EVALUATION OF SCOPE AND FEASIBILITY OF ARTIFICIAL INTELLIGENCE TECHNIQUES IN IMPROVING AUTOMATIC GENERATION CONTROL

A DISSERTATION

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

By

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JUNE, 2006

ID NO: MT-351/2006-26/JKP-RNP

CANDIDATE'S DECLARATION

I hereby declare that the work presented in the dissertation entitled **"Evaluation of scope and feasibility of Artificial Intelligence Techniques in Improving Automatic Generation Control"** submitted in the partial fulfillment of the requirement of the award of degree of **Master of Technology** in **Electrical Engineering** 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 June 2005 to June 2006 under the guidance and supervision of
Dr. R.N. Patel (Lecturer, EED, IITR)

I have not submitted the matter embodied in the report for award of any other degree or diploma.

Date: 28th June, 2006
Place: Roorkee

(P JEEVAN KUMAR)

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

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ACKNOWLEDGEMENTS

I would first like to thank my advisor Dr. R. N. Patel for his constant guidance and encouragement. He inspired me to think critically and build physical intuition on research problems. Without his guidance this dissertation would not have been completed. I am also very grateful to our group leader Prof. J. D. Sharma and other faculty of Power Systems group for their constructive comments that helped me in carrying out this work in positive direction.

I am also thankful to Jacob reglend and Simon, research scholars for providing constant encouragement for my dissertation work.

I cannot sufficiently describe the contribution of my mother and my grand mother in my life. They sacrificed their whole life for our family. They have always cherished my higher studies and wanted me go forward in life and contribute meaningfully to the cause of the society at large.

I feel especially grateful to my Spiritual teachers K. Nireekshan Paul garu, Dr.P.C.Chani and Deepak.J for encouraging me to the highest spirits and providing the prayerful help and the psychological support required to complete this thesis. I am very grateful to every member of my family for their unconditional support during a major crisis of life.

And most importantly I would like to thank my Lord and Saviour Jesus Christ for provinding what are all I required according to His will.

Jeevan kumar Palla

ABSTRACT

The operating point of the power system changes in a daily cycle due to the inherent nature of the changing load. This poses the difficulty in optimizing the conventional controller gains. Thus it may fail to provide the best dynamic response. 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, Particle Swarm Optimization and Genetic algorithms can be applied. A Fuzzy Logic Controller (FLC) is designed. It provides the control action in qualitative and symbolic form. The dynamic response is compared with the dynamic response obtained by the integral controller.

Although the designed Fuzzy Logic controller in the two area hydro thermal for Automatic Generation Control system is available, that may not provide the better dynamic performance in all cases, so in order to improve the dynamic performance of the system a new Fuzzy Logic controller is designed by proper selection of the feedback gain and studying all the variable parameters effect, like Effect of different number of membership functions, rule base of the Fuzzy controller and speed regulation parameters on the dynamic response has been studied. The dynamic response is compared with the dynamic response obtained by the integral controller and the existing FLC controller.

And still to improve the performance of the New Fuzzy logic Controller by tuning the parameters like membership function widths and scaling factors with the help of combined intelligence techniques PSO tuned Fuzzy Logic Controller and Genetic Algorithm tuned Fuzzy Logic Controller were proposed. The dynamic response is compared with the dynamic response obtained by the existing FLC controller and the new Fuzzy logic controller.

The effect of unequal area capacity with respect to the dynamic response and robustness of the new fuzzy logic controller ,exixting fuzzy logic controller and the conventional controller were also studied.

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Nomenclature

Symbol	Description
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	Steam governor time constant (in sec)
K_r	Steam turbine reheat constant
T_r	Steam turbine reheat time constant
T_t	Steam turbine time constant
B_i	Frequency bias constant
$T_{pi} = 2H_i / f\, D_i$	Plant time constant
$K_{pi} = 1/D_i$	Plant gain constant
K_I	Integral gain
K_d	Electric governor derivative gain
K_p	Electric governor proportional gain
K_i	Electric governor integral gain
$\beta_i = \left(D_i + 1/R_i\right)$	Area frequency response characteristic
T_w	Water starting time
ACE_i	Area control error of area i

$a_{12} = -P_{r1}/P_{r2}$	Area capacity ratio
J	Cost function
T	Sampling time period
K_t	Feedback gain of the Fuzzy logic controller

CHAPTER 1

INTRODUCTION

1.1 Introduction

A modern power system network consists of a number of utilities interconnected together and power is exchanged between utilities over tie line by which they are interconnected. An electrical power system must be maintained at a desired operating level characterized by nominal frequency, voltage profile and load flow configuration. It is kept in their nominal state by close control of real and reactive powers generated in the controllable source of the system. Because of the inherent characteristics of changing loads, the operating point of power system may change very much during a daily cycle. The generation changes must be made to match the load perturbation at the nominal conditions, if the nominal state is to be maintained.

The mismatch in the real power balance affects primarily the system frequency but leaves the bus voltage magnitude essentially unaffected. In the power system, it is desirable feature to achieve better frequency constancy than is obtained by the speed governing system alone. It is desirable that each area should take care of its own load increase, so that schedule tie power can be maintained. The problem of controlling the real power output of electric generators in this way is termed as Automatic Generation Control (AGC).

A large interconnected power system is divided into a number of control areas for AGC based on the principle of coherency. A control area is defined as a power system, a part of the system, or a combination of the system to which a common generation control scheme is applied. The electric connections within each control area very strong as compared to the ties with the neighboring area. All the generators in a control area swing in unison or coherently and it is characterized by a single frequency. AGC is defined as: "The regulation of the power output of electric generators within a prescribed area in response to changes in system frequency and/or tie line loading, or the relation of these two with each other, so as to maintain the schedule system frequency and/or the established interchange with other areas within predetermined limits".

The problem of AGC can be subdivided into fast primary control and slow secondary control modes. The fast primary control (governing mechanism) mode tries to minimize the frequency deviations. The fast primary control channel counteracts random load changes and has a time constant of the order of a second. The slow secondary control channel (supplementary control) with time constants of the order of minutes executes secondary power adjustments to satisfy certain economic generators loading requirements and contractual tie-line loading agreements

1.1.1 Scope of Artificial Intelligence techniques in the field of Automatic Generation control

The growth in size and complexity of electric power systems along with increase in power demand has necessitated the use of intelligent systems that combine knowledge, techniques and methodologies from various sources for the real-time control of power systems. 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 like PID control. In practice different conventional control strategies are utilized for AGC. They are Proportional and Integral (PI) , Proportional Integral and Derivative (PID) . The limitation of conventional PI and PID controllers 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.

1.1.2 Comparison of various Intelligent Systems

Table 1.1

Application	**Fuzzy Systems**	**Neural Networks**	**Genetic Algorithms**	**Swarm Optimization**
Optimization problems			**	**
Predictions		**		
Control Applications	**			

So in my work I first used fuzzy controller to improve the performance of the Automatic Generation control system and then used Particle Swarm Optimization and Genetic Algorithm techniques in conjunction with Fuzzy Logic Controller to still improve the Performance of the Automatic Generation Control System

1.2 Literature review

Investigations in the area of AGC problem of interconnected power systems have been reported over the past six decades were vast. Most of the research work in the AGC 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. This would be desirable even if it were possible, to maintain ACE at zero because this would require unnecessary rapid switchings of generator units. Area control error in i^{th} area is normally defined by utility as:

$$ACE_i = .\ P_{tie,i} + B_i.\ F_i \text{..} (1.1)$$

Where,

ACE_i = Area Control Error of i^{th} area in MW.
$.\ P_{tie,i}$ = Deviation in tie-line power in p.u. MW.
B_m = Frequency Bias in p.u. MW/Hz.
$.\ F_i$ = Deviation in frequency in Hz.

Concordia and Kirchmayer [1, 2] have analyzed the AGC problem of two equal area hydrothermal systems. Their studies based on the simulation studies show that for minimum interaction between control areas frequency bias must be set equal to area frequency response characteristics . . Moreover, the investigations deal with non-reheat type steam turbines neglecting generation rate constraints.

Elgerd and Fosha [3, 4] have optimized the gain setting of integral controllers using Integral Square Error (ISE) technique considering several values frequency bias B for a two equal area non-reheat thermal system. Their investigations reveal that for the best dynamic performance is obtained for B = 0.5 . . However, for B < . , the generation change due to secondary control action takes place in a direction opposite to initial contribution due to natural governing response and thus amounts to withdrawal of frequency response assistance which is contrary to the basic objectives of interconnected operation of the power system.

Cohn [5, 6] has dealt with the strategies for the control of bulk power transfer in interconnected power systems. He has extensively studied the static aspect of the net interchange tie- line bias control strategy, particularly the considerations for deciding the frequency bias setting and techniques for time error and inadvertent interchange correction for large multi area power system. His investigations reveal that for minimum interaction between control areas ideally the frequency bias setting of a control area should match the combined generation and load frequency response i.e. area frequency response characteristics of the area. However, Cohn has not addressed to the problem of optimum gain settings and structures of the supplementary controllers from the point of view of the dynamic behavior of the system.

Kothari, Nanda and Hari [7] have investigated the AGC problem in continuous-discrete mode strategy. They have studied the effect of variation of sampling period on supplementary controller gain settings and system dynamic performance. Their analysis reveal that optimum integral gain setting obtained in continuous mode is not acceptable in the discrete mode or continuous-discrete mode of AGC for a sampling period of the order of 2 sec used in practice. They have investigated that a higher sampling time period of the order of 15 seconds is acceptable to the AGC of thermal-thermal system without deteriorating system dynamic responses.

Nanda and Kaul [8] have extensively studied the AGC problem of a two area reheat thermal system, using both parameter plane and ISE techniques for optimization of integral gain setting and for investigating the degree of stability of the system. They have studied the effect of GRC, area capacity effect, speed regulation parameter (R) on optimum controller setting and system dynamic responses.

D. M. Vinod Kumar [9] presented a novel approach of artificial intelligence (AI) techniques, fuzzy logic, artificial neural network (ANN) for the automatic generation control (AGC). Any mismatch between generation and demand causes the system frequency to deviate from scheduled value. Thus high frequency deviation may lead to system collapse. This necessitates an accurate and fast acting controller to maintain constant nominal frequency. So they proposed intelligent controllers, fuzzy logic, ANN approaches that are used for automatic generation control for the single area system and two area interconnected power systems. They compared the performance of the intelligent controllers with the conventional PI and PID controllers for the single area system as well as two-area interconnected power system.

Chown and Hartman [10] have described design, implementation and operational performance of a fuzzy controller as part of the AGC system in Eskimo's National

Control Center. They have integrated FLC designed into the existing off the shelf AGC system with only a few modifications.

J. Nanda and A. Mangla [11] describe Automatic Generation Control of interconnected hydrothermal system in the continuous- discrete mode using conventional integral and fuzzy logic controllers. Effects of variation of sampling time period on dynamic responses have been investigated, both with conventional integral controller and fuzzy logic controllers, considering small step perturbations. Effects of different number of triangular membership functions and inputs for Fuzzy Logic Controller on dynamic response have been explored. Dynamic responses under small step perturbation have been compared, considering integral and fuzzy logic controllers.

Earl Cox [12] and Jihong Lee [13] have presented basic fuzzy logic fundamentals. Cox has discussed the criteria deciding the choice and number of membership functions for Mamdani-fuzzy controller. Lee has discussed the effective way of modifying PI controller with the help of fuzzy controller.
The parameters of the fuzzy logic controller can be tuned so that the performance of the controller can be optimized
Like

1. Membership functions
2. Scaling factors
3. Rule Base

S.P. Ghoshal [14] worked with optimal integral gains and PID gains, designed a new method for calculating fitness function for GA which directly depens upon the dynamic performance. He copared the obtained responses with the conventional controllers. And he concludes that GA /GA-SA has less computations and less burden and he also comes up that all these optimal offline gains can be stored as tables and used with an online fuzzy logic control for varying system parameters.

Chir-Ho Chang; Ying-Chiang Wu [15] have worked with tuning the membership function parameters of the fuzzy logic controller. They proposed coding schemes to encode the allowed shifting range between the adjacent centroid of membership functions and to encode the three parameters of a set of symmetric membership functions (SMPs).

Yung-Yaw Chen and Chiy-Ferng Perng, [16] have worked with tuning the scaling factors of the fuzzy logic controller. They observed that the input scaling factors in a fuzzy control system are commonly used to conduct proper transformations between the real input data and the pre-specified universe of discourses of the fuzzy input variables in the system. Theoretically, they are constant parameters. They noticed that, sometimes, they are also used to fine-tune the performance of the system in a similar way to the tuning of a PID controller.

Rainer Palm [17] has also dealt with the scaling factor tuning of fuzzy logic controller and proposed a method bases on the assumption that in the stationary case an optimally adjusted scaling factor meets a specific statistical input output dependency. A measure for the strength of statistical dependency is the correlation function and the correlation coefficient, respectively. The adjustment of scaling factors using correlation functions is pointed out by means of a single input - single output (SISO) system.

There are many optimization techniques that can optimize the parameters but in order to deal with non linear optimization problems Artificial Intelligence techniques were best suited like

1. Ant colony optimization
2. Particle Swarm Optimization
3. Genetic Algorithm

Yusouf L. Abdel. Magid and M.A. Abido[18] have demonstrated the use of particle swarm optimization for optimizing the parameters of automatic generation control systems (AGC)in their work. They have considered an integral controller and a proportional-plus-integral controller. A two-area reheat thermal system is considered to exemplify the optimum parameter search. They founded the optimal AGC parameters by formulating the optimization problem with a standard infinite time quadratic objective function using PSO algorithm.

Yusouf L. Abdel. Magid and M.M. Dawoud[19] have dealt with the application of genetic algorithms for optimizing the parameters of automatic generation control (AGC) systems. They have considered an integral controller and a proportional-plus-integral controller. They founded the optimal AGC parameters by formulating the optimization problem with objective function as the integral of the square of the error and the integral of time-multiplied absolute value of the error performance indices using Genetic algorithm.

A.A.A. Osim and A.R. Aoki [20] have applied Particle Swarm Optimization for the optimization of parameters of the Fuzzy Logic Controller such as fuzzy membership functions. They found that the performance of the fuzzy logic controller is improved

Jingzhe Yu Zhen Ye* Chen Guo [21] have designed a novel and robust GAS-Fuzzy controller structure. They incorporated the controller with the help of Genetic Algorithms and Fuzzy logic in order to control the complicated and non-linear plant. The GA is used in their work is to optimize the parameters of fuzzy logic and its control rules. From their work they have inferred that work the parameter 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.

Y.L. Karnavas and D.P. Papadoppulos [22] worked on two intelligent load frequency controllers have been developed to regulate the power output and system frequency by controlling the speed of the generator. In their first controller it was developed using fuzzy logic (FL) only, whereas the second one by using a combination of FL, genetic algorithms and neural networks. Their aim of the proposed controller(s) is to restore in a very smooth way the frequency to its nominal value in the shortest time possible whenever there is any change in the load demand etc. The action of these controller(s) provides a satisfactory balance between frequency overshoot and transient oscillations with zero steady-state error.

Koichi and Yoshiburmi [23] have seen the effect of unequal area capacities on the Automatic generation control system. And they observed that the magnitude of the frequency deviation increases by using the regulating decreased level. However, it is the sufficiently practical range. So by incorporating the optimized controller the oscillations can be decreased.

K. Kastura and Y. Mizutani [24] presented a new method of load frequency control to decreasing regulating capacity. Their proposal of the technique is to lighten the tolerance of the frequency fluctuation at the regulating capacity. Then, the decreased level (the regulating decreased level) is added to regulating power plant. And the regulating capacity is made to decrease.

1.3 Out Line of the Dissertation

The brief review of the literature shows that a lot of work concerning AGC has already been done considering conventional or optimal controllers. Because of inherent characteristics of changing loads, the operating point of a power system may change during a daily cycle. Thus, requirement of developing a modern controller arises, because fixed gain controller designed at nominal operation point may fail to provide best dynamic response. This results in developing Fuzzy Logic Controller (FLC).

Although work pertaining to Fuzzy Logic controller application to the two area hydro thermal Automatic Generation Control system is available, those may not provide the better dynamic performance in all cases, so in order to improve the dynamic performance of the system a new Fuzzy Logic controller is designed by studying all the variable parameters effect. And still to improve the performance of the New Fuzzy logic Controller combined intelligence techniques like PSO tuned Fuzzy Logic Controller and Genetic Algorithm tuned Fuzzy Logic Controller were proposed.

In a realistic situation, the system area capacity effect also comes into picture. Therefore, it is of practical significance to consider the varying area capacity effect.

1.3.1 Objectives

In keeping with the above research the objectives of the project are.

1. To consider an interconnected hydro-thermal system in continuous-discrete mode strategy provided with reheat turbine and electric governor and to evaluate the dynamic responses considering conventional integral controllers and Fuzzy Logic controller in both the areas

2. To investigate the effect of different sampling periods and speed regulation parameter on dynamic responses.
3. To compare the dynamic responses obtained with conventional controller, FLC model and the newly developed Fuzzy Logic controller model.
4. To see the effect of different parameter variation of the New FLC model.
5. To optimize the parameters of the New FLC using the selected optimization techniques.
6. To compare the dynamic responses obtained with the FLC model, New FLC model and the optimized FLC models.
7. To investigate the effect of variation of area capacity effect.
8. To compare dynamic responses of the optimized controllers with the other controllers with respect to the above effect.

1.4 Organization of report

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 lays down the objective and the motivation of the present work.

Chapter 2 presents a systematic and a comprehensive approach for the design of conventional controllers and fuzzy logic controller as supplementary control based on the conventional ACE. It also discuses the effect of different parameters on the dynamic system performance.

Chapter 3 proposes a novel Fuzzy controller for hydrothermal system. With dynamic performance in view an attempt is made to optimize it with respect to membership functions and scaling factors. That was done with Genetic Algorithms and Particle Swarm Optimization. The performance of the proposed controller is then compared with that of the existing model and the conventional integral controller.

Chapter 4 presents the realistic situation in which we have unequal areas. The effect of unequal area with respect to the dynamic response of different controllers is discussed.

Chapter 5 brings forth the detailed conclusion of the entire work and presents the recommendations for future work.

CHAPTER 2

AGC OF AN TWO AREA SYSTEM WITH INTEGRAL CONTROLLER AND FUZZY CONTROLLER

2.1 AGC of a two Area System with Conventional Integral Controller

The main objectives of the work are

a) To consider an interconnected hydrothermal system provided with reheat turbine and electric governor and to evaluate the dynamic responses considering conventional integral controllers in both the areas

b) To consider the same above system with fuzzy logic controller and to investigate the effect of different sampling periods on dynamic responses and to investigate the effect of variation in speed regulation parameter on dynamic responses.

2.1.1 System Considered

Investigations have been carried out on an interconnected hydrothermal system, provided with reheat type of turbine and electric governor. Off-line simulation model has been developed using Matlab7. *Figure 2.1* shows the small perturbation transfer function model of a two area hydrothermal system developed in Matlab7. Steam governor has been represented by first order transfer function model, while electric governor has been represented by second order transfer function model. Steam governor controls steam input to turbine by controlling valve position, while electric governor controls the hydro input to turbine by controlling gate position. The turbine time constant (T_t), reheat time constant (T_r), water time constant (T_w) represents delays due to steam chest and inlet piping, reheaters and water flow. Electric governor is supposed to perform proportional, derivative and integrative action.

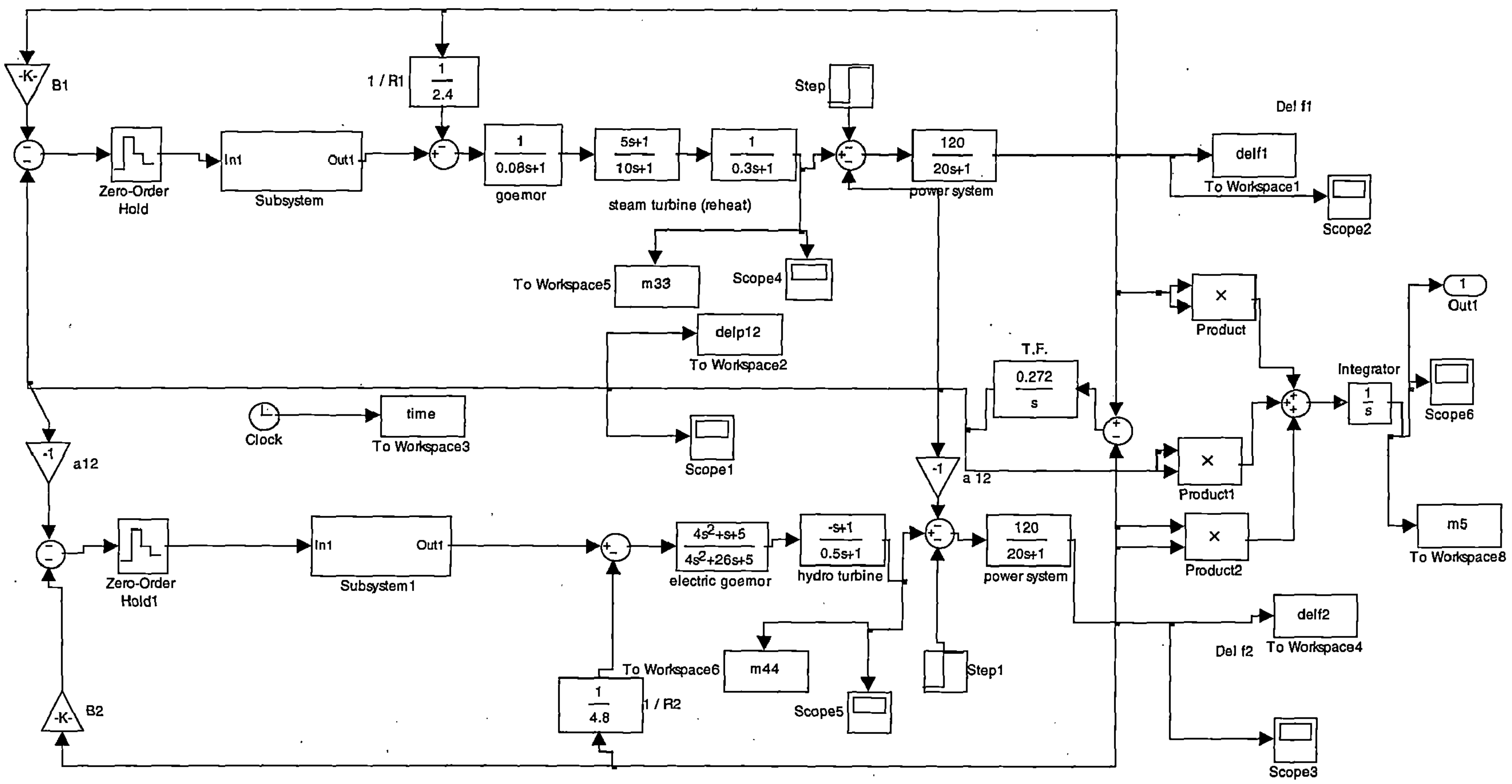


Figure 2.1 Transfer Function Model of an interconnected two-Area Hydro-Thermal System

2.1.2 Performance of the Integral Controller

The optimum value of integral controller gain (K_I) is found by using ISE technique, considering 1% step perturbation in either thermal or hydro area. Suffix 1 is used for thermal area and 2 for hydro area. For ISE technique, the objective function used is given in *equation 3.1*

$$J = \sum_{n=0}^{n=1000} [\Delta f_1^2 + \Delta f_2^2 + \Delta P_{tie}^2]\Delta T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

Where, . T = small time interval during sample
n = iteration count
. P_{tie} = incremental change in tie power
. f = incremental change in frequency.

A sampling period of 2 sec. is considered. The optimum integral gains of K_{I1}^* and K_{I2}^* are the values for which, the cost function J is minimum. The optimal integral gains of K_{I1}^* and K_{I2}^* are found to be 0.125 and 0.09 respectively.

2.1.3 Effect of Different Sampling time Periods

It is important to examine how much sampling time period can be chosen with their corresponding K_I without deteriorating dynamic responses. The optimum integral gains of K_{I1}^* and K_{I2}^*, for different sampling period are given in *Table 2.1.* Dynamic responses (. f_1, . f_2, . P_{tie}) are obtained for 1% step perturbation considered either in thermal area or in hydro area. Sample responses like. $f_1 = f(t)$, . $f_2 = f(t)$ and . $P_{tie} = f(t)$, for 1% step perturbation in hydro area are given in *Figures 2.2-2.4*, for different sampling periods with corresponding optimum gains. It is observed that for AGC, higher sampling period can be comfortably accepted in practice, unlike the present practice of using generally sampling period of 2 or 4 sec. It will reduce the wear and tear of sampler .and its cost.

