# AUTOMATIC FREQUENCY CONTROL OF SYNCHRONIZED GENERATORS USING FUZZY LOGIC

**A PROJECT REPORT**



*Submitted by*


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*in partial fulfillment for the award of the degree*

*of*

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*in*

**ELECTRICAL AND ELECTRONICS ENGINEERING**

**KUMARAGURU COLLEGE OF TECHNOLOGY**

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### BONAFIDE CERTIFICATE

Certified that this project report "**AUTOMATIC FREQUENCY CONTROL OF SYNCHRONIZED GENERATORS USING FUZZY LOGIC**" is the bonafide work of

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26/4/07

EXTERNAL EXAMINER

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# ABSTRACT

The objective of this project is to deliver power in an interconnected system economically and reliably while maintaining the voltage and frequency within permissible limit. This can be done by AUTOMATIC GENERATION CONTROL using PI controller. The power generated at the output is fed back to the input through feedback path.

In any electric power system, the basic requirement is generated power ($P_g$) should meet the demand power ($P_d$) and losses. In case of interconnected systems, when power demand increases/decreases at any one area, accordingly generated power should increase/decreases in one/all area to compensate the demand. But $P_g$ cannot be increased/decreased instantaneously since power input ($P_i$) to turbine is constant. Hence the change in demand is being met by the kinetic energy stored in the rotating parts of power system.

Using 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 powers and memory. In that case a fuzzy controller is incorporated in the system.

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| | |
|---|---|
| $P_m$ | - Mechanical power input |
| $\Delta P_m$ | - Change in mechanical power input |
| e(k) | -Change in error using PI Controller |
| $K_I$ | -Integral error constant |
| $P_e$ | - Electrical power output |
| $P_g$ | - Electrical power generated |
| $\Delta P_e$ | - Change in electrical power output |
| $P_L$ | - Electrical load power demand |
| $\Delta P_L$ | - Change in electrical load power demand |
| $\Delta P_g$ | - Change in electrical power generated |
| $\delta$ | - Torque angle/power angle |
| $\delta_m$ | - Mechanical torque angle/power angle |
| $\delta_c$ | - Electrical torque angle/ power angle |
| H | - Machine inertia constant in system base |
| J | - Machine inertia constant |
| $\omega$ | - Rotor angular velocity with reference to synchronous Rotating frame |
| $\Delta\omega$ | - Change in rotor angular velocity wiyh reference to Synchronous rotating frame. |
| D | - Ratio of percent change in load to percent change in velocity |
| $\tau_g$ | - Time constant of governor |

$P_{12}$ -Tie line power of area 1 and area2

$P_{23}$ -Tie line power of area 2 and area3

$P_{31}$ -Tie line power of area 3 and area1

$P_{01}$ -Power delivered at area1

$P_{02}$ -Power delivered at area2

$P_{03}$ -Power delivered at area3

NV - Negative very large error

NS -Negative small error

ZE -zero error

PS -Positive small error

PV - Positive large error

## 1.1 PROBLEM

Changes in real power affect mainly the system frequency, while reactive power is less sensitive to changes in frequency .LFC loop controls the real power and frequency and the automatic voltage regulator AVR loop regulates the relative power and voltage magnitude. Load frequency control (LFC) has gained importance with the growth of interconnected systems and has made the operation of interconnected systems possible today. It is still the basis of many advanced concepts for the control of large systems.

PI controller is generally used. Using PI controller all the parameters are optimized around an operating point. For certain conditions 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 powers and memory. In conventional schemes mathematical models are developed to find solutions, which has many uncertainties in practice i.e. these models provide for specific situations of power system under respective assumptions, which are not trivial. Therefore, there exist some limitations for mathematical model based schemes.

## 1.2 OBJECTIVE

- To develop a system model and analyze the performance in three interconnected area and to control the power delivered by controlling the voltage and frequency. The normal value of frequency is 50 Hz.
- To simulate the system model using MATLAB 7.
- To design a prototype model of fuzzy controller and test it in the laboratory

## 1.3 SOLUTION

In order to overcome these limitations, application of new intelligent technologies such as fuzzy system, neural network and genetical algorithms have been investigated for reliable and high quality power supply. In fuzzy logic controller the parameters are adjusted to satisfy the controller specification by a fuzzy rule based expert system.

Load frequency control and automatic voltage regulator have gained importance with the growth of interconnected system. This takes care of small changes in load demand while maintaining the frequency and voltage magnitude with in the specified limits. Many investigations in the area of LFC problem of interconnected power system have been reported over the past few decades. A number of control strategies have been employed in the design of load frequency controllers in order to achieve better dynamic performance and so in this project a fuzzy controller, based on empirical rules, being more effective is implemented.

## 1.4 ORGANIZATION OF THE REPORT

The thumbnail that has been discussed in this work has been enumerated below.

Chapter 1 gives a brief introduction, need and the objective of our project.

Chapter 2 deals with application of load frequency control in our project, its advantages and disadvantages.

Chapter 3 explains how automatic generation control is implemented in our project.

Chapter 4 elaborates on fuzzy logic control and simulation.

Chapter 5 discusses the design and fabrication of the hardware part of our project.

Chapter 6 explains hoe various tests were done and the problems faced throughout.

## 2.1 METHODOLOGY

This project deals with control of active and reactive power in order to keep the system in steady state .The main objective of this project deals with power in an interconnected system as economically and deliver power in an interconnected system as economically and reliability while maintaining the voltage and frequency within permissible limit. This can be done by AUTOMATIC GENERATION CONTROL using PI controller. The power generated at the output is fed back to the input through feedback path.

## 2.2 LFC

The main objective of LFC is to maintain reasonably uniform frequency, to divide the load between generators and to control the tie-line interchange schedules. It mainly concentrates on control of real power in the system; thereby the frequency of the system can be controlled since real power is proportional to frequency.

If the system of a single machine is connected to a group of loads, the speed and frequency change is in accordance with the governor characteristics as the load changes. If it is not important to keep frequency constant, no regulation control is required. The frequency normally would vary by about 5% between light load and full load conditions. On the other hand if constant frequency is required the operator can adjust the speed of the turbine by changing the governor characteristic as and when desired.

## 2.3 REASONS FOR LIMITS ON FREQUENCY

The following are the reasons for keeping strict limits on the system frequency variations:

(i) The speed of a.c. motors is directly related to the frequency. Even though most of the a.c. drives are not much affected for a frequency variation of even 50 ± 5 Hz, there are certain

(iii) If the normal frequency is 50 Hz and the turbines are run at speeds corresponding to frequency less than 47.5 Hz or more than 52.5 Hz, the blades of the turbine are likely to get damaged, hence a strict limit on frequency must be adhered to as stalling of the generator will further aggravate the problem if the system is operating at the lower limit of frequency.

(iv) The system operation at subnormal frequency and voltage leads to loss of revenue to the suppliers due to accompanying reduction in load demand.

(v) The most serious effect of subnormal frequency is on the operation of thermal power plants. With reduced frequency the blast by fans decreases, as a result of which the generation also decreases and thus it becomes a cumulative action and may result in complete shut-down of the plant if corrective measures like load shedding is not resorted to. Load shedding is done with the help of under frequency relay, which automatically disconnects blocks of loads. The setting of the under frequency relays is so adjusted that the least important load is disconnected at a relatively higher frequency and vice versa.

## 2.4 LOAD COMPENSATION

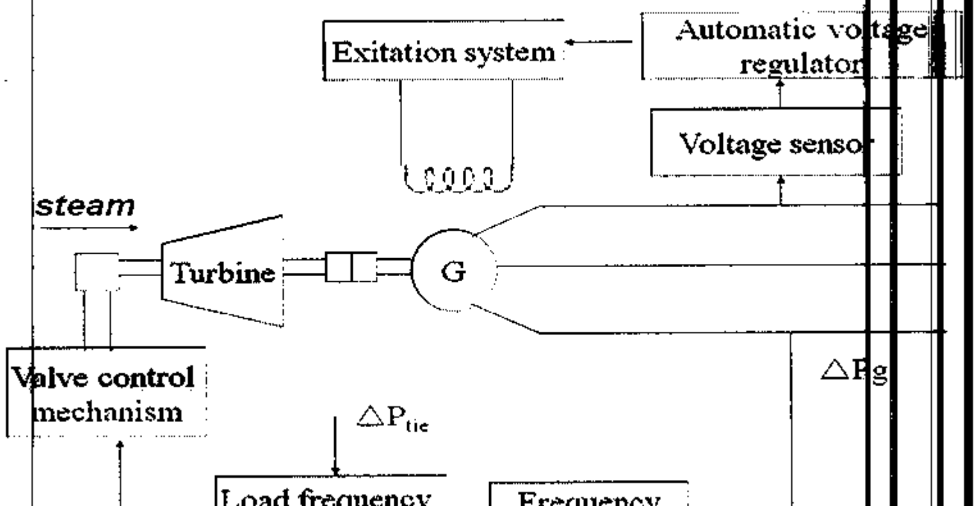
In a single area uncontrolled system whenever a load increase takes place it is taken care of by the system in the following three ways:

(i) 'Borrowed' kinetic energy from the rotating machines of the system i.e., initially the increase in load is supplied from the stored energy of the synchronous generators, as a result the speed of the machine goes down and the system frequency decreases.

coherently, maintaining thereby equal frequency deviations among them. Initially corresponding to synchronous speed the last two components are zero and as the speed decreases, they contribute to the increased generations. However, it is to be noted that the contribution due to the last two factors is very small and the major contribution is due to the increased generation due to governor action.)

## 2.5 NEED FOR LFC:

The operational objectives of load frequency control (LFC) are to maintain reasonably uniform frequency to divide the load between generators and the change in real power is sensed. . The error signal $\Delta F$ and $\Delta P$ are amplified, mixed and transformed into a real power command signal $\Delta Pv$ which is sent to the prime mover to call for an increment in torque. The prime mover therefore brings change in generator output by an amount $\Delta Pg$ will change the frequency and $\Delta Ptie$ within the specified tolerance.



## 2.6 DISADVANTAGES OF PI CONTROLLER

The drawback of PI controller is that mathematical model of the control process may not exist or may too expensive in case of computer processing and memory. A system based on empirical rule 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.

While designing a PI controller following hindrances have to be overcome.viz

(a) Operation interfacing

(b) Smooth switching operation of the components,

(c) Transient parameter changes,

(d) Effects of non-linear actuator,

(e) Maximum and minimum selecting and built up of integral terms i.e. heuristics plays an important part.

## 2.7 ADVANTAGES OF FUZZY LOGIC

Fuzzy Logic represents vague language naturally. They enrich and not replace crisp sets. It allows flexible engineering design. It improves model performance and is simple to implement.

## 3.1 INTRODUCTION

When the load in the system increases turbine speed drops before the governor can adjust the input. As the change in the value of speed decreases the error signal becomes smaller and the positions of governor value get close to the required position, to maintain constant speed. However the constant speed will not be the set point and there will be on offset, to overcome this problem an integrator is added which is automatically adjusted the generation to restore the frequency to it's normal value. This scheme is called automatic generation control (AGC).

