ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

Dynamic Modeling and Active Power Control of Hydro Power Plant Using Fuzzy Logic Controller; Case of Finchaha Hydro Power Plant

A Thesis Submitted to School of Graduate Studies, Addis Ababa Institute of Technology in Partial Fulfillment of Masters of Science in Electrical Engineering (Control)

By

BERHANU DAGIM

Advisor

DR. MENGASHA MAMMO

ADDIS ABABA, ETHIOPIA

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ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
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ELECTRICAL AND COMPUTER ENGINEERING

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By : BERHANU DAGIM

Approved by Board of Examiner

Chairman Graduate Studies Committee Signature

Advisor Signature

Internal Examiner Signature

External Examiner Signature

DECLARATION

I, the undersigned declare that this Thesis is my original work, and has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged

BERHANU DAGIM

Signature ______________________________

ADDIS ABABA, ETHIOPIA

Submission date of _________________

This thesis has been submitted with my approval as a university advisor

DR. MANGASHA MAMMO

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First of all praises and thanks are to God, the lord of all the worlds, the most beneficent, the most merciful for helping me to accomplish this work.

I would like to thank my advisor Dr. Mengasha Mammo, for his guidance, advice, criticism and encouragement throughout the study.

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ABSTRACT

Hydro power plant plays an important role in a safe, stable and efficient operation of electric power systems, Performance of hydro power in terms of frequency and power control increasingly important. This is as a result of sophistication of hydro power plant dynamic modeling.

In this thesis, Finchaha hydro power plant dynamic model, frequency and power control simulation has been performed for different operating conditions. Then, for Grid Connected operation and Isolated Operation power response has been investigated.

An intelligent governor has been design by using a fuzzy logic controller replacing the conventional governor control of Frequency and Power on **Matlab** Simulink.

The simulation result show that the overall system output performance can be improved using the proposed fuzzy logic governor, the fuzzy logic controller resulted less percentage overshoot (0.505%), fewer settling time (2.8sec) and less rise time (439.153ms) as compared to 17.059%, 5.81sec and 717.643ms for PID controller under grid operation, for Isolated operation to fuzzy logic controller resulted less percentage overshoot (0.465%), fewer settling time(2.671sec) and less rise time (1.171sec) as compared to 3.646%,4.32sec and 1.429sec as compared to existing PID controller

Key word

Fuzzy Logic Controller, Governor, Power Control, Hydro Power Plant, Frequency Control, Power Control

TABLE OF CONTENTS

DECLARATION iv

ACKNOWLEDGMENT v

ABSTRACT vi

LIST OF TABLE x

LIST OF FIGURE.......... xi

LIST OF SYMBOL xiii

LIST OF ABBREVIATIONS xv

CHAPTER ONE 2

INTRODUCTION 2

- 1.1 Background 2
- 1.2 Problem of Statement.......... 3
- 1.3 Objective 4
  - 1.3.1General Objective.......... 4
  - 1.3.2 Specific Objective 4
- 1.4 Methodology 4
- 1.5 Contribution of thesis.......... 5
- 1.6 Thesis Outline.......... 6

CHAPTER TWO 7

HYDRO POWER PLANT AND CONTROL MECHANISM 7

- 2.1 Introduction 7
- 2.2 Overview of Finchaha Hydro Power Plant 7
  - 2.2.1 Background and Development of Finchaha Hydro Power Plant 7
  - 2.2.1 Structure and Components of Finchaha hydro power plant 7
- 2.3 Control system using in Finchaha hydro power plant 11
  - 2.3.1 Electronic Digital Governor.......... 11
  - 2.3.2 Operating Mode of Governor in Finchaha Hydro Power Plant 11
  - 2.3.3 Frequency.......... 13
- 2.4 Existing convectional controller.......... 13
- 2.5 Intelligent Fuzzy Logic Controller 14
- 2.6 Previous work related on Modeling and Active Power Control of Hydro Power Plant 21

