الآية

قال تعالى :

(وَقُلِ اعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ)

صدق الله العظيم

سورة التوبة
105

DEDICATION

To our parents who always inspiring and devising us, nothing of this could be done without them, may Allah saves them always for us.

To our brothers and sisters support us to go forward.

To our best friends and colleagues who are always with us step by step.

To anyone who is an integral part of our support group, we dedicate this project.

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The greatest thanks to Allah before and after.

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Most grateful and appreciation to our supervisor

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For their expertise support and endless valuable advices which guided us throughout this work and our engineering career life.

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Special thanks for engineers Omer Ugoul and Ghanim Ibrahim

ABSTRACT

Since a power system are nonlinear there are always small load changes, switching actions, and other transients occurring so that in a strict mathematical sense most of the variables are varying with the time, it is hard to achieve a satisfactory performance by the conventional proportional integral derivative (PID) control scheme. For the dynamic characteristics of the frequency, the fuzzy logic controller in addition to PID controller is proposed to look for performance and robustness improvement.

Fuzzy logic controller with PID controller (FPD&I) is designed to achieve good performance. Simulation results show the effectiveness of the proposed controller compared with conventional ones.

المستخلص

تعتبر نظم القدرة الكهربائية أنظمة غير خطية لذلكفإنالتغيراتالطفيفة في الأحمال أو عملياتالفتح والإغلاق للمفاتيح أو الأعطال والحالات العابرة وبالتالي نجد أن معظم المتغيرات تتغير مع الزمن مما يؤدي الى تغير التردد ومن ثم فقدان المنظومة للتزامن. يصعب تحقيق أداء جيد عن طريق إستخدام المتحكمات التقليدية مثل المتحكم التناسبي التكاملي التفاضلي. لذا في حالة التغييرات الديناميكية للأحمال يمكن تحسين أستجابة التردد عن طريق إستخدام المتحكم الغامض مضافاً إليه المتحكم التناسبي التكاملي التفاضلي .

وبإستخدام برنامج المحاكاة في تطبيقات الحاسوب (الماتلاب). تظهر النتائج أفضلية أداء المتحكم الغامض مضافاً اليه المتحكم التناسبي التكاملي التفاضلي مقارنة مع المتحكم التناسبي التكاملي التفاضلي منفرداً.

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CHAPTER ONE

INTRODUCTION

1.1 General

Energy is the basic necessity for the economic development of a country. Many functions necessary to present-dayliving grind to halt when the supply of energystops. It is practically impossible to estimate theactual magnitude of the part that energy hasplayed in the building up of present-daycivilization. The availability of huge amount ofenergy in the modern times has resulted in ashorter working day, higher agricultural and industrial production, a healthier and more balanced diet and better transportation facilities. As amatter of fact, there is a close relationship between the energy used per person and his standard of living. The greater the per capita consumption of energy in a country, the higher is thestandard of living of its people.

Energy exists in different forms in nature butthe most important form is the electrical energy.The modern society is so much dependent upon the use of electrical energy that it has become a part and parcel of our life [1].

Since electrical energy is produced from energy available in various forms in nature, it is desirable tolook into the various sources of energy such as sun, wind, water, nuclear…..etc. It has two main component voltage, and current this component may have constant value upon a time called Direct Current (DC), or have variable value upon a time known as Alternating Current (AC).

1.2 Problem statement

A power system is predominantly in steady state operation or in astate that could with sufficient accuracy be regarded as steady state.In a power system there are always small load changes, switching actions,and other transients occurring so that in a strict mathematical sense mostof the variables are varying with thetime.In a power system the load demand is continuously changing.

In accordance with in the power input has to vary .If the input – output balance is not maintained a change in frequency will occur. The control of frequency is achieved primary through speed governor mechanism aided by supplementary means for precise control.

1.3 Objectives

To keep the system frequency constant or within limit ($\pm5\%$). And to achieve good performance of the power plant we will:

- ✓ Develop a mathematical model and SIMULINK for power plant.
- ✓ Apply Proportional Integral and Derivative (PID) controller to power plant.
- ✓ Design Fuzzy Logic Controller (FLC) for power plant.
- ✓ Design FLC&PID controller for power plant.
- ✓ Compare FLC&PID controller with PID controller.

1.4Methodology

The mathematical model of power plant has been developed and by using MATLAB TOOLBOX this mathematical model has been converted to SIMULINK. After that Fuzzy Logic controller (FLC) has been designed. Then PID controller was applied to power plant. Finally the response of controllers has been compared.

1.5 Layout

This project consists of five chapters. Chapter one gives introduction, problem statement, objectives, and methodology. Chapter two gives general background, steam power station, speed of steam turbine, control background, and speed control of steam turbine. Chapter three represents Introduction, and the mathematical models of generator, load, turbine, and governor. Chapter four gives introduction to MATLAB, design of fuzzy logic controllerSIMULINK and simulation results. Chapter five gives conclusion and recommendations of the work.

CHAPTER TWO

LITERATURE REVEIW

2.1 General Background

Bulk electric power is produced by special plants known as generating stations or power plants. A generating station essentially employs a prime mover coupled to an alternator for the production of electric power. The prime mover (e.g., steam turbine, water turbine etc.) converts energy from some other form into mechanical energy. The alternator converts mechanical energy of the prime mover into electrical energy. The electrical energy produced by the generating station is transmitted and distributed to various consumers, with the help of conductors. Apart from prime mover-alternator combination, it may be emphasized here that, a modern generating station employs several auxiliary equipment and instruments to ensure cheap, reliable and continuous service [1].

Depending upon the form of energy converted into electrical energy, the generating stations are classified as:

- ✓ Steam power stations
- ✓ Hydroelectric power stations
- ✓ Diesel power stations
- ✓ Nuclear power stations
- ✓ Solar power station
- ✓ Wind power station
- ✓ Tidal power station
- ✓ Chemical oxidation – reduction reaction cells (Batteries)
- ✓ Small - size electric generators

2.2Steam power station

Steam power station simply involves the conversion of heat of coal combustion into electrical energy. A modern steam power station is highly complex and has numerous equipments and auxiliaries. However, the most important constituents of a steam power station are:

- Steam generating equipment
- Condenser
- Electrical equipment.
- Water treatment plant
- Prime mover

2.2.1 Steam generating equipment

This is an important part of steam power station. It is concerned with the generation of superheated steam and includes such items as boiler, boiler furnace, super heater, economizer, air pre-heater and other heat reclaiming devices [1].

- **Boiler**

A boiler is closed vessel in which water is converted into steam by utilizing the heat of coal combustion.Steam boilers are broadly classified into **water tube boilers** in which water flows through the tubes and the hot gases of combustion flow over these tubes. On the other hand **Fire tube boiler** in which the hot products of combustion pass through the tubes surrounded by water.

However water tube boilers have a number of advantages over fire tube boilers viz., they require less space, smaller size of tubes and drum, high working pressure due to small drum, less liable to explosion etc. Therefore, the use of water tube boilers has become universal in large capacity steam power stations [1].

➢ Boiler furnace

A boiler furnace is a chamber in which fuel is burnt to liberate the heat energy. In addition, it provides support and enclosure for the combustion equipment i.e., burners. The boiler furnace walls are made of refractory materials such as fire clay, silica, kaolin etc. These materials have the property to resist change of shape, weight or physical properties at high temperatures. Hereby are three types of construction of furnace walls:

- ✓ Plain refractory walls.
- ✓ Hollow refractory walls with an arrangement for air cooling.
- ✓ Water walls.

The plain refractory walls are suitable for small plants where the furnace temperature may not be high. However, in large plants, the furnace temperature is quite high and consequently, the refractory material may get damaged. In such cases, refractory walls are made hollow and air is circulated through hollow space to keep the temperature of the furnace walls low. The recent development is to use water walls. These consist of plain tubes arranged side by side and on the inner face of the refractory walls. The tubes are connected to the upper and lower headers of the boiler. The boiler water is made to circulate through these tubes. The water walls absorb the radiant heat in the furnace which would otherwise heat up the furnace walls [1].

➢ Super heater

A super heater is a device which superheats the steam i.e., it raises the temperature of steam above boiling point of water. This increases the overall efficiency of the plant. A super heater consists of a group of tubes made of special alloy steels such as chromium-molybdenum. These tubes are heated by the heat of flue gases during their journey from the furnace to the chimney.

The steam produced in the boiler is led through the super heater where it is superheated by the heat of flue gases. Super heaters are mainly classifiedaccording to the system of heat transfer from flue gases to steam into **radiant super heater** in which is placed in the furnace between the water walls and receives heat from the burning fuel through radiation process. It has two main disadvantages. Firstly, due to high furnace temperature, it may get overheated and, therefore, requires a careful design. Secondly, the temperature of super heater falls with increase in steam output. Due to these limitations, radiant super heater is not finding favor these days. On the other hand **Convection super heater** in which is placed in the boiler tube bank and receives heat from flue gases entirely through the convection process. It has the advantage that temperature of super heater increases with the increase in steam output. For this reason, this type of super heater is commonly used these days [1].

- **Economizer**

It is a device which heats the feed water on its way to boiler by deriving heat from the flue gases. This results in raising boiler efficiency, saving in fuel and reduced stresses in the boiler due to higher temperature of feed water. An economizer consists of a large number of closely spaced parallel steel tubes connected by headers of drums. The feed water flows through these tubes and the flue gases flow outside. A part of the heat of flue gases is transferred to feed water, thus raising the temperature of the later [1].

- **Air Pre-heated unit**

Super heaters and economizers generally cannot fully extract the heat from flue gases. Therefore, pre-heaters are employed which recover some of the heat in the escaping gases. The function of an air pre-heater is to extract heat from the flue gases and give it to the air being supplied to furnace for coal combustion. This raises the furnace temperature and increases the thermal efficiency of the plant. Depending upon the method of transfer of heat from flue gases to air, air pre-heaters are divided into **recuperative type** in which consists of a group of steel tubes. The flue gases are passed through the tubes while the air flows externally to the tubes. Thus heat of flue gases is transferred to air. On the other hand **regenerative type** in which consists of slowly moving drum made of corrugated metal plates. The flue gases flow continuously on one side of the drum and air on the other side. This action permits the transference of heat of flue gases to the air being supplied to the furnace for coal combustion [1].

2.2.2 Condensers

A condenser is a device which condenses the steam at the exhaust of turbine. It serves two important functions. Firstly, it creates a very low pressure at the exhaust of turbine, after releasing from nozzles. Secondly, the condensed steam can be used as feed water to the boiler. A steam condensing plant or simply steam condenser consists of:

- Condenser chamber: where steam gets condensed.
- Cooling water supply: This provides cold water to condense steam by heat exchanging.
- Wet Air pumps: They collect condensed steam, the air and un-condensed water vapors and gases from condenser.

- Hot well in which the condensed steam is collected and from it steam boiler feed water may be taken if required.

In a steam condenser, steam is always condensed with help of cooling water, but the techniques are different for different condensers. Depending upon condensation techniques, there are two types of condensers, namely: Jet condenser and Surface condenser.

In a jet condenser, cooling water and exhausted steam are mixed together. Therefore, the temperature of cooling water and condensate is the same when leaving the condenser. Advantages of this type of condenser are: of low initial cost, less floor area required, less cooling water required and low maintenance charges. However, its disadvantages are: condensate is wasted and high power is required for pumping water.

In a surface condenser, there is no direct contact between cooling water and exhausted steam. It consists of a bank of horizontal tubes enclosed in a cast iron shell. The cooling water flows through the tubes and exhausted steam over the surface of the tubes. The steam gives up its heat to water and it is condensed. Advantages of this type of condenser are: condensate can be used as feed water, less pumping power required and creation of better vacuum at the turbine exhaust. However, disadvantages of this type of condenser are: high initial cost requires large floor area and high maintenance charges [2].

2.2.3 Water treatment plant

Boilers require clean and soft water for longer life and better efficiency. However, the source of boiler feed water is generally a river or lake which may contain suspended and dissolved impurities, dissolved gases etc. Therefore, it is very important that water is first purified and softened by chemical treatment and then delivered to the boiler.

The water from the source of supply is stored in storage tanks. The suspended impurities are removed through sedimentation, coagulation and filtration. Dissolved gases are removed by aeration and degasification. The water is then 'softened' by removing temporary and permanent hardness through different chemical processes. The pure and soft water thus available is fed to the boiler for steam generation [1].

2.2.4 Electrical equipments

A modern power station contains numerous electrical equipments. However, the most important items are:

- Alternators. Each alternator is coupled to a steam turbine to convert mechanical energy of the turbine into electrical energy. The alternator may be hydrogen or air cooled. The necessary excitation is provided by means of main and pilot exciters directly coupled to the alternator shaft.
- Transformers. A generating station has different types of transformers:
  - ✓ Main step-up transformers which step-up the generation voltage for transmission of power.
  - ✓ Station transformers which are used for general service (e.g., lighting) in the power station.
  - ✓ Auxiliary transformers which supply to individual unit-auxiliaries.
- Switchgear. It houses such equipment which locates the fault on the system and isolates the faulty part from the healthy section. It

contains circuit breakers, relays, switches and other control devices [1].

2.2.5 Prime movers

The prime mover converts steam energy into mechanical energy. There are two types of steam prime movers viz., steam engines and steam turbines. A steam turbine has several advantages over a steam engine as a prime mover, due high efficiency, simple construction, higher speed, less floor area requirement and low maintenance cost. Therefore, all modern steam power stations employ steam turbines as prime movers [1].

A large portion of the conversion of thermal to electrical energy occurs in steam turbines. This is due to the many advantages of the steam turbine over reciprocating engines. Among these advantages are the balanced construction, relatively high efficiency, few moving parts, ease of maintenance, and availability in large sizes. Internally, the steam turbine consists of rows of blades designed to extract the heat and pressure energy of the steam, which is usually superheated, and convert this energy into mechanical energy. To accomplish this goal, high-pressure steam is admitted through a set of control valves and allowed to expand as it passes through the turbine, to be exhausted, usually to a condenser, at relatively low pressure and temperature. Thus, the type and arrangement of turbine blades are important in extracting all possible energy from the steam and converting this energy into the mechanical work of the spinning turbine rotor and attached electric generator. Steam turbines are generally classified into two types according to the action of steam on moving blades vise [2].