### 3.1.1 Function:

The role of AGC is to divide the loads among the system, station and generator to achieve maximum economy and accurate control of the schedule interchanges of the line power while maintaining a reasonably uniform frequency.

### 3.1.2 Synchronization:

The synchronization of different system to inter connected system depends upon (1) voltage magnitude (2) Frequency (3) phase sequence.

Any wide variation from nominal value of frequency and voltage will lead the system to total collapse. Hence AGC has gained importance with the growth of interconnected systems and with rise in size of interconnected system automation of the control system have aroused. A number of control strategies exist to achieve better performance. Due to non-linearity of power system, system parameters are linearised around an operating point. PI controller is generally used. The gain value is adjusted for satisfactory transient response.

## 3.2 AGC IN SINGLE AREA SYSTEM

With the primary LFC loop, a change in the system load will result in the steady state frequency deviation depending on the governor speed regulation. In order to reduce the frequency deviation to zero, we must provide a reset action. The reset action can be achieved by introducing an integral controller to act on the load reference setting to change the speed set point. Hence the integral controller gain (k1) must be adjusted for a satisfactory transient response.

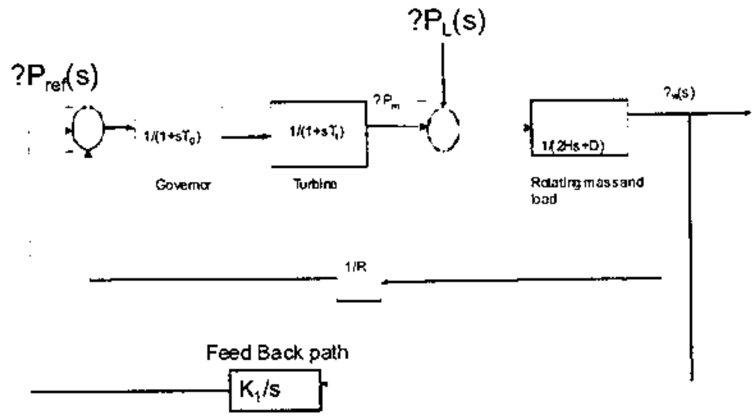
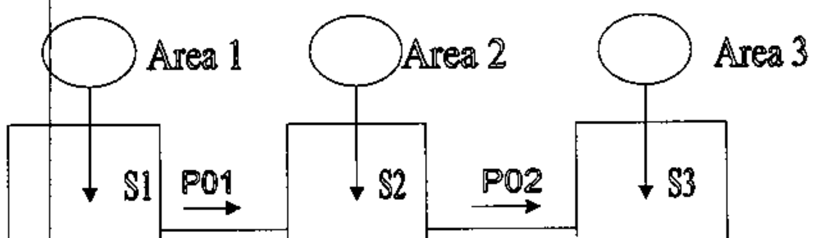



*Figure 3.2 Single-area delta connected system*

## 3.3 AGC IN THREE AREA SYSTEM



The system consisting of a turbine, generator, load and its accessories are shown in fig. Assumption made while developing the block diagram is that there are no generation rate constraints on turbines and generators. Also, generators in a sub area are tightly coupled together so as to form coherent group i.e. all generators responds in unisons to changes in load changer settings. Such a coherent area is called control area, in which frequency is assumed to be constant during static and dynamic condition. For the purpose of developing a suitable control strategy, a control area can be reduced to a single speed governor, turbo-generator and load system

Where,

Incremental tie power can be represented as

$$\Delta Ptie = T12\ (\Delta\delta 1 - \Delta\delta 2)$$

$$\Delta Ptie = 2\ \Pi T12\ [\int f1dt - [\int f2dt]$$

$$ACE1 = \Delta Ptie12 + B1\Delta f1$$

$$ACE2 = \Delta Ptie23 + B2\Delta f2$$

## 3.4 SIMULATION

The simulation is performed using MATLAB 7.0 using various parameters and tools. By interconnecting the tie line areas the following block diagram is obtained.

Here the change in power and the frequency are the two input variables. These input simulated by varying the loads of area1, area2 and area3. Here the interconnection of governor1, turbine1, generator1 and load is denoted as area1. Similarly three areas are constructed. Each area loaded separately.

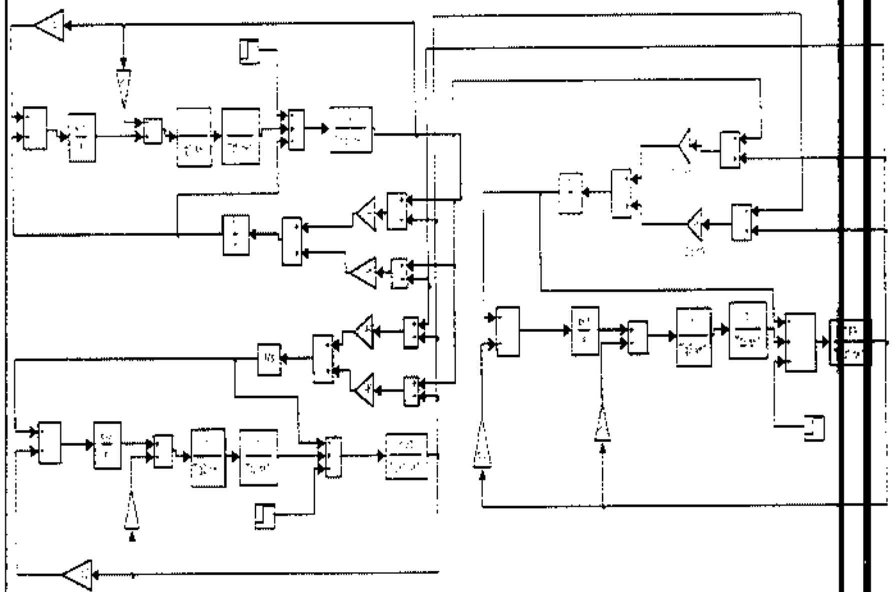


*Figure 3.4 Simulation Diagram of PI controller*

The various cases tested for simulation are

Case1: equal load (p.u)

Case2: unequal load with small changes (p.u)

Case3: unequal load with moderate changes (p.u)

Case4: unequal load with large changes (p.u)

The variation in load causes change in frequency in generation side and similarly the power changes. This change in frequency and tie line power are feedback to the input side i.e. to the PI controller. The operation of the PI controller reduces the error.

- If the load increases the power generated increases, which cause the frequency to decrease. This decrease in frequency is sensed by the sensor and send load frequency controller (here PI and fuzzy controller) through a close path.
- The PI controller controls the prime mover valve to open i.e the gain value is adjusted.
- Now the valve of the prime mover is controlled in such a way to allow require amount of steam to be passed on to the generator.
- The frequency is now comes to normal value.
- Different loads are given to generator and simulated.
- The results are shown in appendices table 3
- Table 2 shows the parameters given to the governor, turbine and generator.

### 3.4.1 Simulation using fuzzy controller:

Here, a fuzzy controller replaces the PI controller and system performance is studied. Rules are developed. IF –THEN logic is used to develop the rules. Rule viewer shown in appendices

The simulation results are as shown in fig that fuzzy controller is too fast in settling the frequency deviation to zero.

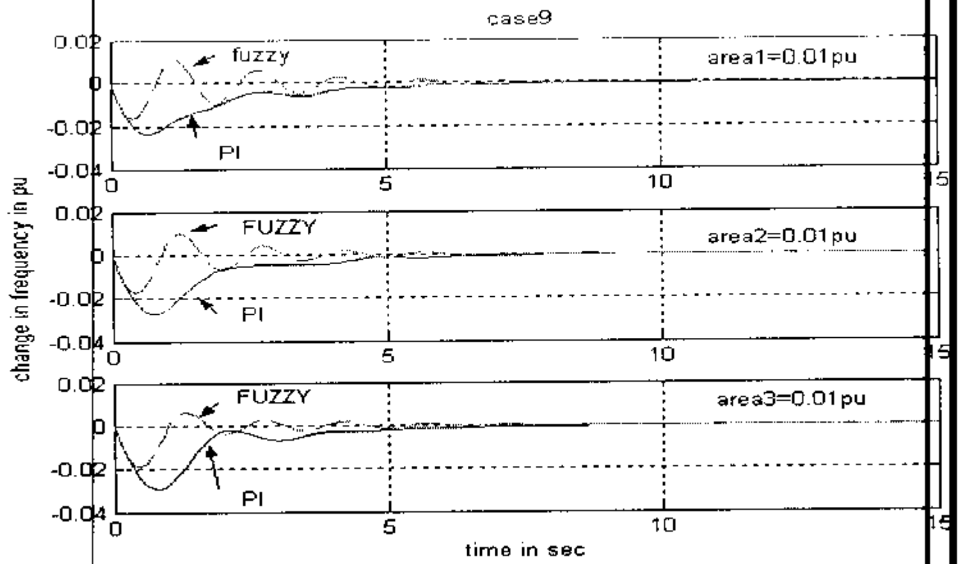



***Fig 3.4.1 Simulation result for unequal loads using PI and FUZZY controller***

Here the load is varied equally in three areas. The load is taken as 0.01 pu. The graphs are indicated by separate colors. i.e. blue indicates the operation result using PI controller and green indicates the operation result using fuzzy controller.

Table 6.1 shows the simulation workspace readings. From the table the three area loaded equally and unequally and the settling time is noted. The settling time is noted by simulating using PI and FUZZY controller.

The change in frequency settles to zero at $T_s$=12 sec using PI controller and it settles to zero at Ts=7.5 sec using fuzzy controller at area1

Some of results are shown below

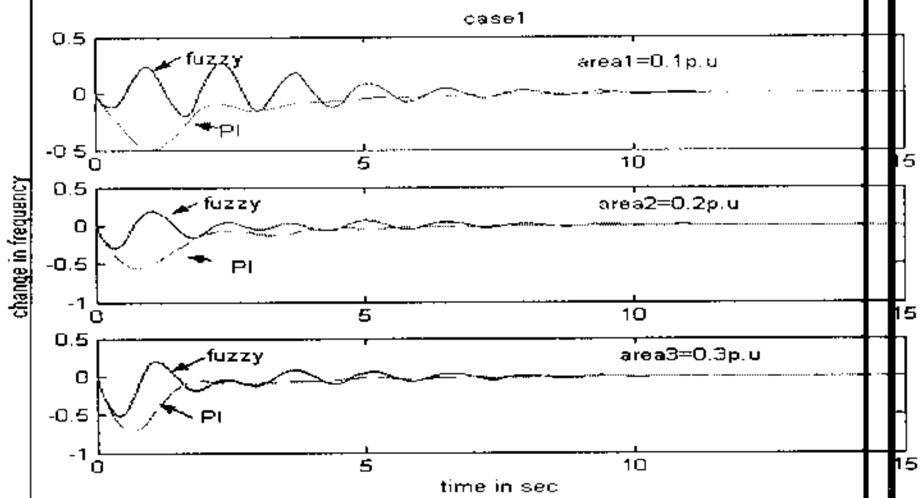
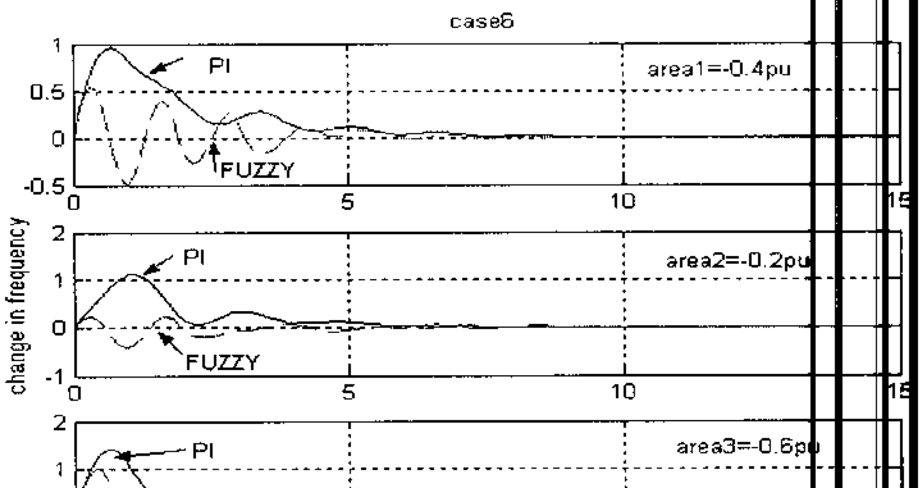



