AUTOMATIC GENERATION CONTROL IN A DEREGULATED POWER SYSTEM USING AI TECHNIQUES

A DISSERTATION

Submitted in partial fulfillment of the
requirements for the award of the degree
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MASTER OF TECHNOLOGY
in
ELECTRICAL ENGINEERING
(With Specialization in Power System Engineering)

By

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CANDIDATE'S DECLARATION

I hereby declare that the work, which is presented in this dissertation report, entitled **"AUTOMATIC GENERATION CONTROL IN A DEREGULATED POWER SYSTEM USING AI TECHNIQUES"**, being submitted in partial fulfillment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY** with specialization in **POWER SYSTEM ENGINEERING,** in the Department of Electrical Engineering, Indian Institute of Technology, Roorkee is an authentic record of my own work carried out from July 2006 to June 2007, under the guidance and supervision of Dr. E . Fernandez, Assistant Professor, Department of Electrical Engineering, Indian Institute of Technology, Roorkee.

The results embodied in this dissertation have not submitted for the award of any other Degree or Diploma.

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CERTIFICATE

This is to certify that the statement made by the candidate is correct to the best of my knowledge and belief.

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BALAJI KUMAR.GUMPENA

ABSTRACT

This thesis deals with optimum selection of controller parameters in the design of an appropriate governor for automatic generation control of an inter-connected power system in deregulated environment. The optimization of the parameters is done using the conventional ISE technique and also with artificial intelligence technique like genetic algorithm. The effect of frequency deviation and tie line power flow deviation on optimal gain settings has been studied.

In deregulated power system, because of inherent characteristic of changing load i.e with change in Disco Participation Matrix (DPM) there is difficulty in optimizing the controller gains. This is because a fixed controller may not be suitable in all operating conditions. To improve the performance of the Automatic Generation Control and to overcome the limitations of Conventional controller has necessitated the use of intelligent systems. Artificial Intelligence techniques like Fuzzy Logic and Genetic algorithms can be applied. In this thesis a new controller i.e a hybrid controller based on fuzzy logic is applied. The optimization of the controller parameters is done using the genetic algorithm technique. The dynamic response is compared with the dynamic response obtained by the conventional integral controller.

Simulation study has been done for a two area non reheat thermal-thermal system in deregulated environment. Dynamic performances of two area system have been studied for different Disco Participation Matrix (DPM). The system study has been done using MATLAB 7.01 and the toolboxes available with it.

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NOMENCLATURE

f	Nominal system frequency
i	Subscript referred to area i (1, 2)
P_{ri}	Area rated power
H_i	Inertia constant
ΔP_{Di}	Incremental load change in area i
ΔP_{gi}	Incremental generation change in area i
$D_i = \Delta P_{Di} / \Delta f_i$	Load frequency characteristic
T_{12}	Synchronizing coefficient
R_i	Governor speed regulation parameter
T_g	governor time constant (in sec)
T_t	turbine time constant
B_i	Frequency bias constant
P_{tie}	tie-line power flow
ΔP_{tie}	incremental change in tie-line power
Δf	Incremental frequency change
$T_{pi} = 2H_i / f\, D_i$	Power system time constant
$K_{pi} = 1/D_i$	Power system gain constant
K_I	Integral gain
$\beta_i = \left(D_i + 1/R_i\right)$	Area frequency response characteristic
ACE_i	Area control error of area i
$a_{12} = -P_{r1}/P_{r2}$	Area capacity ratio
J	Cost function

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

The successful operation of interconnected power systems requires the matching of total generation with load demand and associated losses. As the system load changes continuously, the generation is adjusted automatically to restore the frequency to a nominal value. Frequency control is accomplished by two control actions in interconnected two area power system: Primary control and supplementary control or secondary control action. The primary speed control makes the initial coarse adjustment of the frequency. The supplementary speed control takes over the final adjustment of the frequency by resetting the frequency error to zero through integral action. This scheme is known as Automatic Generation Control (AGC). The primary objective of Automatic Generation Control (AGC) is to regulate frequency to the specified nominal value and to maintain the interchange power between control areas at the scheduled values.

The electric power business at present is largely in the hands of VIUs (Vertically Integrated Utilities) which own Generation-Transmission-Distribution systems that supply power to the customer at regulated rates. Tariffs, how ever, are protected and customers are limited in choosing the supplier of their electricity. This has brought research into new AGC structures that are appropriate for the deregulated environment.

In the deregulated or restructured environment, VIUs (Vertically Integrated Utilities) no longer exist. The first step in deregulation has been to separate the generation of power from the transmission and distribution. So in the new scenario the utilities no longer own generation, transmission, and distribution, instead there are three different entities. The new entities include Generation companies (Gencos), Transmission companies (Transcos), Distribution companies (Discos), and Independent System Operators (ISOs).

With the process of deregulation, competition has been introduced into the power industry. In the new scenario, a Disco can contract individually with a Genco for power and these transactions are done under the supervision of the ISO.

The basic features of deregulation are:

- To introduce competition into an monopolistic industry
- In order to achieve the above, separate (unbundling) the functions of power generation, transmission and distribution
- To create several competing electricity generation companies

An AGC system monitors the system frequency and the tie-line flows, computes the net change in the area generation required (generally referred to as Area Control Error, ACE) and changes the set point of the generators with in the area. Automatic Generation Control (AGC) is defined as "The regulation of power output of electric generators within a prescribed area in response to changes in the system frequency and or tie-line loading, or the relation of these to each other, so as to maintain the scheduled system frequency and or the established interchange with other areas with in predetermined limits".

Thus, aims of conventional AGC are:

- To achieve zero static frequency error
- To distribute generation among areas so that interconnected tie-line flows matches the prescribed schedule.
- Balance total generation against total load and the tie line power exchanges.
- To maintain each units generation at the most economical value

1.2 ARTIFICIAL INTELLIGENCE (AI) TECHNIQUES IN AUTOMATIC GENERATION CONTROL

The growth in size and complexity of electrical power system with increase in power demand has necessitated the use of Artificial Intelligent (AI) techniques. The intelligent systems posses human like expertise and learn to do better in changing environments.

The perturbation of the frequencies at the areas and resulting tie line power flow arises due to unpredictable load variation that causes mismatch between the generated and the demanded power. The objective of AGC is to minimize the transient deviations and to provide zero steady state errors of these variables in a very short time although unpredictable load variation exists. Unfortunately because of operating point continuously changes depending on demand of consumers, the selected fixed controller can be unsuitable for other operating points and has to be retuned every time with change in operating point. This result in developing a new controller based on AI techniques.

The conventional controllers like proportional-plus integral(PI)and proportional-plus integral-plus-derivative (PID) exhibits relatively poor dynamic response, since they are slow and lack of efficiency and handling system nonlinearities. In order to improve the performance of the Automatic Generation Control System Artificial Intelligence Techniques were used. Artificial Intelligence techniques like Fuzzy Logic, Artificial Neural networks and Genetic algorithms can be applied for Automatic Generation Control, which can overcome the limitations of conventional controls.

In the present thesis fuzzy logic controller (FLC) in conjunction with genetic algorithm (GA) has been used. The parameters of the FLC are tuned using the genetic algorithm technique.

Table 1.1 shows the major area of application of various AI techniques.

Table 1.1: Comparison of various Intelligent Systems

Application	Fuzzy system	Neural networks	genetic algorithms
Optimization Problems			**
Predictions		**	
control applications	**		

In the thesis, fuzzy logic controller in conjunction with genetic algorithm is used to improve the Performance of the Automatic Generation Control System

1.3 LITERATURE REVIEW:

Most of the research work in the AGC at present deals with "net interchange tie line bias control strategy" making use of Area Control Error (ACE), which reflects mismatch of generation and load in a control area. Area supplementary control would change generation in such a manner as to keep the ACE to a minimum.

Before deregulation Vertically Integrated Utility (VIU) owns both transmission and generating systems. Where as after deregulation VIU is no longer applicable and the power system has been changed and allowed companies for generation, transmission distribution. Disco Participation Matrix (DPM) has been used to visualize the contracts between generation companies and the distribution companies.

A brief overview of some of the relevant literature is presented below:

Jaleeli .et al [1] gives us an idea what Automatic Generation Control (AGC) might be expected to do and what may not be possible for it to do. The purpose and objectives of AGC are limited by physical elements involved in the process .It is desired that AGC act slowly and deliberately over tens of seconds or a few minutes. This paper attempts to describe basics that are applicable to today's power systems and AGC in order to assist interested research parties. It gives a brief description of types of generating units, and the way loads and unit governors respond to various upsets of electric power mismatch in the system.

Elgerd ,et al [2] have given the concept of optimal operation of tie line bias control with the help of modern optimal control theory. [3] Gives the development of a state variable model of the megawatt-frequency control problem of multi area electric energy systems. The model is in a mathematical form necessary for application of theorems of modern optimal control theory. The results of this study allow the authors to suggest feasible ways of greatly improving dynamic response and stability margins of the megawatt-frequency control system.

Ibraheem .et al [3] presented a critical literature review and an up-to-date exhaustive bibliography on the AGC of power systems. Various control aspects concerning the AGC problem have been highlighted. Attention has also been paid to recent developments, such as AGC schemes based on the concepts of neural networks and fuzzy logic and genetic algorithm. The investigations on AGC systems incorporating SMES, wind turbines, FACTS devices, and PV systems have also been discussed.

Jayant Kumar.et al [4] presented AGC simulator model for price-based operation in deregulated power system. They have suggested the modification required in convention AGC to study the load following in priced based market operation. They have highlighted salient differences between the automatic generation control in conventional scenario and restructured scenario. It gives us the idea of generation companies (Genco), Distribution companies (Disco), transmission companies (Transco) and the Independent contract administrator (ICA).This paper has presented three types of transactions, such as bilateral, poolco based and area regulation contracts.

Kah-Hoe .et al [5] review case studies to show the modifications required of conventional AGC software for the new environment. This paper reports three sets of case study results. The first and second case studies illustrate how to simulate bilateral and poolco based transactions respectively in the new marketplace. The third case study considers various (bilateral and poolco based) contracts existing simultaneously in the system.

Christie .et al [6] dealt with LFC issues in deregulated power system. It identifies the technical issues associated with load frequency control and also identifies technical solutions such as standards and algorithms, needed for the operation in this new restructured power system. This paper gives a deregulated utility structure of the US system. It has dealt the concepts such as LFC charged LFC and bilateral LFC.

Donde .et al [7] present AGC of a two area system in deregulated power system. The concept of Disco Participation Matrix (DPM) and Area Participation Factor (APF) to represent bilateral contracts are introduced. However they have not dealt with reheat turbine and hydrothermal work in their work. It gives a clear view on contract violation. They have used trajectory sensitivities to obtain optimal parameters of the system using a gradient Newton algorithm.

Bingsen Wang .et al [8] examined AGC with focus on the practical issues related to the implementation. First, the basics of the AGC are reviewed and the implementation issues in the regulated environment are examined. Then the new possible issues to accommodate the dramatic utility structural changes due to deregulated market based operation are explored. It has given a matter on several types of generating units and some solutions to the difficulties of calculating frequency bias.

Bekhouche [9] has compared load frequency control before and after deregulation. Before deregulation ancillary services, including AGC are provided by a single utility company called a control area that owns both transmission and generation systems. After deregulation, the power system structure has changed allowing specialized companies for generation (Genco), transmission (Transco), distribution (Disco) and independent contract administrator (ICA). The paper focuses on formulation and operation of AGC in the new environment (Deregulated environment). It gives the comparison of AGC in old and the new deregulated power system.

Meliopoulos .et al [10] have given the concept that in a deregulated environment, independent generators and utility generators may or may not participate in the load frequency control of the system. For the purpose of evaluating the performance of such a system, a flexible method has been developed in this paper. The method assumes load frequency control is performed by ISO based on parameters defined by participating generating units. It tells that if the percentage of units participating in this control action is very small, system performance deteriorates to a point that is unacceptable.

Jawad talq .et al [11] proposed an adaptive fuzzy gain scheduling scheme for conventional PI and optimal load frequency controller. A Suguno type fuzzy inference system is used in the proposed controller. The controller has been simulated on a two area inter connected system and by the comparison between the conventional and the proposed controller, the proposed controller in the paper offers better performance than fixed gain controller.

Demiroren .et al [12] have presented a method based on fuzzy logic controllers for automatic generation control of power system including super conducting magnetic energy storage units (SMES).The technique is applied to three areas having two steam turbines and one hydro turbine tied together through power lines. In the present paper a new fuzzy PI controller is proposed and the performance is compared with that of conventional PI controllers and also the positive effects of SMES have been studied in the paper.

Cam .et al [13] presented a fuzzy application to the area of LFC for PI controllers. Using variable values for the proportional and integral controller unit, the dynamic performance is improved. Proposed controller gives a better dynamic response following a step load change.

Demiroren .et al [14] presented Genetic algorithm (GA) application for optimization of integral gains and bias factors to AGC in three area power system after deregulation. They have considered two Gencos for each area in which two areas include steam turbines and the other include hydro turbines. The performance of the system with GA application for optimizing the parameters is compared with that of the conventional controllers. The system has been studied for different operating conditions. The optimization of the ACE parameters are done using continuous parameter GA which is based on real values and the simulation results thus obtained are compared with that of conventional parameters.

Abdel-Magid .et al 15] have dealt with the application of genetic algorithms for optimizing the parameters of AGC systems. An integral controller and a proportional-plus-integral controller are considered. A two-area reheat thermal system is considered to exemplify the optimum parameter search. The integral of the square of the error and the integral of time-multiplied absolute value of the error performance indices are considered in the search for the optimal AGC parameters. The results reported in this paper demonstrate the effectiveness of the genetic algorithms in the tuning of the AGC parameters.

Karnavas .et al [16]: The aim of any controller is to restore in a very smooth way the frequency to its nominal value I the shortest time possible whenever there is change in load demand. This paper has presented two controllers, controller using fuzzy logic (FL) and the other using combination of Fuzzy logic with genetic algorithm and neural networks. The design and performance evaluation of the proposed controller are applied to a single-area power system.

Vinod Kumar [17] presented a novel approach of artificial intelligence (AI) techniques, fuzzy logic, artificial neural network (ANN) for the automatic generation control (AGC). Frequency deviation occurs due to mismatch between generation and the load demand. This high frequency deviation may lead to system collapse. This necessitates an accurate and fast acting controller to maintain constant nominal frequency. This has brought intelligent controllers into existence foe power system applications. Fuzzy logic and ANN approaches are used for automatic generation control for the single area system and two area interconnected power systems. The performance of the intelligent controllers is compared with the conventional PI and PID controllers for the single area system as well as two-area interconnected power system.

Earl Cox [18] had presented basic fuzzy logic fundamentals. This has discussed the criteria deciding the choice and number of membership functions for Mamdani-fuzzy controller. It gives us an idea how to optimize the membership functions, scaling factors and the rule base.

Ghoshal [19] optimal integral gains (for integral gain control) and proportional-integral-derivative gains (for PID control) are computed by genetic algorithm (GA) and then hybrid genetic Algorithm-simulated annealing (GA-SA) techniques. He compared the obtained responses with the conventional controllers. And he concludes that GA/GA-SA optimization methods are much simpler, involve less computational complexity, memory burden and yield more optimal gains than other state adaptive techniques.

Chen Guo .et al [20] presented a novel and robust GA-Fuzzy controller structure. They incorporated the controller with Genetic Algorithms and Fuzzy logic in order to control the complicated and non-linear plant. GA has been used in their work to optimize the parameters of fuzzy logic and its control rules. They inferred that optimization of the fuzzy logic controller can be done with Genetic algorithms in order to improve the dynamic performance of the controller as well as the system. They made simulation studies on an industrial plant and on inverted pendulum.

Elgerd [21] Nagrath and Kothari [22] Give an idea of load frequency control both in single area and two area case. They define the concepts like “control area”, “area control error(ACE)”, “proportional plus integral control”, “economic dispatch control” etc. The block diagram for a two-area load frequency is presented in these references and a state variable model of a two-area system.

1.4 OUTLINE OF THE CHAPTERS

Chapter 1 introduces the AGC problem of an interconnected power system in general and Scope of Artificial Intelligence techniques application in Automatic Generation control and attempts to present the brief literature survey. It clearly gives a view on the present work. It highlights the structural changes that took place with deregulation and the introduction of specialized companies like Genco, Transco, Disco and ISO.

Chapter 2 deals with the fundamentals and objectives of an AGC. It highlights the concept of tie-line bias control .This tells us that the primary objective of Automatic Generation Control (AGC) which is to regulate frequency to the specified nominal value and to maintain the interchange power between control areas at the scheduled values can be met with simple integral control.

Chapter 3 deals with the development of model for two-area non-reheat system. An approach for obtaining the optimum integral gain setting of the supplementary controller has been presented. The dynamic performance of the system has been obtained with AGC operation in contracted and also in contract violation.

Chapter 4 proposes a GA tuned hybrid controller for thermal-thermal system. For obtaining good dynamic response, artificial intelligence techniques have been introduced in the present work. The conventional controller has been replaced with

Hybrid controller. The tuning of the hybrid controller was done with Genetic Algorithm technique. The performance of the proposed controller is then compared with that of the conventional integral controller.

Chapter 5 gives conclusions of the entire work and presents the recommendations for future work.

CHAPTER 2

AUTOMATIC GENERATION CONTROL

The successful operation of interconnected power systems requires the matching of total generation with load demand and associated losses. If the load on the system is increased, the turbine speed drops before the governor can adjust the input of the steam to the new load. As the change in the value of the speed diminishes, the error signal becomes smaller and the position of the governor fly balls gets closer to the point required to maintain a constant speed. However the constant speed will not be the set point and there will be an offset.

One way to restore the speed or frequency to its normal value is to add an integrator. The integral action ensures zero frequency error in the steady state. Because of the ability to return a system to its set point, integral action is known as reset action. Thus as the system load changes continuously, the generation is adjusted automatically to restore the frequency to a nominal value. This scheme is known as *Automatic Generation Control* (AGC).

In an inter connected system, the role of the AGC is to divide the loads among system, stations, and generators so as to control the scheduled interchanges of the tie-line power while maintaining a reasonably uniform frequency. During large transient disturbances and emergencies, AGC is bypassed and other emergency controls are applied.

The primary objective of Automatic Generation Control (AGC) is to regulate frequency to the specified nominal value and to maintain the interchange power between control areas at the scheduled values by adjusting the output of selected generators. This is generally referred to as load frequency control (LFC) .There are two variables of interest, namely, frequency and tie-line power exchanges. Their variations are weighted together by a single variable called *Area Control Error* (ACE).

2.1 CONTROL AREA

It is possible to divide an extended power system (say, national grid) into sub-areas (may be , state electricity boards) in which the generators are tightly coupled together so as to form a Coherent group, i.e., all the generators respond in unison to changes in load or speed changer settings. Such a coherent area is called a Control area in which the frequency is assumed to be the same throughout in static as well as dynamic conditions.

For purposes of developing a suitable control strategy, a control area can be reduced to a single speed governor, turbo generator and load system. In each control area, the generation must be controlled to meet load in such a way that the system frequency is maintained at the nominal value and also the generation in each control area must be regulated to take care of the tie-line transactions.

Direct speed governing (primary control) and the supplemental adjustment of speed governor set points (secondary control) are the methods used for matching generation to load. If the system load increases suddenly, first the kinetic energy of the rotating parts in the system, such as rotors of generators, will be extracted to balance the load. Thus, the speed of the rotating parts will decrease for a certain amount. This “natural response” can settle in one to two seconds. If the speed variation exceeds a certain limit, which is usually 35 mHz, the speed governor will respond by increasing the turbine output. This control action is called primary control, and is usually completed in 10-12 seconds. However the speed cannot be pulled back to its value prior to the load increase. In order to bring the speed to the normal speed, the set point of the speed governor has to be changed. This action is called secondary control, and can be done manually or by automatic generation control.

The simplified primary control and AGC can be explained through *Figure 2.1*

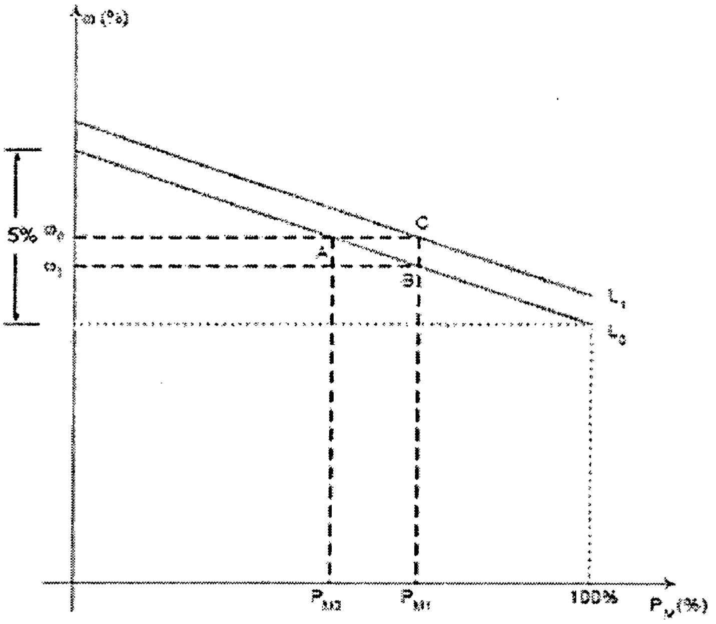


Figure 2.1: speed governor droop characteristic…Ref [8]

Typical speed droops for active governors are in the range of about 5% (which means 5% change in the speed will result in 100% change of the mechanical output power from the prime mover). Initially, the speed governor is operating on curve L_0 and the system is operating at the frequency ω_0 (point A). After the load increase, the system frequency drops to ω_1.The governor will respond by increasing the turbine output from PM_0 to PM_1 (point B). By changing the set point of the speed governor, the droop curve will move from L_0 to L_1.Now, the operation point is at C and system frequency has been brought back to ω_0.

