بسم الله الرحمن الرحيم

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Automatic Generation Control of Two Area Power System Using Fuzzy proportional-Integral – Derivative Controller

التحكم الالى في التوليد لمنطقتي نظام قدرة باستخدام التحكم التناسبي التكامل – التفضل الغامض

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Prepared by:

Ayat Ibrahim Abdalbagi Ibrahum

Supervisor :

Ust: Abdallah Salih Ali mohamoud

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الآية

قَالَ تَعَالَىٰ:

﴿ وَيَرۡزُقۡهُ مِنۡ حَيۡثُ لَا يَحۡتَسِبُۚ وَمَن يَتَوَكَّلۡ عَلَى ٱللَّهِ فَهُوَ حَسۡبُهُۥٓۚ إِنَّ ٱللَّهَ بَٰلِغُ أَمۡرِهِۦۚ قَدۡ جَعَلَ ٱللَّهُ لِكُلِّ شَيۡءٖ قَدۡرٗا ٣ ﴾

صدق الله العظيم

سورة الطلاق الآية (3)

DEDICATION

For my mother

The compassionate person who taught me the meanings of

Ambitious and responsibility.

For my father

The person who teach me the value of hard work through tireless

example.

For my family members

My well-beloved sisters and brothers

For my sincere friends

My well- beloved sister sara

Fathiyah Abdul Azim

Eng. Wafa Abd Alkleg

Eng. Rufida Mohamed

Whom I can't describe their sustain in all of my study stages.

For all supportive in whole aspects life.

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All thanks for Allah –all high and almighty- to give me the force and strength to accomplish this work. It is my pleasure to express my sincere acknowledgements to my supervisor Ust. Abd Alla Salih, I am so grateful for his efforts.

All awfully thanks for Eng. Israa Salih and Eng. Ahmed Osman for their good ideas which they support me. I am also grateful for colleagues in work for opinions and encouragement.

ABSTRACT

Modern power system networks consist of a number of utilities interconnected networks together . Power is exchanged between utilities over tie-line by which they are connected. Automatic generation control (AGC) plays a very important role in power system. Its main role is to maintain the system frequency and tie-line flow at their scheduled values during normal period and also when the system is subjected to small step load perturbations. In this study, a power system with two areas connected through tie-line is considered. The objective of AGC, based on fuzzy PID controller, is to damp transient deviations(frequency and power)and to provide zero steady-state error of these variables in a very short time. The simulation is implemented by using MATLAB/SIMULINK program. To further adding various types of membership functions and applying for more than two area power system.

المستخلص

تحتوي أنظمة القدرة الكهربائية الحديثة على عدد من الشبكات الكهربائية ترتبط مع بعضها البعض. تتبادل الطاقة الكهربائية عن طريق خطوط الربط الكهربائي يلعب التحكم الآلي للتوليد دورا رئيسيا في تثبيت التردد للنظام الكهربائي و كذلك انسياب القدرة خلال الربط الكهربائي بالقيم المبرمجة أثناء دورة التشغيل العادية وأيضا خلال اهتزازات الحمل الكهربائي الخفيفة. في هذه الدراسة، أخذ في الاعتبار نظام القدرة كهربائي يتألف من نظامي قدرة كهربائية يتكونان من منطقتين ترتبطان عن طريق خط ربط كهربائي. الغرض من استخدام التحكم الآلي للتوليد الذي يعتمد علي (المتحكم التناسبي_ التكاملي_التفاضلي الغامض) هو إخماد الانحرافات العابرة للتردد والقدرة وكذلك أن يعطي هذا المتحكم خطأ صفري للحالة المستقرة لهذه المتغيرات في زمن وجيز.تم عمل المحاكاة والتحليل باستخدام برنامج (ماتلاب) عن طريق برنامج رابط المحاكاة.مستقبلا يمكن إضافة أنواع مختلفة من الدوال العضوية لتحسين أداء المتحكم ،وأيضا يمكن تطبيق المتحكم لأكثر من منطقتي قدرة.

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION

CHAPTER TWO: THEORETICAL BACK GROUND AND LITERATURE REVIEW

CHAPTER THREE: MATHEMATICAL MODEL OF SYSTEM

CHAPTER FOUR: SYSTEM DESIGN AND SIMULATION

CHAPTER FIVE: CONCOLUSION AND RECOMMENDATION

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AC	Alternating Current
DC	Direct Current
VR	Voltage Regulator
MHD	Magnetic Hydrodynamic Generator
PV	Process variables
P	Proportional
I	Integral
D	Derivative
Z	Zero
NB	Negative Big
NS	Negative Small
PS	Positive Small
PB	Positive Big
Emf	Electric magnetic force
Rpm	Revolution per minte
PV	Process Variable
UD	universe of Discourse
FIS	fuzzy Inference system
ACE	Area Control Error
ANFIS	Adaptive Neuro Fuzzy Inference System

CHAPTER ONE

INTRODUCTION

1.1 Back ground

Automatic Generation Control (AGC)or load frequency control is an important issue in power system for delivering sufficient and reliable power. Load frequency control is one of important control problems in power system operation. The main objective of AGC is to establish a normal operating state and optimum scheduling of generation with good quality of power. Since load demand varies continuously, so the generation is expected to overcome these variations without any change in the voltage and frequency. Therefore voltage and frequency controllers are installed to maintain the desired megawatt output. To maintain desired megawatt output of a generator unit automatic generation control is required. AGC also controls the frequency of larger interconnected power system. AGC has made the operation of interconnected system possible. The main purpose of designing fuzzy logic based load frequency is to ensure stable and reliable power system operation. Automatic generation control equipments are installed for each generator in the power system. Automatic generation control also helps to maintain the net interchange of power between pool members at pre-specified values. In the conventional control design the integral of control error is taken as the control signal. By using integral controller zero steady state frequency deviation can achieved but it gives poor dynamic response. Due to sudden load change in the system, there occurs fluctuations in the frequency which remains for a long time. One method to restore the frequency to its nominal value is to add integrator in the power system network. But conventional controllers do not better results. The results obtained shows that the performance of fuzzy logic based controller is better than the conventional controller[1] .

1.2 Problem Statement

An industrial process, such as power system, contains different kinds of uncertainties due to change in system parameters, characteristics and load variations. On the other hand, the operating points of power system may change very much during a daily cycle. The load is always changing, this needs to maintain power balance, and generators need to produce more or less power to keep up with the load. When generation is less than load the load the generator speed and frequency will drop and vice versa. So AGC is used to maintain frequency to the nominal value .

1.3 Objectives

- To design FLC and conventional PID controller for two area power system .
- To develop automatic generation control of two area power system using FLC .
- To compare the result between conventional PID and FLC.

1.4 Methodology

In order to reduce frequency deviation to zero, a reset action must be provided. The reset action can be achieved by introducing an integral controller to act on the load reference setting to change the speed set point. Also fuzzy logic controller is used and comparison to conventional controller. Finally the simulation using MATLAB software will be performed to obtain which controller had nominal value of frequency.

1.5 Layout

This research consists of five chapters chapter one illustrates the background, problem statement, objectives and the methodology. Chapter two contains theoretical background and literature review. Chapter three presents the mathematical model of system. Chapter four contains system design and simulation result. Chapter five covers the conclusion and recommendations.

CHAPTER TWO

THEORETICAL BACK GROUND AND LITERATURE REVIEW

2.1 Generation

In electricity generation, a generator is a device that converts motive power(mechanical energy) into electrical power for use in an external circuit. Sources of mechanical energy include steam turbines, gas turbines, water turbines, internal combustion engines and even hand cranks. The first electromagnetic generator, the faraday disk, was invented in 1831 by British scientist Michael Faraday. Generators provide nearly all of power for electric power grids.Before the connection between magnetism and electricity was discovered, electrostatic generators were invented. They operated on electrostatic principles, by using moving electrically charged belts, plates, and disks that carried to high potential electrode. The charge was generated using either of two mechanisms: electrostatic induction or the triboelectric effect. Such generated very high voltage and low current. Because of their inefficiency and the difficulty of insulating machines that produced very high voltages, electrostatic generators had low power ratings, and were never used for generation of commercially significant quantities of electric power. Their only practical applications were to power early X-ray tubes, and later in some atomic particle accelerators. The Faraday disk was the first electric generator. The horseshoe shaped magnet (A) created a magnetic field through the disk (D). When the disk was turned, this induced an electric current radially outward from the center toward the rim. The current flowed out through the sliding spring contact, through the external circuit, and back into the center of the disk through the axle.

A coil of wire rotating in magnetic field produces a current which changes direction with each 180° rotation, an Alternating Current (AC). However, many early uses of electricity required Direct Current (DC). In the first practical electric generators, called dynamos, the AC was converted into DC with a commutator, a set of rotating switch contacts on the armature shaft. The commutator reversed the connection of the armature winding to the circuit every 180° rotation of the shaft, creating a pulsing DC current. Once of the first dynamos was built by HippolytePixii in 1832 [2].

The dynamos was the first electrical generator capable of delivering power for industry. The dynamo-electric machine employed self-powering electromagnetic field coils rather than permanent magnets to create the stator field. Wheatone's design was similar to Siemens with difference that in the Siemens design the stator electromagnets were in series with the rotor, but in wheatstone's design they were in parallel. The use of electromagnets rather than permanent magnets greatly increased the power output of a dynamo and enabled high power generation for the first major industrial uses of electricity. The dynamo machine that developed consisted of a stationary structure, which provides the magnetic field, and a set of rotating windings which turn within that field. On larger machines the constant magnetic field is provided by one or more electromagnets, which are usually called field coils. Large power generation dynamos are now rarely seen due to the now nearly universal use of alternating current for distribution. Before the adoption of AC, very large direct-current dynamos were the only means of power generation and distribution. AC has come to dominate due to the ability of AC to be easily transformed to and from very high voltages to permit low losses over large distances consider an AC supply is connected to the stator terminals of an induction machine. Rotating magnetic field produced in the stator pulls the rotor to run behind it (the machine is acting as a motor).

2.2 Electromagnetic Generator

Electromagnetic generators fall into one of two board categories as follows:

2.2 .1 Dynamo

Dynamo is an electrical generator that creates direct current using a commutator. Dynamos were the first electrical generators capable of delivering power for industry, and the foundation upon which many other later electric power conversation devices were based, including the electric motor, the alternating-current alternator, and the rotary converter. Today, the simpler alternator dominates large scale power generation, for efficiency, reliability and cost reasons. A dynamo has the disadvantages of a mechanical commutator. Also, converting alternating to direct current using power rectification devices (vacuum tube or more recently solid state) is effective and usually economical.

The electrical dynamo uses rotating coils of wire and magnetic fields to convert mechanical rotation into a pulsing direct electric current through Faraday's law of induction. A dynamo machine consists of a stationary structure, called the stator, which provides constant magnetic field, and a set of rotating windings called the armature which turn within that field. Due to Faraday's law of induction the motion of the wire within the magnetic field creates an electromotive force which pushes on the electrons in the metal, creating an electric current in the wire[3].

2.2.2 Alternator

An alternator is an electrical generator that converts mechanical energy to electrical energy in the form of alternating current. For reasons of cost and simplicity, most alternators use a rotating magnetic field with a stationary armature. Occasionally, a linear alternator or a rotating armature with a stationary magnetic field is used. In principle, any AC electrical generator can be called an alternator, but usually the term refers to small rotating machines driven by automotive and other internal combustion engines. Alternators in power stations driven by steam turbines are called turbo-alternators. Large 50 or 60 HZ three phase alternators in power plants generate most of the world's electric power, which is distributed by electric power grids.

A conductor moving relative to a magnetic field develops an electromotive force (emf) in it (Faraday's Law). This emf reverses its polarity when it moves under magnetic poles of opposite polarity. Typically, a rotating magnet, called the rotor turns within an stationary set of conductors wound in coils on an iron core, called the stator. The field cuts across the conductors, generating an induced emf(electromotive force), as the mechanical input causes the rotor to turn. The rotating magnetic field induces an AC voltage in the stator windings. Since the currents in the stator windings vary in step with the position of rotor, an alternator is asynchronous generator.

The rotor's magnetic field may be produced by permanent magnets, or by afield coil electromagnet. Automotive alternators use a rotor winding which allows control of the alternator's generated voltage varying the current in the rotor field winding. Permanent magnet machines avoid the loss due to magnetizing current in the rotor, but are restricted in size, due to the cost of the magnet material. Since the permanent magnet field is constant, the terminal voltage varies directly with the speed of the generator. Brushless AC generators are usually larger than those used in automotive applications.