***Fig 3.4.2 Simulation result for unequal load variation with small changes***



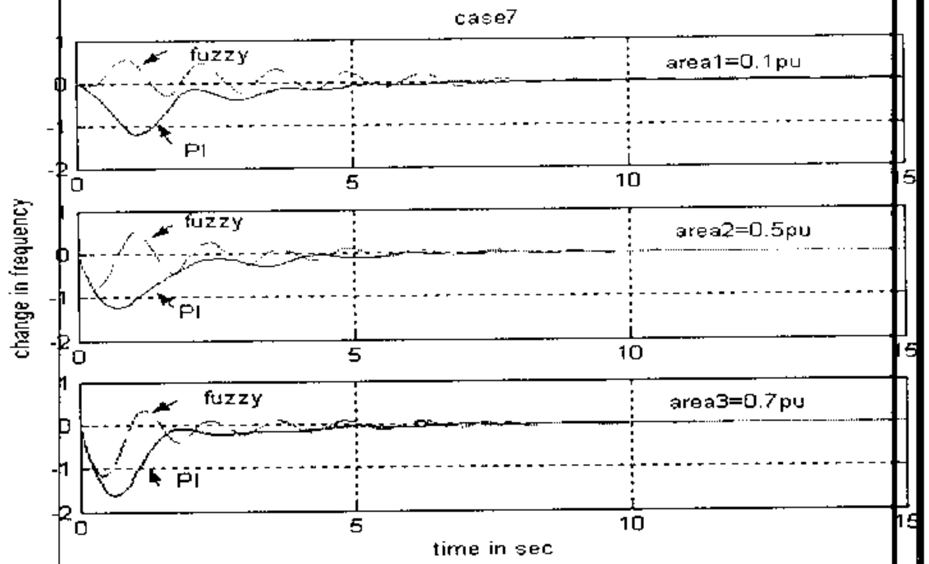
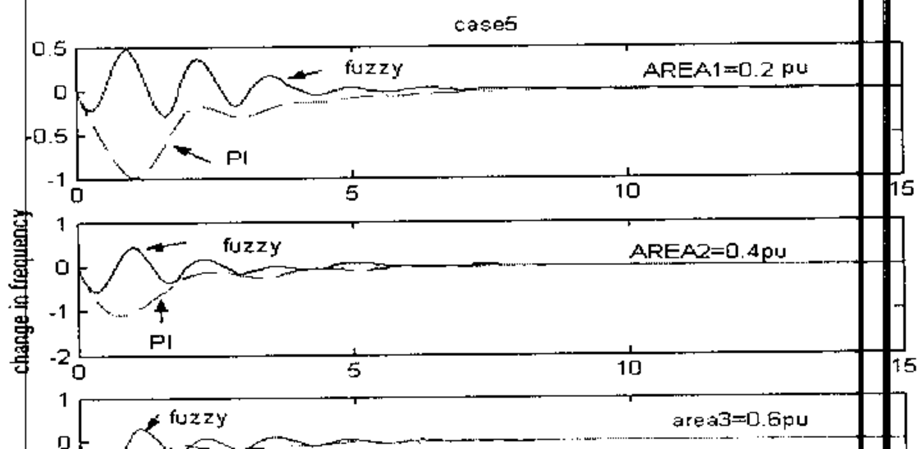



***Fig 3.4.4 Simulation result for unequal load with large changes***

The computer simulation was performed for different load changes in different areas. Some of the results are shown below



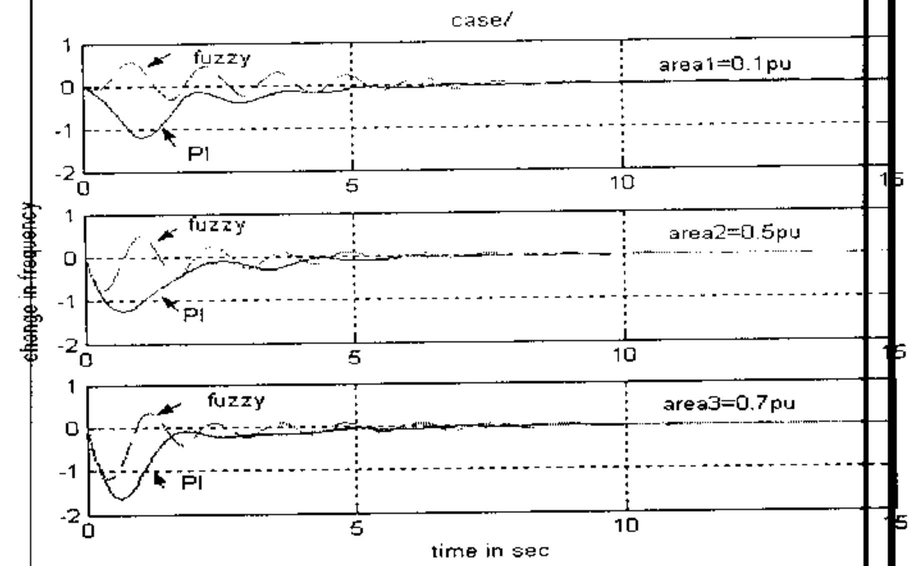
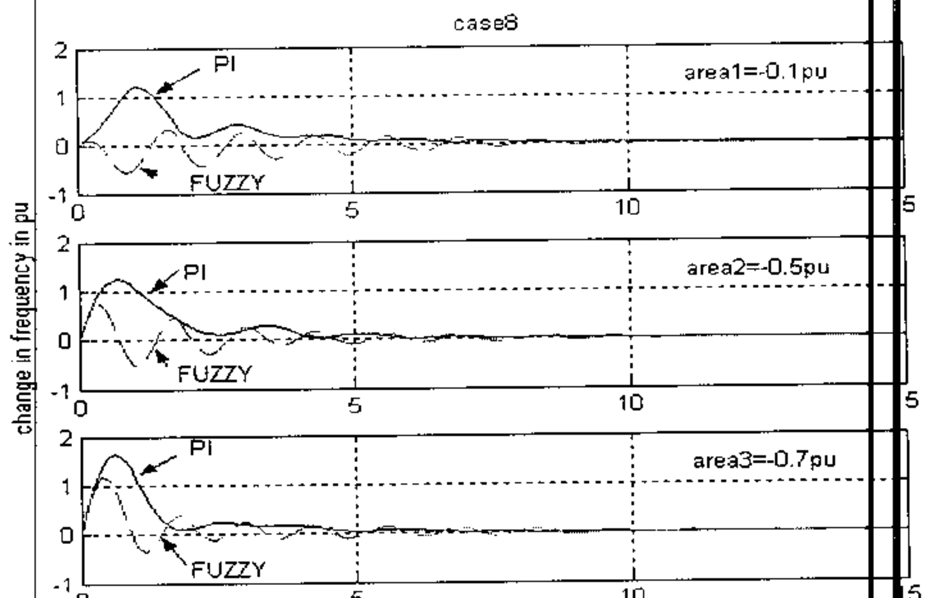



*Fig 3.4.6 load varied unequally with moderate changes in 3 areas*



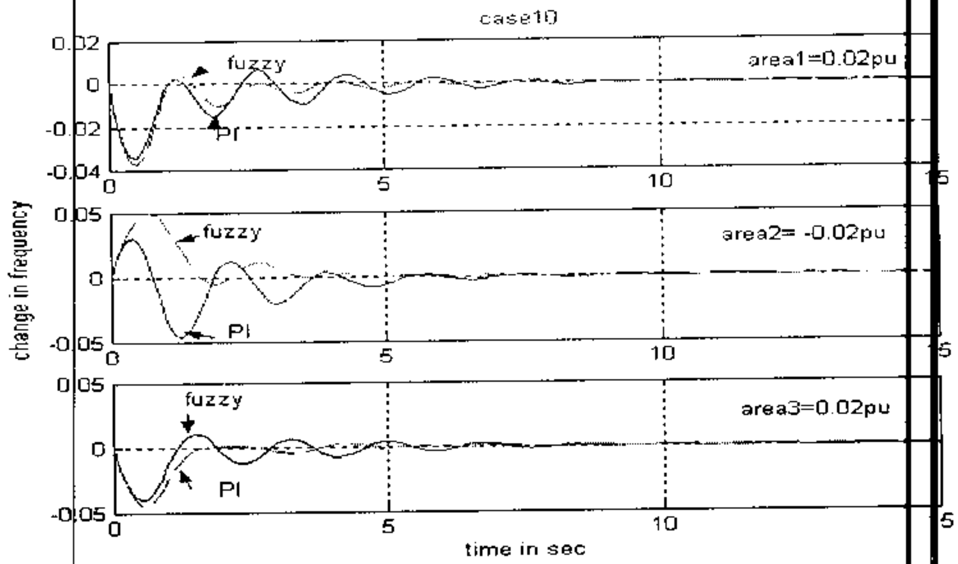
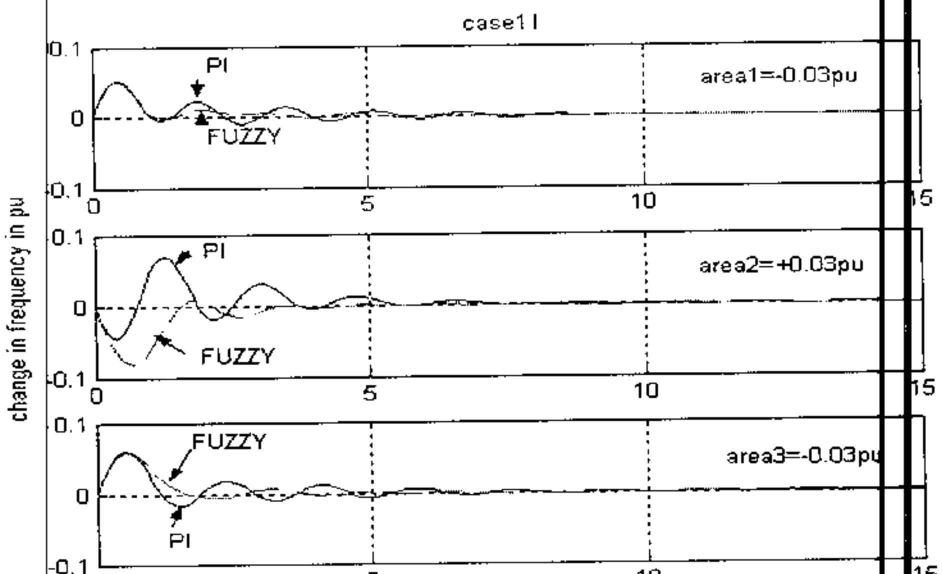