The AGC sends "raise/lower" signals/pulses to the regulated generation units to adjust the set point of the speed governor. So, the AGC performance will be definitely affected by the manner in which the generation units will respond to these control signals. It is necessary to achieve much better frequency constancy than is obtained by the speed-governor system. To accomplish this we must manipulate the speed changer in accordance with some suitable control strategy, here integral control is used as the strategy. The integral control will give rise to zero static error. As long as the error remains, the integrator output will increase causing the speed changer to move. The integrator output, and thus the speed-changer position attain a constant value only when the frequency error has been reduced to zero.

2.2 TIE-LINE BIAS CONTROL

The integral error is proved to be good for single area control because here frequency alone has to be controlled, in case of two-area system, there will be an error in tie-line power flow. Various methods of reset integral control have been tried out. As a result of the original work by Cohn a control standard has developed that has been adopted by most operating systems. The control strategy is called "tie-line bias control" and is based upon the principle that "all operating pool members must contribute their share to frequency control in addition to taking care of their own net interchange".

The current practice of the load frequency control (LFC) action of automatic generation control (AGC) is based on the above strategy "tie-line bias control". In this control strategy each area of an interconnected system tries to regulate its area control error (ACE) to zero, where

$$ACE= (T_a - T_s) - 10\beta (f_a - f_s) \qquad (2.1)$$

The term T_a-T_s is the difference between the actual and the scheduled net interchange on the tie lines. The term representing the area's natural response to frequency deviations is 10β (f_a-f_s). The coefficient, β, is known as the system natural response coefficient (in MW/0.1Hz). This characteristic is expressed as

$$\beta = 1/R + D \qquad (2.2)$$

Where, 1/R is the generator regulation or droop, D is the load damping Characteristic. R is the steady state characteristic relating frequency of a generator to generated power. Typically, droops are designed to range from 3 to 5 percent. D represents the self-regulating characteristic of the load. It is expressed as the percent change in the connected load divided by the percent change in frequency. In-other-words, as system load increases the system frequency decreases. Then, since a portion of the load is frequency dependent, the final load will be less than that at rated frequency. Since a control area's β is continuously changing and no good technique has been developed to measure it in real-time, it must be estimated. The estimated value of β is called the Tie-Line Frequency Bias Coefficient B, the closer B matches β, the better AGC will be able to reduce the number of unnecessary control actions and minimize inadvertent energy flows.

The generator's droop characteristic and the frequency dependency of the load permit frequency management of a control area to be somewhat self-regulating. However, since there is a strong desire to keep frequency at its nominal value, there must be a supplemental control system (AGC) to adjust a unit's output to bring the steady state frequency back to nominal. Since the control areas operate as an interconnected system, it is important for a particular control area's AGC to be able to determine the source of a disturbance (i.e., inside or outside of its area). This task is accomplished with the ACE equation and tie-line bias control. Using the system frequency and the net power flowing over the tie-lines, AGC can differentiate between an internal and external disturbance. If it is an internal disturbance, it will be the task of the local AGC to adjust area generation to meet the load. If it is an external disturbance, the control area's obligation is to provide power to the affected control area in a proportion equivalent to the control area's natural system response coefficient, β.

2.3 INTEGRAL CONTROL

The ACE signal obtained will be have spikes .The spiky ACE signal will cause unnecessary control movements, which will possibly increase the wear and tear on the generation equipment. For this Integral controller is used to filter ACE signal. System frequency specifications are rather stringent and, therefore, much change in frequency cannot be tolerated. In fact, it is expected that steady change in frequency will be zero.

While steady state frequency can be brought back to the scheduled value by adjusting speed changer setting, the system could go intolerable dynamic frequency changes with changes in load. It leads to the natural suggestion that the speed changer setting be adjusted automatically by monitoring the frequency changes. For this purpose, a signal from Δf is fed through an integrator to the speed changer resulting in the block diagram configuration shown in figure 2.2. The system now modifies to a integral controller, which, as is well known from control theory, gives zero steady state error, i.e. Δf /steady state = 0

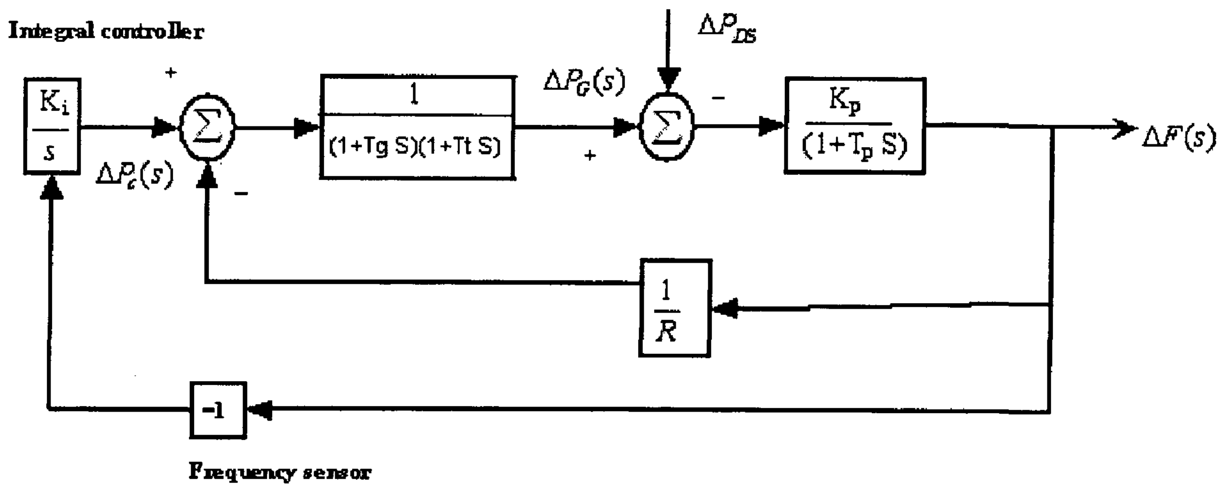


Fig 2.2: Integral load frequency control...Ref [22]

The signal $\Delta P_c(s)$ generated by the integral control is opposite sign to $\Delta F(s)$ which accounts for negative sign in the block for integral controller.

$\Delta f /_{steadystate} = s\Delta F(s) = 0$ .... (2.3)

In the above equation we find that the steady state change in frequency has been reduced to zero by the addition of the integral controller. This can be argued out physically as well. Δf reaches steady state (a constant value) only when $\Delta P_c = \Delta P_d = constant$. Because of the integrating action of the controller, this is only possible only if $\Delta f = 0$.

CHAPTER 3

AGC FOR TWO AREA SYSTEM IN DEREGULATED POWER SYSTEM USING INTEGRAL CONTROLLER

3.1 INTRODUCTION

AGC is among a set of services called ancillary services defined by the Federal Regulatory Commission (FERC).To allow open transmission access and encourage competitive wholesale electric power market, deregulation was introduced by FERC. Before deregulation, ancillary services, including AGC, were provided by a single utility company that owns both transmission and generation systems. This type of utility is known as Vertically Integrated Utility (VIU). In case of deregulated system VIU is no longer applicable and the power system structure has changed and allowed companies for generation (Gencos), transmission (Transcos), distribution (Discos), and Independent System Operator (ISO) to emerge.

A net interchange tie-line bias control strategy has been widely accepted by utilities. The frequency and interchanged power are kept at their desired values by means of feedback of the Area Control Error (ACE) as well as controlling the prime movers of the generators. Under VIU structure AGC is the responsibility of a monopoly company.

For studying the AGC control of power system in deregulated structure, a large interconnected power system has been divided into number of control areas. A control area is defined as a power system, a part of power system or a combination of systems to which a common generation control scheme is applied. All the generators in the control area swing in unison or coherently and it is characterized by a single frequency. In normal steady state operation each control area of power system should strive to meet its own load demand and in addition each control area of power system should participate in regulating the frequency of the system. However, in a deregulated structure, a generating unit in a control area may elect not to participate in load frequency control in which case it must compensate the rest of the system for the benefits it receives. It has been studied that if the number of systems participating in this control action is very small, system performance deteriorates to a point that is unacceptable.

3.2 DISCO PARTICIPATION MATRIX (DPM)

Considering two equal areas and each area consists of two Gencos and two Discos. Each Genco in the control area participate towards Automatic Generation Control (AGC). In deregulated environment, Gencos sell power to various Discos at competitive prices. Thus, Discos have the liberty to choose the Gencos for contracts. They may or may not have contracts with the Gencos in their own area. This makes various combinations of Genco-Disco contracts. The basis, on which the demands of Discos are allocated to various Gencos, introduces the concept of Disco Participation Matrix (DPM). DPM is a matrix with the number of rows equal to the number of Gencos and the number of columns equal to the number of Discos in the system. Each entry in this matrix can be thought of as a fraction of a total load contracted by a Disco (column) toward a Genco (row). Thus, the ijth entry corresponds to the fraction of the total load power contracted by DISCOj from a GENCOi. The sum of all the entries in a column in this matrix is unity. DPM shows the participation of a Disco in a contract with a Genco, hence the name "*DISCO PARTICIPATION MATRIX (DPM)*"

Consider a two-area system in which each area has two Gencos and two Discos in it. Let GENCO1, GENCO2, DISCO1, and DISCO2 be in area I and GENCO3, GENCO4, DISCO3, and DISCO4 be in area II as shown in *Figure 3.1*

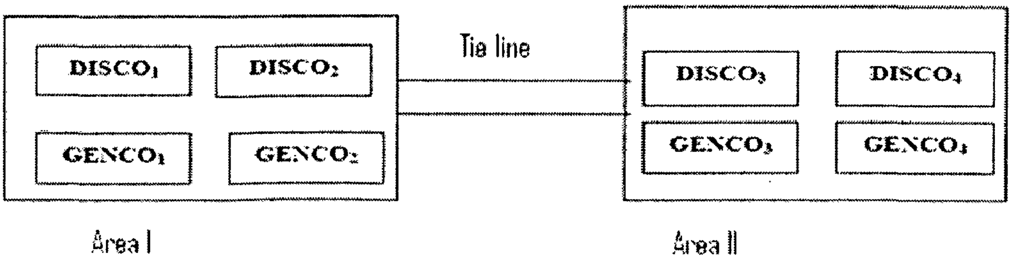


Figure 3.1: Schematic diagram for a two area system in deregulated Environment.

The corresponding DPM for the above system will become

$$\mathrm{DPM} = \left(\begin{array}{cc|cc} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ \hline cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{array}\right)$$

Where, cpf refers to "Contract Participation Factor."

cpf_{ij} =Demand of $DISCO_j$ from $GENCO_i$ / (Total Demand of $DISCO_j$)

It is to be noted that $\Sigma_i\, cpf_{ij}=1$. (i=1, 2, 3, 4)

In DPM the diagonal blocks correspond to local demands. As there are many Gencos in each area, ACE signal has to be distributed among them in order to achieve desired generation as per DPM. Coefficients that distribute ACE to several Gencos are termed as "ACE Participation Factors (APF)".

It is to be noted that $\Sigma_{j=1-m}\, apf_j=1$, where m is the number of Gencos in an area. Here in the present case m=2. DPM and APF are the two main concepts used rigorously in deregulation based Automatic generation control. In the deregulation environment the DPM is chosen on the basis of market economy, however the selection of APF is a sensitive issue. It is still not known on what basis the APF should be selected. Is the basis of selecting APF remaining the same for hydro and thermal Gencos! This is still not known and needs concrete investigation. However, it is clearly understood that APF is an important issue which is to be handled suitably so as to have proper functioning of AGC in deregulated mode.

In the deregulated mode, the demand of Disco for a particular Genco or Gencos must be reflected in the dynamics of the system. Thus, as a particular set of Gencos are supposed to follow the load demanded by a Disco, information signals must flow from a Disco to a particular Genco specifying corresponding demands. The demands are specified by cpfs (elements of DPM) and the p.u. MW load of a Disco. These signals carry information as to which Genco has to follow a load demanded by which Disco. In the contract violation case, the particular Disco which demands power more than its normal allocation is treated as a violation of bilateral contract and the excess demand is treated as a local demand which will be taken care of by the Gencos present in the area where the contract violation took place. This excess load is reflected in the deregulated AGC system block diagram at the point of input to the power system block.

3.3 TRANSFER FUNCTION BLOCK MODEL

The transfer function block diagram of a two area thermal system in deregulated power system is shown in the *Figure3.2.* The main features of AGC in deregulated environment are as follows:

- Computation of set points (CPG) of Gencos using Disco's load demand and Contract Participation Factor.
- Computation of Area Control Errors.
- Computation of local demand Pl1,loc and Pl2,loc

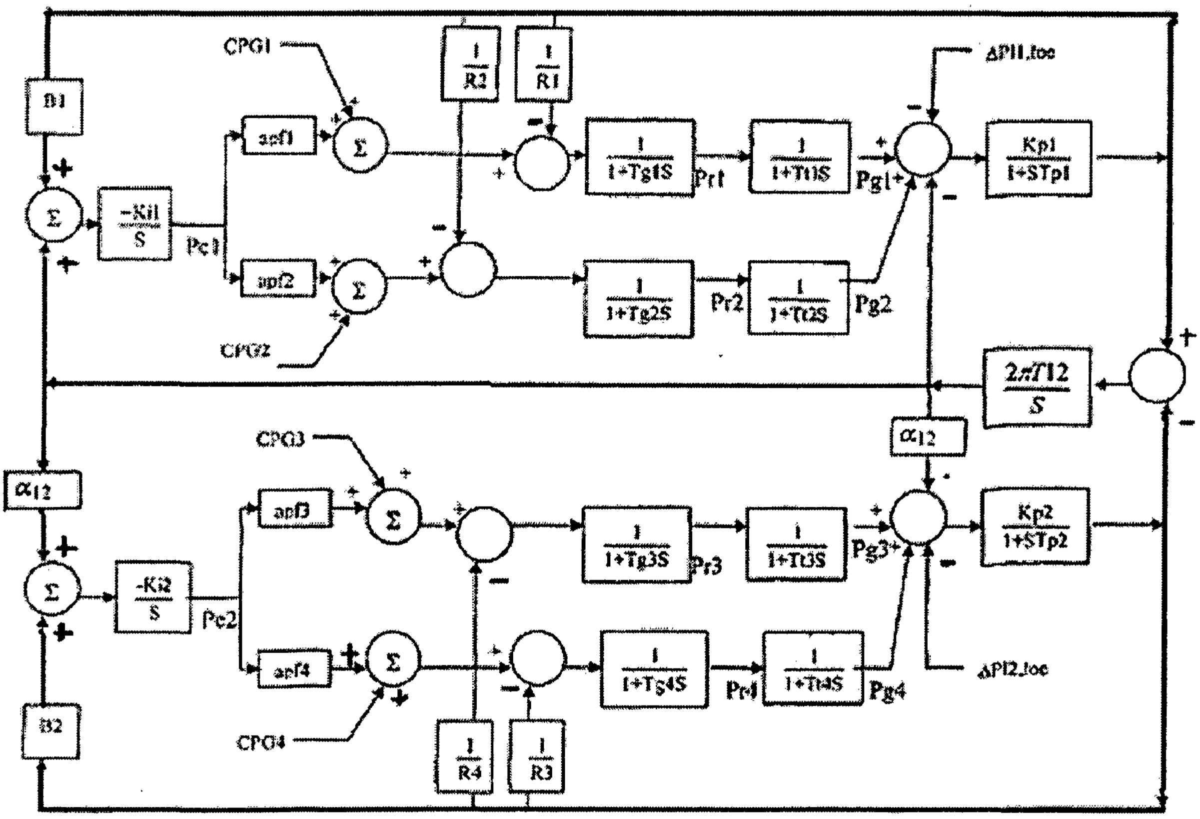


Figure 3.2: A Two-area system block diagram in deregulated system

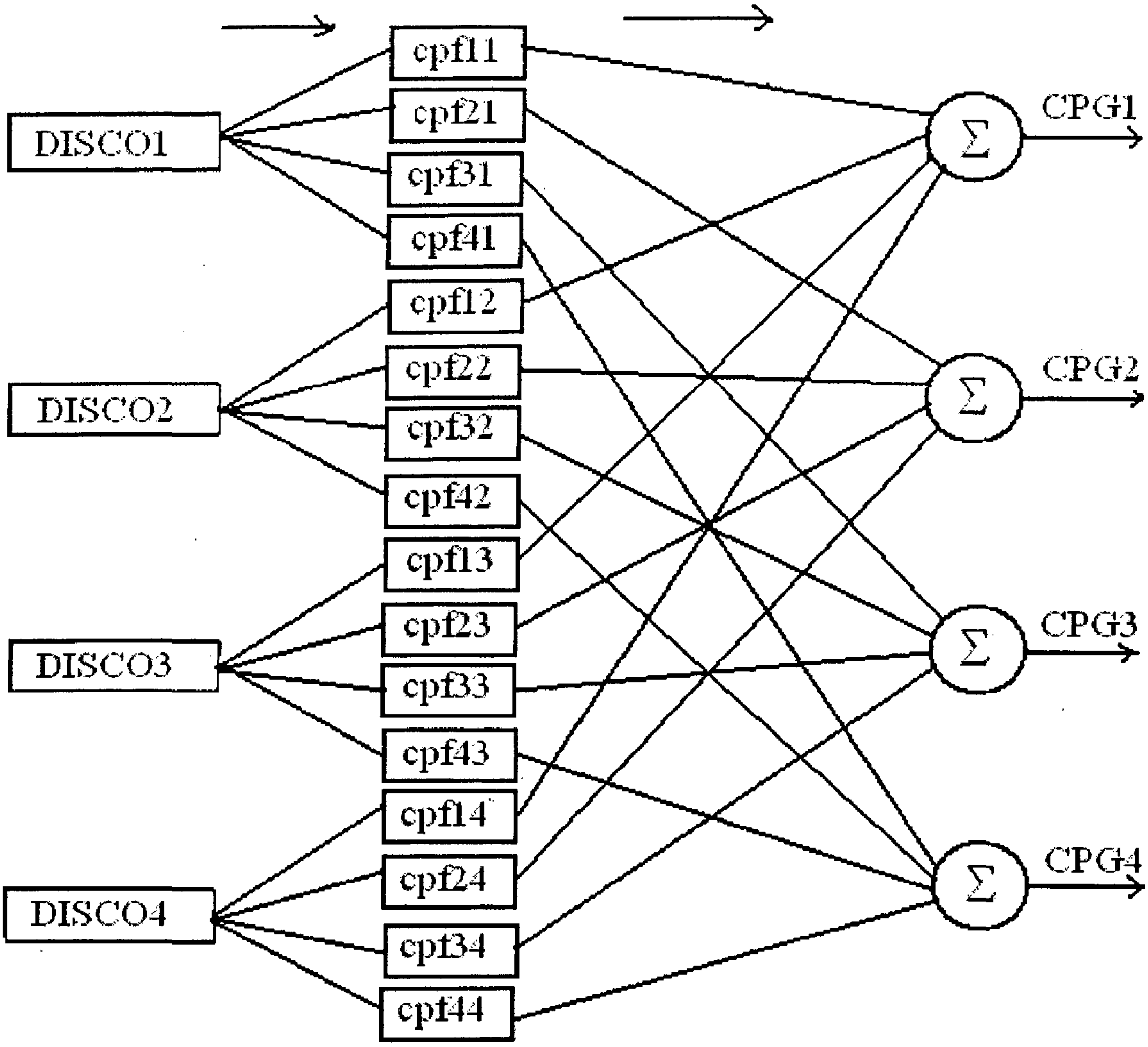


Figure 3.3: computation of contracted power demand for each GENCO

The set point is a new input for each Gencos in deregulated power system and is arrived as per the contract agreement between the different Gencos and Discos. *Figure 3.3* deals with the computation of set points for the Gencos. It can be seen that set point for each Genco depends on the load demand of Discos and contract participation factor of the Genco towards particular Discos. The local loads in area1 and area 2 are denoted by $Pl_{1,loc}$ and $Pl_{2,loc}$ respectively. The local loads in the area constitute of both the contracted load and the uncontracted load. When ever a load demanded by a Disco changes, it is reflected as local load in the area to which the Disco belongs. Coefficients that distribute ACE to several Gencos in an area are defined as Area or ACE Participation Factor (APF).

