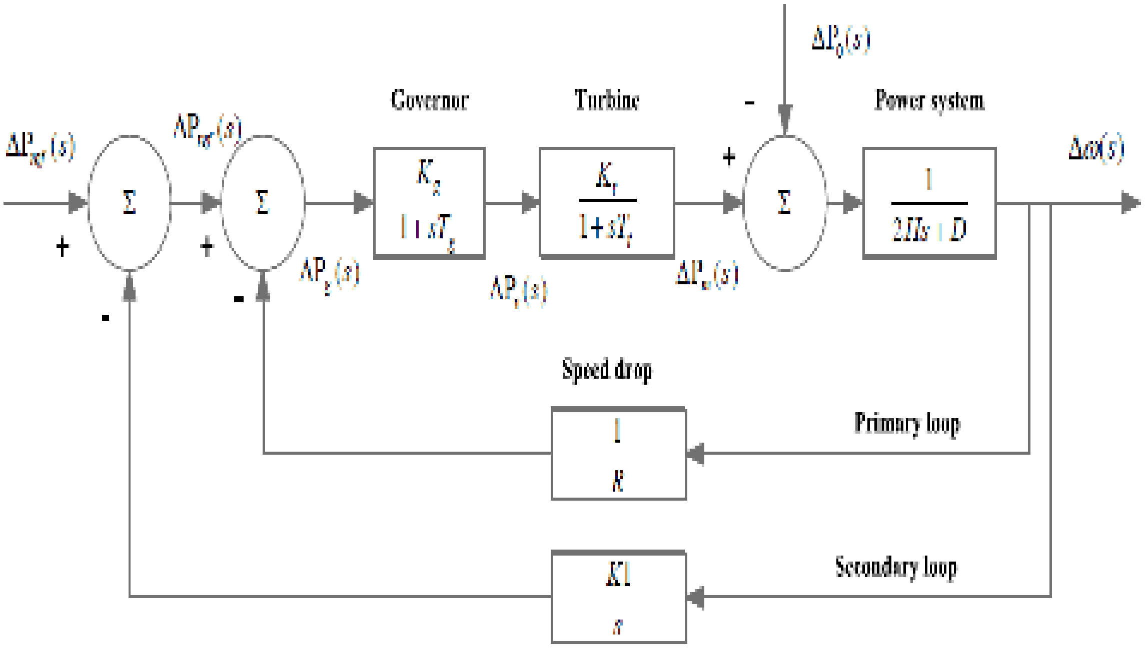


Fig. 3.2: Model of single area ALFC by using secondary control

$$\omega = \frac{1}{D + \frac{1}{R}}[\Delta P_{ref} - \Delta P_o] \tag{28}$$

3.2. TWO AREA SYSTEM

Two area interconnected system which is joined by means of tie-lines for the flow of tie-line power is given in Fig. 3.3. Let the additional input be be the load change in area1 and the respective frequencies of the two areas be

$$\Delta\omega = \Delta\omega_1 = \Delta\omega_2 \tag{29}$$

Let X_{12} be the reactance of the tie line, then power delivered from area 1 to area 2 is

$$P_{12} = \frac{|E_1||E_2|}{X_{12}} \sin\delta_{12} \tag{30}$$

When $X_{12} = X_1 + X_{tie} + X_2$ and $\delta_{12} = \delta_1 - \delta_2$

Equation can be linearized as:

$$\Delta P_{12} = \frac{dP_{12}}{d\delta_{12}}|_{\delta_{12}} \qquad \Delta\delta_{12} = P_s\Delta\delta_{12} \tag{31}$$

The tie-line power deviation:

$$\Delta P_{12} = P_s(\Delta\delta_1 - \Delta\delta_2) \tag{32}$$

Let $\Delta\omega = \Delta\omega_1 = \Delta\omega_2$.

For area 1,

$$\Delta P_{m1} - \Delta P_{12} - \Delta P_{01} = \Delta\omega D_1 \tag{33}$$

$$\Delta P_{m1} = -\Delta P_{m2} = \Delta P_{12} = \Delta\omega D_2 \tag{34}$$

For area 2,

$$\Delta P_{m1} = \frac{-\Delta\omega}{R_1} \tag{35}$$

$$\Delta P_{m2} = \frac{-\Delta\omega}{R_2} \tag{36}$$

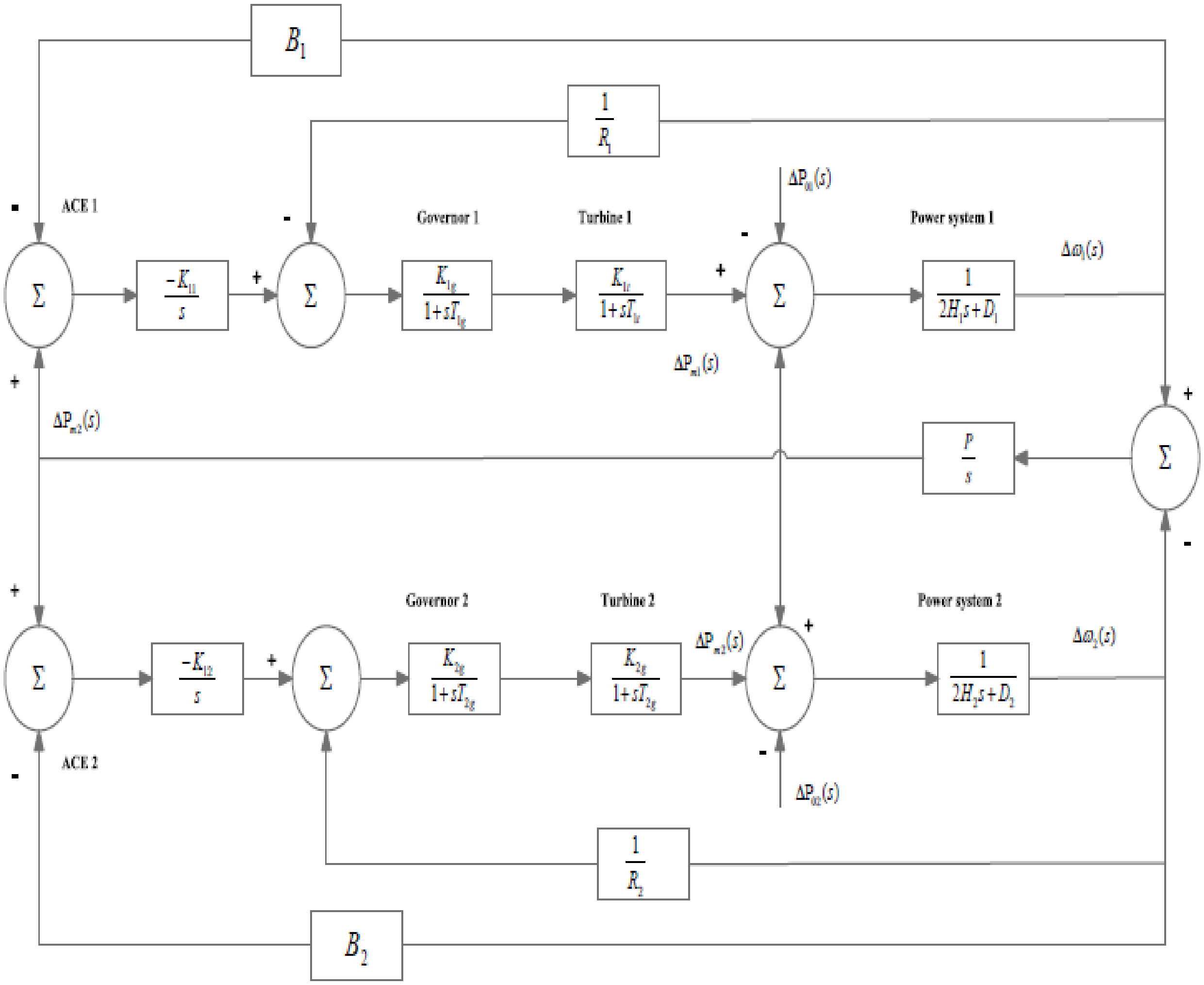


Fig. 3.3: Model of two area system without using secondary loop or using only primary loop control

$$\Delta P_{12} = \frac{-\Delta P_{01}\beta_1}{\beta_1+\beta_2} \qquad (37)$$

Thus rise in load in area 1 reduces the frequency of both the areas and leads to the flow of tie-line power. If ΔP_{12} is negative then power flows from area 2 to area 1. Correspondingly for alteration in load in area 2 (ΔP_{02}) ,

$$\Delta\omega = \frac{-\Delta P_{02}}{\beta_1+\beta_2} \qquad (38)$$

$$\Delta P_{12} = -\Delta P_{21} = \frac{-\Delta P_{02}\beta_1}{\beta_1+\beta_2} \qquad (39)$$

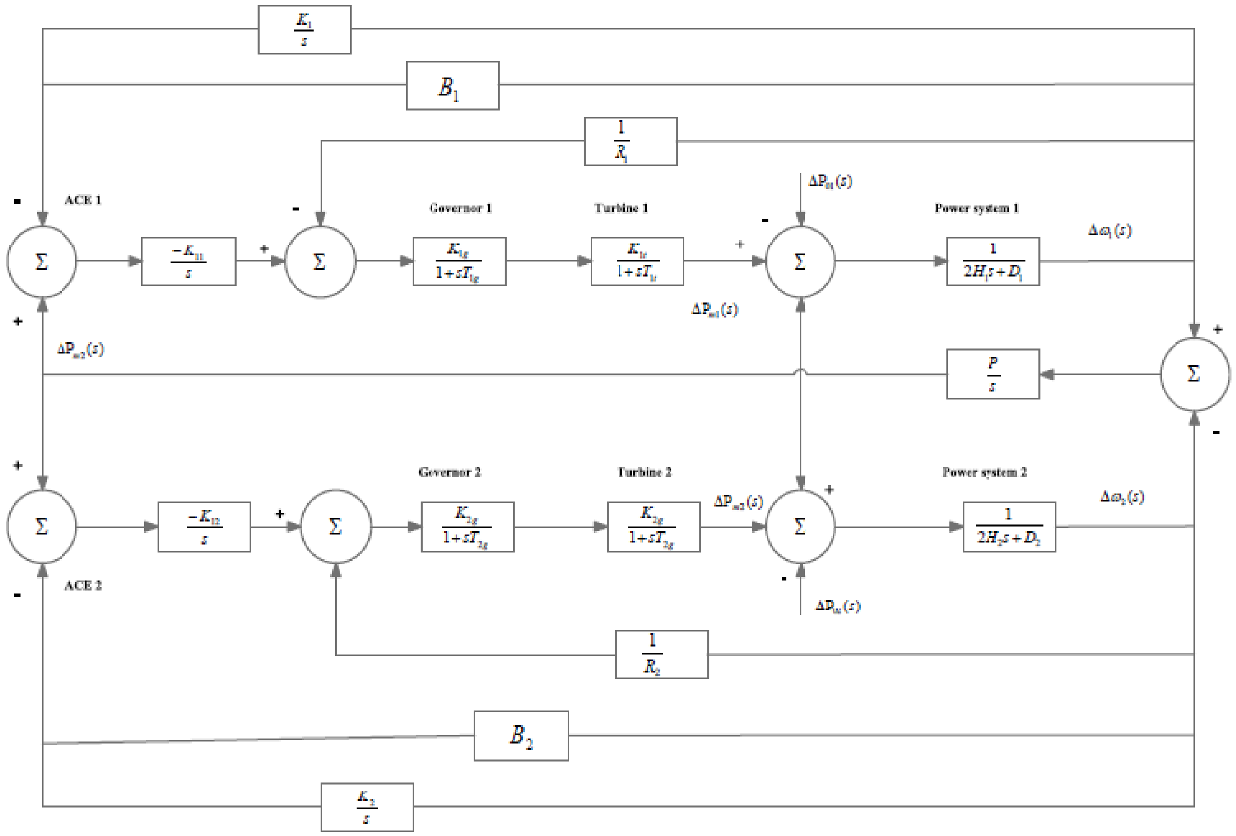


Fig. 3.4: Model of two area system by using secondary loop

The secondary control basically restores balance linking all area load generation which is possible by maintaining the frequency at scheduled value. This is shown in Fig.3.4. Suppose there is a variation in load in area 1 then the secondary control is in area 1 and not in area 2 so area control error (ACE) is being brought to use [5]. The ACE constituting two areas is represented as follows

In case of area 1:

$$\mathrm{ACE1} = \Delta P_{12} + \beta_1 \Delta\omega \tag{40}$$

In case of area 2:

$$\mathrm{ACE2} = \Delta P_{21} + \beta_2 \Delta\omega \tag{41}$$

For an entire load change of the steady state frequency deviation in two areas is

$$\Delta\omega = \frac{-\Delta P_{L1}}{\left(\frac{1}{R_1} + D_1\right) + \left(\frac{1}{R_2} + D_2\right)} = \frac{-\Delta P_{L1}}{\beta_1 + \beta_2} \qquad (42)$$

There can be one ALFC for every control area in an interrelated multi area system. ACEs are the actuating signals that stimulate modifications in reference power set points such that ΔP_{12} and $\Delta\omega$ becomes zero as soon as steady-state is attained.

Each area ACE is a combination of frequency as well as tie-line error.

$$\text{ACEi} = \sum \text{nj} = \Delta Pij + Ki\Delta\omega \qquad (43)$$

3.3. THREE AREA SYSTEM

The control in three area system is like the two area system and is shown in Fig. 3.5. The integral control loop which is used in the single area system and two area system can also be related to the three area systems. Due to change in load there is change in the steady state frequency ( ) so we need another loop apart from primary loop to make the frequency to the initial value, before the load disturbance occurs.

The integral controller which is responsible in making the frequency deviation zero is put in the secondary loop. Three area interconnected system consists of three interconnected control areas. There is flow of tie line power as per the changes in the load demand due to the interconnection made between the control areas.

Thus the overall stability of the system is maintained at a balanced condition in spite of the constant variations in the load and load changes.