Table 2.1 Optimum Value of Integral gains for Different sampling Periods

Sampling Time Period (T)	K_{I1}^*	K_{I2}^*
2 Sec	0.12	0.09
4 Sec	0.11	0.1
8 Sec	0.11	0.1
10 Sec	0.1	0.09
15 Sec	0.07	0.07
20 Sec	0.06	0.06

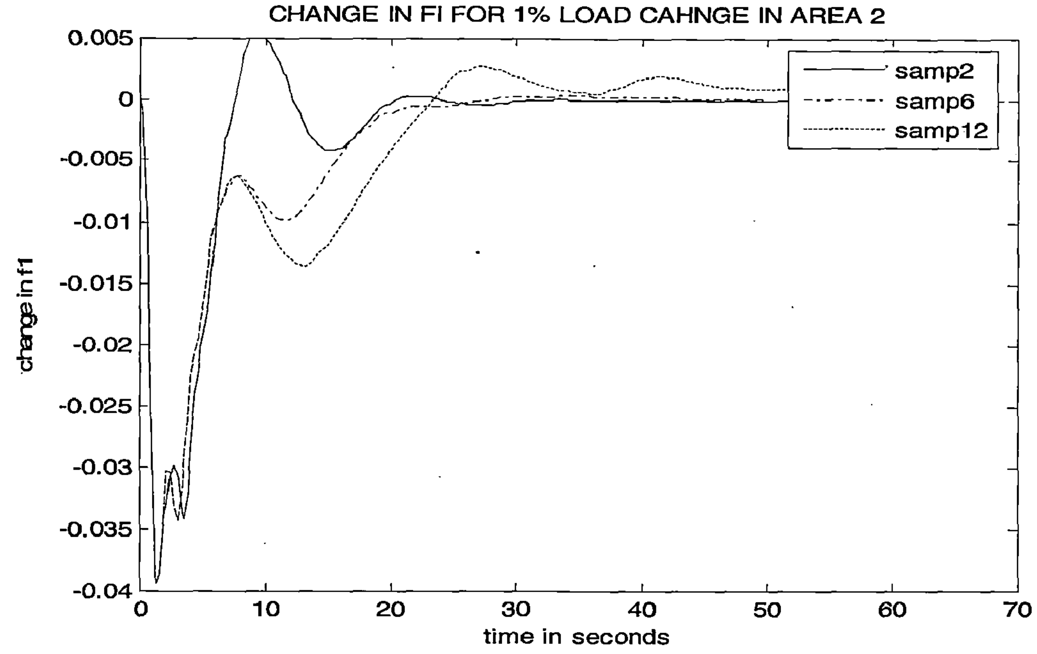


Figure 2.2 Del f_1 = f (t) for Several Sampling Periods

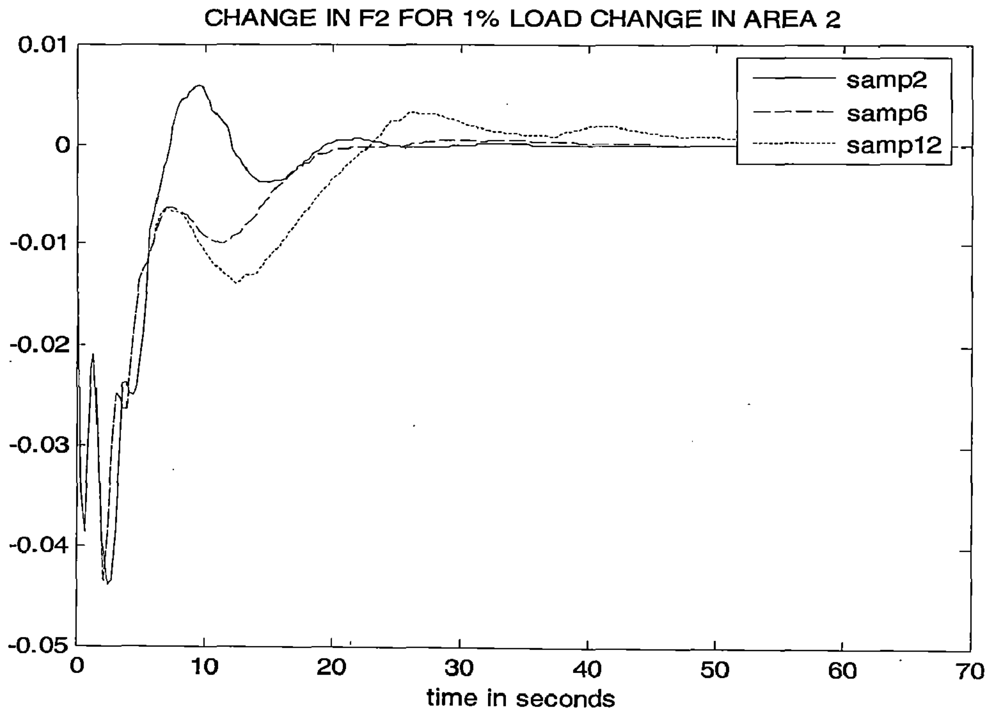


Figure 2.3 del $f_2 = f(t)$ *for Several Sampling Periods*

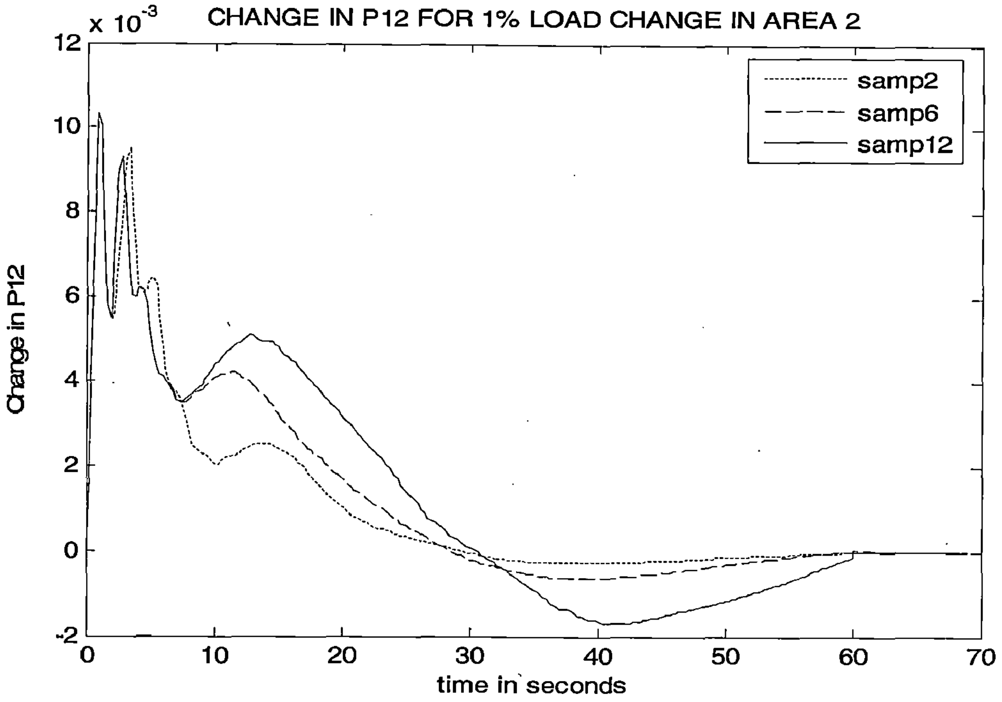


Figure 2.4 . $P_{tie} = f(t)$ *for Several Sampling Periods*

2.14 Effect of variation of Speed Regulation parameter

The problem of AGC can be subdivided into fast (primary) and slow (secondary) control modes. The loop dynamics following immediately upon the onset of load disturbance is decided by fast primary mode of AGC (speed regulation characteristics) 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 (2-4%) 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. Effect of GRC has been considered. The optimum integral gains of K_{I1}^* and K_{I2}^*, for different speed regulation parameters are given in *Table 2.2*

Table 2.2 Optimal integral gains for different R

Speed Regulation parameter ‘R’ Hz/ p.u. MW	K_{I1}^*	K_{I2}^*
2.4	0.048	0.0125
3.6	0.096	0.0288
4.8	0.154	0.0356
6.0	0.167	0.0597

Sample responses like . f_1 = f(t), . f_2 = f(t) and . P_{tie} = f(t), for 1% step perturbation in thermal area given in *Figures 2.5-2.7* different values of R with corresponding optimum gains.

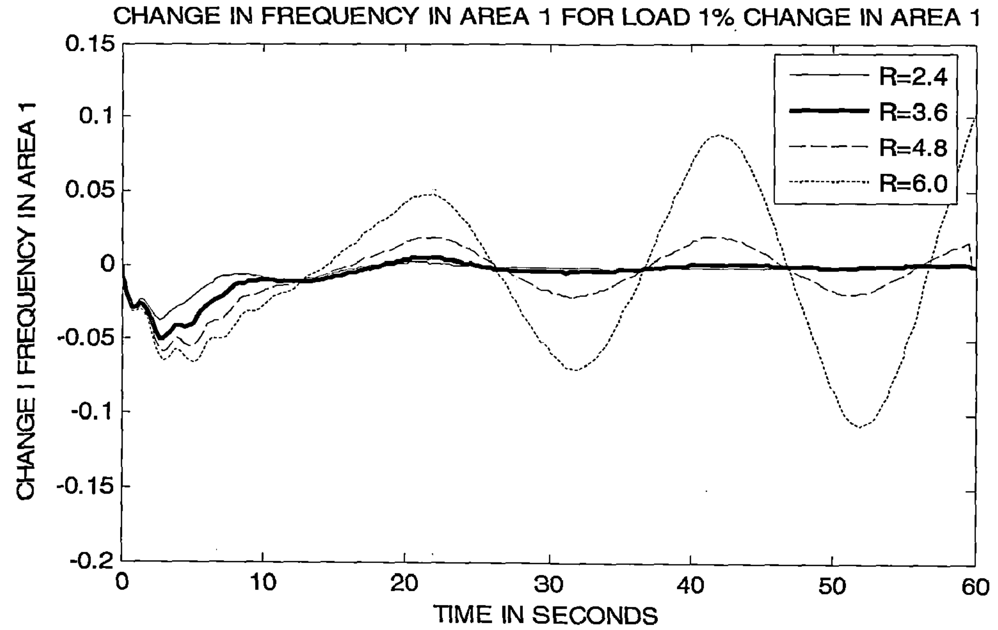


Figure 2.5 . $f_1 = f(t)$ for Different values of R

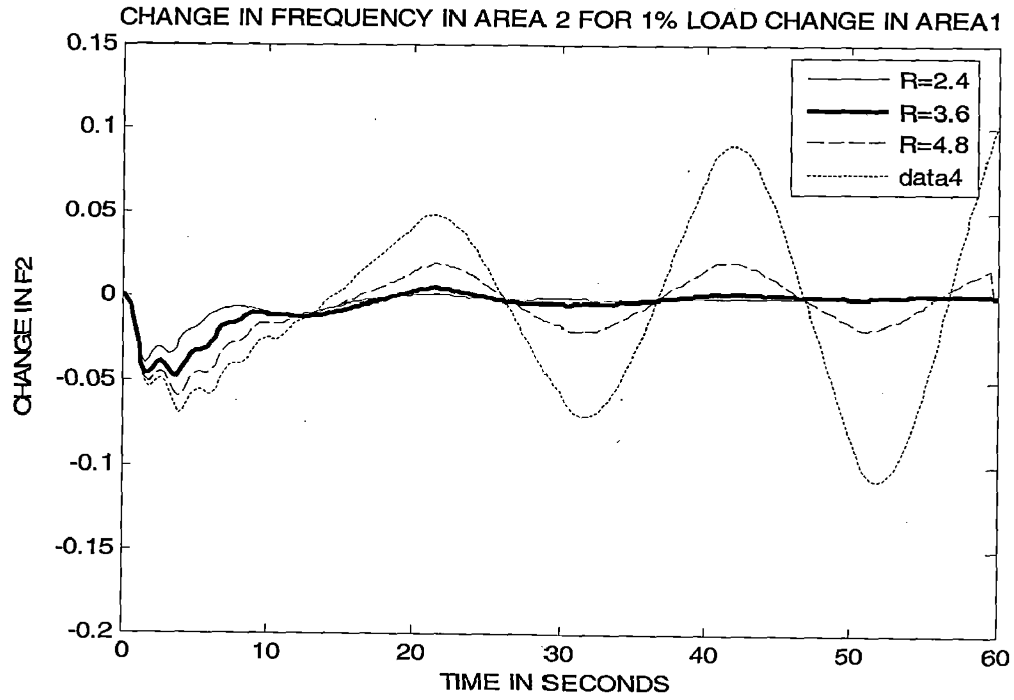


Figure 2.6 . $f_2 = f(t)$ for Different values of R

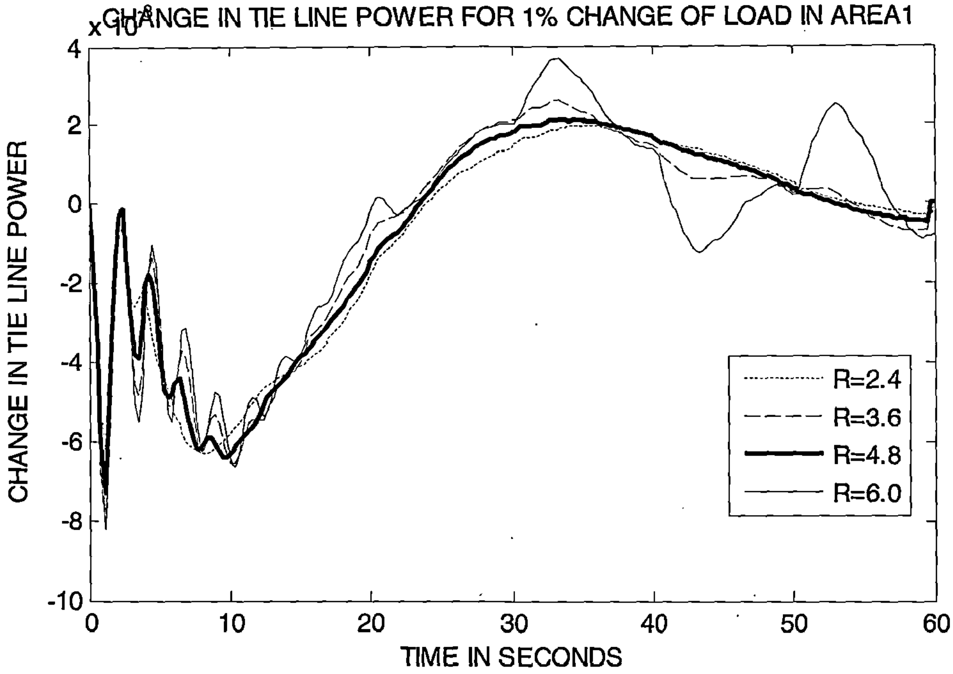


Figure 2.7 . $P_{tie} = f(t)$ for Different values of R

From the dynamic responses shown above, it is observed that for AGC in constrained mode, a value of R = 3.6 Hz / p.u. MW (6%) provides more or less best result in comparison to R = 2.4 Mw / p.u. MW. Above that, dynamic responses provide more oscillations in system, which are not desirable from dynamics point of view. The value of R greater than 10% makes the system unstable.

2.2 AGC of a two Area System with Fuzzy Logic Controller

Supplementary controllers are designed to regulate the area control error to zero effectively. Several modern techniques have been proposed to optimize supplementary controllers. Supplementary controllers regulate the generation to match the load variation. Because of inherent characteristics of changing loads, the operating point of a power system may change during a daily cycle. Thus, requirement of developing a modern controller arises, because fixed gain controller designed at nominal operation point may fail to provide best dynamic response. This results in developing fuzzy logic controllers (FLC). 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.

Literature shows that only few investigations have been carried out using fuzzy logic controller in AGC. Also, all the work till now in FLC is reported in interconnected thermal systems. This chapter describes application of Fuzzy Logic Controller (FLC) for Automatic Generation Control (AGC) of an interconnected hydrothermal system. Also by modifying the parameters of the fuzzy controller with respect to the dynamic response a new fuzzy controller is designed. The performance of FLC has been compared to that of the previous model and the conventional integral controller. So the objectives are

a) To consider an interconnected hydrothermal system with fuzzy logic controller, considering (ACE & $\dot{ACE}$) as inputs to FLC.

b) To investigate the effect of different sampling periods on dynamic responses.

c) To modify the Fuzzy Logic controller for obtaining optimized dynamic response.

d) To compare the dynamic responses obtained with FLC and modified FLC with the integral controllers.

2.2.1 System considered

The investigations have been carried out on the same interconnected hydro-thermal system, *Fig 2.1.* A bias setting of B = . is considered in both hydro and thermal areas. However, the integral controllers have been replaced by fuzzy logic controllers. Matlab version 7 been used, to obtain dynamic responses for . f_1, . f_2, . P_{tie} for 1% step load perturbation in either area or both areas.

2.2.2 Fuzzy Logic Controller model

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. Basically, it provides an effective means of capturing the approximate, inexact nature of real world. The FLC based on fuzzy logic provides an algorithm, which can convert the linguistic control strategy based on expert system knowledge into an automatic control strategy. The FLC is very useful when the processes are too complex. Fuzzy logic allows designers to build controllers even when their understanding of the mathematical behavior is incomplete. The fuzzy inference process used by the FLC in the present work is called Mamdani's fuzzy inference method.

2.2.3 Rules and Membership functions

The ACE is main component required for regulation of AGC. ACE and $\dot{ACE}$, which is derivative of ACE in discrete mode, have been chosen as inputs to FLC. Triangular Membership Function (MF5) numbers is tried. Figure 3.2 shows ACE with five membership functions. *Table.2.3* shows the rule base for five membership function. Membership function (MF) specifies the degree to which a given input belongs to a set. De fuzzification to obtain crisp value of FLC output is done by centre of maximum method

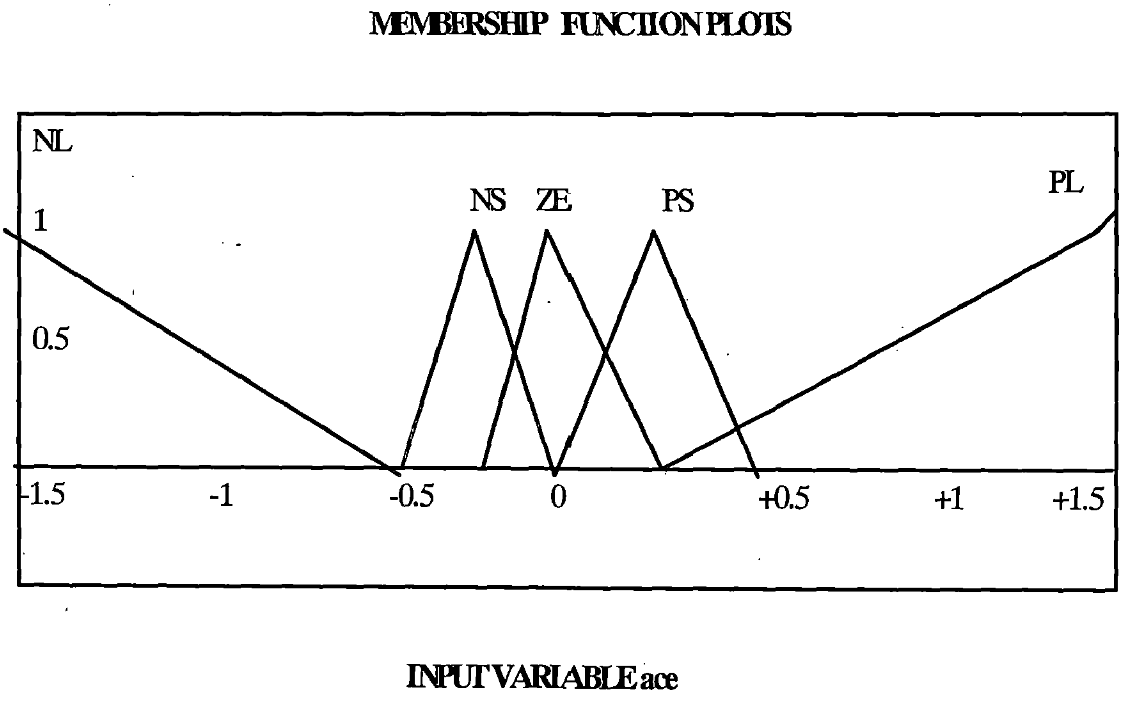


Fig 2.8 ACE with five membership function

Table 2.3

		ACE				
DACE		**NL**	**NS**	**ZE**	**PS**	**PL**
	NL	NL	NL	NS	NS	ZE
	NS	NB	NL	NS	ZE	ZE
	ZE	NS	NS	ZE	PS	PS
	PS	ZE	PS	PS	PL	PL
	PL	ZE	ZE	PS	PL	PL

Fuzzy controller out put

2.2.4 Effect of Different sampling time periods

As discussed in earlier with conventional controllers, study with different sampling time periods is a must in this case. It is found that for different sampling time period, considering 5 number of triangular MF. Dynamic responses are explored for different sampling periods of 2, 4, 8, 10 and 12 sec with 1% step perturbation in both, thermal and hydro area, considering 5 numbers of triangular MF. *Figure 2.10-2.12* show . $f_1 = f(t)$, . $f_2 = f(t)$ and . $P_{tie} = f(t)$ for 1% perturbation in both the areas. Figures reveal that responses up to 10 secs are close from view point of peak deviation and settling time. It is again construed that even for FLC; higher sampling period of 10 sec is permissible like in the case of conventional controllers.

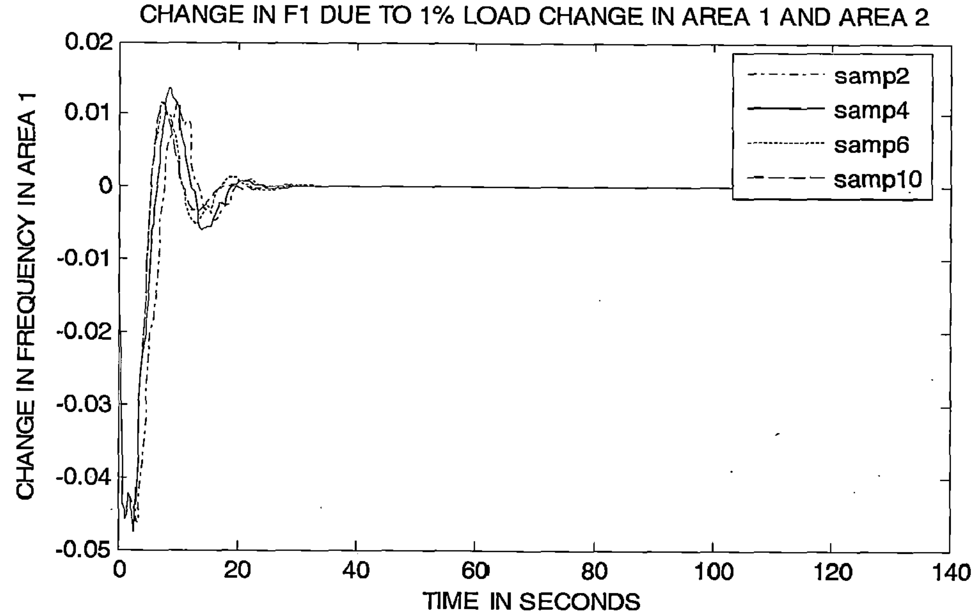


Figure 2.9 . f_1=f (t) for Fuzzy Logic Controller for different Sampling Periods

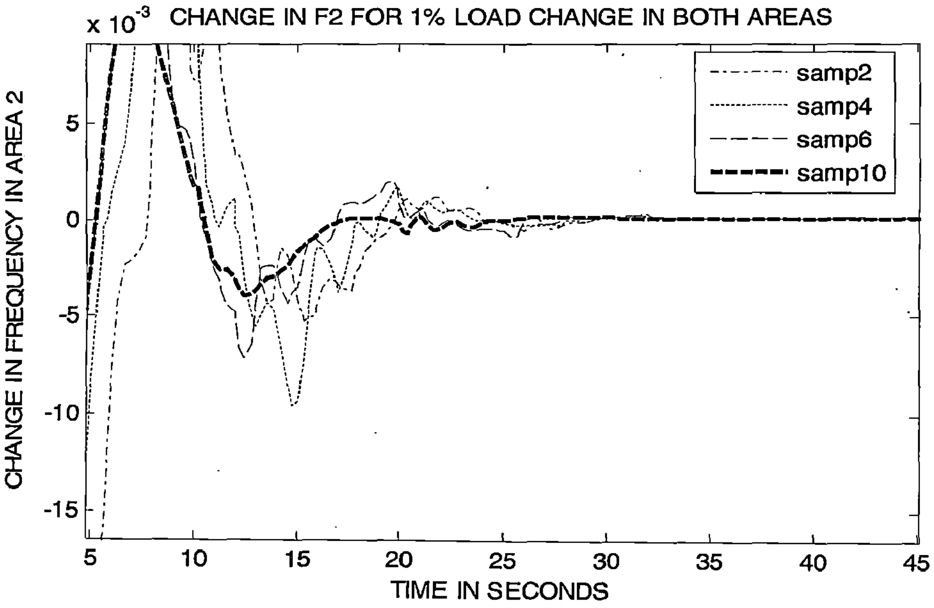


Figure 2.10 . $f_2=f(t)$ for Fuzzy Logic Controller for different Sampling Periods

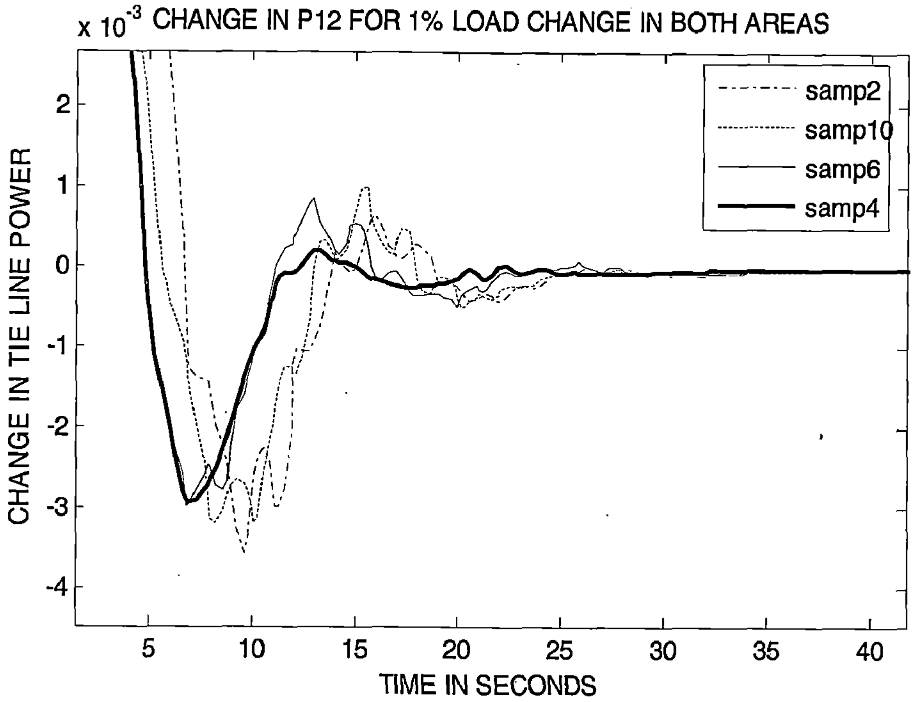


Figure 2.11 . $P_{tie} = f(t)$ with Fuzzy Logic Controller for different Sampling Periods.

2.3 AGC of an two area system with modified Fuzzy Logic Controller

2.3.1 Selection of Feedback Gain K_t

Area Control Error (ACE), which is equal to sum of deviation in tie-power and deviation in area frequency multiplied with frequency bias constant, together with its derivative $AC\dot{E}$ have been considered as inputs to fuzzy logic controller. As discussed below the different number of memberships is designed for best dynamic response. We find that the fuzzy rules for 3 number of triangular MF give the best result in the present case. To evaluate the optimal value of K_t, ISE technique described earlier is used. The appropriate value of K_t is found to be 0.003 and 0.05 for both areas.