3.4 TIE POWER FLOW FORMULATION

The scheduled steady state power flow on the tie line is given as

$\Delta Ptie_{1\text{-}2}$, schedule= (demand of Discos in area II from Gencos in area I) - (demand of Discos in area I from Gencos in area II)...................... (3.1)

$\Delta Ptie_{1\text{-}2,\,error} = \Delta Ptie_{1\text{-}2,\,actual} - \Delta Ptie_{1\text{-}2,\,scheduled}$.. (3.2)

$\Delta Ptie_{2\text{-}1,\,error} = (-Pr_1/Pr_2)\ \Delta Ptie_{1\text{-}2,\,error}$.. (3.3)

Where Pr_1, Pr_2 are the rated power of areas 1 and 2, respectively

Therefore, this error signal is used to generate the respective ACE signals as in the traditional AGC system.

$ACE_1=B_1\Delta f_1+\Delta Ptie_{1\text{-}2,\,error}$.. (3.4)

$ACE_2=B_2\Delta f_2+\Delta Ptie_{2\text{-}1,\,error}=B_2\Delta f_2+a_{12}\Delta Ptie_{1\text{-}2,\,error}$.. (3.5)

Where $a_{12}= -Pr_1/Pr_2$

The block diagram for AGC in a deregulated system is shown in *Figure 3.2*. The local loads in areas I and II are denoted by $\Delta Pl_{1,\,loc}$ and $\Delta Pl_{2,\,loc}$ respectively.

$\Delta Ptie_{1\text{-}2,\,error}$ vanishes in the steady state as actual tie-line power reaches the scheduled value. $\Delta Ptie_{1\text{-}2}$ for deregulated power system varies from traditional AGC as in case of conventional AGC, tie line power flow remains constant for a given time period and in deregulated power system it keeps changing with change in demands from Discos.

The Area Control Error in deregulated power system differs from the conventional ACE as the contract data also forms a part of control error. In deregulated power system, the scheduled tie power flow itself changes every block hour or so contrary to that in regulated system where it remains constant.

3.5 DYNAMIC PERFORMANCE OF TWO AREA SYSTEM FOR A DPM

The AGC system investigated comprises of a two area thermal system provided with integral type supplementary controller. A step load perturbation of 1% of the nominal loading has been considered in both the areas. Nominal values are given in Appendix.

System considered:

$$\text{a. DPM=}\begin{bmatrix} 0.5 & 0.25 & 0 & 0.3 \\ 0.2 & 0.25 & 0 & 0 \\ 0 & 0.25 & 1 & 0.7 \\ 0.3 & 0.25 & 0 & 0 \end{bmatrix}$$

b. Each Disco i.e. DISCO1, DISCO2, DISCO3 and DISCO4 demand 0.01 puMW as per the DPM matrix defined.

c. Frequency bias setting B1=B2=β=0.425 puMW/Hz.

d. K1=K2=0.4

- Dynamic response of the system when all Discos demand 0.01puMW each:

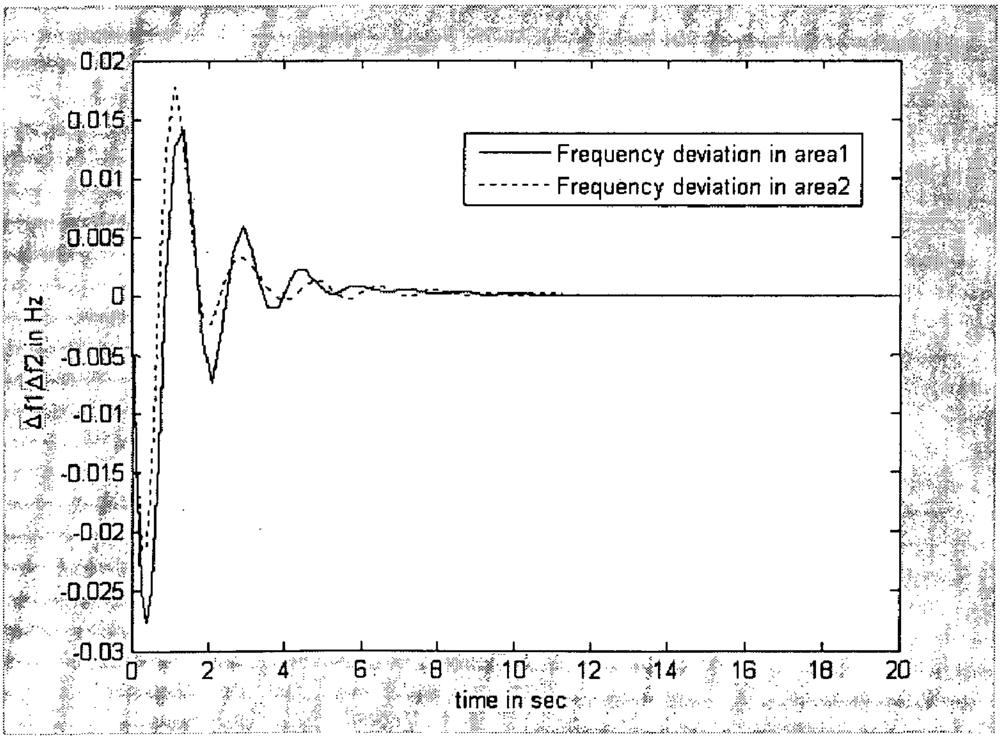


Figure 3.4: Frequency deviation in area1 and area2

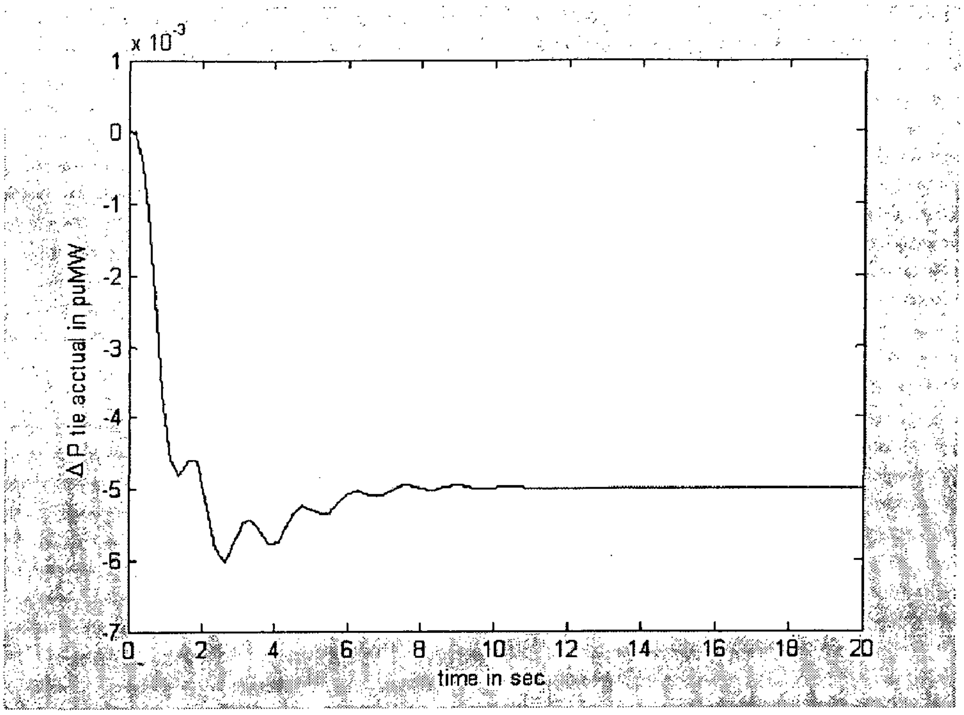


Figure 3.5: Scheduled Tie-line flow from area 1 to 2(Ptie12)

Discos in area1 demand 0.008 puMW of load from area2 and Discos in area2 demand 0.003 puMW of load from area1 as per the DPM. Hence the net flow is 0.005 puMW from area2 to area1.

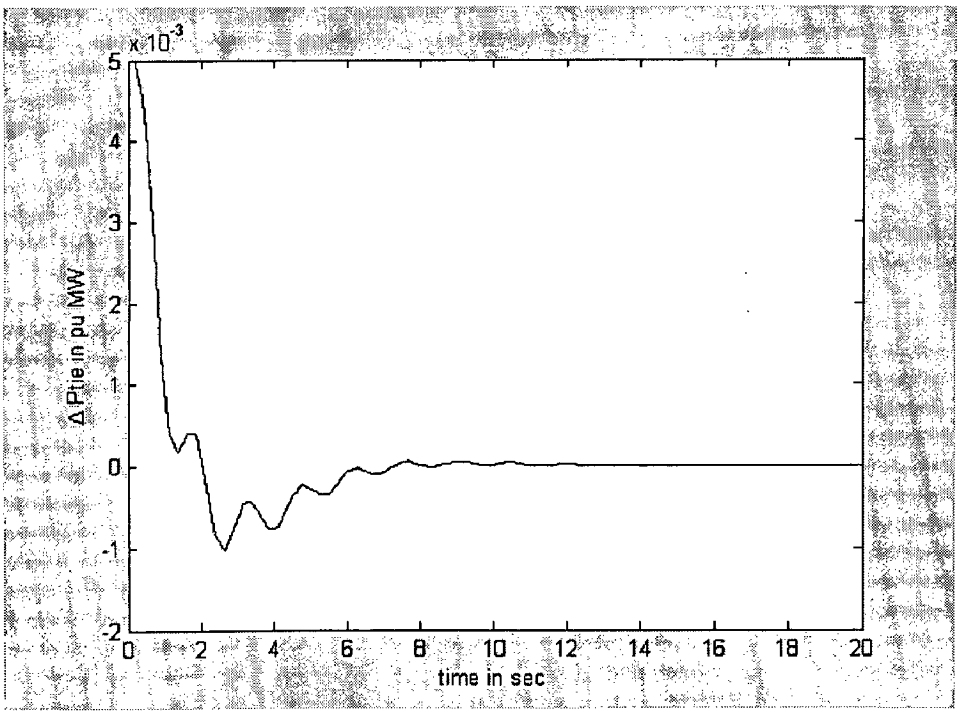


Figure3.6: Tie-line flow deviation from area1 to area2

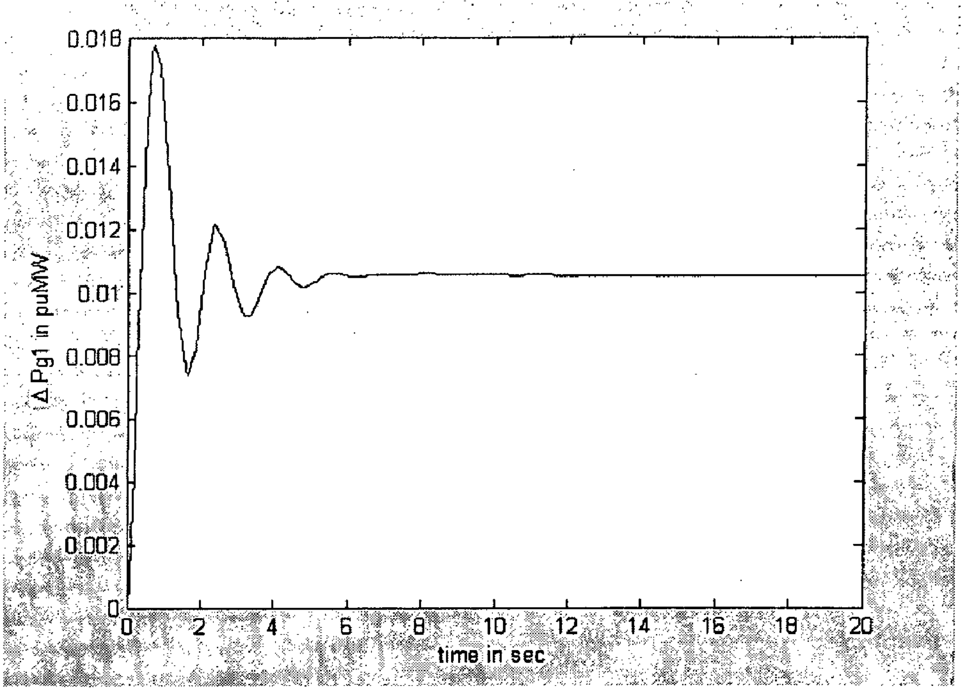


Figure 3.7: Dynamic response of generation of Genco1

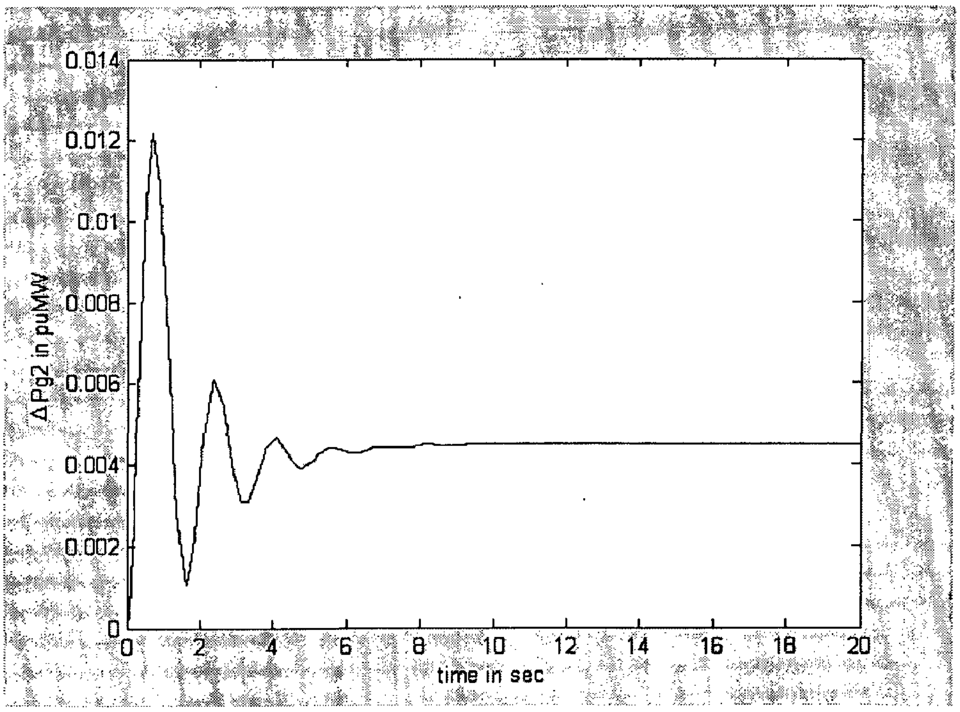


Figure 3.8: Dynamic response of generation of Genco2

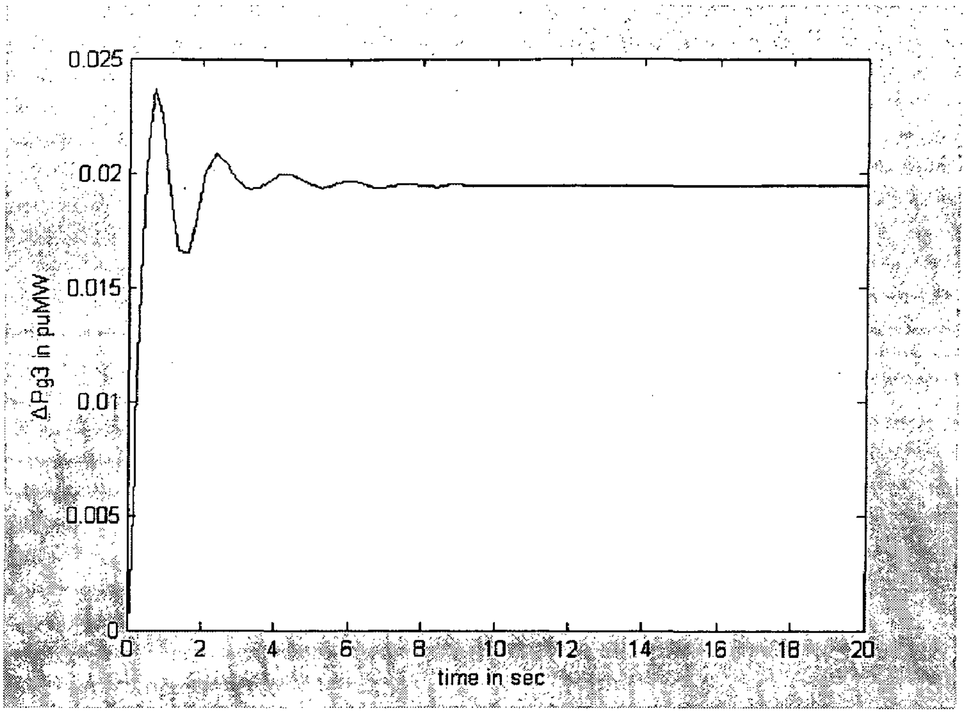


Figure 3.9: Dynamic response of generation of Genco3

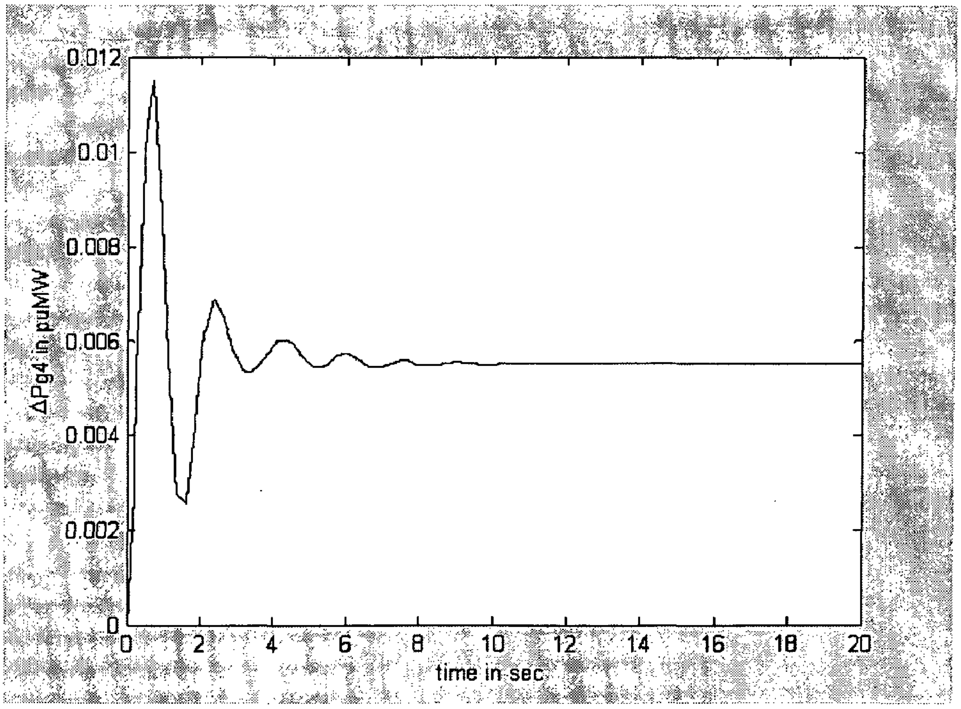


Figure 3.10: Dynamic response of generation of Genco4

3.6 EFFECT OF VARIATION OF SPEED REGULATION PARAMETER

AGC problem can be subdivided into fast (primary) and slow (secondary or supplementary) control modes. The dynamics following after the onset of load disturbance is decided by fast primary mode of AGC which is independent on governor speed regulation parameter 'R'. This fast primary mode of AGC is also known as "uncontrolled" mode since the speed changer position remains unchanged.

The significant parameter of primary control loop is the speed regulation parameter 'R' of the governor which decides the inherent drooping governor characteristics. In the past mostly a low value of R has been proposed. Although in the absence of supplementary controller, a low value of R would provide low steady state frequency error. However, in the controlled mode, a suitable controller can always provide a zero steady state error irrespective of the value of R. A governor with a high value of 'R' is envisaged to be easier for practical realization and more economical. So, it is important to investigate that how much large value of R can be chosen for AGC without deteriorating dynamic responses. The optimum integral gains of K_{I1}* and K_{I2}*, for different speed regulation parameters are given in *Table 3.1*

Table 3.1 Optimal integral gains for different R

Speed Regulation parameter 'R' Hz/ p.u. MW	K_{I1}*	K_{I2}^{*}
2.4	0.44	0.44
3.6	0.56	0.56
4.8	0.62	0.62
6.0	0.69	0.69

The response of Δf_1, Δf_2, ΔP_{tie}, ΔPg_1, ΔPg_3 for 1% step perturbation are given in *Figures 3.11-3.15* different values of R with corresponding optimum gains.

