Frequency Stabilization In An Interconnected Power System In Restructure Scenario

A Project Report

Submitted by

Mohanaprakash . T - 71205415003

in partial fulfillment for the award of the degree
of

Master of Engineering

in

Power Electronics and Drives

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

KUMARAGURU COLLEGE OF TECHNOLOGY

COIMBATORE – 641 006

ANNA UNIVERSITY: CHENNAI 600 025

JULY 2007

BONAFIDE CERTIFICATE

Certified that this project report entitled **"Frequency Stabilization In An Interconnected Power System In Restructure Scenario"** is the bonafide work of

Mohanaprakash. T - Register No. 71205415003

Who carried out the project work under my supervision.

Signature of the Head of the Department

Prof.K.Regupathy Subramanian

Signature of the Guide

Prof. Rani Thottungal

Certified that the candidate with university Register No: 71205415003 was examined in Project viva- voce examination held on 05.07.2007

Internal Examiner

External Examiner

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

KUMARAGURU COLLEGE OF TECHNOLOGY

COIMBATORE - 641 006

MAHENDRA ENGINEERING COLLEGE

FS68172

Mahendhirapuri, Mallasamudram (West), Vadugapalayam (P.O), Thiruchengode (Tk.), Namakkal Dist. - 637 503, Tamil Nadu, India.

CERTIFICATE

Second National Conference on Recent Trends in Electrical, Electronics, Instrumentation & Communication Engineering (RETEEICOM - 07)

9th March 2007

This is to certify that ~~*Ms.*~~ */ Mr. /* ~~*Dr.*~~ T. MOHANAPRAKASH, *of* KUMARAGURU COLLEGE OF TECHNOLOGY, COIMBATORE ~~*participated*~~ */ presented a paper titled* FREQUENCY STABILIZATION IN AN INTERCONNECTED POWER SYSTEM IN RESTRUCTURED SCENARIO *at RETEEICOM - 07 held on 9th March 2007, organized by the department of ECE, EEE and EIE.*

PRINCIPAL

ABSTRACT

When an interconnected power system is loaded/ unloaded, the system frequency is considerably disturbed and becomes oscillatory. The inter area oscillation due to large load and inter area oscillation due to small loads are suppressed by the help of Automatic Generation Control (AGC). In this project work Fuzzy Logic concept is proposed in place of conventional PI controller. A prototype Hardware for controlling inertia oscillation using Fuzzy Logic concept has been designed and tested.

A new controller is designed to regulate the tie-line power regulation through HVDC link in parallel with the existing AC-AC link for stabilizing the frequency oscillation of AC System. The technique of Overlapping Decomposition and Eigen value assignment is applied for the design of power modulation controller. The linear model of AC-DC link is developed and the system responses to various load changes are studied with the help of Mat-Lab simulation. The study shows that the proposed controller is not only effective in damping out the frequency oscillations but is also capable of eliminating the transient frequency swing caused by large load disturbance. Finally it is proved that the performance of Fuzzy logic Controller is better in comparison with PI Controller. The hardware has been tested successfully and the test result are compared to the simulation results.

முன்னுரை

இந்த செயல் முறை திட்டத்தின் மரபு வழி எ.ஜி.சி. (AGC)உடன் ∴பஷி லாஜிக் (Fuzzy logic) கட்டுபாடு செய்யுநர் சேர்த்து ஒரு புதிய கட்டுப்பாடு செய்யுநரை வெளி கொணர செய்துள்ளேன். இது ஒன்றோடு ஒன்று பின்னி இணைந்த மூன்று மின் உற்பத்தி நிலையங்களை கட்டுப்படுத்த வல்லது. இதை ஒரு மின் உற்பத்தி நிலையத்தை கட்டுபடுத்தும் வகையில் மைக்ரோகண்ட்ரோலரைக் கொண்டு அமலாக்கி உள்ளேன். இந்த புதிய கட்டுபாட்டு செய்யுநரின் பிரதி செயலை தொடர்நது கண்காணித்ததில் ∴ பஷி லாஜிக் கட்டுபாடு செய்யுநரானது நடைமுறை மரபு பி.ஐ (PI) கட்டுபாடு செய்யுநரை விட சிறந்தது என நிறுபனம் ஆகி உள்ளது.

எப்பொழுதெல்லாம் ஒரு மாறு திசை மின்நிலையத்தின் மீதான பளு மாறுபடுகிறதோ அப்பொழுதெல்லாம் அதன் அதிர்வெண் ஆனது மாறுபடுகிறது, முக்கியமாக இது ஒன்றோடுஒன்று பின்னி இணைந்த மின் நிலையங்களுக்கு பொருந்தும். இந்த செயல்முறை திட்டத்தில் டை லைன் (Tie line)மின்னாற்றல் பாய்ச்சலை உயர் மின் அழுத்த நேர்திசை மின்னோட்ட இணைப்பின் (HVDC Link) மூலம் நெறிப்படுத்த ஒரு புதிய கட்டுபாடு செய்யுநரை வெளி கொணர செய்துள்ளேன். இந்த புதிய உயர் மின் அழுத்த நேர் திசை மின்னோட்ட இணைப்பானது ஏற்கனவே உள்ள மாறுதிசை மின்னோட்ட இணைப்பிற்கு இணையாக செயல்பட்டு மாறுதிசை மின்னோட்டத்தின் அதிர்வெண் ஊசலாட்டத்தை நிலைப்படுத்துகிறது.

ஒரு மாறுதிசை மற்றும் நேர்திசை மின்னோட்ட இணைப்பின் உருமாதிரியை மேட் லேப் சிமுலேஷன் (MAT Lab Simulation) கொண்டு வெளிகொணர செய்து அதன் பிரதி செயலை கண்காணித்த பொழுது இந்த கட்டுபாடு செய்யுநரானது அதிர்வெண் ஊசலாட்டத்தை நிலைபடுத்துவதோடு மட்டுமின்றி, அது அதிக பழு இடையூறினால் ஏற்படுகிற அற்பாயுள் கொண்ட அதிர்வெண் ஊசலாட்டத்தை நீக்குகிறது என்பது தெளிவாக தெரிகிறது.

ACKNOWLEDGEMENT

The satisfaction and euphoria that accompanies the successful completion of any task would be incomplete without acknowledging the people who were responsible for the completion of the project.

I would like to sincerely thank **Prof. Rani Thottungal** Assistant Professor, Department of Electrical and Electronics Engineering, who spent her precious time. to guide us to complete our project successfully.

I express my sense of gratitude to **Prof.K.Regupathy Subramaniyan**, Head of the Department of Electrical and Electronics Engineering who gave his valuable suggestions to my project.

I would like to thank our honorable Principal **Dr.Joseph Thanikal** who had encouraged me in all moments.

I express my deepest gratitude to the management who gave their full support to our studies through out the curriculum.

I express my deep sense of gratitude to my parent's, friends, my Department staff members and all technical assistants without whom this project would have been virtually impossible.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

List of Symbols and Abbreviations

U	Defuzzified Value
P_m	Mechanical Power
P_e	Electrical Power
P_v	Value Position
ΔP_{tie}	Change in Tie line power
ΔF	Change in Frequency
P_{actual}	Actual Power
$P_{scheduled}$	Scheduled Power
F_{actual}	Actual Frequency
$F_{scheduled}$	Scheduled Frequency
Y	Transferred state vector
W	Transformation Matrix
X	State vector
α, β	Eigen Values
λ	Real Value
X_1, X2	State Variables
$\tilde{S}_1, \tilde{S}_2$	Decoupled systems
$M_{P(New}$	New Percent Overshoot
$\zeta_{(new)}$	New damping ratio
$\omega_{n(new)}$	New un-damped natural frequency
Δf	Changes in the frequency of the area
ΔP_{AC}	Change in AC tie-line power
AGC	Automatic Generation Control
HVDC	High Voltage Direct Current
PI controller	Proportional Integral Controller
LFC	Load Frequency Control
ACE	Area Control Error
NERC	North American Electrical Reliability Council
NE	Negative Very High
NM	Negative Medium

NS	Negative Small
ZE	Zero Position
PS	Positive Small
PM	Positive Medium
PV	Positive Very High
APF	Area Participation Factor
DPM	Disco Participation Matrix

CHAPTER I

INTRODUCTION

1.1. Introduction:

Constancy of system frequency and tie line loading must be maintained for satisfactory performance of transformers, electric clocks, auxiliary induction motor drives of generating units in generating stations and large ac drives of various industries in very large scale integrated system. The role of Automatic Generation Control (AGC) is to control the frequency to nominal value as the load changes continuously. AGC divides the load among the system to achieve maximum economy and accurate control of scheduled interchange of tie line power maintain a reasonably uniform frequency. [2], [4].

There are four methods available for the frequency control in the AC networks,(1) Manual control, (2) Flat frequency control, (3) Flat tie line regulation, (4) Parallel Frequency control. The first case used only in the small isolated generating stations only, for case two and three one station will act as a master station and control the frequency oscillation in the network and also for case two the tie line should also have enough capacity. In case four the frequency oscillation is adjusted simultaneously in all the system and also the swings are shared between all the stations. The HVDC link gives the superior parallel frequency control in the interconnected parallel AC network. In this project an embedded based hardware is developed for the Flat frequency control with fuzzy logic control and the simulation study is done for the parallel frequency control.

In order to avoid non-linearity's of power control strategy and to achieve better performance an integral controller is added to act on the load reference. PI controller is generally used. In PI controller all the parameters are optimized around an operating point. For certain condition the PI controller is not suited. The disadvantage of PI controller is that mathematical model of control process may not exist or may be too expensive in terms of control processing power and memory so a fuzzy controller is incorporated in the system.

Once the system behavior is thoroughly studied using PI controller, a fuzzy simulation is performed using Mat lab Simulink package. The results are compared. Finally concluding that fuzzy controller is fast in action and gives better performance.

.The classical Load Frequency Control (LFC) based on Area Control Error (ACE) is difficult to implement in a deregulated environment. An Alternative concept is thus introduced where selected units are automatically following load changes on the HVDC connection. In this anticipation of these circumstances advanced control strategies are in much need. Recent development of power electronics devices in AC power system provides attractive benefits: economical and innovation of new technologies. [1], [10].

When an AC power system is subjected to load disturbance, the system frequency may be considerably perturbed from the operating frequency. The deviation of frequency oscillation that exceeds the normal limit directly interrupts the operation of power system. The frequency oscillation may experience serious stability problems usually in the form of low frequency oscillation due to in-sufficient system damping.

The conventional LFC system is not very well suited to a deregulated energy market. HVDC connection will cause increased operational strain. An alternative secondary control system can be introduced in which special power station are selected to follow the HVDC load automatically while the rest of the system deviation are handled by conventional (LFC) method.

In this project the advantages of power modulation control by HVDC link to enhance the system damping is used which also extends to stabilize frequency oscillation in AC system. The proposed controller is also used in coordination with conventional governor control for greater efficiency.

1.2. Guide Lines of NERC:

The designed system satisfies the guidelines followed by North American utilities for load frequency control are developed by Operating committee of the North American Electrical Reliability Council (NERC).The following criteria specify the minimum control performance standards set by NERC.

1.2.1. Under Normal Conditions:

A1-criterion: The ACE must return to zero within 10 minutes of previously reaching zero. Violations of this criterion count for each subsequent 10 minute period that the ACE fails to return to zero.

A2-criterion: The average ACE for each of the six 10 minute periods during the hour must be within specific limits, referred to as Ld, that are determined from the control area's rate of change of demand characteristics $L_d = 5 + 0.025\ \Delta L$ MW

ΔL is the greatest hourly change in the net system load of a control area on the day of it's maximum summer or winter peak load.

1.2.2. Under Disturbance Conditions:

Sudden loss of generation or increase of load

B1-criterion: The ACE must return to zero within 10 minutes following the start of the disturbance.

B2-criterion: The ACE must start to return to zero with in 1 minute following the start of the disturbance.

1.3. OBJECTIVE OF THE PROJECT:

The quality of power means consistency of frequency, voltage and level of reliability. The main problem is balancing the total system generation against the system load and losses so that the desired frequency and power interchange (tie –line power flow) is maintained at economically and reliable as possible. Load frequency control (L.F.C) has gained importance with growth of interconnected system. Thus greater reliance is placed on the use of special control aids to enhance system security, facilitates economical design and provides greater flexibility of system operation. With deregulation of power system additional requirement for the operation of power system with high quality auxiliary have risen. In this anticipation of these circumstances advanced control strategies are much in need. Recent development of Power Electronic devices in AC power system provided attractive benefits of economically and innovation of new technologies.

A number of control strategies exist to achieve better performance. Due to non-linearity of power system, system parameters are linearized around an operating point. PI controller is generally used. The drawback of PI controller is that the mathematical model of the control process may not exist or may be too expensive in terms of computer processing powers and memory. A system based on empirical rules will be more effective. In PI control; much stress is laid on the precision of the input, the intermediate steps that process them and model of the system is questioned. Here a Fuzzy Controller is designed to damp the frequency oscillation in the AC power

When an AC power system is subjected to load disturbance, the system frequency may be considerably perturbed from the operating frequency. The deviation of frequency oscillation that exceeds the normal limit directly interrupts the operation of power system. The frequency oscillation may experience serious stability problem usually in the form of low frequency oscillation due to in-sufficient system damping. Hence an HVDC Link is installed in parallel with an AC tie –line in order to supply more power to the area in need. These enhance the system damping which also extend to stabilize frequency oscillation in AC system.

1.4. ORGANIZATION OF THESIS:

This report contains five chapters. The chapter 1 introduces the concept and tells the objective of the thesis. In the chapter 2 introduces the fuzzy logic concept. The fuzzy logic concept contains the details about Fuzzification, Inference, Defuzzification, and tuning and system enhancement. Its application in AGC of power system and the model is the simulated. Simulation of the fuzzy base controller results are compared with the simulation results of conventional PI. Different case studies for various loads are presented in this chapter. Chapter 3 talks about the fabrication of the prototype model and its testing process. Chapter 4 introduces the design of the HVDC link power modulation controller. The simulation results are analyzed. Chapter 5 is culmination of the thesis work.

CHAPTER II

SYSTEM DESIGN

2.1. Fuzzy Introduction:

Fuzzy controllers are used to control consumer products, such as washing machines, video cameras, and rice cookers, as well as industrial processes, such as cement kilns, underground trains, and robots. Fuzzy control is a control method based on fuzzy logic. Just as fuzzy logic can be described simply as ''computing with words rather than numbers''; fuzzy control can be described simply as ''control with sentences rather than equations'' .A fuzzy controller can include empirical rules, and that is especially useful in operator controlled plants. [13], [14].