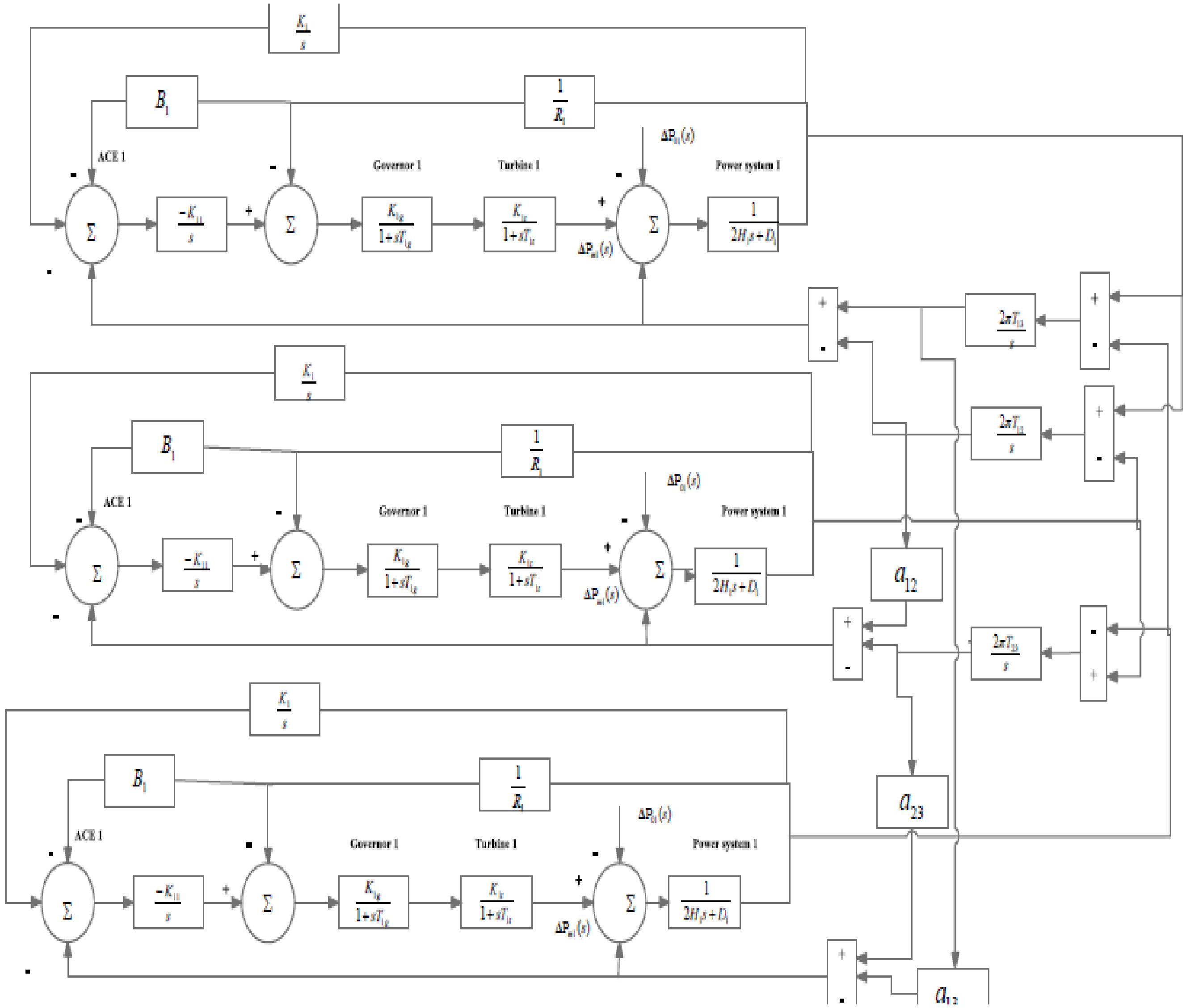


Fig. 3.5: Model of three area system by using secondary loop

Change in frequency for the three areas is as follows:

$$\Delta f_1(s) = -\frac{R_1 K_p m_1\,(s\,T_g + 1)\,(s\,T_t + 1)}{K_p\,(s + Ki_1\,R_1) + R_1\,s\,(s\,T_g + 1)\,(sT_p + 1)\,(s\,T_t + 1)} \qquad (44)$$

$$\Delta f_2(s) = -\frac{R_2 K_p m_2\,(s\,T_g + 1)\,(s\,T_t + 1)}{K_p\,(s + Ki_2\,R_2) + R_2\,s\,(s\,T_g + 1)\,(sT_p + 1)\,(s\,T_t + 1)} \qquad (45)$$

$$\Delta f_3(s) = -\frac{R_3 K_p m_3\,(s\,T_g + 1)\,(s\,T_t + 1)}{K_p\,(s + Ki_3\,R_3) + R_3\,s\,(s\,T_g + 1)\,(sT_p + 1)\,(s\,T_t + 1)} \qquad (46)$$

The tie-line power flow among three areas is as below:

$$\Delta P_{12}(s) = \frac{2\pi T^{o}}{s}[\Delta f_1(s) - \Delta f_2(s)] \tag{47}$$

$$\Delta P_{13}(s) = \frac{2\pi T^{o}}{s}[\Delta f_1(s) - \Delta f_3(s)] \tag{48}$$

$$\Delta P_{23}(s) = \frac{2\pi T^{o}}{s}[\Delta f_2(s) - \Delta f_3(s)] \tag{49}$$

CHAPTER 4

SIMULATION RESULTS OF AUTOMATIC LOAD FREQUENCY CONTROL

By using simulation models we can obtain the performance characteristics of the system very easily and quickly for analysis purposes. Below are the various systems simulink models with their respective responses plotted against time. Here we considered single area, two area and three area systems.

4.1. SINGLE AREA SYSTEM WITHOUT USING SECONDARY LOOP

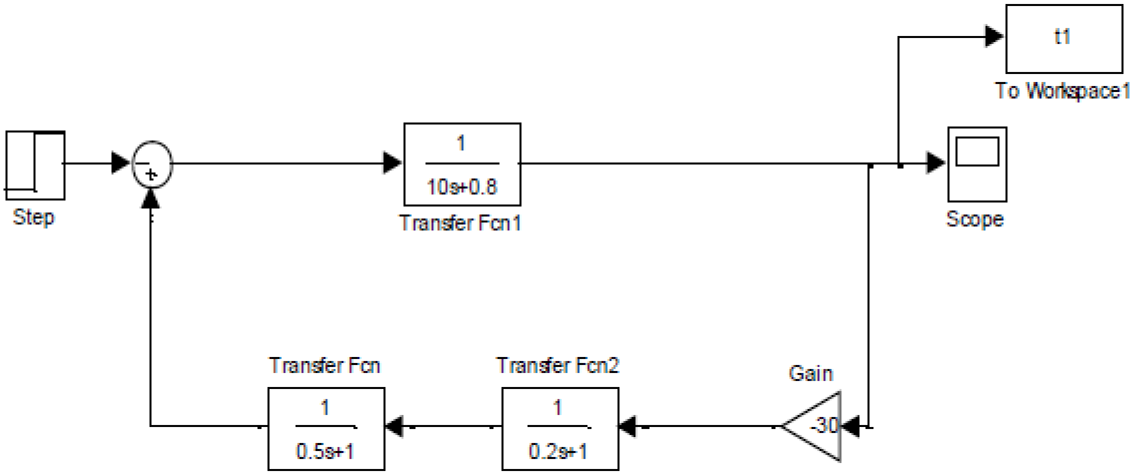


Fig. 4.1: Simulink model of single area system without using secondary loop

TABLE 4.1: System parameters for single area system without using secondary control

Name	Kg	Tg(s)	Kt	Tt(s)	H(s)	D(puMW /Hz)	1/R
Value	1	0.20	1	0.50	5	0.80	30

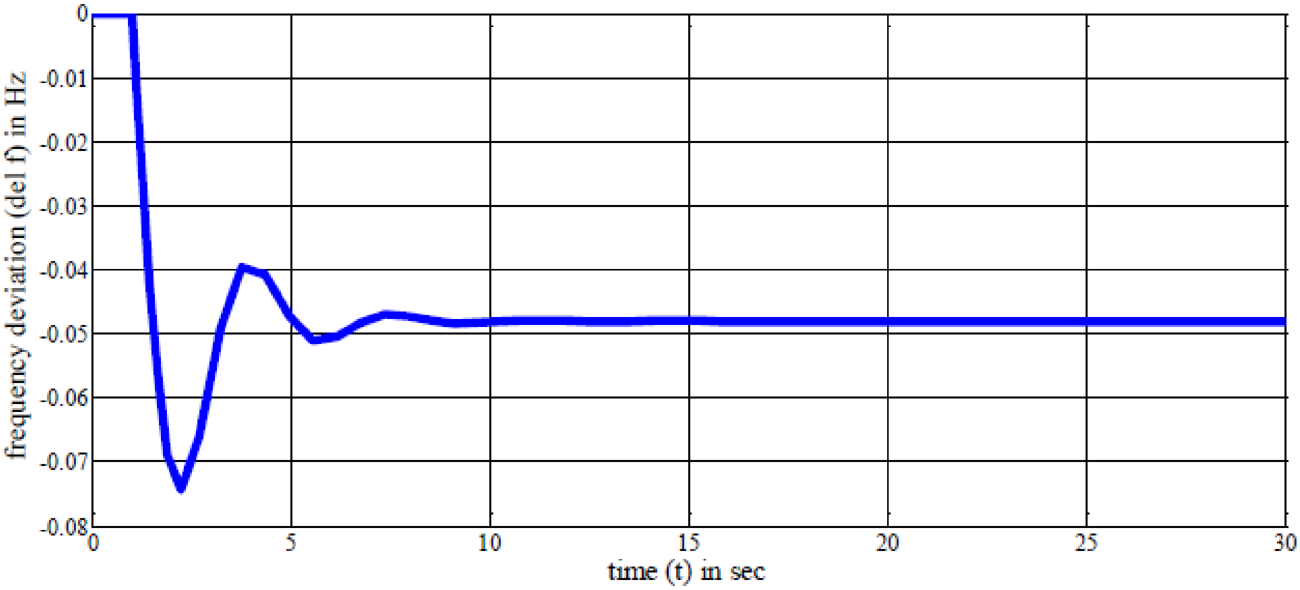


Fig. 4.2: Frequency deviation vs. time for single area system without secondary loop

The plot in Fig. 4.2 which is obtained by simulating the model as shown in Fig.4.1 shows that the change in load causes alteration in speed and that causes deviation in frequency . From the plot we are able to comprehend that the frequency oscillations will gradually stay down to a limited value.

The new-fangled operating frequency is supposed to be lesser than the nominal value. We have taken the values of the different parameters as shown in table 4.1 for modeling the simulink model and its successful operation to obtain the desired results.

4.2. SINGLE AREA SYSTEM BY USING SECONDARY LOOP

In Fig. 4.3 an integral controller by means of a gain i.e. Ki is used to regulate the signal of speed reference i.e. (as given away in Fig. 4.6) so that proceeds to zero (as shown in Fig. 4.5). Fig. 4.4 shows the variation in turbine output with time. The drift in frequency has been brought to zero because of the integral loop. We have taken the values of the different parameters as shown in table 2 for modeling the simulink model and its successful operation to obtain the desired results.

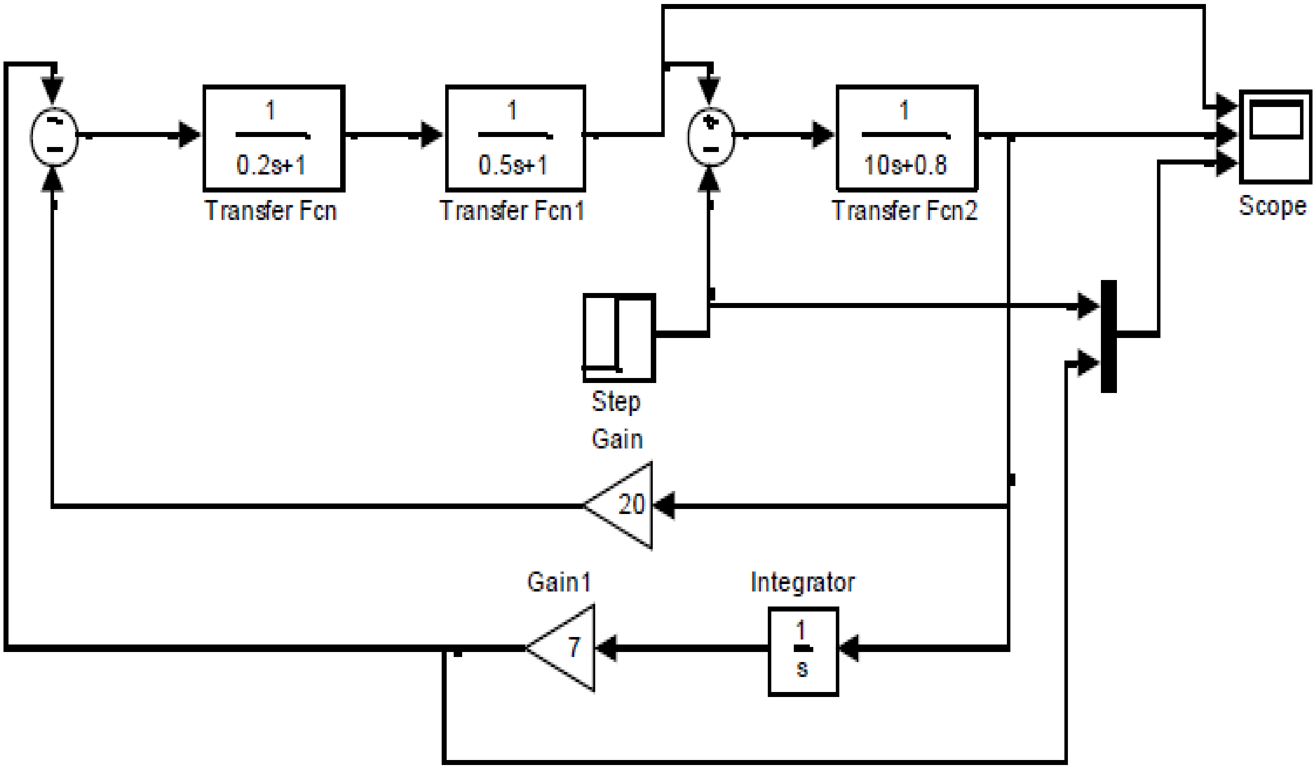


Fig. 4.3: Simulink model for single area system by using secondary loop

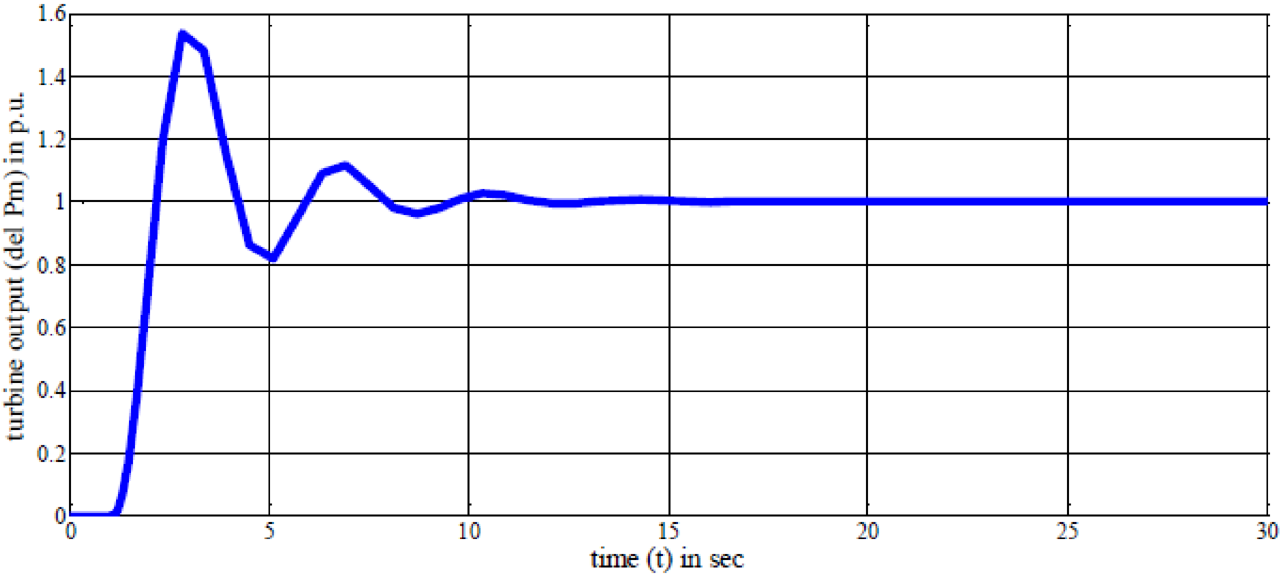


fig 4.4: Change in turbine output vs. time for single area system by using secondary l