An automatic voltage control device controls the field current to keep output voltage constant. If the output voltage from the stationary armature coils drops due to an increase in demand, more current is fed into the rotating field coils through the Voltage Regulator(VR). This increase the magnetic field around the field coils which induces a greater voltage in the armature coils. Thus, the output voltage is brought back up to its original value.

Alternators used in central power stations also control the field current to regulate reactive power and to help stabilize the system power against the effects of momentary faults. Often there are three sets of stator windings, physically offset so that the rotating magnetic field produces a three phase current, displaced by one-third of a period with respect to each other[2].

2.2.3Induction generator

Induction generator is a type of AC electrical generator that uses the principles of induction motors to produce power. Induction generators operate by mechanically turning their rotors faster than synchronous speed. A regular AC induction motor usually can be used as generator, without any internal modifications. Induction generators are useful in applications such as mini hydro power plants, wind turbines, or in reducing high pressure gas streams to lower pressure, because they can recover energy with relatively simple controls.

(a)Principle of operation

An induction generator produces electrical power when its rotor is turned faster than the synchronous speed. For a typical four-pole synchronous speed. For typical four-pole motor (two pairs of poles on stator) operating on a 60 Hz electrical grid, the synchronous speed is 1800 rotations per minute(rpm). The same four-pole motor operating on a 50HZ grid will have a synchronous speed of 1500rpm. The motor normally turns slightly slower than the synchronous speed, the difference between synchronous and operating speed is called slip and is usually expressed as per cent of the synchronous speed.

In normal motor operation, the stator flux rotation is faster than the rotor rotation. This causes the stator flux to induce rotor currents, which create a rotor flux with magnetic polarity opposite to stator. In this way, the rotor is dragged along behind stator flux, with the currents in the rotor induced at the slip frequency[2].

In general operation, a prime mover (turbine or engine) drives the rotor above the synchronous speed. The stator flux still induces currents in the rotor, but since the opposing rotor flux is now cutting the stator coils, an active current is produced in stator coils and the motor now operates as a generator, sending power back to the electrical grid.

An induction machine requires an externally- supplied armature current. Because the rotor field always lags behind the stator field, the induction machine always consumes reactive power, regardless of whether it is operating as a generator or motor. A source of excitation current for magnetizing flux (reactive power) for the stator is still required, to reduce rotor current. This can be supplied from the electrical grid or, once it starts producing power, from the generator itself.

A induction machine can be started by charging the capacitors, with a DC source, while the generator is turning typically at or above generating speeds. Once the DC source is removed the capacitors will provide the magnetization current required to begin producing voltage.Consider an AC supply is connected to the stator terminals of an induction machine. Rotating magnetic field produced in the stator pulls the rotor to run behind it (the machine is acting as a motor).

(b)Active power

Active power delivered to the line is proportional to slip above the synchronous speed. Full rated power of the generator is reached at very small slip values (motor dependent, typically 3%). At synchronous speed of 1800rpm, generator will produce no power. When the driving speed is increased to 1860rpm (typical example), full output power is produced. If the prime mover is unable to produce enough power to fully drive the generator, speed will remain somewhere between 1800 and 1860 rpm range[3].

2.2.4 Magneto-hydro-dynamic generator

Magneto-hydro-dynamic (MHD) is the acronym for magneto hydrodynamic generator. MHD generators are similar to the conventional electric generators. The only difference is that they use electrically conducting fluid instead of solid conductors to generate electric power .basically, magneto hydrodynamics is a research area that involves the study of motion of conducting fluids such as plasma and salt water.

A simple magneto hydrodynamic generator consists of a gas nozzle. The gas nozzle is a combustion chamber that injects a pulse of gas into channel/duct. The walls of the channel act as an electric current is fed to the load by an external circuit that supplies the generated electricity to the desired destination. The MHD generators can be constructed in various designs like the faraday generator, hall generator, and disc generator. Faraday generator was the first designed MHD generator. It used copper disks and a horse-shoe magnet to generate electricity.

Most of the MHD systems use coal or natural gases like argon and helium are also used in some systems. The gas is passed through a nozzle at high speed of 1000 to 2000 meter per second. The generators do not create electric charge, it is inherent in the ionized fluid or gases. Magneto hydrodynamic generators were initially developed to heat the developed to heat the boilers of steam power plants, as they require very high temperatures to function. This was not possible with conventional electric generators. MHD generators have high thermal efficiency that is required for power plants. They do not cause any significant harm to the environment. With more research and innovation, MHD systems will lead to development in the work of thermonuclear fusion reactors[4].

2.3 Control Theory

Control theory in control systems engineering is a subfield of mathematics that deals with the control of continuously operating dynamical systems in engineered processes and machines. The objective is to develop a control model for control action in an optimum manner without delay or overshoot and ensuring control stability. Control theory dates from the 19th century, when the theoretical basis for the operation of governors was first described by James Clerk Maxwell. Although a major application of control theory is in control systems engineering, which deals with the design of process control systems for industry, other application range far beyond this. As the general theory of feedback systems, control theory is useful wherever feedback occurs.

Fundamentally, there are two types of control loops: open loop control and closed loop(feedback) control. Control theory is concerned only with closed loop control. In open loop control, the control action from the controller is independent of the process output or controlled Process Variable(-PV). In closed loop control, the control action from the controller is dependent on feedback from process in the form the value of the Process Variable (PV).

2.4 A Proportional-Integral-Derivative Controller

Is a control loop feedback mechanism commonly used in industrial control systems. A PID controller continuously calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error over time by adjustment of control variable, such as the position of a control valve, a damper, or the power supplied to a heating element, to anew value determined by weighted sum[5].

The time domain equation of PID controller given by:

$$u(t) = K_P e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \qquad (2.1)$$

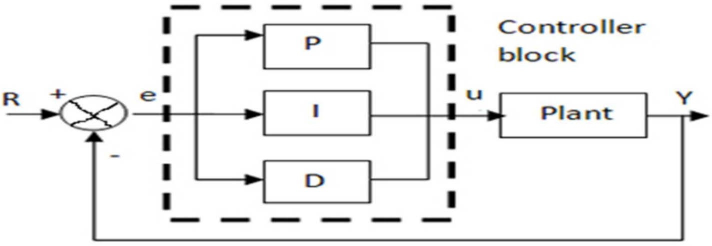


Figure 2.1: PID controller system block diagram

Where $K_p, K_i and K_{d,}$all non-negative, denote the coefficients for the proportional,integral, and derivative terms, respectively(sometimes denoted P ,I and D). P,I and D are account for present, past and possible future values of the error, respectively.

2.4.1 Proportional term

The proportional term produces an output value that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constantK_P, called proportional gain, the proportional term is given by:

$$P_{out} = K_P e(t) \tag{2.2}$$

2.4.2 Integral term

The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have corrected previously. The accumulated error is then multiplied by the integral gain(K_i)and added to the controller output. The integral term is given by:

$$I_{out} = \int_0^t e(t)dt \tag{2.3}$$

2.4.3 Derivative term

The derivative of the process error is calculated by determining the slope of the error over time and multiplying this rate of change by derivative gain[3].The derivative term is given by[6].

$$D_{out} = K_d \frac{de(t)}{dt} \tag{2.4}$$

Table 2.1shows the effects of increasing PID controller gains independently

parameter	Rise Time	Over Shoot	Settling Time	Steady-State Error	Stability
k_p	Decrease	Increase	Small Change	Decrease	Degrade
K_i	Decrease	Increase	Increase	Eliminate	Degrade
K_d	Minor Change	Decrease	Decrease	No Effect	Improve if K_d Small

2.5 Fuzzy Logic

The term ‘fuzzy’ in fuzzy logic was first coined in 1965 by professor LoftiZadeh, he used the term ‘fuzzy sets’ to describe multi valued sets. The entire real world is complex; it is found that the complexity arises from uncertainty in the form of ambiguity. According to Dr. LotfiZadeh, principle of compatibility, the complexity, and the imprecision are correlated, the closer one looks at a real world problem, the fuzzier becomes its solution. The Fuzzy Logic tool was introduced in 1965, also by LotfiZadeh, and it is a mathematical tool for dealing with uncertainty. It offers to a soft computing partnership the important concept of computing with words. It provides a technique to deal with imprecision and information granola[7].

2.5.1 Fuzzy sets and fuzzy logic

In classical set theory, a Universe of Discourse (UD) is defined as a collection of objects all having the same characteristics. A classical set is then a collection of a number of those elements. The member elements of a classical set belong to the set 100 percent. Other elements in the universe of discourse, which are non-member elements of the set, are not related to the set at all. A definitive boundary can be drawn for the set, as depicted in Figure 2.2.

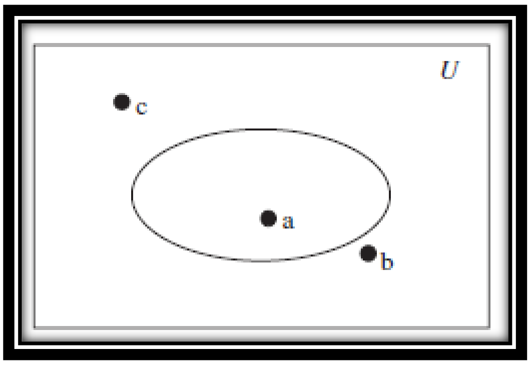


Figure 2.2: Classical/crisp set boundary

In fuzzy set theory, the concept of characteristic function is extended into a more generalized form, known as membership function: μA(x):U → [0, 1]. While a characteristic function exists in a two-element set of {0, 1}, a membership function can take up any value between the unit interval [0, 1]. The set which is defined by this extended membership function is called a fuzzy set. The boundary of a fuzzy set is shown in Figure 2.3.

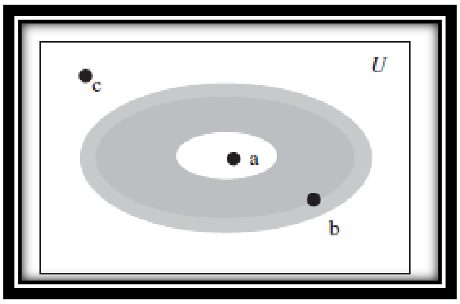


Figure 2.3:Fuzzy set boundary

2.5.2 Types of membership functions

Figure 2.4 shows various types of membership functions which are commonly used in fuzzy set theory.

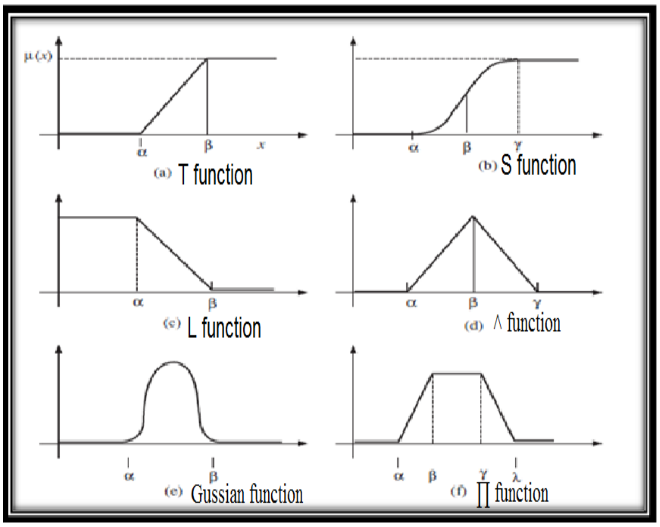


Figure 2.4: Types of membership functions

The choice of shape depends on the individual application. In fuzzy control applications, Gaussian or bell-shaped functions and S-functions are not normally used. Functions such as Γ-function, L-function and Λ-function are far more common[8].

2.5.3 Linguistic variables

The concept of a linguistic variable, a term which is later used to describe the inputs and outputs of the FLC, is the foundation of fuzzy logic control systems. A conventional variable is numerical and precise. It is not capable of supporting the vagueness in fuzzy set theory. By definition, a linguistic variable is made up of words, sentences or artificial language which is less precise than numbers. It provides the means of approximate characterization of complex or ill-defined phenomena[9].

2.5.4 Fuzzy control system

Figure 2.5 shows the block diagram of a typical FLC.