Take for instance a typical fuzzy controller

1. If error is Neg and change in error is Neg then output is NB
2. If error is Neg and change in error is Zero then output is NM

The collection of rules is called a rule base. The rules are in the familiar if-then format, and formally the if-side is called the condition and the then-side is called the conclusion (more often, perhaps, the pair is called antecedent - consequent or premise – conclusion). The input value ''Neg'' is a linguistic *short* for the word negative, the output value ''NB'' stands for negative big and ''NM'' for negative medium. The computer is able to execute the rules and computes a control signal depending on the measured inputs error *and* change in error.

The objective here is to identify and explain the various design choices for engineers. In a rule based controller the control strategy is stored in a more or less natural language. The control strategy is isolated in a rule base opposed to an equation based description. A rule based controller is easy to understand and easy to maintain for a non-specialist end-user. An equivalent controller could be implemented using conventional techniques _ in fact, any rule based controller could be emulated in, say, Fortran it is just that it is convenient to isolate the control strategy in a rule base for operator controlled systems. The fuzzy controllers having the following advantages over the PI controller

1. Fuzzy logic is Simpler, and Faster
2. Fuzzy logic reduces the design development cycle
3. Fuzzy logic simplifies design complexity

5. Fuzzy logic is a better alternative solution to Non-Linear Control

6. Fuzzy logic improves control performance

7. Fuzzy logic simplifies implementation

8. Fuzzy logic reduces hardware costs

2.2. Fuzzy Logic Controller Design:

In place of PI controller it is proposed to introduce the fuzzy controller. The inputs to the fuzzy controller are the 'Δf' and 'ΔP_{tie}' of each area and the output is control signal 'U'. The algorithm for designing of a mamdani type fuzzy controller is as below.

Step 1: -First step is to take input and determine the degree to which they belong to each of the appropriate fuzzy sets in a membership function. The inputs are always a crisp numerical valve limited to the universe of discourse of the input variable and the output is a fuzzy degree of membership in the qualifying linguistic set.

Step 2: - Once the inputs have been fuzzified we know the degree to which each part of the antecedent has been satisfied for each rule. If the antecedent of a given rule has more than one part, the fuzzy operator is applied to obtain one number that represents the result of the antecedent for that rule. This number will then be applied to the output function. For the study 'AND' operator supported by 'Minimum' and 'Product' methods was applied. 'OR' operator supported by 'Maximum' and 'Probabilistic' method that is know as the algebraic sum was also applied while framing the rules.

Step 3: - Every rule has a weight (a number between 0 and 1) that is applied to the number given by the antecedent. Generally this weight is 1, so it has no effect at all on the implication process.

Step 4: -Aggregation is the process by which fuzzy sets that represents the output of each rule are combined into a single fuzzy set. The input of the aggregation process is the list of the truncated output function returned by the implication process for each rule. The three methods used for study are (a) Maximum, (b) Probabilistic and (c) Sum.

Step 5: -The final desired output each variable is generally a simple number. However the aggregate of a fuzzy set encompasses a range of output value, which is demethods are (a) Centroid, (b) Bisector (c) Middle of Maximum (d) Largest of maximum and (e) smallest of Maximum.

The mathematical equation for the memberships for a Mamdani Type Fuzzy Controller: The memberships used in this paper are shown below; membership for PV is defined as in equation (2.1) and figure 2.1.

$$s(x,\alpha,\beta,\gamma)=\begin{cases}1 & \text{For } X\le\alpha\\ 1-2\left(\dfrac{x-\alpha}{\gamma-\alpha}\right) & \text{For } \alpha\le X\le\beta\\ 2\left(\dfrac{x-\alpha}{\gamma-\alpha}\right)^2 & \text{For } \beta\le X\le\gamma\\ 0 & \text{For } X\rangle\gamma\end{cases} \tag{2.1}$$

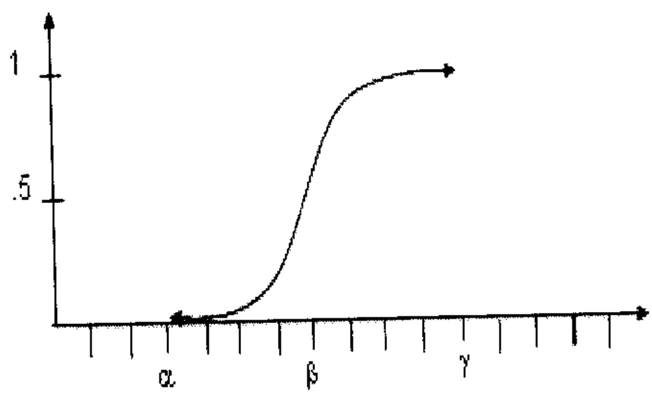


Fig. 2.1. Membership Used for PV

The membership for NV is defined as in equation (2.2) and figure 2.2.

$$s(x,\alpha,\beta,\gamma)=\begin{cases}1 & \text{For } X\le\alpha\\ 2\left(\dfrac{x-\alpha}{\gamma-\alpha}\right) & \text{For } \alpha\le X\le\beta\\ 1-2\left(\dfrac{x-\alpha}{\gamma-\alpha}\right)^2 & \text{For } \beta\le X\le\gamma\\ 0 & \text{For } X\rangle\gamma\end{cases} \tag{2.2}$$

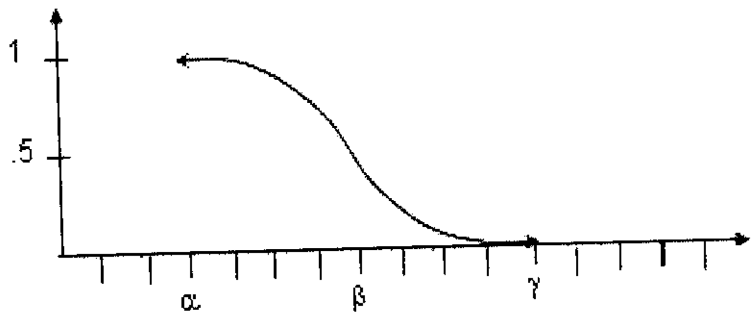


Fig. 2.2. Membership Used for NV

The membership for NM, NS, ZO, PS and PM are defined as in equation (2.3) and figure 2.3.

$$\wedge(U,\alpha,\beta,\gamma)=\begin{cases}1 & \text{For } U\le\alpha\\ \left(\dfrac{U-\alpha}{\beta-\alpha}\right) & \text{For } \alpha\le U\le\beta\\ \left(\dfrac{\alpha-U}{\beta-\gamma}\right)^2 & \text{For } \beta\le U\le\gamma\\ 0 & \text{For } U\rangle\gamma\end{cases} \qquad (2.3)$$

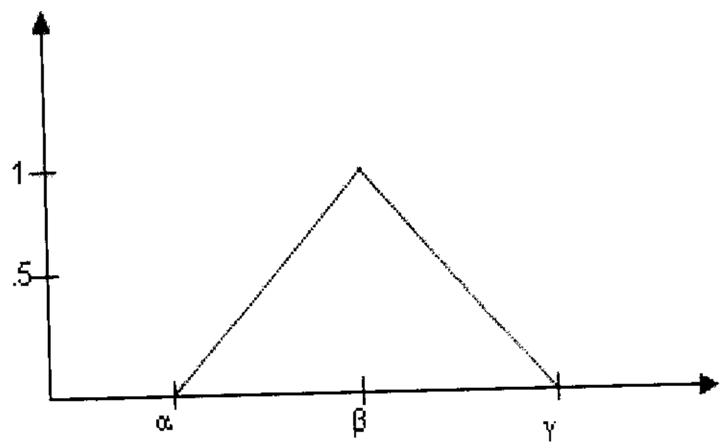


Fig. 2.3. Membership Used for NM, NS, ZE, PS, PM

Any two adjacent membership functions has a cross point level of 0.5 and cross point ratio of 1, this provides the significantly less overshoot, faster rise time and less [illegible] required both for discrete and continues domain.

Scale factor plays a role similar to the gain co-efficient in a conventional controller. They are utmost important with respect to controller performance and stability. The scaling factors are determined by (2.1) heuristic and (2.2) analytic. In this project Heuristic method is followed .It is found to have the best result for a value of 0.98. The purpose of Defuzzification is to obtain a scalar value from μ_u. This is done using Centroid method. It is given in equation (2.4).

$$U = \frac{\sum_{\mu_u} \mu_u(u)u}{\sum_{\mu_u} \mu_u(u)} \tag{2.4}$$

The fuzzy sets NV, NM, NL, ZO, PL, PM and PV are on the domain of [-0.5 0.5] for **Δf.** The fuzzy sets NV, NM, NL, ZO, PL, PM and PV are on the domain of [-0.75 0.75] for **ΔP_{tie}.** The fuzzy sets NV, NM, NL, ZO, PL, PM and PV are on the domain of [-1 1] for **Δu.** The rule base for the controller is given in the table 2.1. [5],[7].

TABLE 2.1. RULE BASE FOR FUZZY CONTROLLER

Change in Frequency ΔF	Change in tie line power ΔP_{tie}						
	NV	**NM**	**NS**	**ZE**	**PS**	**PM**	**PV**
NV	NV	NM	NS	ZE	PS	PM	PV
NM	NV	NM	NS	ZE	PS	PM	PV
NS	PV	NV	NM	NS	ZE	PS	PM
ZE	PM	PV	NV	NM	NS	ZE	PS
PS	PS	PM	PV	NV	NM	NS	ZE
PM	ZE	PS	PM	PV	NV	NM	NS
PV	NS	ZE	PS	PM	PV	NV	NM

2.3. Power System Design:

The first step in analysis and design of control system is Mathematical modeling of the system. The two most common methods are transfer function method and state variable approach. The state variable approach can be applied to portray linear as equations the system must first be linearised. Proper assumptions and approximations are made to linearise the mathematical equations describing the system and a transfer function model is obtained for the following components.

2.3.1. Generator Model:

Applying the swing equation of a synchronous machine we have

$$\frac{2H}{\omega_s}\left(\frac{d^2\Delta\delta}{dt^2}\right)=\Delta P_m-\Delta P_e \tag{2.5}$$

or in terms of small deviation in speed

$$\frac{2H\left(\frac{\omega}{\omega_s}\right)}{\omega_s}=\frac{1}{2H}\left(\Delta P_m-\Delta P_e\right) \tag{2.6}$$

With the speed expressed in per unit, without explicit per unit notation we have

$$\frac{D\Delta\omega}{dt}=\frac{1}{2H}\left(\Delta P_m-\Delta P_e\right) \tag{2.7}$$

Taking laplace transform of (2.7) we obtain

$$\Delta\Omega(s)=\frac{1}{2H_s}\left[\Delta P_m(s)-\Delta P_e(s)\right] \tag{2.8}$$

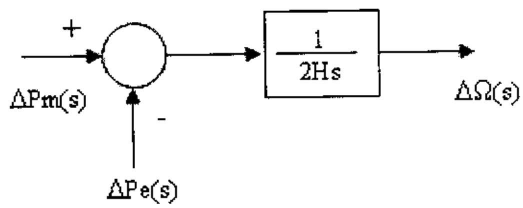


Fig.2.4. Mathematical Model of Generator

2.3.2. Load Model:

The load on a power system consists of a variety of electrical devices. For resistive loads, such as lighting and heating loads, the electrical power is independent of frequency. Motor loads are sensitive to changes in frequency. How sensitive it is to frequency depends on the composite of the speed – load characteristics of all the driven devices. The speed – load characteristics of a composite load is approximated by

$$\Delta P_e=\Delta P_L+D\Delta\omega \tag{2.9}$$

Where ΔPl is the non-frequency – sensitive load change and DΔw is the frequency change in frequency. For example if load is changed by 1.6 percent for a 1 percent change in frequency then D=1.6. Including the load model in the generator block diagram results in the block diagram as shown figure 2.5 eliminating the simple feedback loop results in block diagram as shown in figure 2.6

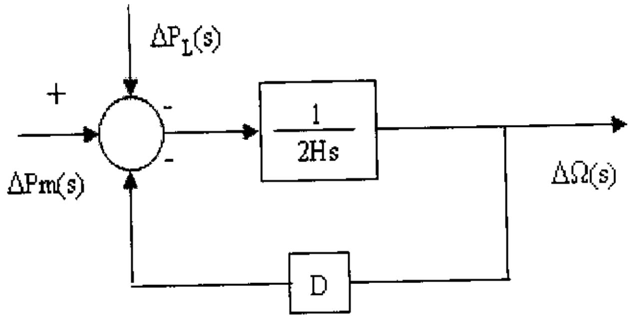


Fig.2.5. Mathematical Model of Load with Feedback

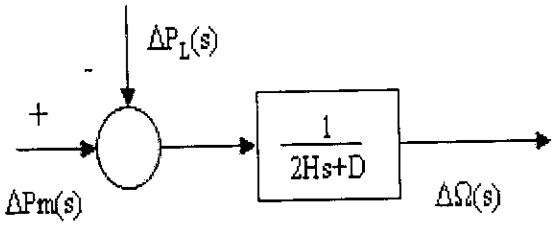


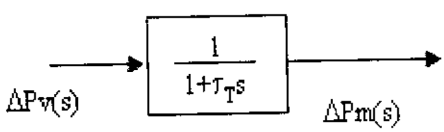
Fig.2.6. Mathematical Model of Load without Feedback

2.3.3. Prime mover Model:

The source of mechanical power, commonly known as the prime mover, may be hydraulic turbine at waterfalls, steam turbines whose energy comes from burning of coal, gas, nuclear fuel, and gas turbine. The Model for the turbine relates changes in mechanical power output ΔPm to changes in steam valve position ΔPv. Different types of turbines vary widely in characteristics. The simplest prime mover model for the non-reheat steam turbine can be approximated with a single time constant τ_T resulting in following transfer function

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{1+\tau s} \tag{2.10}$$

The block diagram for a simple turbine is shown in figure 2.7



The complete block diagram of the load frequency control of an isolated power system is shown in figure2.8 with the load.