CHAPTER THREE.......... 23

DYNAMIC MODEL OF THE FINCHAHA POWER PLANT.......... 23

3.1 Introduction 23
3.2 Model of the Power Plant.. 23
3.3 Basic Mathematical Models of Typical Hydroelectric Power Plant 24
  3.3.1Model of the Hydraulic System 24
  3.3.2 Turbine Model... 28
  3.3.3 Gate Servo Model.. 29
  3.3.4 Generator Unit and Network... 30
3.4 Power and Frequency Control... 30
  3.4.1 Speed Drop Control... 31
  3.4.2 Existing Conventional PID controller 31
  3.4.3 Fuzzy Logic Controller... 32
3.5 Operating Principle and Overall Interconnected System... 32
  3.5.1Grid Connected Operation... 32
  3.5.2 Isolated Operation 33
CHAPTER FOUR.. 35
CONTROLLER DESIGN... 35
4.1 Introduction 35
4.2 Existing PID controller 35
4.3 Fuzzy Logic Controller Design 36
  4.3.1 Input Variables... 37
  4.3.2 Output Variable... 40
  4.3.3 Fuzzy Control Rules... 40
  4.3.4 Defuzzification... 44
CHAPTER FIVE 45
SIMULATION RESULT AND DISCUSSION 45
5.1 Introduction 45
5.2 Simulation Result 45
5.3 Discussion 56
CHAPTER SIX... 58
CONCLUSION AND RECOMMENDATION 58
6.1 Introduction 58
6.2 Conclusion.. 58
6.3 Recommendation 59

6.4 Future works 59
REFERENCE 60
APPENDICES A 62

LIST OF TABLE

Table 2-1 Deduction and Induction 18
Table 3-1 Turbine Linearized Coeficcient 28
Table 4-1 Value of PID controller for Isolated Operation 36
Table 4-2 Value of PID Controller for Grid Connected Operation 36
Table 4-3 Membership of Fuzzy Logic Controller 37
Table 4-4 Rule Base of Fuzzy Membership 41
Table 5-1 Control characterics for One Percent Increase Frequency 48
Table 5-2 Performance of Controller for One Percent Drop of Frequency 49
Table 5-3 Performance of Controller for Power Control at 0.9pu 50
Table 5-4 Time-response specifications of power control at 0.5pu 50
Table 5-5 Time Response Specification under 0.2pu power is added 53
Table 5-6 Time-response specifications of 0.1pu load added 53
Table 5-7 Steady State Performance under 0.2pu Power is Removed 55
Table 5-8 Time-response specifications of 0.1pu load dropped 55
Table 5-9 Time-response specifications of 0.3pu load dropped 56

LIST OF FIGURE

Figure 1:1 Flow Chart of the Research Methodology of the Thesis 5
Figure 2:1 General Layout of Hydro Power Plant 8
Figure 2:2 Finchaha Hydro Power Plants dam 8
Figure 2:3 Pelton Turbines 10
Figure 2:4 Daily characteristics Curve On March 4, 2017 11
Figure 2:5 Data of Generating in One Day 12
Figure 2:6 PID diagram. 14
Figure 2:7 Basic structure of fuzzy logic controller. 19
Figure 3:1 General Representation of Sub Model 23
Figure 3:2 Typical Piping Structure of Finchaha Hydro Power Plant 24
Figure 3:3 Head Race Tunnel Simplified Model 26
Figure 3:4 Surge Tank Simplified Modeled 26
Figure 3:5 Penstocks Simplified Modeled 27
Figure 3:6 Complete Dynamic Block diagram of Hydraulic System 27
Figure 3:7 Block Diagram Representing Linearized Turbine 29
Figure 3:8 Generating Power Simplified Model 29
Figure 3:9 Opening gate modeled 30
Figure 3:10 Power Control Model block diagram 30
Figure 3:11 Mamdani Fuzzy Logic Controllers 32
Figure 3:12 Overall Simplified Model of Interconnected Operation 33
Figure 3:13 Overall Modeled block Diagram for Isolated Operation 33
Figure 4:1 Structure of Error Acquisition System 35
Figure 4:2 Error Input Fuzzy membership isolated system 38
Figure 4:3 Error input membership for grid connected 38
Figure 4:4 Changes in Error Input Membership isolated 39
Figure 4:5 Change in Error input for interconnected operation 39
Figure 4:6 Output Membership functions 40
Figure 4:7 Rule viewer for Finchaha hydro power plant for isolated 43
Figure 4:8 Surface viewers for Isolated 44
Figure 4:9 Surface viewers for Grid connected 44
Figure 5:1 Matlab Simulink Modeled of Interconnected Fuzzy Logic Controller 46
Figure 5:2 Matlab Simulink Model of Interconnected PID controller 46