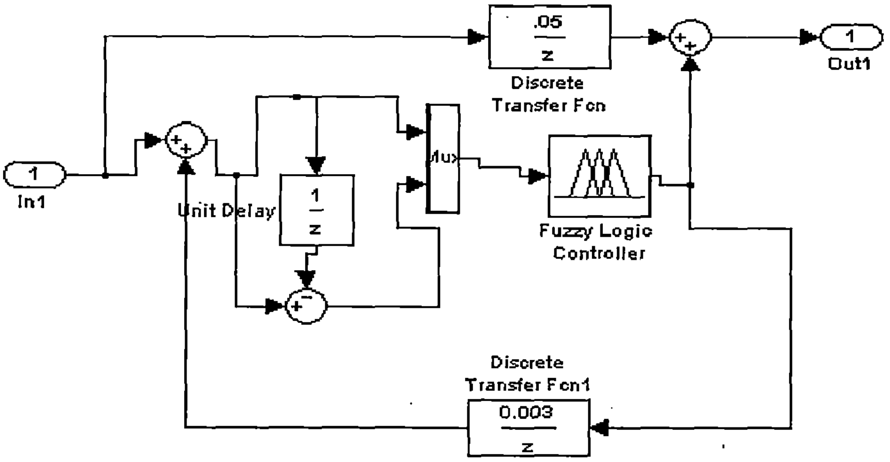


Figure 2.12 Fuzzy Controller with Input, Output and Feedback Gain

2.3.2 Membership Functions and Rules

The ACE is main component required for regulation of AGC. ACE and $AC\dot{E}$, which is derivative of ACE in discrete mode, have been chosen as inputs to FLC. One triangular Membership Function (MF) is used for the ZE component of ACE,

$AC\dot{E}$ and U (t) and two trapezoidal membership functions for the PL and NL components of ACE, $AC\dot{E}$ and U (t) are chosen. *Figure 2.14* shows ACE with three membership functions. *Table 2.4* shows the rule base for three membership function. Membership function (MF) specifies the degree to which a given input belongs to a set. Defuzzification to obtain crisp value of FLC output is done by centre of maximum method

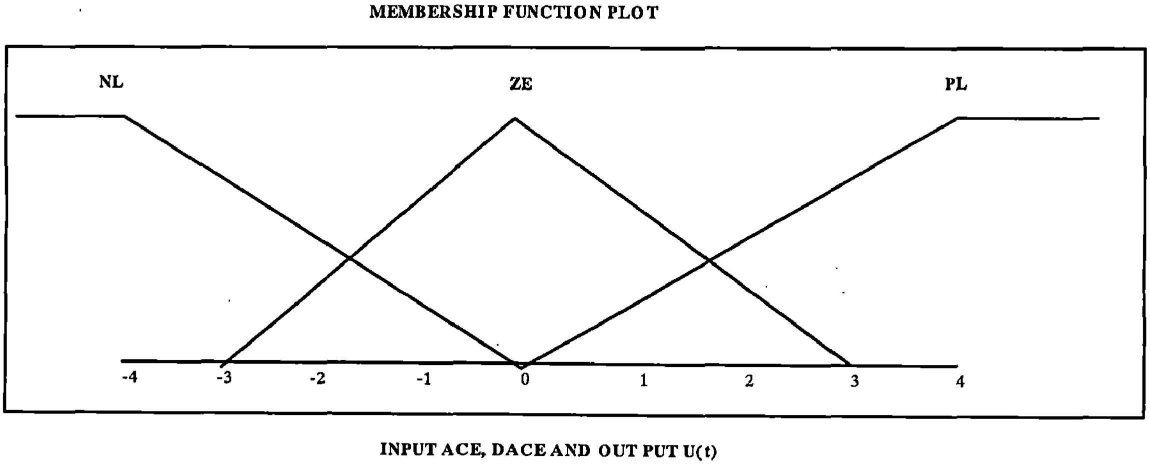


Fig 2.13 Input ACE membership function plot

Table 2.4

		ACE		
		NL	**ZE**	**PL**
DACE	**NL**	NL	NS	ZE
	ZE	NS	ZE	PS
	PL	ZE	PS	PL

FLC out put

2.4 Comparison of Dynamic responses with Integral Controller and Fuzzy Logic Controller

Three types of controllers namely FLC and modified FLC and conventional controllers have been tried out for AGC. Which one provides better result for AGC? To answer this question, we have to compare the dynamic responses. Figure2.16-2.18 shows comparison of dynamic responses between conventional integral controller & FLC considering 1% step perturbation in thermal area as well as in Hydro areas, for a sampling period of 2 sec and with R=2.4 in thermal area and 4.8 in hydro area. Analyses of these responses clearly reveal that modified FLC provides better dynamic responses. Presence of modified FLC in both areas guarantees zero steady state error, irrespective of the location of the perturbation in either area or both areas.

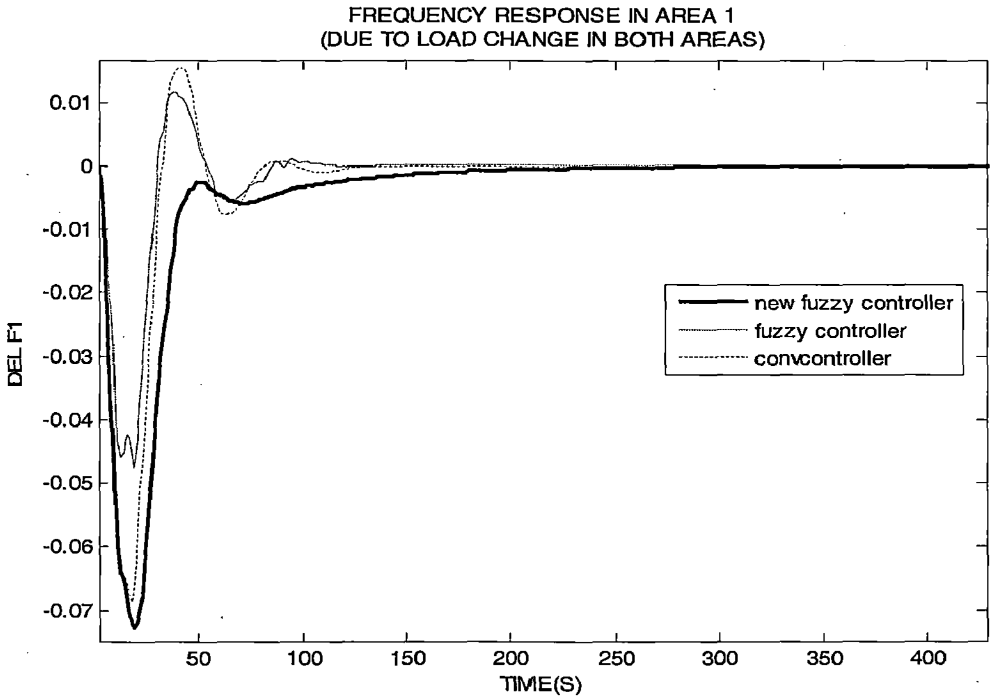


Figure 2.14 . $f_1 = f(t)$ for Integral Controller and Fuzzy Logic Controller.

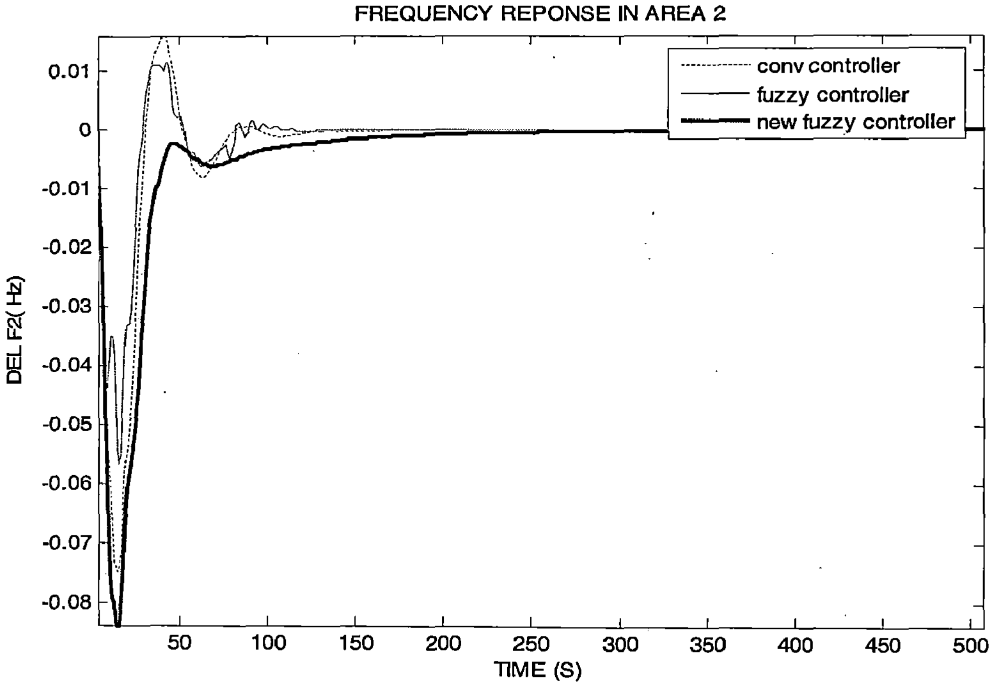


Figure 2.15 . $f_2 = f(t)$ for Integral Controller and Fuzzy Logic Controller.

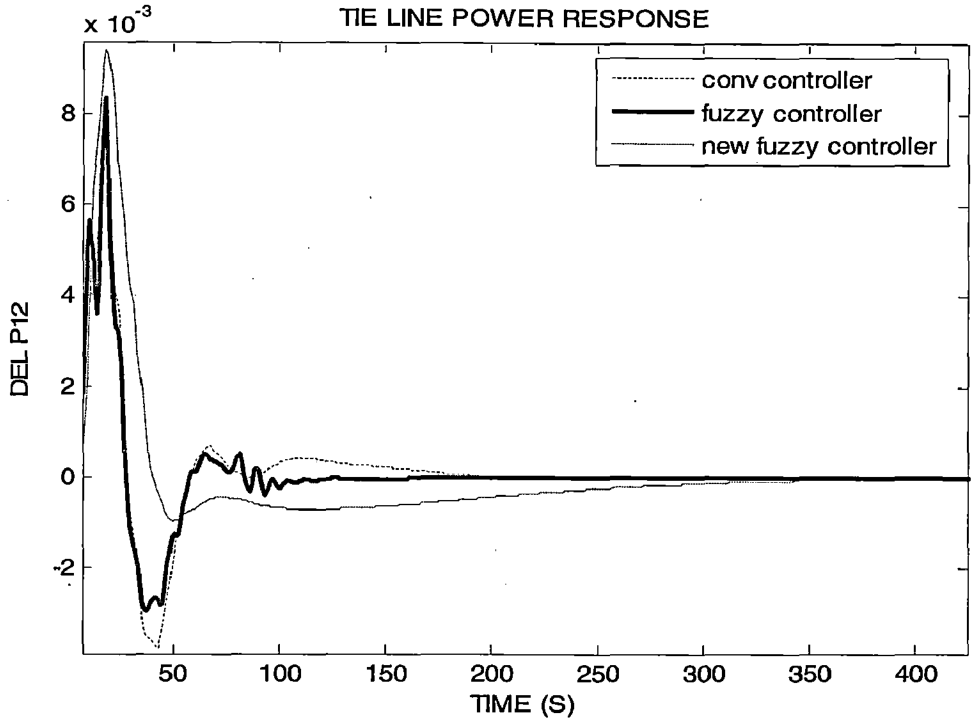


Figure 2.16 . $P_{tie} = f(t)$ for Integral Controller and Fuzzy Logic Controller

2.5 Conclusion

The following are the main conclusions

- With conventional integral controllers present in both the areas, it is permissible to adopt a higher sampling period than a time period of 2 to 4 sec used in practice. Higher value of T will reduce wear and tear of sampler.
- The present trend of using low value of R=4% does not provide best dynamic response from the view point of settling time, as compared to R = 6%. So, AGC should work on these values of R, as supplementary controllers provide zero steady state error in dynamic responses.
- With FLC like in conventional integral controller and in FLC, higher sampling period than the normally used in practice is permissible without deteriorating dynamic responses for all practical purposes.
- Presence of modified FLC in both areas and small step perturbation in either area provides zero steady state error in dynamic responses.
- Presence of modified FLC in both areas and small step perturbation in either area or in both areas simultaneously provides better dynamic response than with FLC and conventional integral controller

CHAPTER 3

AUTOMATIC GENERATION CONTROL OF A TWO AREA SYSTEM USING COMBINED INTELLIGENT TECHNIQUES

3.1 Introduction

Artificial Intelligence Techniques like Fuzzy logic, Genetic Algorithms and Particle Swarm Optimization were used to improve the performance of the Automatic Generation Control system.

The drawbacks of the above methods when used independently such as in the previous chapter Fuzzy Logic controller has fixed parameters of the fuzzy sets of the fuzzy variables as well as large computational time for the rule base to be done. In other words, the considerable time needed for response when fuzzy set theory is applied makes the practical realization quite difficult. So instead of applying Genetic Algorithms, Particle swarm optimization independently for optimizing the parameters of the Automatic Generation Control (AGC) system and Fuzzy logic controller acting as the secondary controller in the AGC system we can use the those techniques in combination (PSO tuned Fuzzy controller for Automatic Generation control system) to see the advantages of both the Artificial Intelligence techniques.

The main objectives of the work are:

a) To consider an interconnected hydrothermal system and Thermal-thermal system in which the fuzzy logic controller is used.

b) To consider tunable parameters of the FLC in order to get optimal dynamic response of the above considered systems

c) To optimize the tunable parameters with Artificial intelligence techniques.

d) To evaluate the dynamic responses of the two systems with optimized FLC by putting load disturbance

e) To compare developed optimal FLC models with their dynamic responses in the above systems considered.

3.2 System considered

Investigations have been carried out on an interconnected hydrothermal system and a Thermal-thermal system, Off-line simulation model has been developed using Matlab7. The dynamic responses obtained through simulation in Matlab7. *Figure 3.1 and Figure 3.2* shows the small perturbation transfer function model of a two area hydrothermal system and Thermal-thermal system developed in Matlab7.

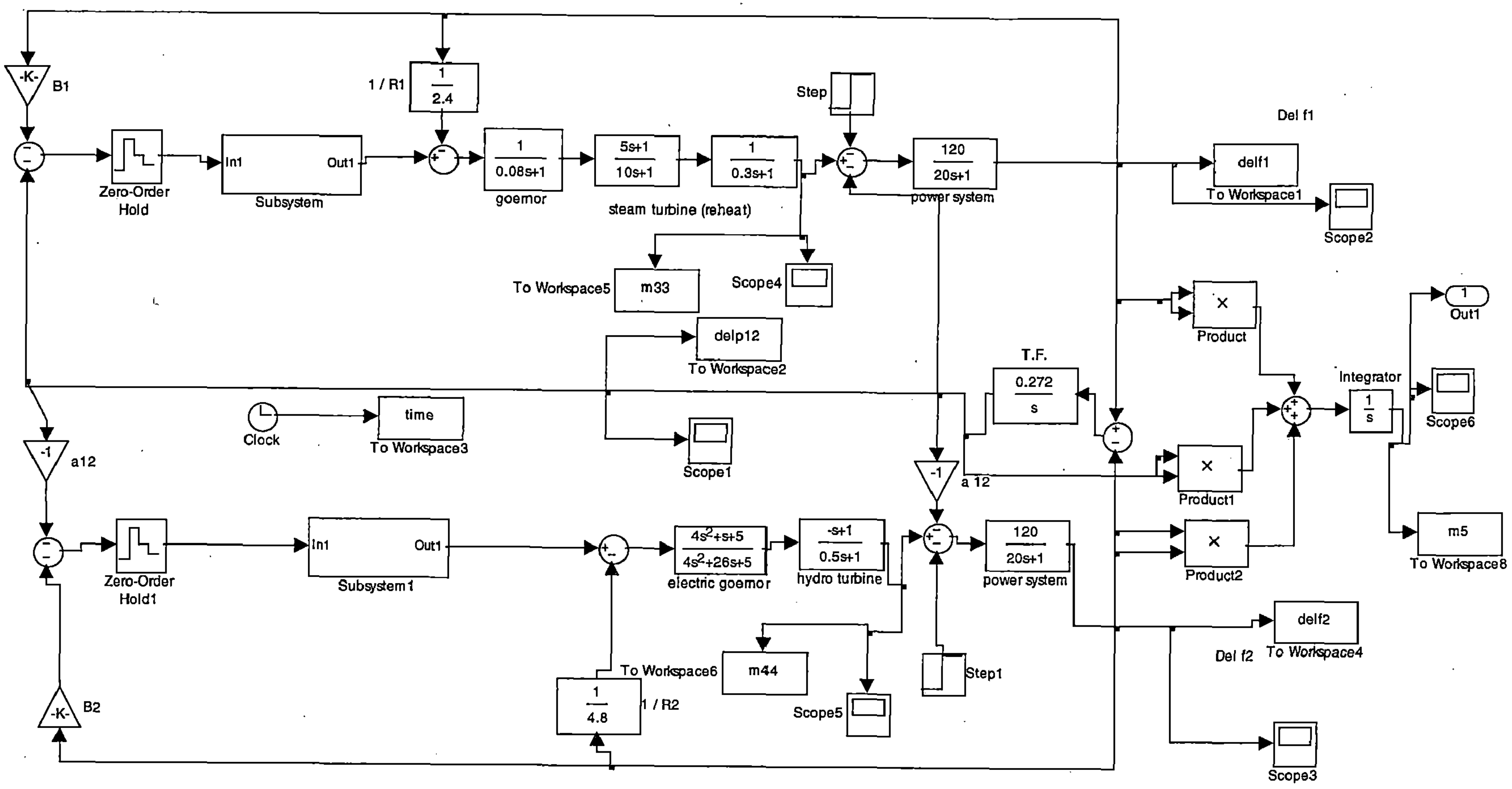


Figure 3.1 Transfer Function Model of an interconnected two-Area Hydro-Thermal System

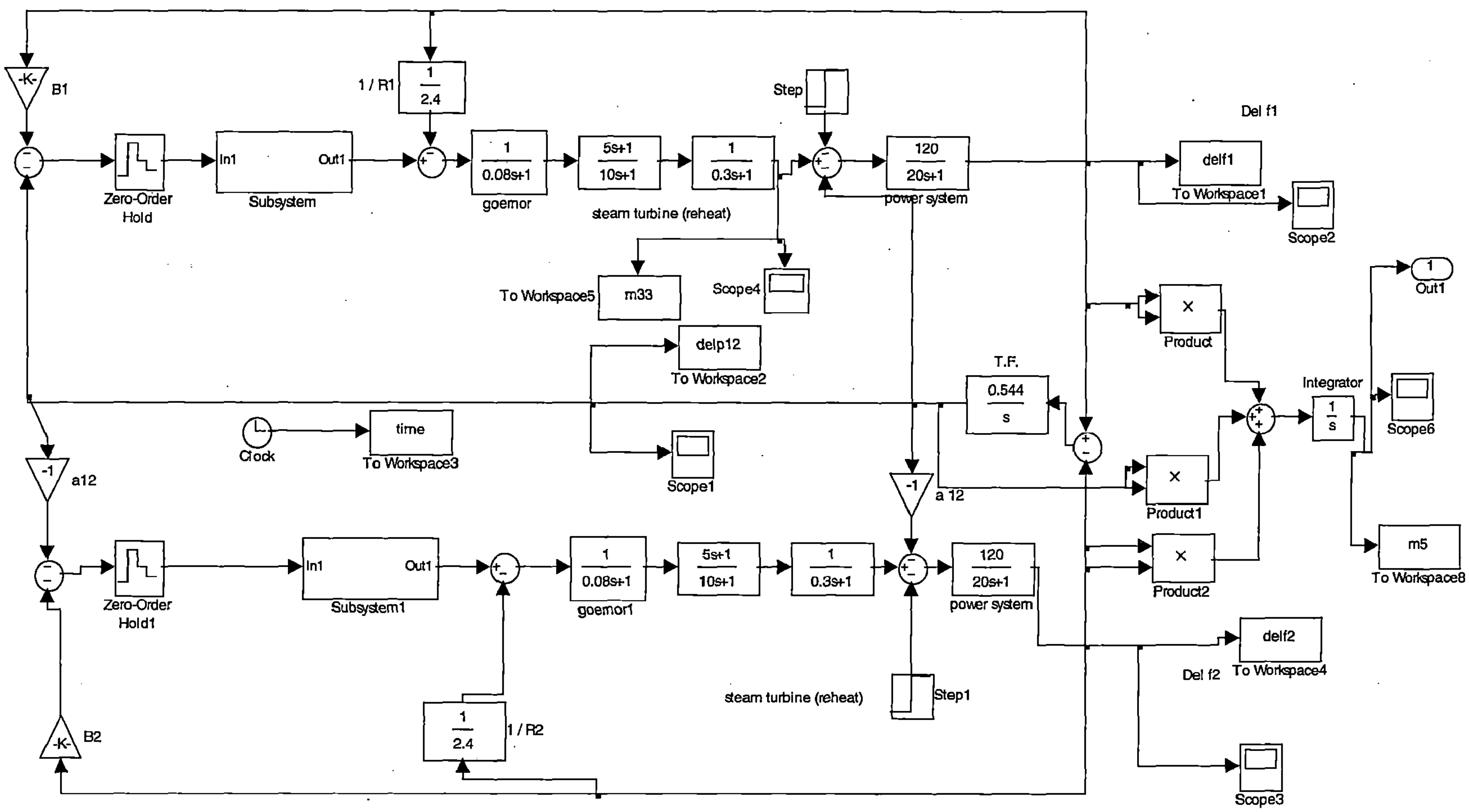


Figure 3.2 Transfer Function Model of an interconnected two-Area Thermal-Thermal System

3.3 Tunable Parameters of the Fuzzy logic Controller

1. Membership function
2. Scaling Factors

3.3.1 Membership function width tuning

The performance of the Fuzzy Logic controller depends on a designed knowledge base in which membership functions and fuzzy control rules are defined. We know that for a fuzzy variable there will fuzzy sub sets like (NL, ZE, PL) which are formed by their membership function once their shape and width and their center position fixed they cannot be altered in the control process. But ... ... as we change the membership function width (we can analyze it as different weighting given by different experts), finally the output of the controller varies as the firing of rules are is different for the same input values but with slightly changed knowledge base.

As we can see in the *Figure 3.3 and Figure 3.4* the centers of the membership functions remains unaltered but the widths are altered.

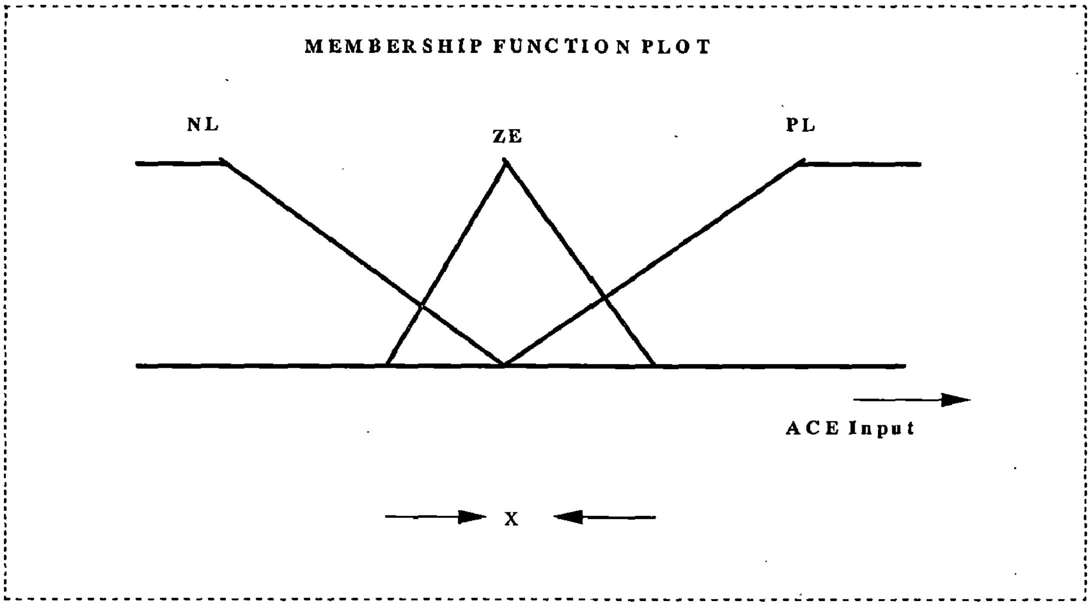


Figure 3.3 Membership function plot

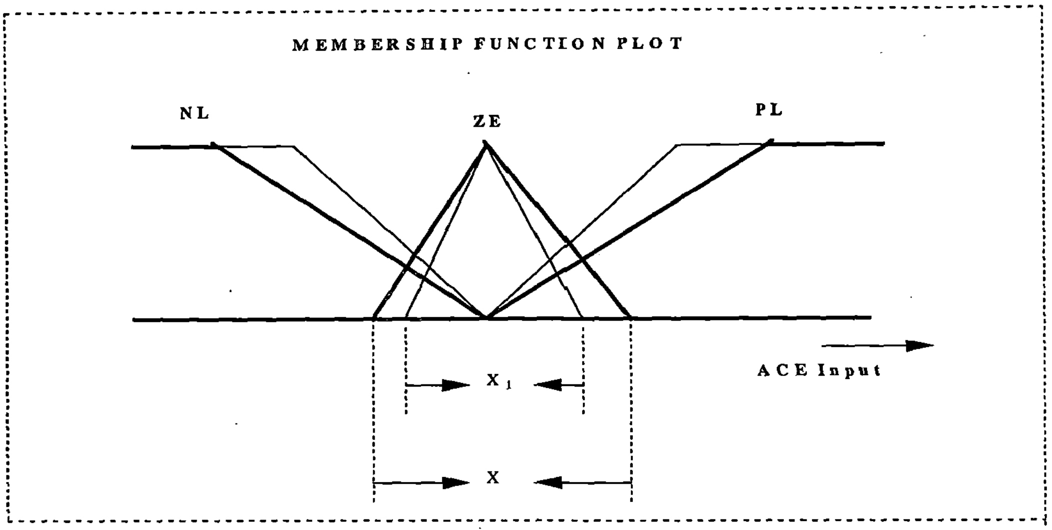


Figure 3.4 Membership function width variation

3.3.2 Scaling factor tuning

Fuzzy logic controller which can be described by five different functional blocks, they are fuzzification, rulebase, data-base, inference engine, and defuzzfication. Since the inputs and the outputs of a fuzzy controller must be real numbers in order to match the sensors and the actuator requirements, fuzzification of input variables and defuzzification of output variables are necessary. The purpose of fuzzification is to transform the real sensor data into fuzzy linguistic terms so that further fuzzy inferences can be performed according to the rule-base.