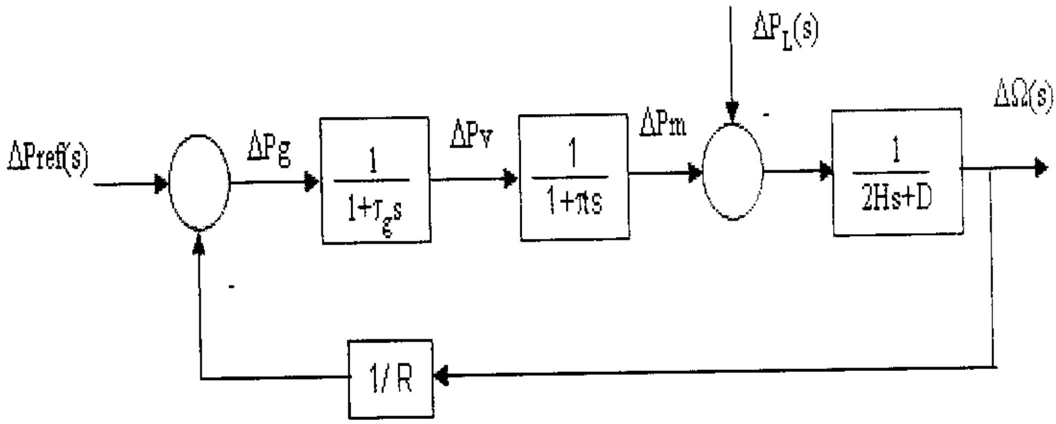


Fig.2.8.Load Frequency Control Block Diagram for an Isolated Power System.

2.4. Simulation Study of Three Area System:

The three area interconnected system is studied with the Matlab Simulation, the results shows that the performance of the Fuzzy controller is better than the PI Controller. The simulated system is shown in figure 2.7.[6].

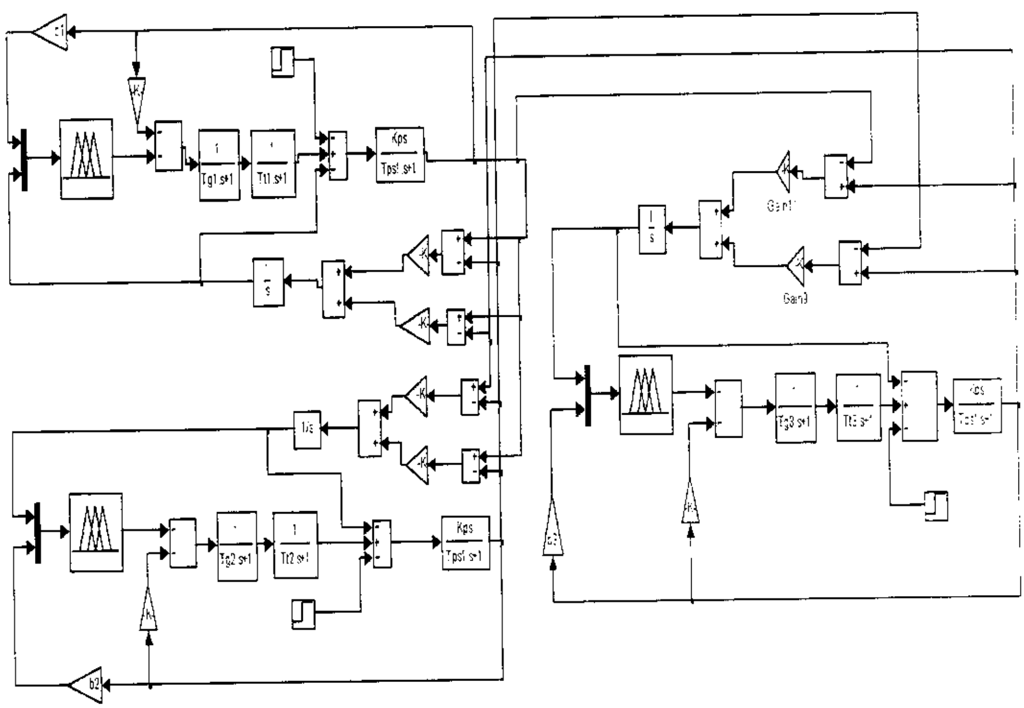


Fig. 2.9. Simulation Diagram of Three Area Interconnected Power

The above system is studied for the following 17 cases the results are shown in the figure 2.10.

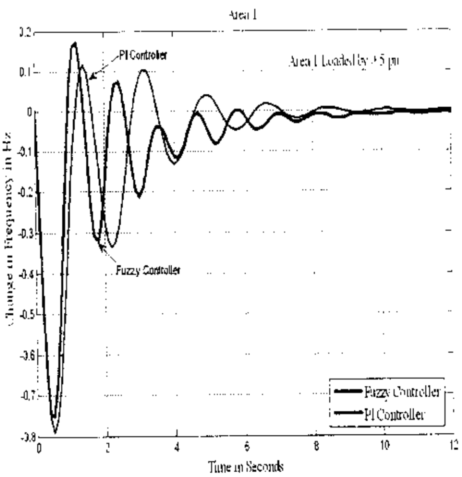


Fig.2.10. (a)

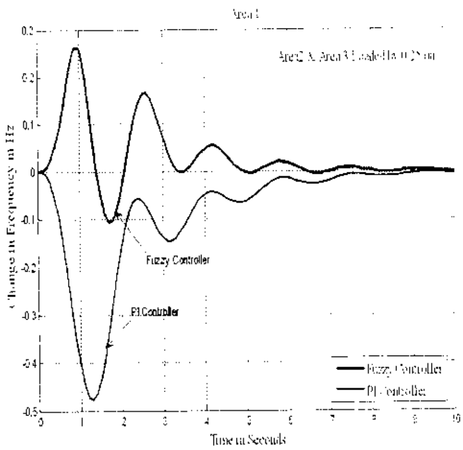


Fig.2.10. (d)

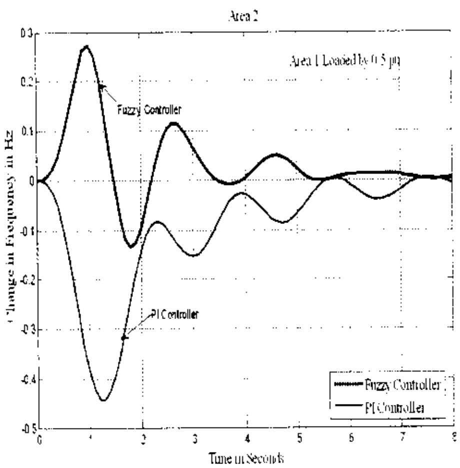


Fig.2.10. (b)

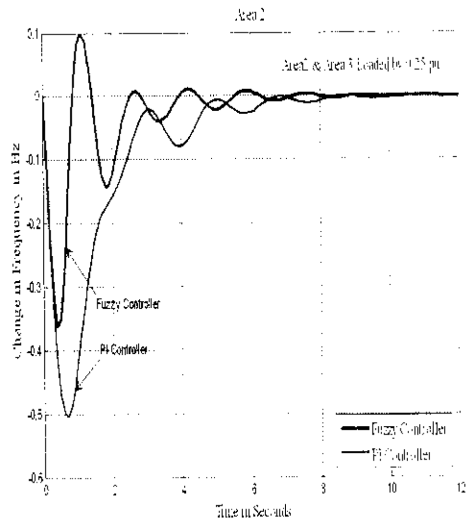
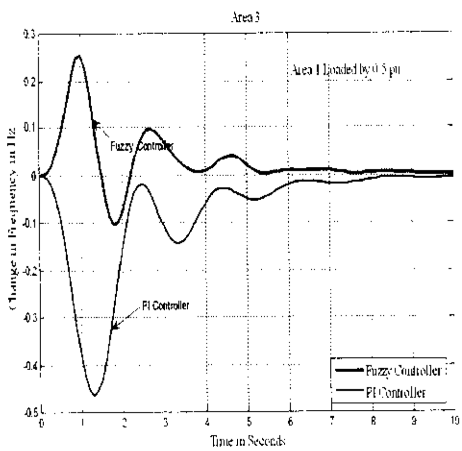
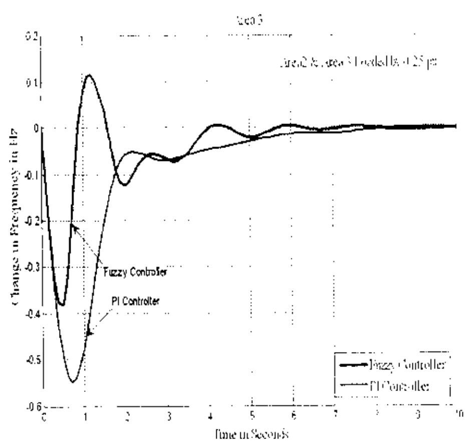


Fig.2.10. (e)





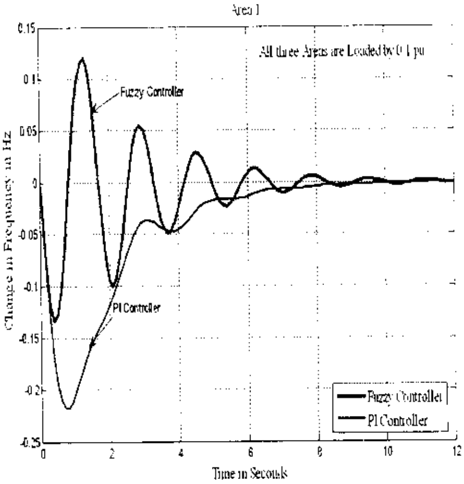


Fig.2.10(g)

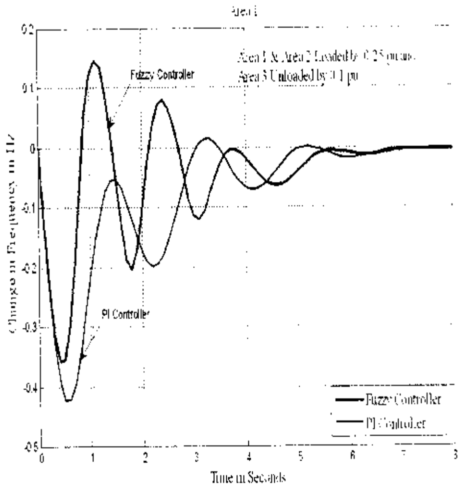


Fig.2.10(j)

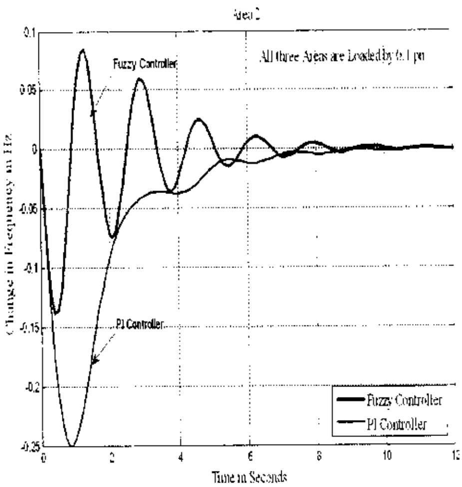


Fig.2.10(h)

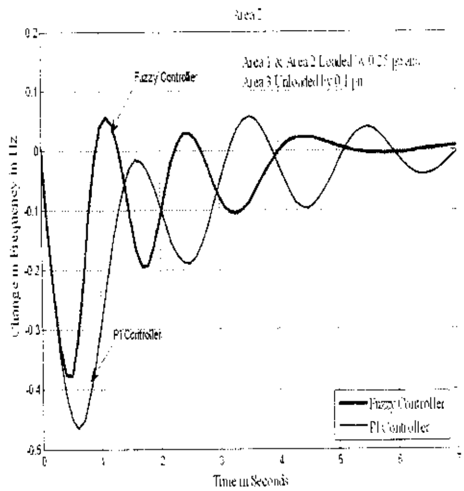


Fig.2.10(k)

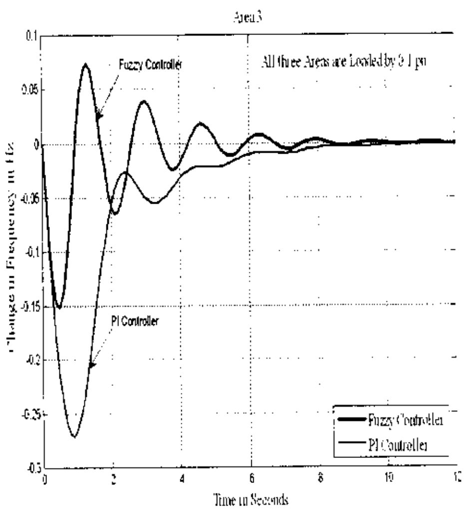


Fig.2.10(i)

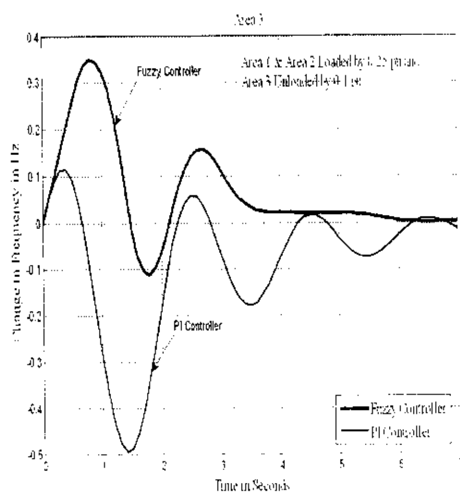


Fig.2.10(l)

Fig. 2.10 Simulation Results of Three Area Interconnected Power

2.5. Modification of Prime Mover:

The actual power system consists of Turbine and generator set for power production but the implementation of proto model it is not possible to get the turbine so here the Turbo Generator is changed into Motor Generator set for the implementation. For the simulation study the Dc shunt motor is modeled and the performance of the system is studied for various load condition and it is compared with the actual proto type model. The name plate detail of the motor which is modeled is given below [3].