TABLE 4.2: System parameters for single area system by using secondary control

Name	Kg	Tg(s)	Kt	Tt(s)	H(s)	D(p.u.MW/Hz)	1/R	K1
Value	1	0.20	1	0.50	5	0.8	20	7

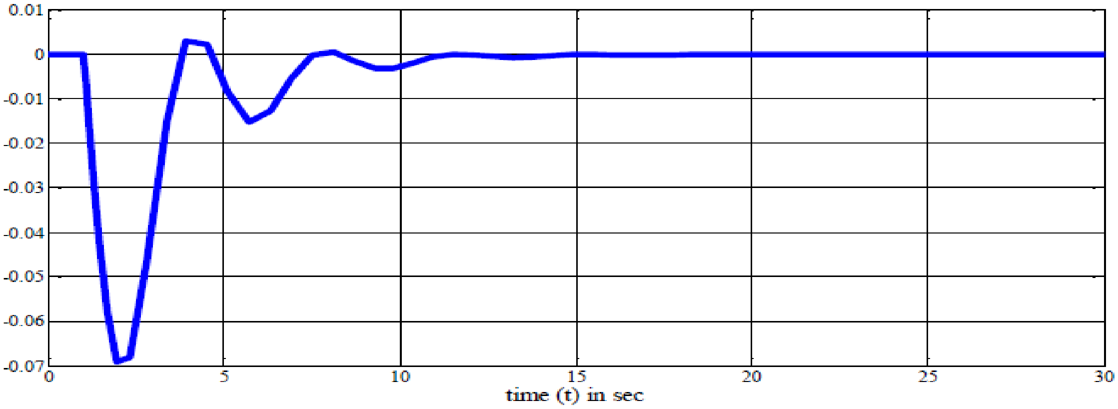


Fig. 4.5: Change in frequency vs. time for single area system by using secondary loop

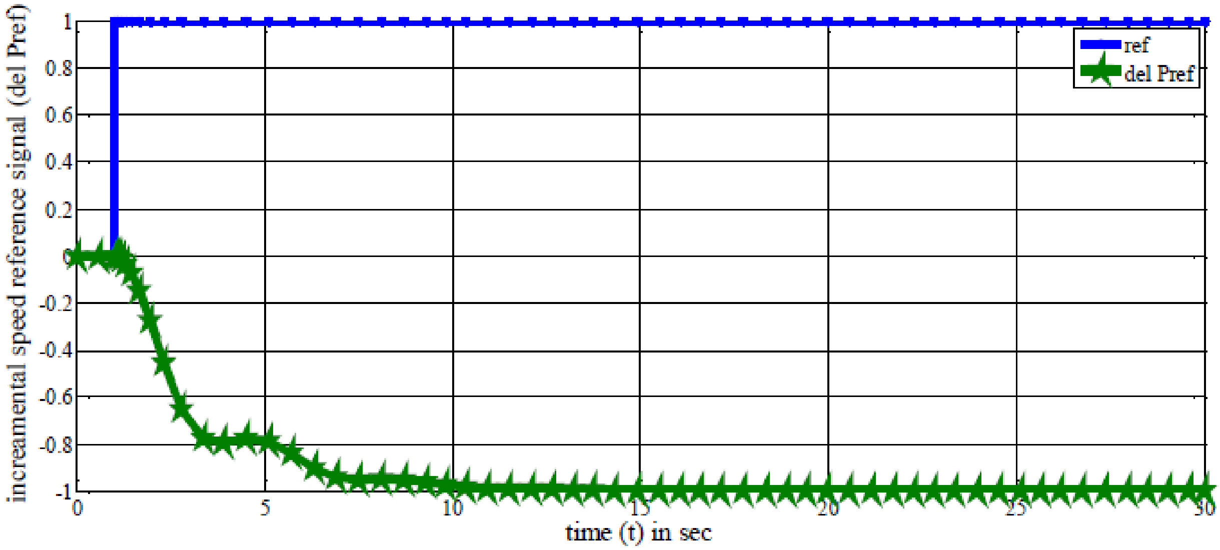


Fig. 4.6: Incremental speed reference signal vs. time for single area by using secondary loop

4.3. TWO AREA SYSTEM WITHOUT USING SECONDARY LOOP

Fig. 4.7 presents that the two systems are being interrelated so the drifts in the frequency of the two are liable to settle down to similar value soon after a few oscillations. The two mechanical inputs changes to minimize the inequality power connecting electrical load in area 1 as well as the mechanical inputs. Area 2 is capable to generate excessive power to distribute the variation in load in area 1. We have taken the values of the different parameters as shown in table 4.3 for modeling the simulink model and its successful operation to obtain the desired results.

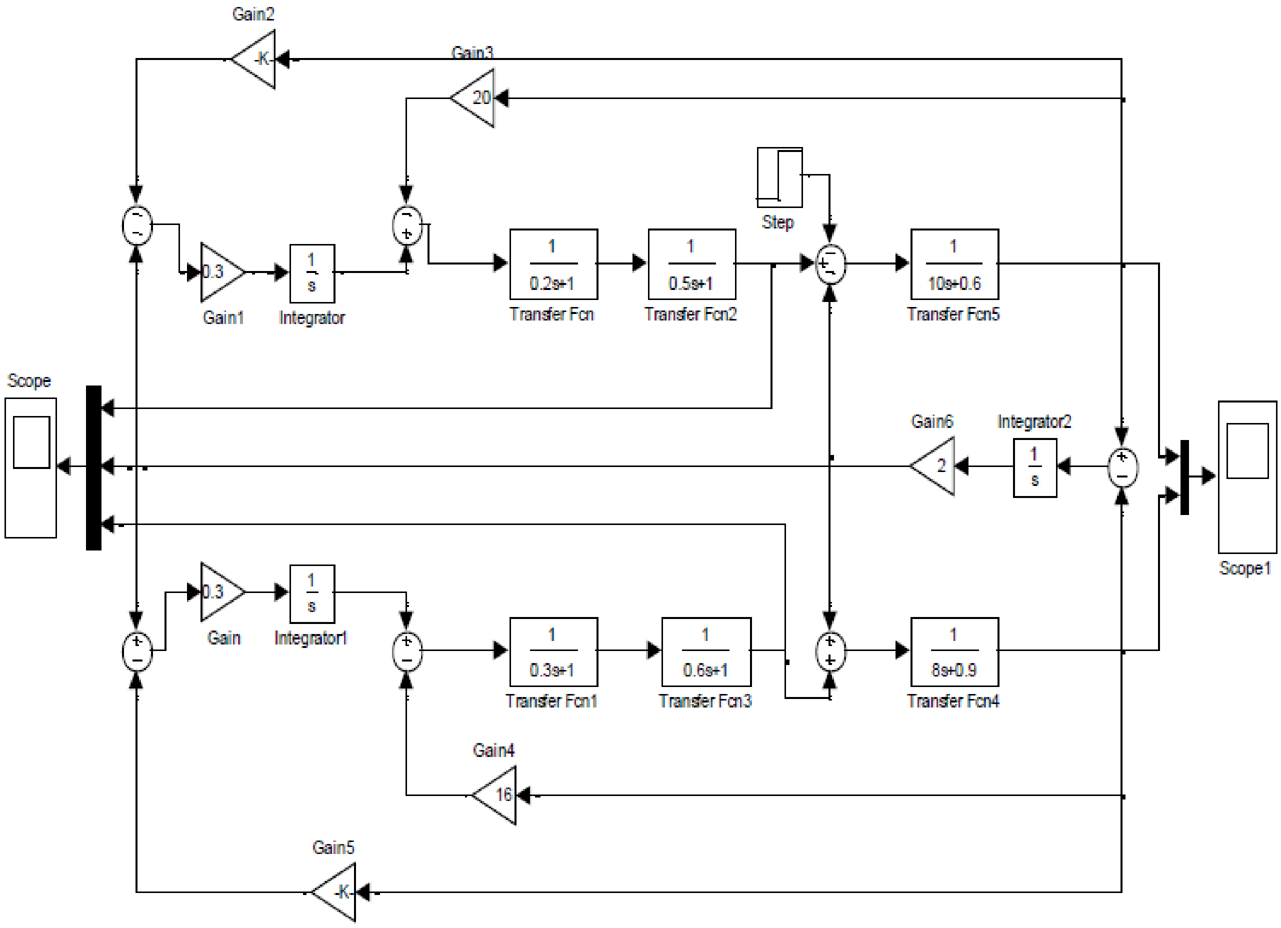


Fig. 4.7: Simulink model of two area system without secondary loop

TABLE 4.3: System parameters for two area system without using secondary control

Name	Kg	Tg(s)	Kt	Tt(s)	H(s)	D(p.u.MW/Hz)	1/R	PL(p.u)
Area 1	1	0.20	1	0.50	5	0.60	20	0
Area 2	1	0.30	1	0.60	4	0.90	16	1

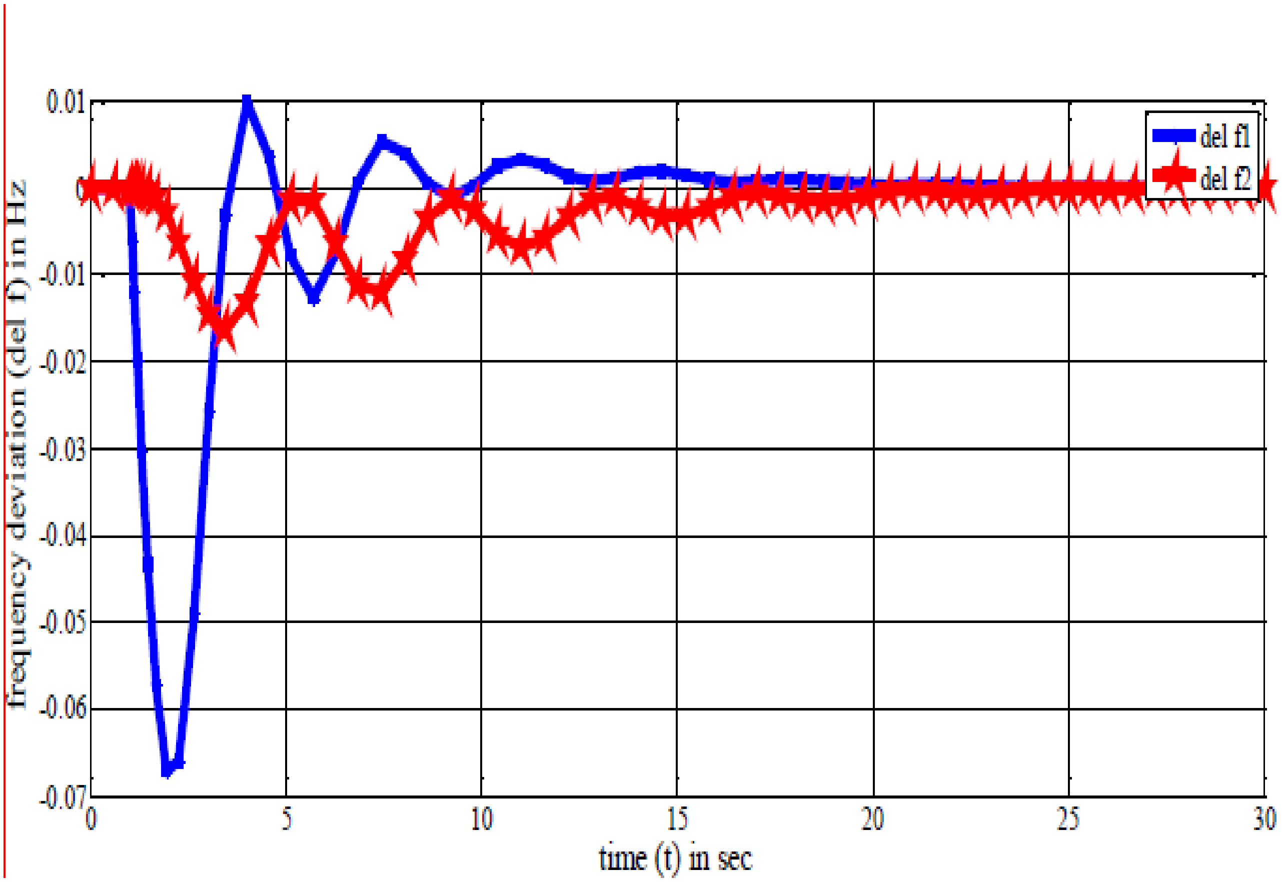


Fig. 4.8: Frequency deviation vs. time for two area system without using secondary loop

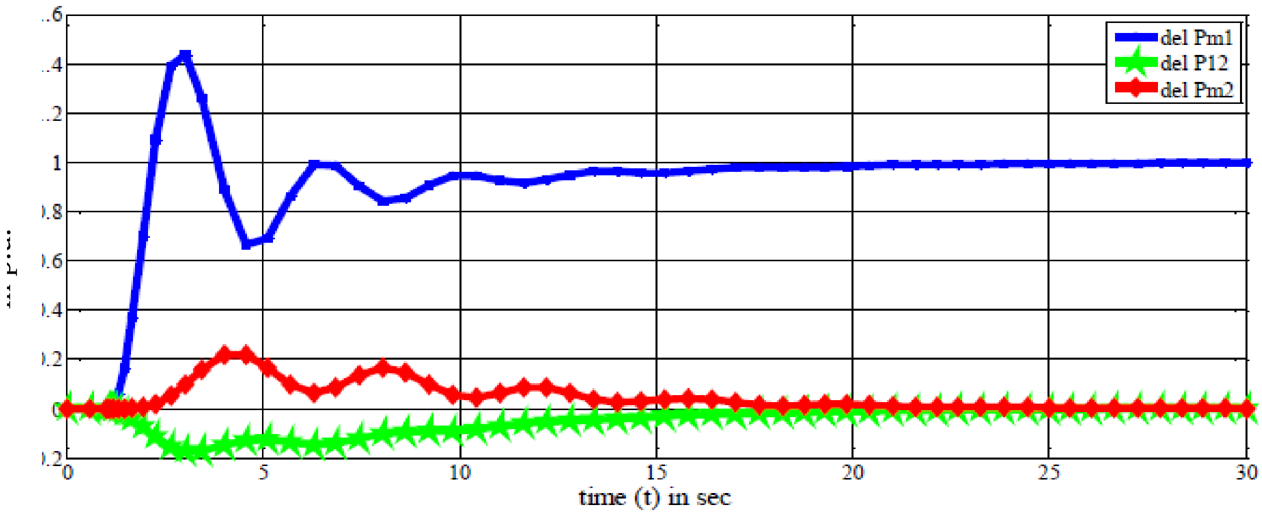


Fig. 4.9: Change in power output vs. time for two area without using secondary loop

Changes in flow of tie-line power might be observed with changes in disturbance by load in area 1 as given away in Fig. 4.9. Fig. 4.8 proves that the frequency can be resolved to a limited value which is less than the actual frequency. Although we get same results as area 1 but stability is improved with interconnection.

4.4. TWO AREA SYSTEM BY USING SECONDARY LOOP

Two area systems by using secondary loop are shown in Fig. 4.10. The secondary loop is responsible for the minimization of drifts in frequency to zero as shown in Fig. 4.11. By changing the secondary loop gain we can see the variation in the system dynamic response characteristics through tie line power as given away in Fig. 4.12. We have taken the values of the different parameters as shown in table 4.4 for modeling the simulink model and its successful operation to obtain the desired results.