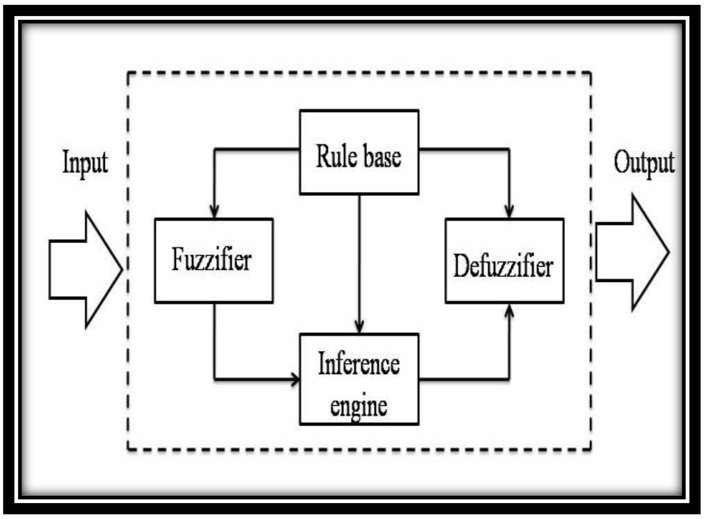


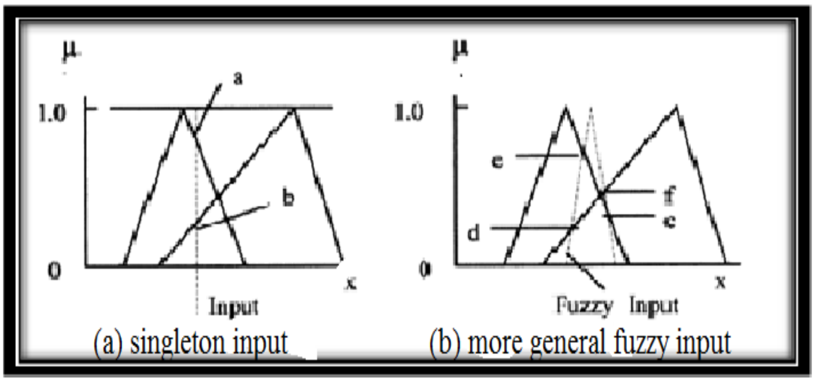
Figure 2.5: A fuzzy logic system

There are five principal elements to a fuzzy logic controller:

- Fuzzification module (fuzzifier).
- Knowledge base.
- Rule base.
- Inference engine.
- Defuzzification module (defuzzifier).

2.5.5 Fuzzification

The operations in fuzzy logic are performed in terms of fuzzy sets. In practice, the input data may also be in terms of fuzzy sets or a singleton (single element with a membership value of unity), which is in fact a special type of fuzzy set. The input data needs to be assigned membership values of one or more fuzzy sets into which the UD has been partitioned. The membership values are found from the intersections of the data sets with the fuzzy sets of the UD. For the singleton in Figure 2.6a, there are two intercepts, i.e., at a and b, which determine the membership values. Whilst for the fuzzy input in Figure 2.5(b) there are four intercepts at c, d, e and f which determine the membership values.



(a) singleton input (b) more general fuzzy input

Figure 2.6: Assigning input data membership values

2.5.6 Defuzzification

This means the reduction of the fuzzy set or subset to a singleton. The fuzzy set is usually the union of several subsets representing the conclusion of a fuzzy proposition. Normally, a fuzzy set cannot be represented by a singleton; therefore defuzzification can only be undertaken with the loss of information. The union of several subnormal (no membership value equal to unity) fuzzy subsets is illustrated in Figure 2.8 and s is the single element on the UD which is deemed to represent the union of the fuzzy subsets.

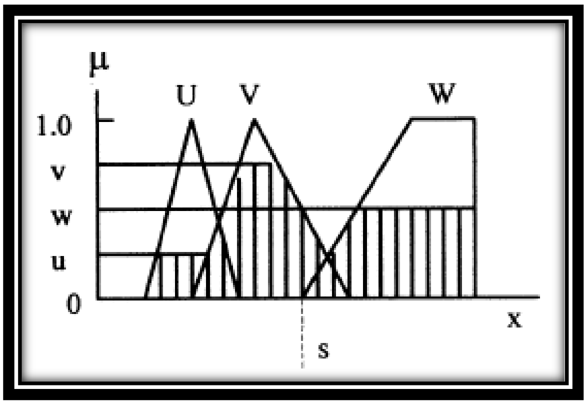


Figure 2.7:The union of several fuzzy subsets

Such a representation discards the span of the conclusion and the membership values of the subsets. But for calculations in design (for example) a specific value is required and provides the motivation for defuzzifying, but it is important not to lose sight of the whole solution. There are several ways of finding a representative number, two common ways are outlined below:

(i) Centroid method

This is probably the most frequently used method and as the name suggests, it involves finding the position of the centre of area of the subsets on the abscissa (s).

Continuous distribution can be calculated as:

$$s = \int_{x=0}^{x=\infty} xda / \int da \qquad (2.5)$$

Discrete distribution can be calculated as:

$$s = \frac{\sum_{i=1}^{i=n} xi\delta Ai}{\sum \delta Ai} \qquad (2.6)$$

(ii) Weighted abscissa method

This is evaluated by taking the sum of the normalized weighting of each of the set principal values, xi (max).

$$s = \sum_{i=1}^{i=n} Mixi \text{ (max)} / \sum \mu i \qquad (2.7)$$

In the trapezoidal shape of fuzzy set, it is the mid-support value that is used for xi. The centroid and weighted abscissa methods generally give somewhat different values of the defuzzified representative number. It may be observed that given a representative number, it is generally not possible to recover the original fuzzy subset [10].

2.4.7 Fuzzy logic implication

Fuzzy implication is an important connective in fuzzy control systems because the control strategies are embodied by sets of IF-THEN rules. There are various different techniques in which fuzzy implication may be defined. These relationships are mostly derived from multi valued logic theory. The following are some of the common techniques of fuzzy implication:

- Mamdani:This method is widely accepted for capturing expert knowledge. It allows us to describe the expertise in more intuitive, more humanlike manner. However, Mamdani type Fuzzy Inference System (FIS) entails a substantial computational burden.
- Takagi-Sugeno:This method is computationally efficient and works well with optimization and adaptive techniques, which makes it very attractive in control problems particularly for dynamic nonlinear systems. These adaptive techniques can be used to customize the membership functions so that fuzzy system best models the data.

The most fundamental difference between Mamdani type FIS and Sugeno type FIS is the way the crisp output is generated from the fuzzy inputs. While Mamdani type FIS uses the technique of defuzzification of a fuzzy output Sugeno type FIS uses weighted average to compute the crisp output. The expressive power and interpretability of Mamdani output is lost in the SugenoFIS since the consequents of the rules are not fuzzy. But Sugenohas better processing time since the weighted average replace the time consuming defuzzification process. Due to the interpretable and intuitive nature of the rule base Mamdani type FIS is widely used in particular for decision support application. Other differences are that Mamdani FIS has output membership functions whereas Sugeno FIS has no output membership functions. Mamdani FIS is less flexible in system design in comparison to Sugeno FIS as latter can be integrated with Adaptive Neuro Fuzzy Inference System (ANFIS) tool to optimize the outputs[11].

2.6 Automatic Generation Control

In an electric power system, AGC is a system for adjusting the power output of multiple generators at different power plants, in response to changes in the load. Since a power grid requires that generation and load closely balance moment by moment, frequent adjustments to the output of generators are necessary. The balance can be judged by measuring the system frequency, if it is increasing, more power is being generated than used, which causes all the machines in the system to accelerate. If the system frequency is decreasing, more load is on the system than the instantaneous generation can provide, which causes generators to slow down.

Before the use of automatic generation control, one generating unit in a system would be designated as the regulating unit and would be manually adjusted to control the balance between and load to maintain system frequency at desired value. The remaining units would be controlled with speed droop to share the load in proportion to their ratings. With automatic systems, many units in system can participate in regulation, reducing wear on a single unit's controls and improving overall system efficiency, stability, and economy.

Where the grid has tie interconnections to adjacent control areas, automatic generation control helps maintain the power inter changes over the tie lines at the scheduled levels. With computer-based control system and multiple inputs, an automatic generation control system can take into account such matters as the most economical units to adjust, the coordination of thermal, hydroelectric, and other generation types, and even constraints related to the stability of the system and capacity of interconnections to other power grids.In electrical power generation, droop speed control is a speed control mode of prime mover driving a synchronous generator connected to an electrical grid. This mode allows synchronous generators to run in parallel, so that loads are shared among generators in proportion to their power rating.

The frequency of a synchronous generator is given by:

$$f = P * \frac{N_S}{120} \qquad (2.8)$$

Where:

f is frequency (in H_Z).

P is the number of poles.

$N_S$is the speed of generator (in rpm).

The frequency (f) of synchronous generator is directly proportional to its speed (N_S). when multiple synchronous generators are connected in parallel to electrical grid, the frequency is fixed by the grid, since individual power output of each generator will be small compared to the load on a large grid.

Synchronous generators connected to the grid run at various speeds but they all run at the same frequency because they differ in the number of poles (P).

A speed reference as percentage of actual speed is set in this mode. As the generator is loaded from no load to full load, the actual speed of the prime mover tends to decrease. In order to increase the power output in this mode, the prime mover speed reference is increased. Because the actual prime mover speed is fixed by the grid, this difference in speed reference and actual speed of the prime mover is used to increased the flow of working fluid (fuel, steam, etc.) to the prime mover, and hence power output is increased. The reverse will be true for decreasing power output. The prime mover speed reference is always greater than actual speed of the prime mover. The actual speed of the prime mover is allowed droop or decrease with respect to the reference.

As frequency is fixed on the grid, and so actual turbine speed is also fixed, the increase in turbine speed reference will increase the error between reference and actual speed. As the difference increases, fuel flow is increased to increase power output, and vice versa. This type of control is referred to as straight proportional control. If the entire grid tends to be overloaded, the grid frequency and hence actual speed of generator will decrease. All units will see an increase in the speed error, and so increase fuel flow to their prime movers and power output[12].

CHAPTER THREE

MATHEMATICAL MODEL OF SYSTEM

3.1 Introduction

Power systems consist of control areas representing a coherent group of generators. generators which swing in unison characterized by equal frequency deviations. In addition to their own generations and to eliminate mismatch between generation and demand these control areas are interconnected through tie-lines for providing contractual exchange of power under normal operating conditions. One of the control problems in power system operation is to maintain the frequency and power interchange between the areas at their rated values. Automatic generation control is to provide control signals to regulate the real power output of various electric generators within a prescribed area in response to changes in system frequency and tie-line loading so as to maintain the scheduled system frequency and established interchange with other areas. The performance of the automatic generation control depends upon how various power generating units respond to these signals. The speed of their response is limited by natural time lags of the various turbine dynamics and the power system itself. In other words the design of automatic generation controller depends upon various energy source dynamics involved in the AGC of the area. The various generations are connected by a stiff network that is why the frequency deviations are assumed to be equal in an area. The load over a day varies which is evident from a daily load curve. Therefore the contributions of generations from various sources in an area are adjusted to meet the load variations. The performance of the Automatic Generation Control may also vary in respect to the changes in the share of different type of power generations to the total generation of the area. In order to obtain the optimum realistic AGC performance, the automatic generation controller parameters have to be optimized for various nominal loading conditions. Due to the lower power production cost a typical generation in an area may be contributing to its maximum by running at its rated load capacity while others may not be. In such case the typical generation is regulated by the speed governor alone but its dynamics will also play a role in the selection of the automatic generation controller parameters for other generation area[13].

3.2 Generator Model

Applying swing equation of asynchronous machine given by to small perturbation, we have:

$$\frac{2H}{\omega_s}.\frac{\mathrm{d}\,\Delta\delta}{dt} = \Delta P_m - \Delta P_{\mathrm{t}} \qquad (3.1)$$

Where H,Δ□,ΔP_m ,ΔP_t and ωs are inertia constant, , mechanical power deviation, turbine power deviation and steady state frequency respectively.

Or in terms of small deviation in speed:

$$\frac{\frac{d\Delta\omega}{\omega_S}}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \qquad (3.2)$$

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

$$\frac{d\Delta\omega}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_m) \qquad (3.3)$$

By taking Laplace transform of(3.3), we obtain:

$$\Delta\Omega(s) = \frac{1}{2H}[\Delta P_m(s) - \Delta P_e(s)] \qquad (3.4)$$

Where ΔΩ(s) is speed deviation.

The above relation is shown in Figure (3.1).

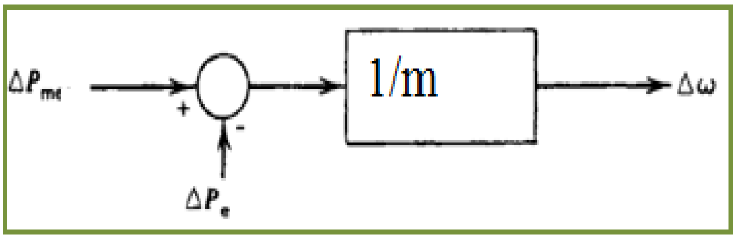


Figure3.1: Generator block diagram.