*Fig 3.4.8 load varied equally (area1 loaded to 0.02 pu., area 2 loaded to – 0.02 p.u area 3 loaded to +0.02 pu)*



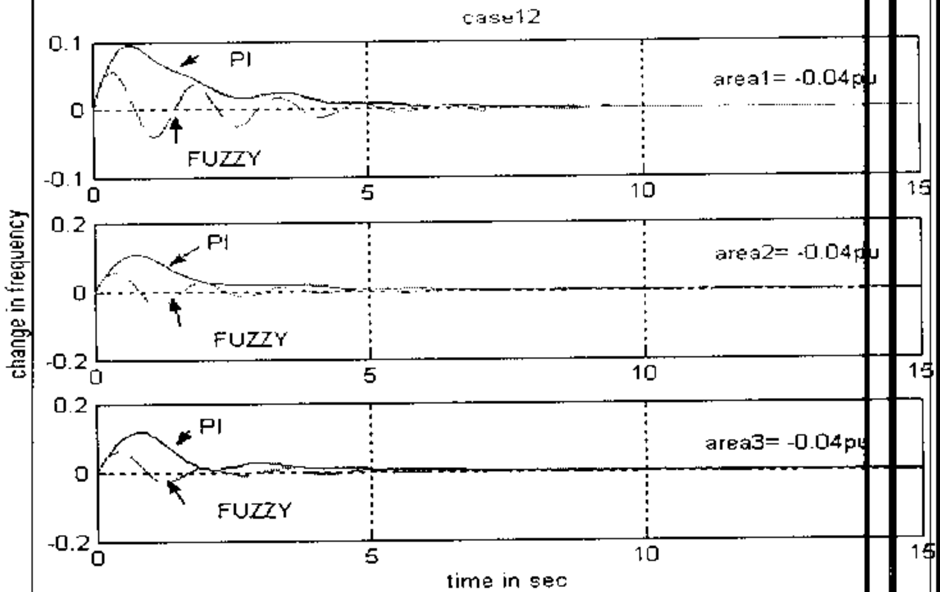



*Fig 3.4.10 load varied equally (area1 loaded to- 0.04 pu., area 2 loaded to -0.04 pu area 3 loaded to –0.04 pu)*

## 3.5 DESIGN OF PROTOTYPE CONTROLLER

It is decided to design a prototype for a generator of rating 415v in the laboratory.

### 3.5.1 DIFFICULTIES FACED

1. Selection of turbines as a prime mover to run generators

   It is difficult to install a turbine in the laboratory and change the output of the generator. Hence, we a dc shunt motor is selected as a prime mover to run the generator.

In our lab no machines with identical ratings are available. Hence we are not able to synchronize the machines. Instead of doing it for multi - area system, we have done the project for single area system and we can generalize the results to multi - area system.

Fuzzy logic is super-set of Boolean logic, which has been extended to allow partial truths. This means that it can handle things, which are neither completely true nor completely false. Fuzzy logic is not a logic that is fuzzy, but a logic that is used to describe and cope with fuzziness. Fuzzy Logic is the theory of fuzzy sets, sets that calibrate vagueness and uncertainty. FL is a problem-solving control system methodology that lends itself to implementation in various systems. FL incorporates a simple, rule-based IF X AND Y THEN Z approach to a solving control problem.

## 4.1 Why Fuzzy Logic??

Fuzzy Logic can:

- represent vague language naturally
- enrich not replace crisps sets
- allow flexible engineering design
- improve model performance
- are simple to implement

### 4.1.1 Fuzzy Applications:

Fuzzy interference system has been successfully applied in fields such as

1. automatic control
2. data classification
3. decision analysis
4. export systems and

## 4.2 Fuzzy System

Fuzzy logic implemented in three phases.

1. Fuzzification (crisp input to fuzzy set mapping)
2. Inference (Fuzzy rule generation)
3. Defuzzification (Fuzzy to crisp output transformation)

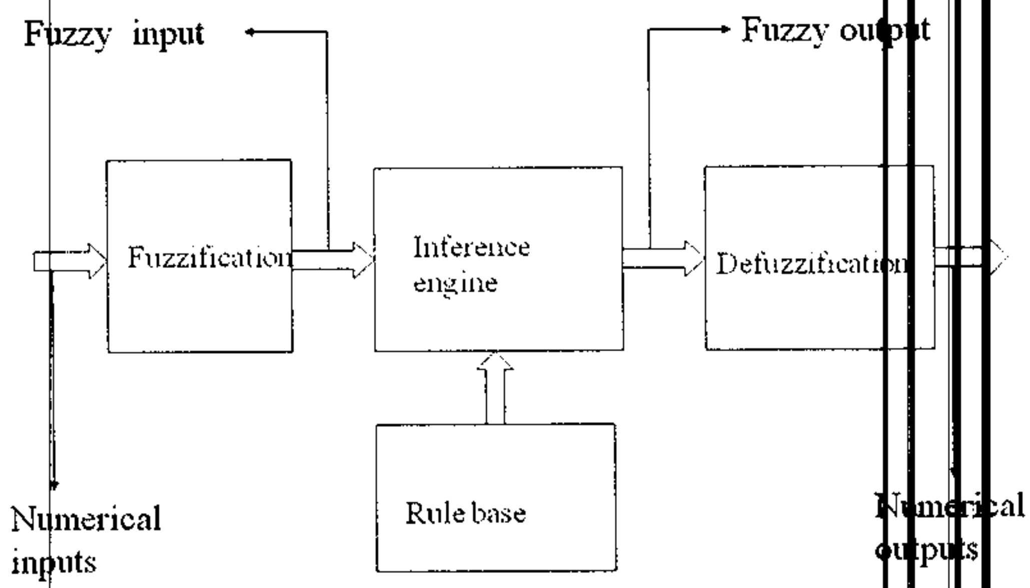



*Figure 4.2 Fuzzy Logic Implementation*

### 4.2.1 Fuzzification:

- It converts crisp values into fuzzy values.
- Two Inputs (x, y) and one output (z)
- Membership functions:
  - low(t) = 1 - ( t 10 )
  - high(t) = t 10

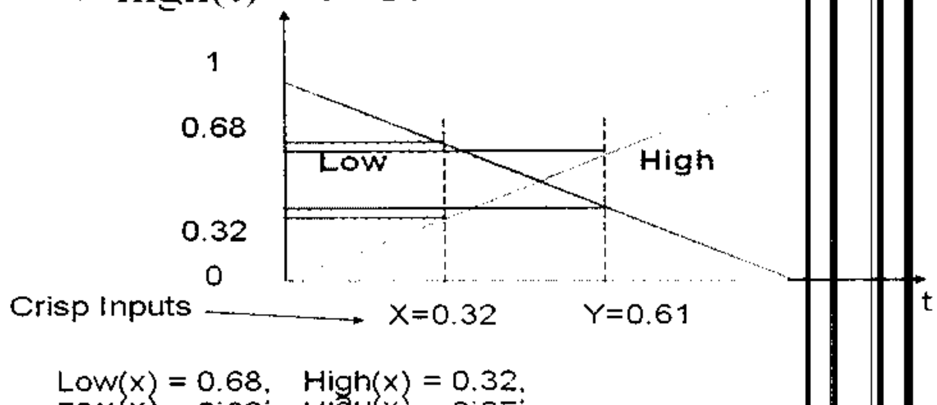



*Figure 4.2.1 Fuzzification*

**4.2.2 Inference Rules:**

The next step is to define the fuzzy rules. The fuzzy rules are merely a series of if-then statements as mentioned above. An expert usually derives these statements to achieve optimum results. The inputs are received by the system interference and all IF -THEN rules are evaluated determining the truth-values. If a given input does not precisely correspond to an IF- THEN rule then partial matching of input data is used to incorporate an answer.

The logical products for each rule must be combined or inferred before being passed on

| | 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 | | 297[illegible] | | [illegible]394.82 | |
| Del P | -970 | | -742 | | -347 | | 0 | | 277 | | 76[illegible] | | [illegible]178 | |
| NV | 1454 | | 1478 | | 1462 | | 1428 | | 1470 | | 14[illegible]4 | | [illegible]452 | |
| | 112 | -1.6 | 108 | -0.73 | 102 | -1.27 | 104 | -2.4 | 93.2 | -1 | 90 | [illegible] | 9[illegible] | -1.6 |
| NM | 1480 | | 1488 | | 1478 | | 1454 | | 1480 | | 14[illegible]4 | | [illegible]464 | |
| | 108 | -0.67 | 104 | -0.4 | 100 | -0.73 | 100 | -1.53 | 90 | -0.67 | 90 | [illegible] | 8[illegible] | -1.2 |
| NS | 1486 | | 1494 | | 1492 | | 1498 | | 1494 | | 14[illegible]4 | | [illegible]478 | |
| | 106 | -0.47 | 102 | -0.27 | 98 | -0.27 | 96 | -0.07 | 88 | -0.2 | 88 | [illegible] | 8[illegible] | -0.73 |
| ZE | 1500 | | 1500 | | 1500 | | 1500 | | 1500 | | 15[illegible] | | [illegible]500 | |
| | 104 | 0 | 102 | 0 | 98 | 0 | 93.2 | 0 | 90 | 0 | 88 | [illegible] | 8[illegible] | 0 |
| PS | 1512 | | 1504 | | 1516 | | 1508 | | 1504 | | 15[illegible]6 | | [illegible]502 | |
| | 102 | 0.4[illegible] | 102 | 0.13 | 94 | 0.53 | 94 | 0.2[illegible] | 86 | [illegible] | 86 | [illegible] | 7[illegible] | 0.07 |
| PM | 1522 | | 1568 | | 1544 | | 1524 | | 1512 | | 15[illegible]2 | | [illegible]516 | |
| | 98 | 0.73 | 96 | 2.27 | 90 | 1.47 | 92 | 0.8 | 88 | 0.4 | 84 | [illegible] | 7[illegible] | 0.53 |
| PV | 1552 | | 1588 | | 1568 | | 1550 | | 1528 | | 15[illegible]8 | | [illegible]528 | |
| | 94 | 1.73 | 90 | 2.93 | 86 | 2.27 | 88 | 1.67 | 82 | 0.93 | 80 | [illegible] | 8[illegible] | 0.93 |
| | SPEED in RPM | | | | | | | | | | | | | |
| | Voltage across Motor Field in Volt | | | | | | | Change in Frequency in Hz | | | | | | |

*Table 4.2.2 Rule Base*

### 4.2.3 Defuzzification:

Combines all fuzzy conclusions obtained by interference into a single conclusion. Different fuzzy rules have different conclusion. So it is necessary to consider all rules. There are number of composition methods are available but they lie beyond the scope of this introduction.