Figure 5:3 Result of One Percent Increase in Frequency 47
Figure 5:4 Results of One Percent Drops in Frequency 48
Figure 5:5 Result of Power Control at 0.9 Value of Power Input 49
Figure 5:6 Graph of power control at 0.5pu 50
Figure 5:7 Matlab Simulink Modeled of Isolated Fuzzy Logic controller 51
Figure 5:8 Matlab Simulink Model of Isolated PID controller 51
Figure 5:9 Result of fuzzy and PID isolated increase by load 0.2pu 52
Figure 5:10 Graph power generated at 0.1pu load added 53
Figure 5:11 Graph of 0.3pu load added to the system 54
Figure 5:12 Result of fuzzy and PID isolated removed by load 0.2pu 54
Figure 5:13 Graph of 0.1pu load drop 55
Figure 5:14 Thirty percent load drop isolated operation 56

LIST OF SYMBOL

ag = Gravitational acceleration constant(m/s^2)

Fc = Set-point frequency (Hz)

Fg =Actual system frequency

Ƞ = Efficiency factor

Pg = Generator electric power (W)

Pm = Mechanical power of turbine (W)

Pref = Reference power (W)

q = per unit flow rate deviation

fn = rated frequency (1pu)

ρ = drop of turbine governor characterics

Pout = proportional term of output

Tw= water starting time(s)

Δf = frequency deviation(Hz)

e= error

t = time(s)

Iout = integral term of output

Pr = generator rated power output (MW)

X= rated speed (m/s)

Dout = output of derivative term

Mgo=load torque (per unit)

Ta=generator unit mechanical time (second)

Eg=load self-regulation factor

Ƞ= efficiency of turbine

Q= rate of turbine

H= head of turbine (m)

H_R = head of turbine (m)

L_1 = length of tunnel (m)

A_1 = cross sectional area of tunnel (m^2)

H_S = head of surge tank (m)

q = per unit flow rate deviation (Pu)

ω = speed

y = per unit gate deviation (Pu)

m_t = momentum of turbine

Te = wave reflection (s)

a = wave speed (m/s)

L_2 = penstock length (m)

A_2 = penstock cross sectional area (m^2)

A_s = cross sectional area of surge tank (m^2)

T_s = filling time of surge tank(s)

Kp =Proportional gain

LIST OF ABBREVIATIONS

HPP	Hydro power plant
NLDC	National Load Dispatch Center
LFC	Load Frequency Control
PC	Power Control
SC	Speed Control
e.g.	For example
PID	Proportional Integral Derivative
Pu	per Unit
NB	Negative Big
NM	Negative Medium
NS	Negative Small
Z	Zero
PS	Positive Small
PM	Positive Medium
PB	Positive Big
FLC	Fuzzy Logic Controller

CHAPTER ONE

INTRODUCTION

1.1 Background

Today, global warming is a major problem in the world. The generation of electricity using renewable hydro energy resource is an essential nature protection. Among all renewable energy sources, water has the lowest cost and is most reliable resource. Hydroelectricity is an important component of the world's renewable energy supply. Electricity generation in the world has been on the increase over the last few decades especially in the developing nations where hydro power remains the major source of electricity generation [1].

Hydro power uses hydraulic turbines to convert energy in flowing water into electricity. Such a source is one way of electrical generation from renewable potential sources. Usually, a hydropower plant comprises the reservoir, water tunnel, surge tank, penstock, hydraulic turbine, speed governor, generator and grid [2].