3.3 Load Model

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

$$\Delta P_e = \Delta P_L + D\Delta\omega \qquad (3.5)$$

Where:

ΔP_L is non frequency sensitive load change.

$D\Delta\omega$is the frequency sensitive load change.

D is expressed as percentage in change load divide by percentage change in frequency. For example if the change by 1.6 percentage for 1 percentage change in frequency, then D=1.6. Figure3.2 shows the block diagram of the generator and load.

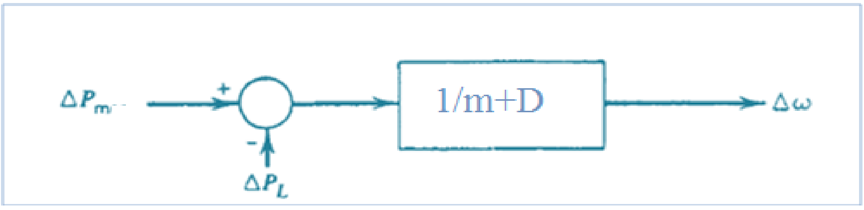


Figure3.2: Generator and load block diagram

3.4 Prime Mover Model

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

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_V(s)} = \frac{1}{1+\tau_T(s)} \tag{3.6}$$

The block diagram for simple turbine shown in Figure 3.3.

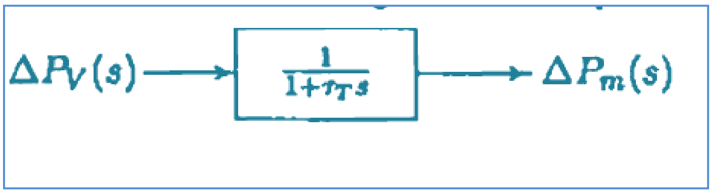


Figure 3.3: Block diagram for simple steam turbine.

The time constant τ_T is in range of 0.2 to2.0 seconds.

3.5 Governor Model

When the generator electrical load is suddenly increased, electrical power exceeds mechanical power input. This power deficiency is supplied by kinetic energy stored in 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 governor which acts to adjust turbine input valve to change the mechanical power output to bring the speed to new steady state. The earliest governors were the watt governors which sense speed by means rotating fly balls and provide mechanical motion in response to speed change. However, most modern governor use electronic means to sense speed change. Figure 3.4 shows schematically the essential elements of a conventional watt governor which consist of the isochronous governors cannot be used when there are two or more units connects to the same system since each generator would have precisely the same speed setting[13].

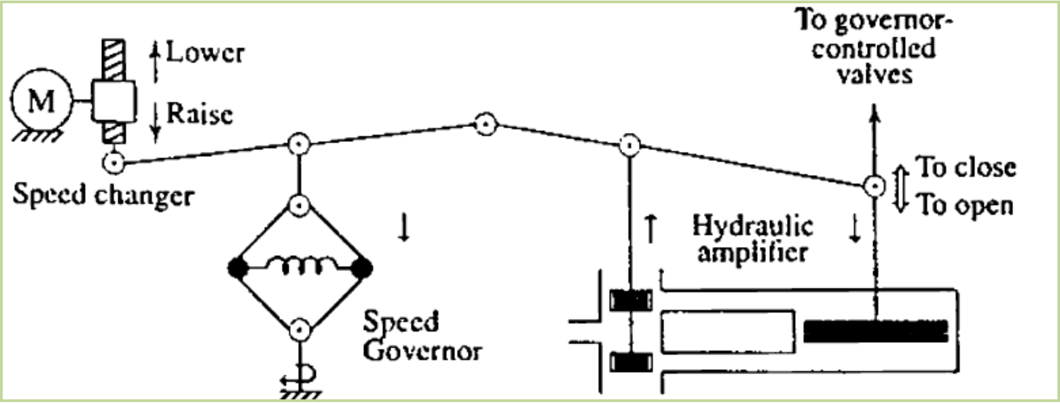


Figure 3.4: Speed governor system

1.speed governor : The essential part are centrifugal fly balls driven directly or through gearing by turbine shaft. The mechanism provides upward and downward vertical movements proportional to change in speed.

2. Linkage mechanism: These are link to transforming fly balls movement to the turbine through hydraulic amplifier and provide feedback from the turbine valve movement.

3. Hydraulic amplifier: Very large mechanical forces are needed to operate the steam valve. Therefore, governor movement are transformed into high power force via several stages of hydraulic.

4. speed changer: The speed changer consist of a servo motor which can be operated manually or automatically for scheduling at nominal frequency.

By adjusting this set point, a desired load dispatch can be scheduled at nominal frequency[1]. For stable operation, the governors are designed to permit the speed to drops as the load is increased . The steady state characteristics of such a governor is shown in Figure3.5

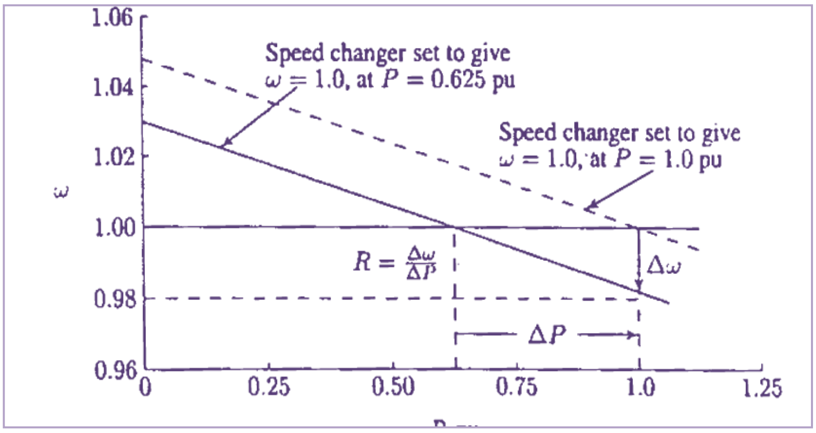


Figure3.5: Governor steady-state speed characteristics.

The slope of the curve represents the speed regulation R. Governor typically have speed regulation of 5-6 percent from zero to full load the speed governor mechanism acts as comparator whose output ΔP_g is difference between the reference set powerΔP_{ref} and the power $1/R\Delta\omega$ as given from governor speed characteristics:

$$\Delta P_g = \Delta P_{\mathrm{ref}} - \frac{1}{R\Delta\omega} \qquad (3.7)$$

Or in S-domain:

$$\Delta P_{\mathrm{g}}(\mathrm{s}) = \Delta \mathrm{P}_{\mathrm{ref}}(\mathrm{s}) - \frac{1}{\mathrm{R}}\Delta\Omega(\mathrm{s}) \qquad (3.8)$$

The command $\Delta \mathrm{P}_{\mathrm{g}}$ is transformed through hydraulic amplifier to the steam position command ΔP_V. Assuming the linear relationship and considering a simple time constant τ_g, we have the following s-domain relation:

$$\Delta P_V(s) = \frac{1}{1+\tau_g}\Delta P_g(s) \qquad (3.9)$$

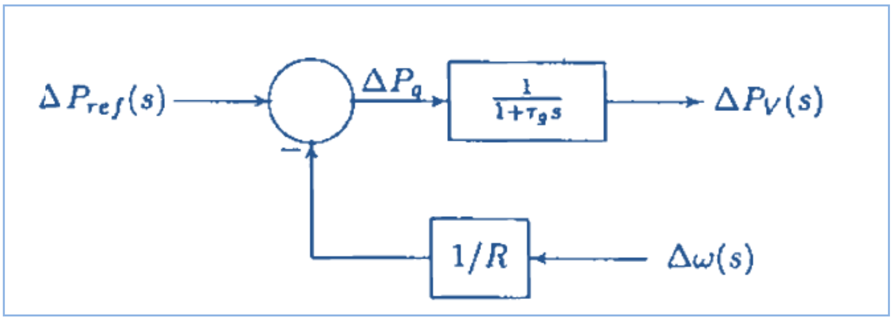


Figure 3.6: Block diagram of representation of speed governing system for steam turbine.

Equations (3.8) and (3.9) are representing in block diagram as shown in figure 3.6. Combining block diagram in Figure3.2, 3.3and3.6 results in complete block diagram of the load frequency control of an isolated power station shown in Figure3.7.

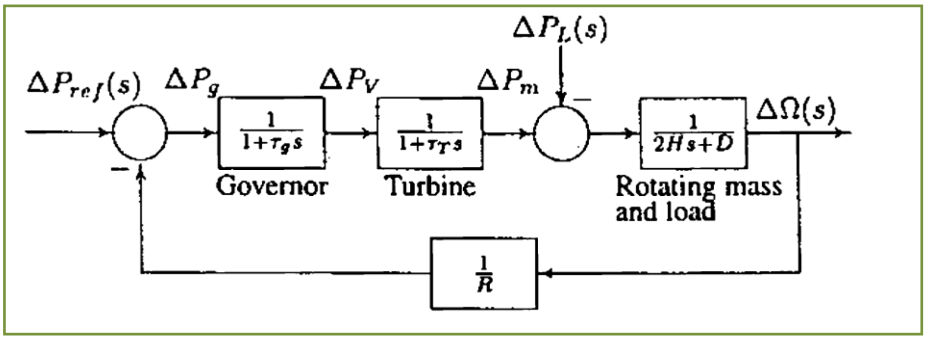


Figure 3.7: Load frequency control block diagram of an isolated power system

Change -$\Delta P_L(S)$as the input and frequency deviation $\Delta\Omega(s)$ as the output results in block diagram shown in figure3.8.

The open loop transfer function of the block diagram in Figure3.8 is:

$$KG(s)H(s) = \frac{1}{R}\frac{1}{(2H(s)+D)(1+\tau_g s)(1+\tau_T s)} \qquad (3.10)$$

And the closed- loop transfer function relating the load change ΔP_L to the frequency deviation $\Delta\Omega$ is:

$$\frac{\Delta\Omega(s)}{-\Delta P_L(s)} = \frac{(1+\tau_g s)(1+\tau_T s)}{(2Hs+D)(1+\tau_g s)(1+\tau_T s)+\frac{1}{R}} \qquad (3.11)$$

Or:

$$\Delta\Omega(s) = -\Delta P_L(s)T(s) \qquad (3.12)$$

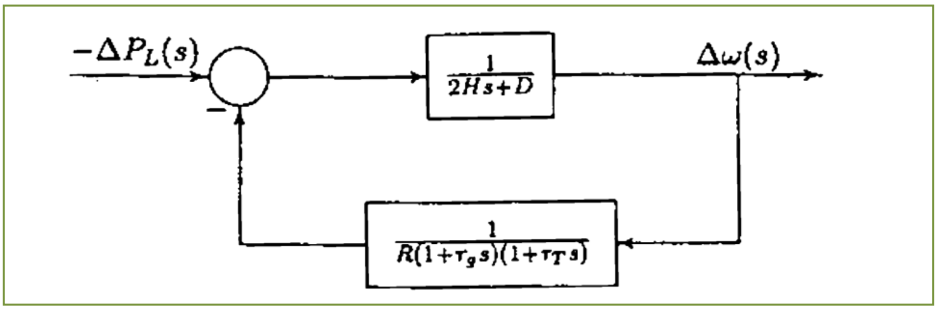


Figure3.8:LFC block diagram with input$\Delta P_L(s)$ and outputΔ Ω(s).

The load change is step input, $\Delta P_L(S)=\Delta P_L/S$. Utilizing the final value theorem, the steady state value of $\Delta\omega$ is:

$$\Delta\omega_{ss} = \lim_{s\to 0} s\Delta\Omega(s) = (-\Delta P_L)\frac{1}{D+\frac{1}{R}} \qquad (3.13)$$

It is clear that for the case with no frequency sensitive load (with D=0), the steady state deviation in frequency is determined by the governor speed regulation, and is:

$$\Delta\omega_{ss} = (-\Delta P_L)R \qquad (3.14)$$

When several generators with governor speed regulating R1, R2,…,RN are connected to the system, the steady state deviation in frequency is given by:

$$\Delta\omega_{ss} = \frac{(-\Delta P_L)1}{D+\frac{1}{R_1}+\frac{1}{R_2}+\quad 1/R_n} \tag{3.15}$$

3.6 Automatic Generation Control

If load on the system increase, the turbine speed drops before the governor can adjust input steam to new load. As the change in the value of speed diminishes, the error signal become smaller and the position of governor fly balls gets closer to the point required to maintain constant speed. However the constant speed will not be a set point , and there will be an offset. One way to store speed or frequency to it is nominal value is to add an integrator. The integral unit monitors the average error over a period of time and will overcome the offset. Because of it is ability to return a system to it is set point. Integral action is also known as reset action. Thus as the system load changes continuously , the generation is adjusted automatically to restore the frequency to nominal value. This scheme known as the AGC. In an interconnected system consisting on several pools, the role of AGC is to divide the load among the system, stations, generators so as to achieve maximum economy and correctly control scheduled interchanges of tie line power.While maintaining reasonably uniform frequency. Of course, implicitly assuming that the system is stable, so the steady state achievable. During large transient disturbances and emergencies, AGC is bypassed and other emergency controls are applied. In the following section, we consider the AGC in single area system and in an interconnected power system[13].