In our project we are implementing the **Centre of Gravity** method of defuzzification.

$$C = \frac{\int_{Min}^{Max} tf(t)\,dt}{\int_{Min}^{Max} f(t)\,dt}$$

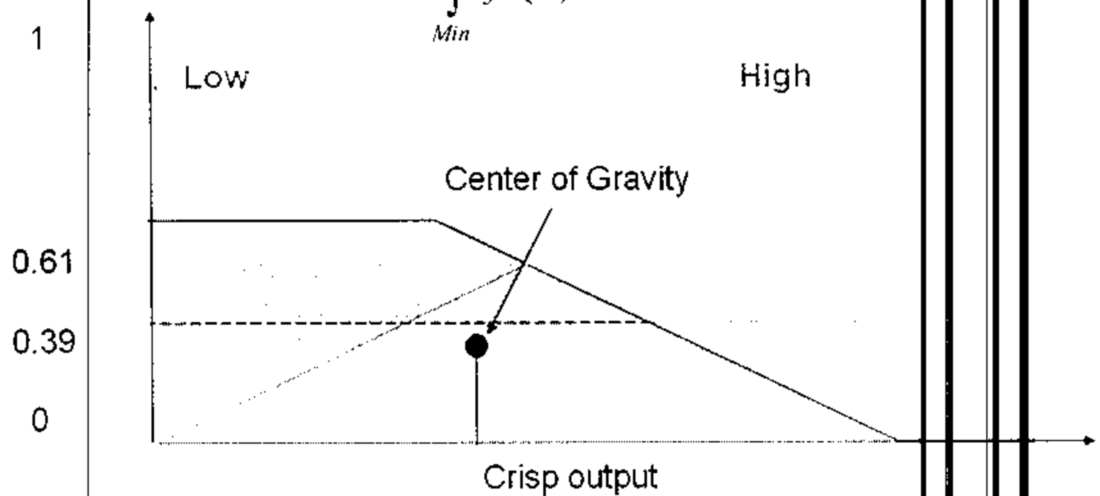
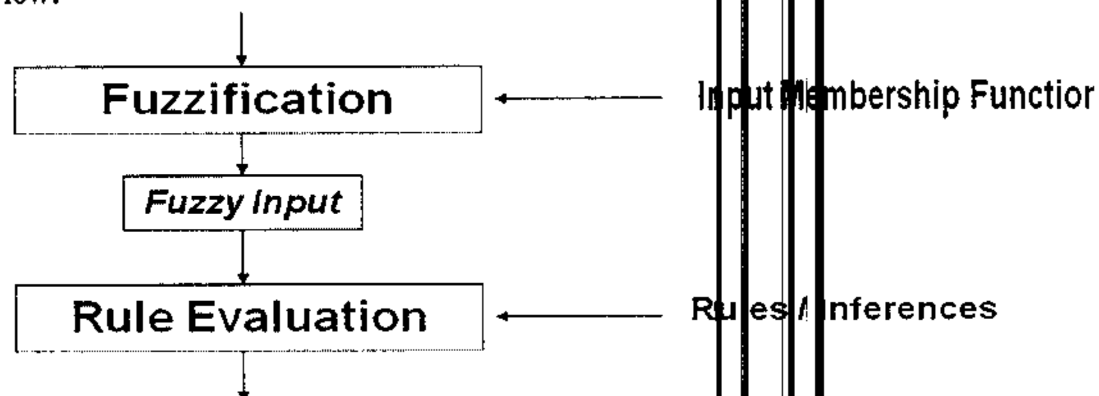



***Figure 4.2.3 Defuzzification***

**4.2.4 Operational Flow:**



### 4.2.5 Membership Function:

The membership function reflects the designer's knowledge and provides smooth transition between member and nonmembers of a fuzzy set. It is simple to calculate and the typical shapes of the membership functions are Gaussian, trapezoidal and triangular.

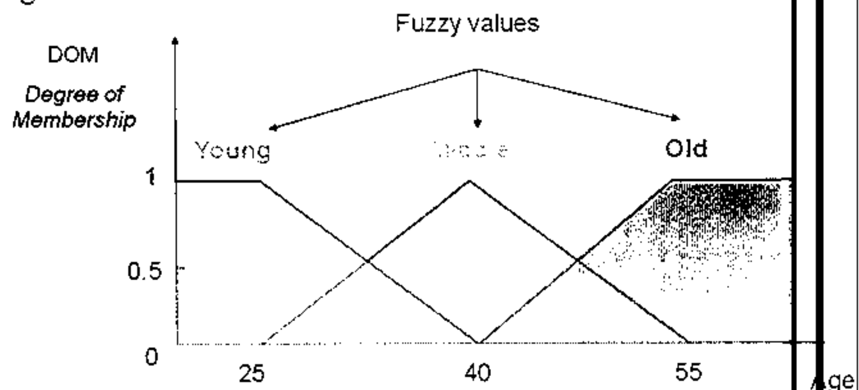



*Figure 4.2.5 Membership function of Fuzzy Logic*

#### 4.2.5.1 Input Membership Function (ΔPtie):

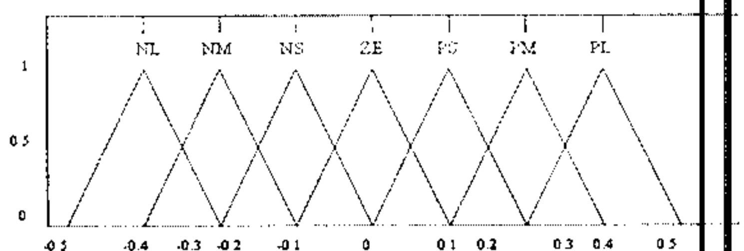



*Figure 4.2.5.1*

#### 4.2.5.2 Input Membership Function (ΔF):

#### 4.2.5.3 Output Membership Function Control Signal:

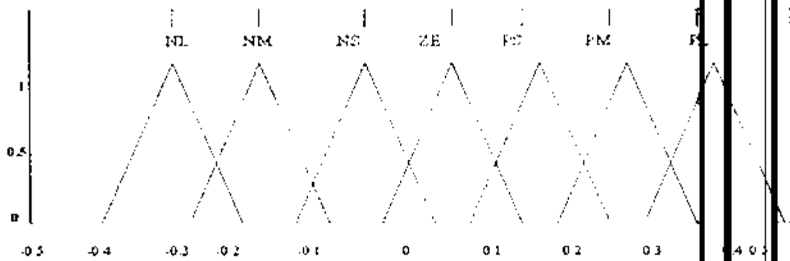
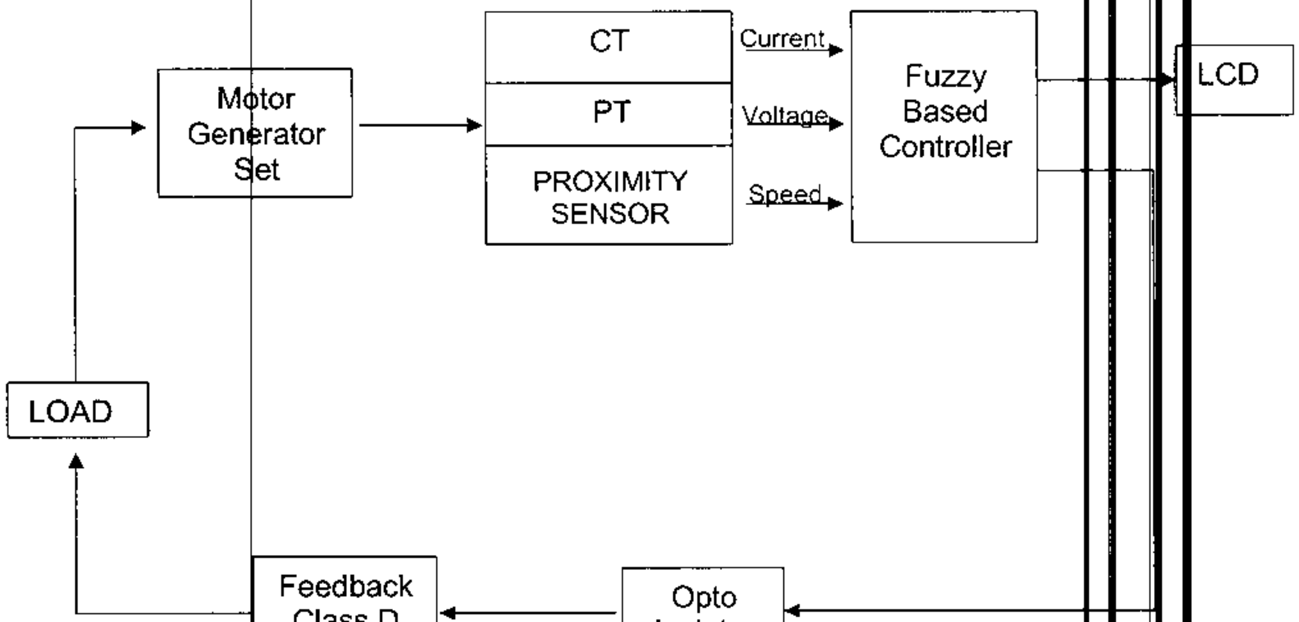



*Figure 4.2.5.3*

## 5.1 INTRODUCTION:

Load frequency control (LFC) and automatic voltage regulator (AVR) has gained importance with growth of interconnected system. They take care of small changes in load demand to maintain the frequency and voltage magnitude with in the specified limits. The operational objectives of load frequency control (LFC) are to maintain reasonably uniform frequency to divide the load between generators and to sense the change in real power. The error signal $\Delta F$ and $\Delta P$ are amplified, mixed and transformed into a real power command signal $\Delta Pv$ which is sent to the prime mover to call for an increment in torque. The prime mover therefore brings change in generator output by an amount $\Delta Pg$ will change the frequency and $\Delta Ptie$ within the specified tolerance. So the inputs to the fuzzy controller in this case would be $\Delta Ptie$ and $\Delta F$.

## 5.2 BLOCK DIAGRAM



Now let us explain each of the above circuits in detail.