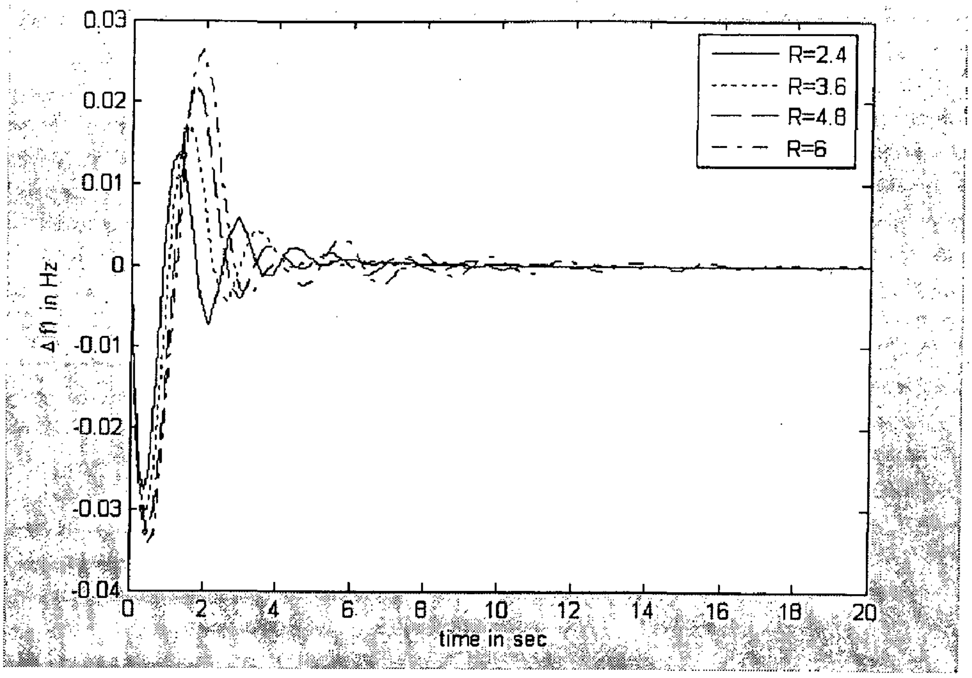


Figure 3.11 Δf_1 *for Different values of R*

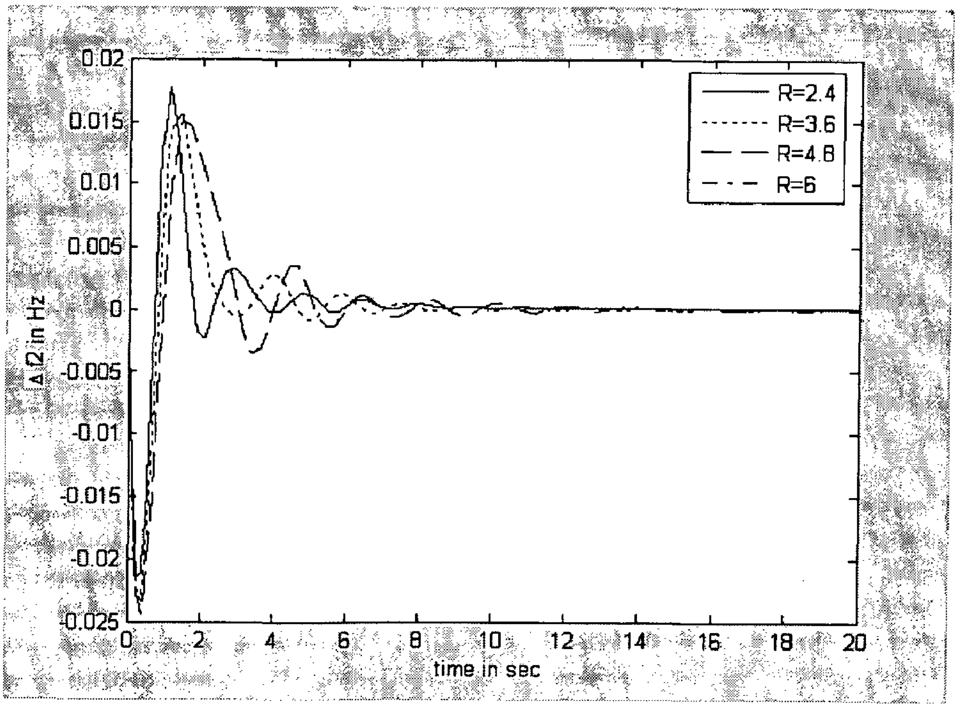


Figure 3.12 Δf_2 *for Different values of R*

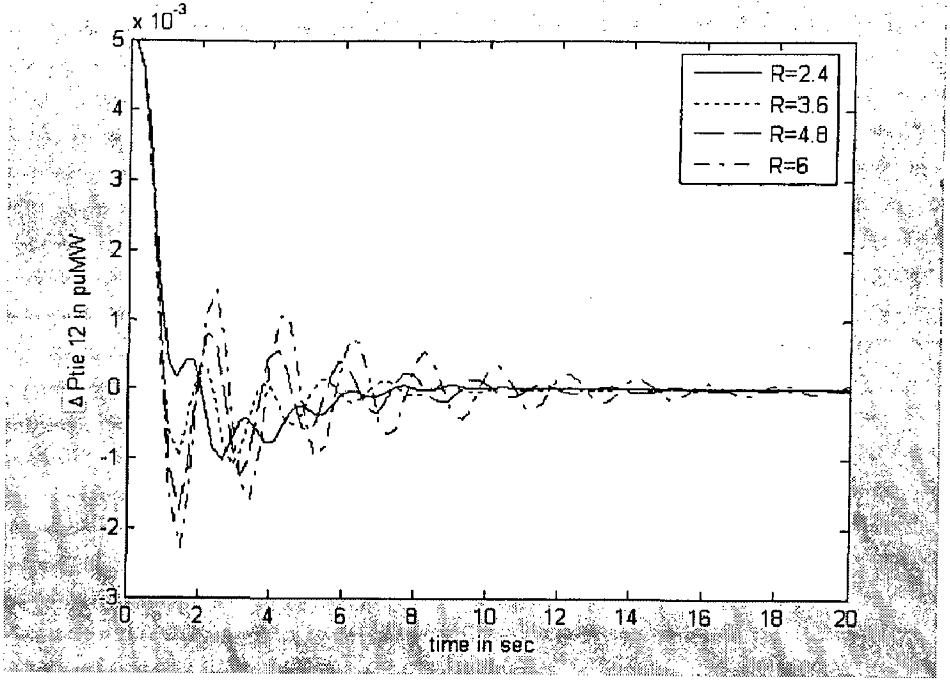


Figure 3.13 ΔPtie for Different values of R

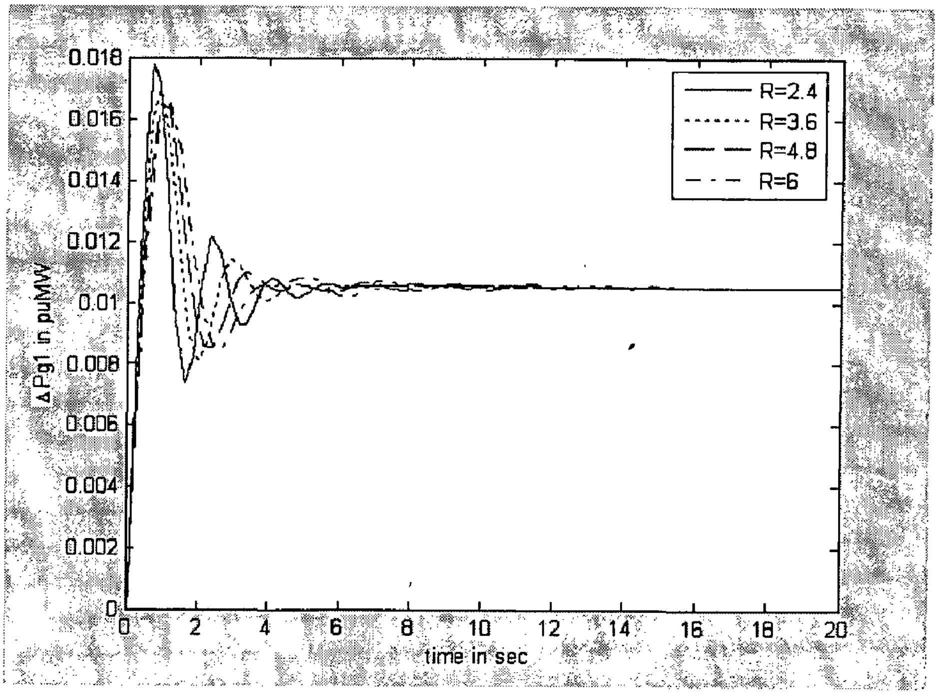


Figure 3.14 ΔPg_1 for Different values of R

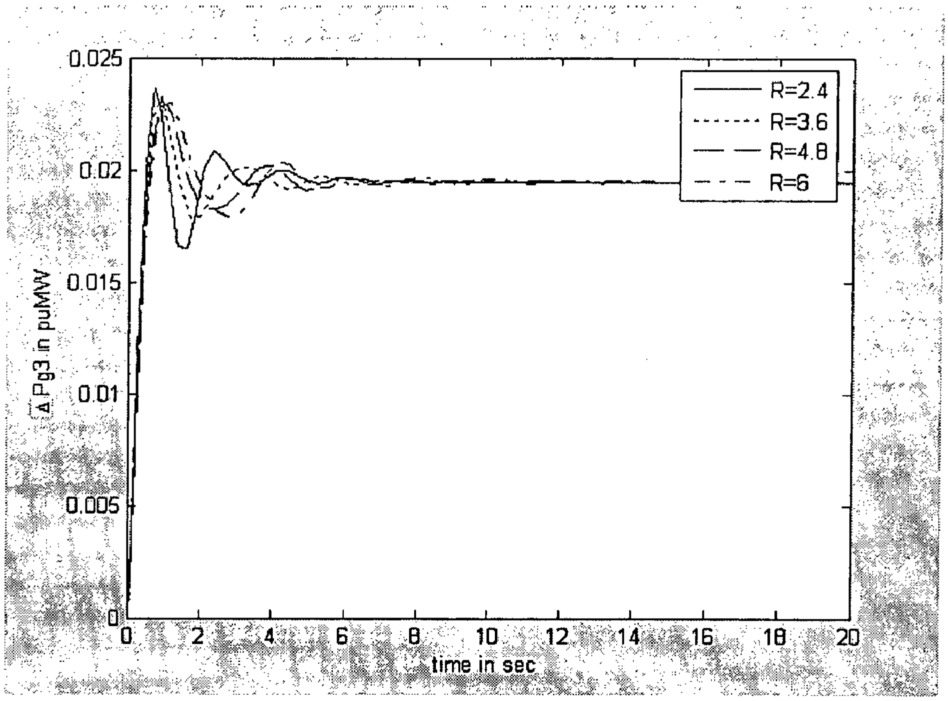


Figure 3.15 ΔPg_3 *for Different values of R*

From the dynamic responses shown above, it is observed that for AGC in constrained mode, a value of R = 2.4 Hz / p.u. MW provides more or less best result in comparison to others. Above 2.4 Hz / p.u. MW dynamic response is oscillatory, which are not desirable.

3.7 BEHAVIOR OF THE SYTEM UNDER CONTRACT VIOLATION

Consider the case when Disco1 demands 0.012 puMW excess power than that specified in the contract. This condition is termed as “Contract Violation”. The uncontracted power must be supplied by the Gencos in the same area of the Disco.

For the present case we use all the previous data except that Disco1 demands an uncontracted power of 0.012puMW.