KW-6.7 HP-5 Volts-230 Amps-19A

RPM-1500 Excitation 130 V / 0.7 A

The below tables shows the operating characteristics of the machine

TABLE.2.2. NO LOAD TEST DATA OF DC MOTOR

Field Current	Speed in RPM	Angular Speed in rad/sec
1.24	1164	121.832
1.10	1209	126.542
1.00	1249	130.728
0.90	1300	136.066
0.80	1363	142.660
0.70	1456	152.394
0.66	1500	157.000

TABLE.2.3. MOTOR FIELD IMPEDANCE

Field Voltage In Volts	Field Current in mA	Impedance in ohm
50	13.0	3846.154
70	15.0	4666.667
90	18.0	5000.000
110	20.5	5365.854
130	23.0	5652.174
150	25.0	6000.000
170	28.0	6071.429
190	30.5	6229.508
210	32.5	6461.538
230	35.0	6571.429
Average		**5586.475**

The Field resistance of motor = 165 ohm

The Field reactance $X_f = \sqrt{(Z_f^2 - R_f^2)}$ (2.11)

$X_f = 5584.037$ ohm

The Field Inductance $L_f = \dfrac{X_f}{2\pi f}$ (2.12)

$$L_f = 17.784 \text{ H}$$

The Field time Constant $T_f = \dfrac{L_f}{R_f}$ (2.13)

$$T_f = 0.1077$$

The Machine Constant is calculated from Field Current Vs Angular Speed characteristics, it is shown in figure 2.4. The machine time Constant

$$K_m = \frac{K_f}{R_f * B} \qquad (2.14)$$

$$K_f = K_a \frac{I_a}{I_f} \qquad (2.15)$$

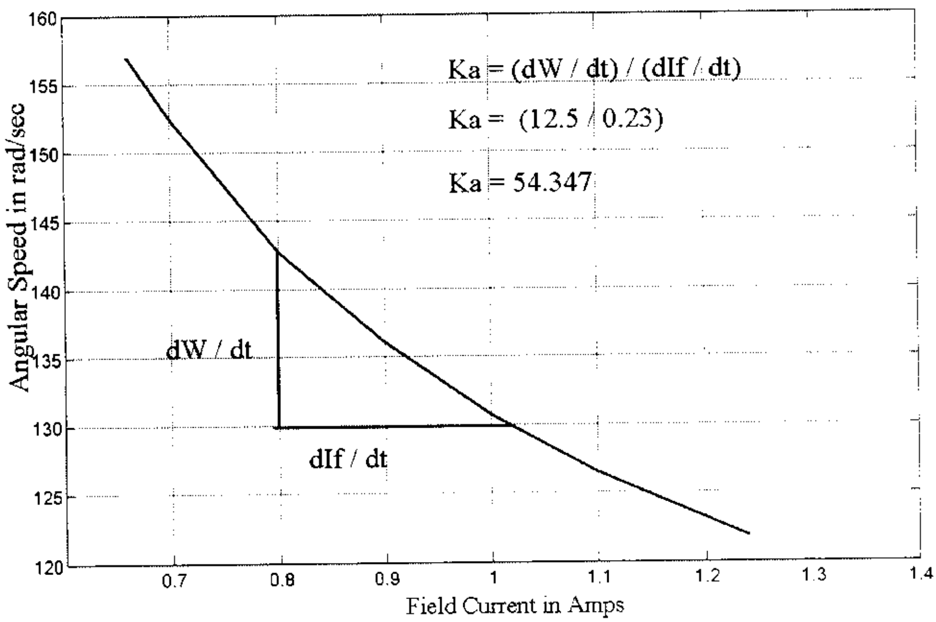


Fig. 2.11. Field Current Vs Angular Speed

Field Constant $K_f = 58.08$

The moment of inertia and spring constant are taken as unity

The machine constant Km = 0.352

The transfer Function of the Dc shunt motor for field control is given as

$$\frac{d\theta}{dV} = \frac{K_m}{S(1+ST)(1+ST)} \qquad (2.16)$$

$$\frac{d\theta}{dV} = \frac{0.352}{S\ (1+S)(1+0.1077S)} \tag{2.17}$$

2.6. Simulation Results of Proto Type Model:

The above transfer function is included in the Simulation instead of the Turbine and the steady state characteristic of the system was studied using Matlab. The System is shown in the figure 2.5. and the results are shown in figure 2.6.

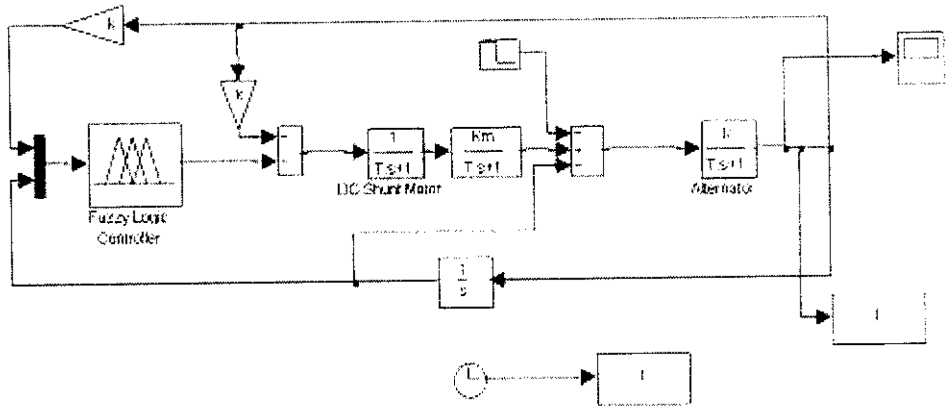


Fig. 2.12. Simulation Diagram of Proto Model

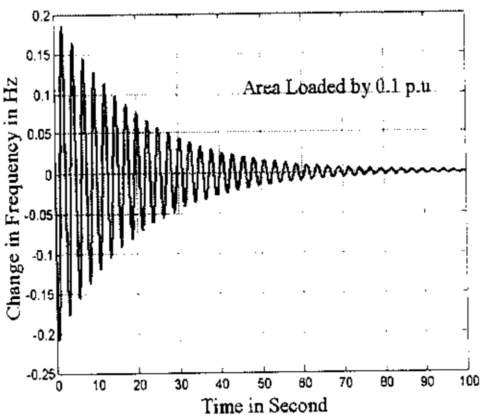


Fig. 2.13. (a)

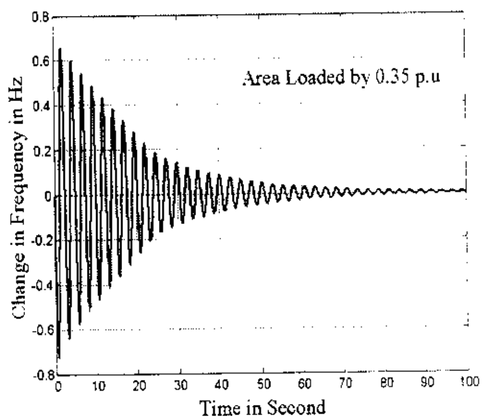
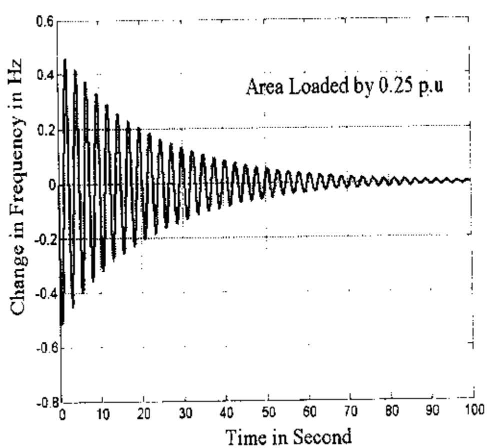
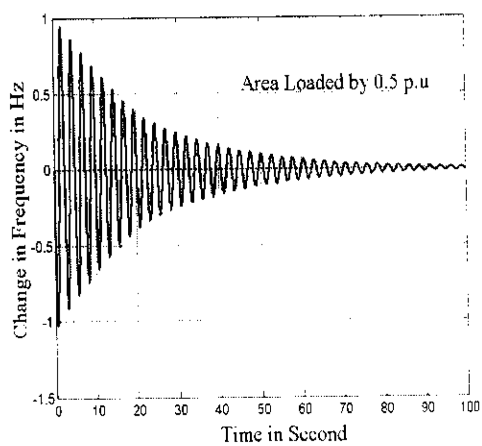


Fig. 2.13. (c)





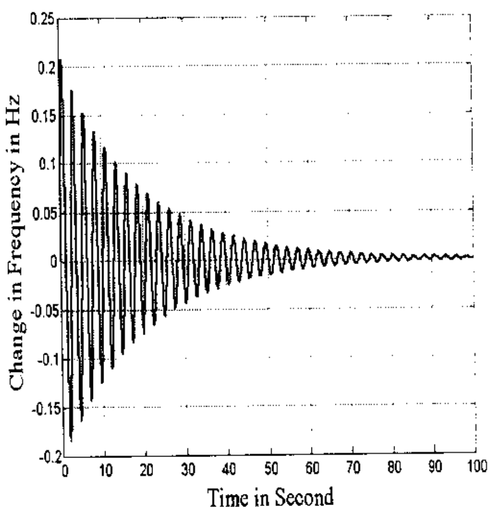


Fig. 2.13. (e)

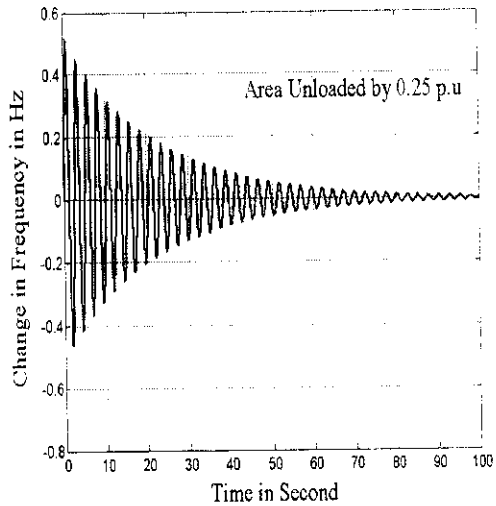


Fig. 2.13. (f)

Fig. 2.13. Simulation Result of Proto Model

2.7. Conclusion:

The computer simulation was performed for different load changes in different areas. This simulation results are compared. The results clearly indicate that the fuzzy controller minimizes the oscillation and settling time comparing to PI controller. The fuzzy logic approach to integral gain scheduling yields overall better performance regarding transient responses in comparison to the case of fixed integral gain.

Hence when fuzzy system is applied to appropriate problems in control systems, their typical characteristics show a faster and smother response than conventional system. These translate to efficient and more controllable operation for controlling various parameters in a plant. In fuzzy control system proposed rules are usually simpler, easier and often requiring fewer rules, thus the system execution is faster.

This fuzzy system often achieves tractability, robustness and overall cost effectiveness. Hence implementation of this technology in the area of power system leads to increase reliability and better quality of power supply to the consumers.

The fuzzy logic controller applies very simple and sophisticated methods, and the integral gain constants are adjusted to a value, which makes the system to operate in a very quick manner than that of conventional PI controller.

CHAPTER III

HARDWARE DESIGN

3.1. Introduction:

. The general block diagram of the hardware is shown in the figure 3.1. It consist of following units

Motor Alternator set

Variable load

Current, Voltage and Speed sensor units

Fuzzy Logic controller

Chopper

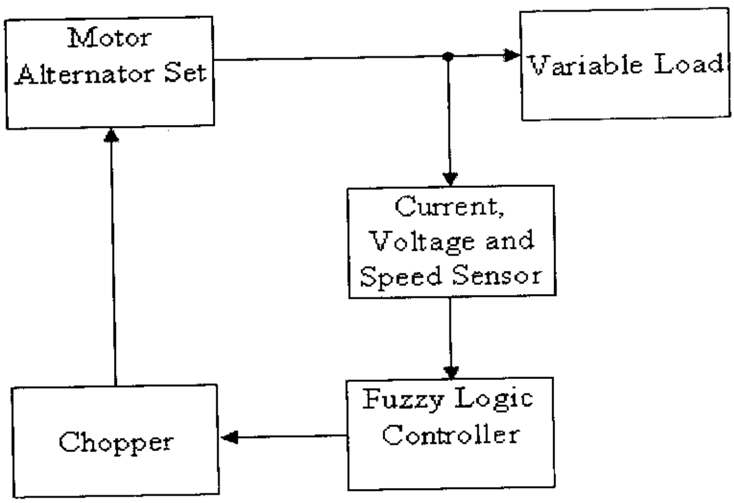


Fig.3.1. Generalized Block of Hardware

The Motor Alternator set is used instead of the Turbo Alternator for the proto type model. The power output of the alternator is increased by increasing the prime mover input of the alternator as like by increasing the turbine input in actual case. The speed of the prime mover is varied by varying the field current of the DC shunt motor. The variable load used here is three phase resistive load. The alternator is loaded for the different load condition by choosing the proper switch in the resistive load.

The load current is sensed with the help of the current transformer, generated voltage is sensed by using the potential transformer and the speed is sensed with the help of proximity sensor. These three parameters are given as input to the fuzzy controller. The Fuzzy Logic controller is designed with the help of microcontroller. The Fuzzy Controller is implemented in microcontroller in look up table format. This look up table is created based on the load test data of the motor alternator under chopper. The chopper is used to vary the voltage across the field of the DC motor; by varying the voltage of the field we can able to vary the speed of the motor.

3.2. Motor Alternator Set:

In this project Motor Alternator set is used instead of the Turbo Alternator. The hardware is done only for single area, to implement in multi area the ratted voltage of the alternator should be the same. There are five Alternators available in the laboratory, all the five where tested and there performance where analyzed and finally there is only one alternator suited for the experiment

3.2.1. Reason for Single Area:

The reason for implementing the hardware in the single Motor Alternator set is shown in table 3.1.

TABLE 3.1. ANALYSIS RESULT OF DIFFERENT ALTERNATORS IN THE LABORATORY

Bed No.	Prime mover Input (RPM)	Alternator Excitation	Problem Identified
DC5	1410	200V/1.9 A	Required Prime mover input is 1500 RPM
DC2	1500	110V/5A	Excitation current is more than load current and also the distance is so long.
DC15	1500	240V/1.1A	Both the Alternator has same ratted voltage but they withstand only the load of 80%
DC16(1)	1500	30V/1.5A	When started with ratted voltage of 220 V it goes beyond the ratted speed

The data sheet of the Alternator used for the hard ware implementation is shown in table 3.2

TABLE 3.2. DATASHEET OF MG SET

Motor	Alternator
KW-6.7	KW-3KVA
HP-5, Volts-230V	Volts-400V
Amps-19A	Amps- 4.3A
RPM-1500	RPM-1500
Excitation 130 V / 0.7 A	Excitation 115V / 0.75A

3.3. Fuzzy Controller:

The fuzzy controller is implemented in the PIC 16F877A using IF and THEN rules, the input to the fuzzy controller are change in power and the change in frequency. The change in power is calculated by using the scheduled power and actual power, change in frequency is the difference between the actual frequency and the scheduled frequency. The output of the fuzzy control is the ON time for the chopper.

$$\Delta P = P_{Actual} - P_{Scheduled} \quad (3.1)$$

$$\Delta F = F_{Actual} - F_{Scheduled} \quad (3.2)$$

The power is calculated by using the formula

$$Power = \sqrt{3} * V * I_L \quad (3.3)$$

$$Frequency = Speed / 30 \quad (3.4)$$

The $P_{Scheduled}$ is the valve of power when the relay is changed from normally closed position (NC) to normally opened position (NO) this value is fixed for the entire process. The actual power P_{Actual} is power at the particular instant, the difference of this power is given as one of the input to the fuzzy controller. The scheduled frequency is 50 Hz for the system, actual frequency is frequency at that moment, the difference between this two will be the change in frequency.