- ✓ Impulse blades

The steam expands and its pressure drops as it passes through a nozzle, leaving the nozzle at high velocity as shown in Figure 2.1. This kinetic energy is converted into mechanical energy as the steam strikes the moving turbine blades and pushes them forward.

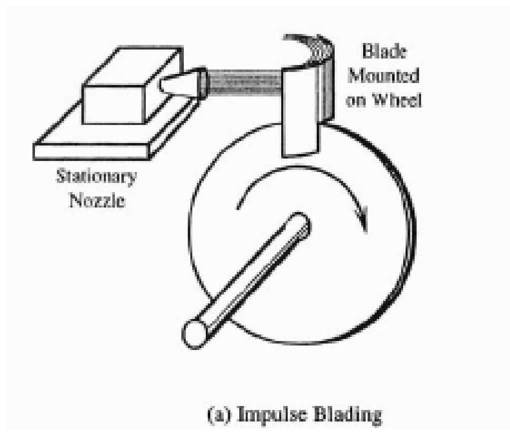


Figure 2.1 Impulse blades turbine

- ✓ Reaction blades

Operate on a different principle, as illustrated in Figure 2.2. Here the "nozzle" through which the steam expands is moving with the shaft, giving the shaft a torque due to the unbalanced forces acting on the blade intake and exhaust surfaces.

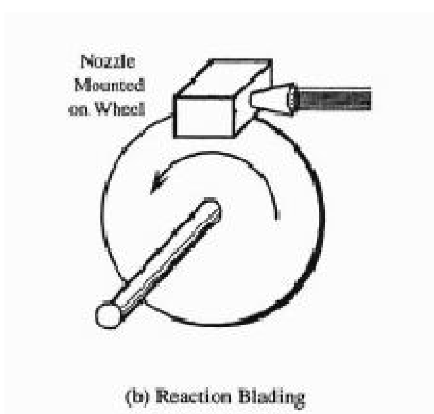


Figure 2.2 Reaction blade turbines

In many turbines, impulse stages are used at the high-pressure, high-temperature end of the turbine and reaction blades at lower pressures. This is because there is no pressure drop across impulse stages and hence there is little tendency for the high-pressure steam to leak past these stages without doing useful work. As the steam expands is passing through the turbine, its volume increases by hundreds of times. At the lower pressures, reaction blades turbine is used. Here, the steam expands as it passes through the blades and its pressure drops. The steam velocity increases as it passes through fixed blades, but it leaves the moving blades at a speed about equal to the blade speed. The impulse stage nozzle directs the steam into buckets mounted on the rim of the rotating disk and the steam flow changes to the axial direction as it moves through the rotating disk. In reaction blades, the stationary blades direct the steam into passages between the moving blades and the pressure drops across both the fixed and moving blades. In impulse blades, pressure drops only across the nozzle. In the velocity compound stages, steam is discharged into two reaction stages. The velocity stage uses a large pressure drop to develop a high-speed steam jet. Fixed blades then turn the partially slowed steam before it enters the second row of moving blades, where most of the remaining energy is absorbed [1][2].

2.3 Speed of steam turbine

Each turbine shaft material has its own natural frequency, when turbine rotates on such a speed that frequency of shaft become close to its natural frequency, when machine causes noise & high vibrations because of resonance due to matching of frequency. Running of Steam "TURBINE" on this speed is avoided and this is called Critical speed. A turbine may have more than one critical speed, which may depend upon number of couplings.
A second critical speed is when the Turbine blade tips approach the speed of

sound. This effectively limits the speed of a turbine and explains why power plants tend to have turbines of the same capacity.

Critical speed of the turbine is the rotor speed at which natural frequency of the assembled rotor (rotor shaft with discs, blades, shrouding strips etc. in assembled condition) becomes equal to the operating speed. This is usually expressed as a range (critical speed range).

There are multiple critical speeds. However, the operating speed of the turbine may be above or below the first and lowest critical speed. In order to achieve that we have to control the speed of turbine by adding control loop [3].

2.4 Control background

Controlmeans measuring the value of the controlled variable of the system and applying the control signal to the system to correct or limit deviation of the measured value from a desired value.Control systems are designed to perform specific tasks. The requirements imposed on the control system are usually spelled out as performance specifications. The specifications may be given in terms of transient response requirements (such as the maximum overshoot and settling time in step response) and of steady-state requirements (such as steady-state error in following ramp input) or may be given in frequency-response terms. The specifications of a control system must be given before the design process begins.

Control theories commonly used today are: classical control theory (also called conventional control theory) such as proportional integral derivative (PID), and state space, modern control theory,such as neural network, and fuzzy logic and robust control theory. Automatic control is essential and integral part of space-vehicle systems, robotic systems, modern manufacturing systems, and any industrial operations involving control of temperature, pressure, humidity, flow, etc. It is desirable that most engineers and scientists are familiar with theory and practice of automatic control.

As modern plants with many inputs and outputs become more and more complex, the description of a modern control system requires a large number of equations. Classical control theory, which deals only with single-input, single-output systems, becomes powerless for multiple-input, multiple-output systems [4].

2.5 Speed control of steam turbine

Stability of power system means the ability of power in a system to maintain synchronism and maintain voltage when any transient disturbances occur like faults, line trips and large variation of load. Generally, the power systems operate within standard operating limits i.e. 50 ± 2.5 Hz. Under any fault conditions or abnormal or exceptional situation, the frequency is permitted to move outside of the mentioned limits. In large power generation case (1000 MW to 1320 MW)or in feed losses, the maximum frequency range is contained within the assigned limits i.e. not exceeding 5 % above or below 50 Hz (50±2.5 Hz.), range of 47.5 to 52.5 Hz [5].

Drop is defined as a decrease in speed or frequency with an increase in load Drop is expressed as the percent that the speed drops below no load speed when the turbine is fully loaded. Drop control can also be referred to as "proportional only" control. On a steam turbine, a drop (proportional) only governor produces a change in valve position proportional to the signal between the speed set point and the actual speed. There is a fixed linear relationship between the turbine speed and the position of the turbine governor valve or valve rack. The main disadvantage of drop only control is that it cannot completely eliminate the error caused by a change in load. In other word, any change in turbine load will result in a corresponding change in turbine speed [3].

All thermal power plants have been controlled by conventional controller techniques, especially conventional PID controllers because of their easy implementation and simple structure. Because of changes to cover power demands, quality differences of the coal and contamination of the boiler heating surfaces, conventional three term PID control schemes will not attain a high degree of control performance. Since the dynamic behavior, even for a reduced mathematical model of a power plant, is usually non-linear, time variant and governed by strong cross coupling of the input variables. Special care has to be taken in the design of the corresponding controllers and their schemes.

On the other hand, the growing needs of complex large modern combinational power plants require optimal and flexible operation. Not only because of the effects discussed above but also taking into account the expected economical benefits, an improvement in once through boiler control is necessary. To utilize the heat energy released by burning coal with very little loss and also to meet the variations in energy output requirements, recently, modern adaptive control concept have been applied to such power systems, either in simulations or real time. These studies have shown that power and enthalpy outputs of adaptive controllers perform better than those of conventional controllers. Both to optimize and improve the outputs of the system and to take care of the above mentioned problems, decoupling networks and advanced control techniques, including fuzzy logic, have been used in such power plants.

2.5.1 Proportional controller (P)

In this control mode, the output of the controller is simple proportional to the error e(t). The relation between the error e(t) and the controller output p is determined by constant called proportional gain constant denoted as Kp. The output of the controller is a linear function of the error. e(t). Thus each value of the error has unique value of the controller output. The range of the error which covers 0% to 100% controller output is called proportional band [6]. Hence mathematically the proportional control mode is expressed as

$$P(t) = Kpe(t) + Po \tag{2.1}$$

Where

Kp = Proportional gain constant

Po = controller output with zero error

2.5.2 Integral controller (I)

In the proportional control mode, error reduces but cannot go to zero. It finally produces an offset error. It cannot adapt with the changing load conditions. To avoid this, another control mode is often used in the control systems which are based on the history of the errors [6]. This is called integral mode or reset action controller. Mathematically is it expressed as:

$$\frac{dp(t)}{dt} = kie(t) \qquad (2.2)$$

Where

ki: Constant relating error or integral constant

2.5.3 Derivative controller (D)

In practice the error is function of time and at a particular instant it can be zero, but it may not remain zero forever after that instant. Hence some action is required corresponding to the rate at which the error is changing. Such a controller is called derivative controller [6]. The mathematical equation for the mode is

$$P(t) = Kd\frac{de(t)}{dt} \tag{2.3}$$

Kd = Derivative gain constant.

2.5.4 Proportional &Derivative mode (PD control mode)

The series combination of proportional and derivative control modes gives proportional plus derivative control mode [6]. The mathematical expression for the PD composite control is

$$P(t) = Kpe(t) + KpKd\frac{de(t)}{dt} + P(0)(2.4)$$

2.5.5 Proportional & Integral (PI) type of controller

A controller in the forward path, which changes the controller output corresponding to the proportional plus integral of the error signal is called PI controller [6].

Output of controller $= Ke(t) + Ki\int e(t)\,dt$(2.5)

2.5.6 Proportional, Integral, & Derivative (PID) type of controller

As PD improves transient and PI improve steady state, combination of two may be used to improve overall time response of the system [6]. This can be shown in figure 2.3

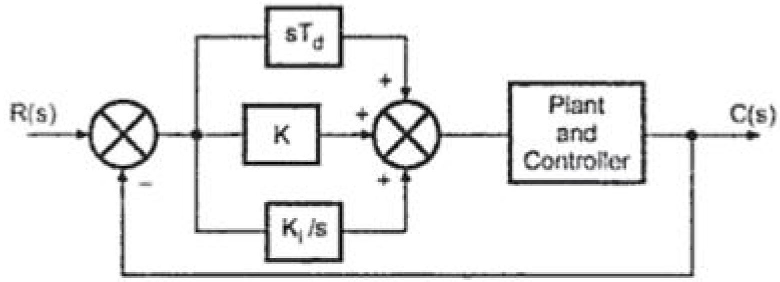


Figure 2.3 PID controller

2.6 Fuzzy logic controller (FLC)

The fuzzy logic control has been an active research topic, for automation and control theory since the work of Mamdani in 1974 based on fuzzy sets theory of Zadeh 1965 to deal with system control problems which are not easy to model.

The concept of fuzzy logic control is to utilize the qualitative knowledge of system to design practical controller. For process control system a fuzzy control algorithm embeds in experience of an operate designer and researcher. The control doesn't need accurate mathematical model of plant and therefore, it is suits well to a process where the model is unknown or defined and particularly to system with complex dynamics. Of course fuzzy control algorithm can be refined by adaption based on learning and fuzzy model of plant.

In general a fuzzy control consist of a set of heuristic decision rules and can be regarded as adaptive and non-mathematical control algorithm based on linguistic process in contrast to a conventional feedback control algorithm. Fuzzy control using linguistic information possesses several advantages such as robustness, and model-free [7].

2.6.1 Fuzzy logic concept

The way that people think inherently is fuzzy. The way that we perceive the world is continually changing and cannot always be defined in true or false statement.

The basis of the theory lies in making the membership function lie over a range of real numbers from 0.0 to 1.0. The fuzzy set is characterized by (0.0, 0, and 1.0). Real world is vague and assigning rigid values to linguistic variables means that some of the meaning and semantic value is invariably lost. Fuzzy logic operates on a concept of membership such as the statement Omer is old can be translated as Omer is a member of the set of old people and can be written symbolically as m(OLD), where m is the membership function that can return a value between 0.0 and 0.1 depending on the degree of membership. In Figure 2.4 the objective term "tall" has been assigned fuzzy values. At 150 cm and below, the person does not belong to fuzzy class while for above 180, the person certainly belongs to category "tall." However, between 150 and 180 the degree of membership for the class "tall" can be assigned from the curve varying linearly between 0 and 1. The fuzzy concept "tallness" can be extended into "short," "medium," and "tall" as shown in Figure 2.5. This is different from the probability approach that gives the degree of probability of an occurrence of an event.

The fuzzy set theory attempts to follow more closely the vagueness that is inherent in most natural language and in decision-making processes. In a conventional logic approach, this inherent fuzziness of membership and categorization is not incorporated. Fuzzy logic has found many real-world applications that involve imitating or modeling human behavior for decision-making in the real world. Development of intelligent systems incorporating the basics of fuzzy set theory has helped advance techniques for handling imprecision in soft computing. The primary idea in soft computing is to mimic human reasoning through building models of natural language variables, human interpretation and reasoning and it has found numerous applications in business and finance sectors, mobile robotics and also in social and behavioral sciences. The dynamics and complexity of social systems are being explained and modeled through the use of fuzzy theory. In geography and environmental sciences, conventional cartographic representations for geographic phenomenon used definite boundaries for demarcation or differentiation in human and physical systems. Research in GIS and analysis of remotely sensed data has explored the use of fuzzy logic for representation of transition zones and imprecise categories. Again soft computing techniques have resulted in interesting developments in the field of geographic modeling, representation and analysis. The infinite-logic approach in fuzzy-set theory has also been one of the few attempts to respond to the "sorties paradox." The integration of fuzzy logic in relational database systems has also advanced conventional query techniques to incorporate linguistic variables and semantic concepts [7].