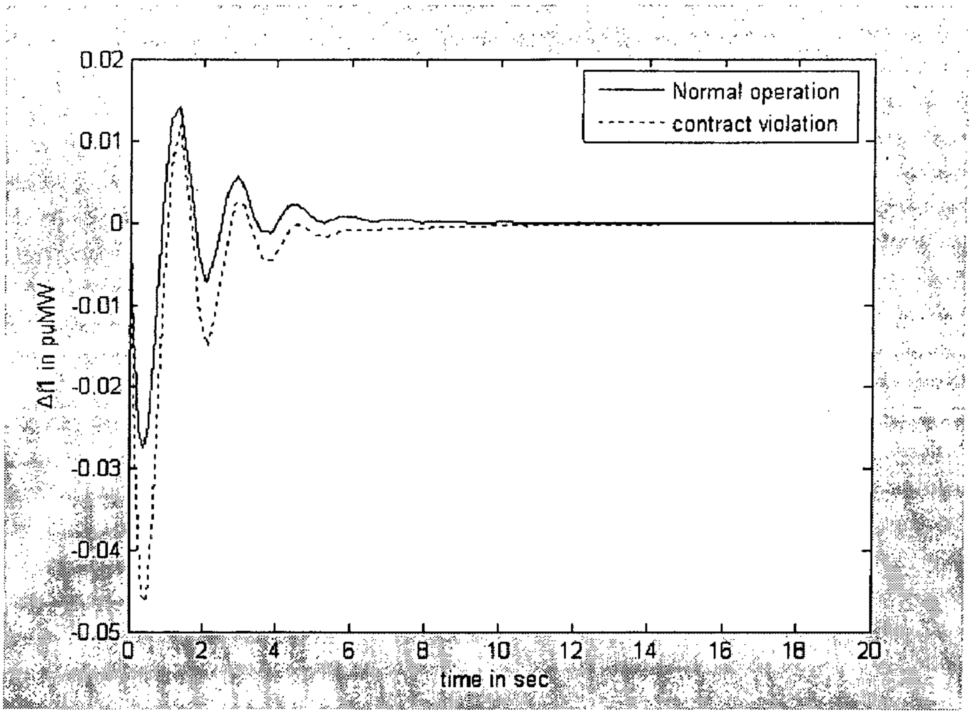


Figure 3.16: Dynamic response of Frequency deviation in area1

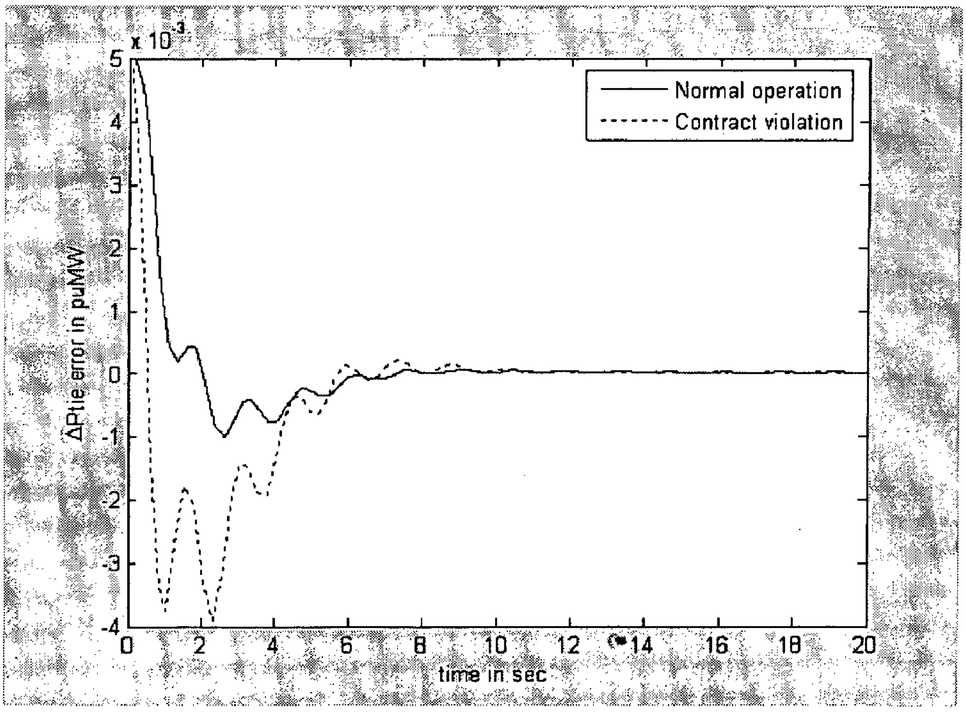


Figure 3.17: Dynamic response of Tie-line power deviation from area1 to area2

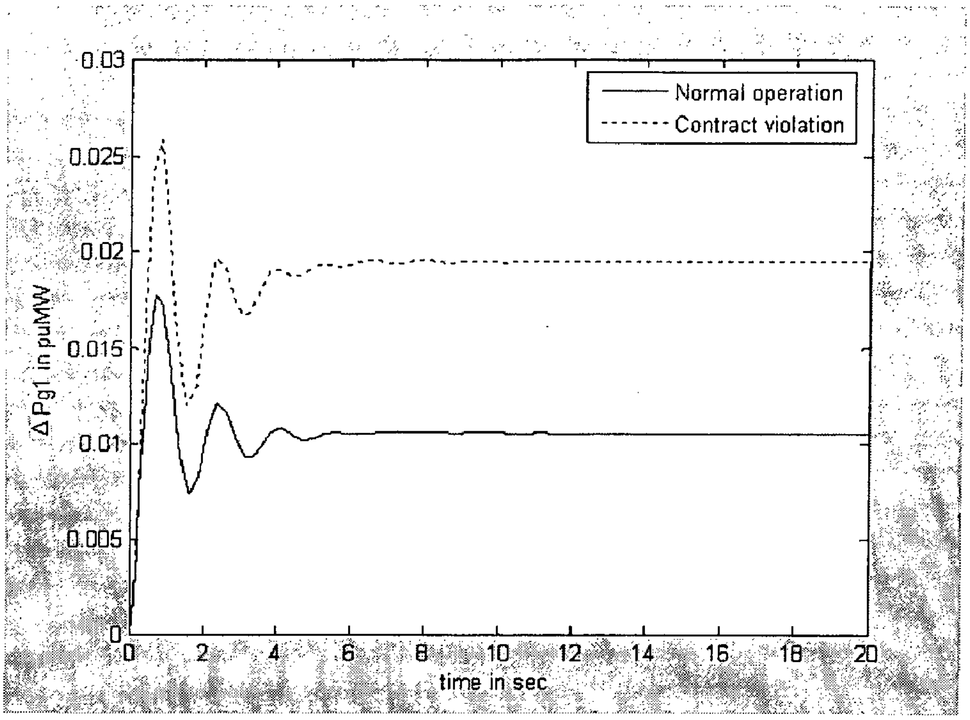


Figure 3.18: Dynamic response of generation of Genco1

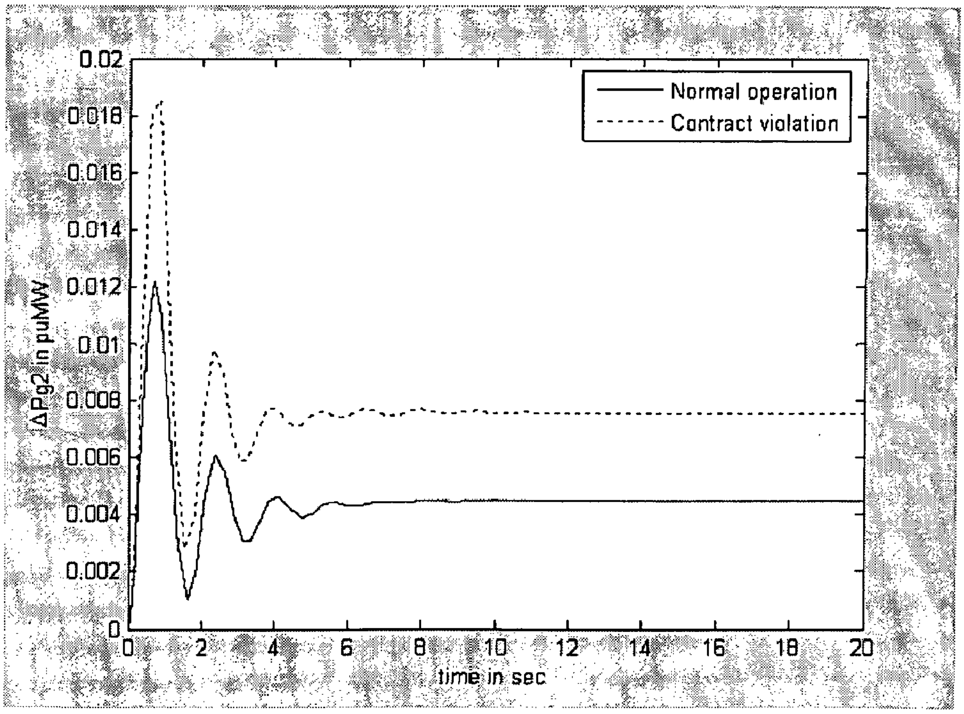


Figure 3.19: Dynamic response of generation of Genco2

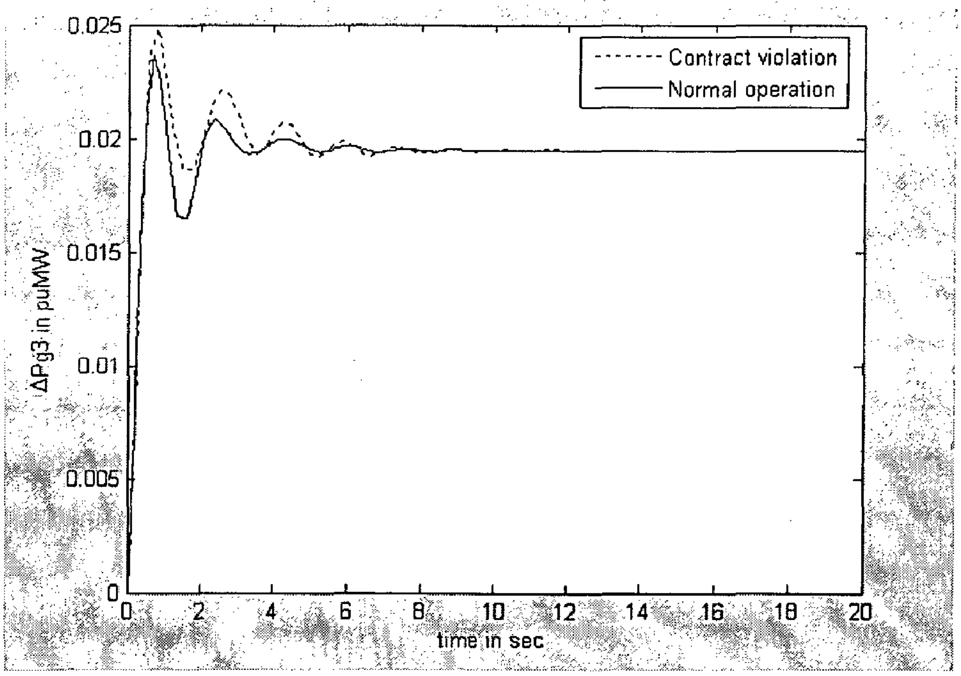


Figure 3.20: Dynamic response of generation of Genco3

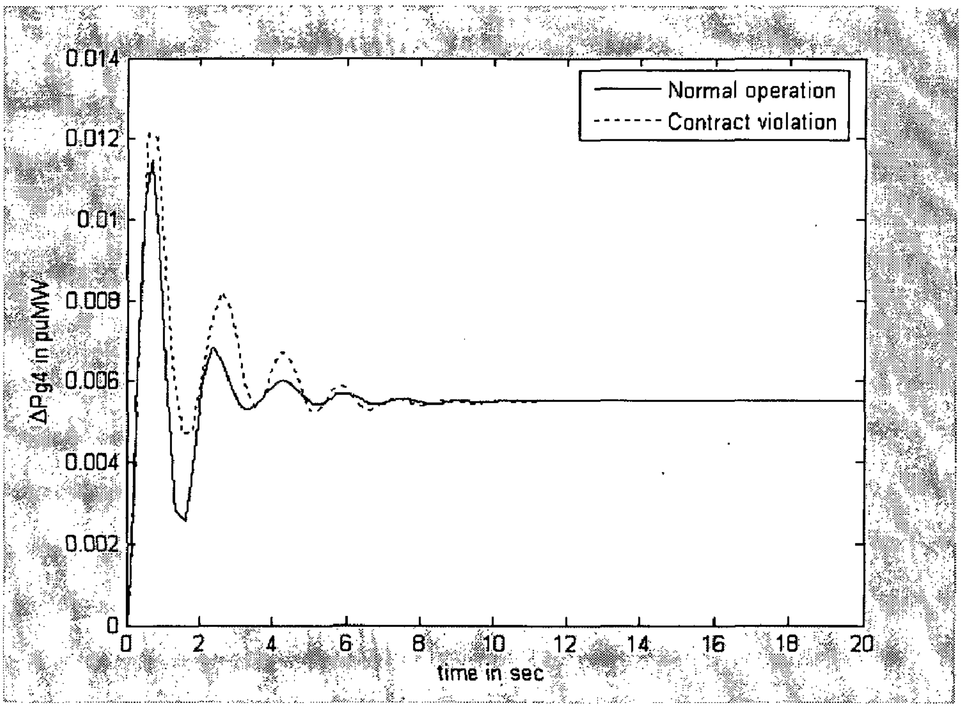


Figure 3.21: Dynamic response of generation of Genco4

- In the case of contract violation, the distribution of load to generators in the effected area depends on their participation factors.

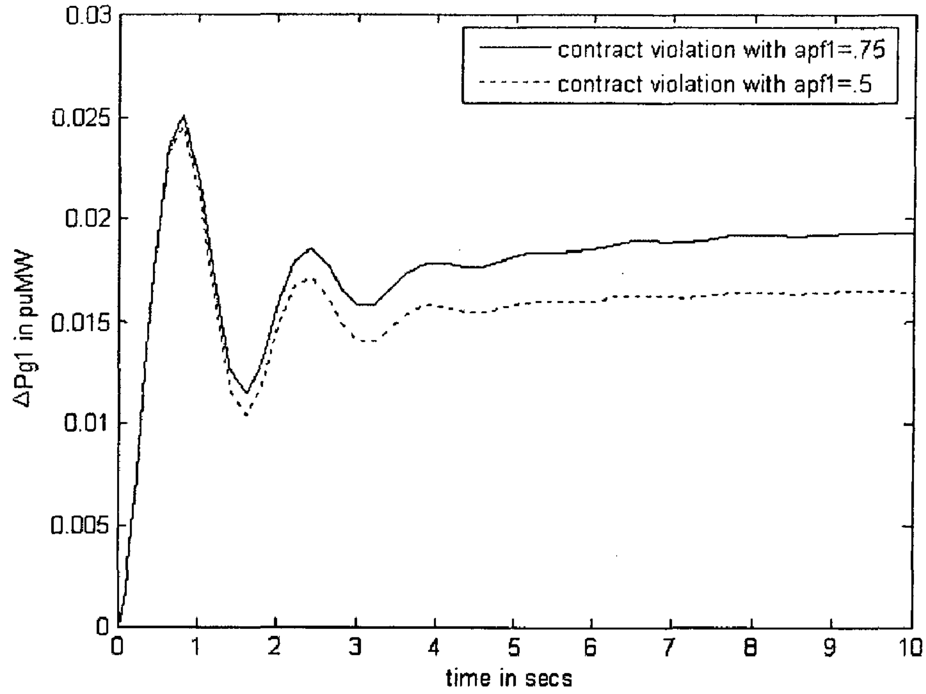


Figure 3.22: Dynamic response of generation of Genco1 under contract violation

3.8 CONCLUSION

1. AGC model for a two-area thermal system has been developed under deregulated environment.
2. Presence of AGC in both the areas and small perturbations in either area or in both provides zero steady state error in the dynamic response.
3. The optimum value of supplementary controller parameter K is dependent on the PDM i.e contract agreement, Hence with change in DPM matrix there will be corresponding change in the optimum value of K
4. The effect of variation of speed regulation parameter 'R' was also studied and found that there is change in the response with change in the value of 'R'. It is shown that a value of 2.4 Hz / p.u. MW provides more or less best result in comparison to others.
5. The dynamic behavior of the system has been studied with demands from each Disco.

6. During contract violation the extra load is taken care of by the generators of the same area, but the tie-line flow and the frequency deviation become zero in the steady-state.
7. Under contract violation case, apf of the generators decide the distribution of the uncontracted load.

CHAPTER 4

AUTOMATIC GENERATION CONTROL IN A DEREGULATED POWER SYSTEM USING AI TECHNIQUES

In the previous chapter the controller for automatic generation control (AGC) was taken as integral controller. The perturbation of the frequencies at the areas and resulting tie line power flow arises due to unpredictable load variation that causes mismatch between the generated and the demanded power. The objective of AGC is to minimize the transient deviations and to provide zero steady state errors of these variables in a very short time although unpredictable load variation exists. Unfortunately because of operating point continuously changes depending on demand of consumers, the selected fixed controller can be unsuitable for other operating points and has to be retuned every time with change in operating point. This result in developing a new controller based on fuzzy logic. It gives the advantage of no mathematical modeling requirement. Fuzzy logic controllers are known to be more robust and their performance is less sensitive to parameter variation than the conventional controllers.

A hybrid type supplementary controller is proposed in this thesis. The integral controller has been augmented with fuzzy logic controller and the dynamic response of the hybrid controller for supplementary control of AGC is studied. The parameters of the fuzzy controller and of the augmented integral controller are tuned with respect to the dynamic response using genetic algorithm(GA) technique .The performance of the hybrid controller with GA tuning has been compared to that of the conventional integral controller.

Fuzzy logic controller has some advantages:

a) It provides an efficient way of coping with imperfect information
b) It offers flexibility in decision making.
c) It provides an interesting man/machine interface by simplifying rule extraction from human experts.

To damp out the oscillations due to instantaneous load perturbations as fast as possible, the supplementary integral controller for AGC with FLC is used. The results obtained show that the controller performance improves effectively the damping of the oscillations, after the load deviation in one of the areas in the interconnected system compared to the conventional controller.

4.1 OBJECTIVE:

Main objective is

a) To design a hybrid controller for two area thermal system in a deregulated power system and to tune the controller parameters using genetic algorithm technique

b) To compare the dynamic responses obtained with GA tuned FLC with that of the conventional integral controllers.

4.2 FUZZY LOGIC CONTROLLER (FLC)

The essential part of FLC is a set of linguistic control rules related by the dual concepts of fuzzy implication and the compositional rule of inference. In essence, then, the FLC provides an algorithm that can convert the linguistic control strategy based on expert knowledge into an automatic control strategy.

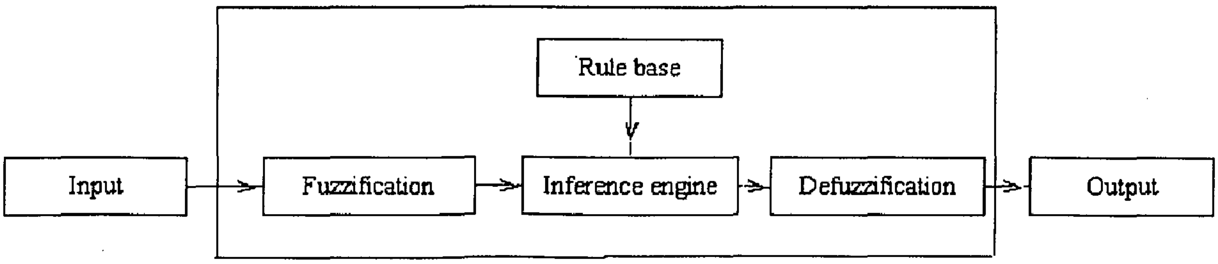


Figure 4.1: components of fuzzy system...Ref [18]

The fuzzy logic structure for all controller design is shown in the *Figure 4.1*. There are four main blocks in the fuzzy system: the fuzzifier, the inference engine, the rule base and the defuzzifier.

The fuzzyfication inference involves the following functions:

a) Measures the value of the input variables.
b) Performs a scale mapping that transfers the range of values of input variables into corresponding universe of discourse.
c) Performs the function of fuzzyfication that converts input data into suitable linguistic values which may be viewed as labels of fuzzy sets.

The rule base (RB) comprises knowledge of the application domain and the attendant control goals. It consists of a data base and linguistic control rules. The database provides necessary definitions, which are used to define linguistic control rules and the fuzzy data manipulation in an FLC. The rule base characterizes the control goals and the control policy of the domain experts by means of a set of linguistic control rules. A fuzzy system RB consists of IF-THEN rules and membership functions characterizing the fuzzy sets.

From the point of view of fuzzy set theory the inference engine is the heart of the fuzzy system. It is the inference engine that performs all the logic manipulations in a fuzzy system. The result of the inference process is an output represented by a fuzzy set, but the output of the fuzzy system should be numeric value.

The defuzzification inference performs the scale mapping, which converts the range of values of output variable into corresponding universe of discourse.

Many fuzzy controller structure based on various methods have been presented earlier. The most widely used method in practice is the Mamdani method proposed by Mamdani and his associates who adopted the min-max compositional rule of inference based on an interpretation a control rule as a conjunction of the antecedent and consequent. Conventional controllers are derived from control theory technique based on mathematical model of the open-loop process to be controlled. For instance, a conventional proportional-integral (PI) controller can be described by the function
$u=Kp + Ki \int e \, dt$, where e is the control error and Kp is proportional gain and Ki is the integral gain. According to the conventional automatic control theory, the performance of

the PI controller is determined by its proportional parameter Kp and integral parameter Ki .The proportional term provides control action equal to some multiple of the error, while the integral term forces the steady state error to zero.

Usually, fuzzy control rules are constructed by summarizing the manual control experiences of an operator who has been controlling the industrial process skillfully and successfully. The operator intuitively regulates the executer to control the process by watching the error and the change rate of the error between output of the system and the set-point value given by the technical requirement. It is no practical way for the operator to observe the integration of the error of the system. Therefore it is impossible to explicitly abstract fuzzy control rules from the operator's experience. Hence, it is better to design a fuzzy controller that possesses the fine characteristics of the PI controller by using only ACE and ΔACE.

4.2.1 System investigated:

In this thesis, the simulation has been done using MATLAB simulink program and MATLAB fuzzy logic toolbox (FLT). The investigations have been carried out on the same interconnected thermal-thermal system shown in *Figure 3.2*. However, the integral controllers have been replaced by GA tuned hybrid controller. The nominal parameters are also the same and as given in Appendix.

The proposed controller is shown in *Figure 4.2.*

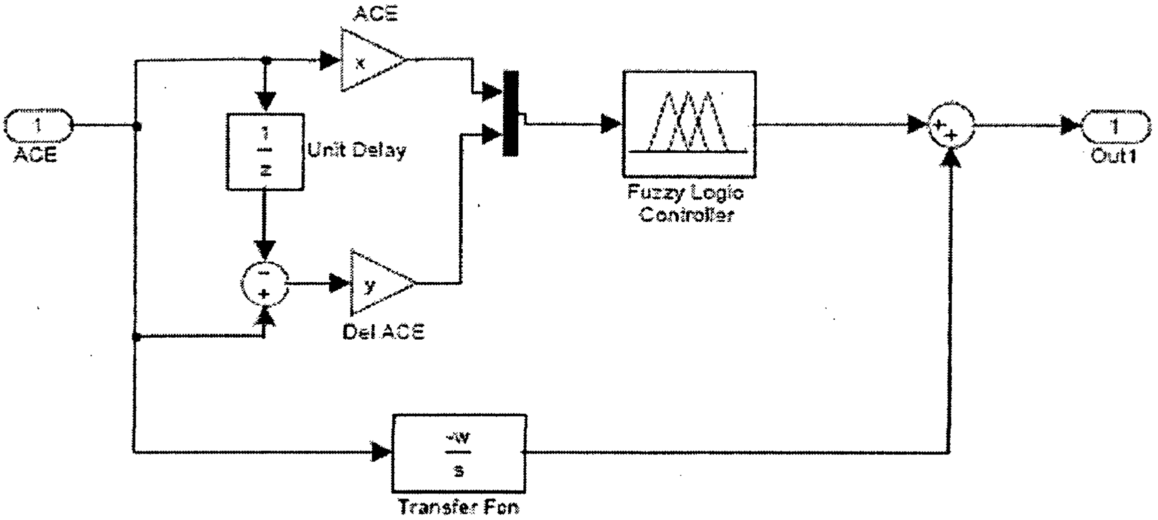


Figure 4.2: Hybrid controller

Fuzzy controller is based on fuzzy logic which is a logical system that is much closer in spirit to human thinking and natural language than traditional logical systems. The FLC is very useful when the processes are too complex. The inputs to the proposed FLC are ACE and rate change in ACE (ΔACE). In this study, the control rules and the membership functions are in such a way that it exhibits a linear PD control characteristic. The rule base with the minimum number of rules that satisfies the above mentioned controller characteristics is given in the *Table 4.1.*

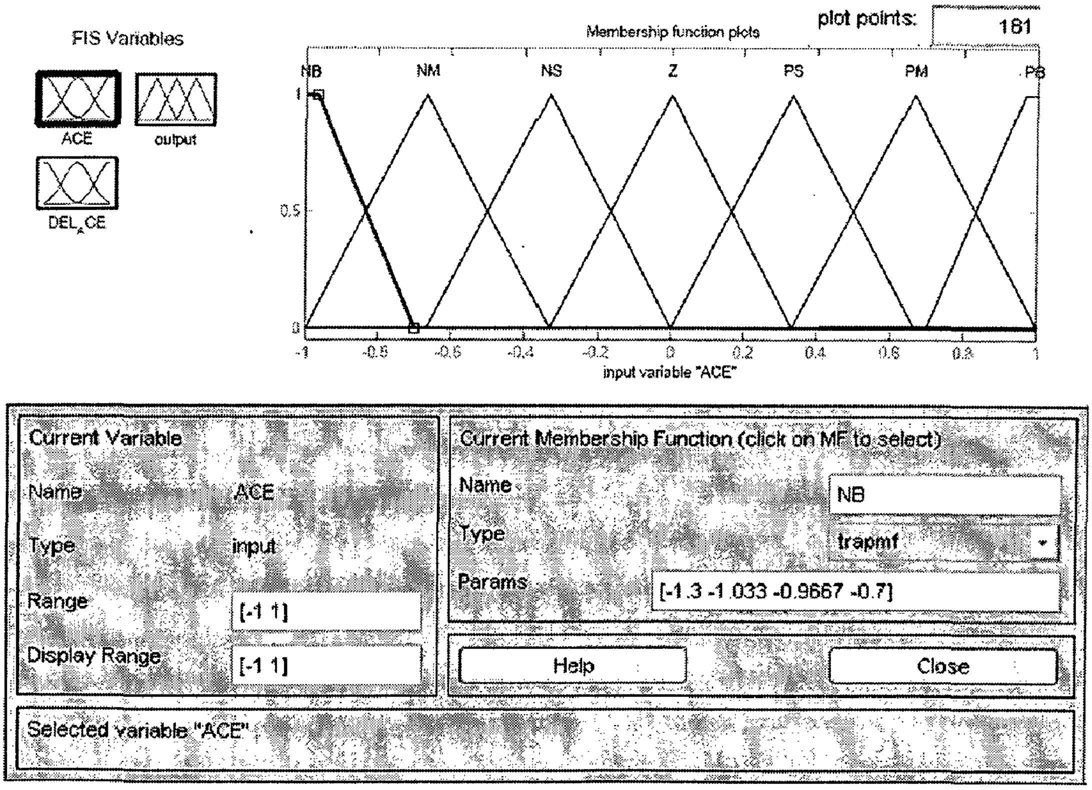
ΔACE / *ACE*	**NB**	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
NB	NB	NM	NS	NS	NS	NS	Z
NM	NM	NM	NS	NS	NS	Z	Z
NS	NS	NS	NS	NS	Z	NS	PM
Z	NS	NS	NS	Z	PS	PM	PM
PS	NS	NS	Z	PS	PS	PS	PS
PM	NS	Z	NS	PM	PS	PM	PM
PB	Z	PS	PM	PB	PB	PB	PB

Table 4.1: Rule table for the proposed fuzzy logic...Ref [12]

NB=Negative Big

NM=Negative Medium
NS=Negative Small
Z=Zero
PS=Positive Small
PM=Positive Medium
PB=Positive Big

The fuzzy logic shows experience and the preference through its membership functions. These functions have different shapes depending on the system expert's experience. The membership functions that are chosen are shown in *Figures 4.3-4.5*



plot points: 181

Name ACE

Type input

Range [-1 1]

Display Range [-1 1]

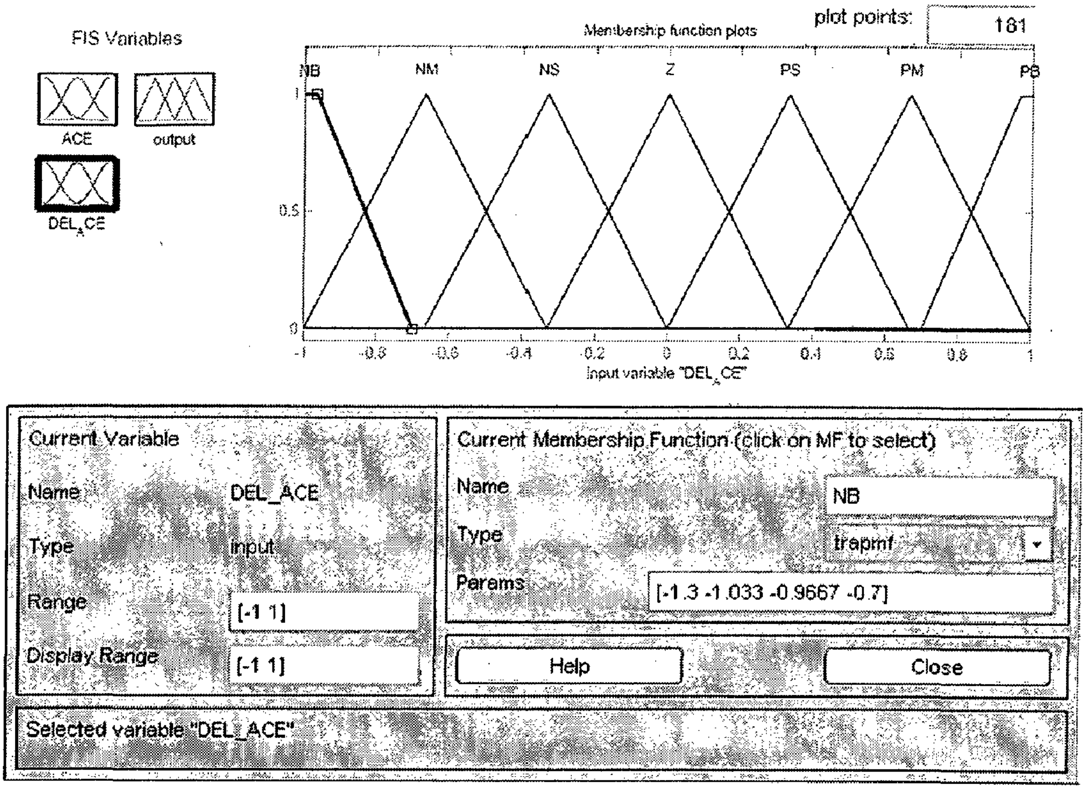
Name NB

Type trapmf

Params [-1.3 -1.033 -0.9667 -0.7]