. TABLE 4.4: System parameters for two area system by using secondary control

Name	Kg	Tg(s)	Kt	Tt(s)	H(s)	D(p.u.MW/Hz)	1/R	PL(p.u)	K1
Area 1	1	0.20	1	0.50	5	0.60	20	0	7
Area 2	1	0.30	1	0.60	4	0.90	16	1	7

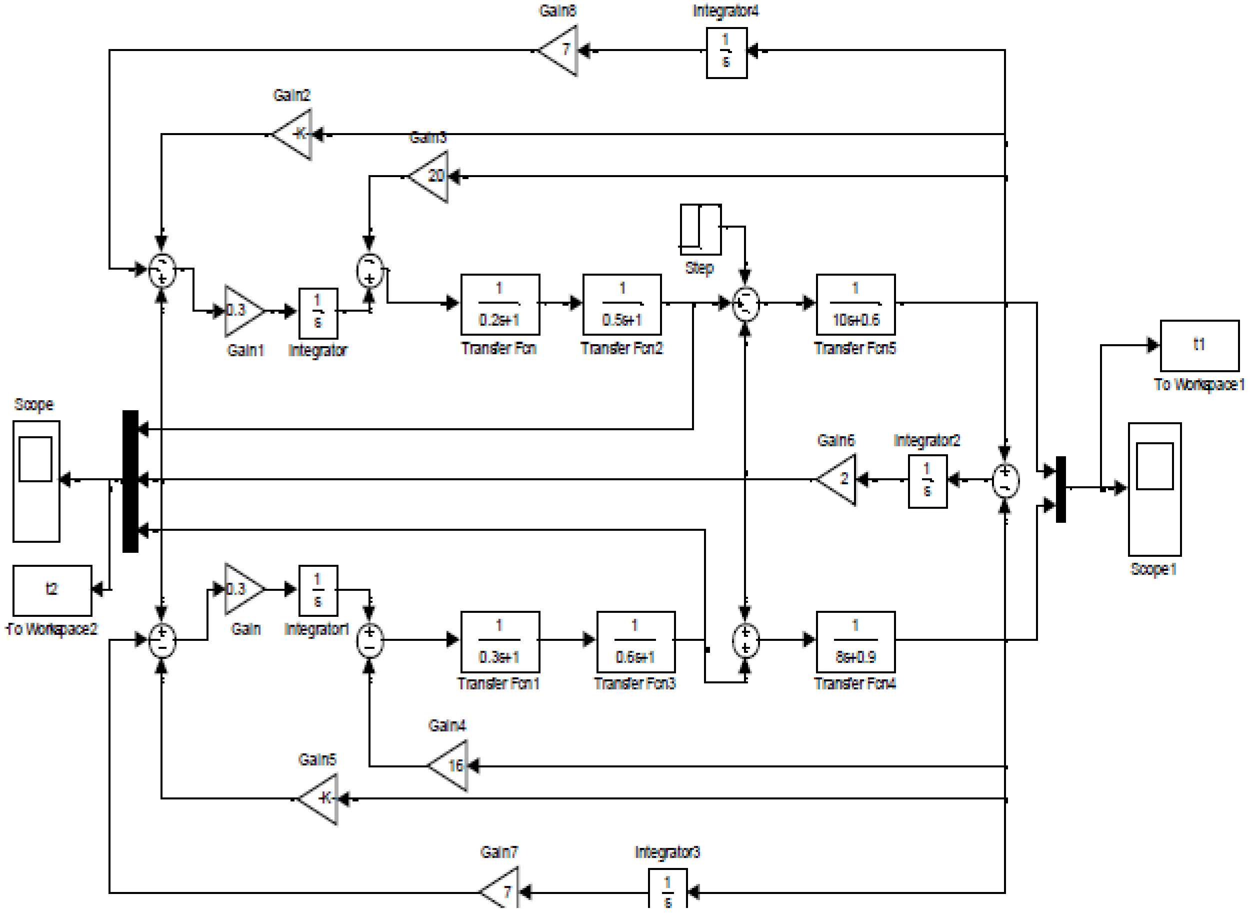


Fig. 4.10: Simulink model for two area system by using secondary loop

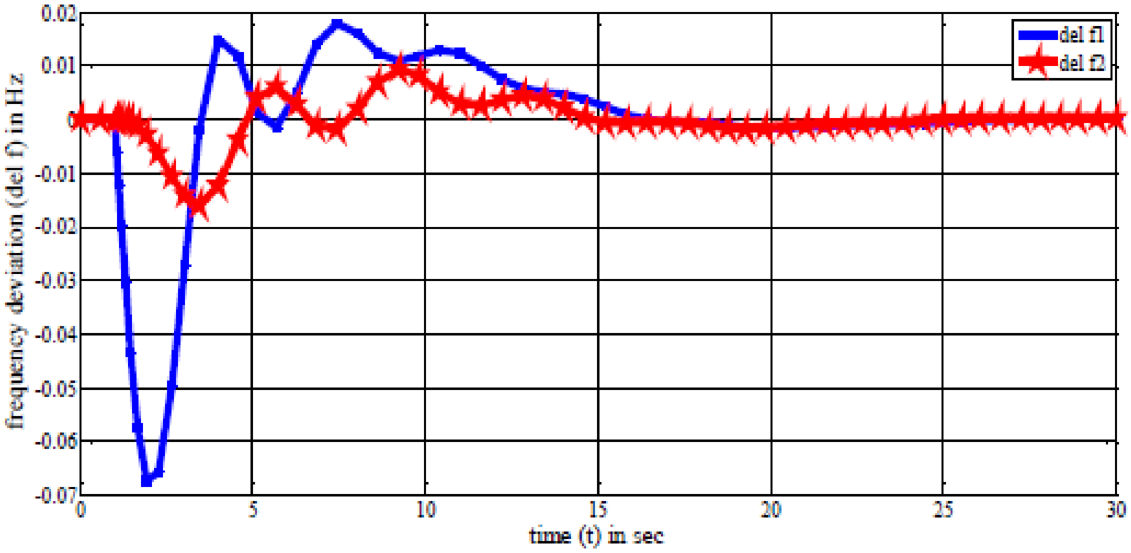


Fig. 4.11: Frequency deviation vs. time for two area by using secondary loop

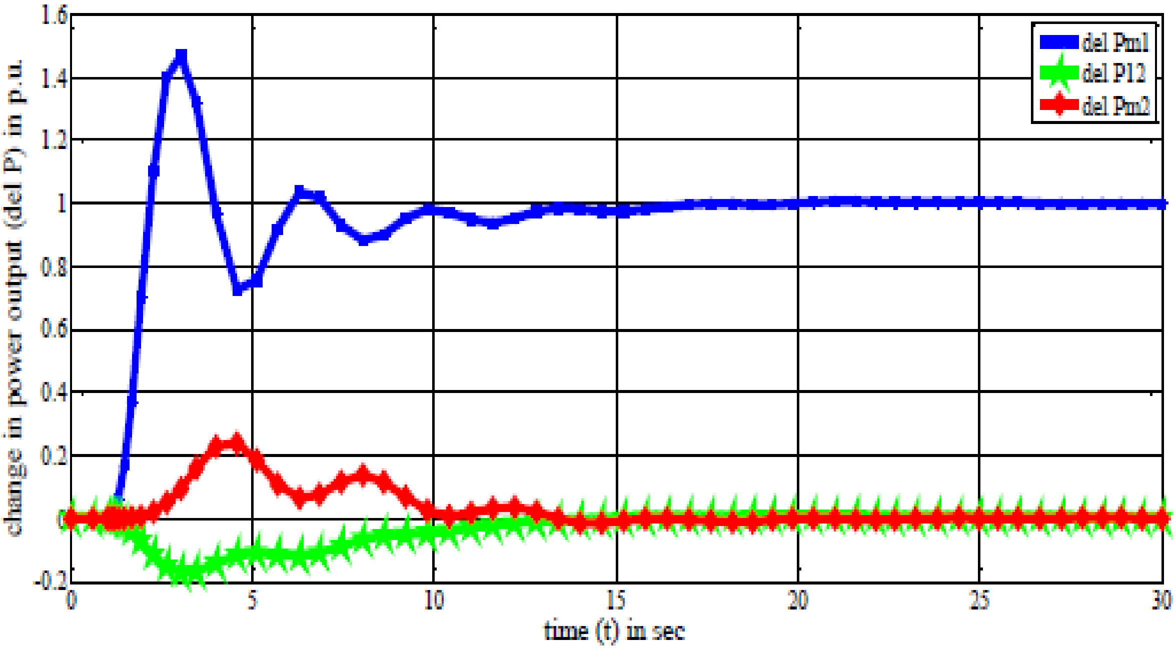


Fig. 4.12: Change in power output vs. time for two area by using secondary loop

4.5. THREE AREA SYSTEM WITHOUT USING SECONDARY LOOP

Three area interconnected systems without using secondary loop is given in Fig. 4.13. Fig. 4.14 represents the settling down of frequency to a finite value which is less than the actual frequency. Fig. 4.15 shows the power change due to tie- line on account of the deviation in the load. Here stability is improved with interconnection. We have taken the values of the different parameters as shown in table 4.5 for modeling the simulink model and its successful operation to obtain the desired results.

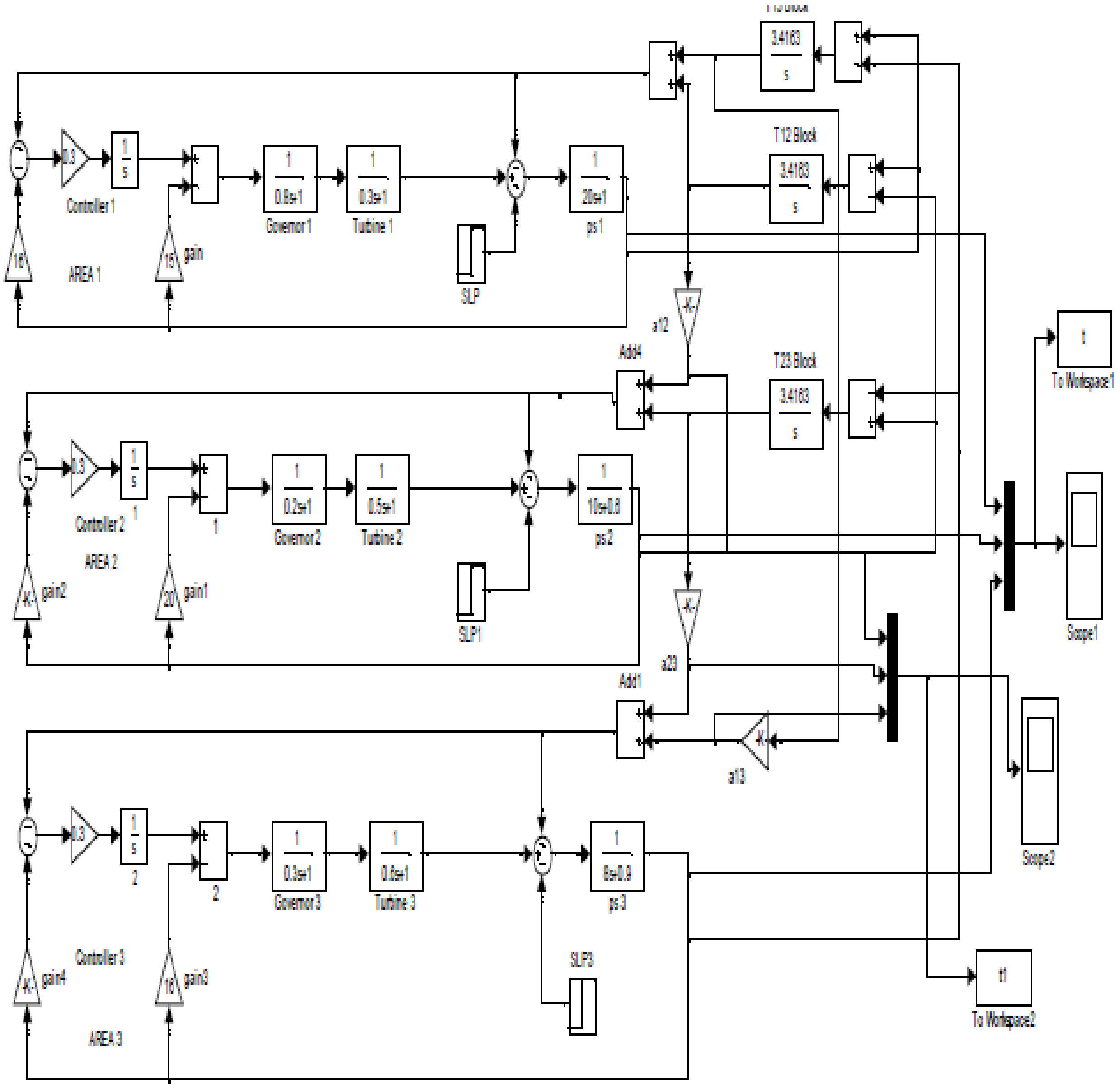


Fig.4.13: Simulink model of three area system without using secondary loop

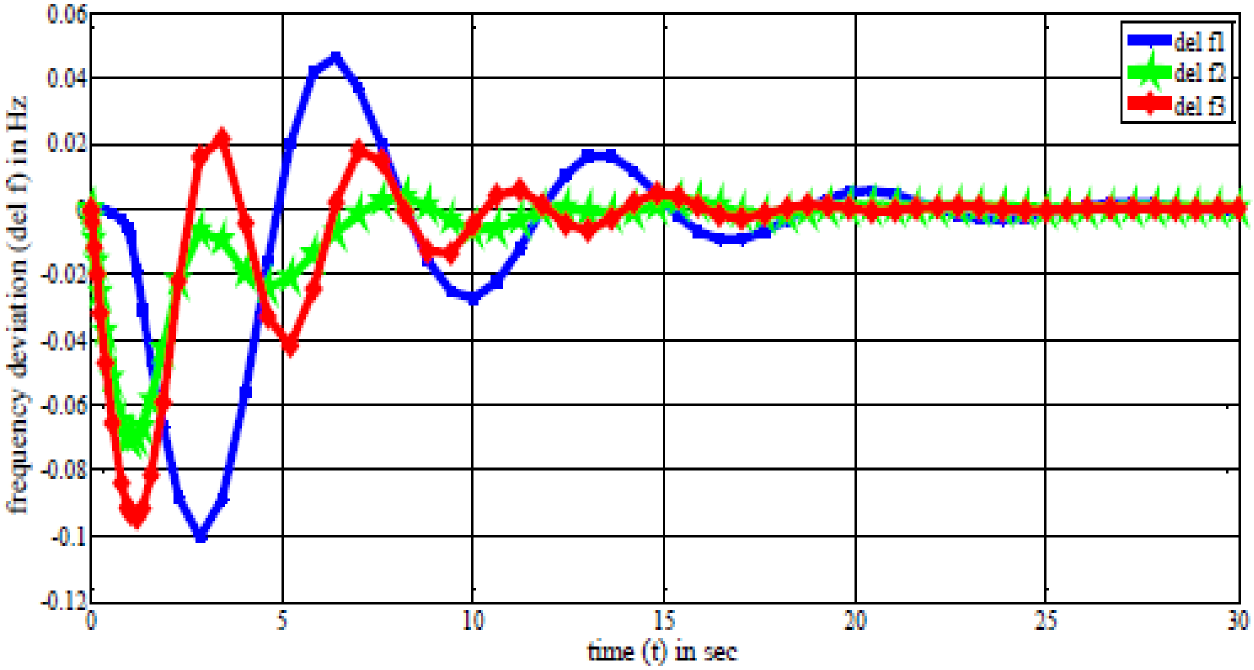


Fig:frequency deviation vs time for three area system without using secondary loop

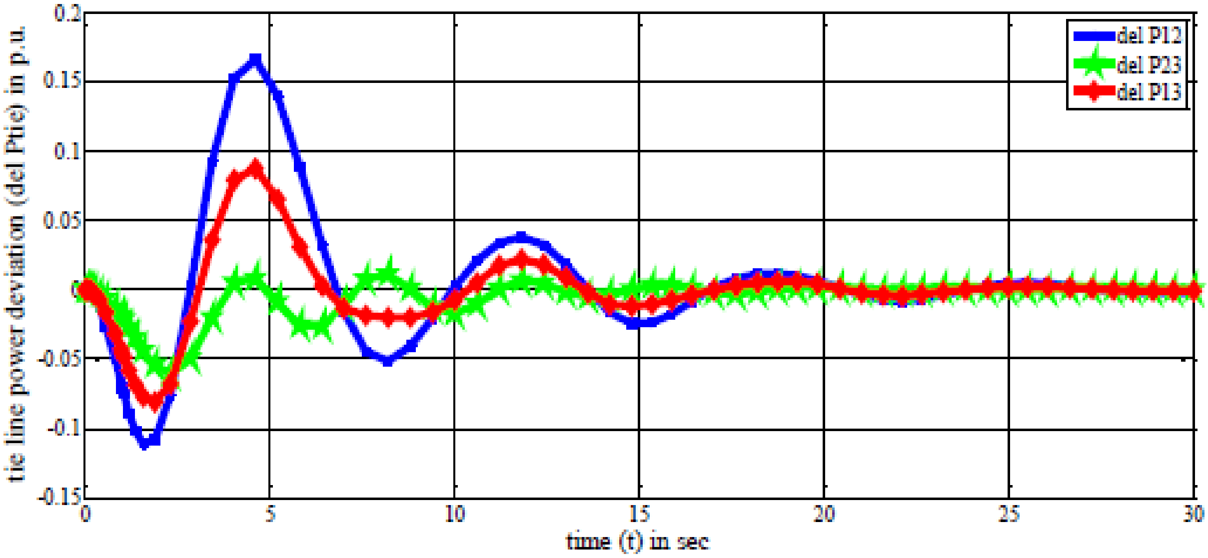


Fig. 4.15: Tie line power deviation vs. time for three area system without using secondary loop

Area 2	1	0.20	1	0.50	5	0.60	20	0
Area 3	1	0.30	1	0.60	4	0.90	16	0

4.6. THREE AREA SYSTEM BY USING SECONDARY LOOP

The model for the three area system including the secondary control is given away in Fig.4.16. The results of the variation in frequency as well as tie line power output with respect to time are being shown in Fig. 4.17 and Fig. 4.18.