The fuzzy controller will decide the ON time of the chopper according to this input. The controller will produce the output based on the knowledge base table; the knowledge base table for this controller is shown in table 3.3.

TABLE.3.3. KNOWLEDGE BASE TABLE FOR FUZZY CONTROLLER

	NV		NM		NS		ZE		PS		PM		PV	
I_L	1.8		2.2		2.7		3.2		3.6		4.3		4.9	
P_L	1247.07		1524.20		1870.61		2217.03		2494.15		2979.13		3394.82	
Del P	-970		-742		-347		0		277		762		1178	
NV	1454		1478		1462		1428		1470		1474		1452	
	112	-1.6	108	-0.73	102	-1.27	104	-2.4	93.2	-1	90	-0.87	90	-1.6
NM	1480		1488		1478		1454		1480		1484		1464	
	108	-0.67	104	-0.4	100	-0.73	100	-1.53	90	-0.67	90	-0.53	82	-1.2
NS	1486		1494		1492		1498		1494		1494		1478	
	106	-0.47	103	-0.27	99	-0.27	96	-0.07	88	-0.2	88	-0.2	82	-0.73
ZE	1500		1500		1500		1500		1500		1500		1500	
	104	0	102	0	98	0	93.2	0	90	0	88	0	88	0
PS	1512		1504		1516		1508		1504		1506		1502	
	102	0.4	101	0.13	94	0.53	94	0.27	86	0.13	86	0.2	70	0.07
PM	1522		1568		1544		1524		1512		1522		1516	
	98	0.73	96	2.27	90	1.47	92	0.8	88	0.4	84	0.73	78	0.53
PV	1552		1588		1568		1550		1528		1538		1528	
	94	1.73	90	2.93	86	2.27	88	1.67	82	0.93	80	1.27	82	0.93

SPEED in RPM

3.4. Fuzzy Controller Table Interpretation:

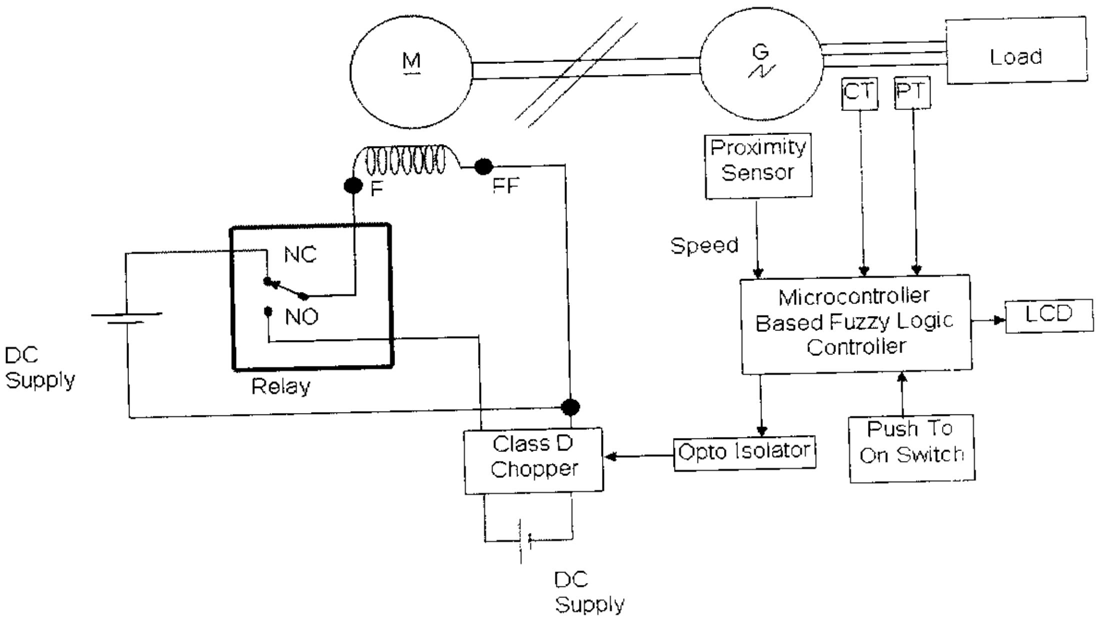
The above Fuzzy Controller table is minimized into a single membership for the interpretation as shown in table3.4

TABLE 3.4. SIMPLIFIED FUZZY TABLE		
	NV	
I_L	1.2	
P_L	1247.07	
Del P	-950	
NV	1454	
	112	-1.6

The above table shows that when the alternator is loaded for 1.2 Amps the power generated will be 1247.07 Watts, so the change in power ΔP will be -950 Watts. The speed will reduced to 1454 rpm so the frequency is reduced to 48.466 Hz. It gives the change in frequency Δf equal to -1.6 Hz, the field voltage of the DC shunt motor at this moment will be 112 V. Now the change in frequency is negative value so to make the change in frequency to zero the voltage across the field is reduced to 104 V as shown in the above table in ZE condition.

3.5. Fabrication:

The detailed block diagram of hardware implementation is shown in figure 3.2.



. The devices used in the circuit are given below.

MOSFET – IRF 840

Feedback Diode – 1N5408

Opto Isolators 4N25

Microcontroller – PIC 16F877A

Speed Sensor – Metal Proximity Sensor

Snubber – RC Snubber

Current Transformer

Potential transformer

3.5.1. Microcontroller:

The controller used in this project is PIC 16F877A , it is a 40 IC with DIP package, the Pin diagram of controller is shown in figure 3.3., it has the following features

Haward Architecture

Single Word Instructions

Instruction Pipeline

Single Cycle Instruction

Reduced Instruction Set

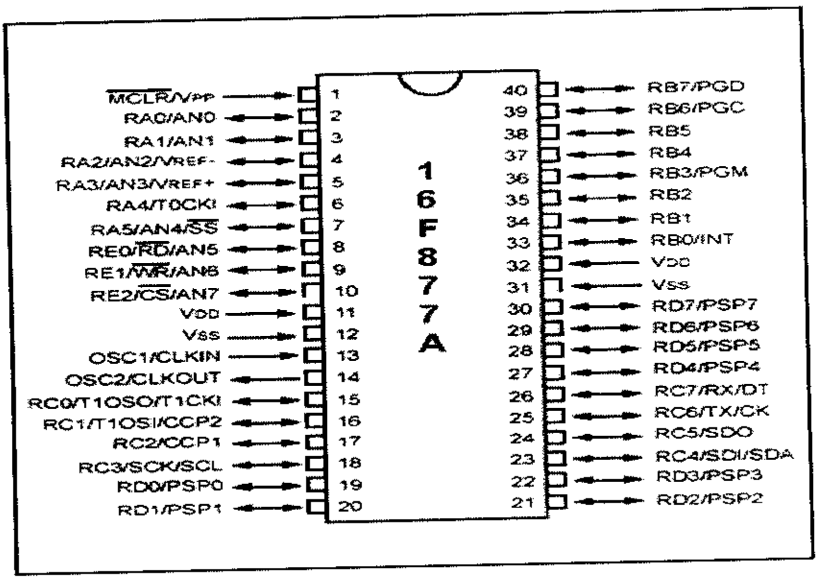


Fig. 3.3. Pin Diagram of PIC 16F877A

3.5.2. Sensor Units:

The voltage, current and speed are sensed for operation of the system, they are sensed using potential transformer, current transformer, and proximity sensor

The range of the potential transformer used in this project is 4 60 / 12V, the output of the PT is rectified using diode bridge rectifier and it is given to the microcontroller through a potential divider, a filter capacitor is connected across the diode bridge to minimize the ripples. The purpose of the potential divide is to calibrate the input signal to match the controller output. The circuit diagram of the voltage sensing circuit is shown in figure 3.4.

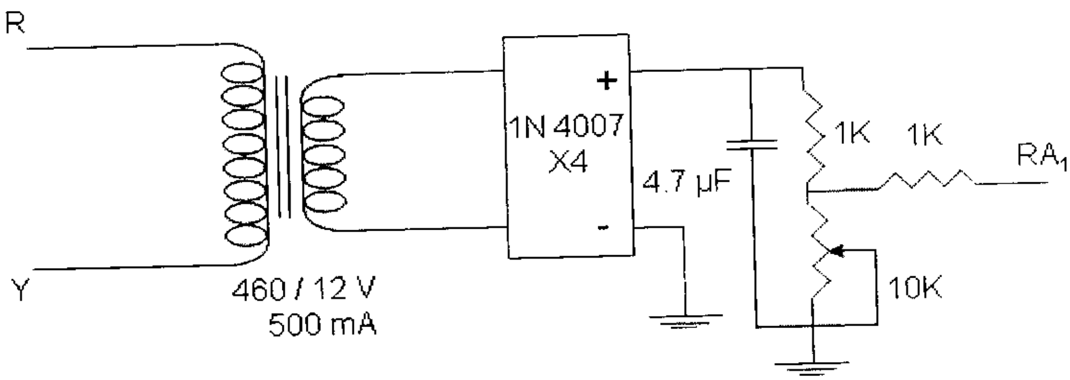


Fig. 3.4. Circuit Diagram of Voltage Sensing Unit

The current transformer used in the project is of 10: 1 ratio. The output of the CT is rectified through the diode bridge and it is output is given to the controller through the negative feedback amplifier, the op Amp used here is LM 358, the negative feedback amplifier have high gain and stability. The circuit for current measurement is shown in figure 3.5.

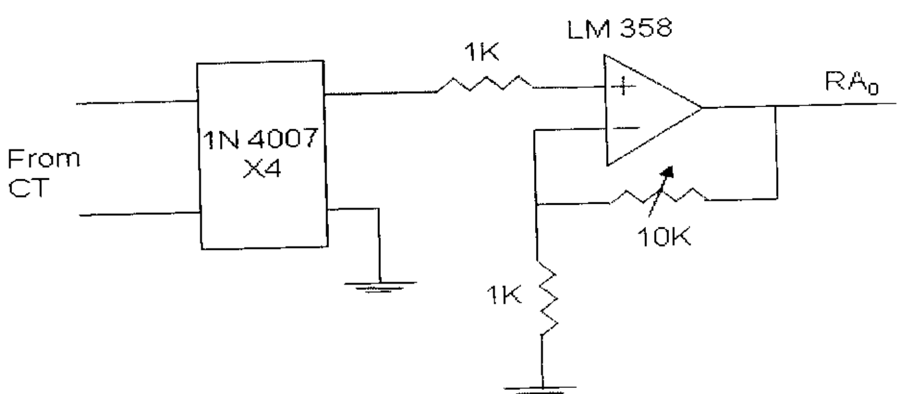


Fig. 3.5. Circuit Diagram of Current Sensing Unit

The speed of the motor is sensed by using a Proximity sensor; Inductive proximity sensors generate an electromagnetic field and detect the eddy current losses induced when the metal target enters the field. A coil, wrapped round a ferrite core, which is while entering the electromagnetic field produced by the coil, will decrease the oscillations due to eddy currents developed in the target. If the target approaches the sensor within the so-called "sensing range", the oscillations cannot be produced anymore: the detector circuit generates then an output signal controlling a relay or a switch.

3.5.3. Chopper Power Module:

The Chopper used in this project is class D chopper; the circuit diagram is shown in figure 3.6. The output of the chopper is connected across the field of the motor, the

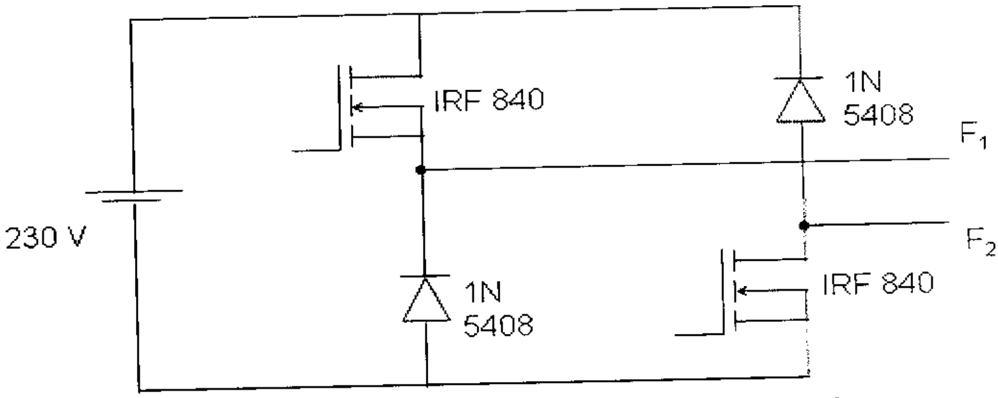


Fig. 3.6. Circuit Diagram of Chopper Unit

Chopping period of the chopper is controlled by the controller according to the input of the controller input. During the ON period the MOSFET are conducting and in OFF period diodes are conducting, the pulses are provided through the pulse transformer, it provides the isolation between the controller and power module. The output of the controller is driving the transistor which is connected in series with the pulse transformer the circuit diagram for gate pulse is shown in figure 3.7.

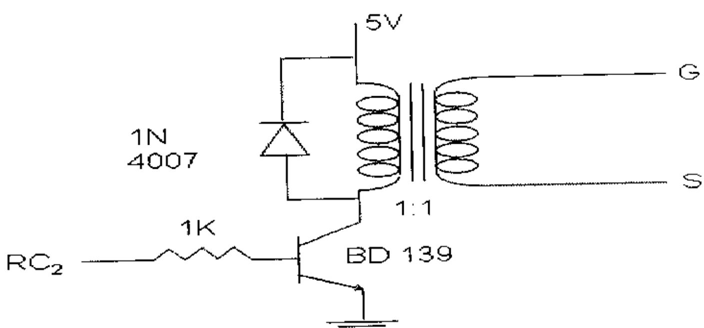


Fig. 3.7. Circuit Diagram For Gate Triggering

3.5.4. Relay Unit:

The relay unit is used to change open loop into closed loop control; the control signal for the relay operation is given from the microcontroller. The signal is given when the Push to ON switch is pressed; the relay circuit used in this project is shown in figure 3.8.