Selected variable "ACE"

Figure 4.3: Membership functions of ACE



Current Variable

Name DEL_ACE

Type input

Range [-1 1]

Display Range [-1 1]

Current Membership Function (click on MF to select)

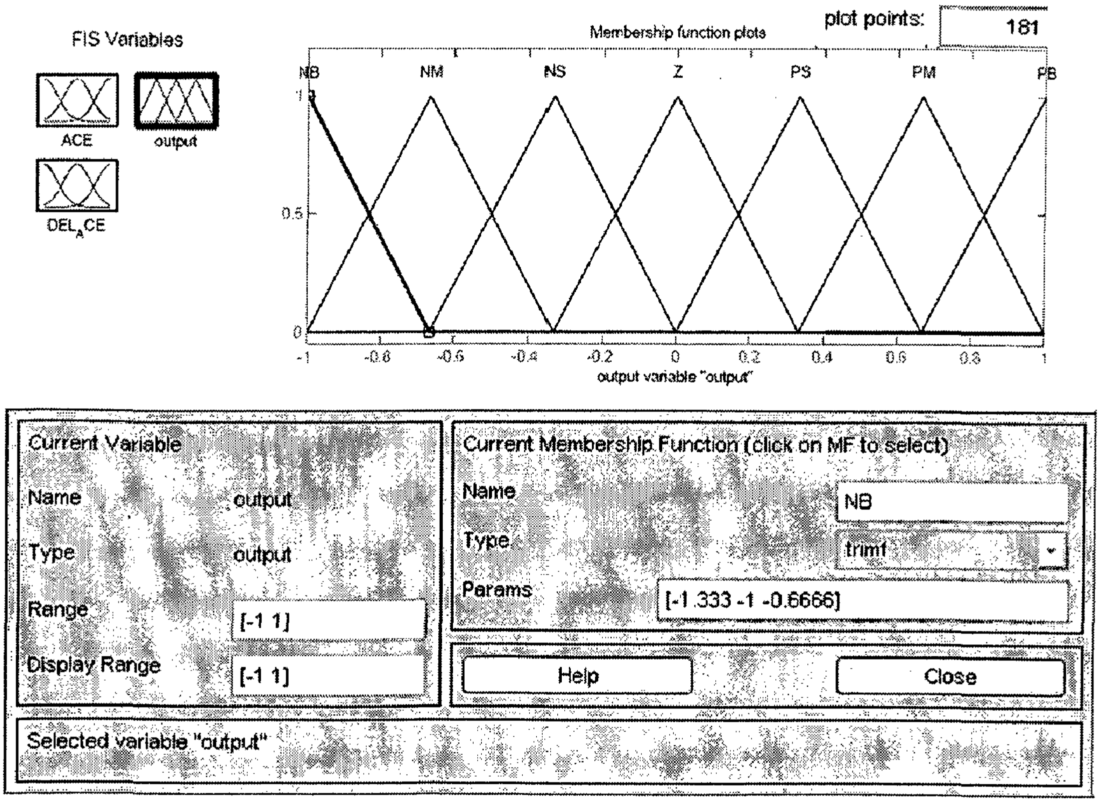
Name NB

Type trapmf

Params [-1.3 -1.033 -0.9667 -0.7]

Selected variable "DEL_ACE"

Figure 4.4: Membership functions of ΔACE



Current Variable

Name output

Type output

Range [-1 1]

Display Range [-1 1]

Current Membership Function (click on MF to select)

Name NB

Type trimf

Params [-1.333 -1 -0.6666]

Selected variable "output"

Figure 4.5: Membership functions of output

In the proposed controller, the membership functions taken are triangle shaped and only at the boundary of the universe of discourse, trapezoidal membership function are considered.

4.3 TUNING OF CONTROLLER PARAMETERS USING GA TECHNIQUE

Genetic algorithms are global search techniques, based on the operations observed in natural selection and genetics. They operate on a population of current approximations-initially drawn at random, from which improvement is sought. Individuals are encoded as strings (chromosomes) constructed over the binary alphabet {0, 1}.

Genetic operators can be divided into three main categories, reproduction, crossover, and mutation.

4.3.1. Reproduction

In the reproduction stage, a fitness value is derived from the individual performance measure given by the objective function, and used to bias the selection process. Highly fit individuals will have increasing opportunities to pass on to successive generations. In this way, the genetic algorithms search from many points in the search space at once and yet continually narrow the focus of the search to the areas of the observed best performance. An example of a common selection technique is the 'Roulette Wheel' selection method. Multiple copies of the same string may be selected for reproduction and the fitter strings should begin to dominate.

4.3.2. Cross-over

Once the selection process is complete, the crossover algorithm is initiated. The crossover operations swap certain parts of the two selected strings in a bid to capture the good parts of old chromosomes and create better new ones. Genetic operators manipulate the characters of a chromosome directly, using the assumption that certain individual's gene codes, on average, produce fitter individuals. The crossover probability indicates how often crossover is performed. A probability of 0% means that the 'offspring' will be exact replicas of their 'parents' and a probability of 100% means that each generation will be composed of entirely new offspring. In the present thesis I have used two-point cross over in which the bits between successive crossover points are exchanged to produce new offspring

Example: If the string 11111 and 00000 were selected for crossover and the multipoint crossover positions were selected to be 2 and 4 then the newly created strings will be 11001 and 00110 as shown below.

$$\begin{array}{c|c|c} 11 & 11 & 1 \\ 00 & 00 & 0 \end{array} \longrightarrow \begin{array}{c} 11001 \\ 00110 \end{array}$$

4.3.3. Mutation

Using selection and crossover on their own will generate a large amount of different strings. However there are two main problems with this:

a) Depending on the initial population chosen, there may not be enough diversity in the initial strings to ensure the GA searches the entire problem space.
b) The GA may converge on sub-optimum strings due to a bad choice of initial population.

These problems may be overcome by the introduction of a mutation operator into the GA. Mutation is the occasional random alteration of a value of a string position. It is considered a background operator in the genetic algorithm. The probability of mutation is normally low because a high mutation rate would destroy fit strings and degenerate the genetic algorithm into a random search. Mutation probability values of around 0.1% or 0.01% are common, these values represent the probability that a certain string will be selected for mutation i.e. for a probability of 0.1%; one string in one thousand will be selected for mutation. Once a string is selected for mutation, a randomly chosen element of the string is changed or 'mutated'. For example, if the GA chooses bit position 4 for mutation in the binary string 10000, the resulting string is 10010 as the fourth bit in the string is flipped as shown below.

$$10000 \xrightarrow{\text{Mutate}} 10010$$

The selected individuals are thus modified through the application of genetic operators, in order to obtain the next generation. Genetic operators manipulate the characters (genes) that constitute the chromosomes directly, following the assumption that certain genes code, on average, for fitter individuals than other genes.

4.3.4 Genetic Algorithm Process

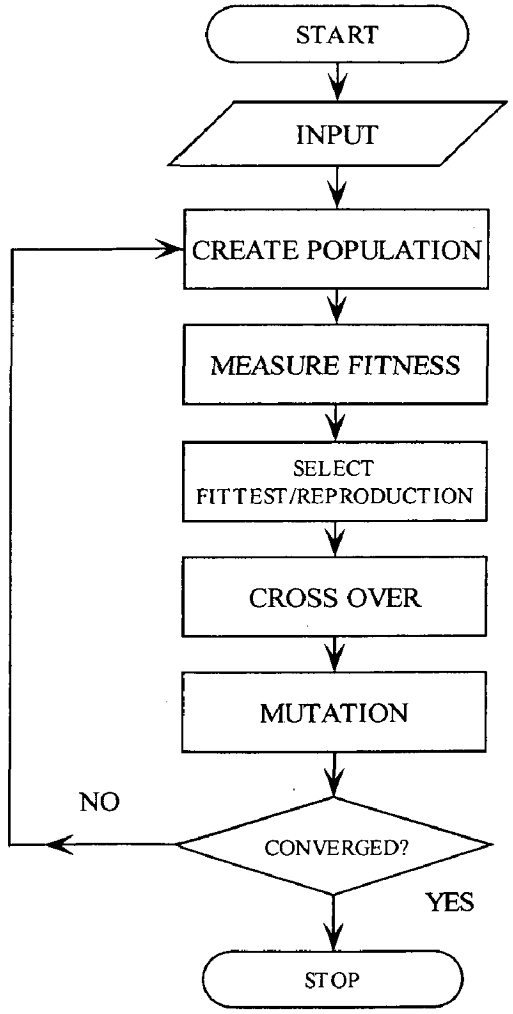


Figure 4.6: functional flow chart of GA

The steps involved in creating and implementing a genetic algorithm are as follows:

1. Generate an initial, random population of individuals for a fixed size.
2. Evaluate their fitness.
3. Select the fittest members of the population.
4. Reproduce using a probabilistic method (e.g., roulette wheel).
5. Implement crossover operation on the reproduced chromosomes
6. Execute mutation operation with low probability.
7. Repeat step 2 until a predefined convergence criterion is met.

The convergence criterion of a genetic algorithm is a user-specified condition e.g. the maximum number of generations or when the string fitness value exceeds a certain threshold.

Genetic algorithms are more likely to converge to global optima than conventional optimization techniques, since they search from a population of points. Conventional optimization techniques are ordinarily based on deterministic hill climbing methods, which, by definition, will only find local optima.

In a typical run of the GA, an initial population is randomly generated. This initial population is referred to as the 0th generation. Each individual in the initial population has an associated performance index value. Using the performance index information, the GA then produces a new population. The application of a genetic algorithm involves repetitively performing two steps.

a) The calculation of the performance index for each of the individuals in the current population. To do this, the system must be simulated to obtain the value of the performance index.
b) 2. The genetic algorithm then produces the next generation of individuals using the reproduction, crossover and mutation operators.

Our goal is to find the global minimum value. For this purpose, after the performance index is evaluated for each chromosome, they are ranked from the lowest to the highest performance index value. Unacceptable chromosomes are discarded after the ranking. So, the algorithm determines which chromosomes out of the initial population are fit enough to survive and possibly reproduce offspring in the next generation. The best members of the population are retained for the next iteration of the algorithm and the rest die-off. Initially the best population is obtained using the Roulette-wheel approach.

Fuzzy control is difficult from the tuning point since tuning is accomplished by trail and error. Instead of applying Genetic Algorithm, fuzzy logic independently for the AGC system, we can use these techniques in combination (GA tuned Fuzzy controller for Automatic Generation control system) to see the advantages of both the Artificial Intelligence techniques. The parameters that need to be optimized are the input scaling factors x and y and w.

4.4 PROCEDURE FOR TUNING THE SCALING FACTOR PARAMETERS USING GA

1. Define the number of fuzzy sets for fuzzy variables ACE and Δ ACE and output.
2. Define the fitness function.
3. Determine the Generation number, population size, crossover rate, mutation rate.
4. Give the range and length of bit for strings for x, y and w, produces an initial number of chromosomes in random manner.
5. Increment the iteration count.
6. Calculate the error, change in error then execute fuzzification, fuzzy inference and defuzzification for the particles in this iteration.
7. Evaluate the fitness function in the generation for each population
8. Reproduce new generation by roulette wheel selection.
9. Crossover pair of population in the new generation according to the crossover rate.
10. Mutate the population in the new generation according to the mutation rate.
11. Reserve the population having high fitness value from the old generation to new generation

12. If the iteration number reaches the predetermined one then stop other wise go to step 5
13. Decode the highest fitness value chromosomes for x, y and w
14. Replace the old values of the x, y and w (scaling factors) with the new ones.

4.5 SIMULATIONS

Simulation study has been done on the model of two area thermal-thermal system in deregulated power system as shown in chapter3 .The parameters of the two area inter connected power system are the same as given in the Appendix. The frequency bias parameter B is chosen equal to area frequency response characteristic (β).A step load perturbation of 1% of the nominal loading has been considered by disco1 in area1.

The system is stable and the control task is to minimize the system frequency deviation $\Delta f1$ in area 1, $\Delta f2$ in area 2 and the deviation in the tie line power flow $\Delta Ptie12$ between the two areas under load disturbance of 1% of nominal loading in area1.Nominal values are given in Appendix.

System considered:

a. $$DPM1 = \begin{bmatrix} 0.5 & 0.25 & 0 & 0.3 \\ 0.2 & 0.25 & 0 & 0 \\ 0 & 0.25 & 1 & 0.7 \\ 0.3 & 0.25 & 0 & 0 \end{bmatrix}$$

b. Each Disco i.e. DISCO1, DISCO2, DISCO3 and DISCO4 demand 0.01 puMW as per the DPM matrix defined.

c. population size = 60.

d. cross over rate=0.5.

e. Mutation rate=0.01.

f. Length of each chromosome = 66

The optimal values of the scaling factors are of x, y and w for the above DPM are obtained using the GA technique. The following *table4.2* shows the optimal values of the scaling factors for the GA tuned hybrid controller for which the system dynamic response is good.

Table 4.2 comparison of the controller parameters with DPM1

	x	y	w
controller parameters not optimized	1	1	1
controller parameters optimized using ISE technique	0.1	0.2	0.01
controller parameters optimized using GA technique	0.0561	0.2462	0.0016

Following *Figures 4.7-4.9* show the comparative responses of frequency deviation in area1 and area2 and also the dynamic response of tie line power flow following a 1% load disturbance.

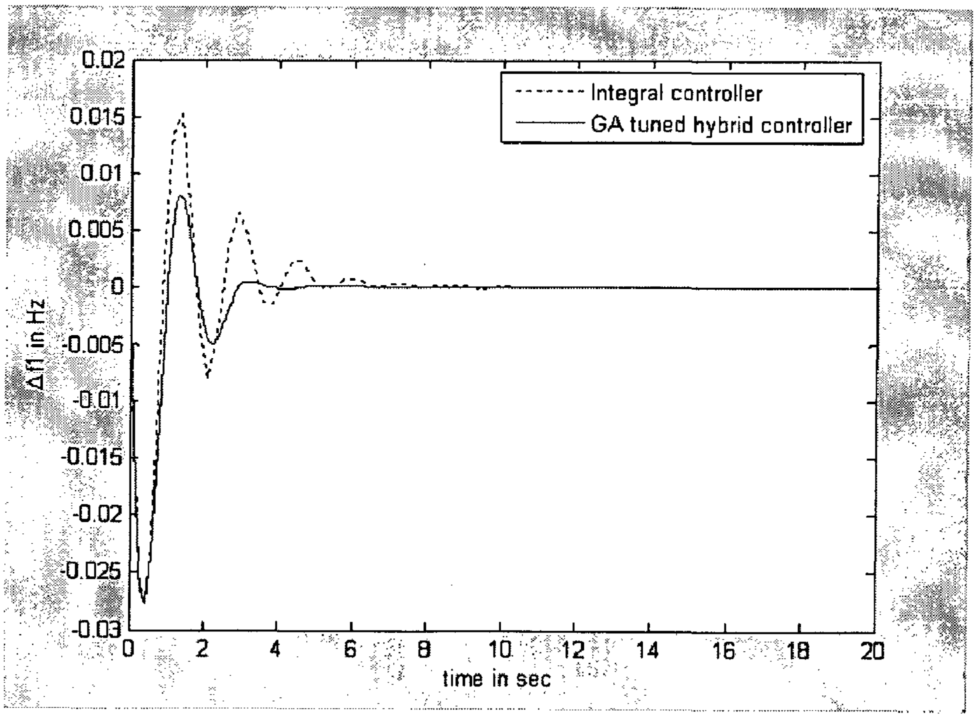


Figure 4.7: Dynamic response comparison of frequency deviation in area1 with integral and hybrid controller

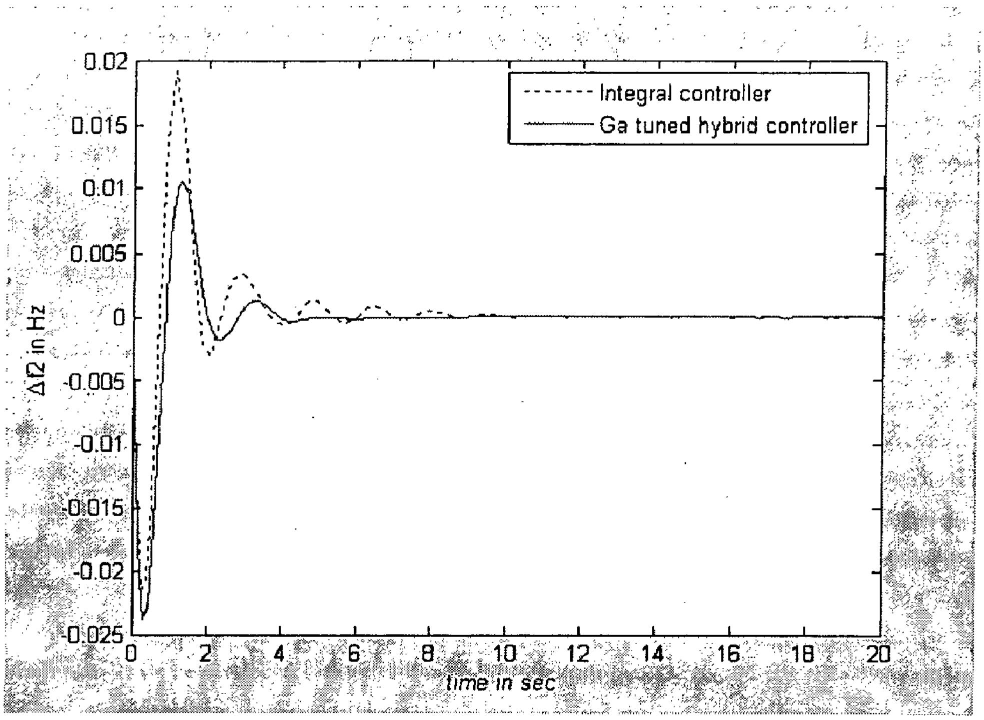


Figure 4.8: Dynamic response comparison of frequency deviation in area2 with integral and hybrid controller.

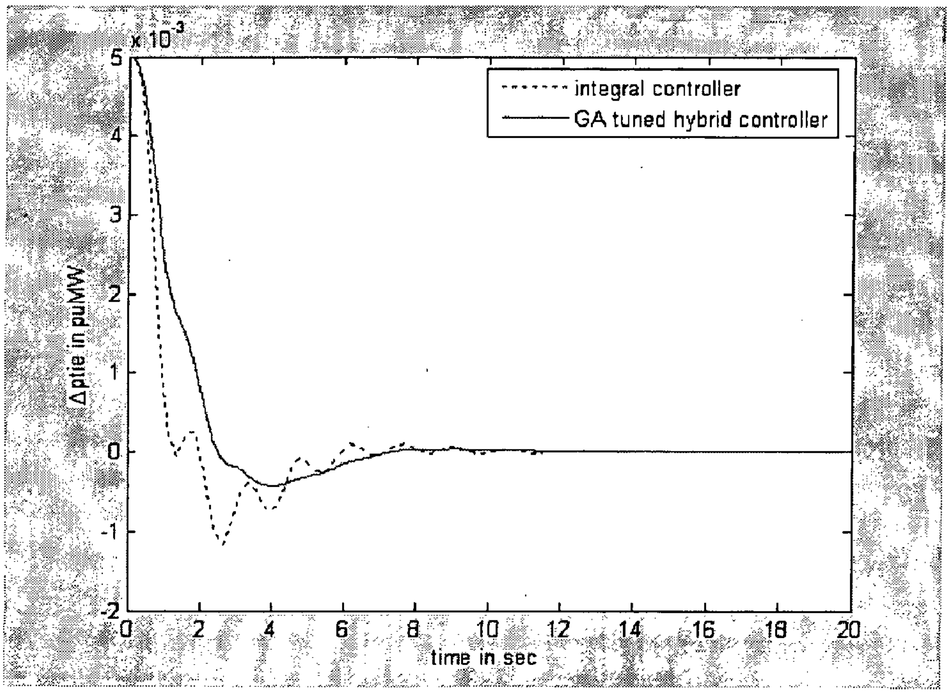


Figure 4.9: Dynamic response comparison of tie-line power deviation with integral and hybrid controller

Following *Figures 4.10-4.13* show the comparative responses of GENCOS in area1 and area2 following a 1% load disturbance.