Commonly used set of fuzzy terms are shown in *Figure 3.5*

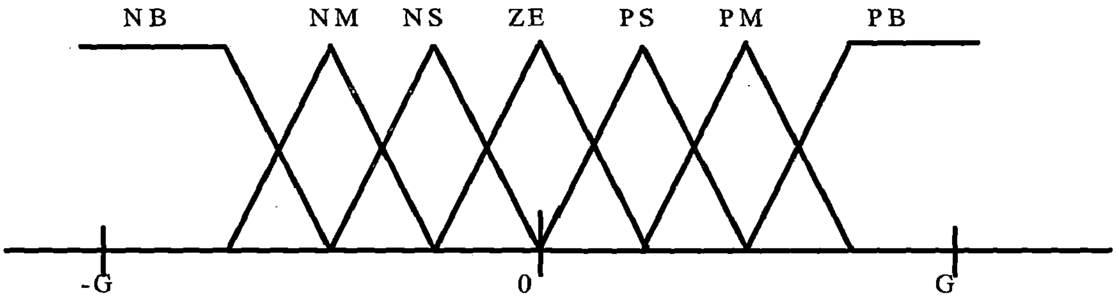


FIG 3.5 Membership functions of Fuzzy Terms

To simplify the notation, the fuzzy linguistic terms in the premise of the rules in the rule-base are sometimes defined within the range of [0, 1]. As a result, it is necessary to normalize the actual variations of the sensor inputs into the interval of [0, 1]. The input scaling factors, G_E and G_{CE}, are determined by the experts or designers so that the universe of discourse of the input variables are mapped into the unity interval. As shown in *Figure 3.6*

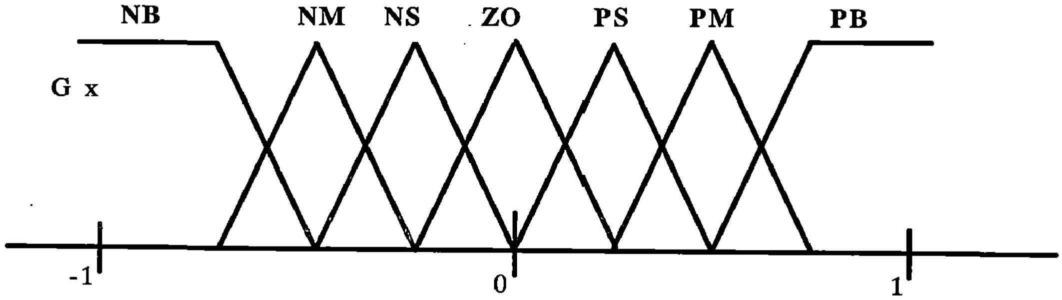


FIG 3.6 Normalised Linguistic Terms

It can be easily seen that an input scaling factor of G_1 and a normalized set of linguistic terms are equivalent to a set of linguistic terms with the universe of discourse between

$$\left[-\frac{1}{G_1}, \frac{1}{G_1}\right]$$

Now the scaling factors G_E and G_{CE} are altered during the tuning process and become

G_E^1 and G_{CE}^1 there must exist a real numbers such that

K_E and K_{CE} Therefore

$G_E^1 = K_E \text{ x } G_E$ 3.1

And $G_{CE}^1 = K_{CE} \text{ x } G_{CE}$ 3.2

And the fuzzy controller can be represented as shown in the *Figure 3.7*

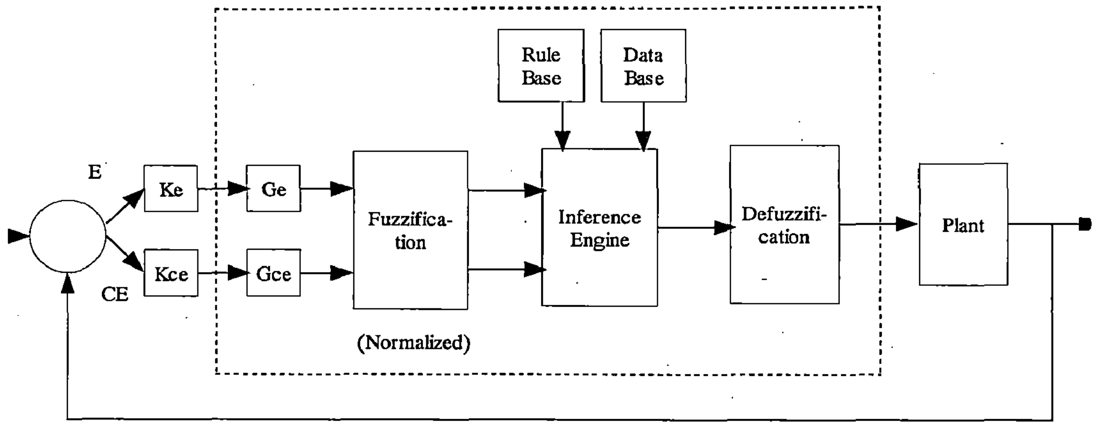


FIG 3.7 Tuning Parameters of Input Scaling Factors

The input scaling factors are the coefficients between the universe of discourse of the input variables and the unity interval, which are supposedly constant if the range of input variations, are approximately known. For an auto-tuning or learning controller design, most of the parameters are not known and the tuning of a set of parameters according to a learning scheme, such as the genetic algorithm, may be able to improve the system performance and to derive a better controller. The set of tuning parameters involved may include the input scaling factors. However, if the relation between the ranges of inputs and the unity interval are known, tuning of the scaling factors becomes meaningless because those parameters are supposed to be constant coefficients.

3.4 PSO tuned Fuzzy controller in a two area AGC system

The successfulness of fuzzy application depends on number of parameters such as fuzzy membership functions, rule base and scaling factors. The definition of these fuzzy rules, fuzzy membership functions are generally affected by subjective decisions and having lot of influence on the performance of the system. According to the fuzzy variable definition the problem can be tackled in different ways, further tuning of the parameters like membership functions and scaling factors could improve the system performance considerably.

The fuzzy controller parameters are formulated as a search problem, where each point in the search space represents a valid parameter. The problem is formulated for searching two types of parameters

1. Membership function width
2. Scaling factors

So to tackle this searching, Particle swarm Optimization (PSO) technique is introduced. Particle swarm optimization is similar to other evolutionary programming computation techniques in conducting searching for optimal solution using an initial population of individuals. The individuals of this initial population are then changed according to some kind of process such that they are moved to a better solution area.

The evolutionary algorithms are motivated by evolutionary seen in nature. They adopted the principle of competition and survival of the fittest from there. Particle Swarm Optimization, on the other hand, is motivated form the simulation of social behavior. It adopts the principle of cooperation and competition among the individual themselves.

The application of Particle Swarm Optimization involves repetitively performing two steps

1. The calculation of the objective functions for each of the particles in the current population. To do this, the system must be simulated to obtain the value of the objective function.
2. The particle swarm optimization then updates the particle coordinates based on equations (1) and (2).

These two steps are repeated from population to population until a stopping criterion terminates the search producing the optimum parameters.

3.4.1 *Procedure for the tuning the membership function parameters using PSO*

1. Define the number of fuzzy sets for fuzzy variables ace and change in ace and U (t).
2. Define the fitness function.
3. Give the range and length of bit for strings for $eP_1, eP_2, ceP_1, ceP_2, UP_1, UP_2$
4. Initialize an array of the population of particles with random positions and velocities in D dimensions in the problem space.
5. Update 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 D variables for each particle.
8. Compare each particle's fitness evaluation with its pbest. If the current value is better than pbest, then save the current value as pbest and let its location correspond to the current location in D-dimensional space.
9. Modify the velocity and position of the particle according to the following equations

$$V_{id} = V_{id} + c_1 r_1 (p_{nd} - X_{id}) + c_2 r_2 (p_{gd} - X_{id})$$
$$X_{id} = X_{id} + V_{id}$$

10. If the iteration number reaches the predetermined one then stop other wise go to step 5
11. Replace the old values of the eP_1 ,eP_2 ,ceP_1 ,ceP_2 ,UP_1 ,UP_2 (membership function widths) with the new ones

The block diagram representation is shown in *Figure 3.8*

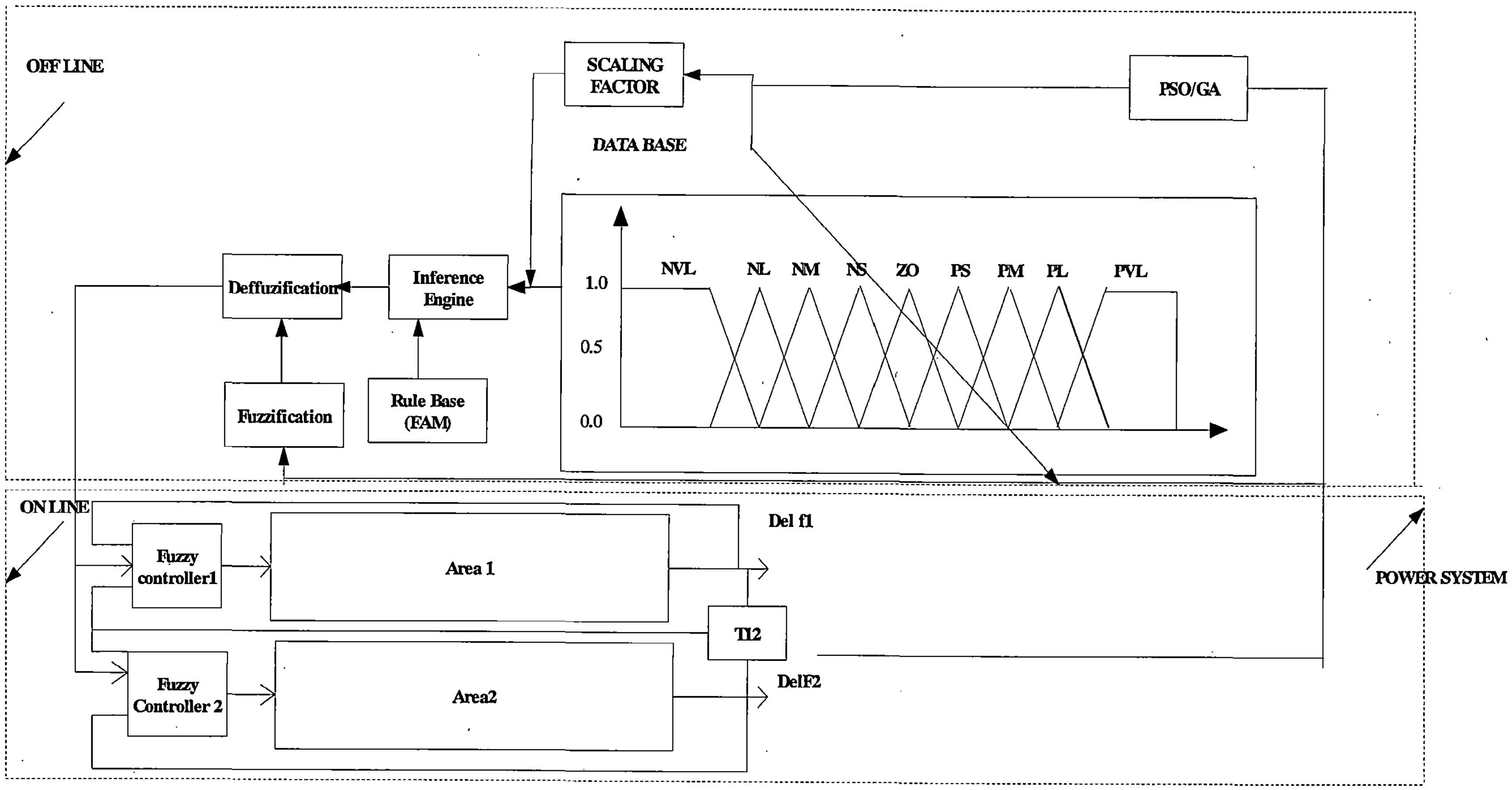


Figure3.8 Blockdaigram

The optimal values of the membership function widths are of eP_1 ,eP_2 ,ceP_1 ceP_2 UP_1 , UP_2 were obtained using the PSO technique. Dynamic responses for the two area hydro thermal system and two area thermal-thermal system (. f_1, . P_{tie} ,ISE) are obtained.

3.4.2 Results

For 1% step perturbation considered either in thermal area or in hydro area of the two area ***hydro thermal system*** is considered. The sample responses like . f_1 = f(t), . f_2 = f(t) and . P_{tie} = f(t), for 1% step perturbation in thermal area are given in *Figures 3.9-3.11*

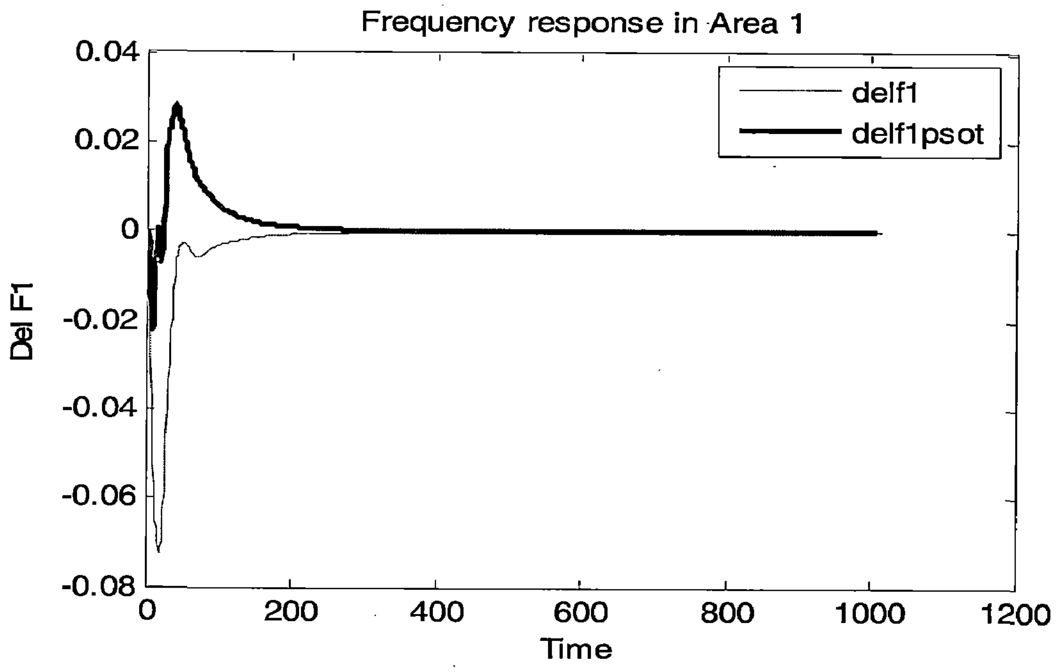


Figure 3.9 Frequency response of area 1

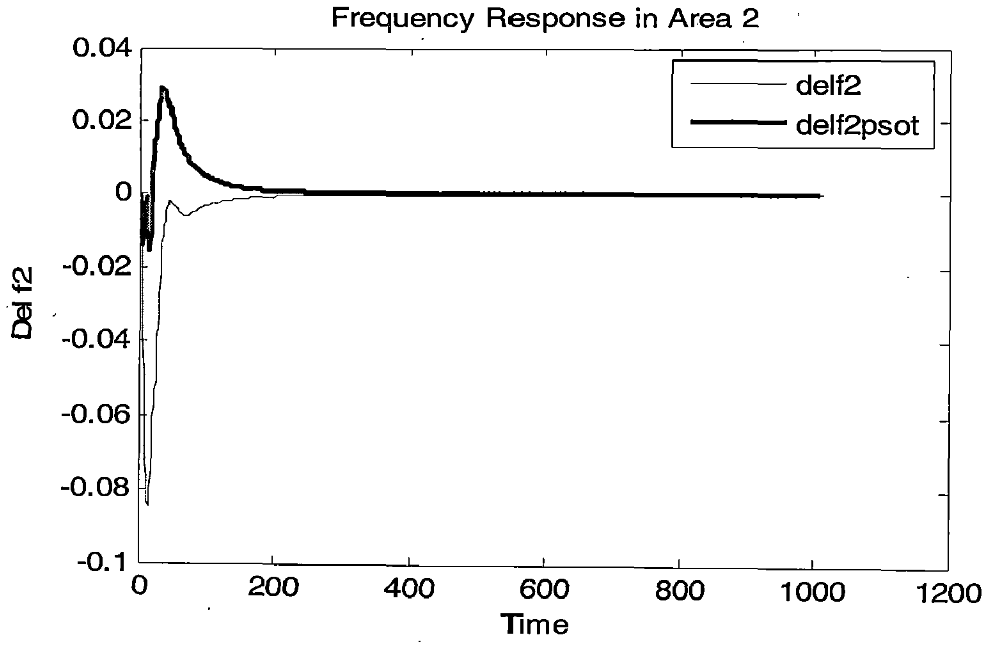


Figure 3.10 Frequency response of area 2

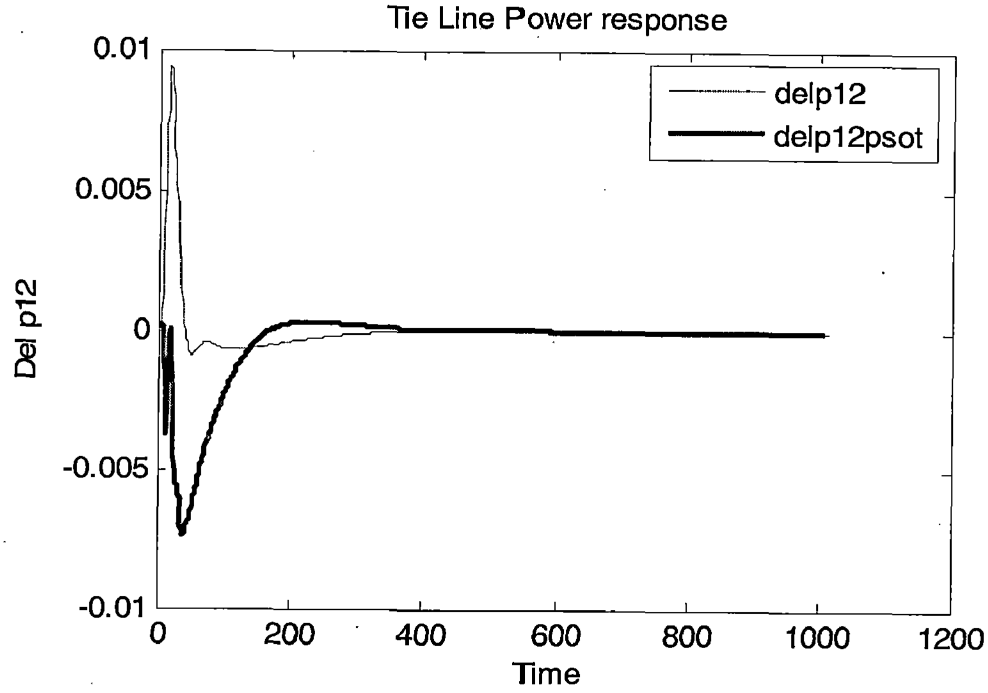


Figure 3.11 Tie line power responses

For 1% step perturbation considered in either area of the two area *Thermal-thermal system* is considered. The sample responses like . $f_1 = f(t)$, . $f_2 = f(t)$ and . $P_{tie} = f(t)$, for 1% step perturbation in first area are given in *Figures 3.12-3.13*

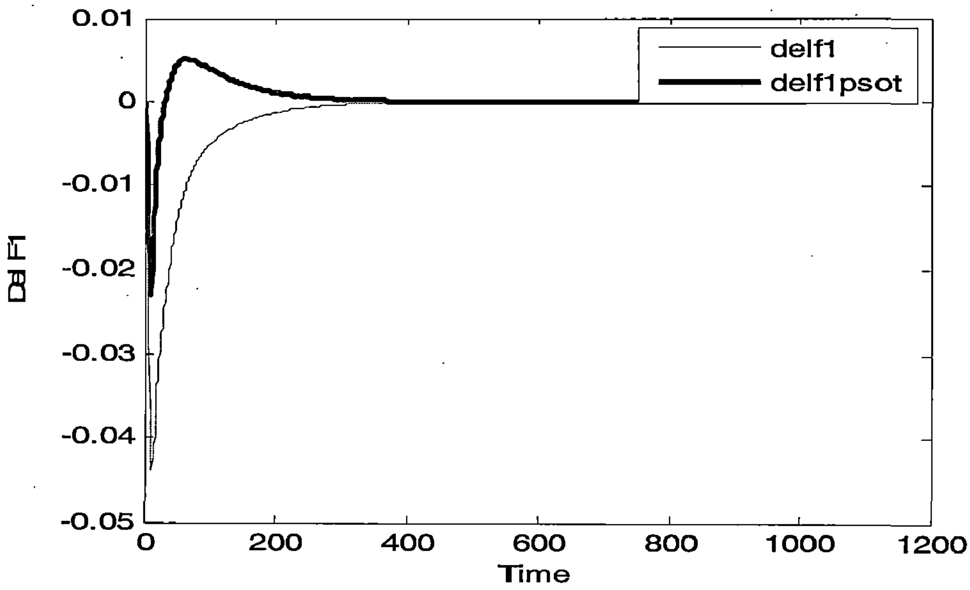


Figure 3.12 Frequency response of area 1

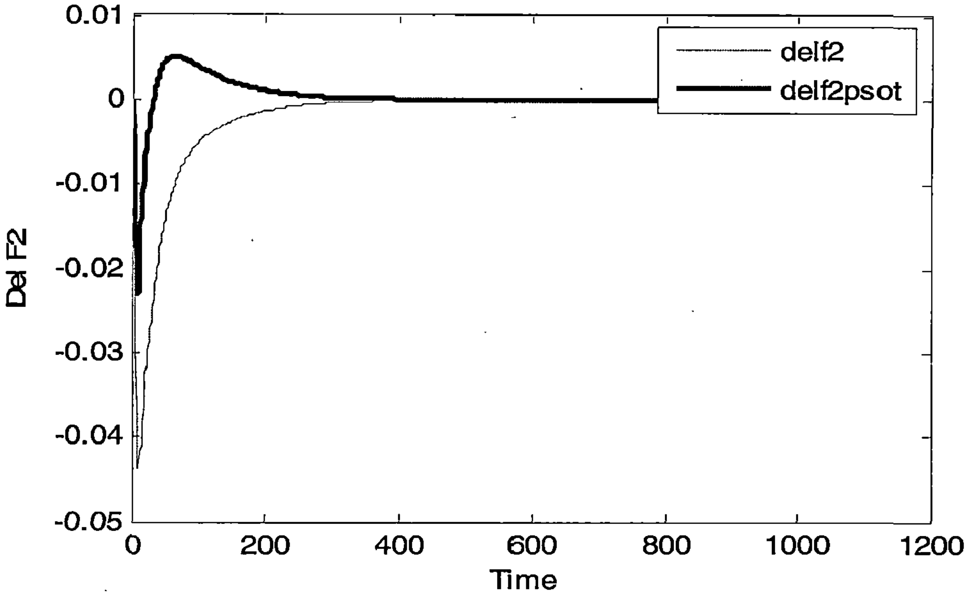


Figure 3.13 Frequency response of area 2

3.4.3 *Procedure for the tuning the scaling factor parameters using PSO*

1. Define the number of fuzzy sets for fuzzy variables ace and change in ace and U (t).
2. Define the fitness function.
3. Give the range and length of bit for strings for x and y.
4. Initialize an array of the population of particles with random positions and velocities in D dimensions in the problem space.
5. Update 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 D variables for each particle.
8. Compare each particle‘s fitness evaluation with its pbest. If the current value is better than pbest, then save the current value as pbest and let its location correspond to the current location in D-dimensional space.
9. Modify the velocity and position of the particle according to the following equations

$$V_{id} = V_{id} + c_1 r_1 (p_{nd} - X_{id}) + c_2 r_2 (p_{gd} - X_{id})$$
$$X_{id} = X_{id} + V_{id}$$

10. If the iteration number reaches the predetermined one then stop other wise go to step 5
11. Replace the old values of the x and y (scaling factor) with the new ones

The block diagram representation is shown in *Figure 3.8*

The optimal values of the scaling factors are of x and y was obtained using the PSO technique. The following *table 3.1* shows the optimal values of the scaling factors for the fuzzy controller for which the system dynamic response is good.

Table 3.1

	System Investigated	x	y
Controller parameters not Optimized	Hydro thermal system	1	1
	Thermal-thermal System	1	1
Controller Parameters Optimized by PSO	Hydro thermal system	4.286	5.000
	Thermal-thermal System	4.312	4.522

Dynamic responses for the two area hydro thermal system and two area thermal-thermal system (. f_1, . f_2, . $P_{tie,}$,ISE) are obtained

3.4.4 Results

For 1% step perturbation considered in either area of the two area *Hydro-thermal system* is considered. The sample responses like . $f_1 = f(t)$, . $f_2 = f(t)$ and . $P_{tie} = f(t)$, for 1% step perturbation in first area are given in *Figures 3.15-3.17*