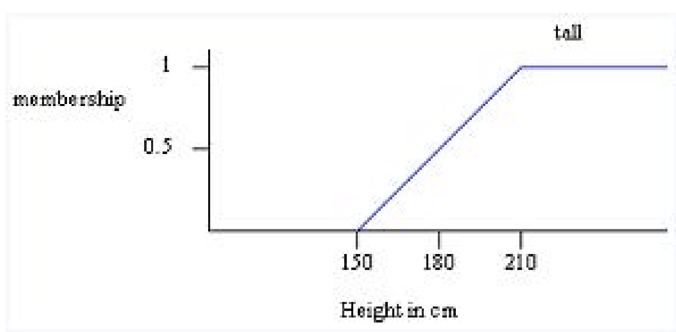


Figure 2.4 Graph showing membership functions for fuzzy set 'tall'

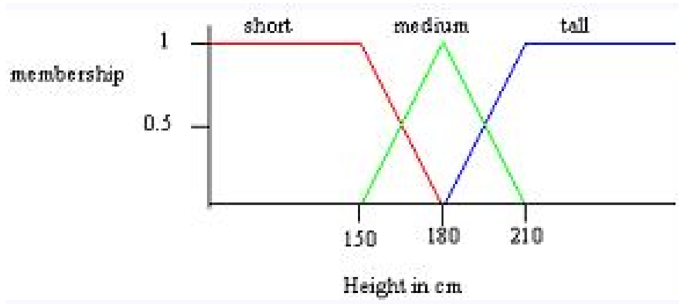


Figure 2.5Graph showing membership functions for fuzzy sets 'short','medium',and 'tall'

2.6.2 Fuzzy controller

While it is relatively easy to design a PID controller, the inclusion of fuzzy rules creates many extra design problems, and although many introductory textbooks explain fuzzy control, there are few general guidelines for setting the parameters of a simple fuzzy controller.

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' and □control with sentences rather than equations ' a fuzzy controller can include empirical rules and that is especially useful in operator controlled plants.

Take for instance a typical fuzzy controller:

- ✓ If error is Neg. and change of error is Neg. then output is NB.
- ✓ If error is Neg. and change of error is zero then output is NM.

The collection of rules is called a rule base. The rule is in the familiar if – then format and formally the □if' side is called the condition and □then' side is called conclusion (more often, perhaps, the pair is called antecedent consequent or premise conclusion). Fuzzy controllers are being used in various control schemes, the most obvious one in direct control, where the fuzzy controller is in the forward path in a feedback control system. [8]

2.6.3 Structure of fuzzy logic controller

There are specific characteristic component of fuzzy controller to support a design procedure. In the block diagram in Figure 2.6 the controller is between a preprocessing block and a post-processing. The following explains the block diagram.

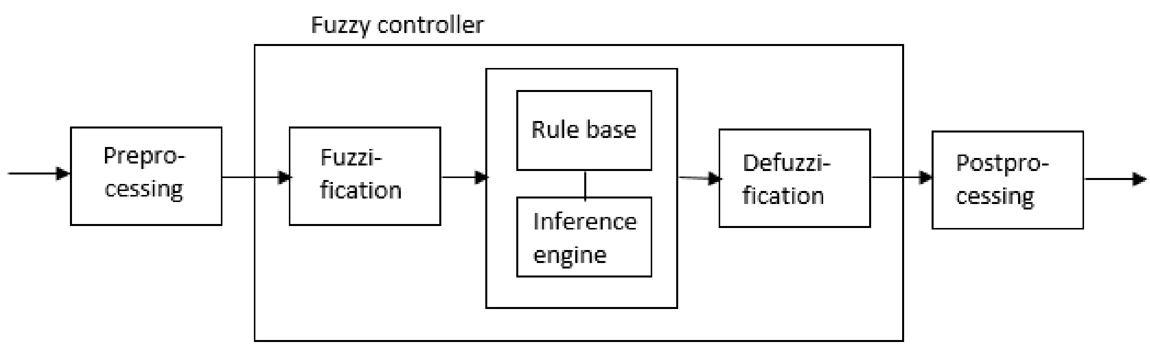


Figure 2.6 Blocks of fuzzy controller

- ✓ **Preprocessing**

This block performs the measurement signal conditioning - (quantization, filtering, differentiation) - before they enter the controller.

- ✓ **Fuzzification**

The first block inside the controller is Fuzzification, which convert each piece of input data to degree of membership by a lookup in one or several membership functions. The fuzzification block thus matches the input data with conditions of the rules to determine how well the condition of each rule matches that particular input instance. There is a degree of membership for each linguistic term that applies to the variable.

- ✓ **Inference engine**

FIS is a computational framework based on the concepts of fuzzy sets, fuzzy if- then rules and fuzzy reasoning. The basic structure of FIS consists of three conceptual components: a rule-base, which contains a selection of fuzzy rules, a database (or dictionary), which defines the membership function used in the fuzzy rules and a reasoning mechanism, which performs the inference procedure upon the rules and given facts to derive a reasonable output or conclusion. There are three types of fuzzy inference systems (models). The differences between them lie in the consequents of their fuzzy rule and they are Mamdani type, Sugeno type and Tsukamoto fuzzy models (jang).

- ✓ **Defuzzification**

The resulting fuzzy set must be converted to a number that can be sent to the process as a control signal. This operation is called defuzzification, the resulting fuzzy set is thus defuzzified into a crisp control signal.

- ✓ **Post processing**

Output scaling is also relevant. In case the output is defined on a standard universe this must be scaled to engineering units. For instance, volts, meters or tons per hour an example is the scaling from the standard universe [-1, 1] to the physical units [-10, 10] volts. The post processing block often contains an output gain that can be tuned, and sometimes also an integrator.[9]

2.6.4 Fuzzy controller operation

The inference engine is the heart of fuzzy controller (and any rules system) operation. Its actual operation can be divided in to three steps as shown in Figure 2.7.

Step1, Fuzzification: actual inputs are fuzzified and fuzzy input are obtained.

Step2, Fuzzy processing: processing fuzzy inputs according to the rules set and producing fuzzy output.

Step3, Defuzzification: producing a crisp real value for a fuzzy output.[10]

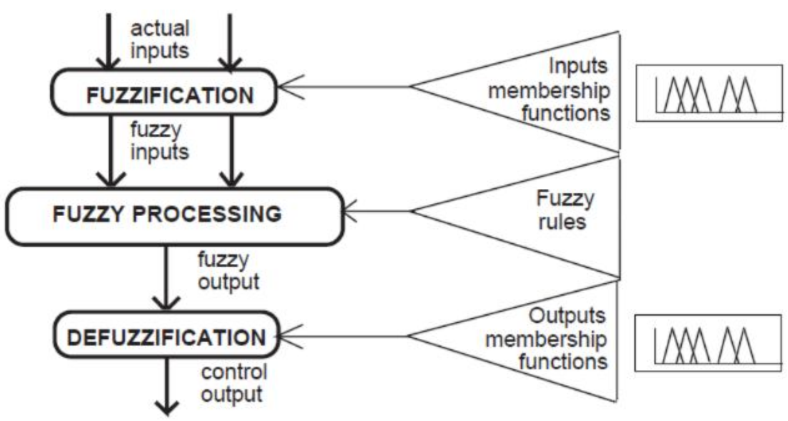


Figure 2.7 Fuzzy operation

2.7 Fuzzy and conventional PID controller

When the control problem is regulate process output around set point, it is natural to consider error as an input, even to a fuzzy controller, and its follows that the integral of the error and the derivative of the error may be useful input as well. In a fuzzified PID controller, however it is difficult to tell the effect of each gain factor on the rise time, over shoot and settling time since its most often nonlinear and has more tuning gains than a PID controller.

However it has been known that conventional PID controllers generally do not work well for nonlinear system, high order and time- delay linear system, and particularly complex and vague systems that have no mercies mathematical models. To overcome these difficulties, various type of modified conventional PID controller such as automatic and adaptive PID controller [8].

2.7.1 Fuzzy Proportional controller

Proportional control is the simplest from continuous control that can be used in closed-loop system. Proportional action can reduce the steady-state error and provides a fast response, but too much it can cause the stability of deteriorate [9].The input to fuzzy proportional FP controller is the error “e” and the output signal is “U” as shown in Figure 2.8.

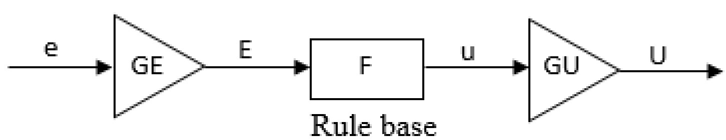


Figure 2.8 Fuzzy proportional controllers

FP controller has two gains GE and GU. The conventional signals are written in lower case before gains and upper case after gains.

2.7.2 Fuzzy PD controller

Proportional derivative controller use the derivative action to improve closed-loop stability and help to predict the error (reduce the over shoot, but it may be sensitive to noise as well as an abrupt change of the reference causing a derivative kick). The input of fuzzy PD controller is the error ‘e’ and derivative of the error ‘ce’ as shown in Figure 2.9.

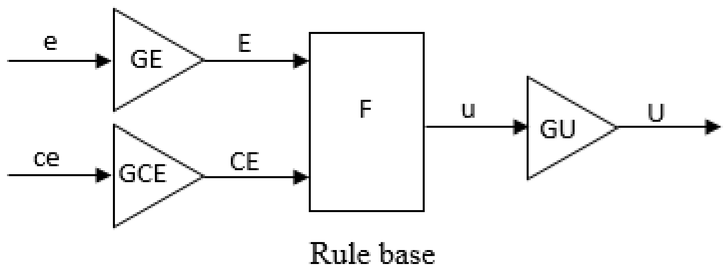


Figure 2.9 Fuzzy PD controllers (FPD)

2.7.3 Fuzzy PD&I controller

Integral action will eliminate the stead-state error. I-controllers are much slower in their response than P-controller. It is often used when measured variables need to remain within every narrow range and require fine tuning control.The input to fuzzy PD&I controller is the error “e” and derivative of the error “ce” and integral of the error “ie”.A rule base with three inputs will become very big, and rule connecting the integral action troublesome. There for it is common to be separate the integral action as in the fuzzy PD&I controller as shown in Figure 2.10 [8].

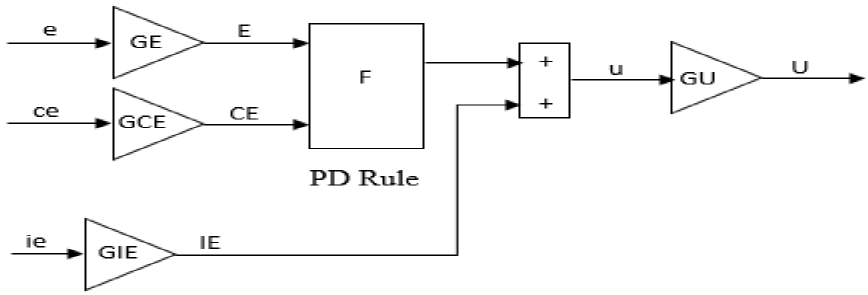


Figure 2.10 Fuzzy PD&I controller (FPD+I)

CHAPTER THREE

SYSTEM MATHEMATICAL MODELING

3.1 Introduction

Electric power is generated by converting mechanical energy into electrical. The rotor mass which contains turbine and generator unit, stored kinetic energy when sudden increase in the load. Neglecting the rotation losses, a generator unit is said to be operating in steady-state at a constant speed when the difference between electrical torque (T_e) and mechanical torque(T_m) is zero.

When the electrical power demand increases suddenly, the electrical torque increases. However without any feedback mechanism to alter, the mechanical torque remains constant. Therefore the accelerating torque becomes negative causing a deceleration of the rotor mass as the rotor deceleration; kinetic energy is released to supply the increase in the load. The system frequency, which is proportional to the rotor speed, also decreases. Therefore, any deviation in the frequency from it is nominal value is indicative of the imbalance between (T_m) and (T_e) [12][11].

3.2 Generator model

When there is a load change it is reflected instantaneously as a change in the electrical torque output $T_e$of the generator. This causes a mismatch between the mechanical torque T_m and electrical torque T_e which in turn result in speed variation.

The transfer function in Figure 3.1 represents the relationship between rotor speed as a function of the electrical and mechanical torques.

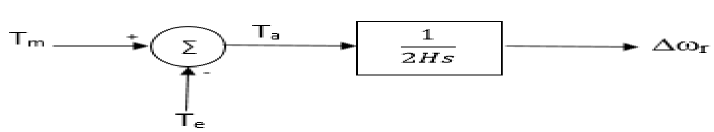


Figure 3.1 relationships between rotor speed and the electrical and mechanical torques

Where:

s= Laplace operator.

T_m = Mechanical torque (Pu).

T_e = Electrical torque (pu).

T_a = Accélération torque (pu).

H= Inertia constant (MW-Sec/MVA).

$\Delta\omega_r$ = Rotor speed deviation (Pu).

It is preferable to express the above relationship in terms of mechanical and electrical power rather than torque .The relationship between power P and torque T is given by:

$$\mathrm{P} = \omega r \times \mathrm{T} \tag{3.1}$$

By considering a small deviation (denoted by prefix Δ) from initial values (denoted by subscript ◦) we may write:

$$P = Po + \Delta P \tag{3.2}$$

$$T = To + \Delta T \tag{3.3}$$

$$\omega r = \omega o + \Delta\omega r \tag{3.4}$$

From equation (3.1):

$$Po + \Delta P = (To + \Delta T) + (\omega o + \Delta\omega r) \tag{3.5}$$

The relationship between the perturbed values, with higher order terms neglected, is given by:

$$\Delta P = \omega o\Delta T + To\Delta\omega r \tag{3.6}$$

Therefore,

$$\Delta P = \omega o(\Delta Tm - \Delta Te) + \Delta\omega r(Tm - Te) \tag{3.7}$$

Since, in the steady state, electrical and mechanical torques is equal $Tm = Te$ with speed expressed in Pu. $\omega o = 1$.

Hence:

$$\Delta Pm - \Delta Pe = \Delta Tm - \Delta Te \tag{3.8}$$

The relationship between rotor speed and the electrical and mechanical torques can now is expressed in terms of ΔPm and ΔPe in Figure (3.2).