## 5.3 Motor - Generator set:

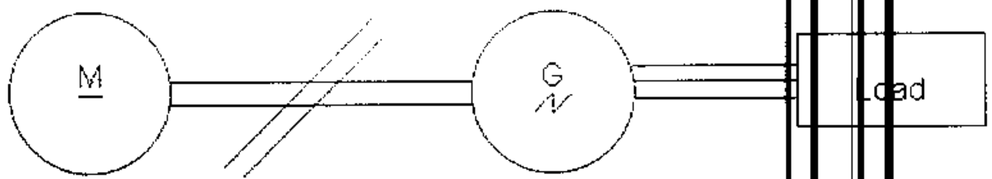
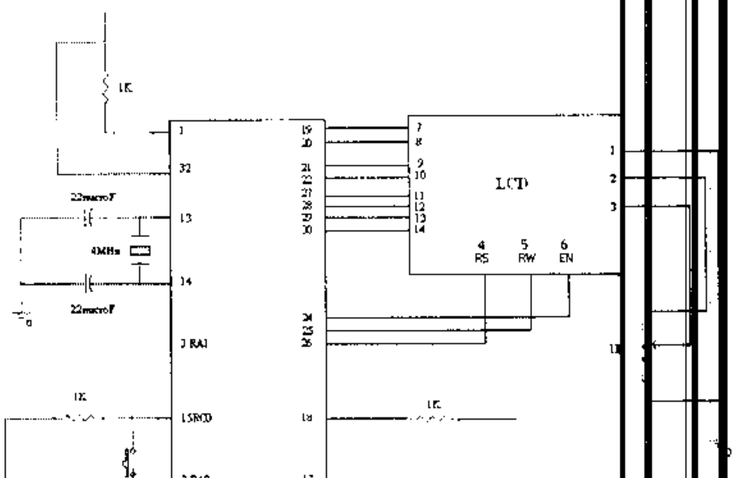



*Figure 5.3*

- A dc Motor coupled with a generator is used.
- A loading rheostat is also included in the set.
- A dc shunt motor is chosen because here, field control method may be used to increase/decrease the speed of the generator.

## 5.4 Micro-Controller Circuit:



### 5.4.1 PIC Micro Controller:

Micro controller is the tiny chip. It has inbuilt memory, timer, ports and other additional features. There are several companies, manufacturing the micro controllers like Intel, Motorola and Microchip. PIC is the product of microchip. The special characteristics of the PIC are

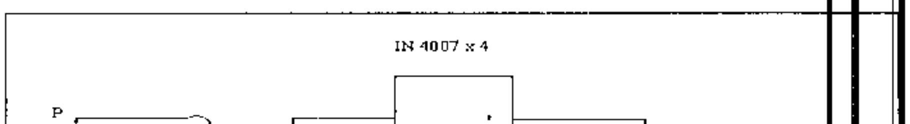
### 5.4.2 Features of the PIC:

1. Long Word Instructions
2. Single Word Instructions
3. Instruction Pipeline
4. Single Cycle Instruction
5. Reduced Instruction Set

For the pin diagram and functional block diagram of the PIC refer to APPENDIX A and APPENDIX B.

### 5.5 Potential Sensor:

They are used to transform the high voltage of the power to lower value. The primary winding of the transformer is connected across the line carrying the voltage to be measured. Since the potential transformer will be working with very high primary voltage the insulation between primary and secondary winding must be able to withstand the large potential difference. In our project the step down transformer of the 230/12V is used for sensing the voltage level.



### 5.5.1 Characteristic of potential transformers:

**1. Effect of secondary current or VA:**

If we increase the secondary burden the secondary current is increased and therefore the primary current increases. Both primary and secondary voltage drops increases and thus for a given value of $V_p$ the value of $V_s$ decreases and hence the actual ratio increases as the burden increases. The ratio error increases becoming negative with increase in burden. This variation of ratio error is almost linear with change in burden.

With regard to phase angle, the voltage $V_p$ is more advanced in phase because of increased voltage drops with increase in secondary burden. The phasor $V_s$ reversed is retarded in phase owing to increase in secondary winding voltage drops. Thus, with increase in burden the phase angle between $V_p$ and $V_s$ reversed increases becoming more negative.

**2. Effects of power factor of secondary burden:**

If the power factor of secondary circuit burden is reduced, angle ? is increased. This makes current $I_p$ to shift towards current $I_0$. The voltage $V_p$ and $V_s$ come more nearly into phase with $E_p$ and $E_s$ respectively since the voltage drops are almost constant. The result is an increase in $V_p$ to relative $E_p$ reduces relative to voltage $V_p$ . The voltage $V_s$ reduces relative to $E_S$. Therefore the transformation ratio increases as the power factor $V_S$ is advanced in phase and $V_p$ retarded in phase. The phase angle ( -ve ) reduces with decrease in secondary power factor (lagging).

changes in voltage ratio because of change in frequency are dependent upon relative values $I_0$ and leakage reactance since the effects produced by them oppose each other.

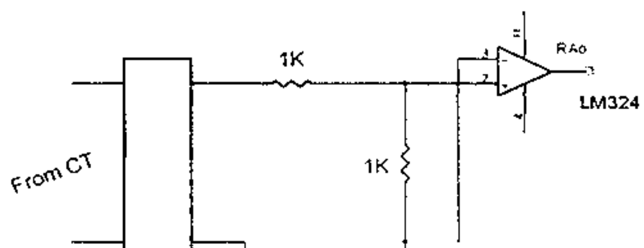
As regards phase angle error, both affects due to increase in frequency advance $V_p$ and the increase in secondary reactance retards Vs and therefore the phase angle is increased as the frequency increases.

**4. Effect of primary voltage:**

There is no wide variation of supply voltage to which the primary winding of the P.T. is connected. Therefore the study of variation of ratio and phase angle errors with supply voltage is of no importance.

## 5.6 Current Sensor:

They are used to transform the high value of current to lower value . The primary winding of the transformer is connected across the line carrying high current to be measured. The secondary winding is connected across a low range ammeter. The primary winding consists of large no. of turns and hence will be thick while secondary winding will have fewer no. of turns.



The current induced in the secondary is calculated as

$$I_2 = (N_2/N_1)*I_1$$

Where

$N_2$ - No. of turns in secondary

$N_1$ - No. of turns in primary

$I_1$ - Current flowing through primary

**5.6.1 Features of Current Sensor**

1. Inherent Short Circuit Protection
2. Variable Output Voltage
3. Low Current Device
4. Current Boosting Capability

**5.6.2 Construction**

It has two separate sections. One section consisting of zener diode, constant current source and e reference amplifier producing a fixed voltage ($V_{ref}$) the constant current source forces zener to operate at a fixed point so that the zener outputs a fixed voltage.

Other section of the IC consists of an error amplifier. This error amplifier compares the sample of the output voltage applied at the inverting input terminal (INV) to the reference voltage $V_{ref\ applied}$ at the non-inverting input terminal (NI). These two sections are not internally connected but the various points are brought out on the IC package.

## 5.7 Proximity sensor:

Inductive proximity sensors are widely used in various applications to detect metal devices. They can be used in various environments (industry, workshop, lift shaft...) and need high reliability.

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 used by a transistorized circuit to produce oscillations, generates the field. The target, 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.

## 5.8 Power Supply Circuit:

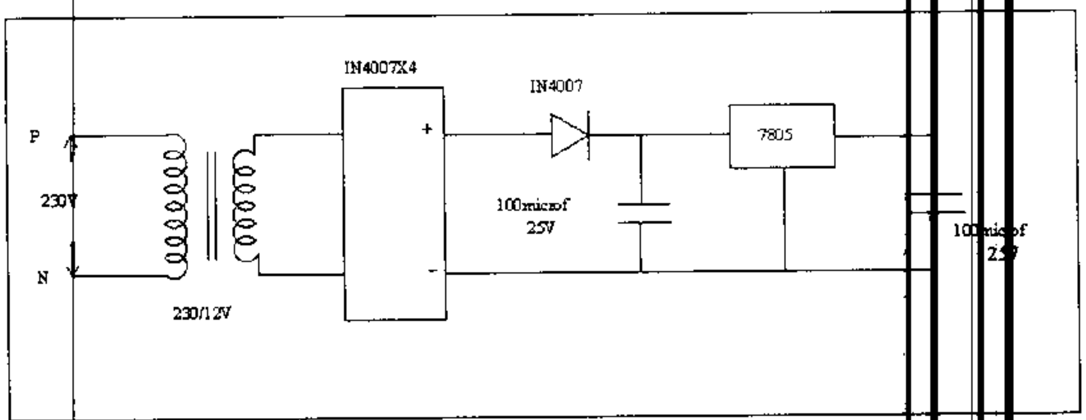



*Figure 5.8*

For the functioning of system we are in need of 5volt supply. This is developed by

The important features of a bridge rectifier:

- Current in both primary and secondary of the supply transformer flows form the entire A.C cycle and hence for a given power, power transformer of small size may be conducted.
- Less ripple voltage as compared to half wave rectifier.
- No center-tapped transformer is needed for rectification.
- Since two diodes are presented in series at each conduction path, the peak inverse voltage is shared equally by two diodes.

### 5.8.3 Filter

The filter circuit uses a capacitor filter, which filters out the A.C components of the rectified output. The output of a rectifier is pulsating in nature and contains large ripple components. Ideally the output of the rectifier system should be perfectly free from all ripple voltages. In this capacity filter stores the energy during the conduction period and delivers the energy to the load during the non-conduction period. Through this process the time interval during which the current passes through the load gets prolonged and the ripple components gets considerably reduced.

The filter waveform is essentially a D.C voltage with negligible ripples which is ultimately fed to the load.

The time constant of capacitor filter is given by, ?= C x $R_L$. The advantages of using capacitor filter in the circuit are:

### 5.8.4 Voltage regulator

A voltage regulator is a circuit that supplies a constant voltage regardless of the changes in load current. IC voltage regulators are versatile and are available with facilities such as programmable output, current / voltage boosting, internal short circuit current limiting and thermal shutdown. The power supply unit employ in this project uses 7805 voltage regulator ICs.

## 5.9 Conclusion

The ratings of the motor-generator couple used in our project are as follows:

### MOTOR RATING:

| | | |
|---|---|---|
| SPEED | : | 1500rpm |
| VOLTAGE | : | 230v |
| ARMATURE CURRENT | : | 19A |
| EXCITATION VOLTAGE | : | 130v |
| EXCITATION CURRENT | : | 0.7A |

### GENERATOR RATING:

| | | |
|---|---|---|
| SPEED | : | 1500rpm |
| VOLTAGE | : | 415v |
| ARMATURE CURRENT | : | 7A |

### 5.9.1 Details of the PIC

| Key features | PIC 16f877A |
|---|---|
| Operating Frequency | DC - 20 MHz |
| RESETS (and Delays) | POR, BOR (PWRT, OST) |
| FLASH Program Memory (14-bit words) | 8K |
| Data Memory (bytes) | 368 |
| EEPROM Data Memory | 256 |
| Interrupts | 14 |
| I/O Ports | Ports A,B,C,D,E |
| Timers | 3 |
| Capture/Compare/PWM Modules | 2 |
| Serial Communications | MSSP, USART |
| Parallel Communications | PSP |
| 10-bit Analog-to-Digital Module | 8 input channels |
| Instruction Set | 35 instructions |

***Table 5.9.1***

The ratings of the potential transformer used in our project are as follows: **460/11**

The ratings of the current transformer used in our project are as follows: **10:1**

## 6.1 HARDWARE MODULES

The hardware module we have developed consists of

- PT
- CT
- Chopper module
- Fuzzy logic controller
- Relay
- Proximity sensor

## 6.2 HARDWARE COMPONENTS TESTING

### 6.2.1 PT TESTING

Connections are properly made to check the generated voltage. The autotransformer is gradually varied in steps. Now, the voltage generated in motor can be measured using (PT) in the hardware. Any variations in the set value and the value shown in the display could be adjusted using voltage preset.