3.7 AGC in Single Area System

With primary LFC loop, a change in system load will result in steady state frequency deviation, depending on the governor speed regulation. In order to reduce the frequency deviation to zero, we must provide rest action. The rest action can achieved by introducing an integral controller to act on the load reference setting to change the speed set point. The integral controller increases the system type by 1 which forces the final frequency deviation to zero. The LFC system, with addition secondary loop, is show in Figure 3.9. The integral controller gain K_I must be adjusted for a satisfactory transient response. Combining the parallel branches result in equivalent block diagram shown in Figure 3.10.

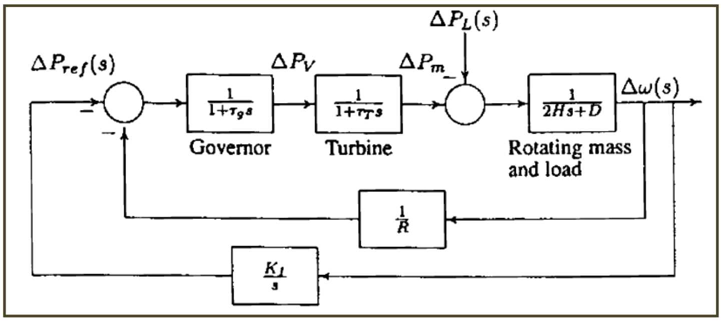


Figure 3.9:Block diagram of AGC for an isolated power system

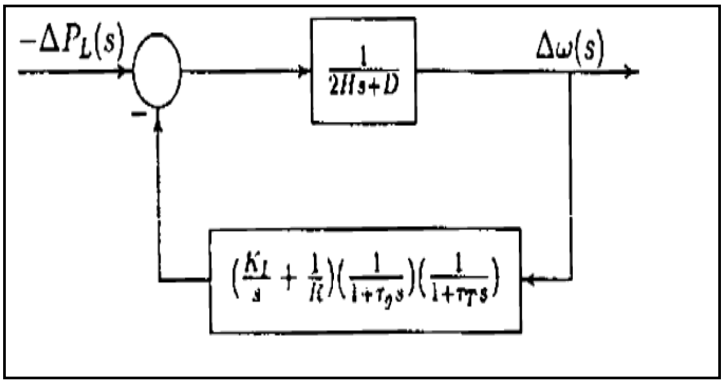


Figure 3.10: The equivalent block diagram of AGC for an isolated power system

The closed-loop transfer function of the control system shown in figure 3.10 with only -ΔP_L as input becomes:

$$\frac{\Delta\Omega(s)}{-\Delta P_L(s)}=\frac{s\left(1+\tau_g s\right)(1+\tau_T s)}{s(2Hs+D)\left(1+\tau_g s\right)(1+\tau_T s)+\frac{s}{R}} \tag{3.16}$$

3.8 AGC in The Multi Area System

In many causes , a group of generators are closely coupled internally swing in unison furthermore, the generator turbines tend to have the same characteristics. Such as a group of generators are said be coherent. Then it is possible to let the LFC loop represent by the whole system, which is referred to as a control area. The AGC of multi area system equivalent generating unit interconnected by lossless tie line reactanceX_{tie}, each area is represent by voltage source behind an equivalent reactance as show in figure 3.11[13].

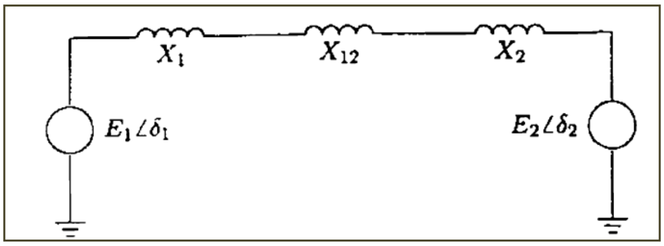


Figure 3.11: Equivalent net work for two- area power system

During normal operation, the real power transferred over the tie line is given by:

$$P_{12} = \frac{|E_1||E_2|}{X_{12}}\sin\delta_{12} \tag{3.17}$$

Where the X_{12}= X_1+X_{tie}+X2, and$\delta_{12} = \delta_1 - \delta_2$. For small deviation in the tie line flowΔP_{tie} from the nominal value:

$$\Delta P_{12} = \frac{dP_{12}}{d\delta_{12}}\Big|\Delta\delta_{12} = P_s\Delta\delta_{12} \tag{3.18}$$

The tie line power deviation then takes on the form :

$$\Delta P_{12} = P_s(\Delta\delta_1 - \Delta\delta_2) \tag{3.19}$$

The tie line power appears as a load increase in one area and a load decrease in the other area, depending on the direction of the flow. The direction of the flow is dictated by phase angle difference, if $\Delta\delta_1 > \Delta\delta_2$,the power flows from area1 to area2. A block diagram representation for two area system with LFC containing only the primary loop is shown in Figure3.12.

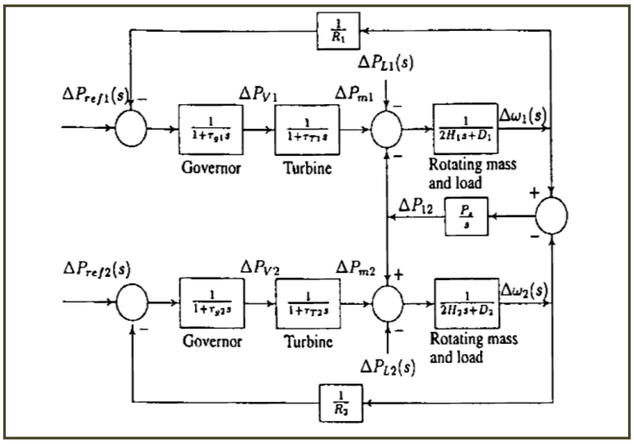


Figure 3.12: Two-area system with only primary LFC loop

Let us consider a load change ΔP_{L1} in area 1, in the steady state, both areas will have same steady state frequency deviation:

$$\Delta\omega = \Delta\omega_1 = \Delta\omega_2 \tag{3.20}$$

And

$$\Delta P_{m1} - \Delta P_{12} - \Delta P_{L1} = \Delta\omega D_1 \tag{3.21}$$

$$\Delta P_{m2} + \Delta P_{12} = \Delta\omega D_2 \tag{3.22}$$

The change in mechanical power is determined by the governor speed characteristic, given by:

$$\Delta P_{m1} = -\frac{\Delta\omega}{R_1} \tag{3.23}$$

$$\Delta P_{m2} = -\frac{\Delta\omega}{R_2} \tag{3.24}$$

Substituting from (3.23) into (3.24), and solving for$\Delta\omega$, we have:

$$\Delta\omega = \frac{-\Delta P_{L1}}{\left(\frac{1}{R_1}+D_1\right)+\left(\frac{1}{R_2}+D_2\right)} = \frac{-\Delta P_L}{B_1+B_2} \tag{3.25}$$

Where:

$$B_1 = \frac{1}{R_1} + D_1 \tag{3.26}$$

$$B_2 = \frac{1}{R_2} + D_2 \tag{3.27}$$

$B_1 and\ B_2$ are known as the frequency bias factors[13].

3.9 Tie Line Bias Control

In the normal operating state ,the power system is operated so that the demands of areas are satisfied at the nominal frequency.

A simple control strategy for the normal mode is :

(i) Keep frequency at nominal value (50 H_Z).

(ii) Maintain the tie line flow about schedule.

(iii) Each area should absorb its own load change.

Conventional LFC is based upon tie line bias control, where each area tends to reduce the Area Control Error(ACE) to zero. The control error for each area consists of a linear combination of frequency and tie line error.

$$ACE_i = \sum_{j=1}^{n} \Delta P_{ij} + K_i \Delta\omega \qquad (3.28)$$

The
area biasK_i determines the amount of interaction during a disturbance in neighboring areas. An overall satisfactory performance is achieve whenK_i is selected equal to the frequency bias factor of that area,$B_i = 1/R_i + D_i$. Thus the ACEs for a two-area system are:

$$ACE_1 = \Delta P_{12} + B_1 \omega_1 \qquad (3.29)$$

$$ACE_2 = \Delta P_{21} + B_2 \omega_2 \qquad (3.30)$$

Where$\Delta P_{12} and\ \Delta P_{21}$ and are departures from scheduled interchanges. ACEs are used as accounting signal to activate changes in the reference power set points, and when steady state is reached,P_{12} and $\Delta\omega$ will be zero. The integrator gain constant must be chosen small enough so as not cause the area to go into a chase mode. The block diagram of a simple AGC for two- area system is shown in Figure 3.13. We can easily extend the tie line bias control to an n-area system[13].

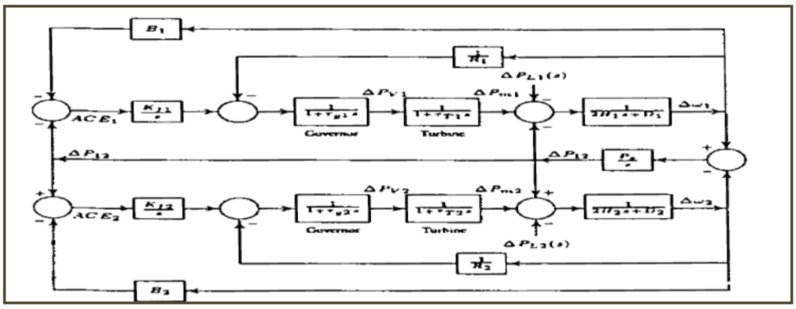


Figure 3.13: AGC block diagram for two-area power system

CHAPTER FOUR

SYSTEM DESIGN AND SIMULATION

4.1 Introduction

In this chapter the study is extended to deal with frequency stability issues in interconnected power system. The operation of power system in normal state is characterized by steady frequency and voltage profile with assured system reliability. Automatic generation control is an important issue in the field of power system operation and control for dispatching reliable electric power with constant frequency. A multi-area interconnected power system can be divided into different control areas those are connected through the tie lines. The frequency of the system depends on balance of active power. A change on demand of active power at one place is reflected in other places however for satisfactory operation the frequency should remain almost constant [5]. In this study, the simulation is executed by using MATLAB/SIMULINK program and MATLAB fuzzy logic toolbox. The controllers which used to control power system are conventional PID and fuzzy PD+I. Two area power system connected by tie-line has the parameters which are used in simulation shown in Table 4.1.

Table 4.1: Power system parameters

	Area1	Area2
Governor Speed Regulation	R1=0.05	R2=0.0625
Frequency Bias Factors	D1=0.6 P.U	D2=.9 P.U
Inertia Constant	H1=5	H2=4
Base Power	1000 MVA	1000MVA
Governor Time Constant	$T_{g1=}0.2$	$T_{\mathbf{g2}=}0.3$
Turbine Time Constant	$T_{\tau 1}= 0.6$	$T_{\tau 2} = 0.8$
Load Change	$\Delta P_{L1} = 0.1p.u$	$\Delta P_{\mathrm{L}2} = 0$
Synchronizing Coefficient(T)	T=2p.u	

4.2 Single Area Power System

Single area power system with the parameters area1 is studied with AGC.

4.2.1 AGC using PID

The single area is now with the PID control loop gains $K_p = 44, K_d = .46\ and\ K_i = 1.2$. Block diagram of single area power system with AGC using PID shows in figure 4.1. The simulation result of frequency deviation step response is shown in Figure 4.2.