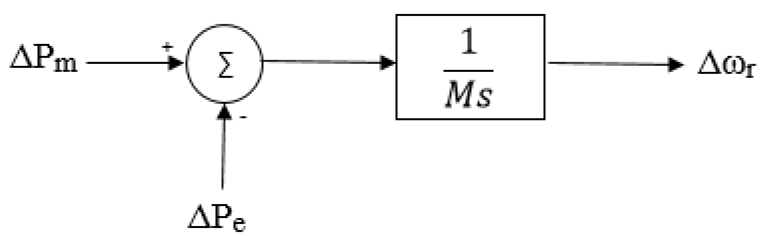


Figure 3.2 relationships between rotor speed and the electrical and mechanical power

Within the range of speed variations with which we are concerned, the turbine mechanical is essentially a function of valve or gate position and independent of frequency [12].

3.3 Load model

In general, power system loads are a composite of a variety of electrical devices. For resistive loads, such as lighting and heating lads, such as funs and pumps, the electrical power changes with frequency due to changes in motor speed. The overall frequency-dependent characteristic of composite load may be expressed as:

$$\Delta Pe = \Delta P1 + D\Delta\omega r \tag{3.9}$$

Where:

$\Delta P1$= non-frequency-sensitive load change.

$D\Delta\omega r$ = frequency- sensitive load change.

D = load-damping constant.

The damping constant is expressed as a percent change in load for one percent change in frequency. Typical values of D are 1 to 2%. A value of D=2 means that a 1% change in frequency would cause a 2% change in load.

The system block diagram including the effect of the load damping is shown in Figure 3.3.The generator and load SIMULINK model is shown in Figure 3.4

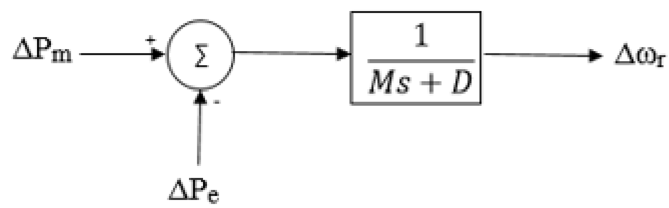


Figure 3.3transfer function of the load and generator

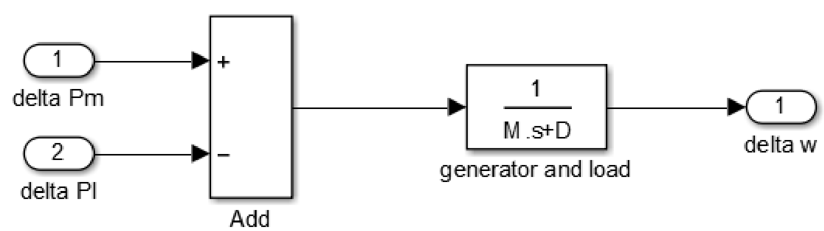


Figure 3.4 SIMULINK model of the generator and load

In the absence of speed governor the system response to the load change is determined by the inertia constant and damping constant. The steady-state speed deviation is such that the change in load is exactly compensated by the variation in load due to frequency sensitivity [11].

3.4 Turbine model

The source of mechanical power is commonly known as the prime-mover, may be hydraulic turbine at waterfalls, steam turbine whose energy comes from the burning of coal, gas, nuclear fuel, and gas turbine.

The model of the turbine relates changes in mechanical power output $\Delta Pm$to changes in steam valve positionΔPv. Different types of turbines vary widely in characteristics. The simplest prime mover model for the non-reheat steam turbine can be approximate with a single time constant τ_T (the time constant τ_T is in the range of 0.2 to 2 second) ,resulting in the following transfer function[11].The block diagram for a simple turbine is shown in Figure 3.5.And The turbine SIMULINK model is shown in Figure 3.6

$$G_T(s) = \frac{\Delta Pm(s)}{\Delta\ Pv(s)} = \frac{1}{1+\tau T(s)} \quad (3.10)$$

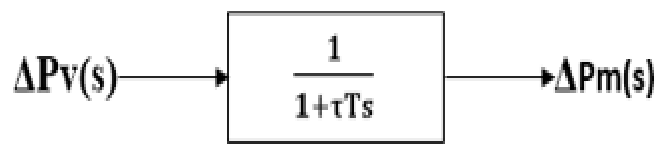


Figure 3.5 turbine transfer function

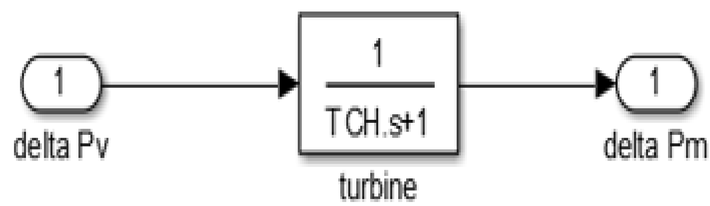


Figure 3.6 SIMULINK model of the turbine

3.5 Governor Model

When the generator electrical load is suddenly increased, the electrical power exceeds the mechanical power input. This power deficiency is supplied by the kinetic energy stored in the rotating system. The reduction in kinetic energy causes the turbine speed and consequently the generator frequency to fall. The change in speed is sensed by the turbine governor which acts to adjust the turbine input valve to change the mechanical power output to bring the speed to a new steady-state. The transfer function of the governor is shown in Figure (3.7). And Figure 3.8 shows the speed governor SIMULINK model [11].

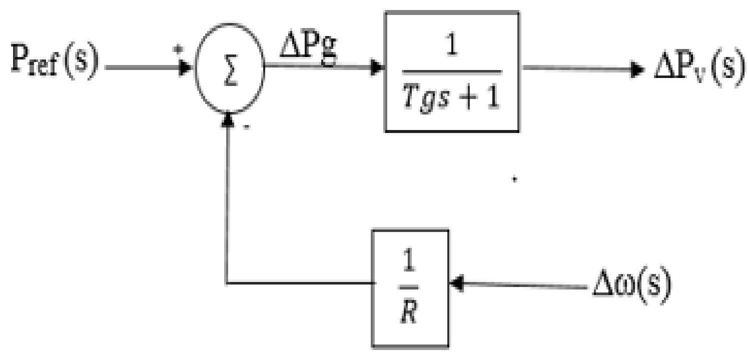


Figure 3.7 the transfer function of the governor

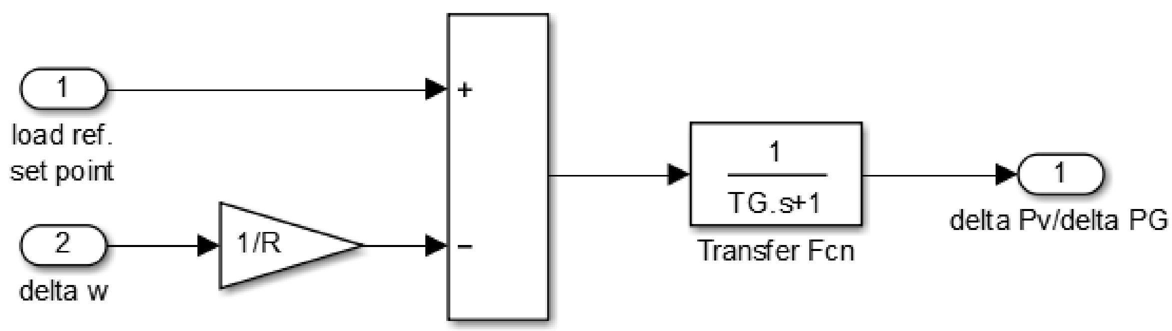


Figure 3.8 SIMULINK model of the speed governor.

Where:

T_G: governor time constant.

1/R: Net gain.

P_G: Governor Power.

Complete SIMULINK block diagram of an isolated power system (turbine, generator and governor) is shown in figure 3.9.

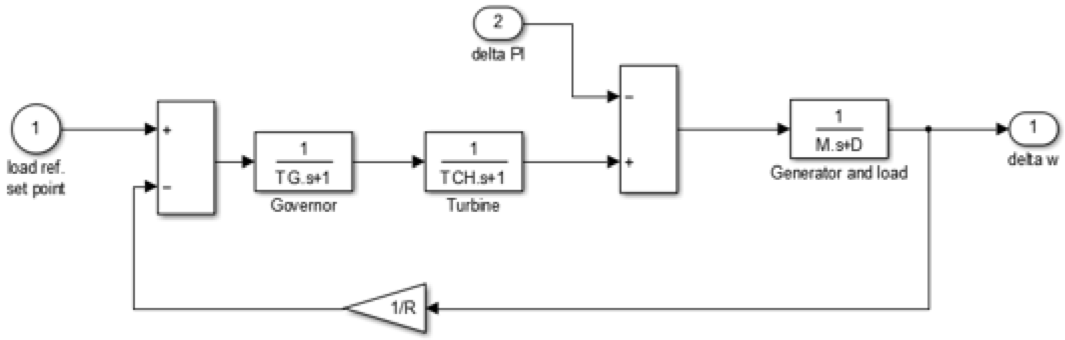


Figure 3.9 SIMULINK model of an isolated power system

CHAPTER FOUR

SIMULATION AND RESULTS

4.1 Introduction

MATLABis the high-leveltechnical computing language and interactive environment used by millions of engineers and scientists worldwide. It lets you explore and visualize ideas and collaborate across disciplines including signal and image processing, communications, control systems, and computational finance.SIMULINK is a graphical environment for simulation and Model-Based Design of multi-domain dynamic and embedded systems. MATLAB and SIMULINK enable the design and development of a wide range of advanced products, including automotive systems, aerospace flight control and avionics, telecommunications and other electronics equipment, industrial machinery, and medical devices. More than 5000 colleges and universities around the world use MATLAB and SIMULINK for teaching and research in a broad range of technical disciplines [13].

4.2 Fuzzy logic controller design

In recent years, fuzzy logic has emerged as a powerful tool and is starting to be used in various power system applications. The application of fuzzy logic control technique appears to be the most suitable one whenever a well-defined control objective cannot be specified, the system to be controlled is a complex one, or its exact mathematical model is not available. Fuzzy logic controllers (FLCs) are robust and have relatively low computation requirements. They could be constructed easily using a simple microcomputer.

Fuzzy controller consists of an input stage, processing stage and output stage. The processing stage extract each appropriate rule and generates a result for each stage then combines the result of the rules, finally the output stage convert the combine result back in to a specific control output value. The selection of control variables (controller inputs and outputs) depends on the nature of the controlled system and the desired output. It is more common to use the output error (e) and the rate or derivative of the output (Δe) as controller inputs. Some investigators have also proposed the use of error and the integral of error as an input to the FLC.

The input and the output are transformed into five linguistic variable NB, NS, Z, PS, and PB which refer to negative big, negative small, zero, positive small, and positive big respectively. As each of the two fuzzy variable are quantized to five sets this leads to a 5 x 5 FAM rule matrix, as shown in table 3.1 [10].

Building system using the graphical user interface (GUI) is provided using Fuzzy Logic toolbox. There are five primary GUI tools for building, editing, and observing Fuzzy inference system in the Fuzzy Logic toolbox; Fuzzy Inference System (FIS Editor), the membership function editor, rule editor, the viewer, and the surface viewer.

Table 4.1 fuzzy rule

e \Δe	NB	NS	Z	PS	PB
NB	NB	NB	NS	NS	Z
NS	NB	NS	NS	Z	PS
Z	NS	NS	Z	PS	PS
PS	NS	Z	PS	PS	PB
PB	Z	PS	PS	PB	PB

4.2.1 Fuzzy inference system editor (FIS editor)

The FIS editor displays information about a fuzzy inference system, and can be opened by typing the command □fuzzy” at the MATLAB command window. The FIS Editor opens and displays a diagram of the fuzzy inference system with the names of each input variable on the left, and those of each output variable on the right, as shown in figure 4.1The FIS Editor GUI tool also allows you to edit the highest level features of the fuzzy inference system, such as the number of input and output variables, the defuzzification method used, and so on [13].

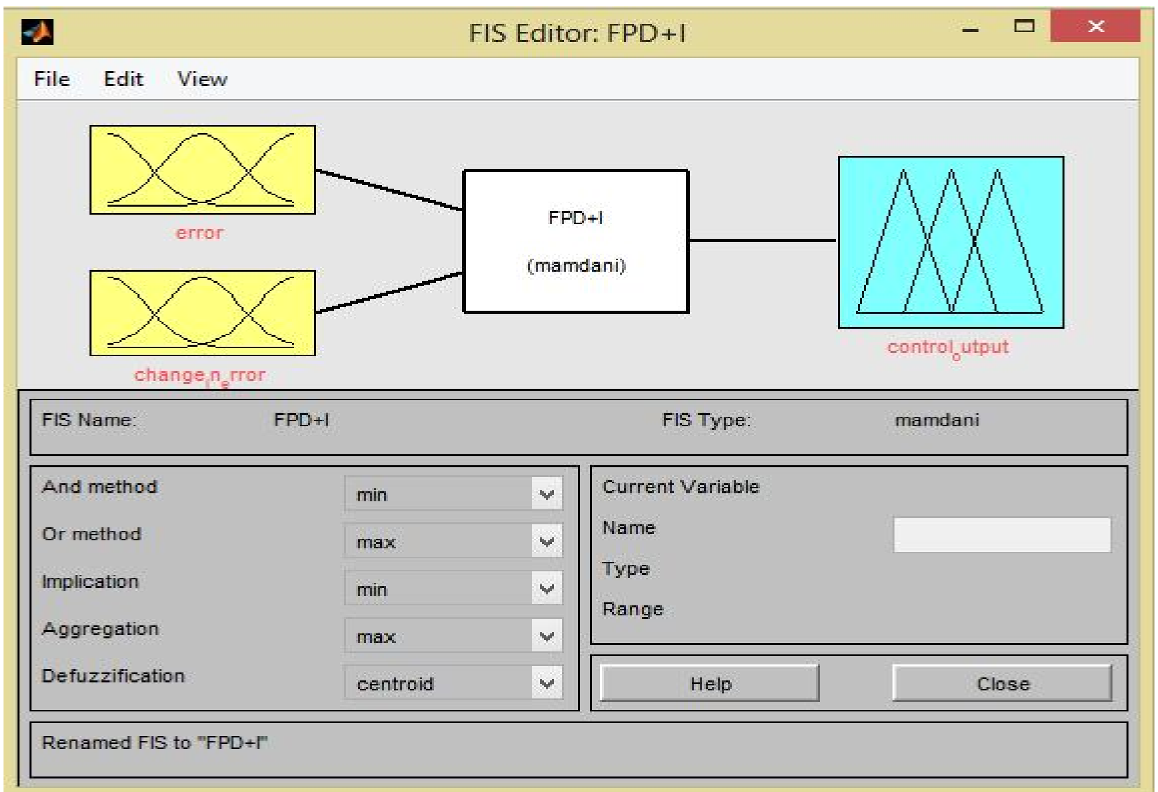


Figure 4.1 Fuzzy inference systems

4.2.2 Membership function editor

The membership function editor is the tool that lets you display and edits all of the membership function associated with all of the input and output. For each membership function you can change the name, the type, and the parameters. Eleven built-in membership functions are provided for you to choose from, although of course you can always create your own specialized versions. The membership function of the first input "error" is shown in Figure 4.2, for the second input "change in error" in figure 4.3. And the output "control output" in Figure 3.11