### 6.2.2 CT TESTING

Connections are properly made to check the load current. The three-phase load is varied gradually in steps. Now, the increase in load current at each load can be measured using (CT) in hardware. Any variations in the set value and value in display can be adjusted using current preset.

**PROBLEM:**

The current variations are meager to large variations in load.

**SOLUTION:**

The resistor variations are made larger according to changes in load to get actual value of current.

### 6.2.3 PROXIMITY SENSOR TESTING

It is a sensor that is used to sense the speed of the disturbances crossing the sensor. The sensor senses the disturbance and gives pulses to the unit. The time interval between the consecutive disturbances is used to calculate the speed of the shaft.

**PROBLEM:**

Due to increased speed of the shaft, the sensor quickly senses the disturbances and sends it to the unit. The time interval is very less such that the hardware unit cannot be able to respond to small changes in speed (i.e.) timer gets overflowed.

Usually the speed increases in steps of '60' since the speed has been assigned as integer in fuzzy logic coding.

**SOLUTION:**

The speed has now been assigned as float in coding such that the sensor can now sense

## 6.2.4 LOAD TEST

Load test is conducted on the dc motor – alternator set to measure the performance of machine and to calculate the change in power (ΔP) and change in frequency (Δf) under load.

## 6.4.1 LOAD TEST DIAGRAM:

These parameters (Δf & ΔP) are measured for nearly 80% of the rated load and the range upto that the power frequency deviates is noted.

From this, rules or inference table can be drawn.

| Change in freq ? F | Change in Tie line power ? $P_{tie}$ | | | | | | |
|---|---|---|---|---|---|---|---|
| | NL | NM | NS | ZE | PS | PM | PL |
| NL | NL | NL | NL | NL | NS | NM | ZE |
| NM | NL | NL | NL | NL | NM | ZE | PM |
| NS | NL | NL | NS | NM | ZE | PM | PS |
| ZE | NL | NM | NS | ZE | PS | PM | PL |
| PS | NS | NM | ZE | PM | PS | PL | PL |
| PM | NM | ZE | PM | PS | PL | PL | PL |

## 6.5 SIMULATION

At the MATLAB prompt, typing SIMULINK the SIMULINK BLOCK appears. The SIMULINK block library containing seven icons and five pull down heads appears. Each icon contains various components in a titled category. To see the content of each category double click on it's icon. The easy to use pull down menus allow to create a SIMULINK block diagram or open an existing file, perform the simulation and make any modifications. Basically one has to specify the model of the system (state space, discrete, transfer functions, non linear ode's etc) the input (source) to the system, and where the output of the simulation of the system will go. Generally when building a model, add the blocks to the model window before adding the lines that connect them.

SIMULINK is an interactive environment for modeling, analyzing and simulating a wide variety of dynamic systems. SIMULINK provides a graphical user interface for constructing block diagram models using "drag and drop" operations. A system is configured in terms of block diagram representation from a library of standard components. SIMULINK is very easy to learn. A system in block diagram representation is built easily and simulation results are displayed quickly.

Simulation algorithms and parameters can be changed in the middle of the simulation with intuitive results thus providing the user with ready access learning tool for simulating many of operational problems found in the real world. SIMULINK is particularly useful for studying the effects of nonlinearities on the behavior of the system, and such, tit also an ideal research tool.

The key features of simulink are

- Unlimited hierarchical model structure.
- Scalar and vector connections.
- Mask facility for creating custom blocks and block libraries. SIMULINK provides an open architecture that allows extending the simulation environment.
- We can easily perform "What if" analyses by changing model parameters – either interactively or in batch mode. While the simulation are running.
- Creating customs blocks and block libraries with own icons and user interfaces from MATLAB
- The C code can be generated from SIMULINK models for embedded applications and for rapid prototyping of control systems.
- We can create hierarchical models for embedded applications and for rapid prototyping of control systems.
- SIMULINK provides immediate access to the mathematical, graphical and programming capabilities of MATLAB. We can analyze data, automate procedures and optimize directly from SIMULINK.
- The advanced design and analysis capabilities of the toolboxes can be executed from with a simulation using mask facility in SIMULINK.
- The SIMULINK block library can be extended with special – purpose block sets. The DSP block set can be used for DSP algorithm development, while the fixed point block set extends SIMULINK for modeling and simulating digital control systems and digital

The simulation was done for four different cases that include both loading cases and unloading cases. In case of loading the settling time is more whereas in case of unloading settling occurs faster.

The simulation block diagram is as shown:

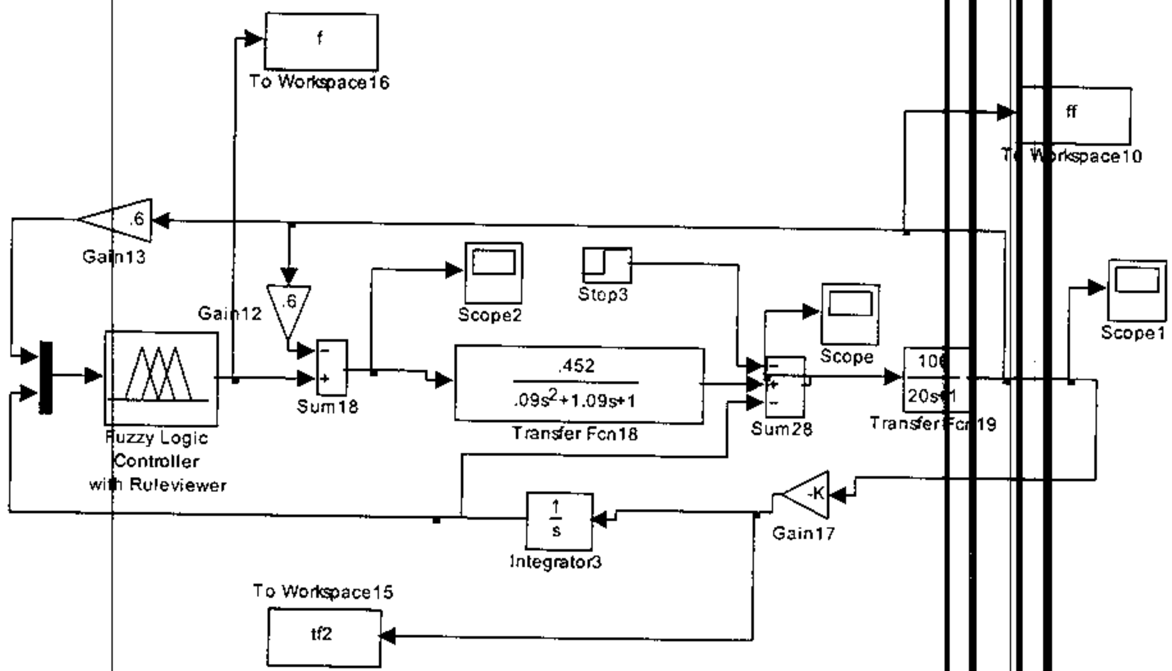
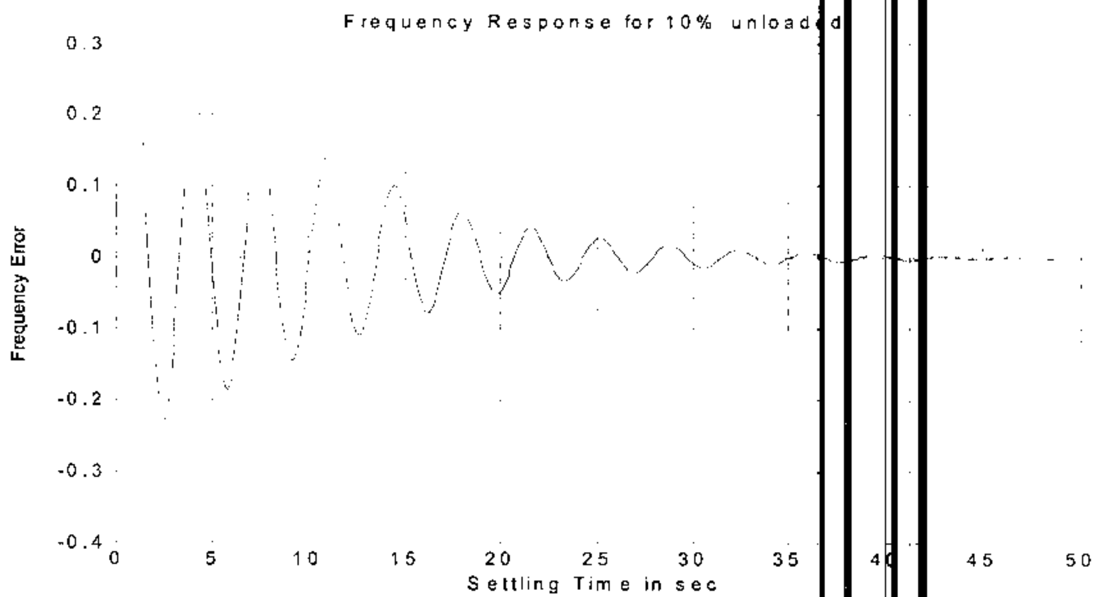
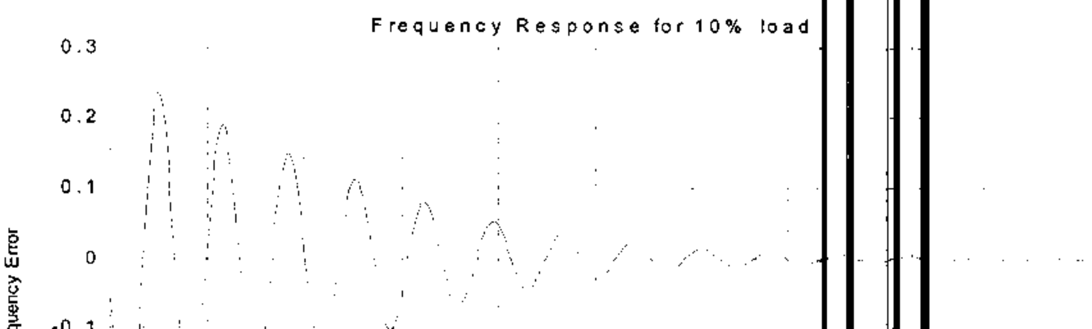