The system operates in a similar way to that of the two area system, taking into consideration the changes in the load.

We have taken the values of the different parameters as shown in table 4.6 for modeling the simulink model and its successful operation to obtain the desired results.

TABLE 4.6: System parameters for three area system by using secondary control

Name	Kg	Tg(s)	Kt	Tt(s)	Tp (s)	H(s)	D (p.u.MW/Hz)	Ki	1/R	PL (p.u.)
Area 1	1	0.80	1	0.30	20	10	1.00	7	17	1
Area 2	1	0.20	1	0.50	10	5	0.60	7	20	0
Area 3	1	0.30	1	0.60	8	4	0.90	7	16	0

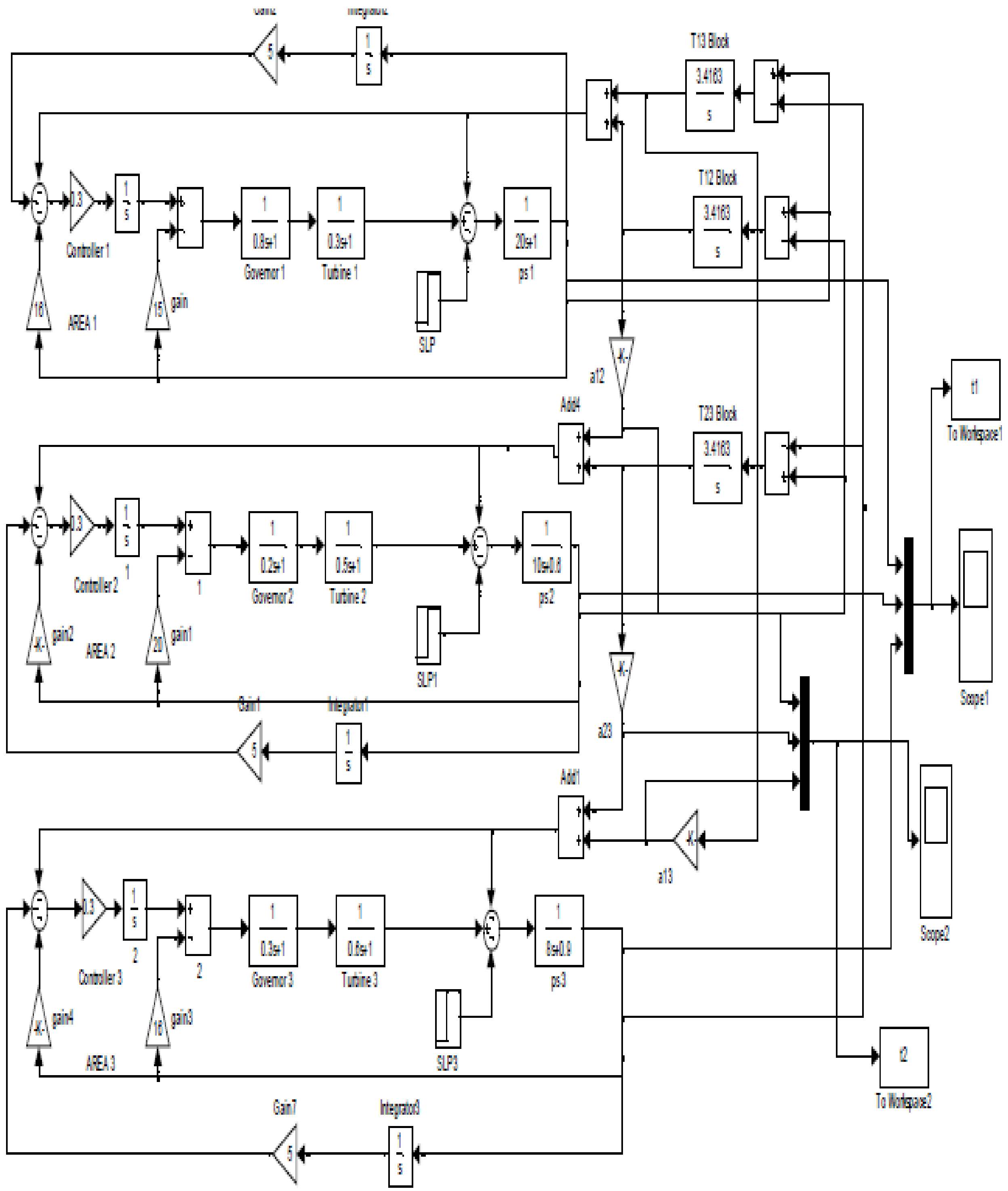


Fig. 4.16: Simulink model of three area system by using secondary loop

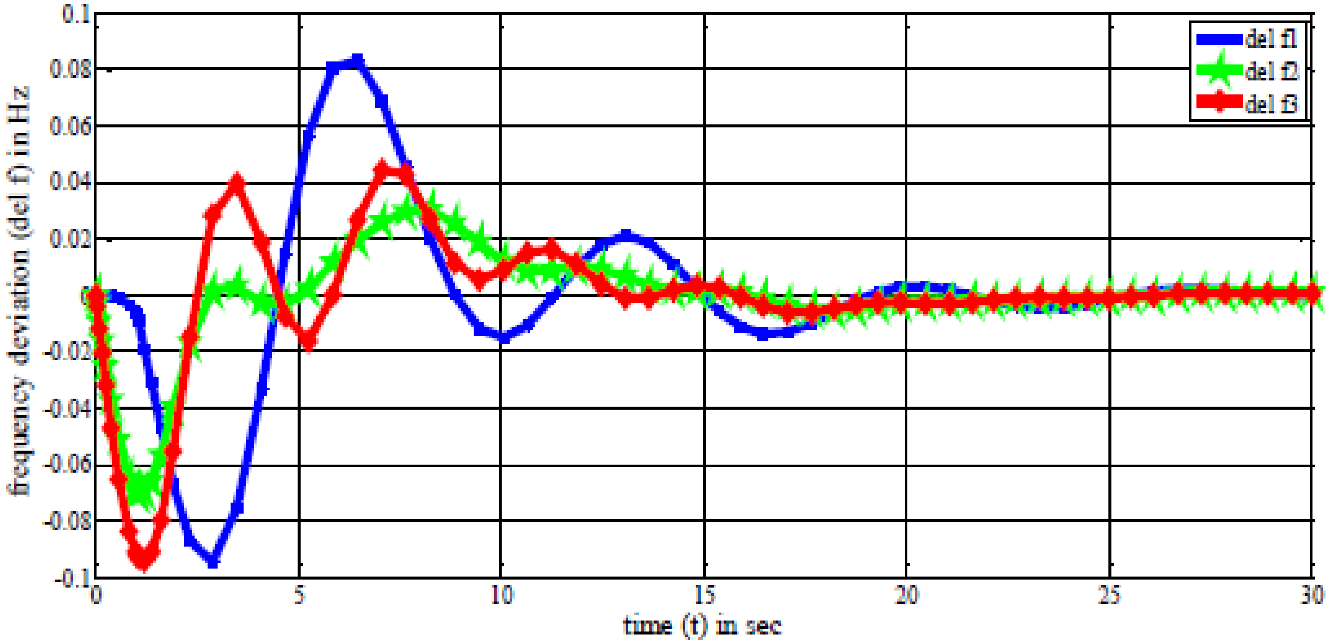


Fig.4.17: Frequency deviation vs. time for three area system by using secondary loop

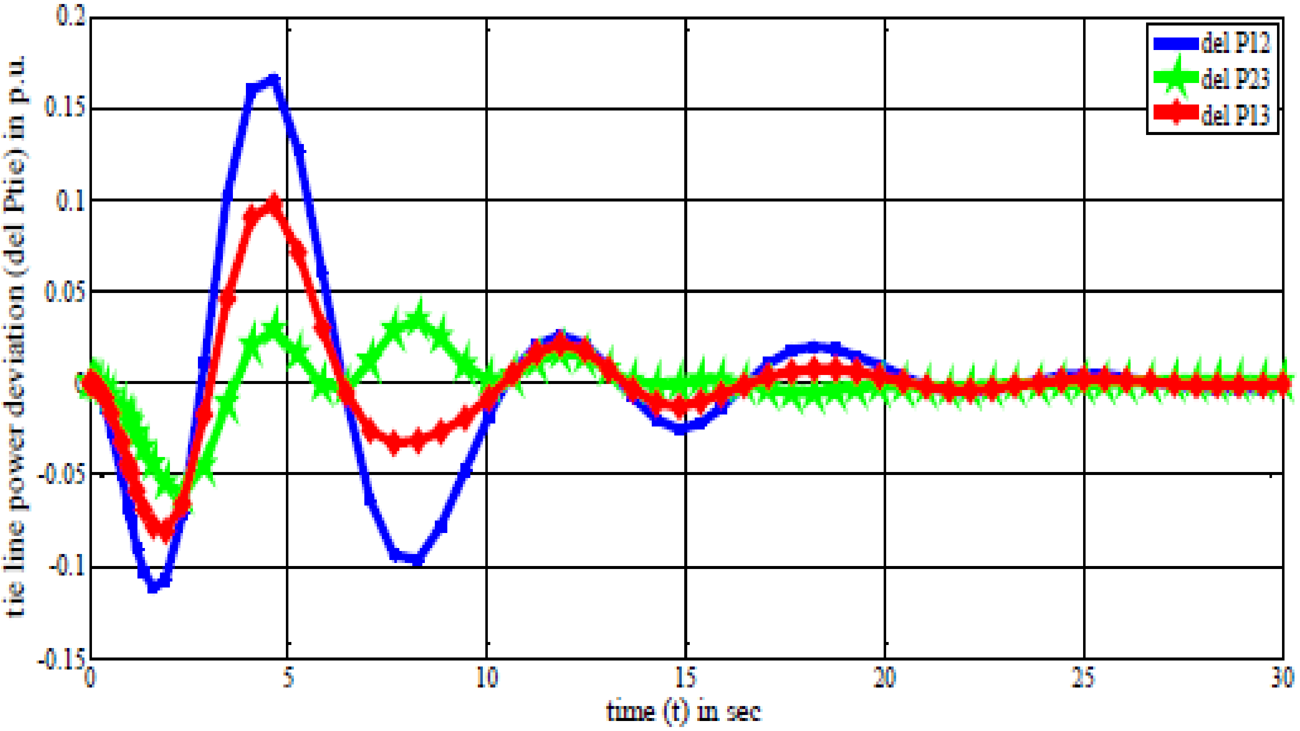


Fig.4.18: Tie line power deviation vs. time for three area system by using secondary loop

4.7. OBSERVATION

By considering the above-stated simulation graphs it could be seen that the system encounters drifts in the frequency succeeding a disturbance in the load and it is primarily because of the mismatch involving the electrical load as well as the mechanical input which is given to the prime mover/turbine. Fluctuations in the system is more in the single area system than two area systems for the reason that all the variations in the load are to be handled by one area only. Moreover variation in frequency is made to be zero by using a secondary loop in both single area in addition to two area systems. we also see that the three area system also operates in a similar manner like that of two area system.

4.8. CONCLUSION

Thus we see that developing models in SIMULINK help us to understand the principles behind LFC including challenges. In case A load changes so speed change and thus drifts in frequency is settled down near to a limited value and so new working frequency is less as compared to the supposed value. In case B frequency drift is made zero by integral loop. In case C there is stability improvement with interconnection. In case D secondary loop is responsible for making the frequency drift to zero value and by changing gain dynamic response is observed. In case E the system operates similar to that of case D although it consists of three control areas. Thus the advantage of interconnection is understood and we see that the dynamic response is chiefly administered by means of the secondary loop. But in case of three area system tuning of the parameters is quiet a tiresome work by using simple hit and trial method. Therefore we have opted for Bacteria Foraging Optimization Technique (BFOA) intended for tuning the various parameters of the system simultaneously by taking into consideration all the effects related to it.

CHAPTER 5

BACTERIA FORAGING OPTIMIZATION ALGORITHM (BFOA)

5. 1. INTRODUCTION

Bacterial foraging optimization algorithmic program (BFOA) could be a global optimization algorithmic program for distributed control, management and optimization. It is impressed as a result of the social hunt performance of Escherichia coli. BFOA is extremely economical to find a solution for dealing with real-world optimization issues. The thought about the foraging procedure of E.coli from the point of view of biology is emulated in a very remarkable and peculiar manner and used as an easy and reasonable optimization program. Bacteria Foraging Optimization Algorithmic program (BFOA), put forward by Passino [1], is one amongst the many optimization algorithms those are being inspired from the nature. Following a similar development of swarm-based algorithmic programs, Passino presented the BFOA. The use of cluster hunt policy of a group of E.coli bacterium in multi-optimal optimization of functions is the crucial thought of the above presented algorithmic program. Each bacterium looks around for nutrients in order to make the most of energy acquired per unit time. Individual bacterium simultaneously keeps up a correspondence with others by delivering signals. An individual bacterium will take foraging judgment after taking into consideration two prior factors. The process when a bacterium is all set for finding the nutrients with small steps is named as chemo taxis and principle concept of BFOA is chemo tactic locomotion mimicking within the region of problem search for the virtual bacterium.

Bacteria discover the direction to food in the surroundings on the basis of the gradients of chemicals. Similarly, bacterium secretes attracting along with repellant chemicals into the surroundings and is able to discover one another in the similar way. Locomotion mechanisms with the help of flagella, bacterium is used to make it able to move about in their surroundings, sometimes going around wildly (tumbling and spinning), and rest of the times moving in a determined path (swimming).