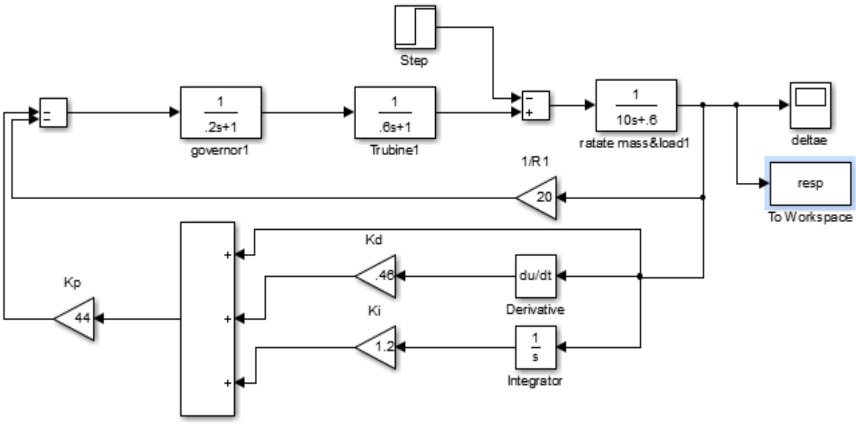


Figure 4.1: Block diagram of single area power system with AGC using PID

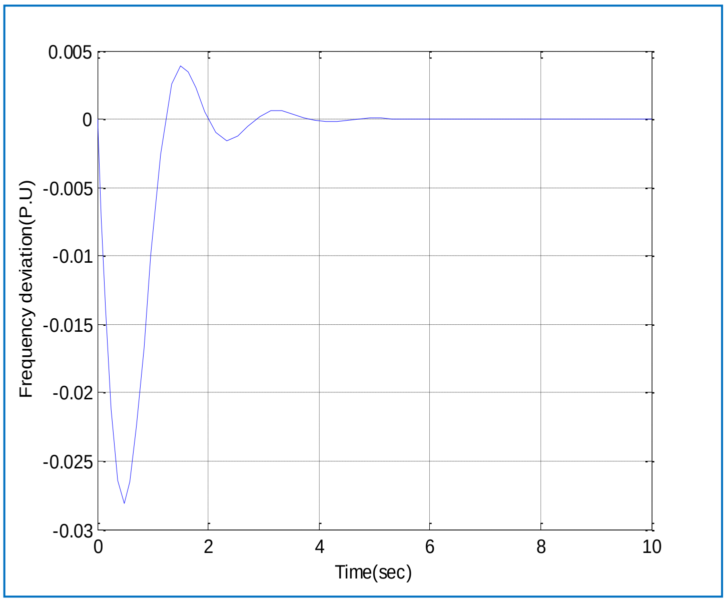


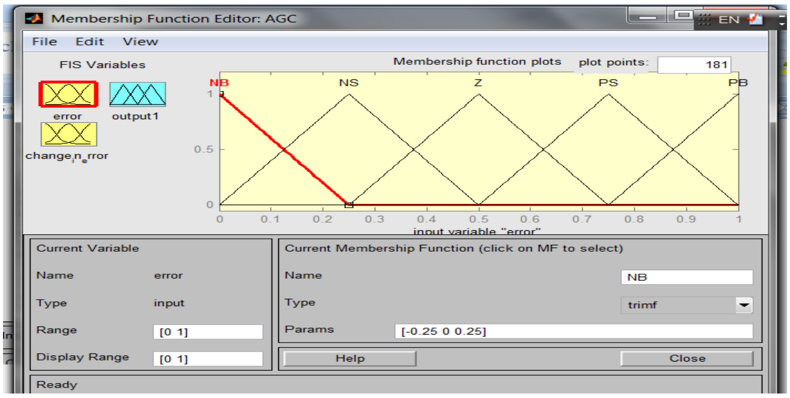
Figure 4.2: Frequency deviation step response of AGC using PID

4.2.2 AGC using FLC

Fuzzy logic control consists of main stages: input stage , process stage, output stage, the process stage executes rule and generates a result for each, then combines the result of the rules. The type of FLC obtained is Mamdani-type. Inputs(an error and change error)and output area defined on the common normalized domain [-0.5,0.5]. Inputs and outputs are transformed to five fuzzy linguistic variable (NB),(NS),(Z),(PS),(PB), which stand for Negative Big, Negative Small, Zero, Positive Small and Positive Big respectively. As each of the three fuzzy variables are quantized to five fuzzy sets, so total 25 rules are required to generate a fuzzy sets output relating two inputs fuzzy rules play major role in FLCs as shown in Table 4.2. Symmetrical triangular member ship function is considered here for all the three variables of error, change error and output as shown in figure 4.3. The simulation block diagram of the FLC is constructed using fuzzy toolbox as shown in figure 4.4. Trial and error method is applied to find the FLC gains GU=1.5, GE=7, GCE=10 and GIE=7.The simulation result of frequency deviation step response is shown in Figure 4.5.

Table 4.2: Fuzzy sets output relating two inputs fuzzy rules

	CHANGE IN ERROR					
ERROR		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



plot points: 181

Current Variable
Name error
Type input
Range [0 1]
Display Range [0 1]

Current Membership Function (click on MF to select)
Name NB
Type trimf
Params [-0.25 0 0.25]

Ready

Figure 4.3: Symmetrical triangular member ship function

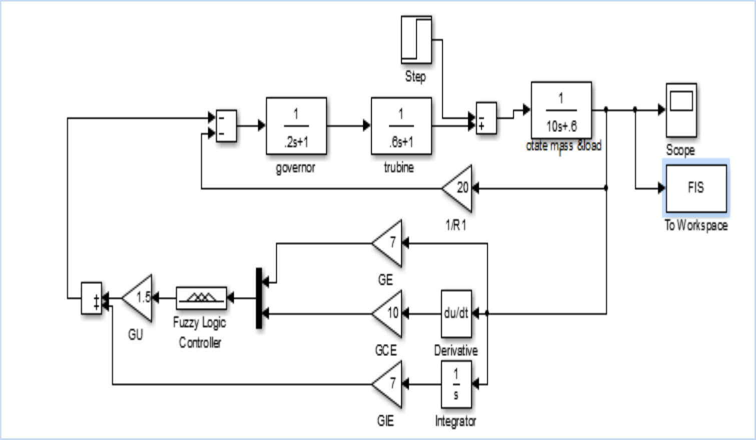


Figure 4.4: block diagram of FLC for single area power system

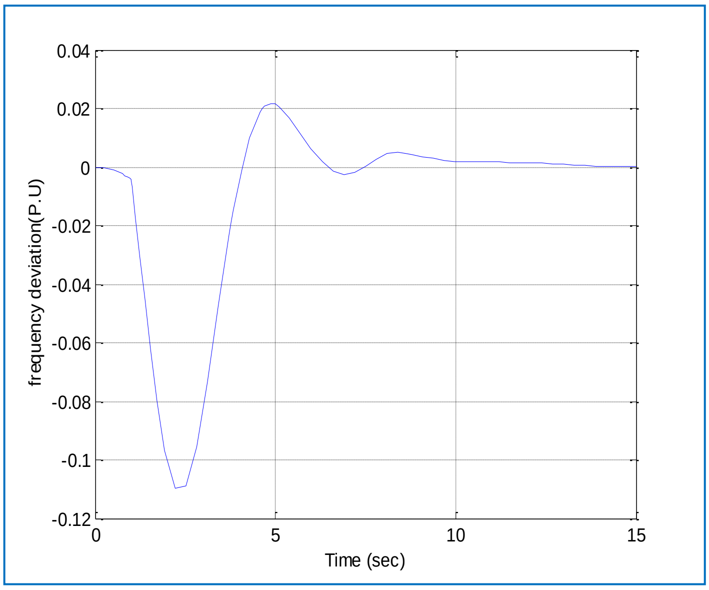


Figure 4.5: Frequency deviation step response of AGC using FLC

4.3 Two Area Power System

Two area power system with parameters of area1and area2 tie-line are studied and simulated with AGC, the same method which applied for single area power system will be applied here.

4.3.1 Two- area without AGC

The simulation block diagram of two area power system is shown in figure 4.6.Figure 4.7 and 4.8 show the frequency deviation step response and power deviation response of two area power system without AGC, respectively.

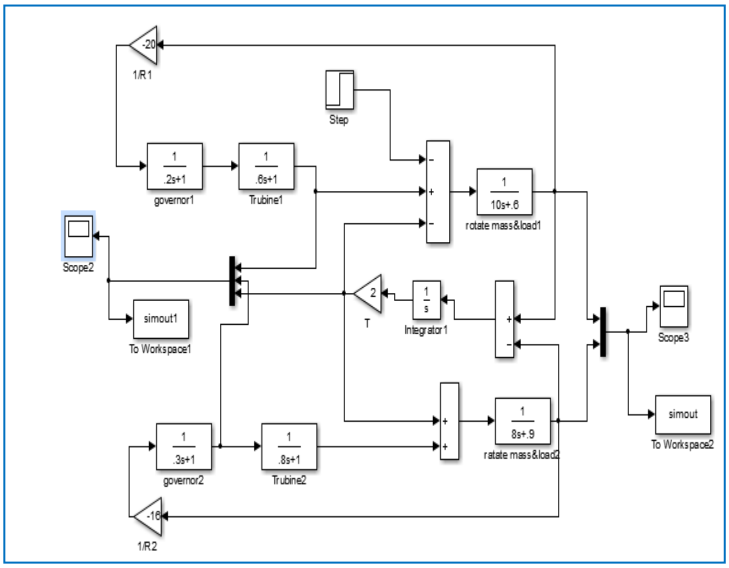


Figure 4.6: block diagram of two area power system

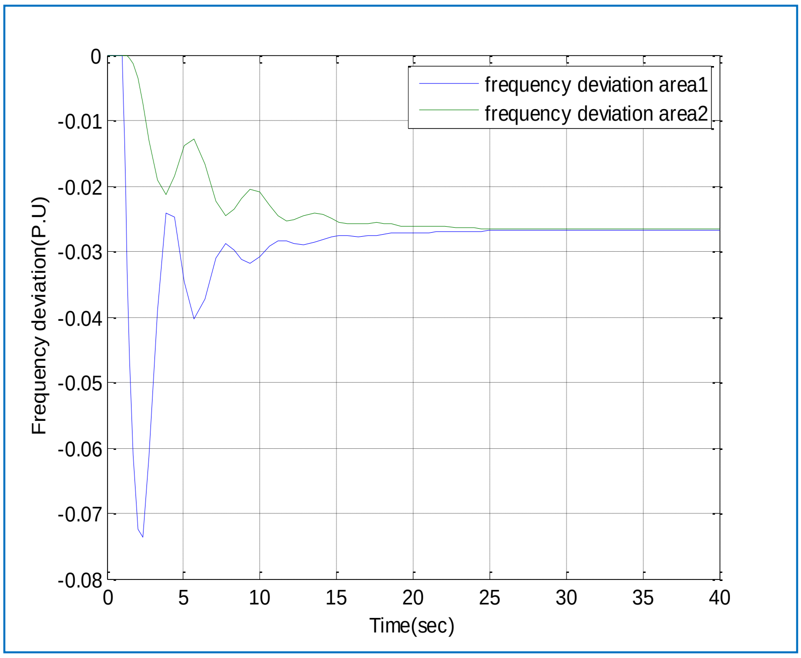


Figure 4.7: Frequency deviation step response of two area power system without AGC

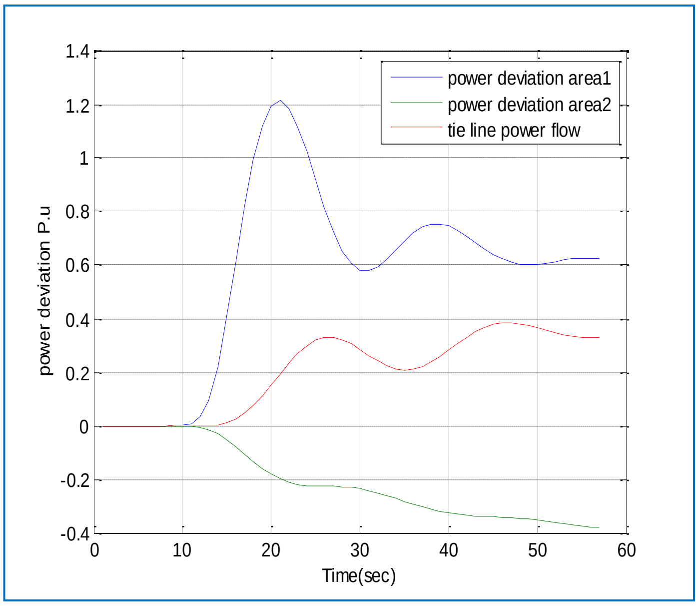


Figure 4.8: Power deviation response of two area power system without AGC

4.3.2 AGC using PID

MATLAB/SIMULINK block diagram for two area with AGC control using PID is shown in Figure 4.9. PID gains are tuned using trial and error tuning method$K_p = 2, K_d = .8\ and\ K_i = 1.3$ in area1, $K_p = 1.6, K_d = .7 and\ K_i$=1.2 in area2. The simulation results for PID is shown in figure 4.10 which represents the frequency deviation response. The simulation for power deviation response and tie line power flow is shown in Figure 4.11.