In a hydroelectric power plant, stored water flows from a high elevation to the hydro turbine; gravitational potential energy is converted into kinetic energy. Then, the turbine shaft, getting mechanical energy from the conversion, drives the machine to generate electricity [3].In a turbine, the power is controlled by regulating the flow into the turbine using the position of the wicket gates or nozzles. This regulation is achieved by the turbine governor, which is also called the speed governing system or turbine governing system [4] . To suppress the power grid frequency fluctuation, generating units change their power output automatically according to the change of grid frequency, to make the active power balanced again, for this frequency regulation generation station exhibit a significant contribution to system frequency, from Ethiopian hydro power generation, Finchaha hydro power plant unit is one and, the unit has two operating modes: frequency control and power control. Frequency control is used for start-up in island operation and grid connected operation. Power control mode is used for primary frequency control while the unit is supplying power to 230kv networks [6], Controllers are used to contribute to the safe operation of the power system by maintaining system voltages, frequency, and other system variables within acceptable limits. Regulation of frequency is closely related to active power control while voltage regulation is closely related to reactive power control [7].

Basic Requirements for all Generating Unit

Active power imbalances in the power system are reflected throughout the system by a change in frequency. For satisfactory operation of a power system, the frequency must remain in the admissible ranges. Therefore, generating units have to be equipped with speed governors providing the speed control action. The relationship between speed and load can be adjusted by changing the load reference set-point of the speed controller or through a power controller[1]. Controller is equipped with

a. Hydraulic Turbine Governor and
b. Excitation Control.

- Hydraulic turbine governor control the frequency intern speed of the turbine according to load variation.
- Reactive power requirement is controlled by Excitation system

The control of Active and reactive power keeps the system in the steady state to control the Frequency and power, the controller reads the speed of turbine after every sampling period. The controller existing is conventional PID controller for all operating condition[8]. Matlab Simulink is used in building system models and simulates their behavior.

PID controller is applies to the system to control the gate of the running water and thus control the rotor speed of the turbine. The PID controller is eventually replaced by Fuzzy logic controller since Fuzzy controller is better robust and transient response than PID controller [9]. fuzzy logic are an important technology and a successful branch of automation and control theory, which provides good results in control of power system [10] ,is expected to perform better than PID controller for power control and frequency under grid connected operation mode and isolated operation mode.

1.2 Problem of Statement

The modern power system is increasing rapidly in size and complexity due to the high load demands from power energy consumers, therefore it is necessary to produce electricity in large scale and economically. Technological advancement has resulted most power utilities to be interconnected into one control area (Addis) to control frequency. Due to increased load demands from consumers, which may cause power system network to be in highly stressed conditions, the need for increasing the efficiency of generating station is a rising. The means of increasing this efficiency is to model and simulate the generating stations, these evaluate behavior of hydropower unit in grid connected and isolated operation system through modeling and simulating of the hydropower plant in this case Finchaha hydro power plant. Unsuitable control structures and control parameter setting in hydro units are the main cause of for existing frequency controls of the problem in a country, so active power control in individual generating unit have a positive contribution for grid frequency stability. The frequency performance of a power system results from the summary effect of its individual units, frequency control Finchaha hydro power plant it is achieved a desired value of power under PID controller, but PID controller has many draw back such performance, steady state error, a high percentage overshoot, large resetting time, large peak time when compared to Fuzzy logic controller, so in this thesis I have been designed fuzzy logic controller to control active power of a unit under grid connected operation and isolated operation.

1.3 Objective

1.3.1General Objective

The primary aim of this thesis is to model Finchaha hydro power plant unit and to reach optimum active power output of the unit using fuzzy logic controller under parallel network and isolated operation model.

1.3.2 Specific Objective

- Modeling of existing Finchaha hydro power unit,using associated transfer Functions.
- Determining required parammeter of existing generation system.
- Building up simulation model using Matlab/Simulink software for both grid connected and isolated System.
- Designing fuzzy logic controller
- Simulating the fuzzy logic controller and existing PID Control for both an isolated and grid connected using Matlab-Simulink.