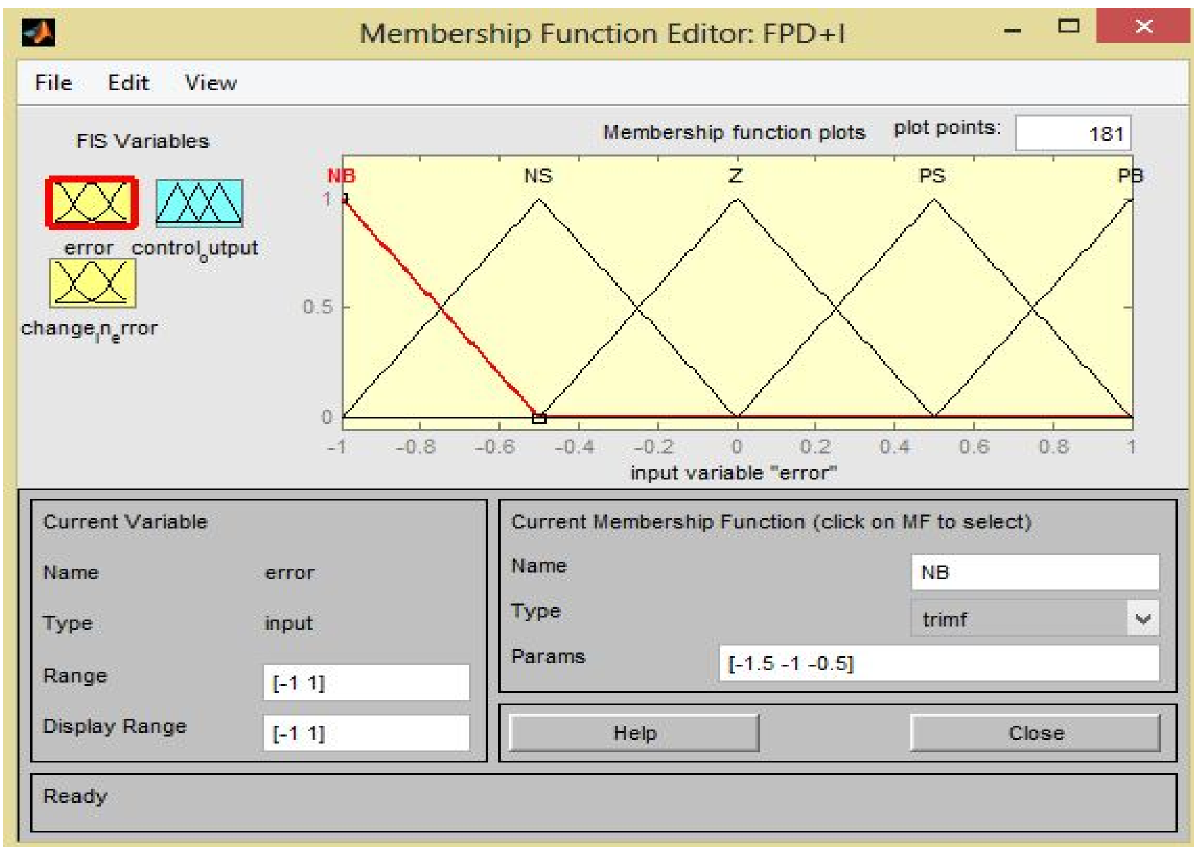


Figure 4.2 membership function of input (1) "error"

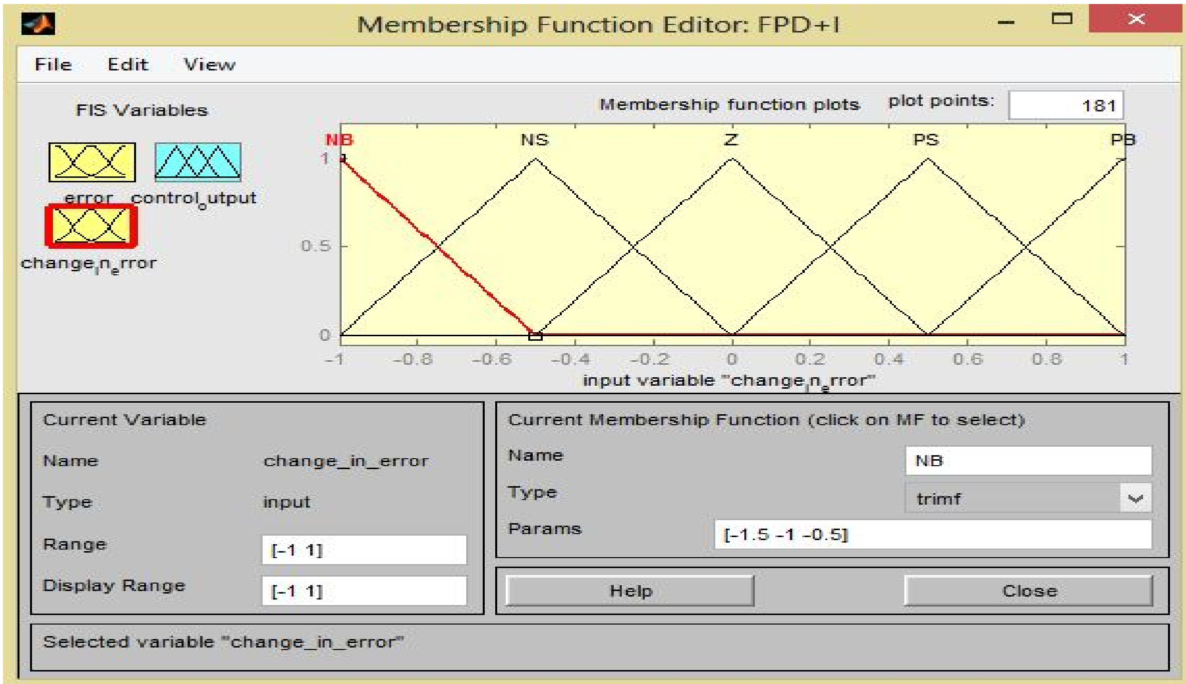


Figure 4.3 membership function of input (2) □change in error”

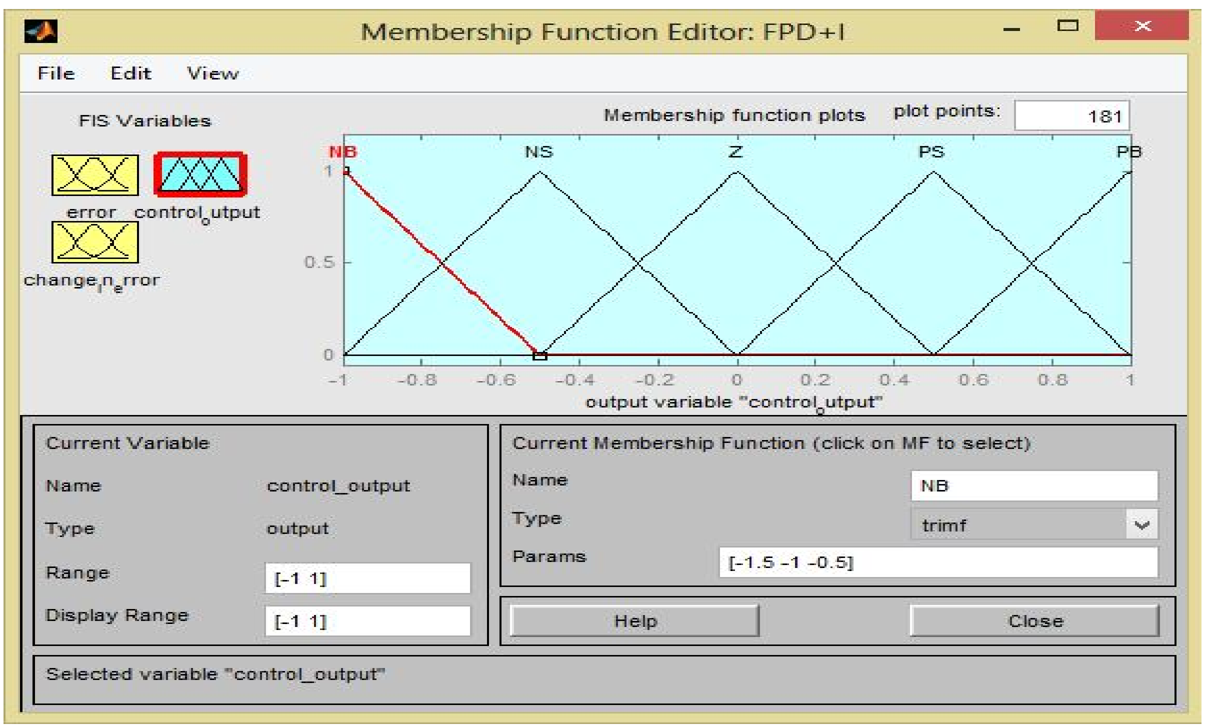


Figure 4.4 membership function of the output

4.2.3 Rule editor

To use this editor to create rules, you must first define all of the input and output variables you want to use with the FIS editor. You can create the rules using the list box and check box choices for input and output variables, connections, and weights. Constructing rules using the graphical Rule Editor interface is fairly self-evident which is shown in figure 4.5. Based on the descriptions of the input and output variables defined with the FIS Editor, the Rule Editor allowsyou to construct the rule statements automatically from the GUI, you can:

- ✓ Create rules by selecting an item in each input and output variable box, selecting one Connection item, and clicking Add Rule. You can choose none as one of the variable qualities to exclude that variable from a given rule and choose not under any variable name to negate the associated quality.
- ✓ Delete a rule by selecting the rule and clicking Delete Rule.
- ✓ Edit a rule by changing the selection in the variable box and clicking Change Rule.
- ✓ Specify weight to a rule by typing in a desired number between 0 and 1 in weight. If you do not specify the weight, it is assumed to be unity [13].

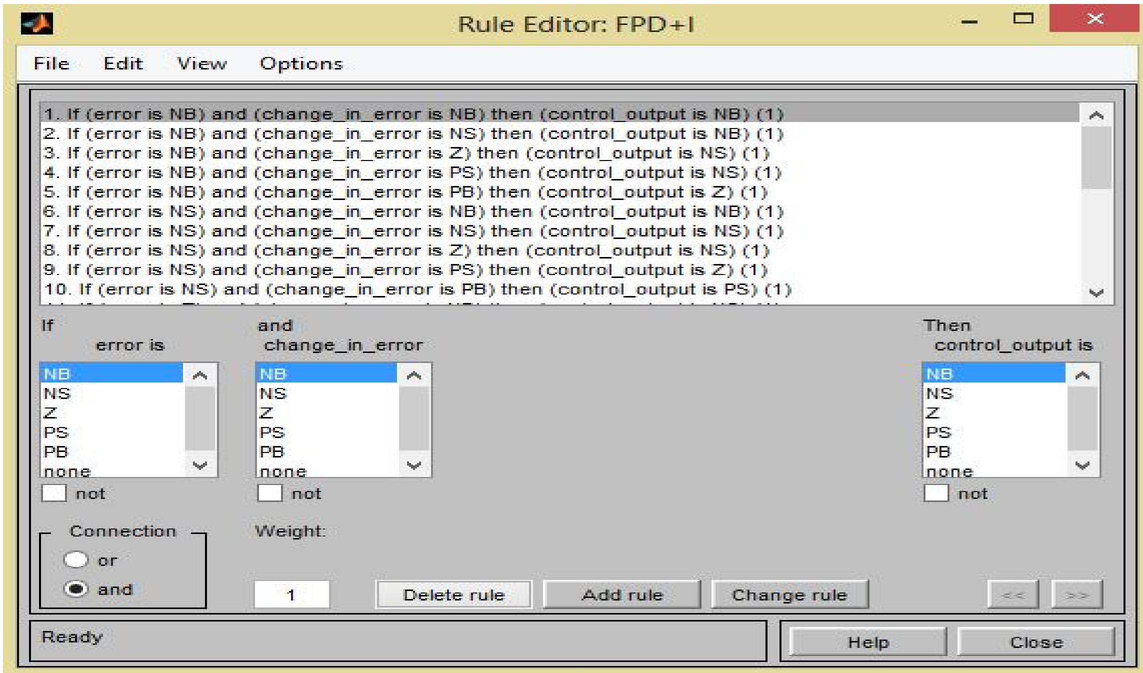


Figure 4.5 rule editor

4.2.4 Rule viewer

To show the rule viewer from FIS you can click □view” on the menu and select □rule”. The Rule Viewer displays a roadmap of the whole fuzzy inference process. It is based on the fuzzy inference diagram described in the previous section. You see a single figure window with 25 plots nested in it. The three plots across the top of the figure represent the antecedent and consequent of the first rule. Each rule is a row of plots, and each column is a variable. The rule numbers are displayed on the left of each row. You can click on a rule number to view the rule in the status line which is shown in figure 4.6.