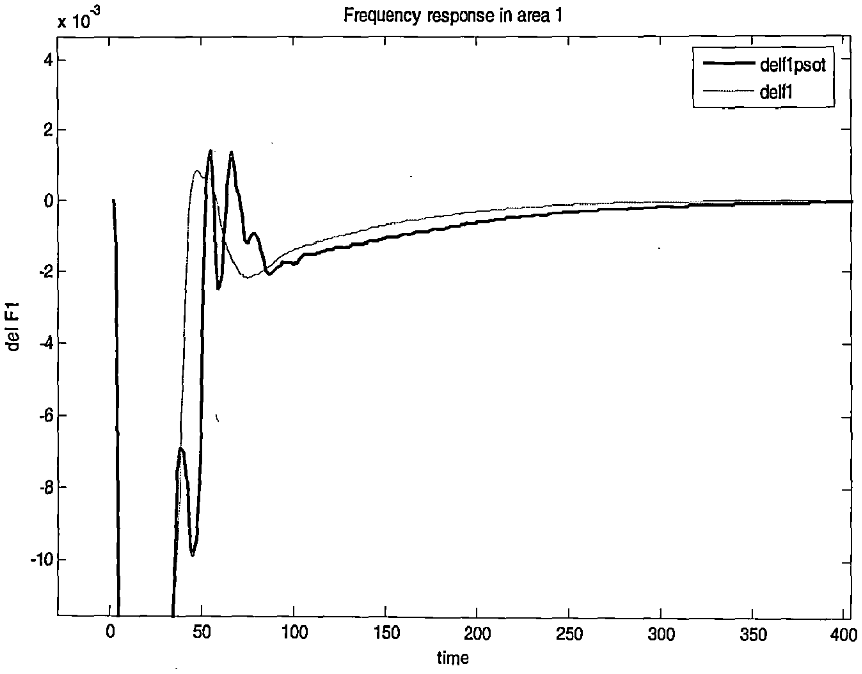


Figure 3.14 Frequency response of area 1

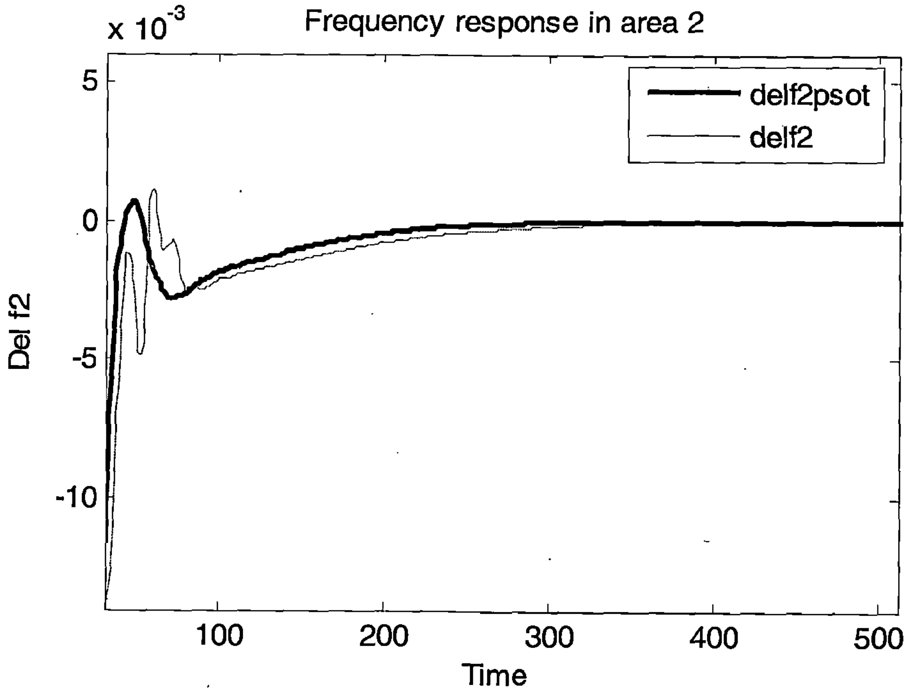


Figure 3.15 Frequency response of area 2

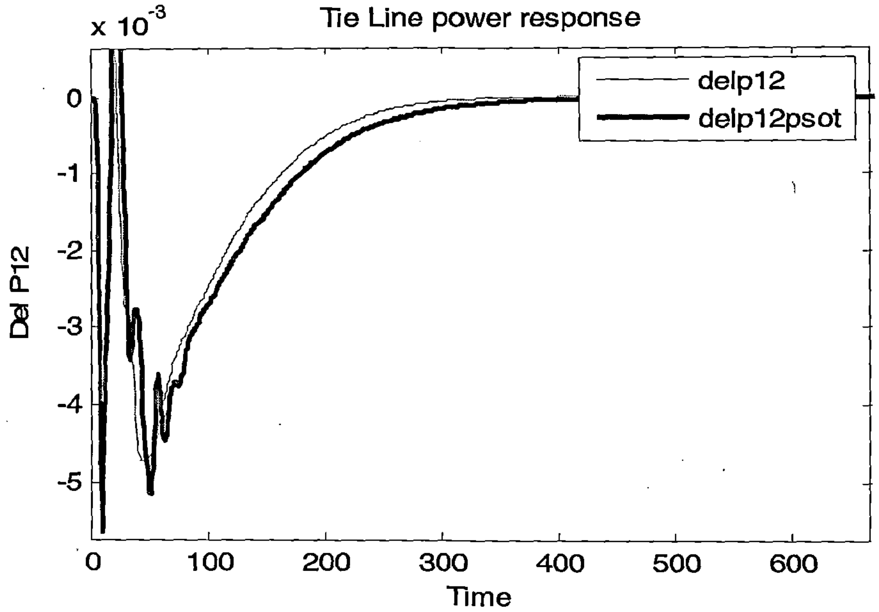


Figure 3.16 Tie line power response

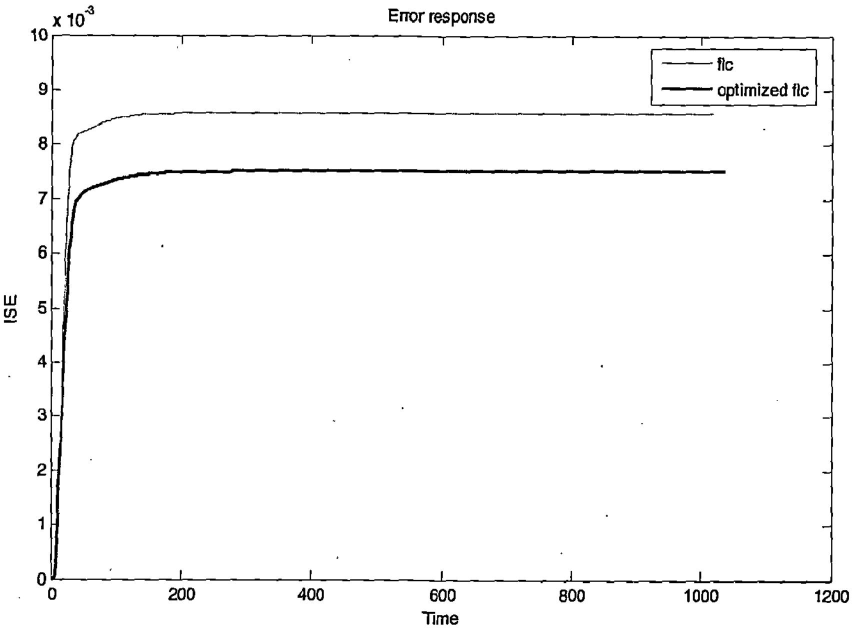


Figure 3.17 Error response

For 1% step perturbation considered in either area of the two area Thermal-*thermal system* is considered. The sample responses like . $f_1 = f(t)$, . $f_2 = f(t)$ and . $P_{tie} = f(t)$, for 1% step perturbation in first area are given in *Figures 3.18-3.21*

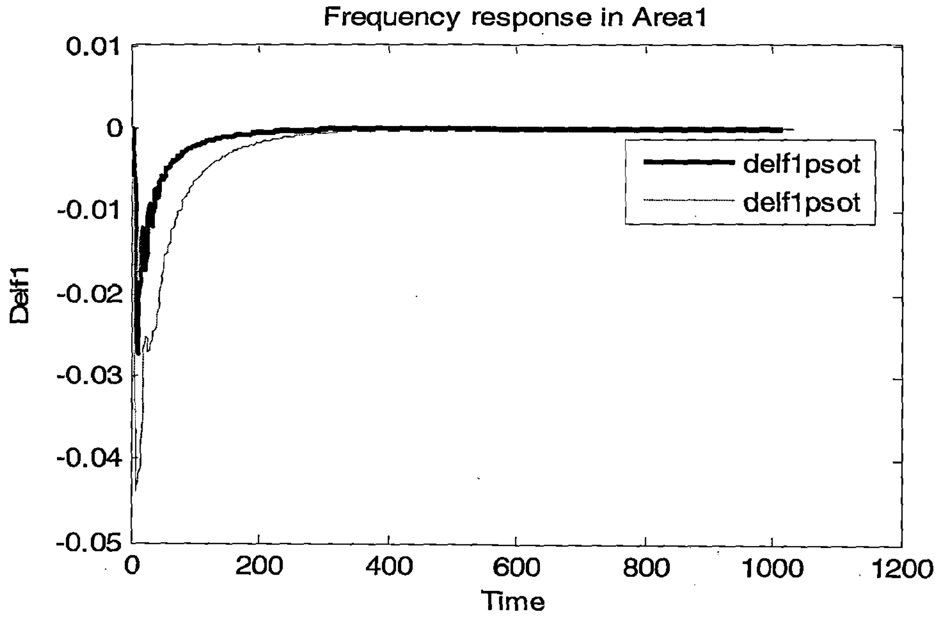


Figure 3.18 Frequency response of area 1

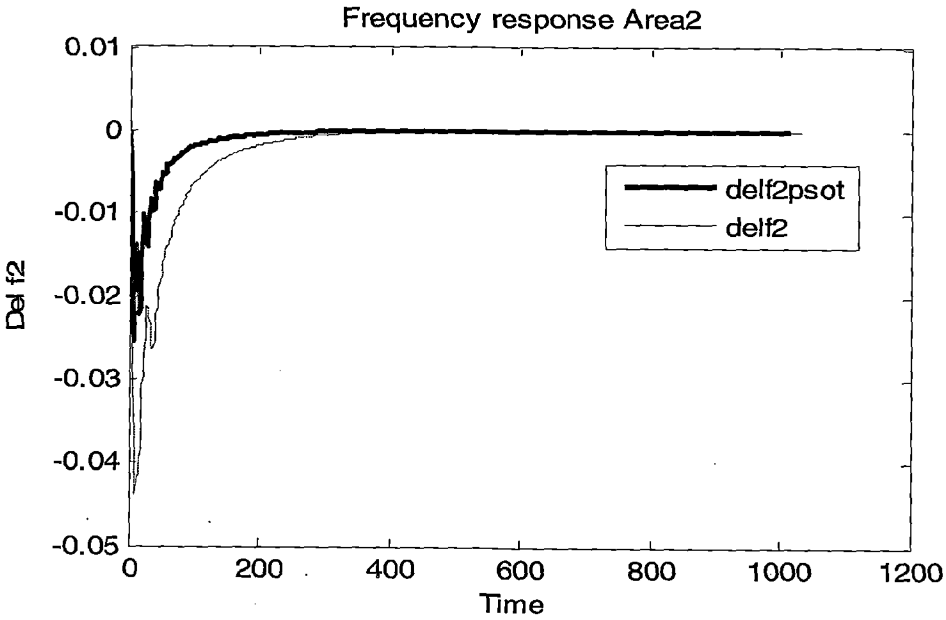


Figure 3.19 Frequency response of area 2

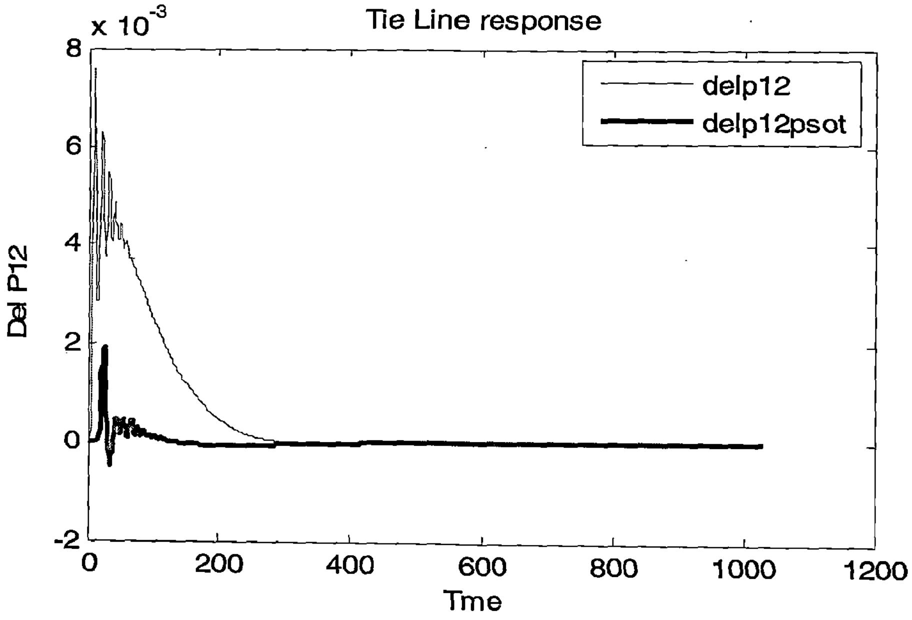


Figure 3.20 Tie line Power Response

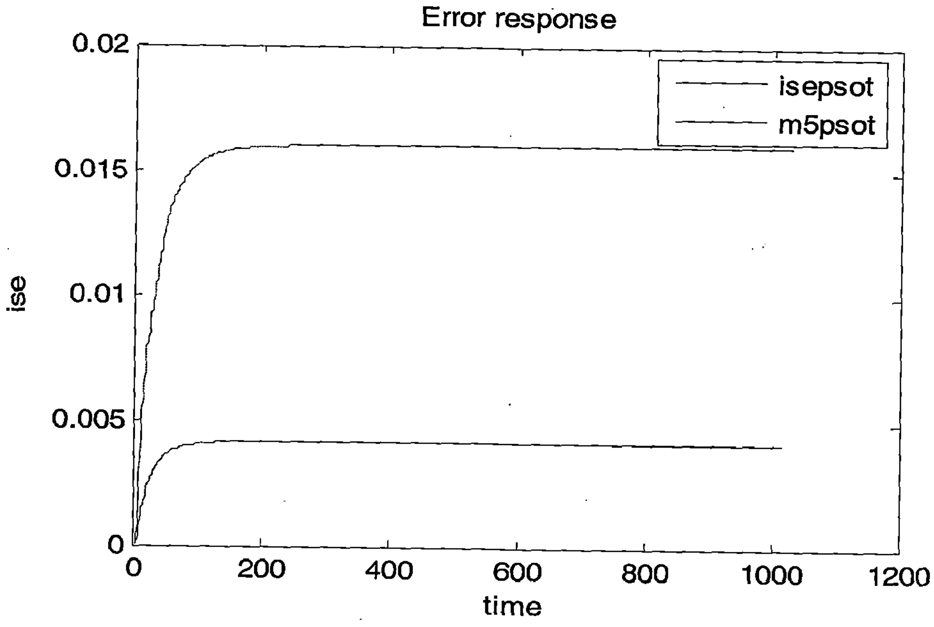


Figure 3.21 Error response

3.5 Genetic Algorithm tuned Fuzzy controller in a two area AGC system

It is well known that fuzzy logic control has more advantages in the control of nonlinear system, especially with system that are difficult to model by using conventional methods. But in fuzzy logic control, the membership functions and fuzzy rules are chosen mainly based on experience, making any fine tuning. The shape of membership functions in fuzzy logic controller will affect control performance, so fuzzy controller can be optimized by changing the shape of membership function and also by scaling the inputs. So here to achieve the advantages of optimized fuzzy logic controller, Genetic algorithm is used for optimizing the parameters.

The fuzzy controller parameters are formulated as a search problem, where each point in the search space represents a valid parameter. The problem is formulated for searching two types of parameters

1. Membership function width
2. Scaling factors

So to tackle this searching Genetic Algorithms (GA) technique is introduced. Genetic algorithms (GA) are global search techniques, based on the operations observed in natural selection and genetics. Genetic operators can be divided into three main categories, reproduction, crossover, and mutation.

(1) Reproduction selects the fittest individuals in the current population to be used in generating the next population.

(2) Cross-over causes pairs, or larger groups of individuals to exchange genetic information with one another.

(3) Mutation causes individual genetic representations to be changed according to some probabilistic rule.

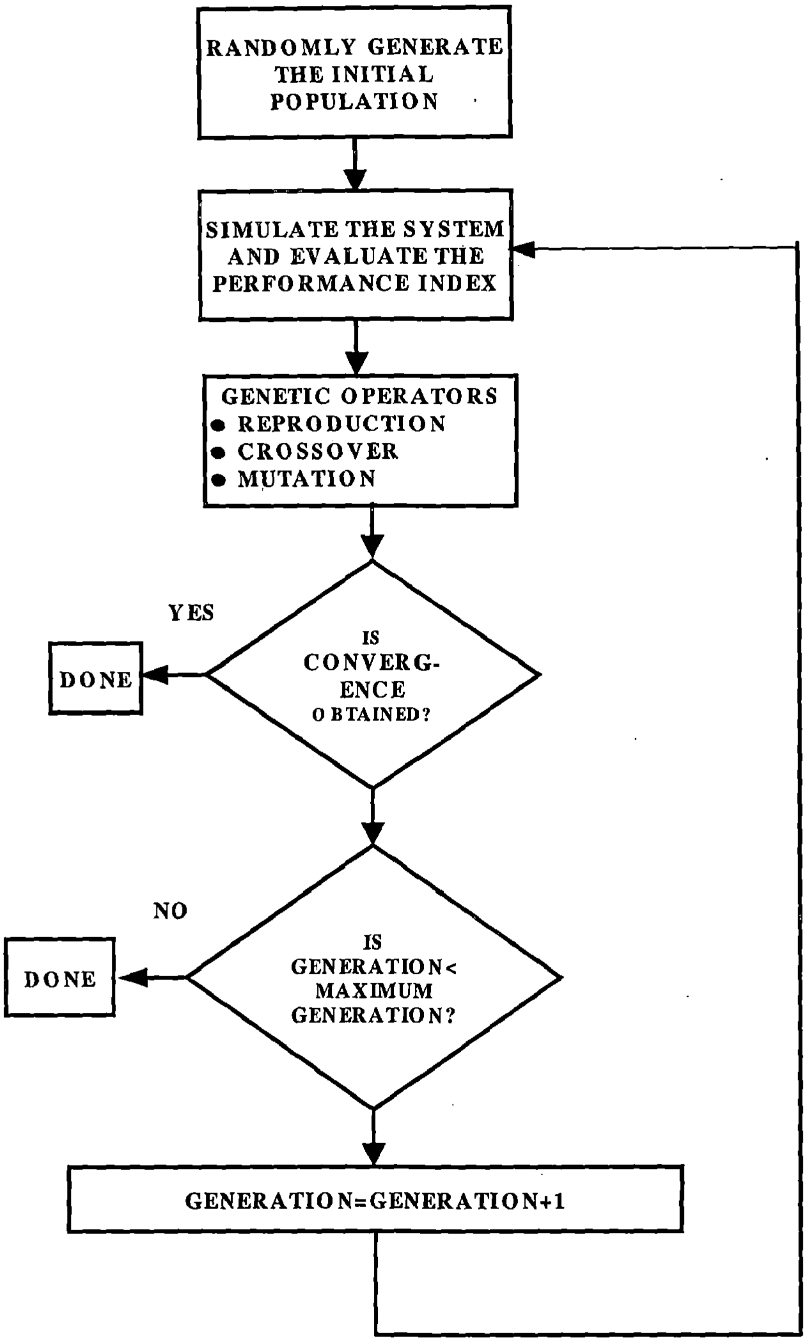


Figure 3.22 flow chart of GA

3.5.1 *Procedure for the tuning the membership function width parameters using GA*

1. Define the number of fuzzy sets for fuzzy variables ace and change in ace and U (t).
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 eP1 ,eP_2 ,ceP_1 ,ceP_2 ,UP_1 ,UP_2 . Produce 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 eP1 ,eP_2,ceP_1,ceP_2,UP_1,UP_2.
14. Replace the old values of the eP_1 ,eP_2 ,ceP_1 ,ceP_2 ,UP_1 ,UP_2 (membership function widths) with the new ones

The optimal values of the membership function widths are of eP_1 ,ceP_1 , UP_1 were obtained using the GA technique. Dynamic responses for the two area hydro thermal system and two area thermal thermal system (. f_1, . f_2, . P_{tie} ,ISE) are obtained

3.5.2 Results

For 1% step perturbation considered in either area of the two area *Hydro-thermal system* is considered. The sample responses like . $f_1 = f(t)$, . $f_2 = f(t)$ and . $P_{tie} = f(t)$, for 1% step perturbation in first area are given in *Figures 3.24-3.27*

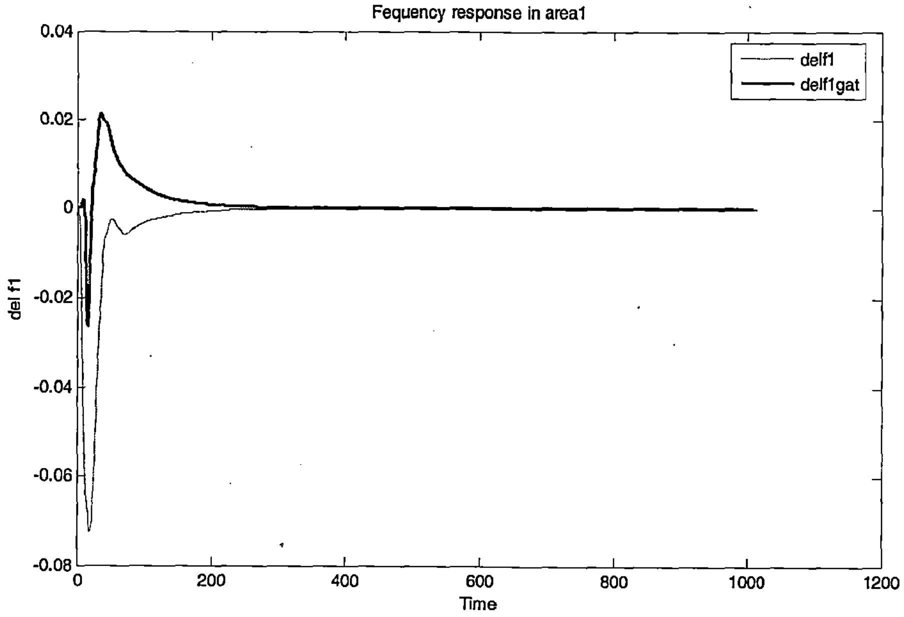


Figure 3.23 Frequency response of area 1

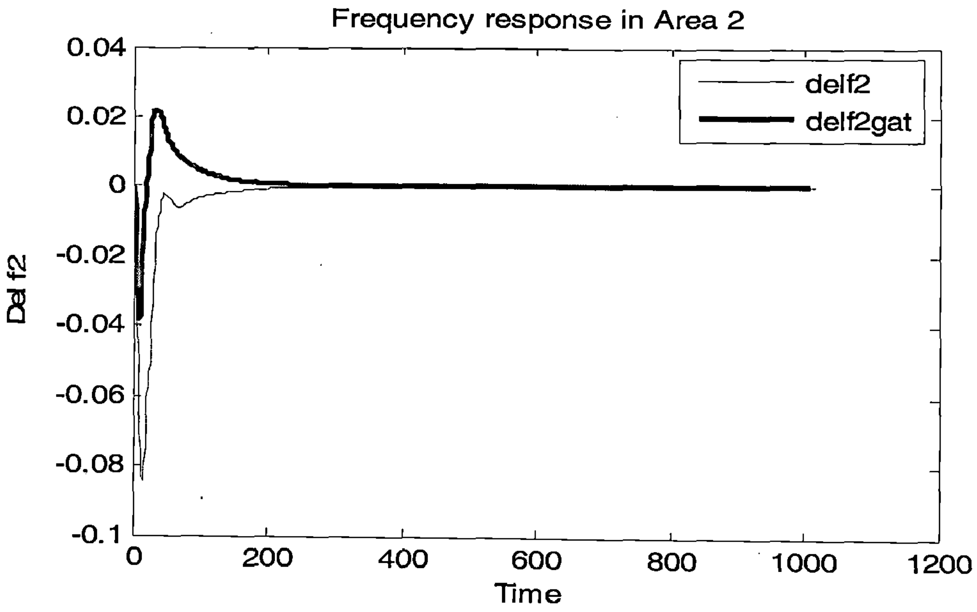


Figure 3.24 Frequency response area2

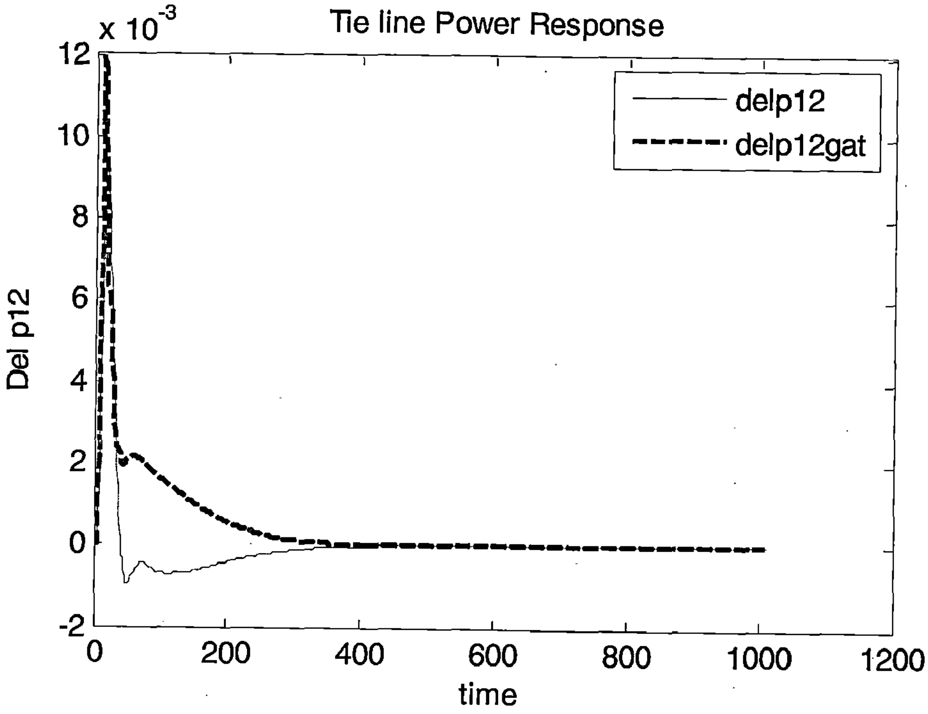


Figure 3.25 Tie line power Response

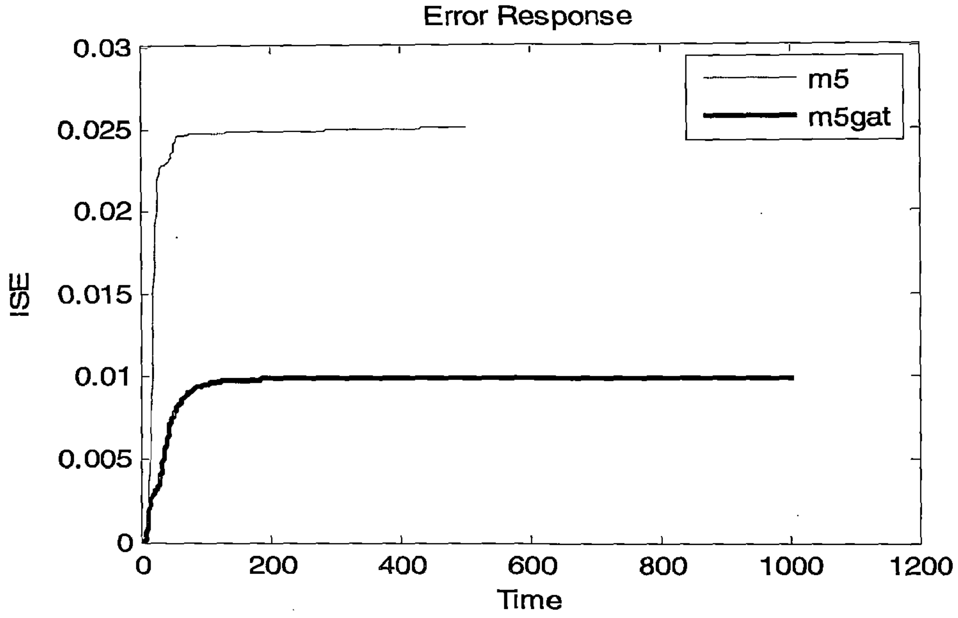


Figure 3.26 Error response

For 1% step perturbation considered in either area of the two area *Thermal-thermal system* is considered. The sample responses like . f_1 = f(t), . f_2 = f(t) and . P_{tie} = f(t), for 1% step perturbation in first area are given in *Figures 3.28-3.30*