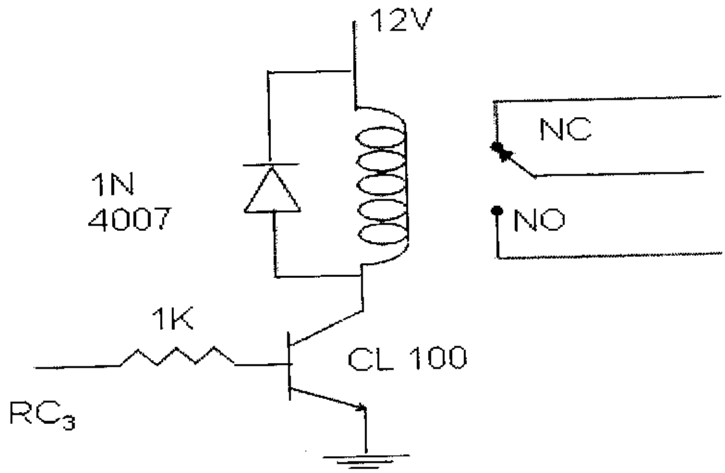


Fig. 3.8. Circuit Diagram of Relay Unit

3.5.5. Power Supply Unit for Controller Circuit:

The power supply unit used in this project is shown in figure 3.9. It consists of a step down transformer and a diode bride rectifier unit, filter capacitor is used to minimize the output ripples and voltage regulator is used to regulate the output voltage. The voltage regulator used here is 7805 it produce a fixed output of +5 volt.

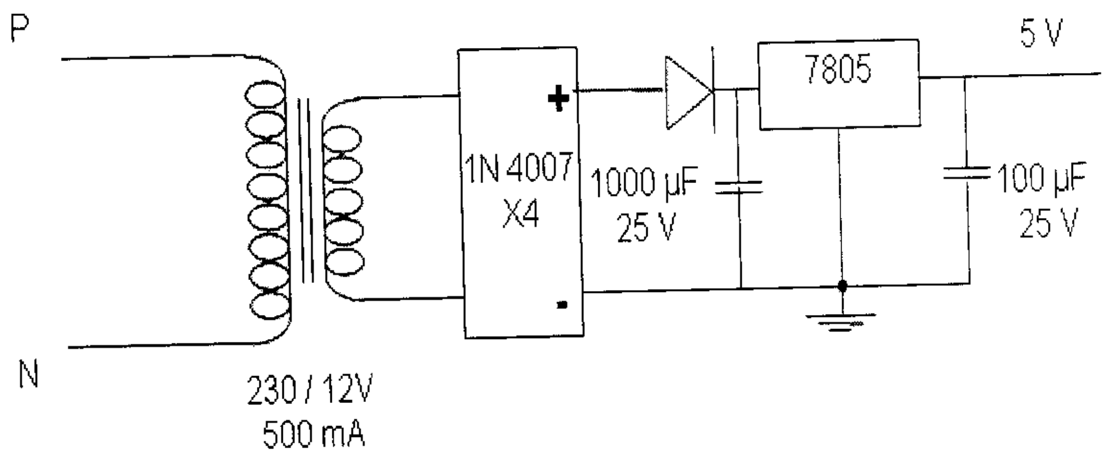


Fig. 3.9. Circuit Diagram of Power Supply Unit

3.6. Testing Of Hardware:

The hardware tested unit by unit in both Online and Offline, the voltage sensing unit is tested with help of auto transformer in Offline and the input to the controller is varied by varying the potential divider according to match the controller output to the

The current sensing unit is tested by means of a separate load in offline; the gain of the Op-amp is varied by varying the feedback resistor according to match the controller output to the input of the current transformer. Similarly the speed sensor is also tested.

The entire hardware is connected to the system and the output the chopper is tested in offline, i.e. All the inputs to the controller is taken from the alternator and the output of the chopper is measured across the rheostat whose resistance is equal to the resistance of the field winding in the motor. The output of the chopper unit is near to the value of the fuzzy controller table output. Finally the hardware is connected in online and the field of the motor is entirely controlled by the chopper unit. The system is initially run in open loop with 80% of rated load. The rated voltage and rated speed are set. The system is made now into closed loop by press the push to on button. Now if the load is varied on the system, there will be change in terminal voltage and speed of the alternator. This change in speed and voltage is the input to the microcontroller. These values are converted into power and frequency.

The change in power and frequency is given as input to the fuzzy logic controller and the output is duty ratio of the chopper. The chopper used is Class D. The fuzzy controller increase or decrease the duty ratio according to the input signals. The performance of the hardware is satisfactory and the settling time of the hardware is some what high when compared to the simulation output this is mainly because of the generation rate constant in the practical case.

3.7. Conclusion:

The proto type model is studied for the different load condition and the simulation result of proto type model with fuzzy logic controller is compared with the prototype fuzzy controller experimental result. There is a time lag for the settlement of frequency in comparison with simulation result. It is due to dead band and rate of limiter in the DC-DC converter.

CHAPTER IV

INTRODUCTION TO HVDC AND IT'S ADVANTAGE

4.1. Introduction:

The demand of power in an area is increased due to installation of large loads with a sudden change such as installation of large steel mill / Magnetic levitation transportation / an arc furnace etc.. This causes a serious problem of frequency oscillations in that area. The capabilities of frequency control of governors in this area are not enough. On the other hand other area of interconnected system has enough frequency control capabilities to compensate to that area in the trouble as shown in figure 4.1. Hence an HVDC Link is installed in parallel with an AC tie –line in order to supply more power to the area in need. This is shown with 2 areas AC-DC Link. The power modulation controller is designed to control the power flow through the HVDC link.[8]

The proposed HVDC Link Power modulation controller is superior to the governor, the conventional frequency control in terms of high-speed performance. When a sudden load disturbance occurs in an area, a HVDC link quickly starts the control system to suppress the peak value of transient frequency deviation; subsequently governor controller eliminates the steady state error of frequency deviation. In design the HVDC link control, the dynamics of the governor in the areas are neglected.

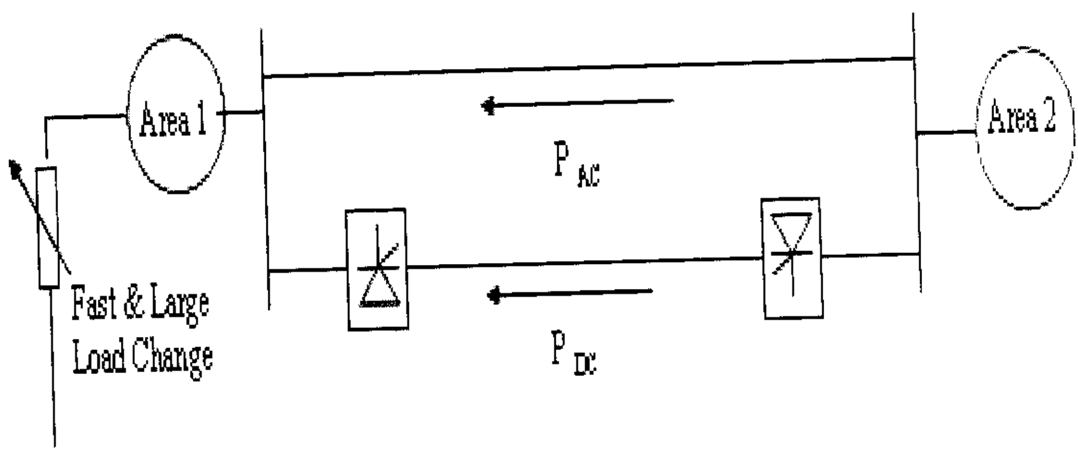


Fig.4.1. AC-DC Link for 2 Area Power Systems

4.1.1. Power Modulation Controller:

The proposed installation of the Power modulation controller is shown in figure 4.2, implemented in 3 area-interconnected systems. The system is linearized to include the dynamic Power modulation controller. ΔP is the total tie line power deviation ($\Delta \mathbf{P}_{AC}$ + $\Delta \mathbf{P}_{DC}$).

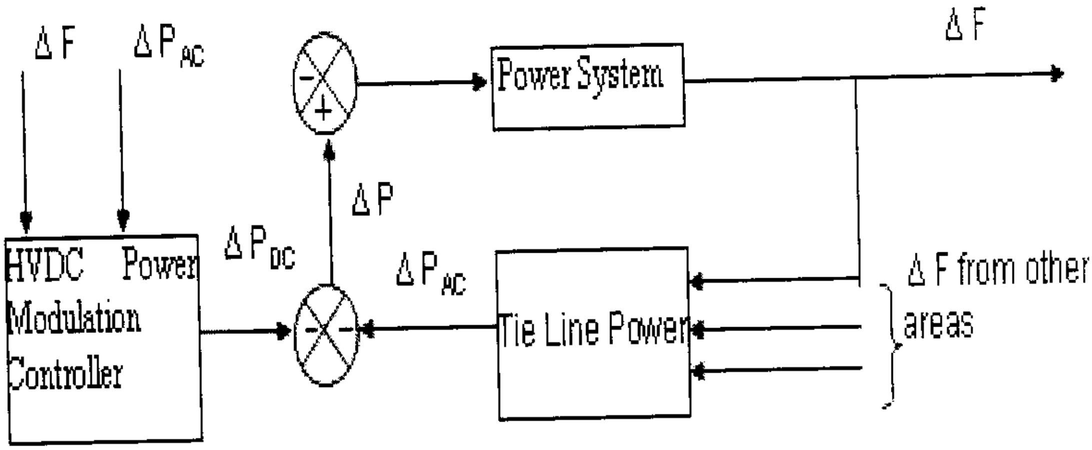


Fig.4.2. HVDC Power Modulation Controller Implemented in the System

To simplify the control design the state equation of the system shown in Figure 4.2 can be expressed as follows (for 3 area system) where subscript 1, 2 & 3 represent the $Area_1$, $Area_2$ and $Area_3$.Where D_i damping coefficient of area i, Mi is the inertia constant of area i, A_{ij} is an area capacity ratio between area i and j. The matrix 'S' can be Decomposed (overlapping) and Eigen Value assignment can be applied.[9]

$$S=\begin{bmatrix}\Delta f_1\\ \Delta P_{AC}\\ \Delta f_2\\ \Delta f_3\end{bmatrix}=\begin{bmatrix}-D_1/M_1 & -1/M & 0 & 0\\ 2\Pi T_{12} & 0 & -2\Pi T_{12} & -2\Pi T_{12}\\ 0 & A_{12}/M_2 & -D_2/M_2 & 0\\ 0 & 0 & -A_{13}/M_3 & -D_3/M_3\end{bmatrix}\begin{bmatrix}\Delta f_1\\ \Delta P_{AC}\\ \Delta f_2\\ \Delta f\end{bmatrix}+\begin{bmatrix}-1/M_1\\ 0\\ A_{13}/M_2\\ A_{13}/M_3\end{bmatrix}\Delta P_{DC} \quad (4.1)$$

Here the control scheme for the power modulation controller (ΔP_{DC}) is designed by the Eigen Value assignment method, so that the dynamic aspects of the inter area oscillation mode between areas are specified. This mode can be explicitly expressed after applying the variable transformation.

$$Y = WX \quad (4.2)$$

Where 'Y' is the transferred state vector, 'W' is transformation Matrix and 'X' is the state vector in (4.1). Therefore the transferred system can be expressed as (4.3).

$$\begin{bmatrix}\Delta y_i\\ \Delta y_2\\ \Delta y_3\\ \Delta y_4\end{bmatrix}=\begin{bmatrix}\alpha & \beta & 0\\ -\beta & \alpha & 0\\ 0 & 0 & \lambda\\ -\beta & \alpha & 0\end{bmatrix}\begin{bmatrix}\Delta y_i\\ \Delta y_2\\ \Delta y_3\\ \Delta y_4\end{bmatrix}+\begin{bmatrix}\gamma_1\\ \gamma_2\\ 0\\ 0\end{bmatrix}\Delta P_{DC} \tag{4.3}$$

"W" consists of two diagonal blocks with complex Eigen value $\alpha \pm j\beta$ and real value λ. The complex Eigen Value corresponds to the inter area oscillation mode, while the real eigen value represents the system inertia center mode. Hence it is concluded that HVDC link between the two areas is effective to stabilize the inter-area mode only. Hence the input to terms Δy_3 and Δy_4 are zero. This means that HVDC link cannot control the inertia center mode. To solve this crux, it is expected that governors in all the areas are responsible for suppressing the frequency deviation due to the inertia mode.