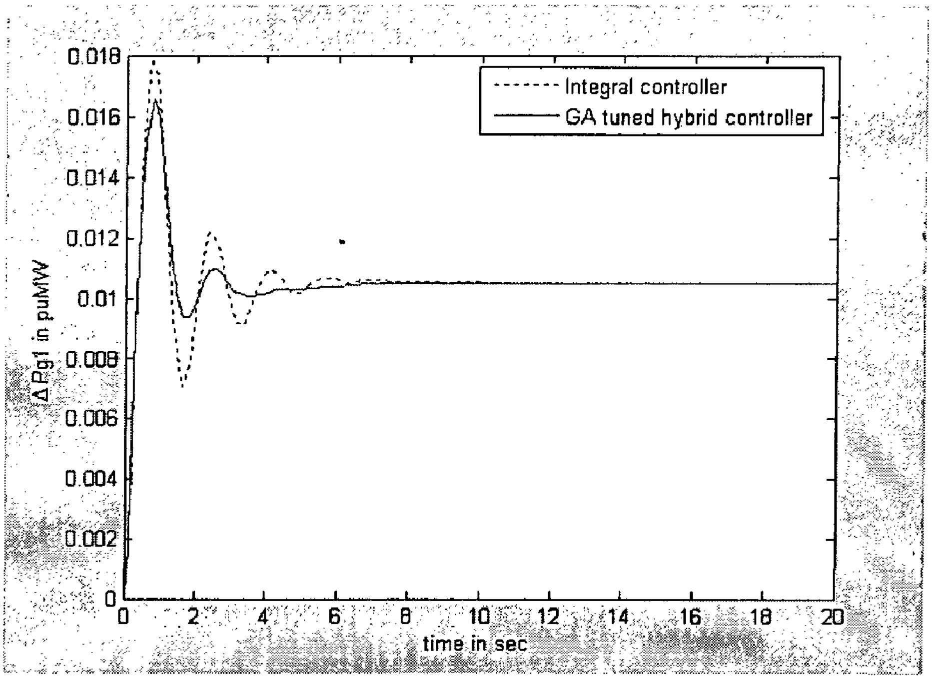


Figure 4.10: Dynamic response comparison of GENCO1 in area1 with integral and hybrid controller

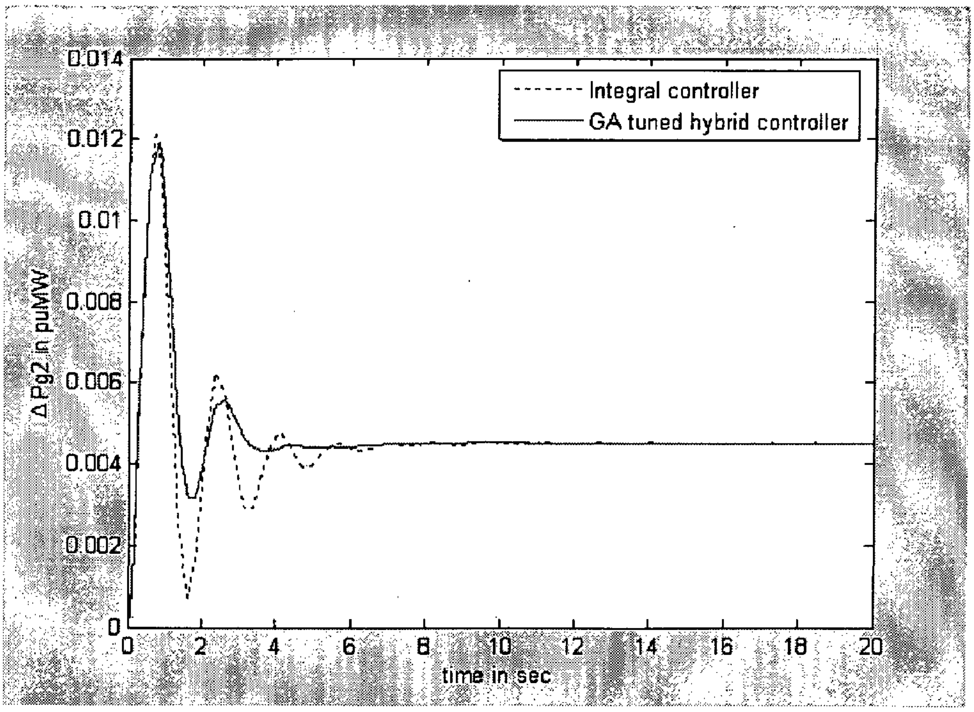


Figure 4.11: Dynamic response comparison of GENCO2 in area1 with integral and hybrid controller

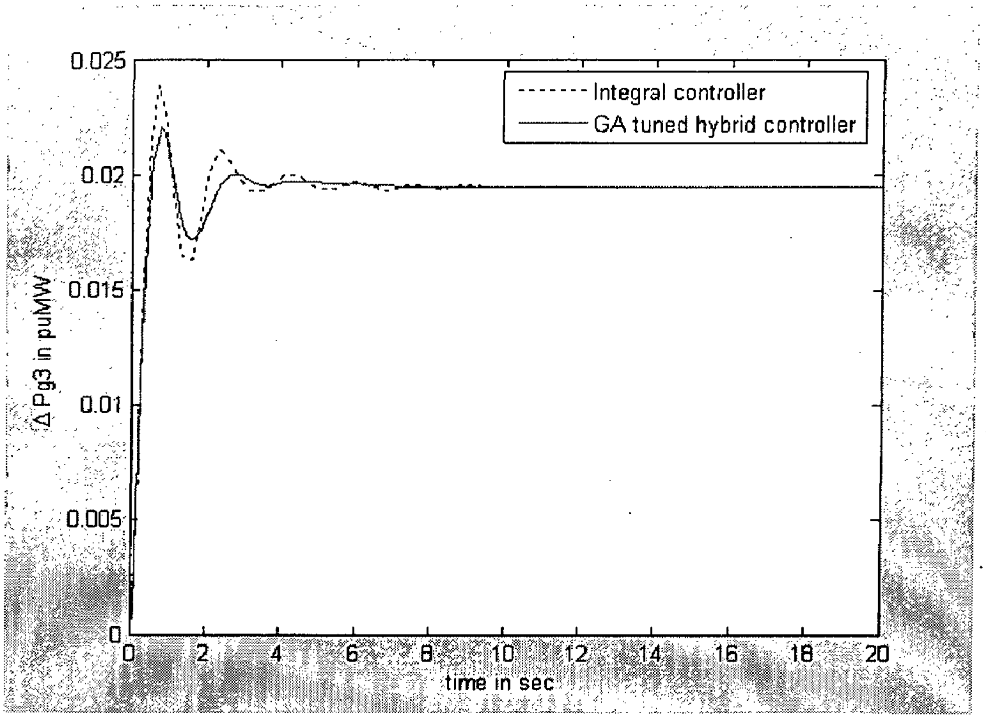


Figure 4.12: Dynamic response comparison of GENCO3 in area2 with integral and hybrid controller

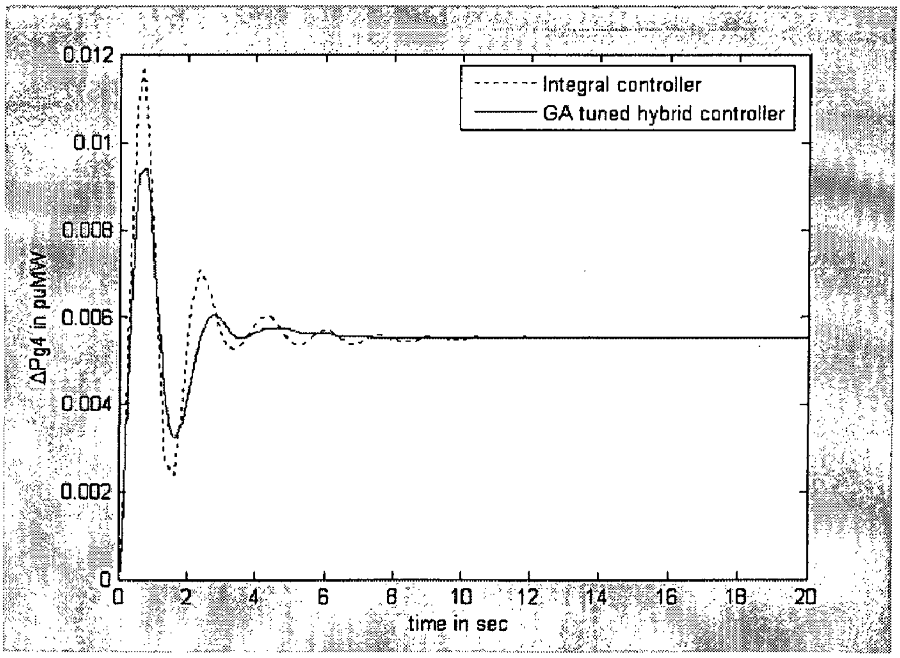


Figure 4.13: Dynamic response comparison of GENCO4 in area2 with integral and hybrid controller

From the above Figures it is evident that with the GA tuned fuzzy type controller the peak deviation and the settling time of frequency deviation in area 1 and area2 is small compared to that with integral controller for the same perturbation.

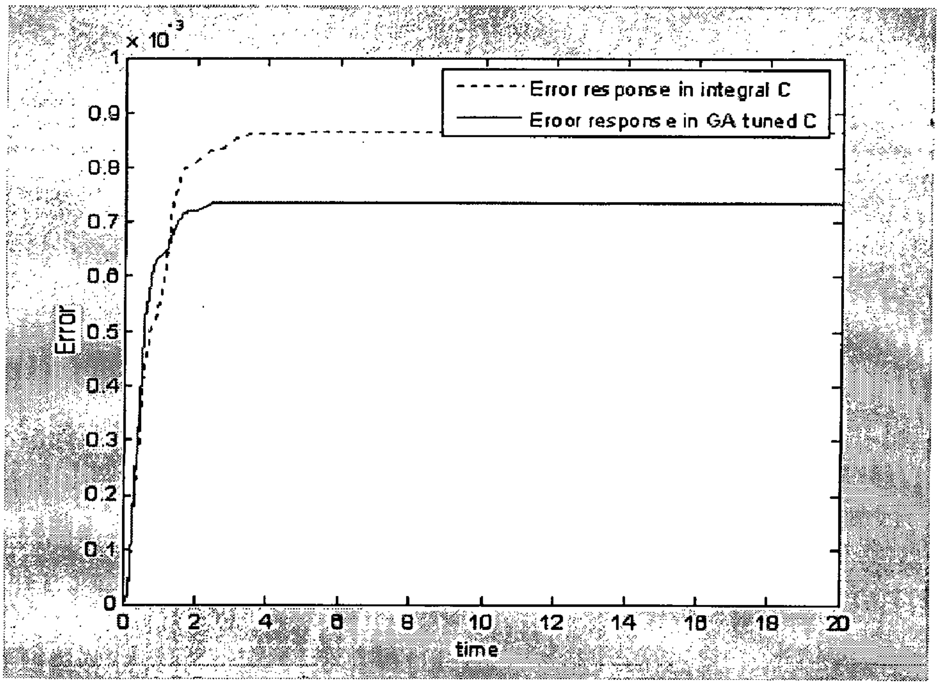


Figure 4.14: Error response

Figure 4.14 shows the comparison of error performance following a small perturbation of 0.01 pu in both the areas with integral controller and with proposed GA tuned hybrid controller. It can be seen that the error has been reduced with the proposed controller.

4.5.1 Behavior of the system under Contract violation:

Consider the case when Disco1 demands 0.012 puMW excess power than that specified in the contract. This condition is termed as "Contract Violation". The uncontracted power must be supplied by the Gencos in the same area of the Disco.

For the present case Disco1 demands an uncontracted power of 0.012puMW

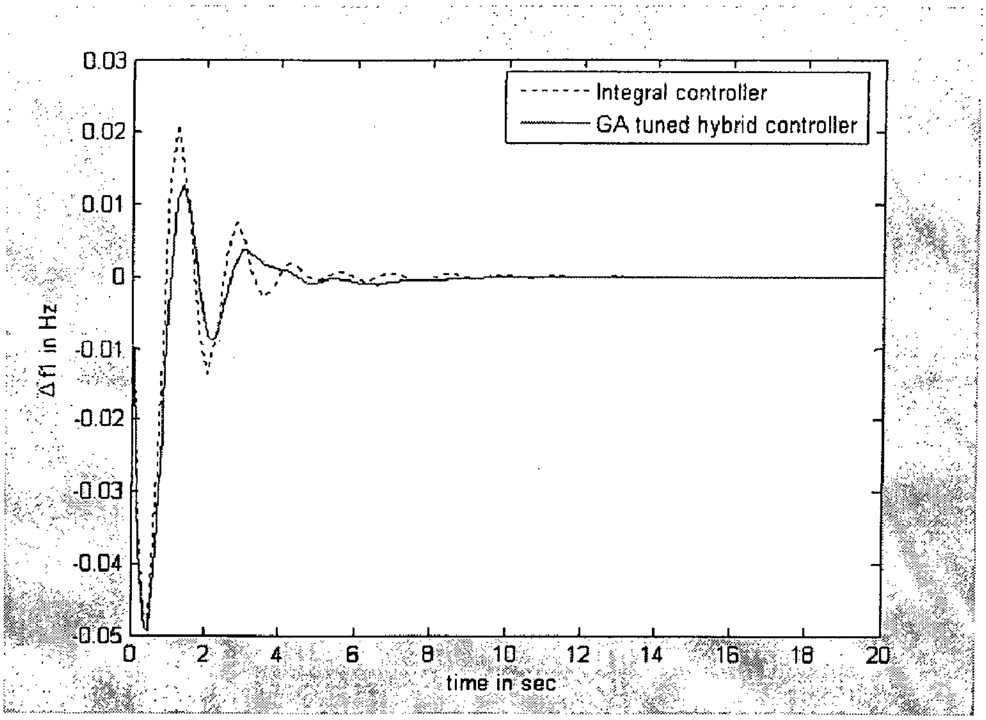


Figure 4.15: Dynamic response comparison of frequency deviation in area1 with integral and hybrid controller

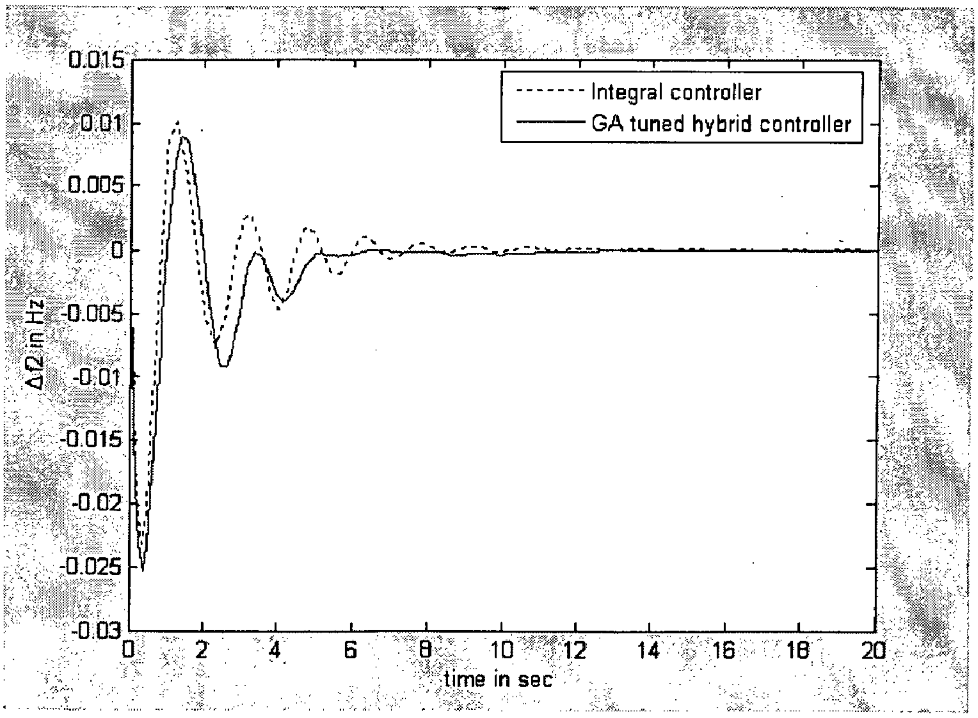


Figure 4.16: Dynamic response comparison of frequency deviation in area2 with integral and hybrid controller

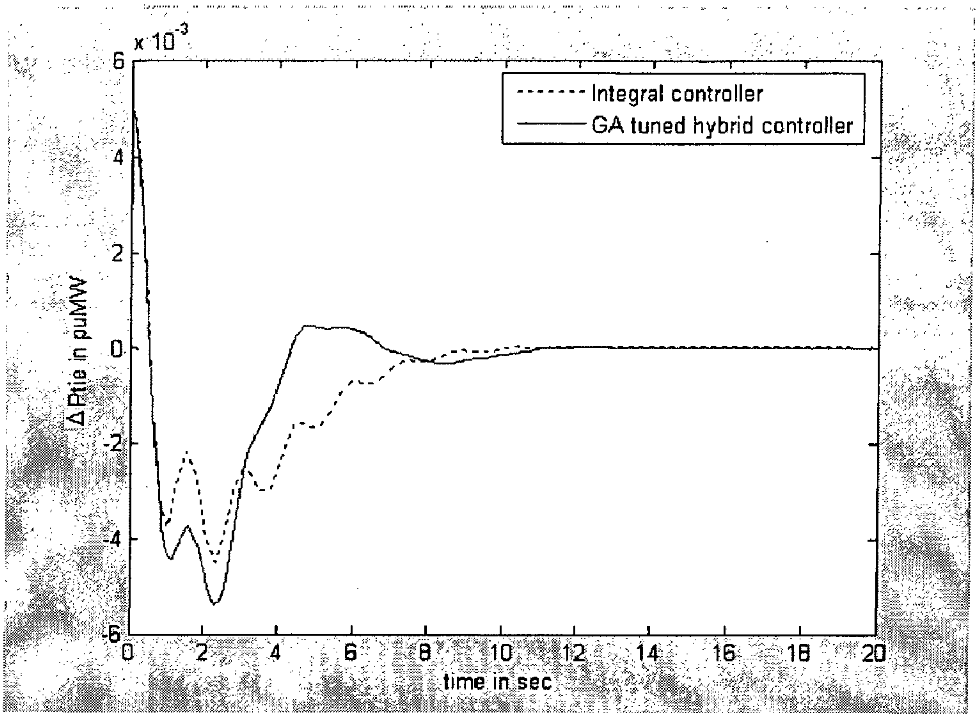


Figure 4.17: Dynamic response comparison of tie line power deviation with integral and hybrid controller

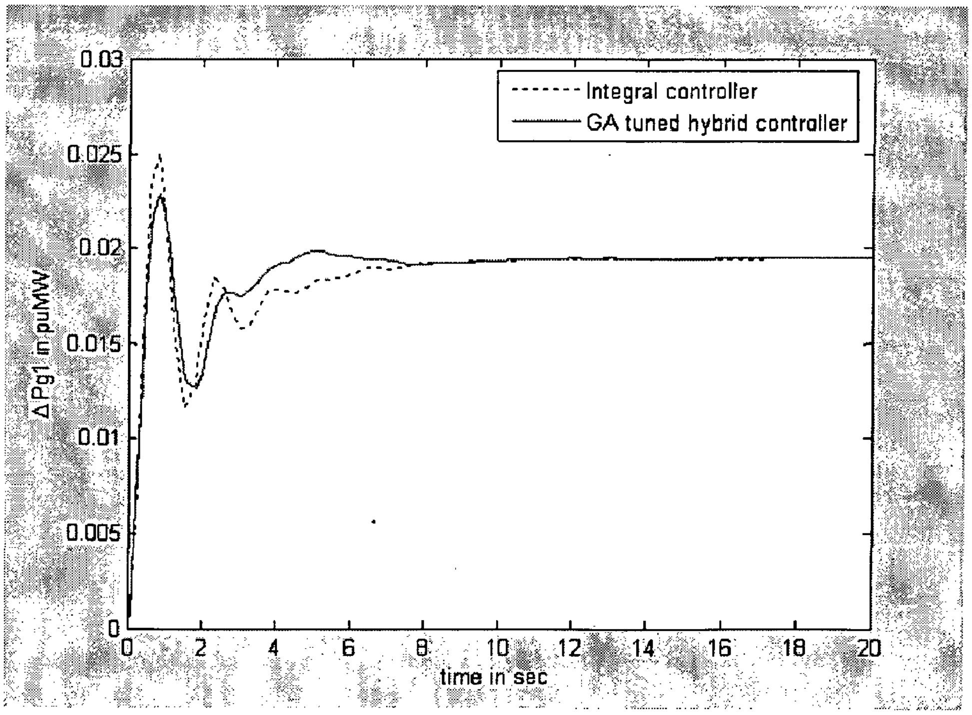


Figure 4.18: Dynamic response comparison GENCO1 in area1 with integral and hybrid controller

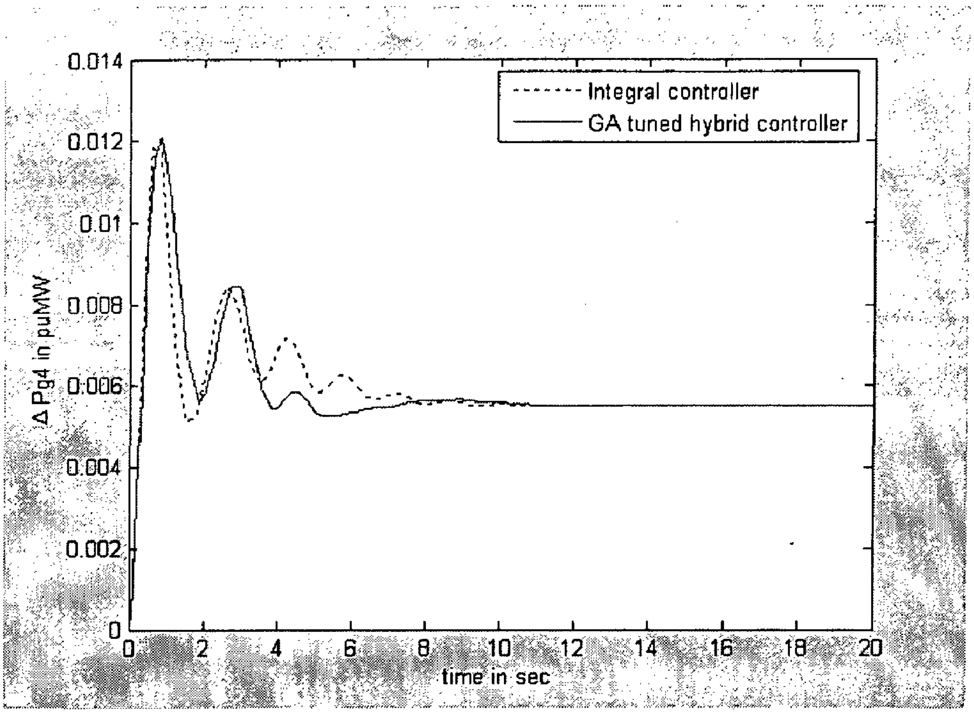


Figure 4.19: Dynamic response comparison of GENCO4 in area1 with integral and hybrid controller

4.5.2 System performance with different DPM

Following DPM matrix was introduced with the proposed supplementary controller and the performance of the system with 1% load perturbation by a Disco in area1 was studied. A step load perturbation of 1% of the nominal loading has been considered in both the areas. Nominal values are given in Appendix.