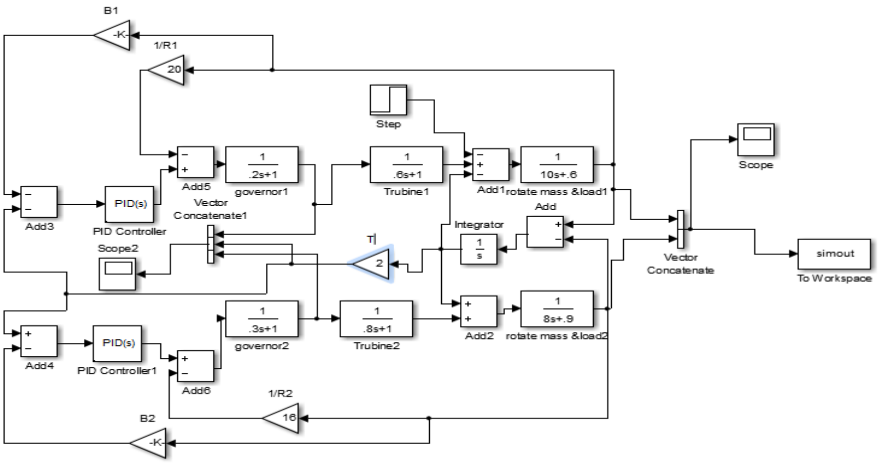


Figure 4.9: block diagram for two area power system with AGC control using PID

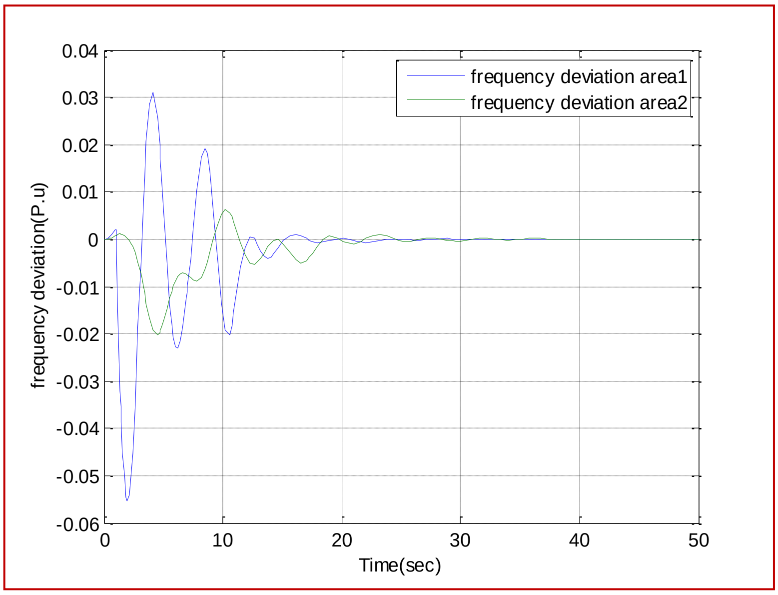


Figure 4.10: Frequency deviation step response of two area using PID

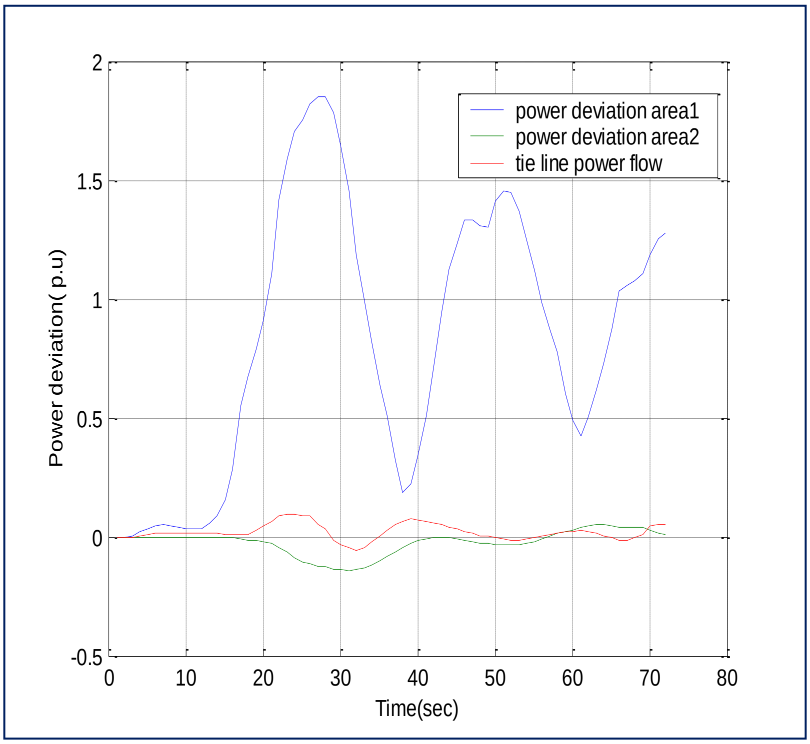


Figure 4.11: Power deviation response of two area using PID

4.3.3 AGC using fuzzy PD+I

As mentioned before in single area power system case, the type of the FLC obtained is Mamdani-type which has rules of the form IF-THEN rules. All membership function for control all inputs (error and change in error)and controller output are defined on the common normalized domain[-0.5,0.5]. The simulation block diagram for two area power system with AGC control using FLC is shown in Figure 4.12. The simulation result with FLC gains GU1=0.8, GE1=1, GCE1=2.5and GIE1=1.2 for area1, GU2=.3, GE2=1, GCE2=4 and GIE2=1.5 for area2. Figure 4.13 shows frequency deviation response for two area. Power deviation for area1, area2 and tie line power flow is shown in Figure 4.14.

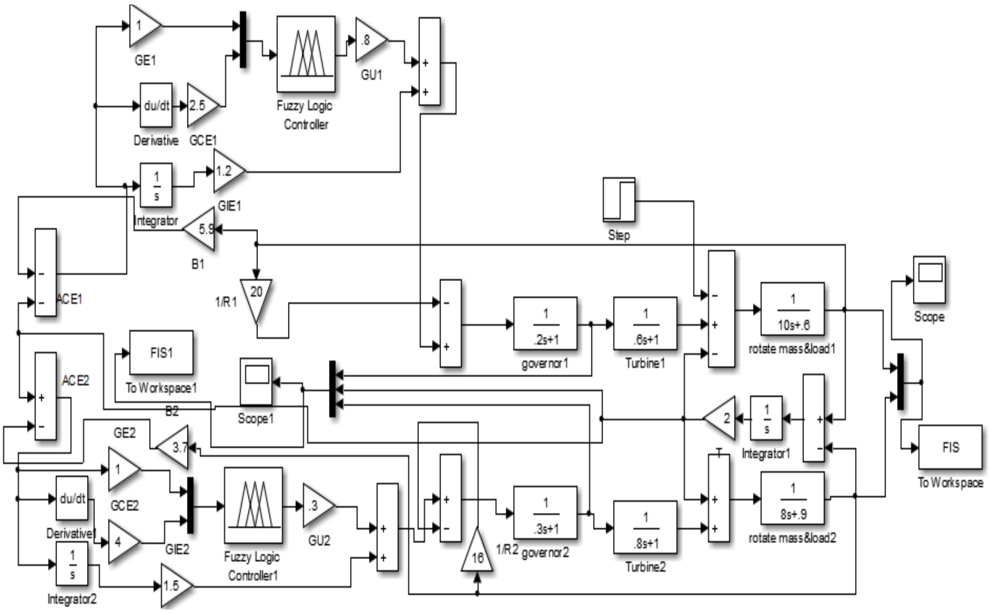


Figure 4.12: Block diagram for two area power system with AGC using fuzzy PD+I

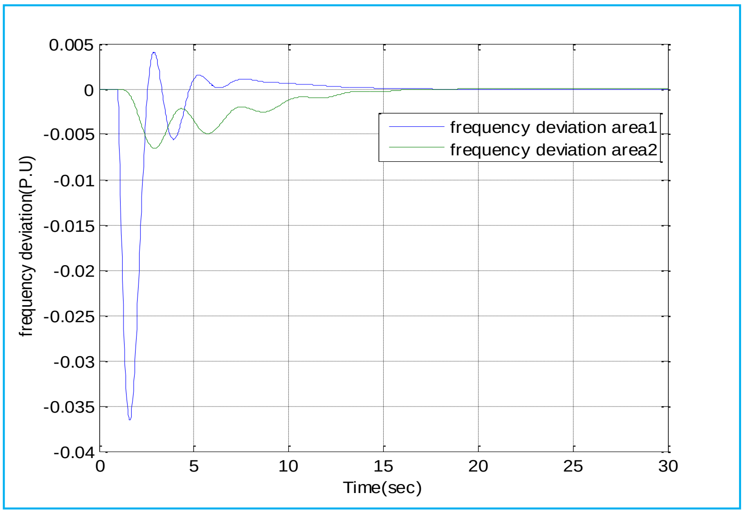


Figure 4.13: Frequency deviation step response of two area using fuzzy PD+I

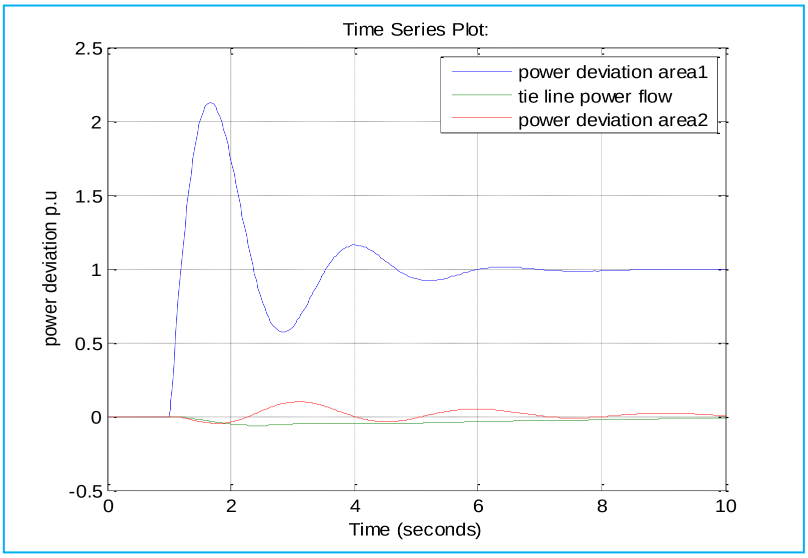


Figure 4.14: Power deviation response of two area power system

Figure 4.13 and Figure 4.14 show that the fuzzy logic controller forced the ACE (the combination of frequency and tie-line errors) to zero in the steady- state. The power change in area1 is absorbed by generation in area1. More details about the fuzzy logic controller construction using MATLAB are shown in Appendix.

4.4 Comparative Results

Table 4.4 shows the time response specifications for single area of all cases.

Table 4.4: The time response specifications for single area of all cases

For Single Area	Steady-State Error	Settling Time	Maximum Over Shoot
AGC using PID	0	49	-0.1
AGC using Fuzzy PD+I	0	28	-0.027

Table 4.5: The time response specification for two area power system

Cases of simulation	Area	Steady-state error	Settling time	Maximum over shoot
Without AGC	1 2	-0.02 -0.03	55 55	-0.07 -0.02
AGC using PID	1 2	0 0	9.9 16.3	-0.05 -0.02
AGC using Fuzzy PD+I	1 2	0 0	7.3 9.9	-0.031 -0.007

Table 4.6 shows the steady state power deviation for two area power system.

Table 4.6: Steady –state power deviation for two area power system

Cases of Simulation	Area1 (P.U)	Area2 (P.U)	Tie – Line(P.U)
Without AGC	0.6	0.4	-0.4
AGC using PID	1	0	0
AGC using Fuzzy PD+I	0.1	0	0

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study has investigated the performance of conventional PID controller and fuzzy logic based controller (F+PID) on two area systems. The frequency deviation and power deviation are observed and analyzed. Then the comparison are made to see which controller gives better performance. The simulation results illustrates that, the frequency deviation and power deviation steady state errors in both single area and two area power system are increasing with increase in load changes. By using AGC controller in power system, steady state errors are forced to zero.

The simulation results for proposed fuzzy PD+I controller compared to frequency deviation and power deviation are stable in case of fuzzy PD+I than in conventional PID controller. The settling time and maximum overshoot are less with conventional PID controller.

5.2 Recommendations

- The controller can also be built using various types of membership functions.
- Apply FLC to AGC in power system with more than two area.