In order to extract the sub system where the inter-area oscillation mode is preserved between the areas from the system 'S', the technique of Overlapping Decomposition is applied. The state variables of original system 'S' are classified into $X_1 = [\Delta f_1]$, $X_2 = [\Delta P_{ac}]$, $X3 = [\Delta f_2]$, $X4 = [\Delta f_3]$, According to overlapping decomposition, the system 'S' can be expanded as (4.4).[11]

$$\tilde{S}:\begin{bmatrix}Z_1\\ Z_2\end{bmatrix}=\begin{bmatrix}a_{11} & a_{12} & 0 & a_{13}\\ a_{21} & a_{22} & 0 & a_{23}\\ a_{31} & 0 & a_{32} & a_{33}\\ a_{31} & 0 & a_{32} & a_{33}\end{bmatrix}\begin{bmatrix}Z_1\\ Z_2\end{bmatrix}+\begin{bmatrix}b_{11}\\ b_{21}\\ b_{21}\\ b_{31}\end{bmatrix}\Delta P_{DC} \tag{4.4}$$

Where $Z_1 = [X_1^T, X_1^T]^T$ and $Z_2 = [X_2^T, X_2^T]^T$. The system '$\ddot{S}$' can be written into two interconnected overlapping sub systems as (05) and (06).

$$\tilde{S}_1 : Z_1\left(\begin{bmatrix}a_{11} & a_{12}\\ a_{21} & a_{23}\end{bmatrix}Z_1+\begin{bmatrix}b_{11}\\ b_{21}\end{bmatrix}\Delta P_{DC}\right)+\begin{bmatrix}0 & a_{13}\\ 0 & a_{23}\end{bmatrix}Z_2 \tag{4.5}$$

$$\tilde{S}_2 : Z_2\left(\begin{bmatrix}a_{22} & a_{23}\\ a_{32} & a_{33}\end{bmatrix}Z_2+\begin{bmatrix}b_{21}\\ b_{31}\end{bmatrix}\Delta P_{DC}\right)+\begin{bmatrix}a_{21} & 0\\ a_{31} & 0\end{bmatrix}Z_2 \tag{4.6}$$

As a result of decoupled system $\tilde{S}_1$ and $\tilde{S}_2$ can be expressed as (4.7) and (4.8).

$$\tilde{S}_{D1} : Z_1 = \left(\begin{bmatrix}a_{11} & a_{12}\\ \dots & \dots\end{bmatrix}Z_1+\begin{bmatrix}b_{11}\\ b\end{bmatrix}\Delta P_{DC}\right) \tag{4.7}$$

$$\tilde{S}_{D2} : Z_2 = \left(\begin{bmatrix} a_{22} & a_{23} \\ a_{32} & a_{33} \end{bmatrix} Z_2 \right) \quad (4.8)$$

S''_{D1} Can be expressed as (4.9)

$$\begin{bmatrix} \Delta f_1 \\ \Delta P_{AC} \end{bmatrix} = \begin{bmatrix} -D_1/M_1 & -1/M_1 \\ 2\pi T_{12} & 0 \end{bmatrix} \begin{bmatrix} \Delta f_1 \\ \Delta P_{AC} \end{bmatrix} + \begin{bmatrix} -1/M_1 \\ 0 \end{bmatrix} \Delta P_{AC} \quad (4.9)$$

Here the control purpose of HVDC link is to damp the peak value of frequency deviation after sudden load disturbance

The new percent overshoot $M_{P(New)}$ for new damping ratio $\zeta_{(new)}$ is calculated by (4.10).

$$M_{p(new)} = \exp\left(-\zeta_{new}\pi / \sqrt{1-\zeta_{new}^2}\right) \quad (4.10)$$

The new un-damped natural frequency is given as

$$\omega_{n(new)} = \beta_{new} / \sqrt{1-\zeta_{new}^2} \quad (4.11)$$

As a result new Eigen value $\alpha_{new} \pm \beta_{new}$ can be calculated as in (4.12).

$$\alpha_{new} = \zeta_{new}\, \omega_{n(new)} \quad (4.12)$$

By Eigen value assignment method the feed back control scheme of ΔP_{DC} can be expressed as (4.13).

$$\Delta P_{DC} = -K_{\Delta f_1} \Delta f_1 + K_{\Delta P_{AC}} \Delta P_{Ac} \quad (4.13)$$

The state feed back scheme is constructed by two measurable signals 'Δf' changes in the frequency of the area and 'ΔP_{AC}' change in AC tie-line power.

4.2. Simulation model:

A 3-area delta interconnected system (400 Mw, 2000Mw & 500 Mw) with reheat steam turbine is used for the system study is shown in figure 4.3 and the simulation diagram is shown in figure 4.4. The Software's like Mat lab, Simulink and Control System toolbox were used to carry out the simulation study. As per the standard the change in transient frequency should not exceed the ± 0.50Hzs. Most preferably the deviation should lie between ± 0.02Hzs. For the case studies a large steel mill and an arc furnace factory with a combine load demand of 4 Mw (0.01pu) is used as sudden

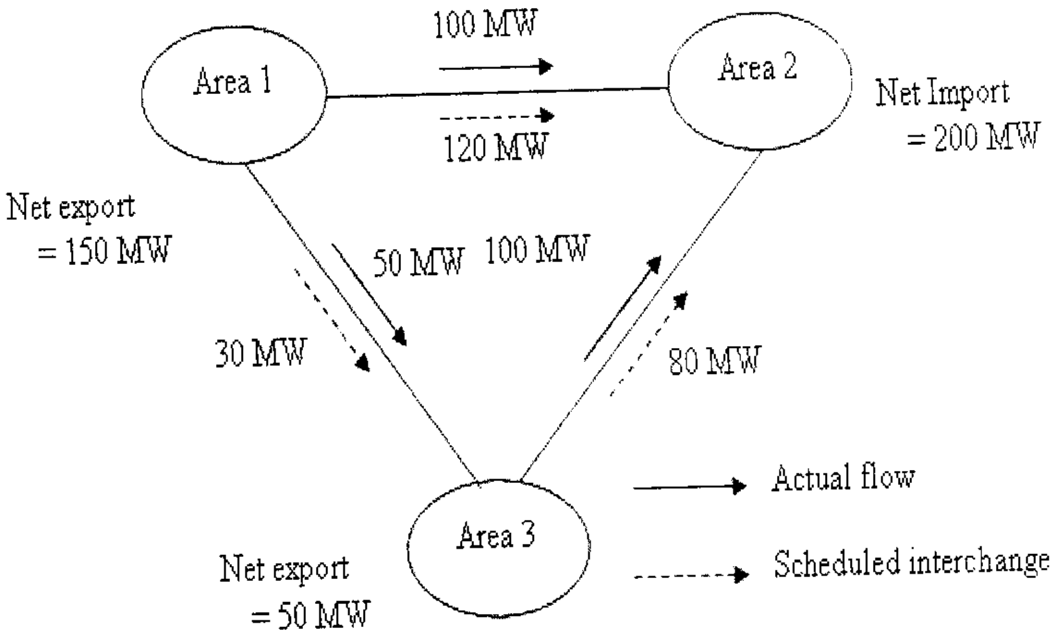


Fig.4.3. Delta Interconnected System

The three-area delta system was simulated with only AC-AC link alone with the conventional governor control. Then the system was simulated with only AC-DC link alone. The last simulation was done with AC-AC link & AC-DC link in parallel. Sudden loading and unloading in different areas solely and simultaneously was applied for the study. All the above conditions are ideal case hence; loading of the system in time invariant condition is also simulated.

TABLE 4.1 DEMAND OF SUDDEN LOAD

Case	Area1 (pu)	Area2 (pu)	Area3 (pu)
1	0.1	0.0	0.0
2	0.0	0.1	0.0
3	0.0	0.0	0.1
4	0.1	0.1	0.0
5	0.0	0.1	0.1
6	0.1	0.0	0.1
7	0.1	0.1	0.1
8	-0.1	0.0	0.0
9	0.0	-0.1	0.0
10	0.0	0.0	-0.1
11	-0.1	-0.1	0.0
12	0.0	-0.1	-0.1
13	-0.1	0.0	-0.1
14	-0.1	-0.1	-0.1
15	0.5	0.0	0.0
16	0.0	0.25	0.25

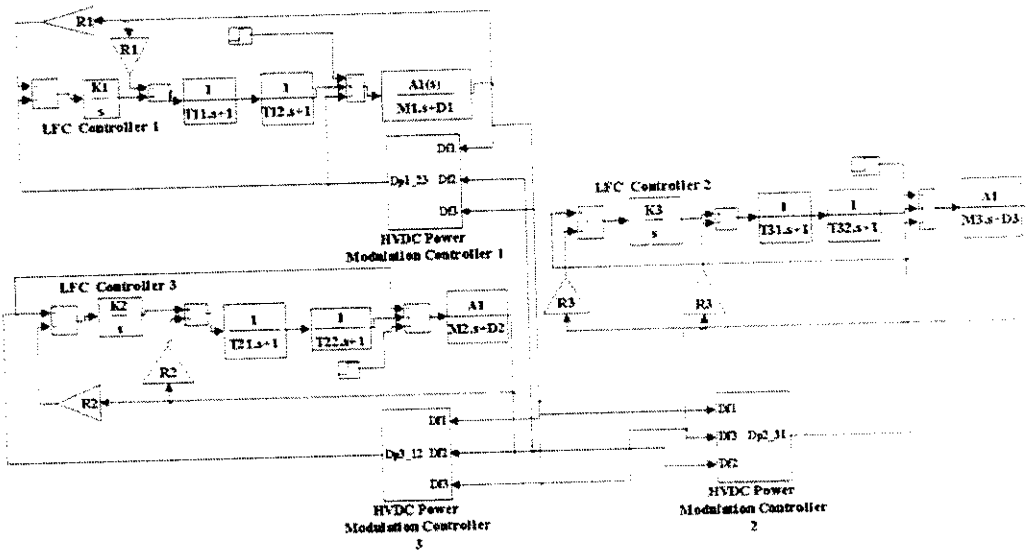


Fig.4.4.Linearized Model of Three Area System with HVDC Control

4.3. Results:

The system is studied for all the above cases and the results were shown in figure4.5.

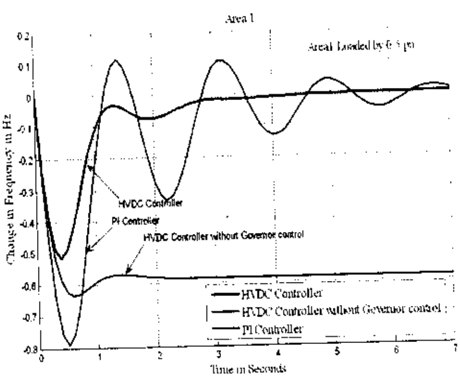


Fig.4.5 (a)

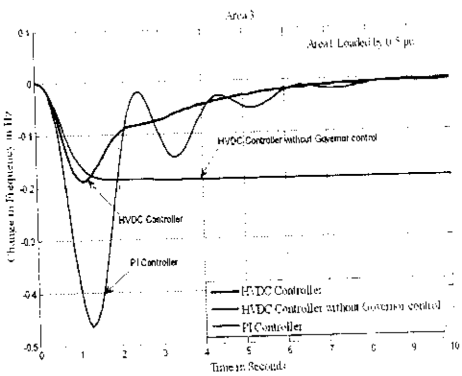
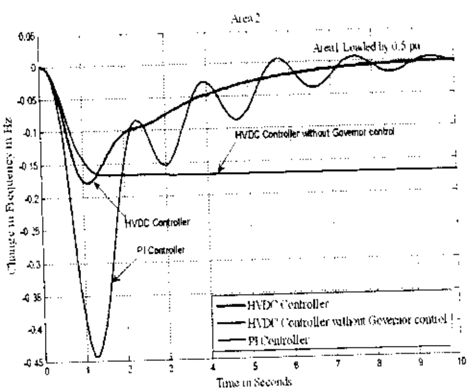
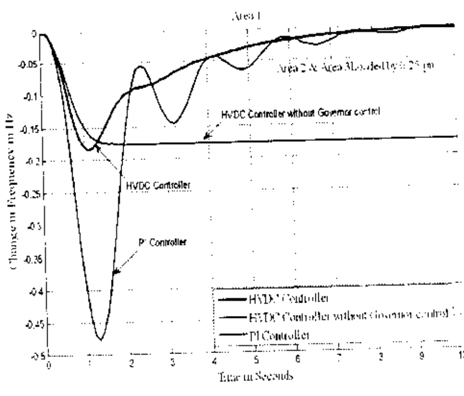


Fig.4.5 (c)





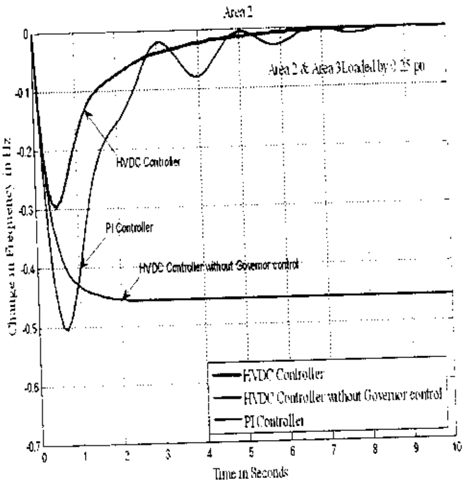


Fig.4.5 (e)

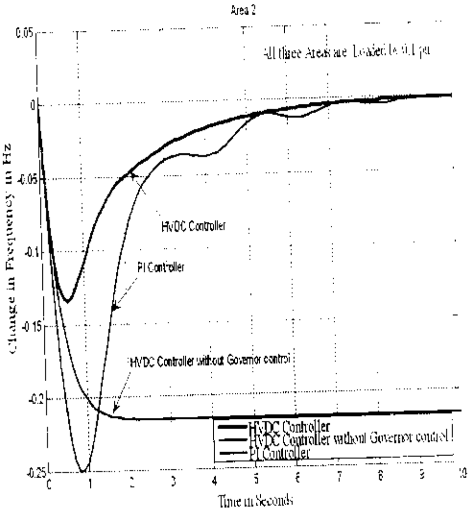


Fig.4.5 (h)

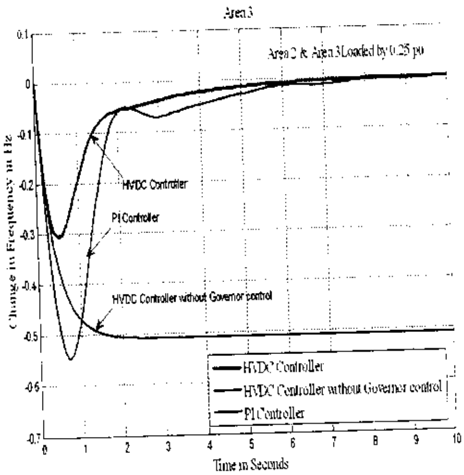


Fig.4.5 (f)