The bacterial cells are usually treated resembling mediators in particular surroundings, by means of their food perception and various other cells as a motivating factor to move about, and random tumbling as well as swimming movement on the way to re-locate. On the basis of the cell-cell interactions, cells might swarm a source of food, and/or might directly repel or else ignore one another.

Bacterial Foraging Optimization Algorithmic program is being used for reducing a cost function. Bacterium cost is determined by means of its interaction with various other cells. Calculation of this interaction function is done by using the parameters such as: a given cell, attraction coefficients, repulsion coefficients, the cells number within the population, the dimensions number on a given position vector of cells, the total number of cells maintained within the population, the total elimination-dispersal steps number, the total reproduction steps number, the total chemo taxis steps number, the total swim steps for a given cell, a random direction vector with identical range of dimensions because the problem region, and also the cells probability of being subjected to elimination plus dispersal.

CHARACTERISTICS

- The algorithmic program was intended for optimization problem domains applications
- The loops given within the algorithmic program, it could be designed in various ways to obtain completely dissimilar search behavior. It is normal to possess a great number of chemo taxis iterations, in addition to other iterations in small number.
- The swarming behavior coefficients with their default values.
- The step size is generally a minor portion of the search region, such as 0.1.
- At the time of reproduction, generally half of the total population having a lesser profile according to the health meter are not taken into consideration, and two replicas of every member from the first half i.e. the greater-health region of the population are being kept back.The probability of elimination as well as dispersal (P_{ed}) is usually placed relatively high, for example 0.25.

5.2. DESCRIPTION

During the foraging process of a true bacterium, locomotion is accomplished by means of a group of flagella which is tensile. Flagella facilitate an *E.coli* bacterium to undergo tumble or swim. These two are the essential operations carried out by a bacterium during foraging. While they turn around the flagella in the clockwise direction, every flagellum drags the cell such that the flagella moves freely and eventually the bacterium tumbles with reduced number of tumbling but during a damaging situation it tumbles often to seek out a nutrient gradient.

The movement of the flagella in the counterclockwise direction promotes the swim of the bacterium at quite a very faster speed and the bacterium undergoes chemo taxis in which they prefer to travel towards a nutrient gradient by avoiding toxic surroundings. Typically the bacterium moves for an extended distance during a favorable surrounding.

When they search out sufficient food they elongate length wise and in existence of appropriate temperature they breakdown in the central point portion to form two exact duplicates. This phenomenon shows reproduction in BFOA. Events of unexpected changes in environmental conditions or attack destroy the chemo tactic progress furthermore a set of bacteria move to another places or some other are introduced to the concerned swarm. Thus the process of elimination-dispersal takes place in the population. Each and every bacterium in that particular region is either killed or a cluster of bacteria is moved to a new location.

Thus it can be said that BFOA consists of four chief mechanisms as seen in an actual bacterial system: chemo taxis, swarming, reproduction, elimination-dispersal to resolve an optimization problem. A virtual bacterium is in fact a trial answer or a search mediator which moves on the functional plane to find the global optimum.

Let us consider

b = The indicator for the chemo tactic step

c = The indicator for the reproduction step

d = The indicator for the elimination-dispersal event
p = Search space dimension
S = Number of total bacteria within the population,
Sc = Chemo tactic steps number
S_s = Length for swimming
S_{re} = Reproduction steps number
S_{ed} = Elimination dispersal steps number
P_{ed} = Probability of elimination-dispersal
C(a) = Step size considered randomly in any direction stated by the tumble

The four processes in BFOA are described below:

i) Chemo taxis

In this process the bacteria moves in hunt of food in two different ways: swimming in addition to tumbling with the help of flagella. The bacterium will swim in the predetermined direction and it will tumble by moving in different directions. By deciding upon the flagella rotation of each bacterium, the decision is made about going for swimming or else tumbling in their whole lifetime. During chemo taxis the movement of the bacterium can be shown by

$$\theta^{a}(b+1, \mathrm{c}, \mathrm{d}) = \theta^{a}(\mathrm{b}, \mathrm{c}, \mathrm{d}) + C(\mathrm{a})\Phi(\mathrm{a}) \tag{50}$$

i.e.
$$\theta^{a}\left(b+1, \mathrm{c}, \mathrm{d}\right) = \theta^{a}\left(\mathrm{b}, \mathrm{c}, \mathrm{d}\right) + C\left(a\right)\frac{\Delta\left(a\right)}{\sqrt{\Delta^{T}\left(a\right)\Delta\left(a\right)}} \tag{51}$$

Where indicates a vector in the haphazard direction whose elements lie in [-1, 1].

ii) Swarming

During this process a group of bacteria move concentrically and arrange themselves as itmoves towards the richest food location. As a result of which it attracts other bacteria and rapidly converges to a point which gives us the desired solution point. Mathematically it can be shown by the function as follows

$$J_{cc}(\theta, P(\mathrm{b,c,d})) = \sum_{a=1}^{S} J_{cc}^{a}(\theta, \theta^{a}(\mathrm{b,c,d}))$$

$$= \sum_{a=1}^{S} [-d_{attract} \exp(-\omega_{attract} \sum_{m=1}^{p} (\theta_m - \theta_m^a)^2]$$

$$+ \sum_{a=1}^{S} [-h_{repelent} \exp(-\omega_{repelent} \sum_{m=1}^{p} (\theta_m - \theta_m^a)^2] \qquad (52)$$

Where $J_{cc}(\theta, P(b,c,d))$ = the objective function value to be added to the objective function (to be reduced) to show a time changeable objective function

S = number of total bacteria

p = number of variables to be optimized those are existing in each bacterium

$d_{attarct}, w_{attract}, h_{repelent}$ and $w_{repelent}$ = various coefficients that must be selected correctly.

iii)Reproduction

After going through the chemo tactic process the bacteria moves on to the reproduction stage. During this process the bacteria having low health profile eventually die where as each one of the bacteria that is healthier (that yields the objective function having a lesser value) asexually divide into two bacterium, that are then located in the similar location. This is liable to keep the fixed value of the population of the bacteria.

$$J^{a}_{health} = \sum_{b=1}^{S_c+1} J(a,b,c,d) \qquad (53)$$

iv) Elimination and Dispersal

This progression deals with the removal of bacteria as a result of gradual and unexpected variations in the local surroundings where the population of the bacteria might degrade caused by different reasons like considerable rise of temperature or some other sudden influence might put to death a set of bacteria which are present in a particular region. Sometimes there may be some cases which might destroy all the bacteria in a area or disperse a set of bacteria to a new favorable location. Rather than disturbing the whole process the bacteria can find the desired food location during this particular process only so that we can obtain the desired solution point. To simulate the above presented event in BFOA a number of bacteria are being liquidated randomly with a very little probability whereas the new substitutes are being initialized randomly over the region of search.

5.3. THE BFO ALGORITHM

BFO Parameters initialization

- S = total sample number of the bacteria that is to be utilized for finding in the sample region.
- P = total quantity of parameters to be optimized. Here either KIi or (KIi and Ri) or (KIi, Ri and Bi) are optimized
- Ss = length of swimming subsequent to which the tumbling takes place in a chemo tactic loop.
- Sc = iterations number in a chemo tactic loop.
- Sre = utmost number of steps of reproduction
- S = total sample number of the bacteria that is to be utilized for finding in the sample region.

- P = total quantity of parameters to be optimized. Here either KIi or (KIi and Ri) or (KIi, Ri and Bi) are optimized.

- Ss = length of swimming subsequent to which the tumbling takes place in a chemo tactic loop.

- Sc = iterations number in a chemo tactic loop.

- Sre = utmost number of steps of reproduction.

- Sed = utmost number of elimination and dispersal action forced on the bacteria.

- Ped = probability for the continuation of elimination as well as dispersal process.

- Each bacterium P has a location that is stated by the arbitrary quantities within [1,-1].

- Value of C(a) is considered to be fixed for simplification.

II. Algorithm for optimization

1) Elimination-dispersal loop: $d=d+1$

2) Reproduction loop: c=c+1

3) Chemo taxis loop: $b=b+1$

i) For a =1, 2,…S take a chemo tactic step for bacterium a and calculate fitness function, $J(a, b, c, d)$.

Let,

$$J_{sw}\text{ (a, b,c,d)} = J\text{ (a, b,c,d)} + J_{cc}\ (\theta^{a}\text{ (b,c,d)}, P\text{ (b,c,d))} \qquad (54)$$

(i.e. insert on the cell-to cell attractant–repellant effect/profile for simulating the behavior of swarming)

Where,

$$J_{cc}(\theta, P(\mathrm{b,c,d})) = \sum_{a=1}^{S} J_{cc}^{a}(\theta, \theta^{a}(\mathrm{b,c,d}))$$

$$= \sum_{a=1}^{S}[-d_{attract}\exp(-\omega_{attract}\sum_{m=1}^{p}(\theta_m - \theta_m^a)^2]$$

$$+\sum_{a=1}^{S}[-h_{repelent}\exp(-\omega_{repelent}\sum_{m=1}^{p}(\theta_m - \theta_m^a)^2]$$

Let J_{last}=J_{sw} *(a, b, c, d)* to preserve this quantity because we might get a improved cost through a run.
End for this loop

[ii] For *a* = 1, 2,..S tumble/swim decision is taken.

Tumble: the random vector (*a*) is generated on [-1, 1].

Move: Let

$$\theta^{a}(b+1,\mathrm{c,d}) = \theta^{a}(\mathrm{b,c,d}) + C(a)\frac{\Delta(a)}{\sqrt{\Delta^{T}(a)\Delta(a)}} \qquad (55)$$

This gives us a step of size *C* (a) in the path of the tumble for *a-th* bacterium.

Calculate *J* (a, b + 1, c , d) and let

$$J_{sw}(\mathrm{a,b+1,c,d}) = J(\mathrm{a,b+1,c,d}) + J_{cc}\left(\theta^{a}(b+1,\mathrm{c,d}), P(b+1,\mathrm{c,d})\right) \qquad (56)$$

Swim

- ➢ Let *mswim*=0 (counter for swim length).

- ➢ While *mswim*< S_s (if haven't brought down excessively long).

- Let *mswim*=*mswim*+*1*.
- If J_{sw} (a, b + 1, c , d) =J_{last} (if doing better), let $J_{last} = J_{sw}$ (a, b + 1, c , d) and let

$$\theta^a(b+1,c,d)=\theta^a(b,c,d)+C(a)\frac{\Delta(a)}{\sqrt{\Delta^T(a)\Delta(a)}} \qquad (57)$$

And use this θ^a *(b + 1, c, d)* to find the new *J (a, b + 1, c , d).*

- Else, let *mswim*= S_s.
- This ends the while statement.

[ii] Go to the just succeeding bacterium (*a*+*1*) suppose $a \neq S$ (i.e., go to [ii] to continue with the successive bacterium)

4) If $b < S_c$, proceed on to step 3 and carry on with the chemo taxis process since the lifetime of the bacteria isn't ended.
5) Reproduction:

[i] For the known *c* and *d*, and for every *a* = 1,2,…, *S* , let

$$J^a_{health} = \sum_{a=1}^{S_c+1} J_{sw}(a,b,c,d) \qquad (58)$$

be the fitness of the bacterium *a* (a quantity of the number of nutrients it acquired during its lifespan moreover how efficient it was at overcoming toxic substances).

Arrange bacteria and also chemo tactic parameters C (a) in sort of ascending cost J_{health} (high cost gives low health).

[ii] The bacterium with the maximum J_{health} values die and the rest of the S_r bacteria possessing the best values divide (this method is performed by the group of bacteria that are being placed at the similar location where the parent was present).

6) If $c < S_{re}$, proceed on to step 3 because we haven't reached the specified quantity of reproduction steps and therefore we begin the succeeding generation of the chemo tatic method.

7) Elimination-dispersal: For $a = 1,2...,\ S$ possessing probability Ped every bacterium is eliminated and dispersed so as to keep the quantity of bacteria present in the population to a constant value. During this process if a bacterium is removed then simply scatter a new one to any arbitrary position on the optimization domain. When $d = Sed$ then move on to step 2 else end it.

8) Obtain the optimized values of the parameters.

9) Employ BFO for final updating of the various parameters as desired in the system.The flow chart for the Bacteria Foraging Optimization algorithm is as below in the Fig. 5.

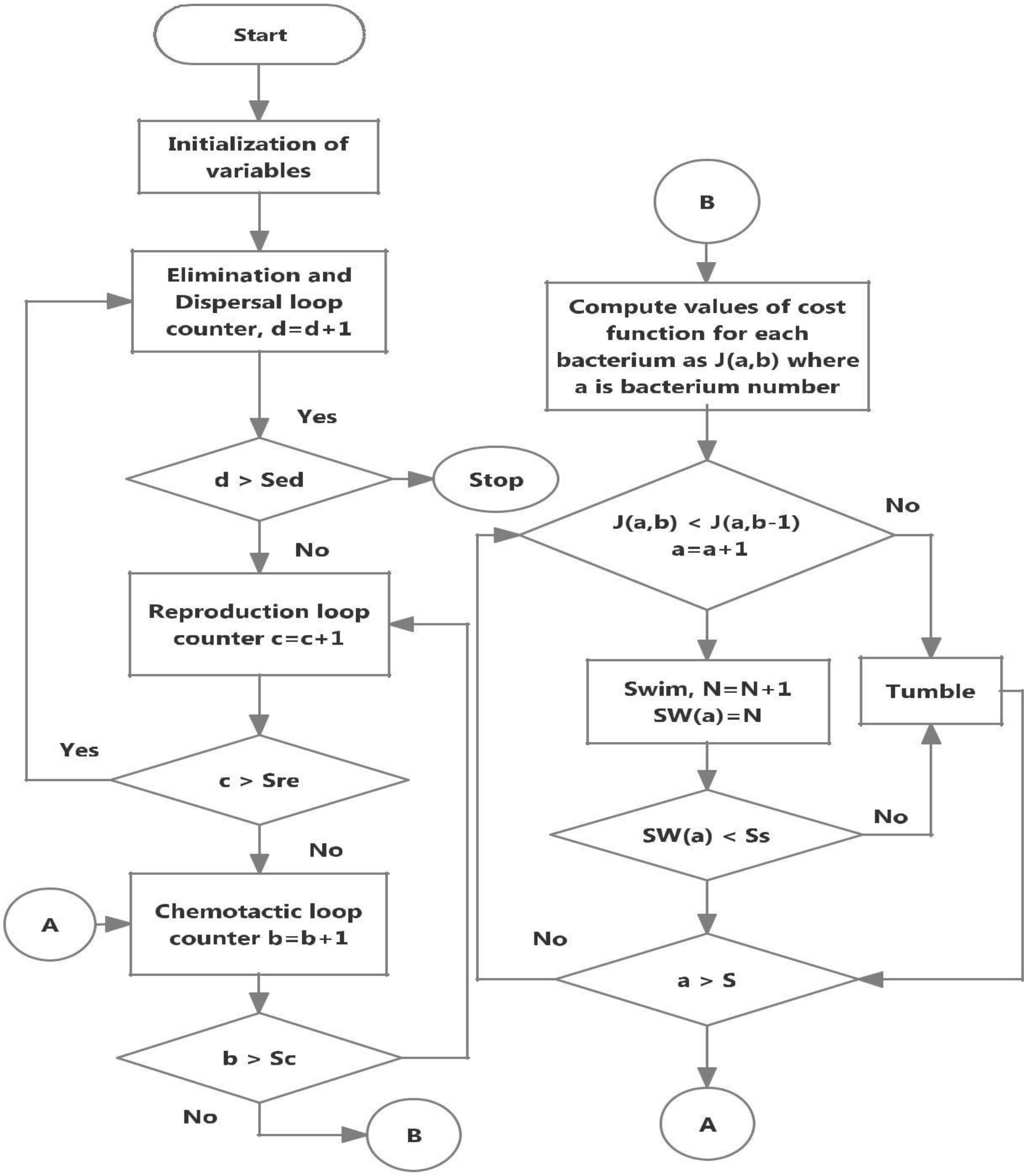


Fig. 5.1**:** Flowchart of the Bacteria Foraging Algorithmic program

CHAPTER 5

5.4. APPLICATION OF BFOA TO THREE AREA POWER SYSTEM

The useful purpose of bacteria foraging (BF) is to optimize many vital constraints in automatic load frequency control (ALFC) of interrelated three unequal area thermal systems, like gains of integral controller for the secondary control, parameters for regulation of governor speed for primary control as well as parameters for frequency bias. BF algorithmic program is very fast to optimize the various parameters which results in decrease in computational load and leading to minimum utilization of resources for the computer. Simultaneous optimization of Ki, Ri and Bi parameters results not only in the most excellent dynamic response for the system but as well make it possible for us to use much higher values of R which will prove to be helpful to the power industries for trouble-free and cheaper governor realization.