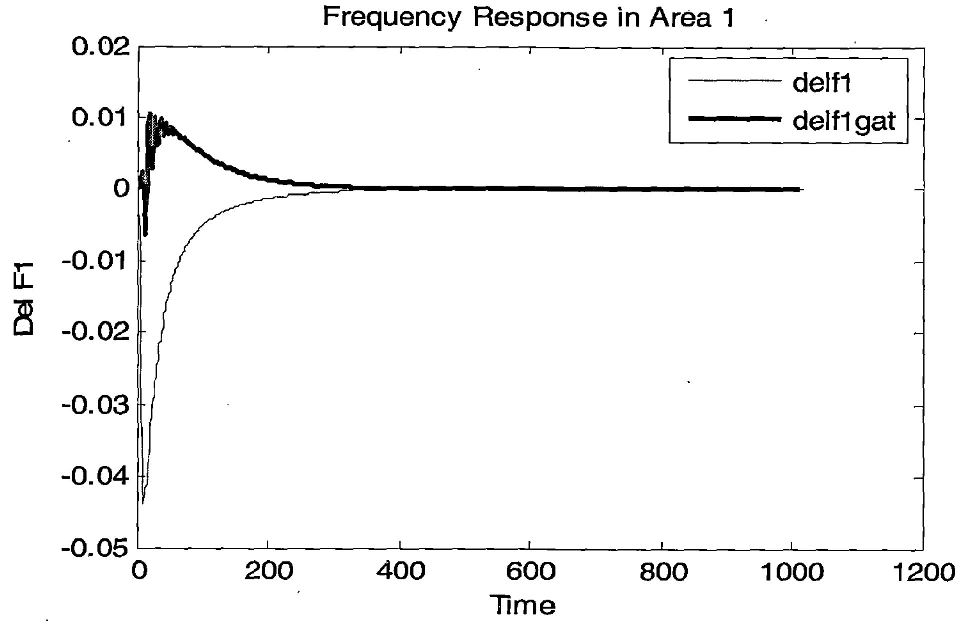


Figure 3.27 Frequency response of area 1

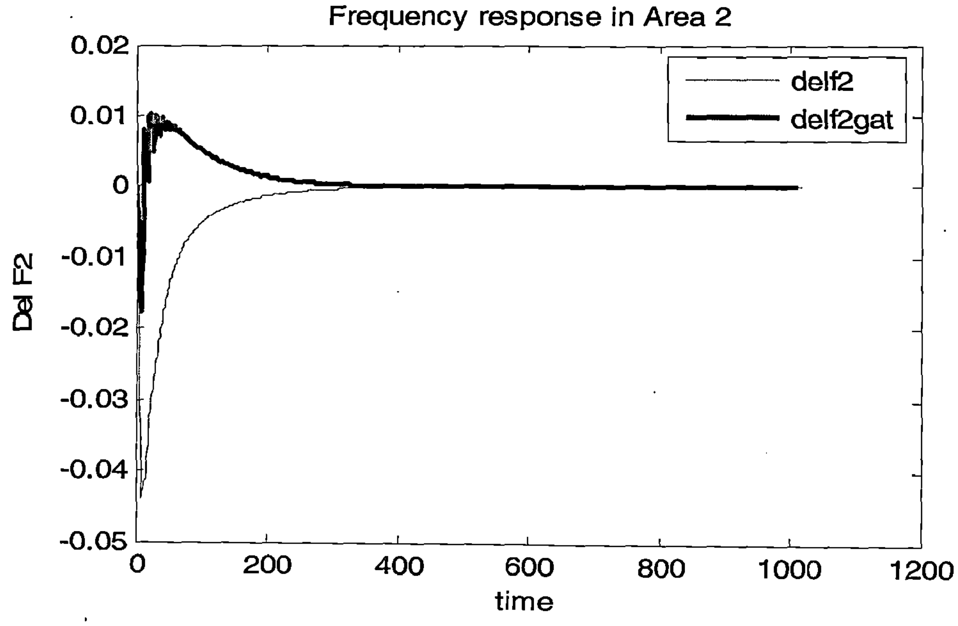


Figure 3.28 Frequency response of area 2

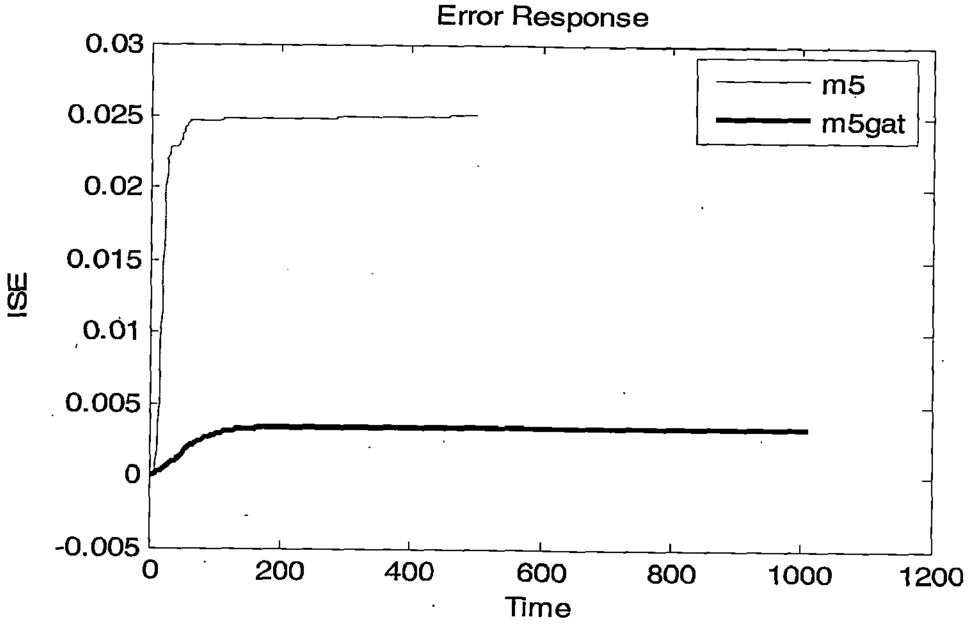


Figure 3.29 Error response

3.5.3 Procedure for tuning the scaling factor parameters using GA

1. Define the number of fuzzy sets for fuzzy variables ace and change in ace and U (t).
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 and y produce 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 and y
14. Replace the old values of the x and y (scaling factors) with the new ones

The block diagram representation is shown in *figure 3.8*

The optimal values of the scaling factors are of x and y was obtained using the GA technique and it was shown in *Figure 3.30a*. The following table shows the optimal values of the scaling factors for the fuzzy controller for which the system dynamic response is good.

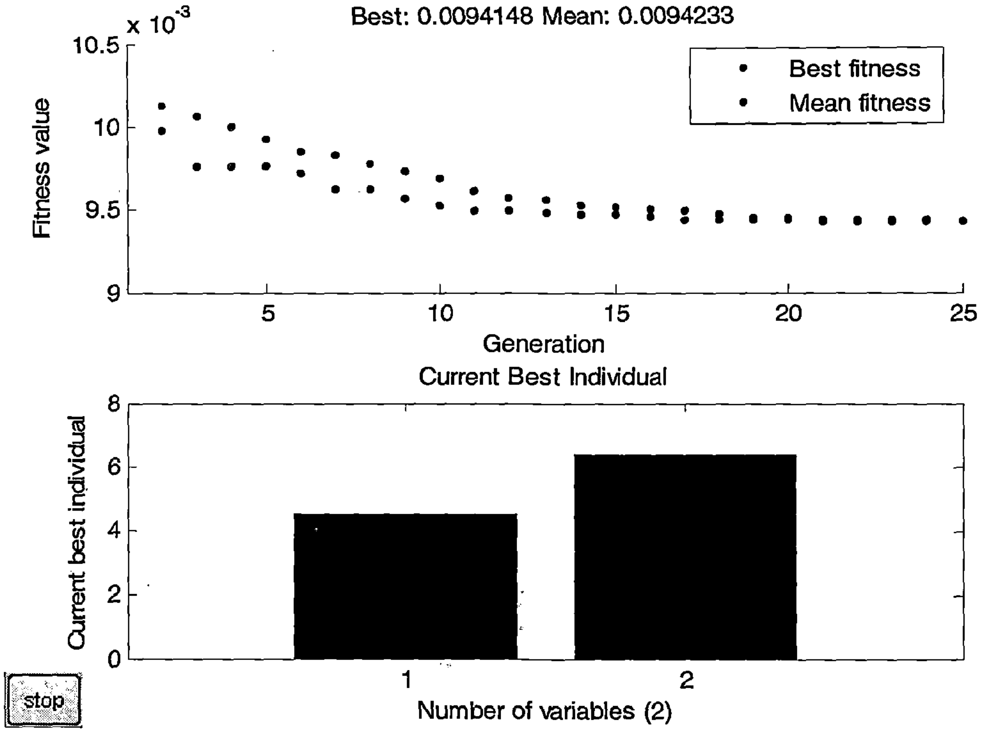


Figure 3.30 shows how the GA tunes with respect to ISE the scaling factors

Table 3.2

	System Investigated	x	y
Controller parameters not Optimized	Hydro thermal system	1	1
	Thermal-thermal System	1	1
Controller Parameters Optimized by GA	Hydro thermal system	4.222	10.200
	Thermal-thermal System	4.231	5.000

Dynamic responses for the two area hydro thermal system and two area thermal-thermal system (. f_1, . f_2, . P_{tie} ,ISE) are obtained

3.5.4 Results

For 1% step perturbation considered either in thermal area or in hydro area. Sample responses like . f_1 = f(t), . f_2 = f(t) and . P_{tie} = f(t), for 1% step perturbation in thermal area are given in *Figures 3.31-3.33,* with corresponding optimum scaling factors.

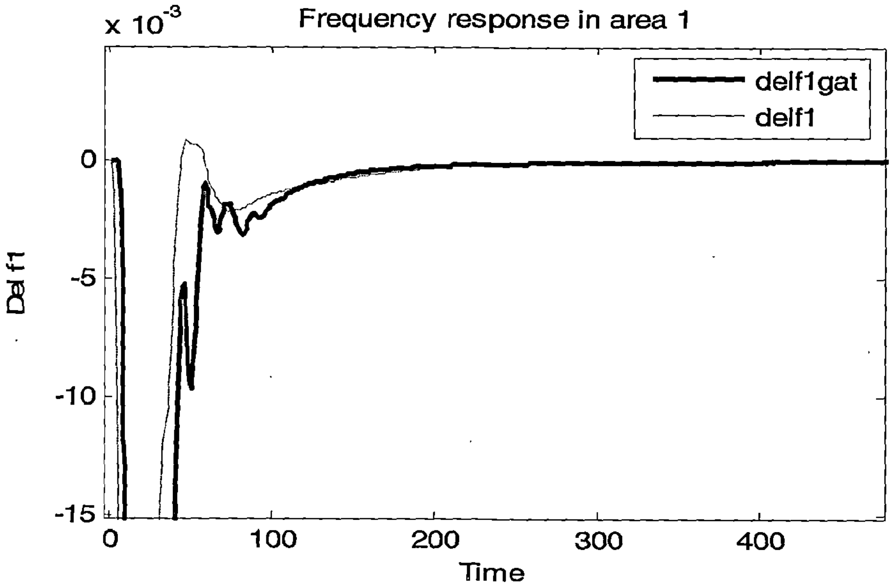


Figure 3.31 Frequency response area1

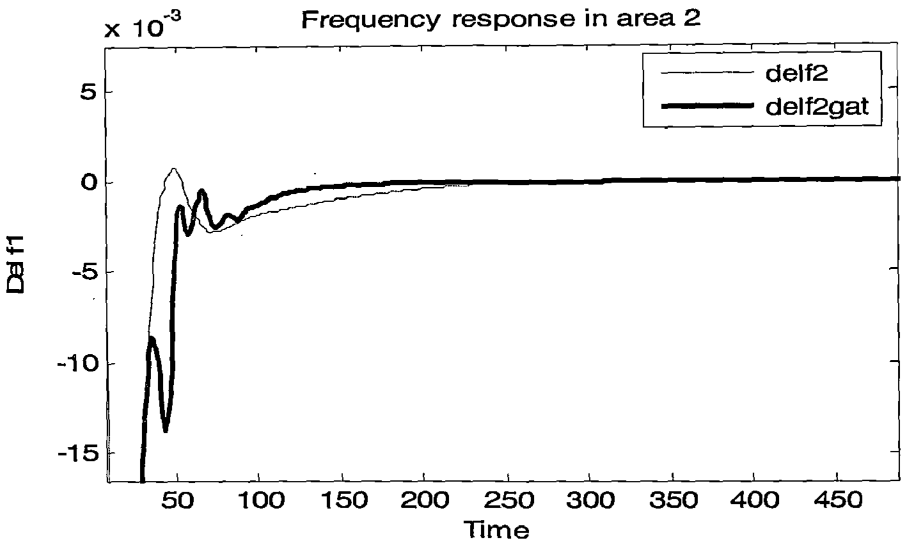


Figure 3.32 Frequency response area2

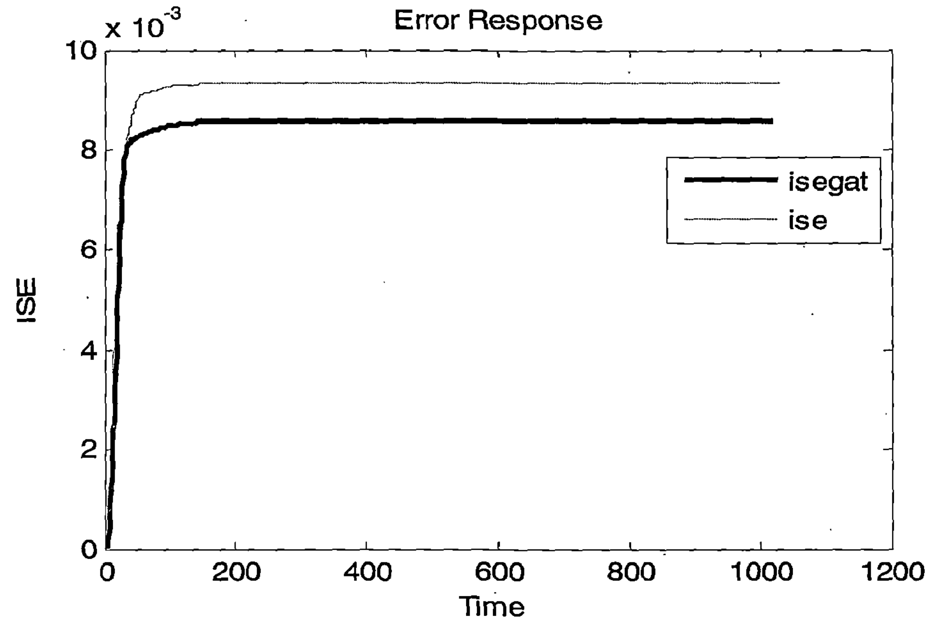


Figure 3.33 Error response

For 1% step perturbation considered either in areas of the thermal thermal system. Sample responses like . $f_1 = f(t)$, . $f_2 = f(t)$ and . $P_{tie} = f(t)$, for 1% step perturbation in second area are given in *Figures 3.34-3.37* for different with corresponding optimum scaling factors

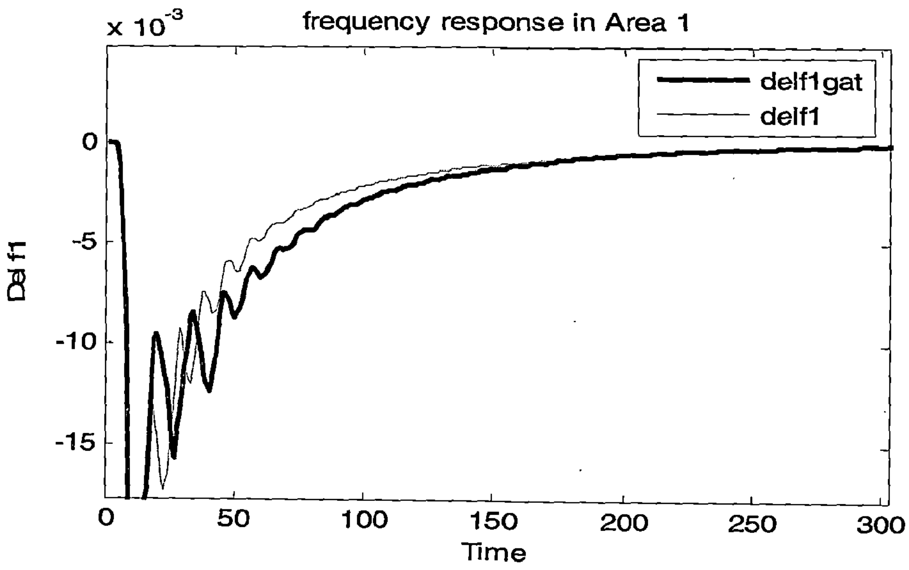


Figure 3.34 Frequency response area1

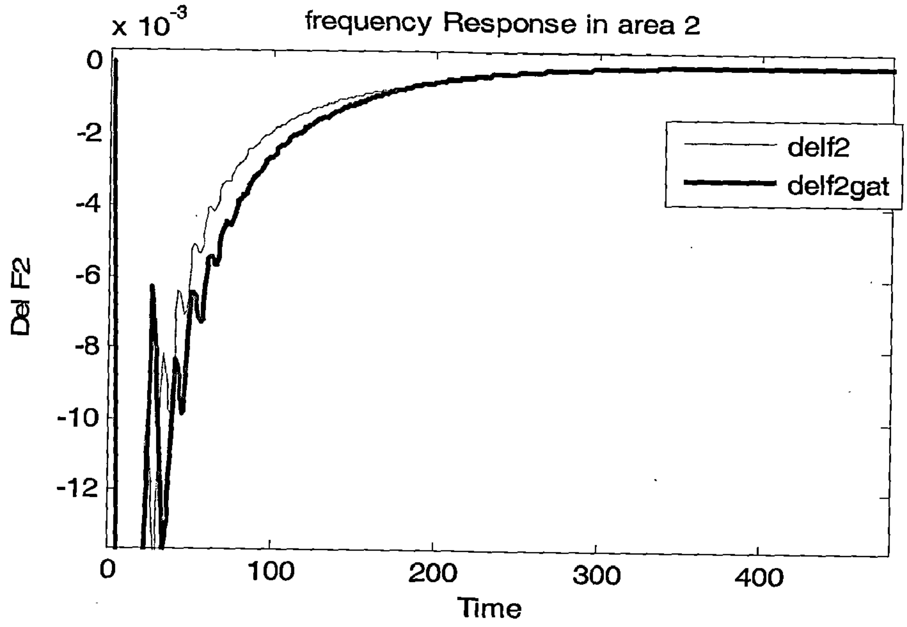


Figure 3.35 Frequency response area2

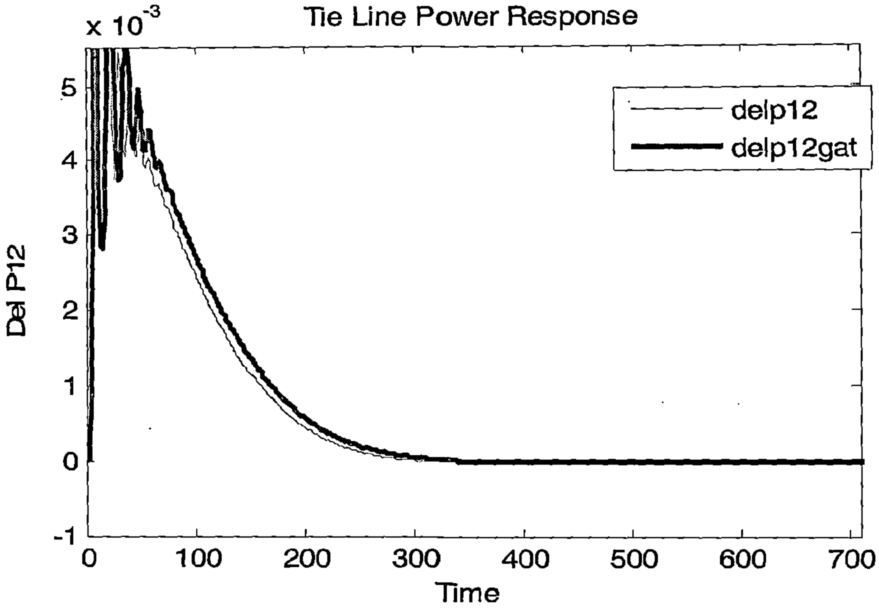


Figure 3.36 tie line power Response

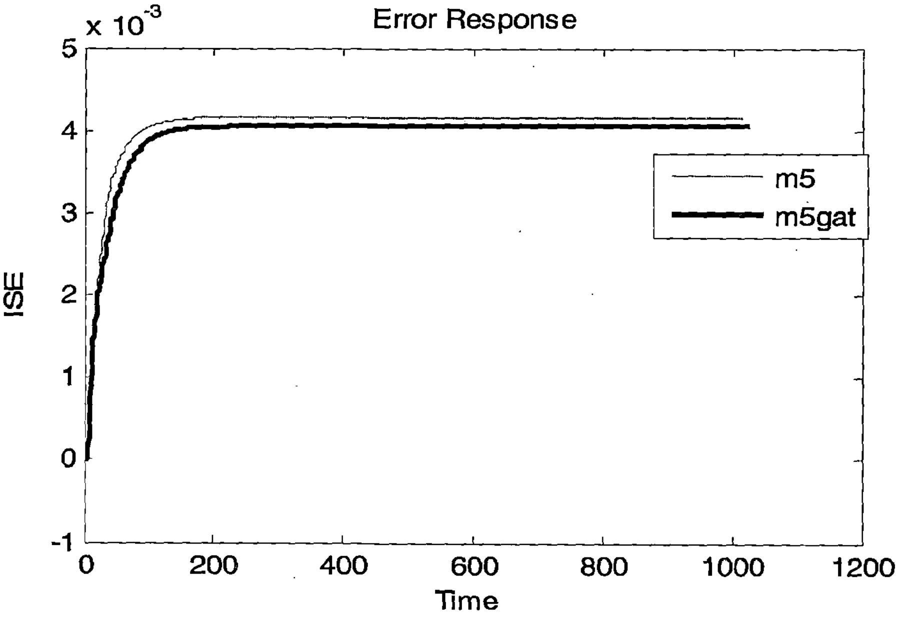


Figure 3.37 Error response

3.6 Comparison of dynamic responses for load change in both areas

3.6.1 Hydro thermal system

The optimized controllers namely PSO tuned FLC and GA tuned FLC controllers have been tried out for AGC of a two area Hydro Thermal system and Thermal-thermal system. Which one provides better result for AGC? To answer this question, we have to compare the dynamic responses. *Figure3.38-3.* shows comparison of dynamic responses between modified FLC, PSO tuned FLC and GA tuned FLC considering 1% step perturbation in thermal area as well as in Hydro areas, for a sampling period of 2 sec and with R=2.4 in thermal area and 4.8 in hydro area. Analyses of these responses clearly reveal that GA tuned FLC provides better dynamic responses. Presence of modified FLC in both areas guarantees zero steady state error and this GA tuned FLC provides less peak overshoot as well as settling time is also less irrespective of the location of the perturbation in either area or in both areas.

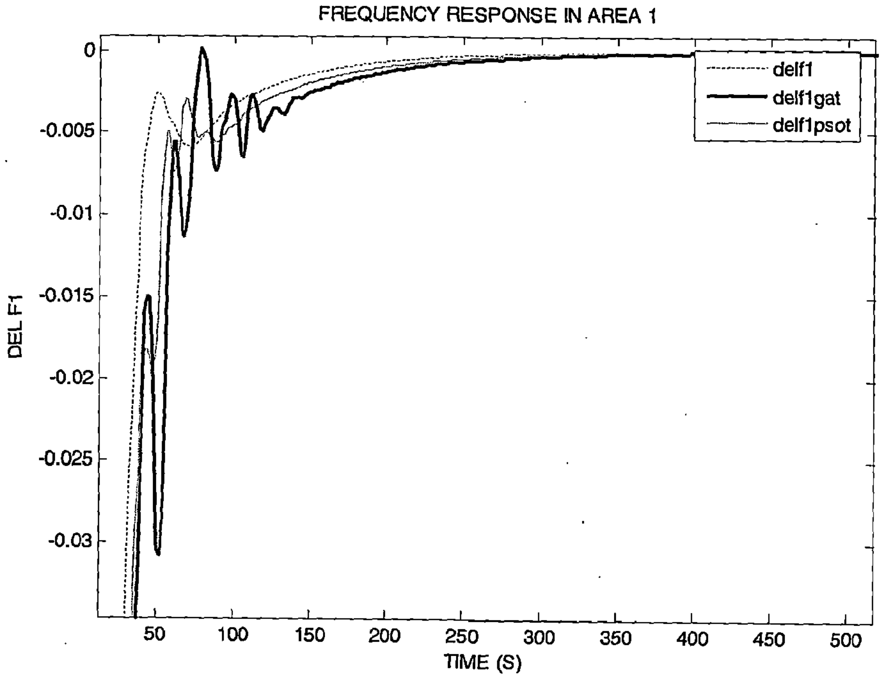


Figure 3.38 Frequency Response in area 1

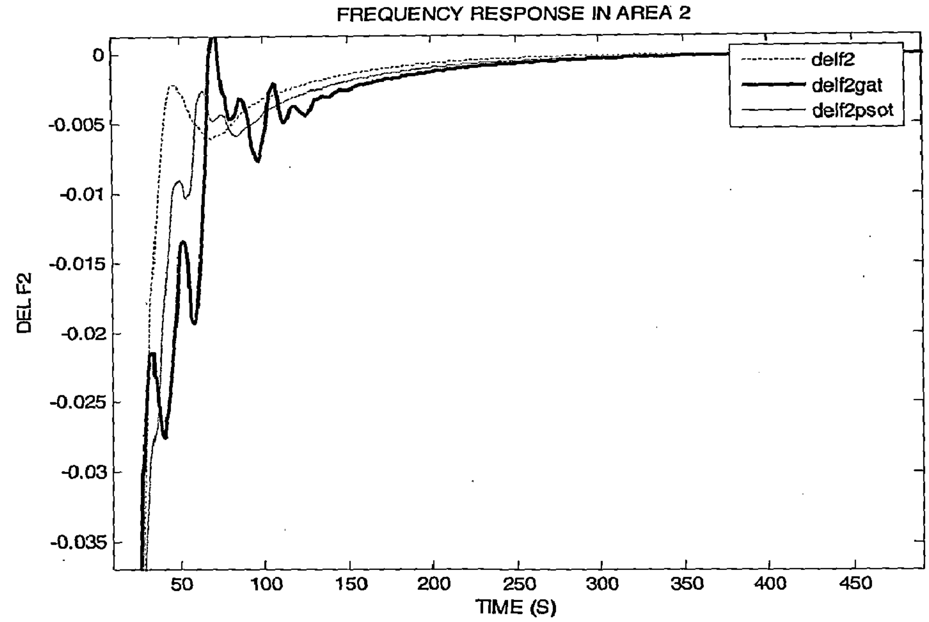


Figure 3.39 Frequency Response in area 2

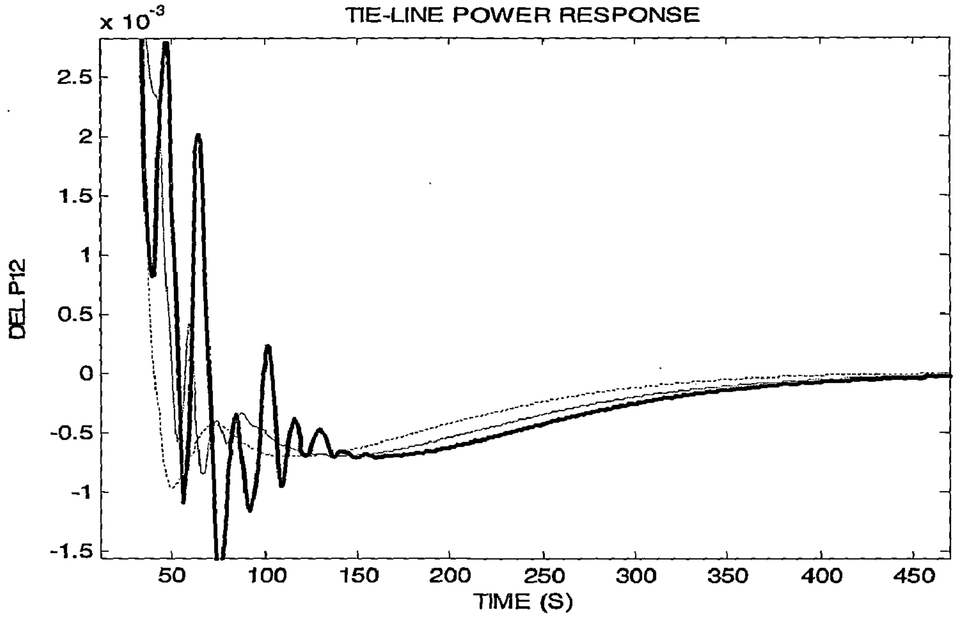


Figure 3.40 Tie line power Response

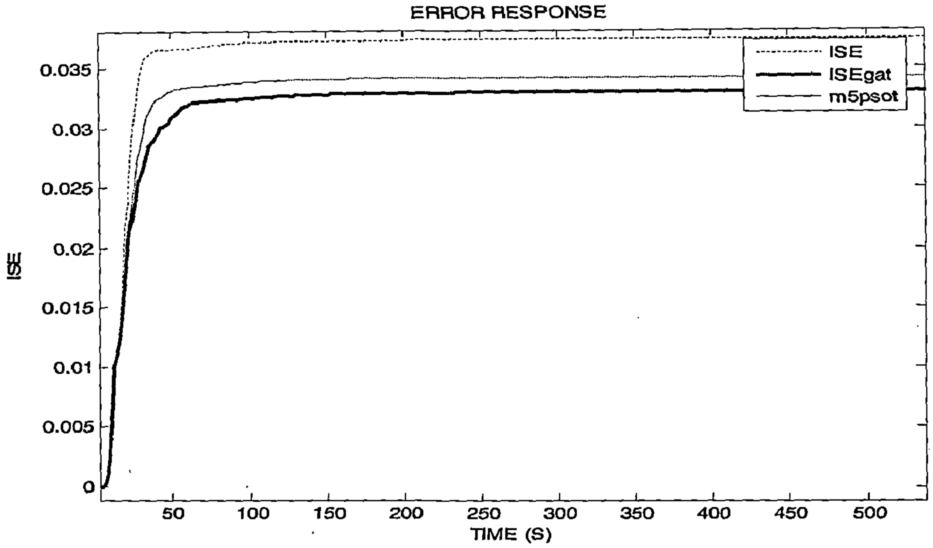


Figure 3.41 Error Response

3.6.2 Thermal-thermal system

The optimized controllers namely PSO tuned FLC and GA tuned FLC controllers have been tried out for AGC of a two area Hydro Thermal system. Which one provides better result for AGC? To answer this question, we have to compare the dynamic responses. *Figure3.41-3.*44 shows comparison of dynamic responses between modified FLC, PSO tuned FLC and GA tuned FLC considering 1% step perturbation in thermal area as well as in Hydro areas, for a sampling period of 2 sec and with R=2.4 in thermal area and 4.8 in hydro area. Analyses of these responses clearly reveal that GA tuned FLC provides better dynamic responses. Presence of modified FLC in both areas guarantees zero steady state error and this GA tuned FLC provides less peak overshoot as well as settling time is also less irrespective of the location of the perturbation in either area or in both areas.