- ✓ The first two columns of plots (the yellow plots) show the membership functions referenced by the antecedent, or thief-part of each rule.
- ✓ The third column of plots (the blue plots) shows the membership functions referenced by the consequent, or the then-part of each rule [13].

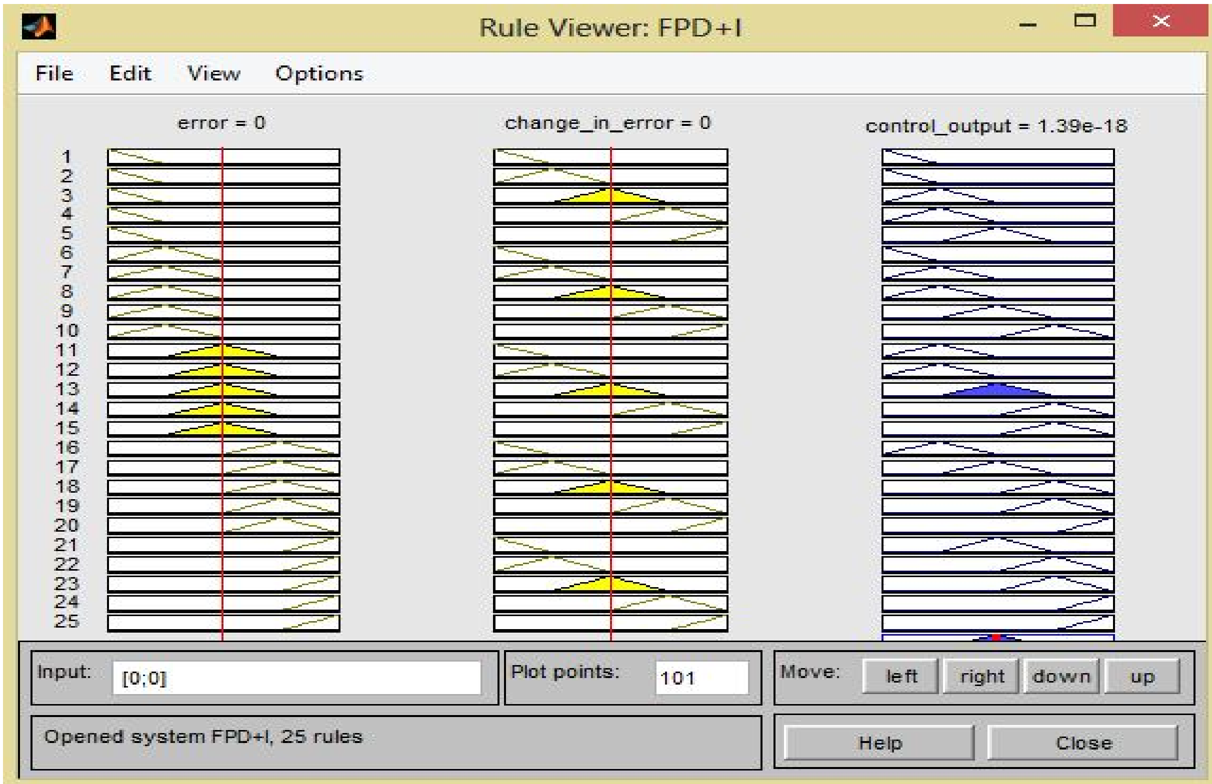


Figure 4.6 Rule viewer

4.3 Simulation with deviation (0.1 pu)

The simulation in this study concentrates on a single machine. A separate results of the system simulation with and without controllers have been obtained. The duration of the simulation is 30 seconds which is enough to view the response of the components and over all sytems. In this case we simulate the system and we assumed the value of load deviation is 0.1 and we compared the results in table 4.3.

4.3.1 Simulation without controller

SIMULINK model of the system without controller is shown in figure 4.7. and the simulation result is shown in figure 4.8. The system parameters shown in table 4.2.

Tg	T_T	H	D	R
0.2	0.5	10	0.8	0.05

Table 4.2 system parameters

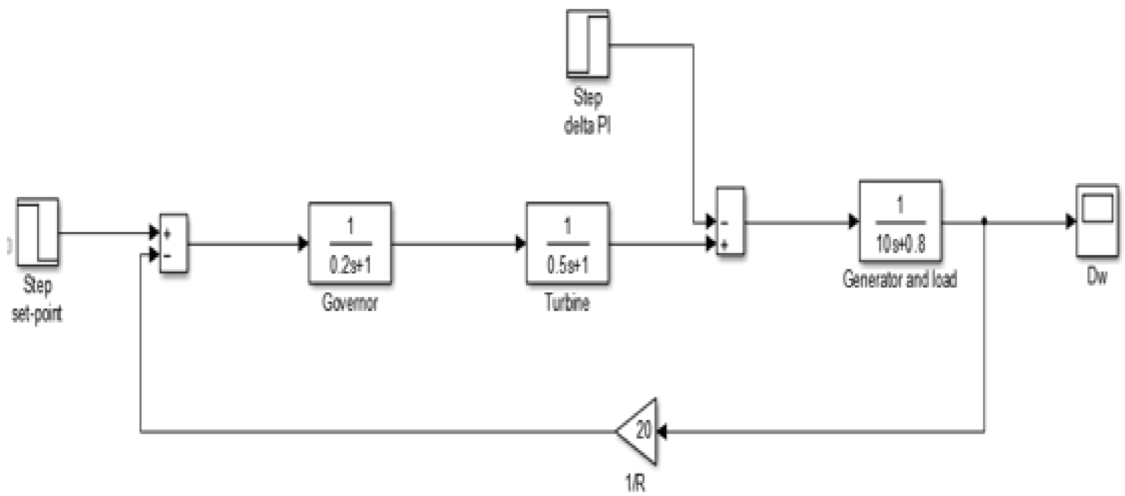


Figure 4.7 SIMULINK model of the system without controller

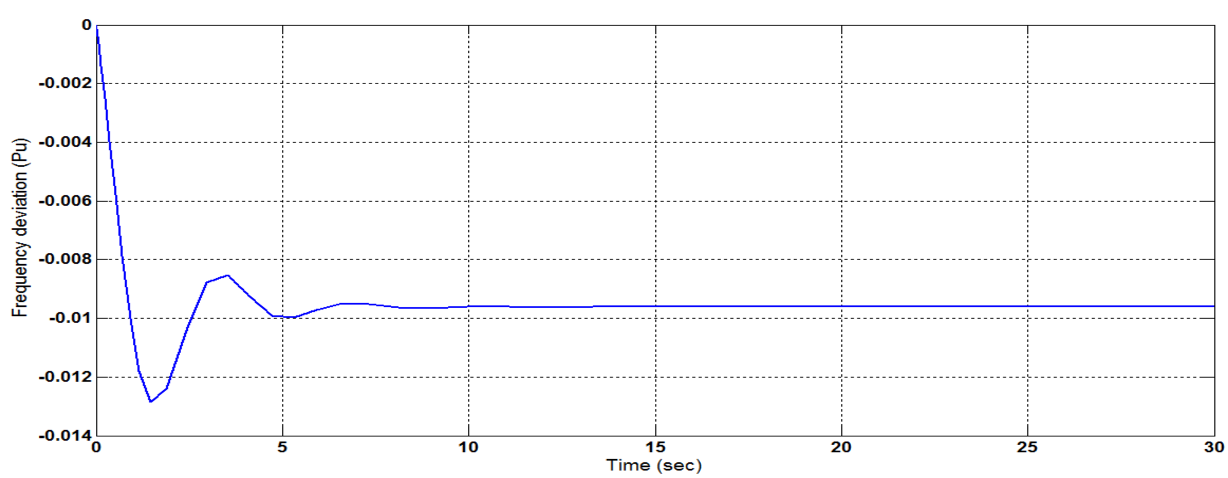


Figure 4.8 Frequency deviation response of the system without controller

4.3.2 Simulationwith PID controller

A SIMULINK model of the system with PID controller is shown in Figure 4.9 and the simulation result is shown in Figure 4.10

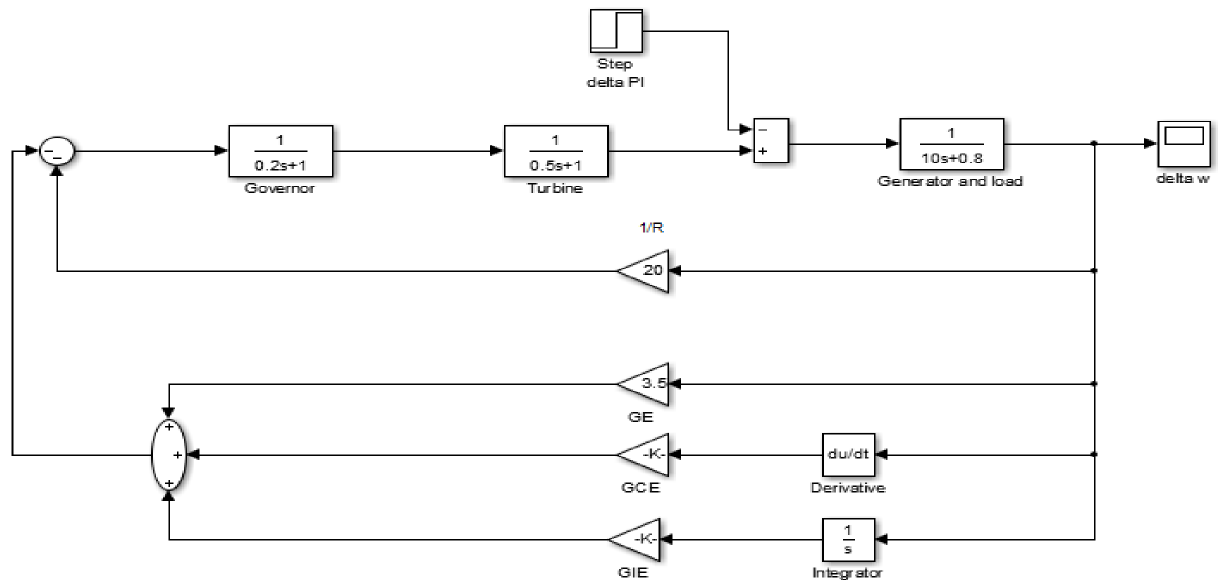


Figure 4.9SIMULINK model of the system with PID

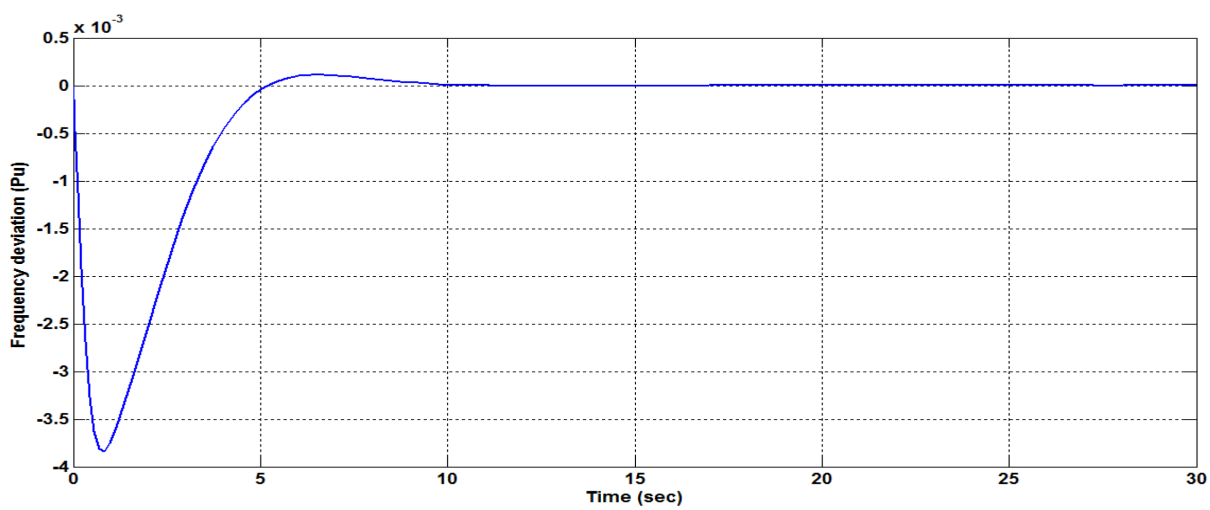


Figure 4.10Frequency deviation response of the system with PID

4.3.3 Simulation withFPD&I

A SIMULINK model of the system with FPD&I controller is shown in Figure 4.11. And the simulation results by using Gaussian membership function is shown in Figure 4.12, using Triangular membership function is shown in Figure 4.13 and using Trapezoidal membership function is shown in Figure 4.14