1.4 Methodology

The research method of the thesis involves several different tasks that are performed to lead towards completion. The first task is to describe the statement of the problem and define the objectives of the research. This is followed by the literature review where all the theoretical information regarding active power control of hydropower plant. A comparison of previous similar research is also presented. A brief description on the fuzzy control theory is presented. A detail mathematical model of Finchaha hydro power plant unit is presented. For the selected turbine unit the rule tables are constructed with the development of membership functions for supervisory fuzzy logic controller. Using the rule base and membership functions of a fuzzy logic controller is designed. Simulation studies are carried out for different power measurement value constants to show the comparison measurement result with simulation result and fuzzy supervisor compared to the conventional active power controller. The final stage is the conclusion based on the research finding

The method used discussed here bellow

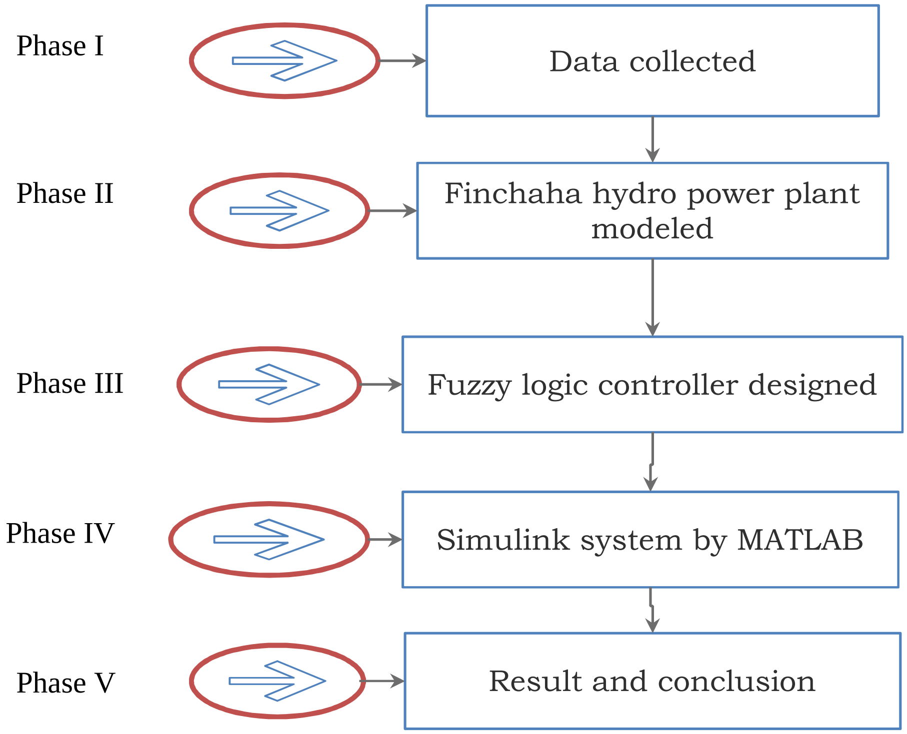


Figure 1:1 Flow Chart of the Research Methodology of the Thesis

1.5 Contribution of thesis

In any kind or type of electrical power generation system there is a need of keeping the operating frequency at the desired and scheduled value. This change in frequency is due to the change in the load level of the system. This frequency variation can be controlled and regulated using a load frequency control. Therefore modeling and designing an appropriate load frequency controller is significant. Therefore, the main contribution of this theses work is to propose the appropriate intelligent controller for Finchaha hydro power plant unit In addition anyone who is going to implement intelligent fuzzy logic controller in different hydropower generation unit can also use as a procedures.

1.6 Thesis Outline

The Thesis is organized into six chapters.

Chapter One: Presents the Introduction, Statement of the problem, Objectives of the thesis and the Method leading towards the completion of the thesis.

Chapter Two: Discusses about Finchaha hydropower plant and its development in Ethiopia, dam construction in Ethiopia, control mechanism existing in Finchaha hydro power plant, detail about Fuzzy logic controller finally, related works are discussed in brief.

Chapter Three: Deals with the detailed model of a Finchaha hydro power plant hydropower plant. Modeling of the hydraulic system, head tunnel, surge tank, turbine penstock and servomotor are described in this chapter. Different active power control option and governing system are also discussed in this chapter.

Chapter Four: Presents the Fuzzy logic controller design. The selection of membership functions and the construction of rule tables for both power error and change in power error are also presented in this chapter.