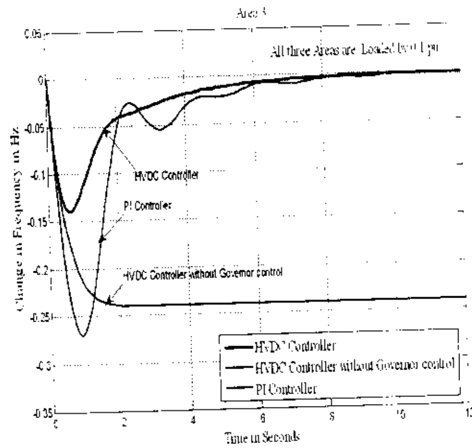
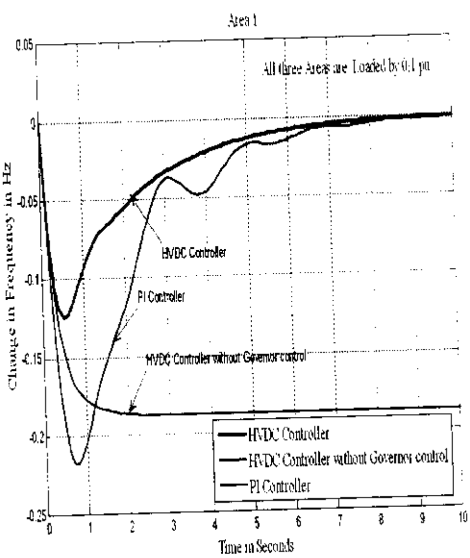
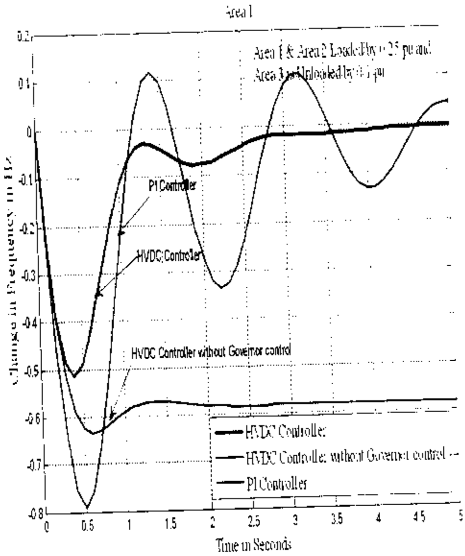


Fig.4.5 (i)





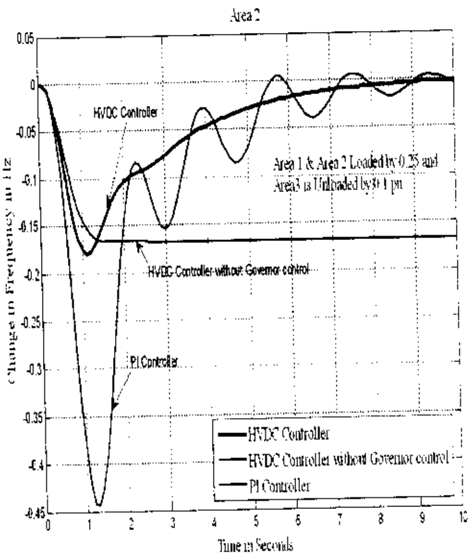


Fig.4.5 (k)

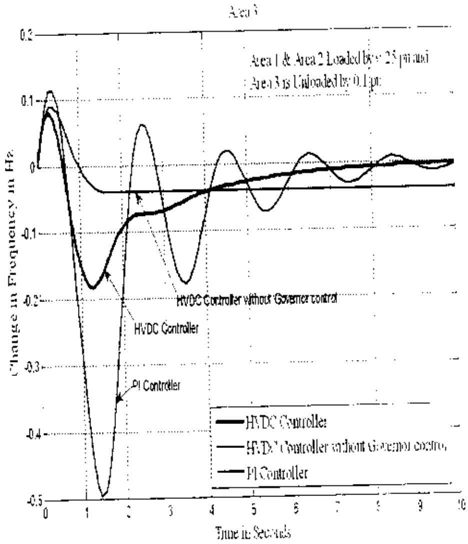


Fig.4.5 (l)

Fig.4.5. Simulation Results of Three Area Interconnected Power System for Different Cases with HVDC Controller

4.4. Conclusion:

In this project a new method for stabilizing frequency oscillation in a parallel AC-DC interconnected power system is discussed. From the result, following conclusions can be derived. Tie line power modulation of HVDC link can be used for stabilizing the frequency oscillation in AC power system. By applying overlapping Decomposition Technique and Eigen value assignment method, power modulation controller of HVDC link can be designed In the study the power modulation controller scheme is simply constructed by a state feedback of two measurable signals i.e. 'Δf' the frequency deviation of that area and 'ΔP_{tie}' the tie line power deviation. Therefore it is easy to implement in real system. From the result it is found that designed controller is very effective in suppressing the frequency Oscillation caused by rapid load disturbances. The proposed control strategy can also be expected as a new ancillary service for stabilizing frequency oscillation in future deregulated power system.

If one of the selected units fails, the rest of the controlled units might not be able to compensate for the missing capacity. A combination with existing regulated power market would be necessary. The problem of overload on transmission line must be examined with more detailed grid models. The selection of units for power modulation controller has to be made from careful studies of the units and local grid characteristics. This is beyond the scope of this paper.

Both LFC and HVDC power modulation controller seem to fulfill the necessary system requirement. Note that the power modulation controller is feasible due to the dominating size of the HVDC connection

For further study the proposed control design of HVDC link will be extended to stabilize the frequency oscillation in a multi-area interconnected deregulated power system with configuration of Area Participation Factor (APF) and Disco Participation Matrix (DPM) included.

CHAPTER V

CONCLUSION AND FUTURE SCOPE

5.1. Conclusion:

In this project hardware is designed for the frequency stabilization for a single area system based on the fuzzy logic controller. It is providing the better performance compared to Proportional integral controller based system. The simulation study of the same system was also done, the settling time of the system is some what low compared to the hardware result, this because the dead band and the generation rate constant in practical case.

The simulation study of the three area interconnected power system is done for both Flat frequency control and Parallel frequency control were done and system was studied for different cases. The results of Flat frequency control system were shows that the fuzzy controller based system is better than that of the Proportional integral controller based system.

In case of parallel frequency control based system the results were shows that the HVDC controller with integral controller is better than that of the Proportional integral controller based system, the HVDC Power modulation controller based system without integral controller results shows that the change in frequency is settling in different values for different case, so finally for the better performance the system should have the HVDC Power modulation controller with integral controller.

5.2. Future Scope:

The hardware is developed for the single area system with only load Frequency Control (LFC). To make the system into a multi area system synchronization of all Motor Alternator set is needed i.e. generated voltage, phase sequence and frequency should be the same. So this proto type model can be implemented into multi area if minimum to motor Alternator set of same rating is available. Then the value of ΔP_{tie} is taken into account instead of ΔP.

Now the simulation study is done for the system control using Flat frequency control and Parallel frequency control, in case of parallel frequency control PI controller is used for HVDC power modulation control. If we implement Fuzzy controller instead of PI we will get the better result. To improve the system

```
                t=((set*256)-t1)+t2;
                set=0;
            }
        }

        if(set==1000)
            set=0;
        if(T0IF==1)
        {
            T0IF=0;
            set++;
        }
/***********SPEED END**********/



        if(TMR1IF==1)
        {
            TMR1IF=0;
            count++;
            if(count==1)
            {
                TMR1=55536+TON;
                TMR1H=TMR1/256;
                TMR1L=TMR1%256;
                RC3=0;
            }
            if(count==2)
            {
                TMR1=55536+TOFF;
                TMR1H=TMR1/256;
                TMR1L=TMR1%256;
                RC3=1;
                count=0;
            }
            if(df>0)
            {
                TON=TON+5;
                TOFF=TOFF-5;
            }
            if(df<0)
            {
                TON=TON-5;
                TOFF=TOFF+5;
            }
        }
    }
```

performance in the Deregulated environment Area Participation Factor (APF) and Disco Participation Matrix (DPM) are need to be included in the AGC network.

REFERENCES

[1]. Prabha Kundur, "Power System Stability and Control", Mc Graw Hill, Inc, USA, (1994).

[2]. B.M.Weedy and B.J.Cary,"Electric Power System", Fourth Edition, John Wiley and Sons, (1999).

[3]. Timothy. J. Ross, "Fuzzy Logic with Engineering Application" ,McGraw Hill Inc, (1997)

[4]. S. Rao, "EHV AC and HVDC Transmission Engineering and Practice", Khanna Publishers Delhi, (1996)

[5]. Raymond T Stefani, Bahram Shaheai, Clement J Savnt Jr., Gene H Hostiller " Design Of Feedback Contol System' Oxford Press (2002).

[6]. MlJ.Nandha and B.L.Kaul, "Automatic generation control of an interconnected power system", *IEEE proceeding ,vol 125,no 5,May 1978, Pages185-191.*

[7]. lC.S.Indulkar and B.Rai "Application of fuzzy controller in Automatic generation control", *Electric machines and power systems ,vol 23,no 2,march April 1995Pages 72-78.*

[8]. Dr S.P Chowdry, S .Chowdry & Dr . S . Choudry , "Automatic generation Control Techniques For Present Demands of Interconnected Power Systems" *Journals of Institute of Engineers (India) Vol78 , March 1998, Pages 219-224.*

[9]. Anbalagan.P.., Rani thottungal "Control Of Load Frequency Of Interconnected Power System Using Fuzzzy Logic With GRC" *Proceedings of NCAC 2002, PSG college of technology,coimbatore,feb 2002,Pages 60-66.*

[10]. Ibraheem, Prabhat Kumar and Dwarka P Kothari, "Recent Philosophies of Automatic Generation Control Strategies in Power Systems", *IEEE Transaction on Power System, Vol. 20, No.1, 2005, Pages346-357.*

[11]. Issarachai Ngamroo, "A Stabilization of Frequency Oscillation in a Parallel AC-DC Interconnected Power System via an HVDC Link", *Science Asia, Vol. 28, 2002, Pages 173-180.*

[12]. Chritee R Bose "Load Frequency Control Issue In Power System Operation after Deregulated", *IEEE Transaction on Power System, Vol.11, No.3, Aug. 1996, Pages1191-1200.*

[13]. Ikeda M, Siljak D D, White D E,"Decentralized control with overlapping information sets" *Journal of Optimization Theory Application, Vol 34, No2 1981, Pages 279-283.*

[14]. Seyedrasoul Saneifard, Nadipuram R. Prasad, Howard A. Smolleck, Jiryes J. Wakileh "Fuzzy-Logic-Based Speed Control of a Shunt DC Motor", IEEE Transactions On Education, Vol. 41, No. 2, May 1998,Pages 243-248.

[15]. J. M. Mendel, "Fuzzy logic systems for engineering: A tutorial," *Proceedings .IEEE, vol. 83, Mar. 1995, Pages 345-357.*

[16]. Hsui .T., Chey.C ., "Design of Fuzzy Power System Stabilities For Multi Machine Power System" *IEEE Proceedings C .137 1990(3),Pages 126-132.*

APPENDIX

PIC MICROCONTROLLER COADING

```
#include<pic.h>
#include<lcd.h>

unsigned int volt1,cur1;
unsigned char
count=1,V1HUN,V1TEN,V1ONE,I1HUN,I1TEN,I1ONE,F1HUN,F1TEN,F1ONE,N
1TENTHO,N1THO,N1HUN,N1TEN,N1ONE;
unsigned int I1,I2,V1,N1,F1;
unsigned int fsch,fact,set;
unsigned int pact,psch,TON,TOFF,TMR1;
signed int df,dp;
signed float f,t1,t2,t,F2,rpm;
void main()
{
        TRISD=0X00;
        TRISE=0X00;
        PORTD=0;
        PORTE=0;


        PR2=249;
        CCPR1L=0X7D;
        CCP1CON=0X0C;

        T2CON=0X05;
        TRISC=0X00;

        T1CON=0x01;

        TRISB=0x03;
        PORTB=0;
        OPTION=0x88;
        GIE=PEIE=INTE=T0IE=TMR1IE=1;
        lcd_init();

        while(1)
        {

                ADCON0=0X81;
                delay();
                ADGO=1;
                while(ADGO);       //status check
                volt1=ADRESH*256+ADRESL;
                delay();
                delay();
```

```
delay();
ADGO=1;
while(ADGO);
cur1=ADRESH*256+ADRESL;
delay();
delay();

V1=volt1/2;
I1=cur1/1;

if(RB1==1)
        RB2=1;

if(RB2==0)
        I2=I1;

V1HUN=V1/100;
V1=V1%100;
V1TEN=V1/10;
V1=V1%10;
V1ONE=V1;

I1HUN=I1/100;
I1=I1%100;
I1TEN=I1/10;
I1=I1%10;
I1ONE=I1;

f=1000000/t;
rpm=f*60;
//              rpm=1480;               //temp

N1=rpm;
F2=rpm;
N1TENTHO=N1/10000;
N1=N1%10000;
N1THO=N1/1000;
N1=N1%1000;
N1HUN=N1/100;
N1=N1%100;
N1TEN=N1/10;
N1=N1%10;
N1ONE=N1;

cursor_loc(0X80);
display_string("V=");
display_data(V1HUN);
display_data(V1TEN);
display_data(V1ONE);
```

```
cursor_loc(0x87);
display_string("I=");
display_data(I1HUN);
display_string(".");
display_data(I1TEN);
display_data(I1ONE);

cursor_loc(0xC0);
display_string("N=");
//  display_data(N1TENTHO);
display_data(N1THO);
display_data(N1HUN);
display_data(N1TEN);
display_data(N1ONE);


F1=F2/3;
F1HUN=F1/100;
F1=F1%100;
F1TEN=F1/10;
F1=F1%10;
F1ONE=F1;

cursor_loc(0xC7);
display_string("F=");
display_data(F1HUN);
display_data(F1TEN);
display_string(".");
display_data(F1ONE);
t=0;
delay2();



/******pwm part********/


psch=1.732*400*I2;
pact=1.732*400*I1;
dp=pact-psch;
fsch=50;
fact=N1/30;
df=fact-fsch;


TON=4043;
TOFF=5957;
```

```
{
        if(dp<=150)
        {
                TON=4043;
                TOFF=5957;
        }
}


if(dp>=-500)
{
        if(dp<=-150)
        {
                TON=4260;
                TOFF=5740;
        }
}


if(dp>=-850)
{
        if(dp<=-500)
        {
                TON=4434;
                TOFF=5566;
        }
}


if(dp<=-850)
{
        TON=4521;
        TOFF=5479;
}

if(dp>=150)
{
        if(dp<=500)
        {
                TON=3913;
                TOFF=6087;
        }
}


if(dp>=500)
{
        if(dp<=900)
        {
```

```
                        TOFF=6181;
                    }
                }


                if(dp>=900)
                {

                    TON=3826;
                    TOFF=6174;
                }


                if(df>0)
                {
                    TON=TON+5;
                    TOFF=TOFF-5;
                }
                if(df<0)
                {
                    TON=TON-5;
                    TOFF=TOFF+5;
                }
        }
}

delay()
{
        unsigned int i=0;
        for(i=0;i<=400;i++);
}

delay2()
{
        unsigned int j=0;
        for(j=0;j<=40000;j++);
}

void interrupt isr()
{
/**********SPEED START***********/
        if(INTF==1)
        {
                INTF=0;
                t1=t2;
                t2=TMR0;
                if(set==0)
                        t=t2-t1;
                else
```