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Appendix

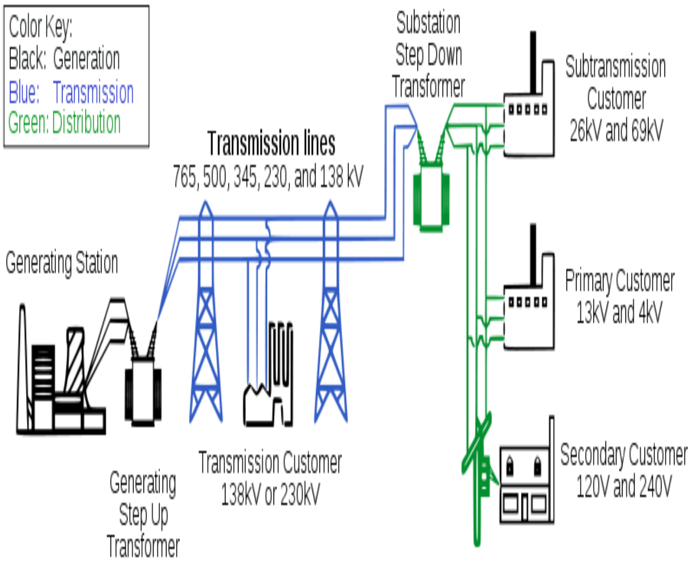
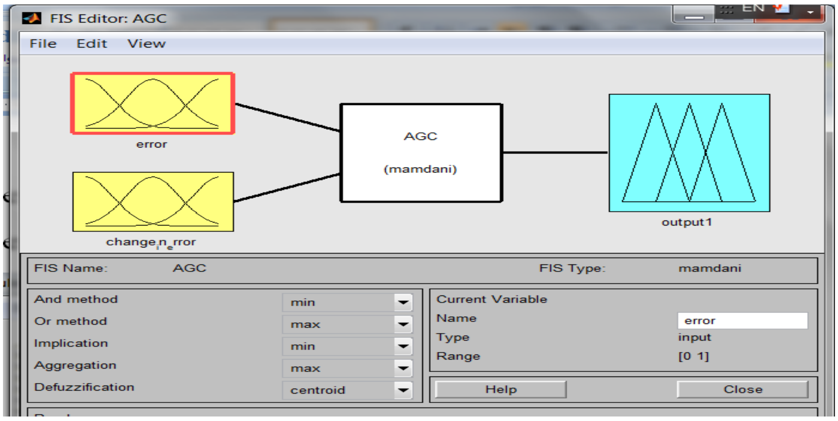


Figure A.1: Basic power system



FIS Name: AGC

FIS Type: mamdani

And method: min

Or method: max

Implication: min

Aggregation: max

Defuzzification: centroid

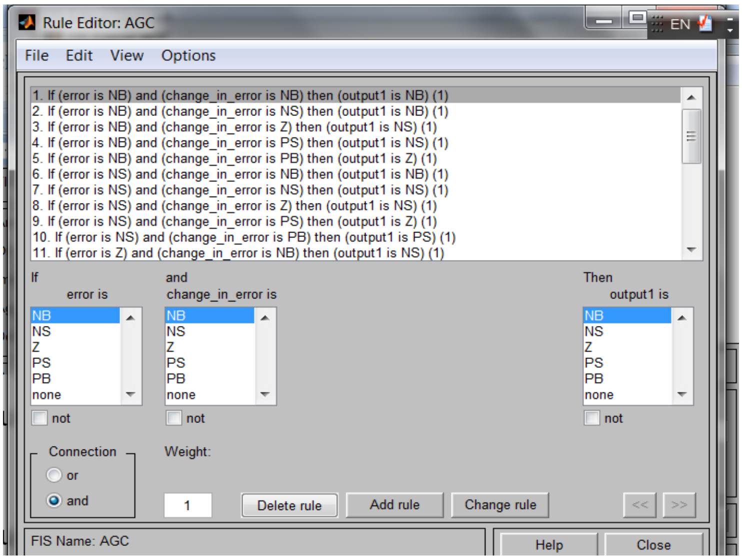
Current Variable

Name: error

Type: input

Range: [0 1]

Figure A.2: Fuzzy inference editor



1. If (error is NB) and (change_in_error is NB) then (output1 is NB) (1)
2. If (error is NB) and (change_in_error is NS) then (output1 is NB) (1)
3. If (error is NB) and (change_in_error is Z) then (output1 is NS) (1)
4. If (error is NB) and (change_in_error is PS) then (output1 is NS) (1)
5. If (error is NB) and (change_in_error is PB) then (output1 is Z) (1)
6. If (error is NS) and (change_in_error is NB) then (output1 is NB) (1)
7. If (error is NS) and (change_in_error is NS) then (output1 is NS) (1)
8. If (error is NS) and (change_in_error is Z) then (output1 is NS) (1)
9. If (error is NS) and (change_in_error is PS) then (output1 is Z) (1)
10. If (error is NS) and (change_in_error is PB) then (output1 is PS) (1)
11. If (error is Z) and (change_in_error is NB) then (output1 is NS) (1)

error is: NB

change_in_error is: NB

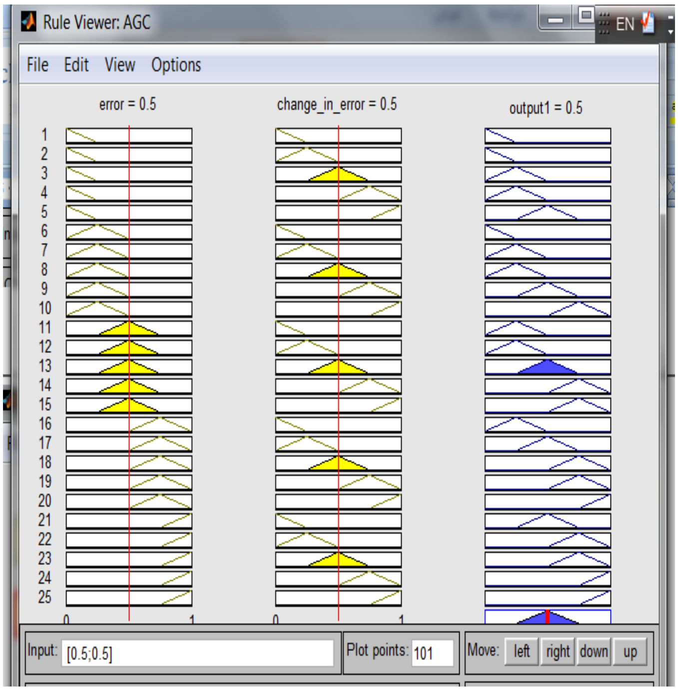
output1 is: NB

Connection: ● and

Weight: 1

FIS Name: AGC

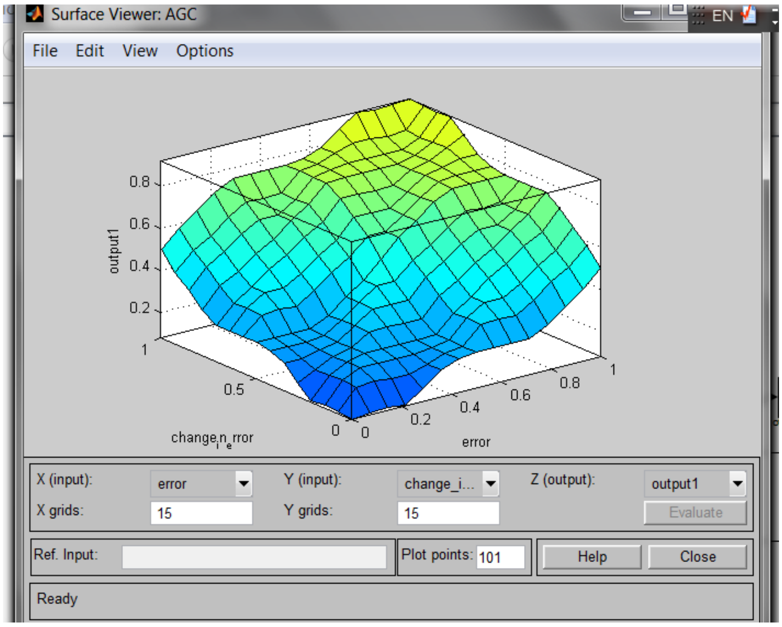
Figure A.3: Rule base editor



Input: [0.5;0.5]

Plot points: 101

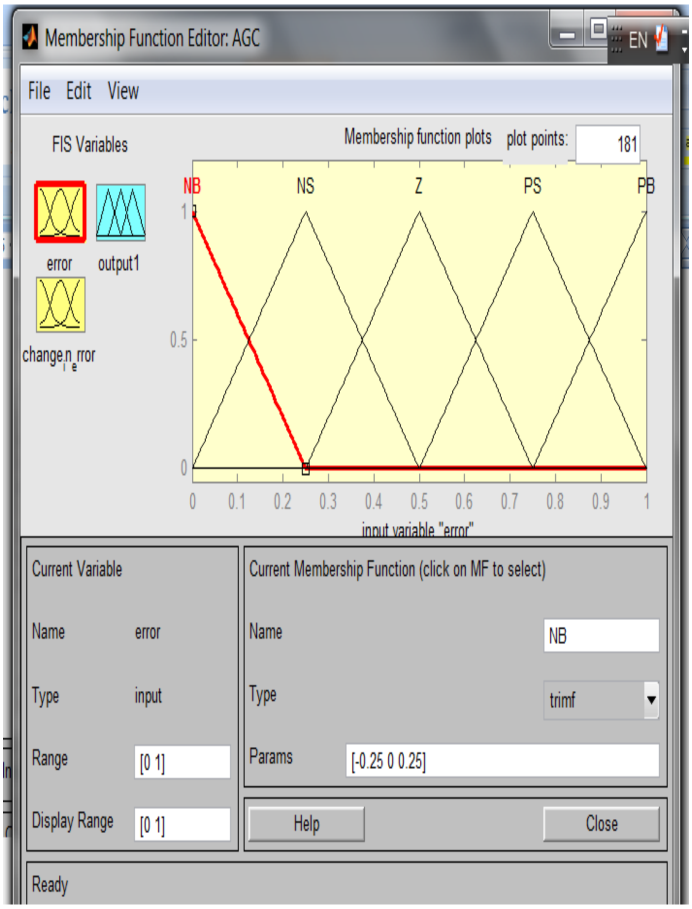
Figure A.4: Rule viewer



Surface Viewer: AGC

X (input): error
Y (input): change_i...
Z (output): output1
X grids: 15
Y grids: 15
Ref. Input:
Plot points: 101
Ready

Figure A.5: Surface viewer



Membership Function Editor: AGC

plot points: 181

Current Variable
Name: error
Type: input
Range: [0 1]
Display Range: [0 1]

Current Membership Function (click on MF to select)
Name: NB
Type: trimf
Params: [-0.25 0 0.25]

Ready

Figure A.6: Membership function editor

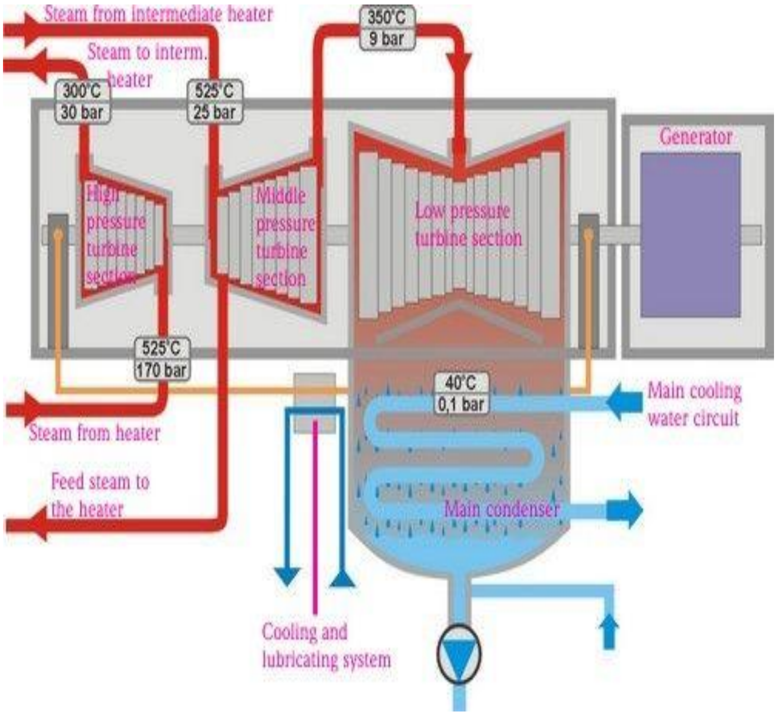


Figure A.7: Power plant (steam turbine)