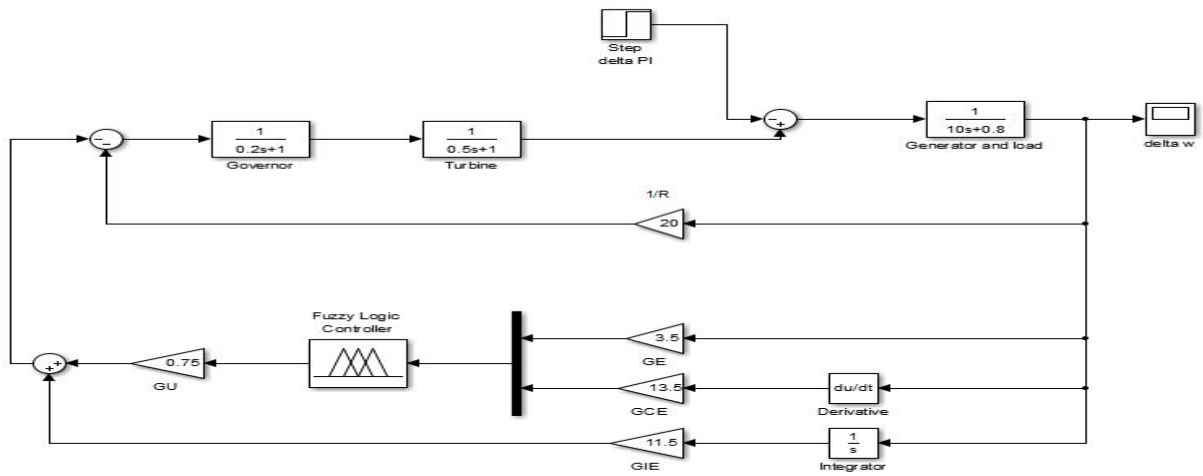


Figure 4.11 SIMULINK model of the system with FPD&I

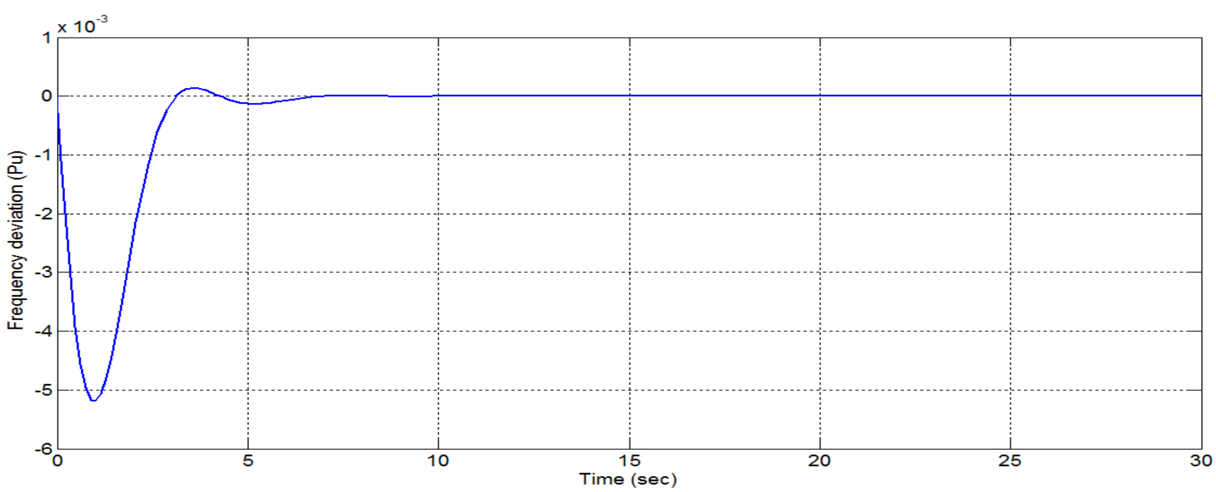


Figure 4.12Frequency deviation response of the system using Gaussian MF

We noticed that the frequency returned to the nominal value in 5.7471 Second.

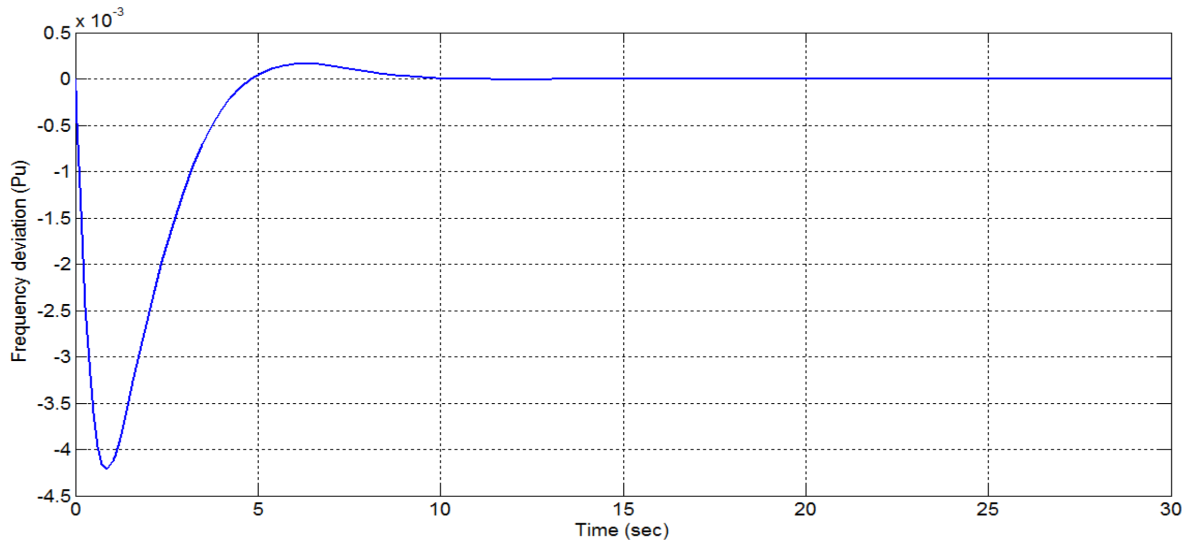


Figure 4.13Frequency deviation response of the system using Triangular MF

From the figure 4.13 we found that the frequency returned to nominal value in 7.771 Second and the max overshoot value more than that in Gaussian by small value that was compared in table 4.1.

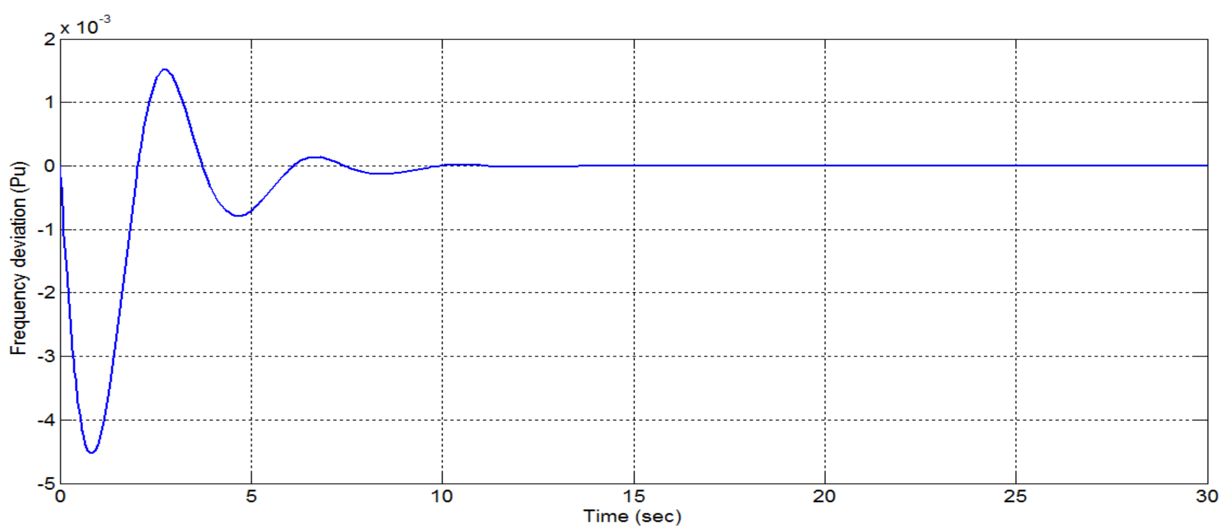


Figure 4.14Frequency deviation response of the system using Trapezoidal MF

We noticed that the maximum overshoot takes high value as shown in figure 4.14 and the frequency returned to its nominal value in 9.1122 Seconds. And to see the difference between the responses we have to make it in one figure which as shown below in figure 4.15.

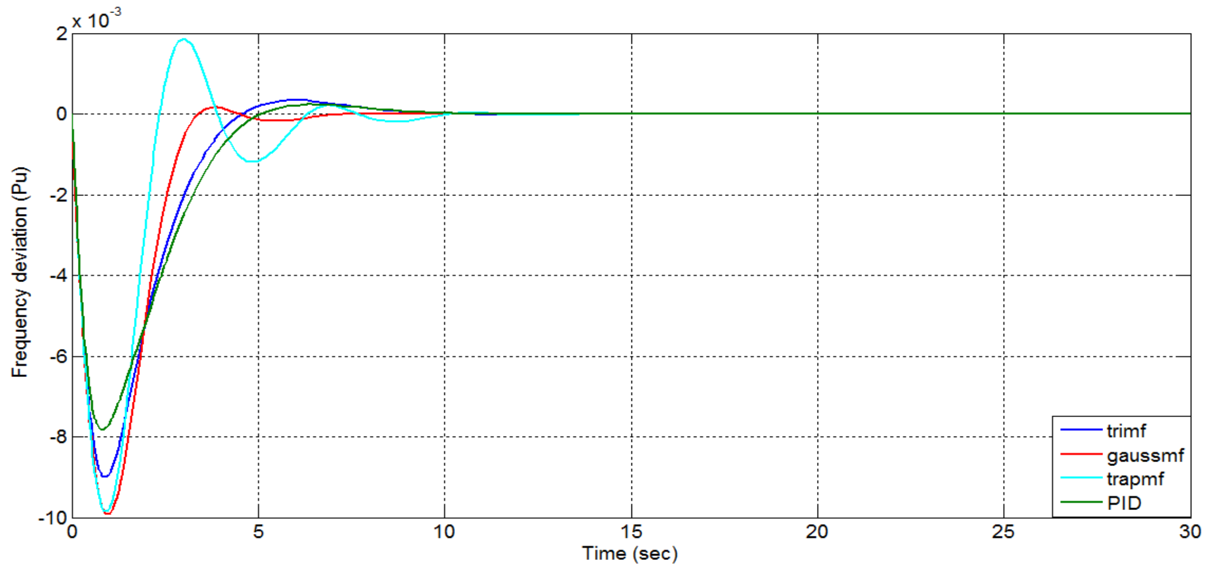


Figure 4.15the difference between the responses

4.4 Simulation with deviation (0.2 pu)

In this case we simulate the system and we assumed the value of load deviation is 0.2 and we compared the results in table 4.4.

4.4.1 Simulation without controller

The simulation result of the system without controller in figure 4.7 after increase the step value from 0.1 to 0.2 is shown in Figure 4.16

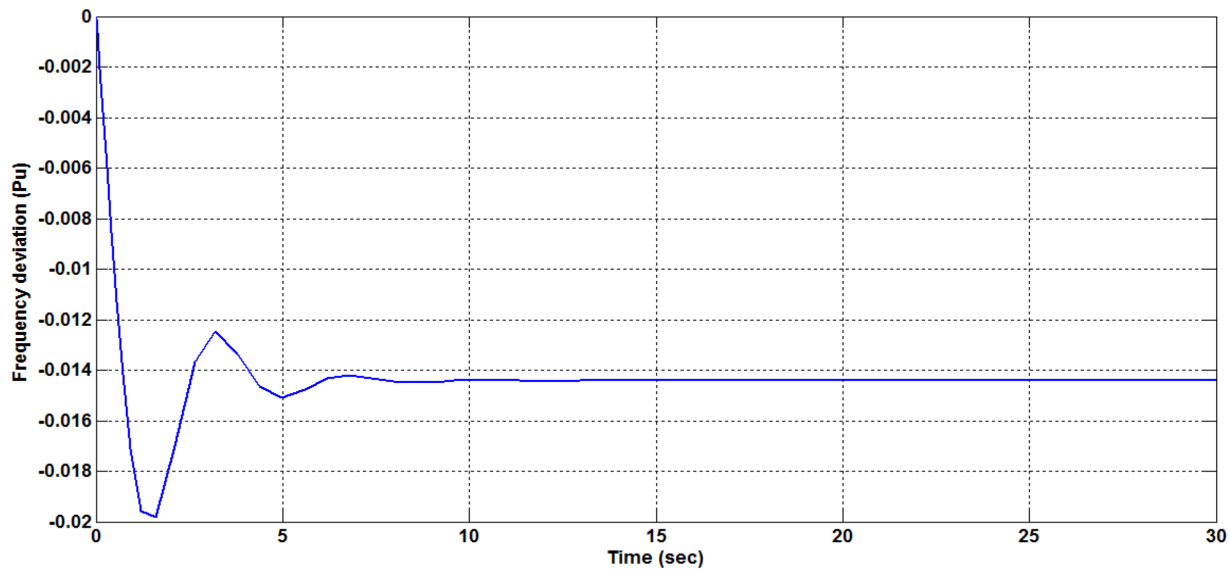


Figure 4.16 Frequency deviation response of the system without controller

4.4.2 Simulation with PID controller

In this case we use same model in figure 4.8 just we change the step value from 0.1 to 0.2 , the result came as in shown below in figure 4.17.

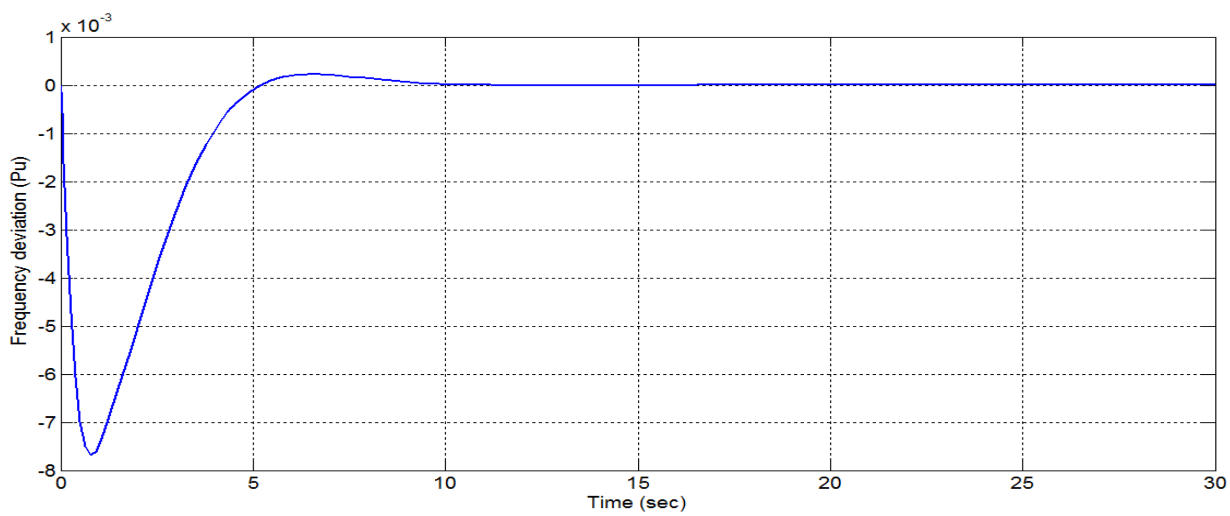


Figure 4.17 Frequency deviation response of the system with PID

As we see in figure 4.17 the frequency returned to nominal value in 7.5104 seconds. Also we noticed the response is approxmatlly similar to the response when we used deviation (0.2 pu).