Chapter Five: The Simulation results got using MATLAB-Simulink and discussions of the results are presented in.

Chapter Six: The final conclusions of this thesis are presented and Recommendations, future work that is recommended to be done is listed.

CHAPTER TWO

HYDRO POWER PLANT AND CONTROL MECHANISM

2.1 Introduction

This chapter presents the review of a Finchaha hydro power plant earth dam construction in Ethiopia; Different mechanisms of controlling the frequency of Finchaha hydro power plant are also discussed in this chapter. The basics of the fuzzy logic controller, overview of software used are discussed and related works are also presented and gap is identified in this chapter.

2.2 Overview of Finchaha Hydro Power Plant

2.2.1 Background and Development of Finchaha Hydro Power Plant

Ethiopia is powerhouse of Africa due to its high potential. Only a fraction of this potential has been harnessed so far. In 2009 less than 10% of Ethiopians had access to electricity and the country was plagued by power outages. In order to overcome this situation, the government has embarked on an ambitious dam building program. Three hydropower plants with a combined capacity of 1.18 GW were commissioned in 2009 and 2010 alone, more than doubling the previous installed capacity of the country. The largest hydroelectric plant in Ethiopia, Belles, began initial operation in May 2010. Contracts for five more large dams have been signed. Once completed, which is expected to be around 2015, these dams would increase the installed capacity by more than 11 GW from less than 1 GW in 2008. The construction of more large dams is foreseen in a Master Plan that aims to bring capacity to 15 GW. Power demand in Ethiopia is constrained by poverty, and the country thus plans to export power to Sudan, Kenya, Djibouti and even Yemen or Egypt. The benefits of the dams are not only limited to hydropower. Many dams are multi-purpose dams that are also designed to provide water for irrigation and flood control. However, hydropower is expected to be the main benefit of the dams. Finchaha hydroelectric power plant is located at head of Lake Tana, found in Oromia region, Horo Guduru Wollega zone location coordinates are latitude 9.558, longitude 37.33663 this infrastructure hydro power plant with design capacity of 134mw, it has 4 units, the first was commissioned in 1974 and the last in 2000.[29]

2.2.1 Structure and Components of Finchaha hydro power plant

General layout of hydro power plant as shown in Fig 2.1 [12]