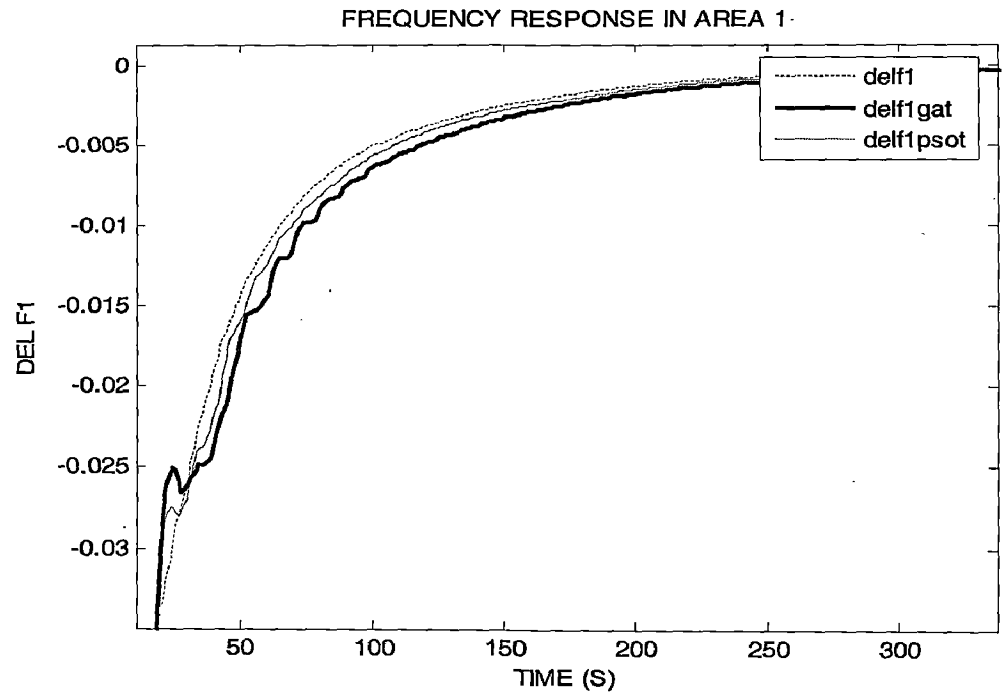


Figure 3.42 Frequency Response in Area 1

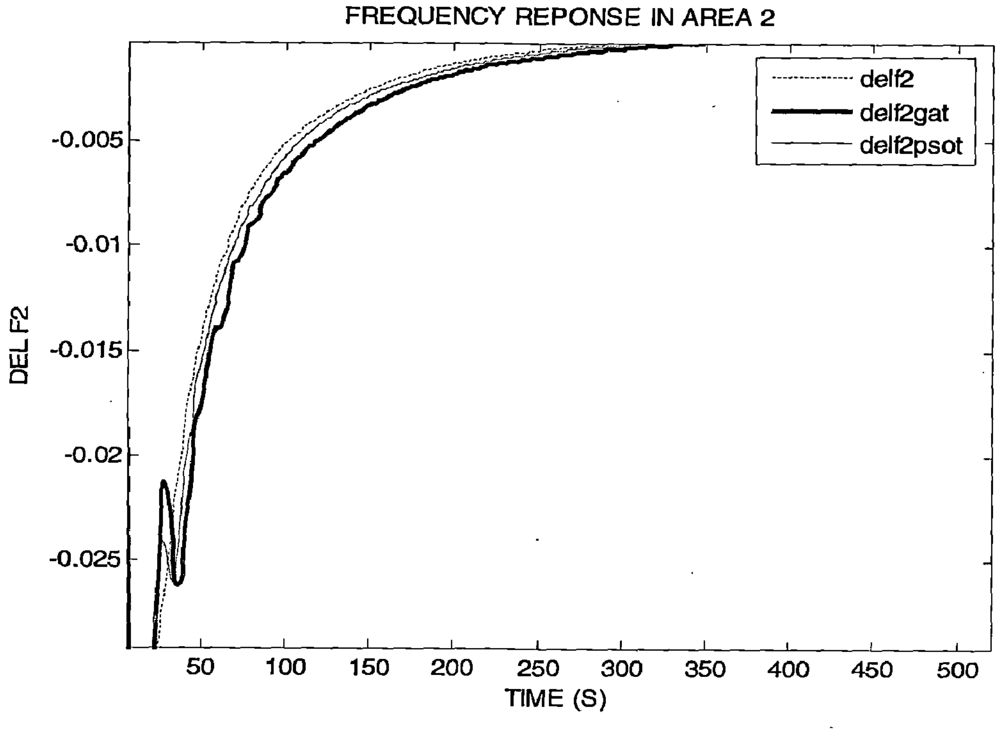


Figure 3.43 Frequency Response in area 1

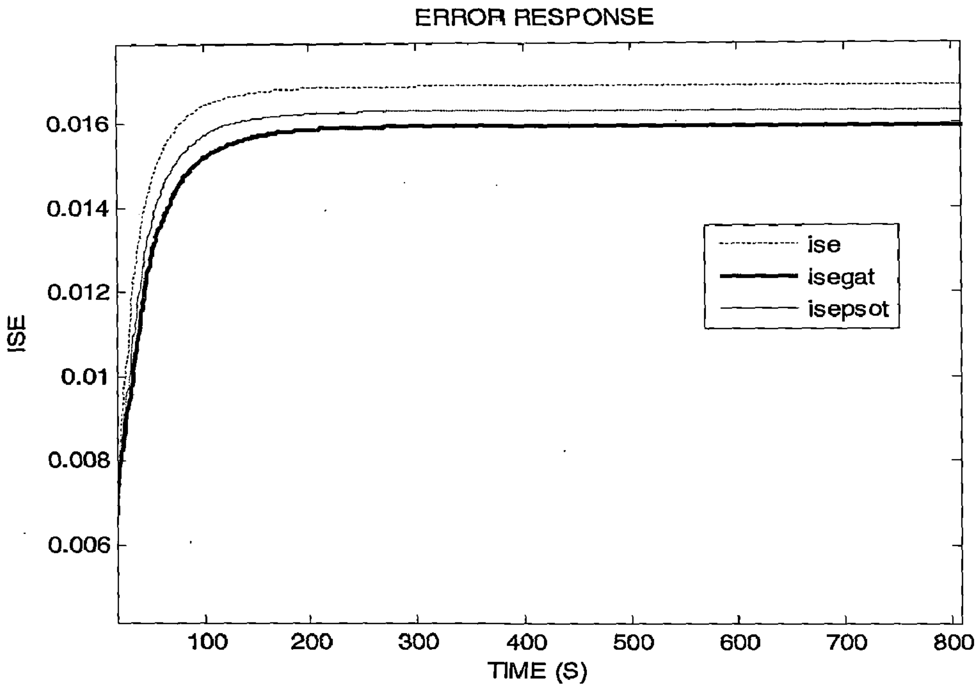


Figure 3.44 Error response

3.7 Conclusion

The following are the main conclusions

- The effect of tunable parameters of Fuzzy controllers present in both the areas of the two area system on the dynamic performance is observed.
- The membership function width tuning of the FLC is done with the help of Particle Swarm Optimization technique.
- Those optimal parameters are used in the system and observation from the Integral squared Error response of the PSO tuned Fuzzy controller compared with the FLC is shown better.
- The scaling factor tuning of the FLC is done with the help of Particle Swarm Optimization technique.

- The obtained optimal parameters are used in the system and observation from the Integral squared Error response of the PSO tuned Fuzzy controller compared with the FLC is shown better as per *Figures 3.18 and 3.22.*
- The membership function width tuning of the FLC is done with the help of Genetic Algorithm technique.
- Those optimal parameters are used in the system and observation from the Integral squared Error response of the GA tuned Fuzzy controller compared with the FLC is shown better as per *Figures 3.27 and 3.30.*
- The scaling factor tuning of the FLC is done with the help of Particle Swarm Optimization technique.
- The obtained optimal parameters are used in the system and observation from the Integral squared Error response of the PSO tuned Fuzzy controller compared with the FLC is shown better as per *Figures 3.33 and 3.37.*
- Finally the scaling factor tuning proves to be the better one for obtaining the best dynamic response
- The two optimally scaling factor tuned controllers (PSO tuned FLC and GA tuned FLC) are compared with their dynamic responses with normal FLC in *Figures from 3.38-3.44.*

  And

- It was finally proved that the GA optimized Fuzzy Logic Controller (where the parameter tuned is scaling factor) is giving better dynamic response even in case where load change occurred in both areas in two types of systems considered as per the *Figures 3.41 and 3.44.* CHAPTER 4

CHAPTER 4

AREA CAPACITY EFFECT IN A TWO AREA SYSTEM

4.1 Introduction

Most of the earlier researchers have considered the problem of AGC for a two equal interconnected areas. However, in a realistic situation, although a particular system can be represented by two control areas, their capacities in general will be unequal. There are situations when new control area of finite capacity may be interconnected to an already existing system of large capacity or a control area may be disconnected from the existing system. In such cases, it would be of practical significance to investigate the effect of capacity ratio of two systems on the selection of their optimum controller settings and on the dynamic response. Area capacity effect on the optimum integral control setting considering the system dynamic model in the continuous mode for a two area thermal-thermal system. However, to the best of our knowledge no work in the area capacity effect in hydrothermal system with intelligent tuned fuzzy logic controller has been attempted in the past

4.2 System Considered

Investigations are done on a two area reheat hydrothermal system with electric governor in the hydro area. The system investigated has the Intelligent tuned Fuzzy controllers (refer Figure 3.1) in both the areas. The p.u. values of the different parameters of the two areas are considered to remain same on their respective bases. In the block diagram representation for the two interconnected hydrothermal areas the block containing the transfer function a_{12} is defined as

$$a_{12} = -\frac{P_{r1}}{P_{r2}} \quad \dots\dots\dots\dots\dots\dots\dots\dots 4.1$$

Where

P_{r1} and P_{r2} are the rated megawatt capacities of the areas 1 and 2 respectively. The terms ΔP_{tie1} and ΔP_{tie2} as indicated below represent the change in tie line power flow outgoing from areas 1 and 2.

$$\Delta P_{tie2} = \frac{P_{r1}}{P_{r2}} \Delta P_{tie1} \quad \ldots\ldots\ldots\ldots\ldots\ldots 4.2$$

$$= a_{12}\, \Delta P_{tie1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.3$$

A step load perturbation of 1% of nominal loading has been taken in both the areas. Frequency bias setting B is chosen equal to the area frequency response characteristic .. A sampling period of T = 2 seconds has been chosen unless otherwise stated. All dynamic responses have been plotted using Matlab 7

4.3 Area Capacity Effect

It is intended to observe the effect of relative area capacity P_{r1}/P_{r2} on the optimum controller settings and the system dynamic response. To have such an analysis, first the rated capacity of the hydro area is kept constant at P_{r2}=2000 MW while the capacity of the thermal area is varied from 1000 MW to 4000 MW and hence a_{12} is varied from 0.5 to 2. Except the area capacities, the rest of the parameters for both the areas are expressed in per unit on their own area capacities and are considered to be the same for the hydro and thermal systems respectively as given in appendix. The responses of the intelligent tuned Fuzzy controller for different ratios of P_{r1}/P_{r2} are compared with the conventional controller and the fuzzy controller as described earlier. Similar study is done then by keeping the area capacity of thermal area constant while the area capacity of the hydro area is varied from 1000 MW to 4000 MW.

4.3.1 Effect of capacity change in Thermal Area

a. Effect of decrease in area capacity

Table 4.1 shows the variation of a_{12} with decrease in area capacity of thermal area. The capacity of hydro area is kept fixed at 2000 MW while the capacity of the thermal system is varied from 2000 MW to 1000 MW. Speed regulation parameter 'R' is chosen as 4% for both hydro and thermal areas with nominal capacity of 2000 MW. *Figures 4.1-42* show variation of frequency and tie flow with decrease in capacity of thermal area.

Table 4.1 a_{12} with decrease in thermal capacity

Pr1(Thermal)	2000	1500	1000
a12	-1	-0.75	-0.5

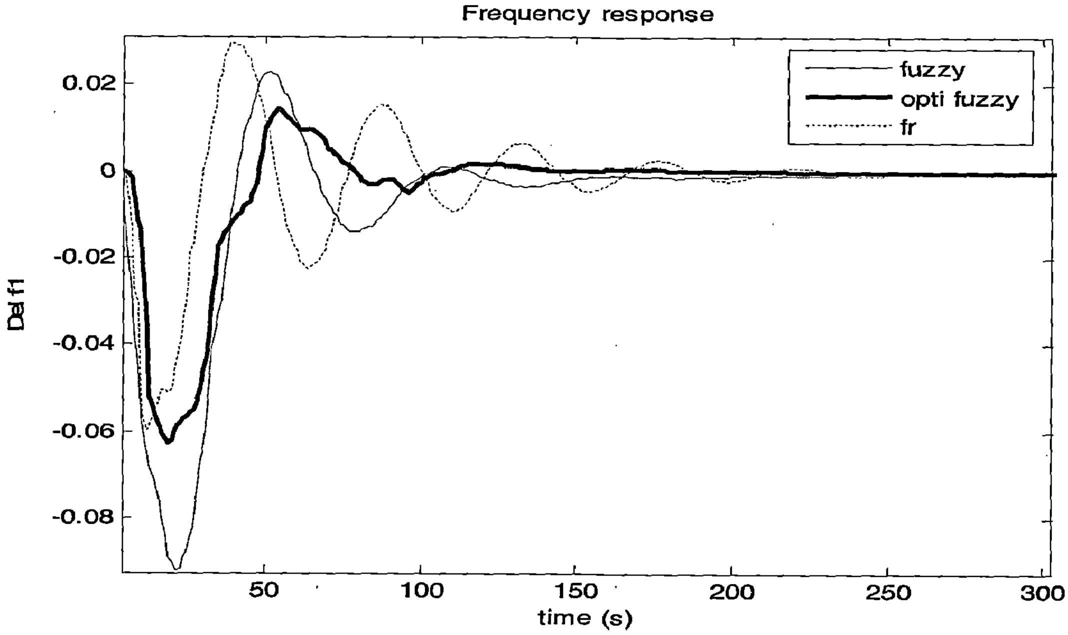


Figure 4.1 Δf_1 = f(t) *for thermal capacity 1000MW*

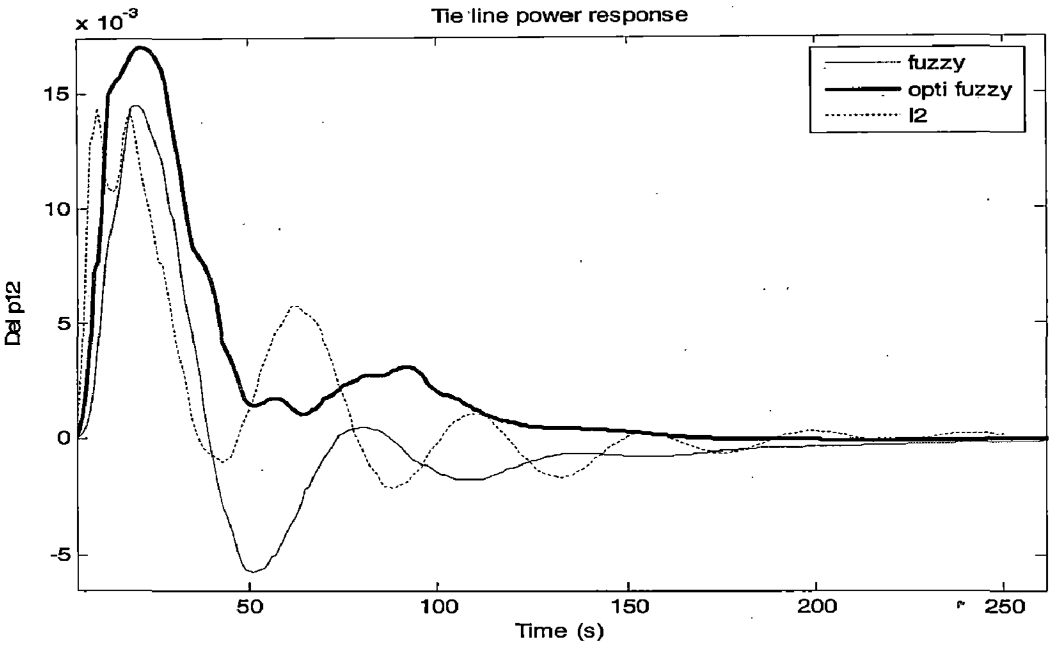


Figure 4.2 ΔP_{tie} = f(t) *for thermal capacity 1000 MW*

b. Effect of increase in area capacity

Table 4.2 shows the variation of a12 with increase in area capacity of thermal area. The capacity of hydro area is kept fixed at 2000 MW while the capacity of the thermal system is varied from 2000 MW to 4000 MW. Speed regulation parameter 'R' is chosen as 4% for both hydro and thermal areas with nominal capacity of 2000 MW. *Figures 4.3-4.4* show variation of frequency and tie flow with increase in capacity of thermal area.

Table 4.2 a_{12} *with increase in thermal capacity*

P_{r1}(Thermal)	2000	3000	4000
A12	1	1.5	2

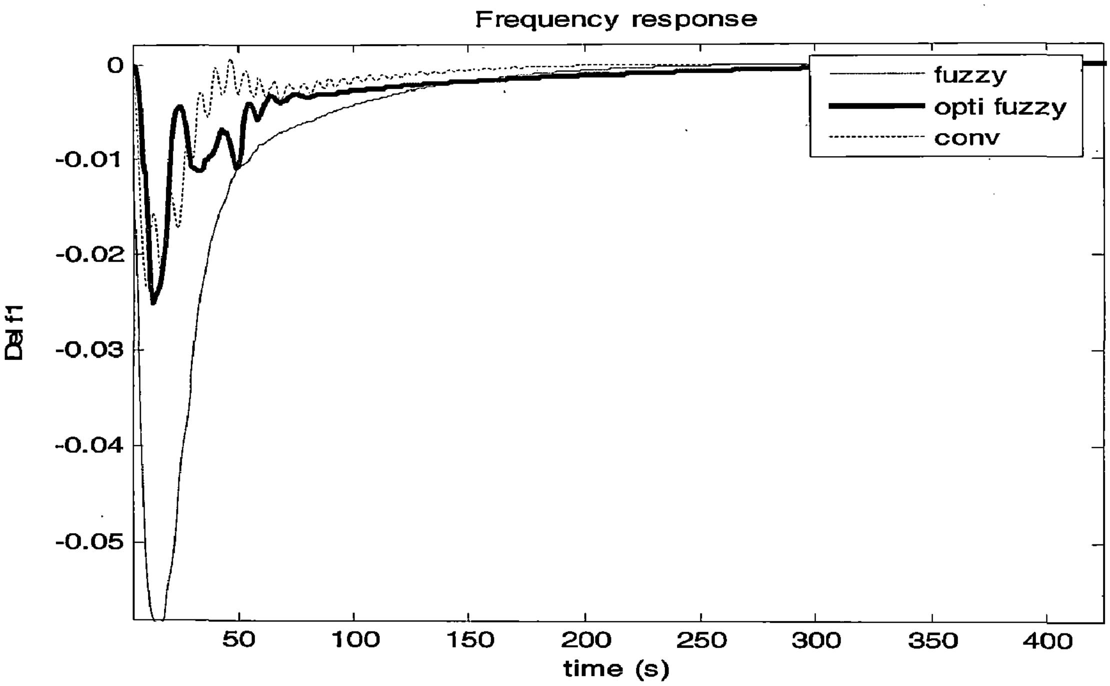


Figure 4.3 Δf_1 = f(t) *for thermal capacity 4000MW*

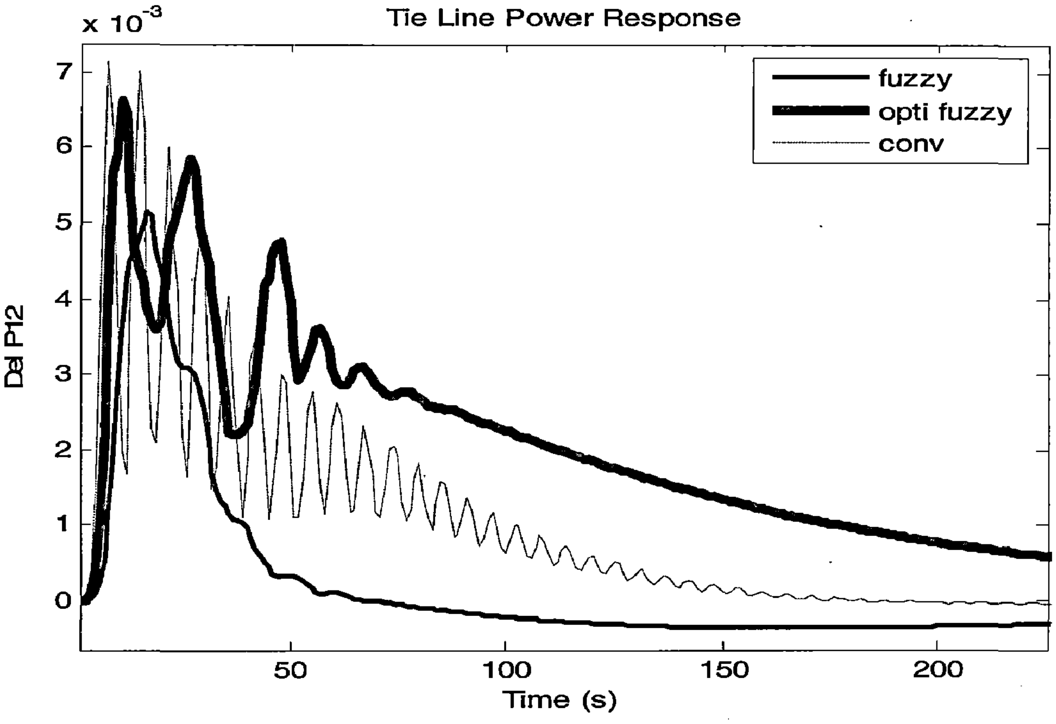


Figure 4.4 ΔP_{tie} = f(t) *for thermal capacity 4000MW*

4.3.2 Effect of change in area capacity in Hydro area

a. Effect of decrease in area capacity

Table 4.3 shows the variation of $a12_t$ with decrease in area capacity of hydro area. The capacity of thermal area is kept fixed at 2000 MW while the capacity of the hydro system is varied from 2000 MW to 1000 MW. Speed regulation parameter 'R' is chosen as 4% for both hydro and thermal areas. *Figures 4.5-4.10* show variation of frequency and tie flow with decrease in capacity of hydro area.