A system of electric energy should be kept at a most wanted operational point described by desired frequency, voltage and also load flow. This can be often attained by close control and management of real along with the generation of reactive powers in the course of the manageable supply of the system. Automatic generation control (AGC) or Automatic load frequency control (ALFC) performs a major part in the power grid by achieving scheduled system frequency and also tie line flow throughout the course of general operating circumstances and also through small perturbations. Numerous surveys of isolated along with interconnected power systems is being performed and presented in the past.

For every optimization method the convergence plus also the optimal quantity acquired are necessary. Classical integral or else controllers having proportional integrals by taking into account integral sq. error (ISE) criterion for their respective gains optimization are to a certain extent in trend. The gain optimization for such classical controller is sort of complicated and time taking process.

When several numbers of parameters that needs to be optimized is huge enough, classical technique for the purpose of optimization is never chosen. Some authors have utilized genetic algorithmic program (GA) to optimize gains of controller for a multi-area AGC system at the same time a lot more efficiently than is feasible with traditional approach. Here the optimization of parameters of secondary control, primary control plus frequency bias is being carried out all together for an AGC system so as to investigate as well as check their optimum values for every area under consideration and their exact effect on the complete dynamics of the respective system as made comparison to the case when only gains of secondary control is being optimized, taking into consideration the values of parameters for regulation of governor speed (Ri) and also parameters for frequency bias (Bi) identical as generally employed in reality. Optimization of parameters simultaneously at the same time additionally throws new conclusions for governor function and layout.

To get rid of the chances of being captured into local minima, no more than two operations crossover along with mutation is being performed. Current research and analysis has brought to notice a few deficiencies in GA performance i.e. the premature convergence of GA make a down fall in its efficiency and decreases search capability. To get out of this problem a new advanced and powerful computational intelligence method bacterial foraging (BF) is employed where we have the several number of parameters that are utilized for searching the whole space for solution is far more greater compared to the ones in GA and therefore the chance of prevailing local minimum in BF is far more greater than in GA. BF technique in the meantime has been put to use productively in a number of the areas in the field of electrical engineering and the superiority of BF over GA is shown clearly.

Thus we’ve got the relevance of BF method for optimization of many factors simultaneously like integral controller gains (KIi), for control of secondary loop, parameters for speed regulation of the governor (Ri) for control of primary loops along with parameters of frequency bias (Bi) for AGC of a three unequal area thermal power grid. It offers through investigation of the dynamic responses and then makes the comparison with those obtained with instantaneous optimization of KIi only (keeping Ri and Bi at values utilized in reality) or else simultaneous optimization of KIi and Ri only (keeping Bi at values utilized in reality) such that one can investigate what important results are lost when we aren't optimizing all the parameters (KIi, Ri, and Bi) at the same time. The performance of BF technique is seen.

5.5. SYSTEM INVESTIGATED

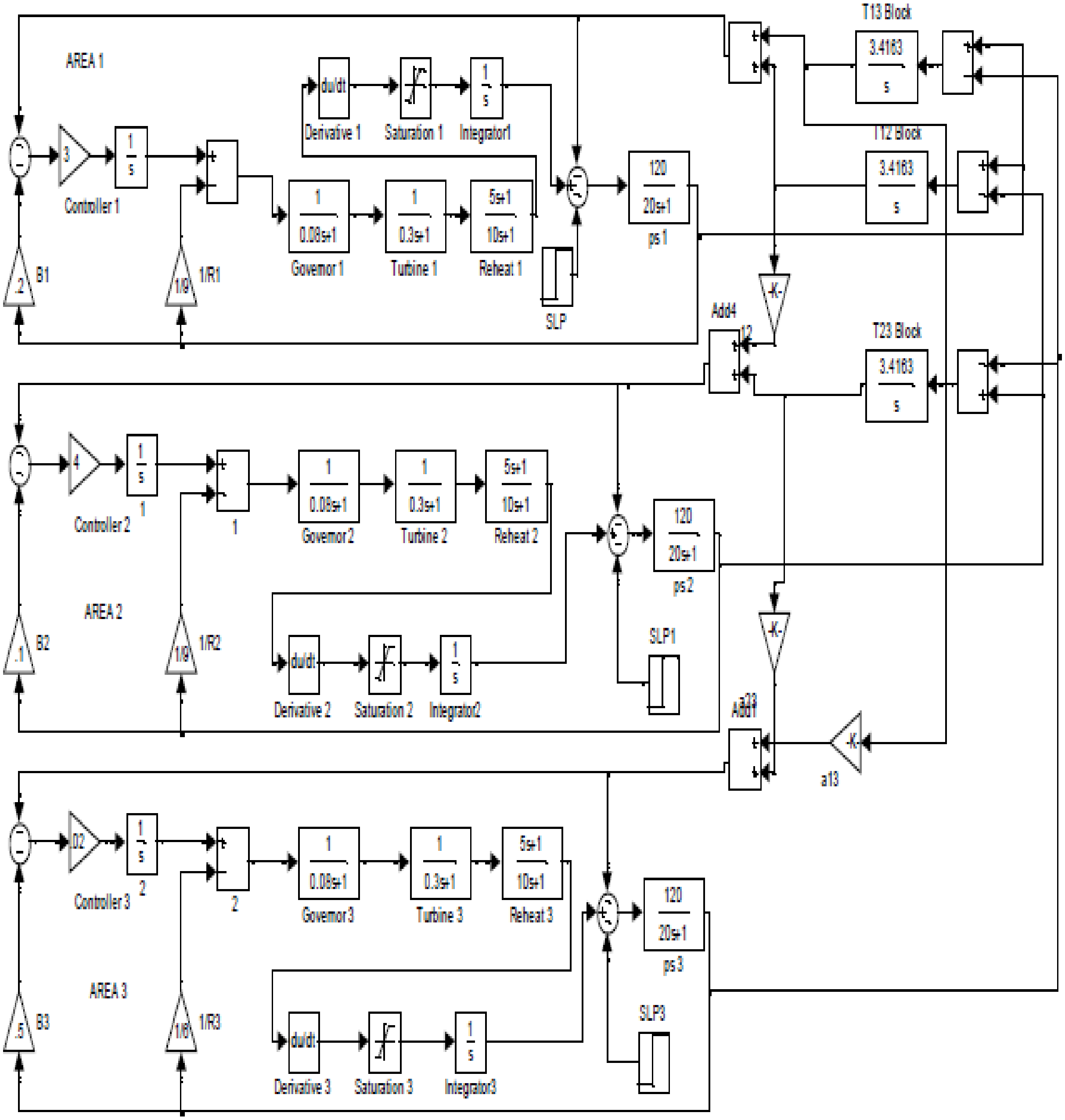


Fig. 5.2: Model of a three-area thermal system

Examinations have been dispensed on three area systems that are not equal. The systems are designed by using single reheat turbines along with integral controllers. We are using MATLAB version 7.01 to acquire dynamic responses.

During the modeling of interlinked areas having capacities that are unequal, the quantities, and are taken into account. The thought given by Elgerd and Fosha [4] can be utilized for the system modeling. The three-area system's transfer function model is as shown in Fig. 5.2

5.6. SIMULATION RESULTS USING BFOA

Three cases is being considered for the study and examination of the three area system based on the number of parameters that are being optimized at a time using the bacteria foraging technique. These are as follows:

CASE A:

Here only one parameter is optimized i.e. the integral gains (KIi) of the three areas are only optimized and the values of speed regulation parameter Ri=2.4 and frequency bias setting Bi=βi=0.425 for three areas respectively.

CASE B:

Here two parameters are optimized i.e. the integral gains (KIi) and also the values of speed regulation parameter (Ri) for the three areas are optimized. The frequency bias setting for the three areas is Bi=βi=0.425 respectively.

CASE C:

"Here there is simultaneous optimization of all the three parameters, the integral gains (KIi), the values of speed regulation parameter (Ri) as well as the frequency bias setting (Bi) which is usually considered equal to βi.