4.4.3 Simulation with FPD&I

the simulation results by using Gaussian membership function is shown in Figure 4.18, using Triangular membership function is shown in Figure 4.19 and using Trapezoidal membership function is shown in Figure 4.20

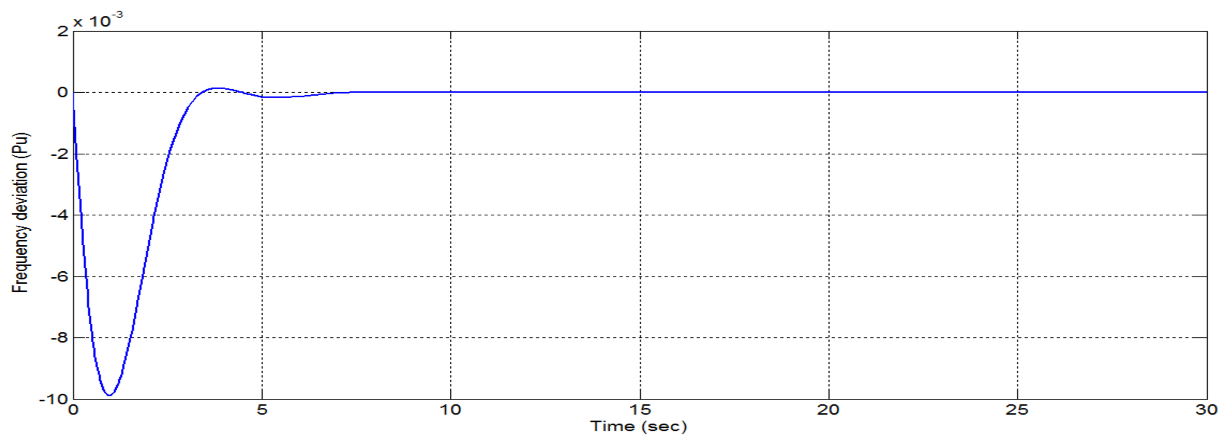


Figure 4.18Frequency deviation response of the system using Gaussian MF

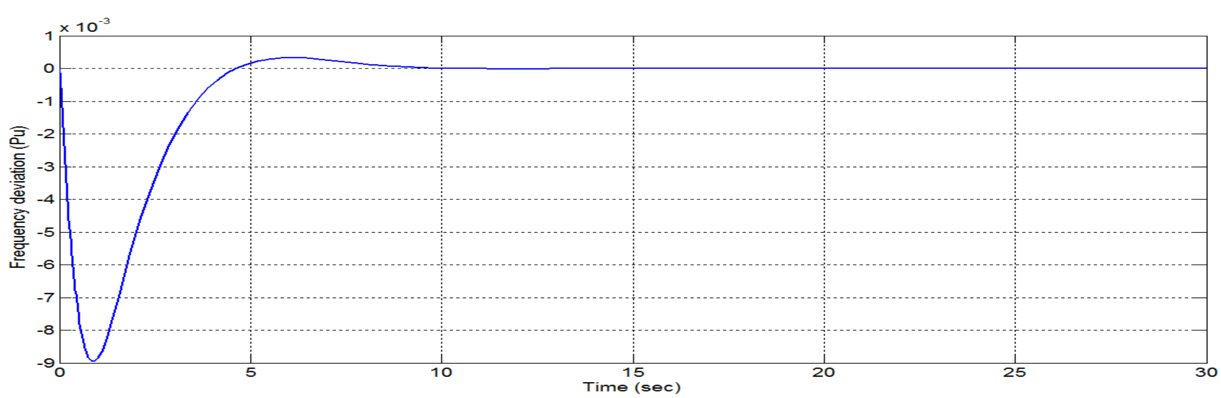


Figure 4.19Frequency deviation response of the system using Triangular MF

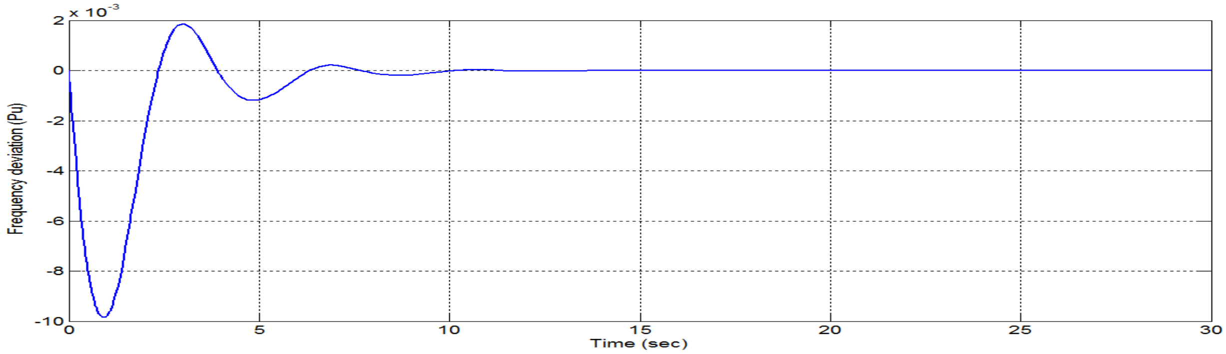


Figure 4.20 Frequency deviation response of the system using Trapezoidal MF

To see the difference between the responses we have to make it in one figure as shown in figure 4.21.

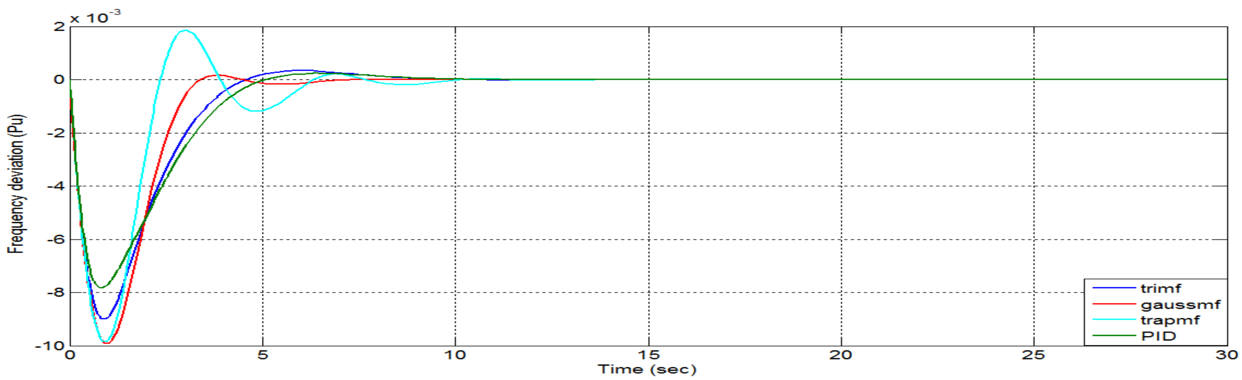


Figure 4.21show the differences between the controller responses

4.5 Results comparison

The system performance on the bases of dynamic parameters i.e. rise time, settling time, overshoot, undershoot, peak, and peak time with and without using controllers is compared in table 4.3 for change in load of 0.1 Pu, and table 4.4 for change in load of 0.2 Pu.

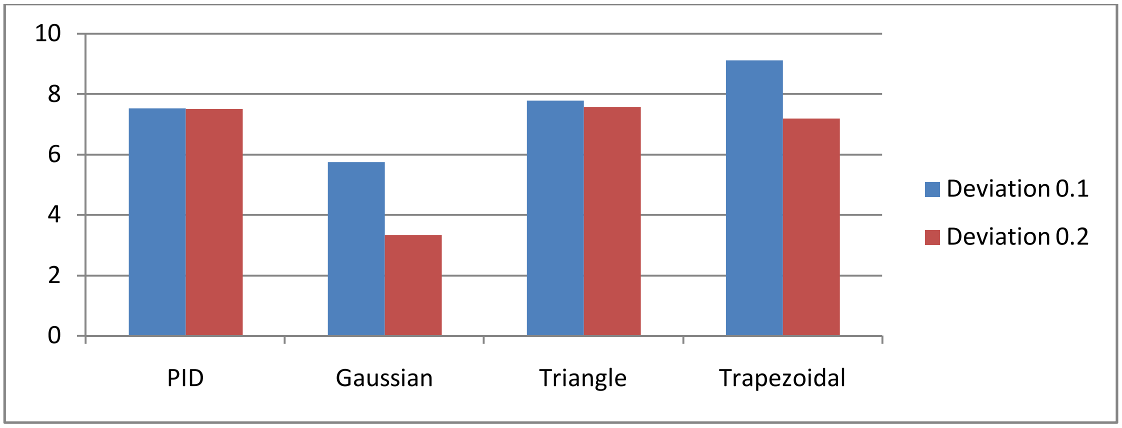
Table 4.3 Step deviation 0.1

	Uncont-rolcase	PID	Fuzzy triangle	Fuzzy Gaussian	Fuzzy trapezoidal
Rise Time	0.6816	0.0409	0.0187	$2.7792*10^{-4}$	$1.8433*10^{-4}$
Settle Time	5.7221	7.513	7.771	5.7471	9.1122
Overshoot	33.7425	$1.0431*10^{+3}$	$2.9117*10^{+3}$	$1.4923*10^{+5}$	$1.5771*10^{+5}$
Undershoot	0	$3.9538*10^{+4}$	$7.6651*10^{+4}$	$4.2487*10^{+3}$	$4.7156*10^{+5}$
Peak	0.0129	0.0038	0.0042	0.0052	0.0045
Peak Time	1.4673	0.8304	0.8689	1.0163	0.85

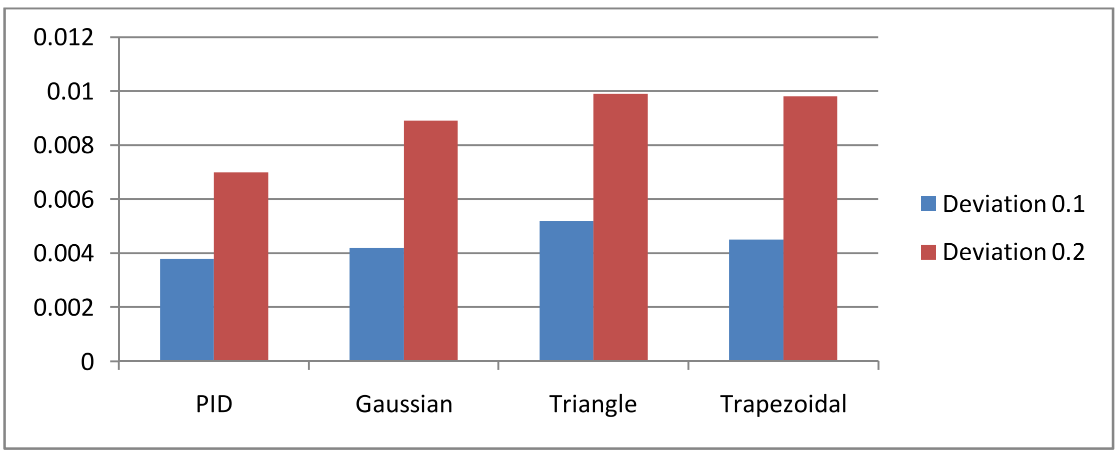
Table 4.2 step deviation 0.2

	Uncont-rolcase	PID	Fuzzy triangle	Fuzzy Gaussian	Fuzzy trapezoidal
Rise Time	0.5793	0.0367	0.0082	$2.4045*10^{-4}$	$8.7818*10^{-4}$
Settle Time	5.6657	7.5104	7.572	3.2173	7.1746
Overshoot	37.273	$1.041*10^{+3}$	$6.716*10^{+3}$	$1.6443*10^{+5}$	$4.4745*10^{+4}$
Undershoot	0	$3.957*10^{+4}$	$1.7915*10^{+5}$	$2.6634*10^{+3}$	$8.5248*10^{+3}$
Peak	0.0198	0.007	0.0089	0.0099	0.0098
Peak Time	1.6021	0.7706	0.9248	0.9736	0.9211

Settling Time



Peak



CHAPTER FIVE

CONCLUSION AND RECOMMEDATIONS

5.1 Conclusion

In this study we introduced the possibility of using the fuzzy logic controller as a new field in designing power control systems.

Model of steam power plant has been developed to achieve best frequency response characteristics when load is dynamically changed. Then fuzzy logic controller has been designed for load frequency control of single area and the dynamic response of the load frequency control problem are studied using MATLAB SIMULINK software. The system performance is observed on the basis of dynamic parameters i.e. settling time, overshoot and undershoot. The system performance characteristics reveals that thefuzzy logic controller has an excellent response with small oscillation, while the PID response shows ripple and some oscillation before reaching the steady state operating point. It was shown that an excellent performance of the fuzzy control in contrast to PID for the control loop of the steam generating station is achieved.

5.2 Recommendation

- The proposed method can be applied to multi area power system load frequency control (ALFC).
- Optimum values can be obtained by Genetic Algorithm and Neural networks.
- The number of the membership function will increase.

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