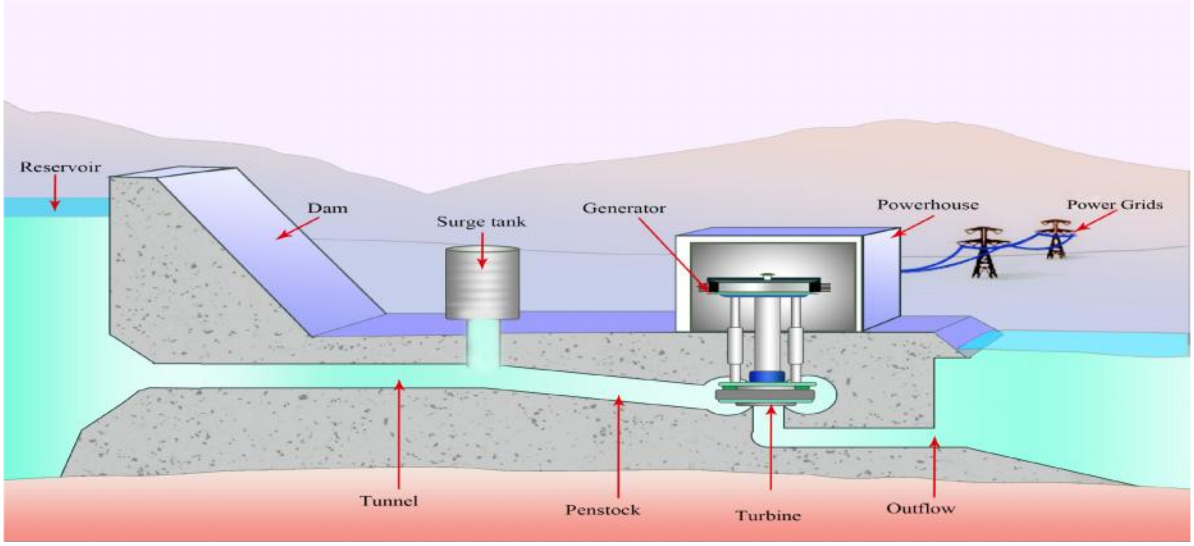


Figure 2:1 General Layout of Hydro Power Plant

Elements of hydraulic power plant

Reservoir

In which large quantity of water is stored. Potential energy of the stored water then can be released in a controlled way[11] and, used to store water which is further utilized to generate power by running the hydroelectric turbines. The level of water in the reservoir area is called head water level.

Dam

Figure 2:2 Finchaha Hydro Power Plants dam

Dam is generally made of concrete, stone machinery. Is to store the water and to regulate the outgoing flow of water to store all the incoming water, in order to generate a required quantity of power it is necessary sufficient head is available

Gate and intake

A gate is used to regulate or control the flow of water from dam and Intake is the inlet of the head race tunnel which is equipped with Trash Rack for preventing big solid objects from entering the tunnel and Gate Door for isolating the tunnel for maintenance [11].

Head race tunnel

Head race tunnel (conduit) connects the reservoir to the penstock near the power house. It can be equipped with sand traps for collecting sand and garbage that had passed through the trash rack in the intake [11].

Surge tank

Additional storage for near to turbine, usually provided in high head plants, also Finchaha are found in high head, is located near the beginning of the penstock. This surge tank is used for To reduce the distance between the free water surface in the dam and the turbine, thereby reducing the water hammer effect on penstock and also protects the upstream tunnel from high pressure rise

Water hammer effect

Water hammer is defined as the change in pressure rapidly above or below normal pressure caused by sudden load changes in the rate of flow through the pipe, according to the demand of prime mover, Surge tank overcomes the abnormal pressure in the conduits when the load on the turbine falls and acts as a reservoir during increase of load on the turbine

Penstock

Penstocks are the water conductor conduit of suitable size connecting the surge shaft to maintain inlet valve, it allows water to the turbine through main inlet valve. Finchaha hydro power use one penstock for four unit of turbine

Main inlet valve

Main inlet valve works as the gate /valve in the water conductor system. It is located before turbine and allows water from penstock to turbine, Act as closing valve. Valve is spherical valve type used in Finchaha hydro power plant.

Turbine

Turbine is used to convert the energy water of falling water into mechanical energy. Water turbine is a rotary engine that takes energy from moving water. Flowing water is directed on to the blades of a turbine runner, creating a force on the blades. Since the runner is spinning, the forces acts through a distance in this way, energy is transferred from the water flow to the turbine. The principal type of turbine used in site is impulse turbine

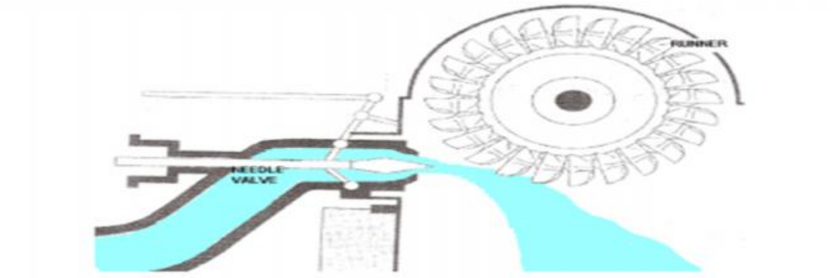


Figure 2:3 Pelton Turbines

The hydraulic turbine is a mechanical device that converts the potential energy exerted by the water as it falls from an upper to lower reservoir, into rotational mechanical energy.