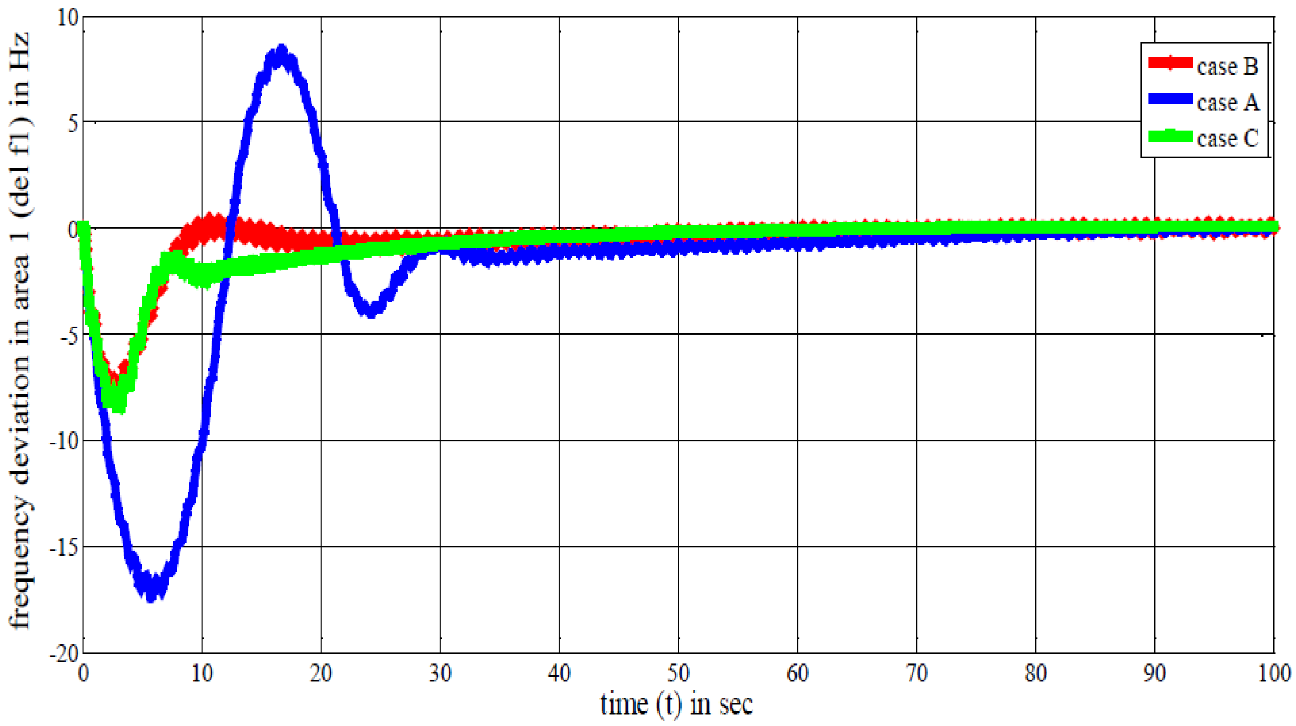


Fig 5.3:Frequency deviation in area1 vs. time

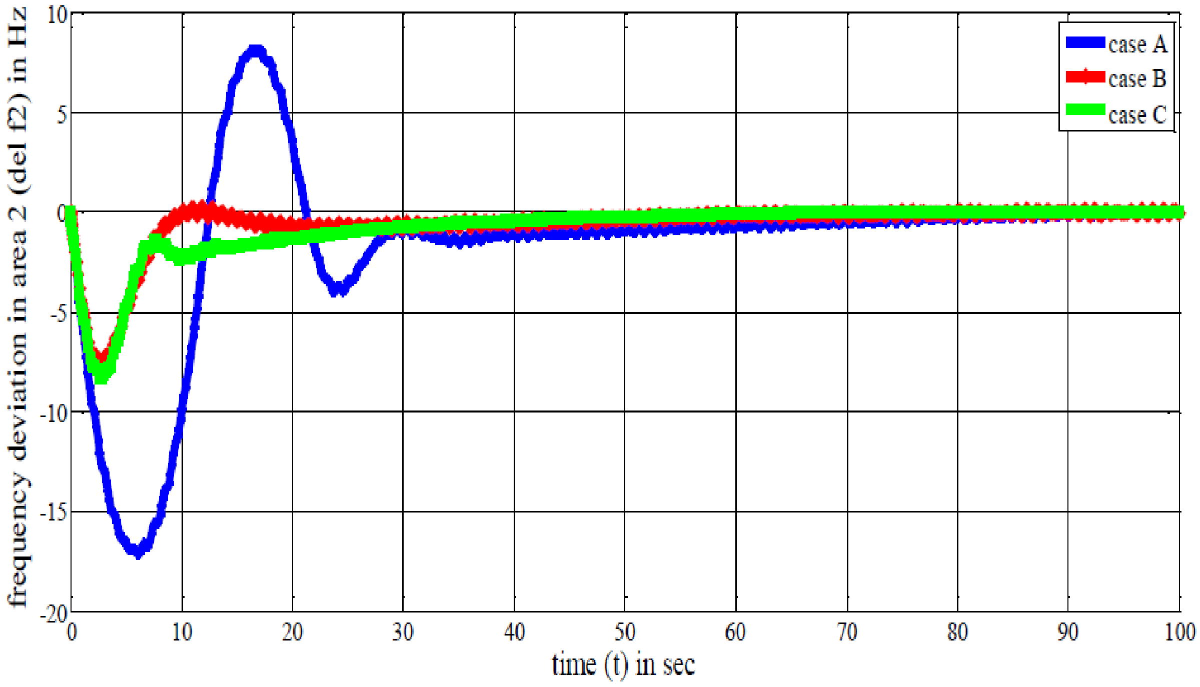


Fig 5.4:Frequency deviation in area 2 vs. time

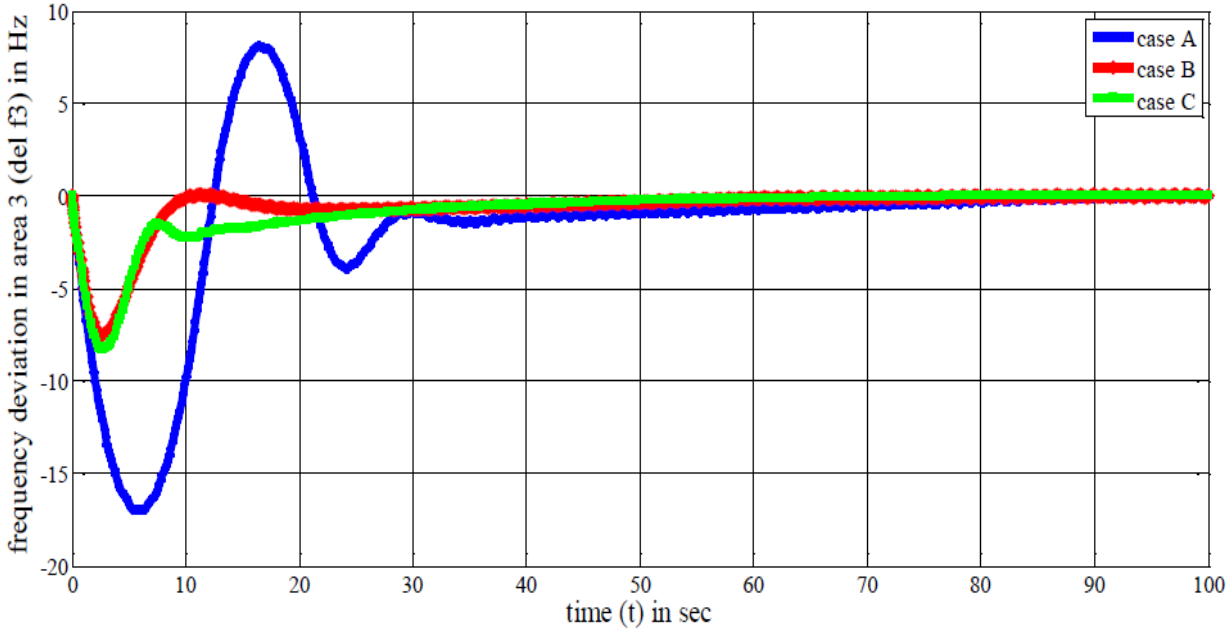


Fig 5.5:Frequency deviation in area 3 vs. time

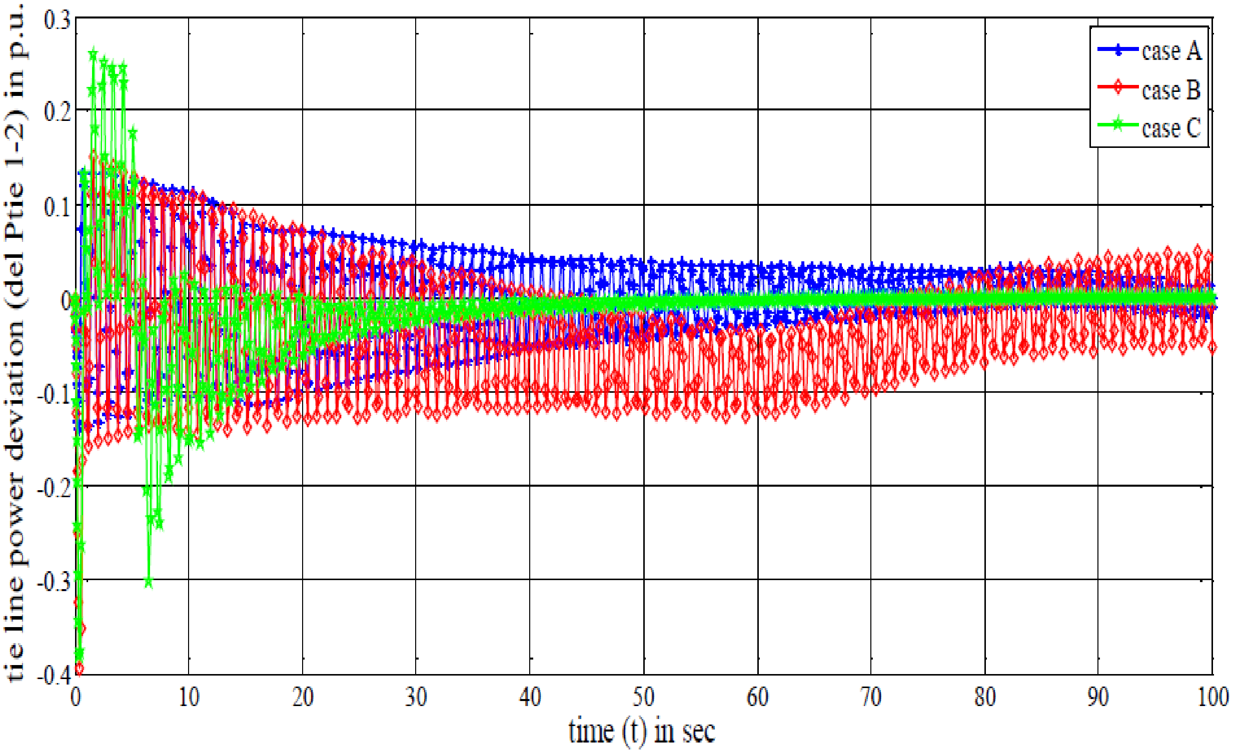


Fig 5.6:Tieline power deviation involving area1 and area 2 vs. time

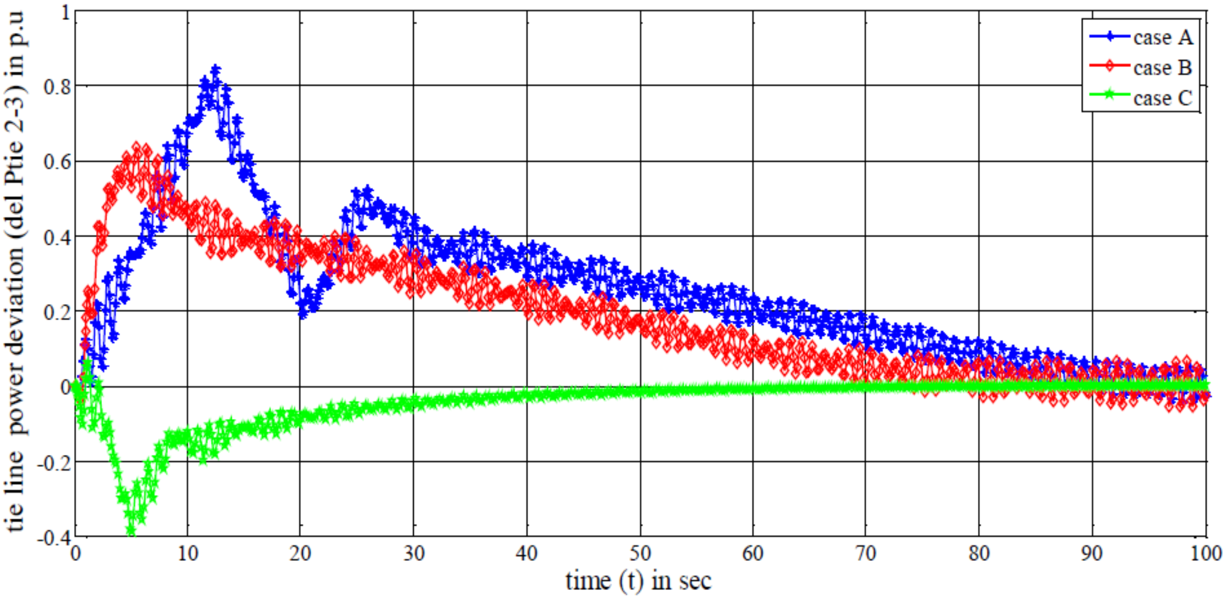


Fig 5.7:Tieline power deviation involving area 2 and area 3 vs. time

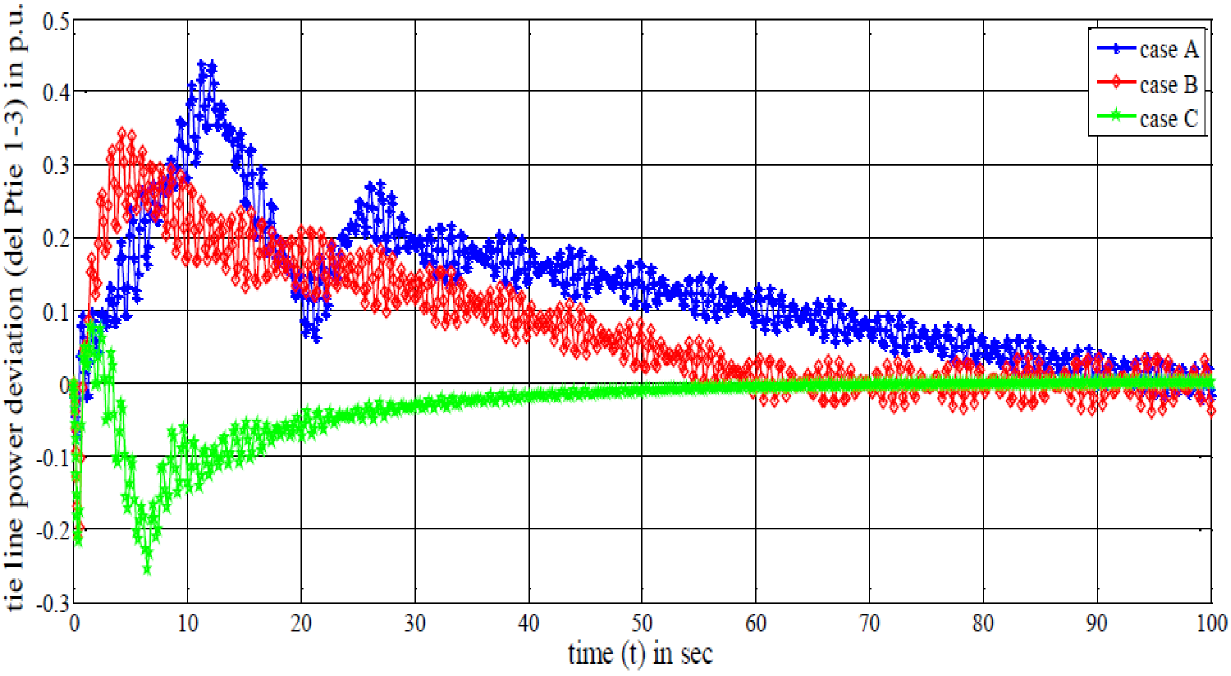


Fig 5.8:Tieline power deviation involving area 3 and area 1 vs. time

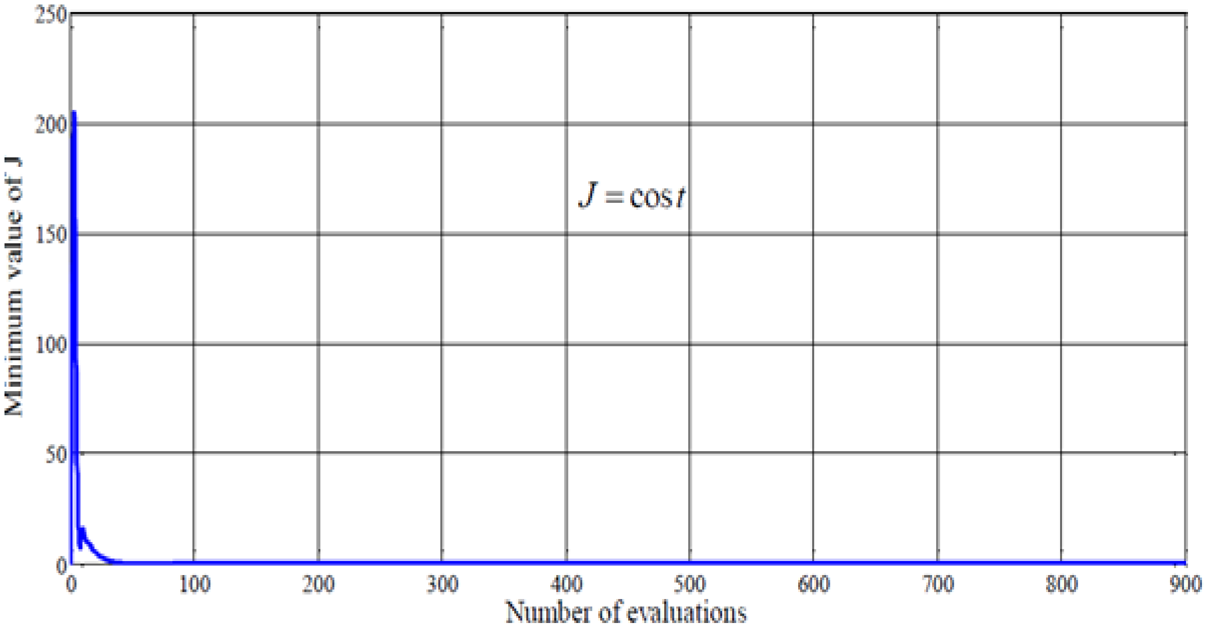


Fig 5.9:Convergence characteristics of BF Algorithm

$$J = \cos t = \int_0^T \{(\Delta f_i)^2 + (\Delta P_{tiei-j})^2\} dt \qquad (59)$$

In the above equation Δf_i represents the deviation in frequency in the i-th area (i=1, 2, 3) and ΔP_{tiei-j}

represents the deviation in the tie line power linking two areas. The equation given by eq.59 is used for plotting the convergence characteristics as shown in the Fig. 5.9.

5.7. RESULTS AND DISCUSSION

In case A just one of the parameters i.e. integral control gain of the system is being optimized for the three areas and the remaining two parameters are kept constant. In case of case B two parameters are optimized viz. integral control gain and speed regulation constant for the three areas and also the frequency bias parameter is kept constant. In case of case C all the three parameters for the three area system is being optimized.

By examination and comparison of the responses for the above three cases viz. case A, case B and case C we are able to say that we obtained the best results in case C where the values of all the three parameters are optimized. This can be said in view of settling time, peak deviation and oscillation value. Also in case C we see that the settling time is reduced as compared to case A and case B. at the same time the deviation and oscillation value is reduced to a greater extent.

Additionally we observe that quiet higher values of R can be thought of in case of simultaneous optimization of the three parameters. Therefore we've the system's best dynamic response. The importance of optimizing the value of Bi rather than making it equal to βa_i is also seen.

The convergence characteristics of bacteria foraging technique is shown by considering the x-axis to be the number of J evaluations and the y-axis to be the minimum value of J. The determination of J takes most of the computation time; thus the quantity of J evaluation is almost identical to the scaled quantity of computational time. The convergence characteristic is also fast.

CHAPTER 6

6. CONCLUSION AND FUTURE WORK

6.1. CONCLUSION

The thesis has chiefly investigated on the frequency change as well as change in the tie line power due to the change in the load and also the techniques that may be used for obtaining the optimized values of various parameters for minimizing the changes.

Firstly a secondary control is being introduced for minimizing the deviations in frequency. This is usually vital in case of a single area system or an isolated system as the secondary control loop i.e. an integral controller is generally responsible for reducing the changes in the frequency deviations and maintains the system stability. Therefore without the presence of secondary loop the system losses its stability.

Secondly interconnection of two or more systems is being introduced to cope up with the load changes through tie line power exchange. Interconnecting two or more areas ensures the sharing of the power among the systems during the times of load changes which may occur in any area at any time. Therefore the burden on the controllers to minimize the changes in the frequency is reduced as a result of the rise in the power demand can be fulfilled by drawing power from the neighboring areas and thus maintains the stability of the system.

Thirdly there’s introduction of an optimization technique i.e. Bacteria Foraging Optimization Algorithmic program to change the values of the various parameters present in the power system under investigation so it can cope up with the changes in the load demand. As a result of which the changes the frequency and also the tie line power is reduced and also the stability of the system is maintained. It is also seen that BF technique has quicker convergence characteristics. BF technique serves to be quite useful for obtaining the optimized values of the various parameters as compared to the general hit and trial technique which is extremely tedious and time taking method.

The investigations has been done for single area system, two area systems and three area systems and the result is being given accordingly.

6.2. SCOPE FOR FUTURE WORK

- Various other optimization algorithmic programs can be used for optimization and the performance can be compared with BF algorithm.

- Various controllers may be used to manage the frequency deviations and changes in tie line power.

- It may be implemented to system with four areas and also the performance of the system may be studied.

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