System considered:

$$\text{a. DPM2}=\begin{bmatrix} 0.3 & 0.3 & 0.1 & 0.1 \\ 0.3 & 0.3 & 0.1 & 0.1 \\ 0.2 & 0.2 & 0.4 & 0.4 \\ 0.2 & 0.2 & 0.4 & 0.4 \end{bmatrix}$$

b. Each Disco i.e. DISCO1, DISCO2, DISCO3 and DISCO4 demand 0.01 puMW as per the DPM matrix defined.

c. population size = 60.

d. cross over rate=0.5.

e. Mutation rate=0.01.

f. Length of each chromosome = 66

The optimal values of the scaling factors are of x, y and w for the above DPM are obtained using the GA technique. The following *table4.3* shows the optimal values of the scaling factors for the GA tuned hybrid controller for which the system dynamic response is good.

Table 4.3 comparison of the controller parameters with DPM2

	x	y	w
parameters not optimized	1	1	1
parameters optimized using GA	0.0003	0.4186	0.0026

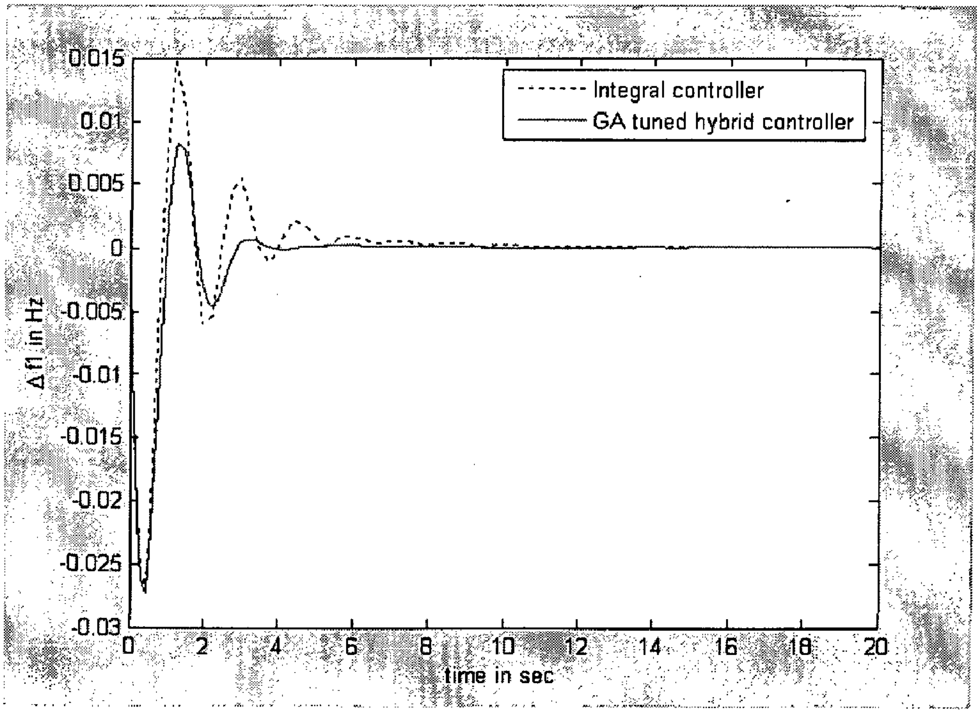


Figure 4.20: Dynamic response comparison of frequency deviation in area1 with integral and hybrid controller

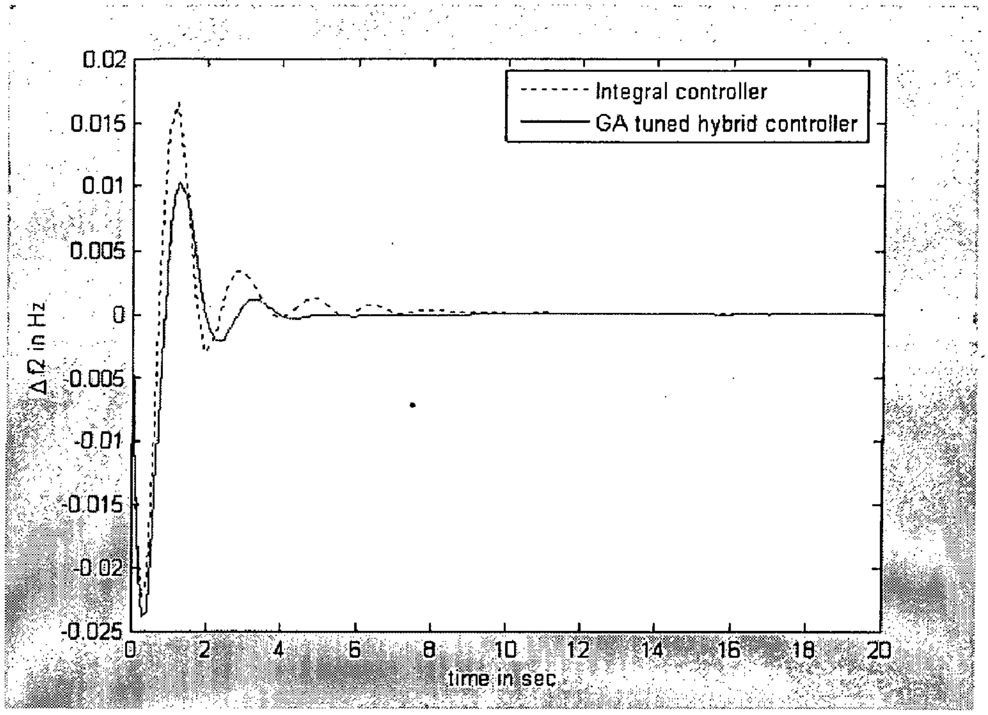


Figure 4.21: Dynamic response comparison of frequency deviation in area2 with integral and hybrid controller

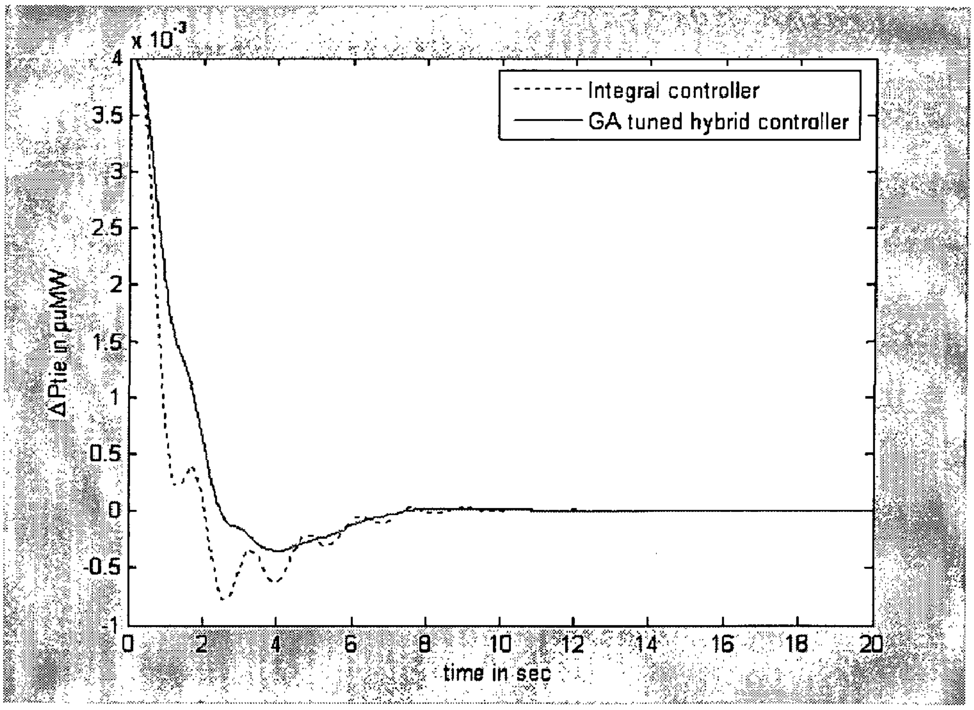


Figure 4.22: Dynamic response comparison tie line power deviation with integral and hybrid controller

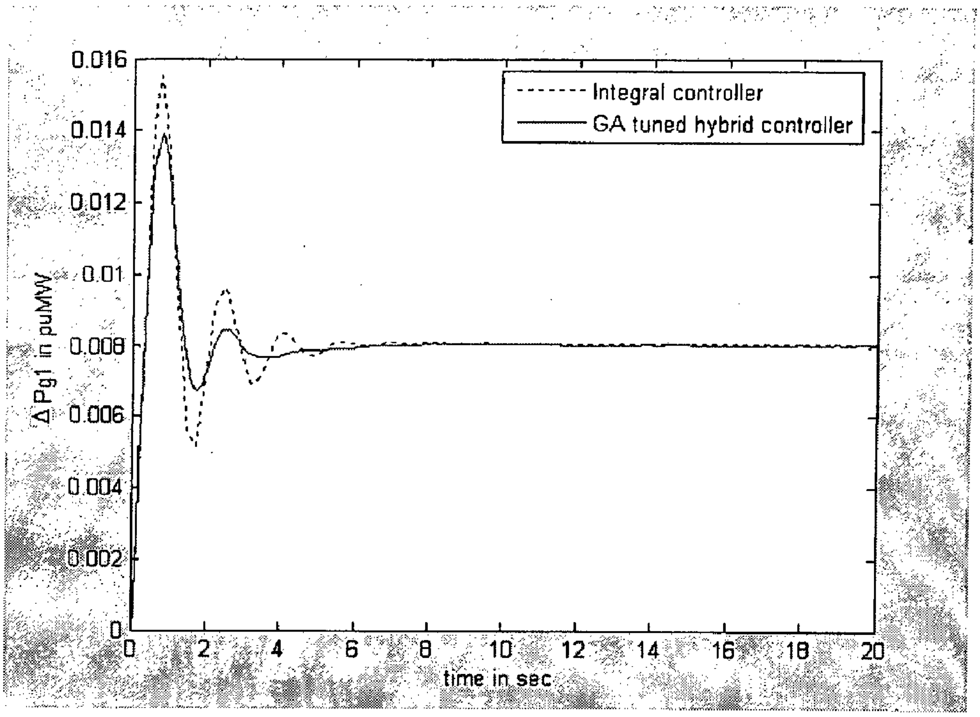


Figure 4.23: Dynamic response comparison of GENCO1 in area1 with integral and hybrid controller

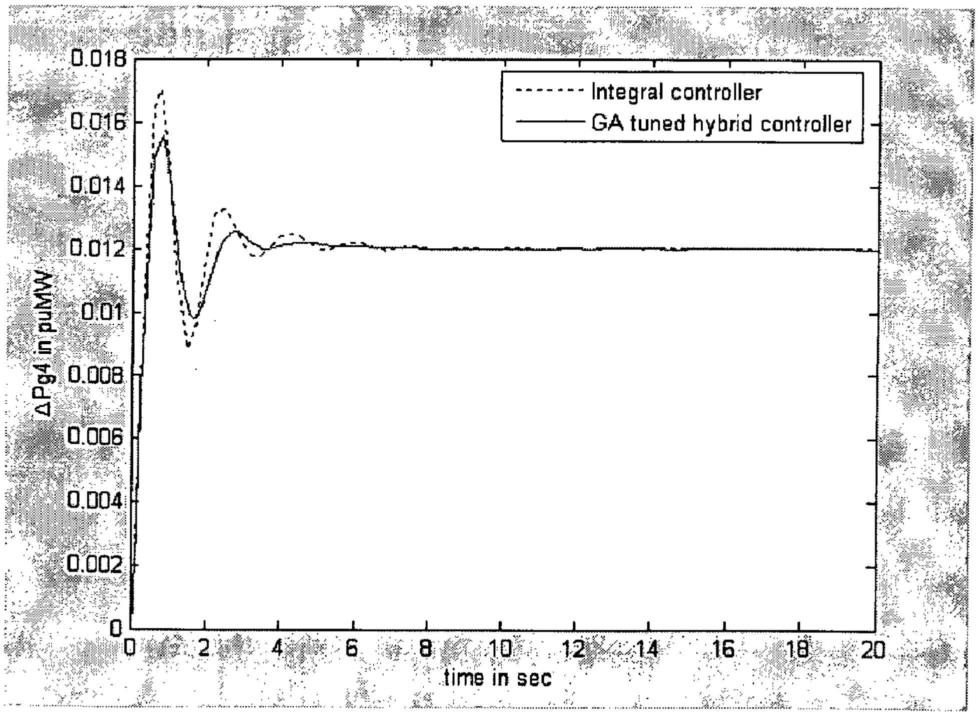


Figure 4.24: Dynamic response comparison of GENCO4 in area2 with integral and hybrid controller

The above *Figures 4.20-4.24* show the comparison of dynamic response of Δf1, Δf2 and ΔPtie12 and of GENCOS respectively with integral controller having optimum gain and with hybrid controller. The peak deviation is reduced when compared with peak deviation with the integral controller. The settling time of the response is also greatly improved.

4.6 CONCLUSION

Performance of the proposed supplementary controller has been compared with that of the conventional integral controller and observed that GA tuned hybrid controller responses outperform the integral controller.

1. From the above figures, it can be seen that for different contract agreements, the dynamic response of frequency, tie line power flow are far better with GA tuned hybrid controller and the controller parameters changes quickly with system dynamics without any parameter estimation as in the case with integral controller where in for every change in DPM or contract agreement, the controller gain needs to be re-estimated.
2. The effect of tunable parameters of Fuzzy controllers present in both the areas of the two area system on the dynamic performance is observed.
3. The settling time and overshoot/undershoot of response with the proposed supplementary controller are very small as compared with integral controller responses.
4. The scaling factor tuning of the hybrid controller is done with the help of Genetic Algorithm (GA) Optimization technique.
5. The optimal parameters used in the system and observation from the Integral squared Error response of the GA tuned hybrid controller compared with the integral controller shown better result.
6. The optimal scaling factor tuned controller (GA tuned controller) is compared with their dynamic responses with normal integral controller in *Figures 4.7-4.24.*
7. It was finally shown that the GA tuned hybrid Controller (where the parameter tuned is scaling factor) is giving better dynamic response.

CHAPTER 5

FINAL CONCLUSIONS AND FUTURE WORK

5.1 OVER VIEW OF THE WORK:

The objective of the thesis is:

1. To consider an interconnected non reheat thermal-thermal system in continuous mode strategy and to evaluate the dynamic responses considering conventional integral controllers and hybrid controller in both the areas.
2. To investigate the effect of speed regulation parameter on dynamic responses.
3. To compare the dynamic responses obtained with conventional controller and GA tuned hybrid controller.
4. To see the effect of variation of DPM on optimal parameters.
5. To optimize the parameters of the New Hybrid controller using the GA optimization technique.

5.1.1 Conclusions:

1. Automatic generation control (AGC) will keep on having important role in deregulated power system but with slight modifications in the simulation model as the contract agreement of the DISCOS also form a part of it.
2. The main features of AGC in deregulated environment are as follows:
    - Computation of set points (CPG) of Gencos using Disco's load demand and Contract Participation Factor.
    - Computation of Area Control Errors.
    - Computation of local demand Pl1, loc and Pl2, loc.
3. The system simulation is done using MATLAB 7.01 and the tool boxes available with it.

4. The optimum value of the supplementary controller K_i is dependent on DPM. Hence for every change in the contract agreement there will be corresponding change in the value of K_i..
5. If at all there is a contract violation by any DISCO, the extra load demand of that DISCO will be taken care by the corresponding area GENCOS to which the DISCO belongs in proportion to the area participation factors.
6. In the present thesis a new Hybrid controller has been proposed for AGC problem in deregulated power system.
7. The hybrid control parameters are tuned using genetic algorithm (GA) technique.
8. The effect of tunable parameters of Fuzzy controllers present in both the areas of the two area system on the dynamic performance is observed.
9. The settling time and overshoot/undershoot of response with the proposed supplementary controller are very small as compared with integral controller responses.
10. The optimal parameters used in the system and observation from the Integral squared Error response of the GA tuned hybrid controller compared with the integral controller shown better result.
11. Even in the contract violation case, the optimal parameters used in the system and observation from the responses of the GA tuned hybrid controller compared with the integral controller shown better result.
12. It has been proved that the GA optimized Fuzzy Logic Controller (where the parameter tuned is scaling factor) is giving better dynamic response even in case when the DPM matrix has been changed.
13. The dynamic responses are reaching their desired values with less number of oscillations and less settling time with GA tuned hybrid controller.
14. Integral square error and Genetic algorithm technique are the two methods used for the optimization of the controller parameters.
15. It was finally shown that the GA tuned hybrid Controller (where the parameter tuned is scaling factor) is giving better dynamic response.

5.2 FUTURE WORK

Recommendations for future work are:

1. Design of Artificial Neural Network Controller.
2. Two-area can be extended to multi-area system in deregulated power system in which some of the areas not at all participating in the AGC. This result in study which help in determining the minimum percentage of generators that should compulsorily participate in the AGC function.
3. Artificial Neural Networks (ANN), Fuzzy Logic (FL) and Genetic Algorithm (GA) can be combined and can be used in AGC of a multi-area system.

APPENDIX

NOMINAL PARAMETRES FOR TWO AREA THERMAL SYSTEM IN DEREGULATED ENVIRONMENT

f = 60 Hz

D1 = D2 = 8.33*10-3 puMW/ Hz

Tg1=Tg2 = Tg3 = Tg4 =0.08 sec

R1 = R2 = R3 = R4 = 2.4 Hz/puMW

Tt1=Tt2 = Tt 3 = Tt 4 = 0.3 sec

B1=B2=0.425 puMW/Hz

H1 = H2 = 5 sec

Kp1=Kp2 = 120 Hz/puMW

Pr1 = Pr2 = 2000 MW

Ptie, max = 200 MW

a12= -Pr1/Pr2 = -1.0

Tp1=Tp2 = 20 sec

T12=0.086 puMW/rad

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