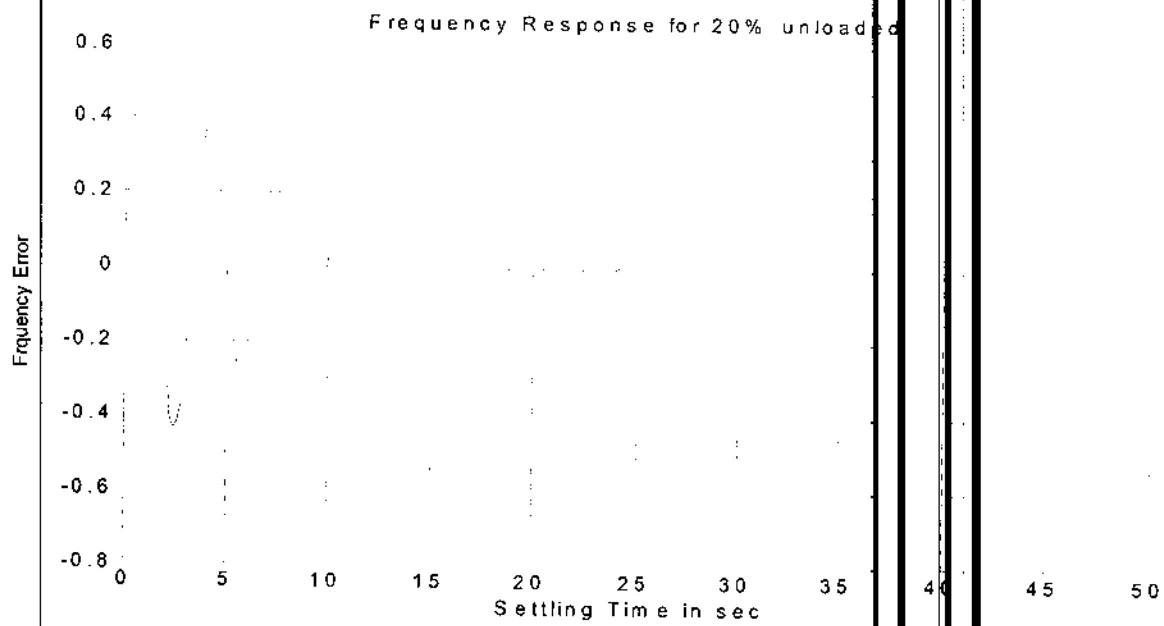

*Figure 6.5*

The following are the cases for which simulation has been done

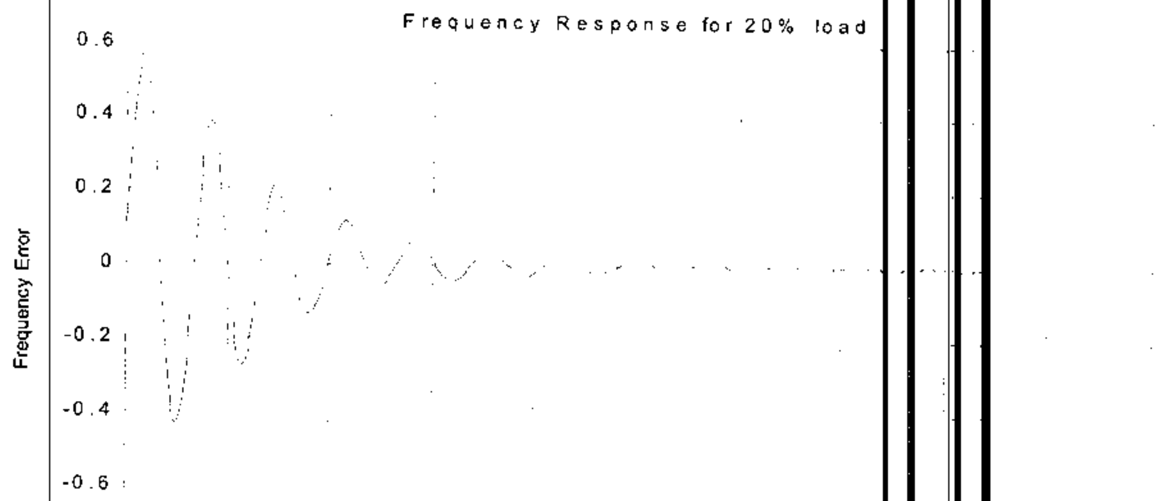
The simulated results are as follows:





Frequency Response for 20% unloaded
Frquency Error
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
5
10
15
20
25
30
35
40
45
50
Settling Time in sec

Frequency Response for 20% load
Frequency Error
0.6
0.4
0.2
0
-0.2
-0.4
-0.6

## 7.1 CONCLUSION

- This project will help in improving the quality and accuracy of the product designed. Thus economical and material waste is minimized to the maximum. Due to accuracy in achieving product specification, product rejection rate will be minimum.
- This project will be highly useful for Textile Industries, Apparel Industries, Rolling mills and Foundries. By maintaining frequency a constant the life of motors is increased, but at low frequency the motor reaches Magnetic Saturation and gets heated.
- The computer simulation was performed for different load changes in different areas. These simulation results were 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.
- The fuzzy logic approach yields automatic, self-adjusting outputs irrespective of widely varying, uncertain of normal conditions.
- The memory burden and computational burden and time reduce drastically in the fuzzy logic approach as it involves only IF-THEN logic in fuzzy interference engine and accordingly output decision is taken.

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

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.

## 7.2 FUTURE ENHANCEMENT

In our project we have implemented fuzzy controller module for single area system .In this we have taken change in power (ΔP) and change in frequency (ΔF) as the input parameters to fuzzy controller and with if-then-else logic the firing angle of the chopper (a) is decided to stabilize the frequency deviations and maintain the frequency at rated value.

If we extend this idea to multi-area system we need to measure the change in tie-line power of the machines connected in synchronous condition. Here the change in tie-line power (ΔPtie) and change in frequency (ΔF) are the input parameters to fuzzy controller to control the frequency deviations.

# ANNEXURE

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

unsigned int volt1,cur1;
unsigned char count=1,V1HUN,V1TEN,V1ONE, I1HUN,I1TEN,I1ONE,F1HUN,F1TEN,
F1ONE,N1TENTHO,N1THO,N1HUN,N1TEN,N1ONE;
unsigned int I1,I2,V1,F1,N1,rpm;
unsigned int fsch,fact,set;
unsigned int pact,psch,TON,TOFF,TMR1;
signed int df,dp;
signed float f,t1,t2,t;

void main()
{
    TRISD=0X00;
    TRISE=0X00;
    PORTD=0;
    PORTE=0;


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

    T2CON=0X05;
    TRISC=0X00;

    TRISB=0x03;
    PORTB=0;
    OPTION=0x88;
    GIE=PEIE=INTE=T0IE=1;

    lcd_init();

    while(1)
```

```
delay();

ADCON0=0X89;
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;
F1=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=F1/30;
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_data(F1ONE);
t=0;
delay2();
```

```
fsch=50;
fact=N1/30;
df=fact-fsch;

if(dp>=-150)
{
        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<=-800)
{
        TON=4521;
        TOFF=547
```

```
            }
    }

    if(dp>=-500)
    {
            if(dp<=900)
            {
                    TON=3826;
                    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()
{
```

```
void interrupt isr()
{
/**********SPEED START***********/

if(INTF==1)
    {
        INTF=0;
        t1=t2;
        t2=TMR0;
        if(set==0)
            t=t2-t1;
        else
        {
            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;
```

```
            RC3=1;
            count=0;
        }
        if(df>0)
        {
            TON=TON+5;
            TOFF=TOFF-5;
        }
        if(df<0)
        {
            TON=TON-5;
            TOFF=TOFF+5;
        }
    }
}
```

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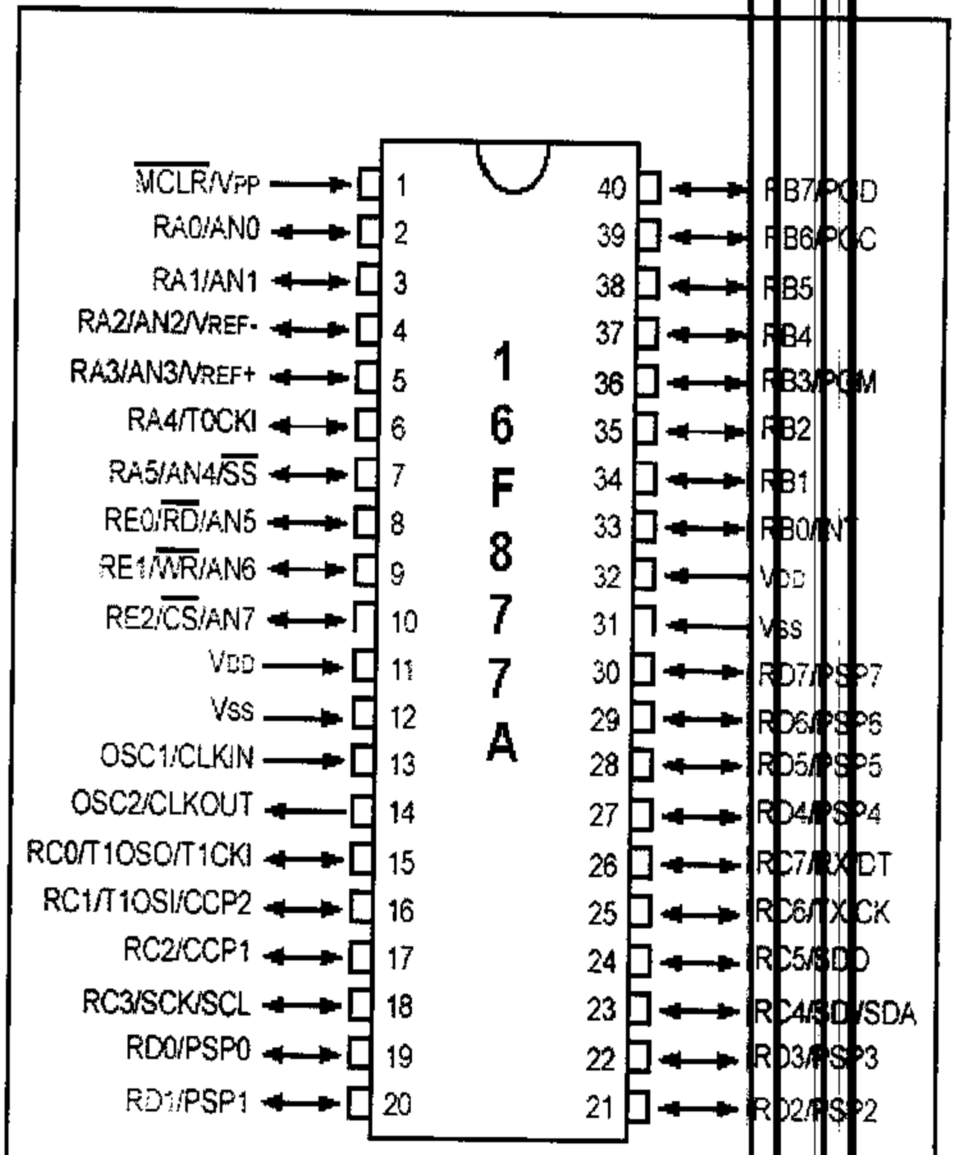
# APPENDIX A

**Pin Diagram (16F877A)**



# APPENDIX B

## Functional Block Diagram (16F877A)