Table 4.3 a_{12} with decrease in hydro area capacity

P_{r2} (Hydro)	2000	1500	1000
a12	1	0.75	0.5

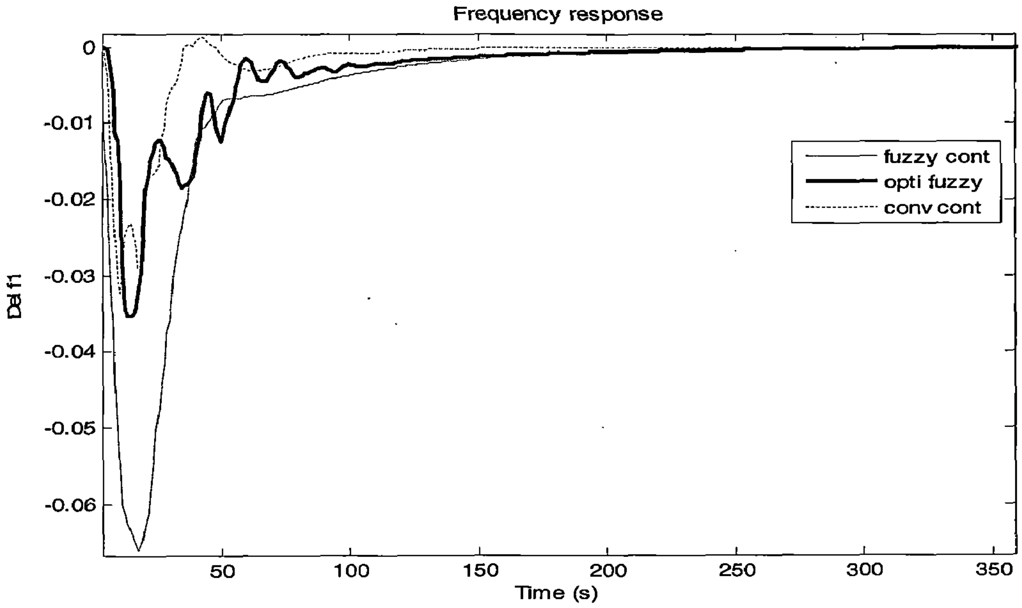


Figure 4.5 Δf_1 = f(t) *for hydro capacity 1500*

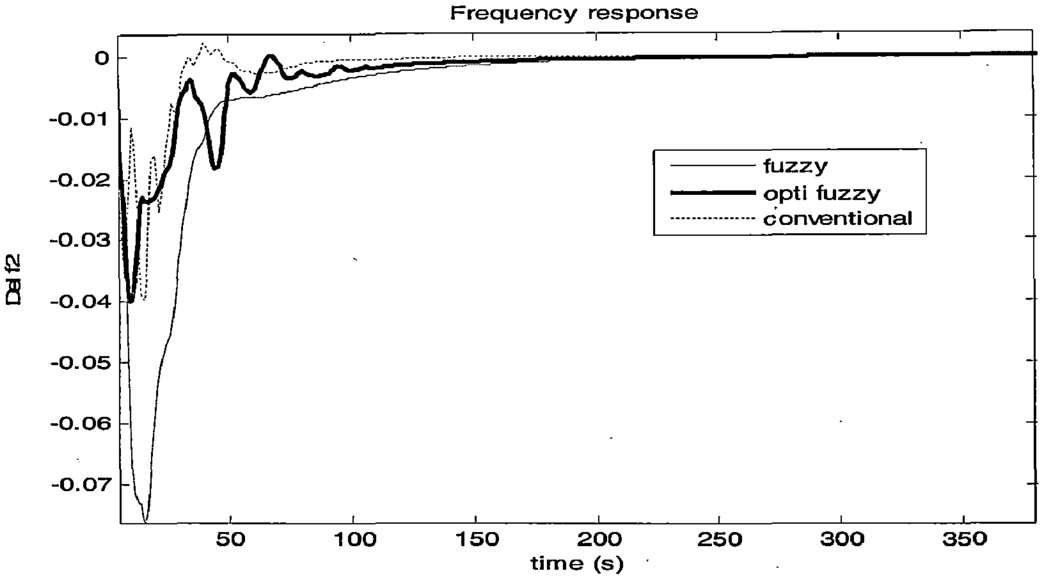


Figure 4.6 Δf_2 = f(t) *for hydro capacity 1500*

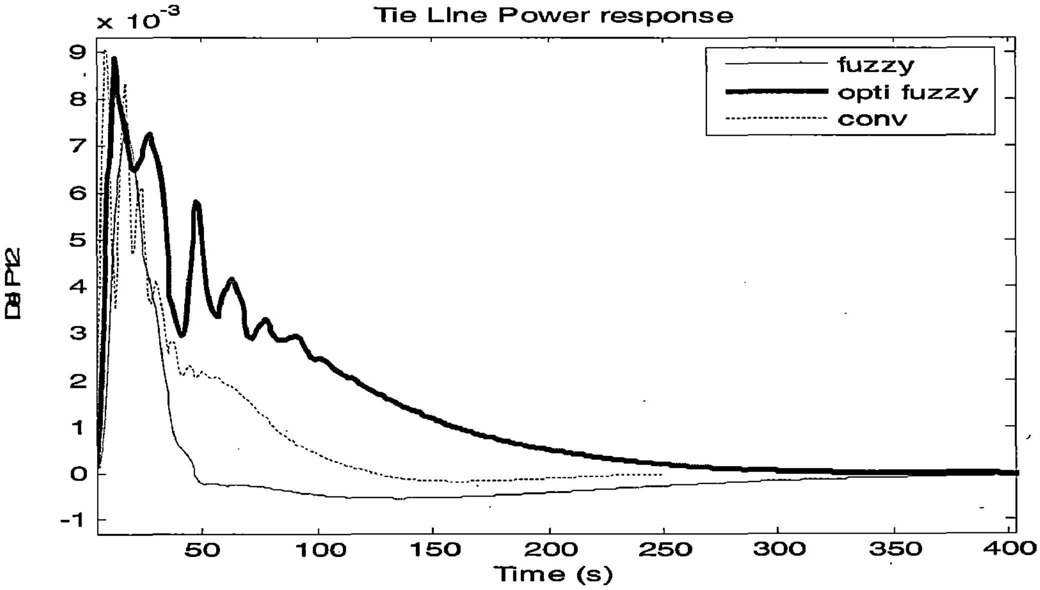


Figure 4.7 ΔP_{tie} = f(t) *for hydro capacity 1500*

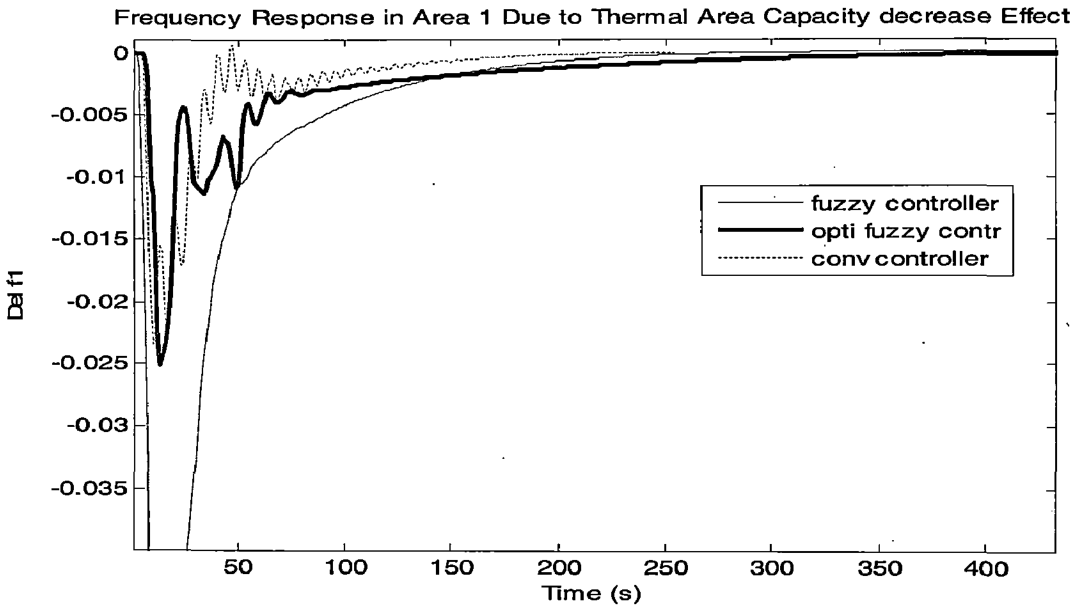


Figure 4.8 Δf_1 = f(t) *for hydro capacity 1000*

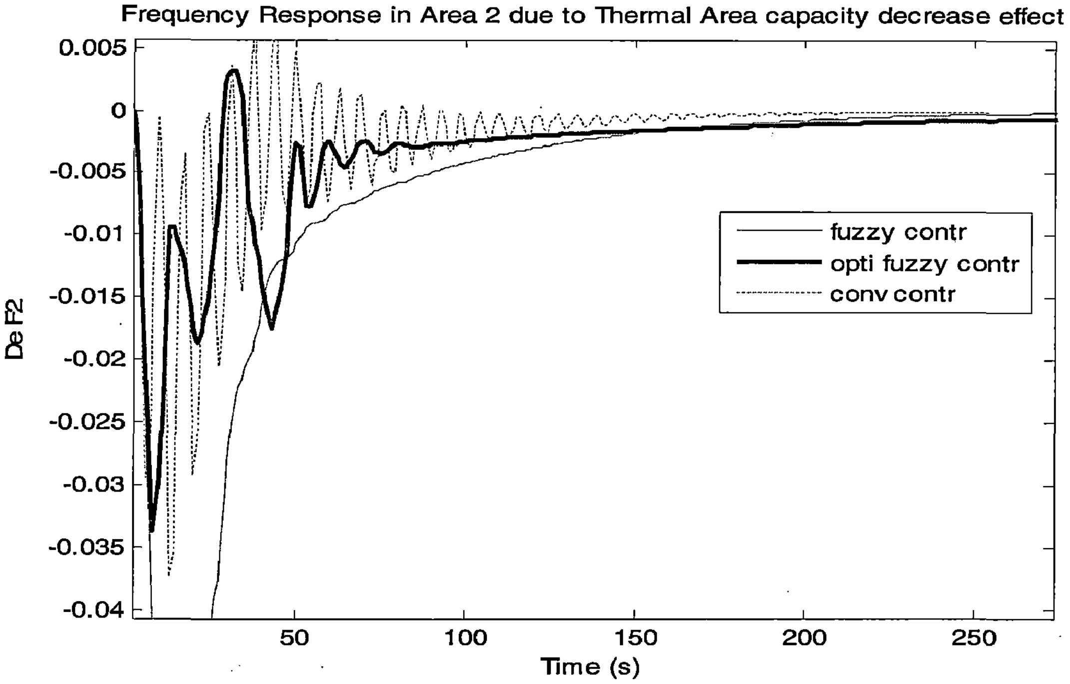


Figure 4.9 Δf_2 = f(t) *for hydro capacity 1000*

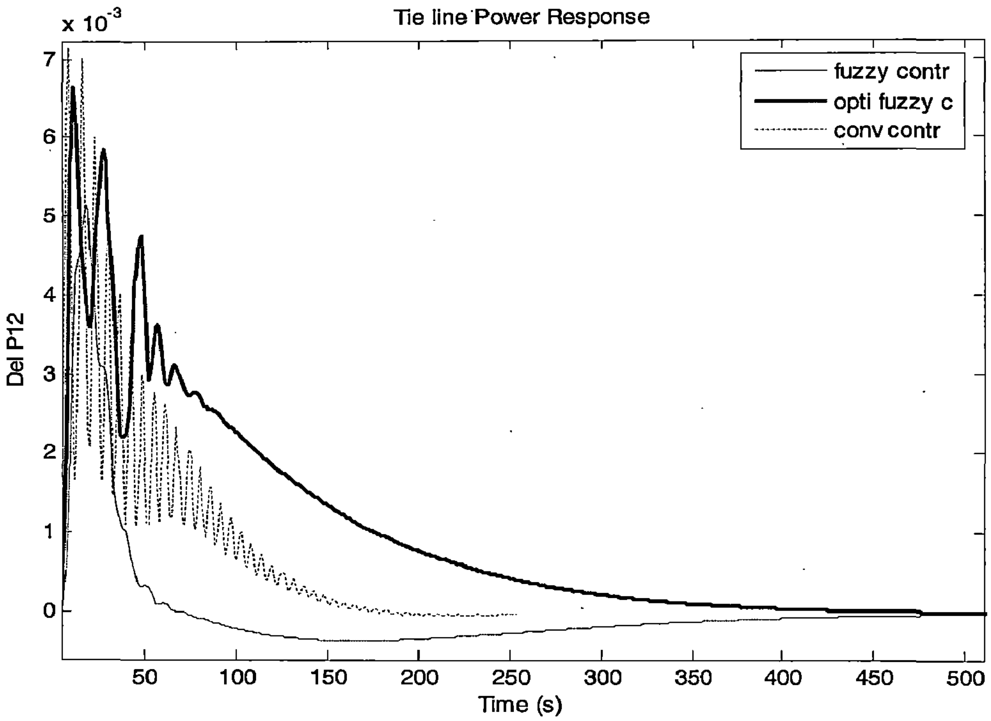


Figure 4.10 ΔP_{tie} = f(t) *for hydro capacity 1000*

b. Effect of increase in area capacity

Table 4.4 shows the variation of $a12_t$ with increase in area capacity of hydro area. The capacity of thermal area is kept fixed at 2000 MW while the capacity of the hydro system is varied from 2000 MW to 4000 MW. *Figures 4.11-4.13* show variation of frequency and tie flow with increase in capacity of hydro area. The settling time remains almost constant. However the peak deviation and the amplitude of oscillation increase with the increase in the capacity of the hydro system.

Table 4.4 a12 with increase in hydro area capacity

P_{r2} (Hydro)	2000	3000	4000
a12	1	1.5	2

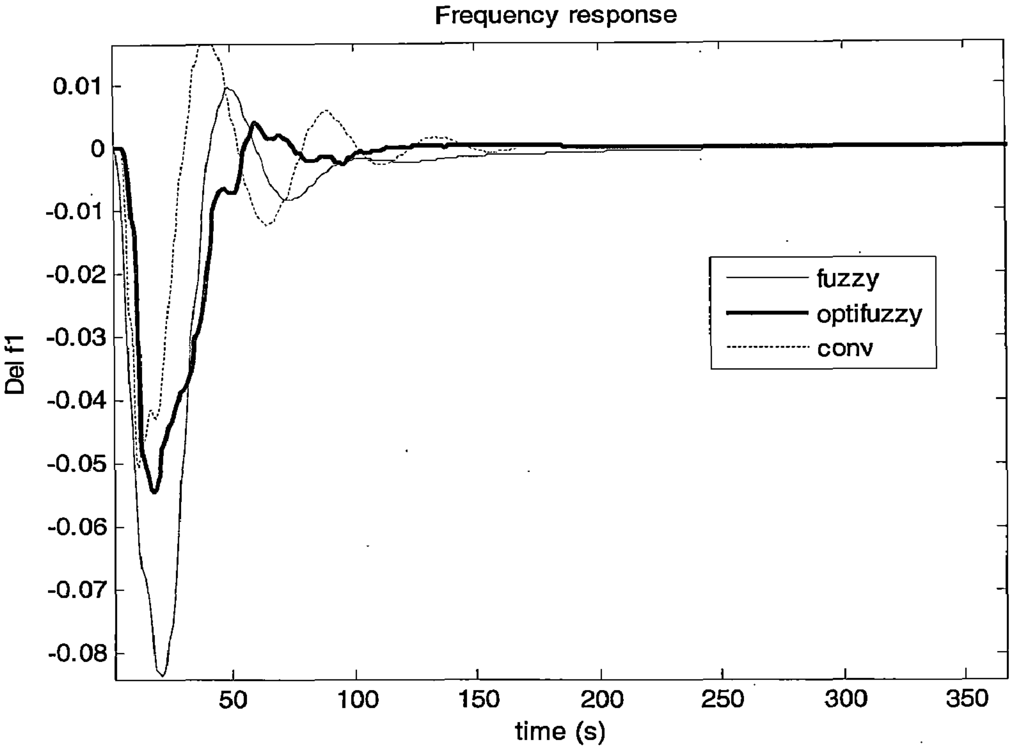


Figure 4.11 Δf_1 = f(t) *for hydro capacity 3000*

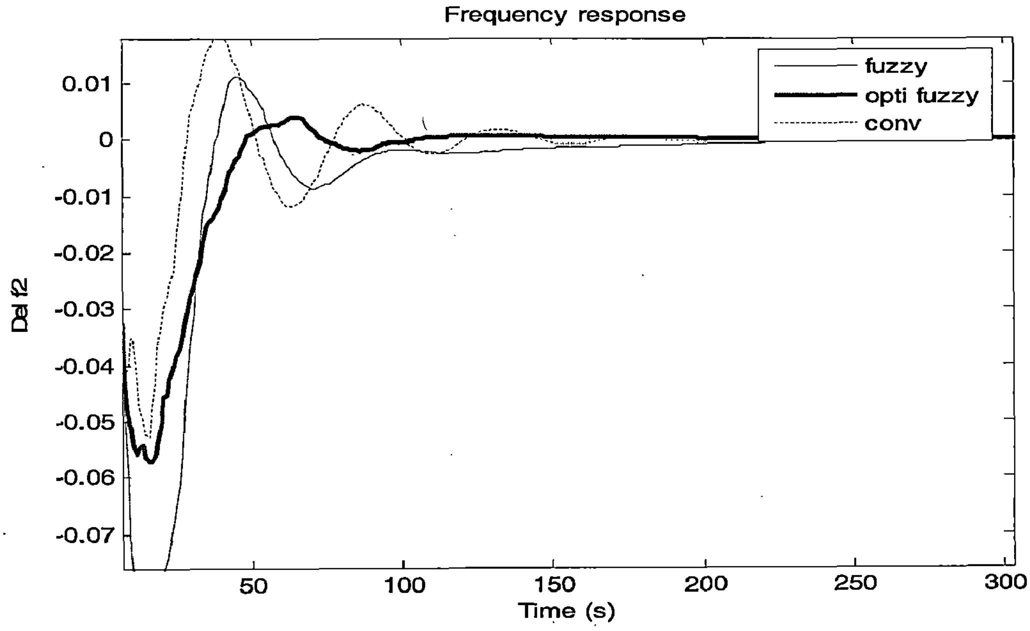


Figure 4.12 Δf_2 = f(t) *for of hydro capacity 3000*

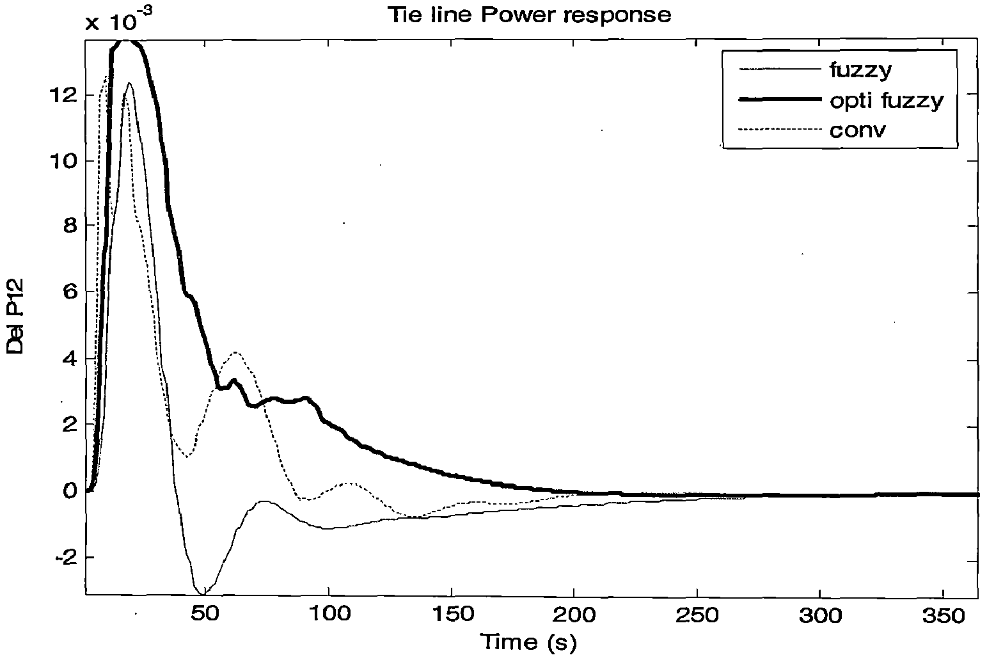


Figure 4.13 ΔP_{tie} = f(t) *for hydro capacity 3000*

4.4 Conclusion

The following are the main conclusions

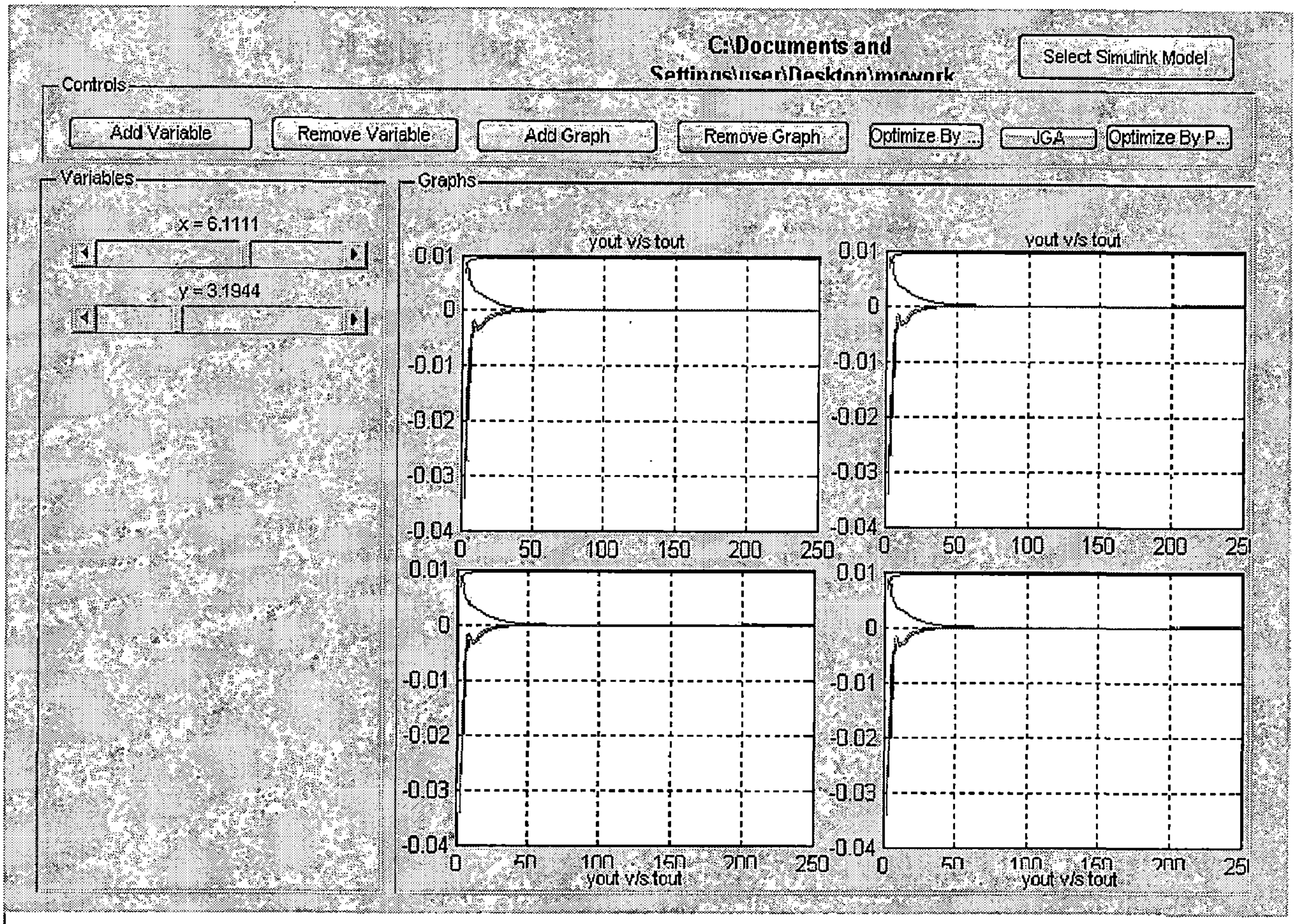
1. As the capacity of the area increases, the peak deviation and the amplitude of oscillation increases and settling time almost remains constant or decreases slightly.
2. As the capacity of the area increases, the speed regulation parameter 'R' of the hydro area needs to be increased to maintain system stability.
3. The optimally tuned FLC is responding better comparing with the FLC and conventional controller as per the *Figures 4.1-4.13.*
4. The optimally tuned FLC is well suited where the change in area capacity effect comes into picture.

CHAPTER 5

GUI IMPLEMENTATION, CONCLUSION AND FUTURE WORK

5.1 Graphical User Interface (GUI) application

All the MATLAB SIMULINK models and the MATLAB m file codes developed in the earlier chapters were interfaced with a GUI designed to show them on a single window. And also here with the help of GUI all the parameters selected can be dynamically controlled.



x = 6.1111

y = 3.1944

Figure 5.1 GUI developed in MATLAB7

5.2 Final Conclusion

- With conventional integral controllers present in both the areas, it is permissible to adopt a higher sampling period than a time period of 2 to 4 sec used in practice. Higher value of T will reduce wear and tear of sampler.
- With FLC like in conventional integral controller and in FLC, higher sampling period than the normally used in practice is permissible without deteriorating dynamic responses for all practical purposes.
- Presence of modified FLC in both areas and small step perturbation in either area or in both areas simultaneously provides better dynamic response than with FLC and conventional integral controller
- The effect of tunable parameters of Fuzzy controllers present in both the areas of the two area system on the dynamic performance is observed.
- The optimal membership function width parameters are used in the system and observation from the Integral squared Error response of the PSO tuned Fuzzy controller compared with the FLC is shown better.
- The optimal scaling parameters are used in the system and observation from the Integral squared Error response of the PSO tuned Fuzzy controller compared with the FLC is shown better.
- The optimal membership function width parameters are used in the system and observation from the Integral squared Error response of the GA tuned Fuzzy controller compared with the FLC is shown better.
- The optimal scaling parameters are used in the system and observation from the Integral squared Error response of the PSO tuned Fuzzy controller compared with the FLC is shown better.
- The two optimally scaling factor tuned controllers (PSO tuned FLC and GA tuned FLC) are compared with their dynamic responses with normal FLC

- It was finally proved that the GA optimized Fuzzy Logic Controller (where the parameter tuned is scaling factor) is giving better dynamic response even in case where load change occurred in both areas in two types of systems considered
- The optimally tuned FLC is responding better comparing with the FLC and conventional controller in the situation of change in area capacity effect.

5.3 Future work

With this work as the basis, the recommendations for future work are as follows:

1. Proper design of the Fuzzy Controller for two area system in a deregulated environment
2. Design of Artificial Neural Network Controller and Rough Controller for two area hydrothermal system.
3. ANN, FL and GA can be combined and can be used in AGC of a multi area system
4. Real Time Control and Hardware in the Loop implementation for AGC of any system.

APPENDIX

Nominal parameter of two area system investigated

$f = 60$ Hz

$T_g = 0.08$ sec

$T_r = 10.0$ sec

$H_1 = H_2 = 5$ sec

$P_{r1} = P_{r2} = 2000$ MW

$P_{tie,\ max} = 200$ MW

$K_r = 0.5$

$D_1 = D_2 = 8.33*10^{-3}$ p.u. MW/ Hz

$R_1 = R_2 = 2.4$ Hz/per unit MW

$T_t = 0.3$ sec

$K_p = 1.0$

$K_d = 4.0$

$K_i = 5.0$

$T_w = 1.0$ sec

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