The type of turbine used in Finchaha hydro power plant is impulse (Pelton) vertical turbine consists of needle, deflector and runner with bowl shaped bracket, the structure is shown bellow

Power generation

The amount of electricity that can be generated by a hydro power plant depends on two factors

- **Flow rate** : the quantitty of water flow in a given time
- **Head** :the height from which the water falls

The greater the flow and head, the more electricity produced [12] as per equation 2.1

$P=\eta QHg$... 2.1

The generation set point and capacity of Finchaha hydro power plant in one specific day is as shown in figure 2.4, It was produced as a power is given manually by operator because to balance the demand and supply power, when the demand and generated is equally no frequency fluctuation is happen, frequency is constant means generation is synchronized, this frequency is always related with active power as the reactive power is related with voltage of power system

March 4, 2017 value of generated unit, at 50 Hz

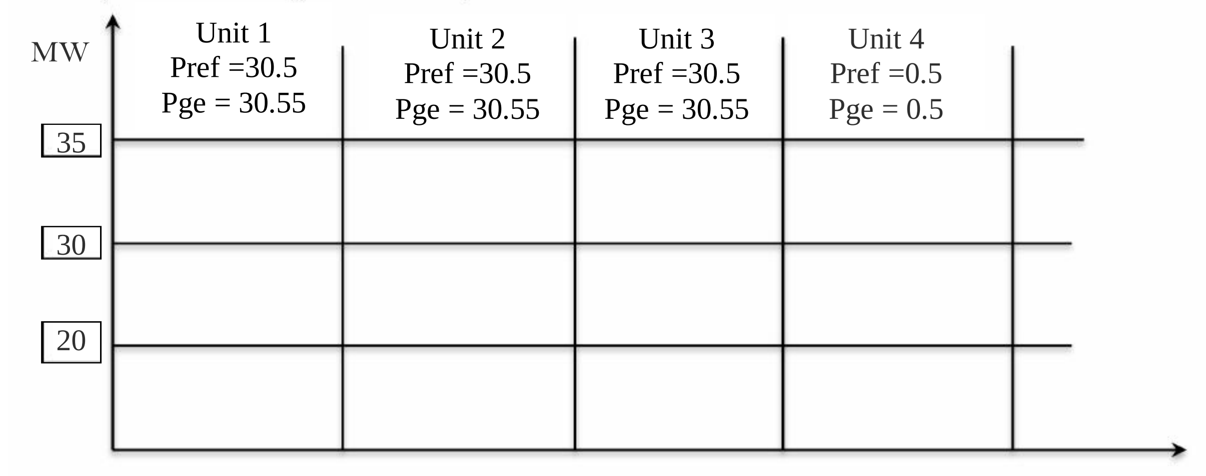


Figure 2:4 Daily characteristics Curve On March 4, 2017

2.3 Control system using in Finchaha hydro power plant

Control mechanism in Finchaha hydro power plant during my survey about governor. Governor and accompanying equipment enable turbine control at turbine start and stop, operation turbine unit in parallel with grid and in an isolated system [10].

2.3.1 Electronic Digital Governor

Electronic turbine speed governor basically maintains the same turbine speed at any unit load when the unit is operating in isolated system .when operating in parallel with common grid, the governor keeps the governor power constant. Governor output operates all the time on injectors' servomotor to determine the right flow through turbine [10].

Main governor functional units are:

- Turbine Speed Measurement,
- PID regulator with water hammer compensating function,
- Power control loop, speed drop, opening limiter, position loop for injectors and deflector servomotor.

2.3.2 Operating Mode of Governor in Finchaha Hydro Power Plant

Unit can operate in the following three modes[10].

- Operation in Isolated system – frequency control
- Operation in parallel with other units, connected to national grid in power control, opening control or frequency control
- Idle run of unit – speed control

I have been used for my thesis, parallel operation to grid connected mode (power control and frequency control) and isolated operation to control frequency.

Operation in an isolated system

When the unit operates in an isolated system, the governor maintains the system frequency on the level determined by speed reference signal “C”.in steady state conditions the system frequency does not change if the speed regulation is set to e_p=0% else it does follow the speed droop characterics.

Operation in Parallel Network

When the unit is connected to the Grid, the unit rotating speed is determined by system frequency. Change power reference signal, the wicket gate opening will be changed proportionally to reference change. If the reference signal is constant and the system frequency is changing, the unit power will change speed drop character tics. It means that the governor is active in primary frequency regulation .the governor can operate in parallel run in power control mode ,opening control mode or frequency mode .these mode can be selected by selector switch [10].

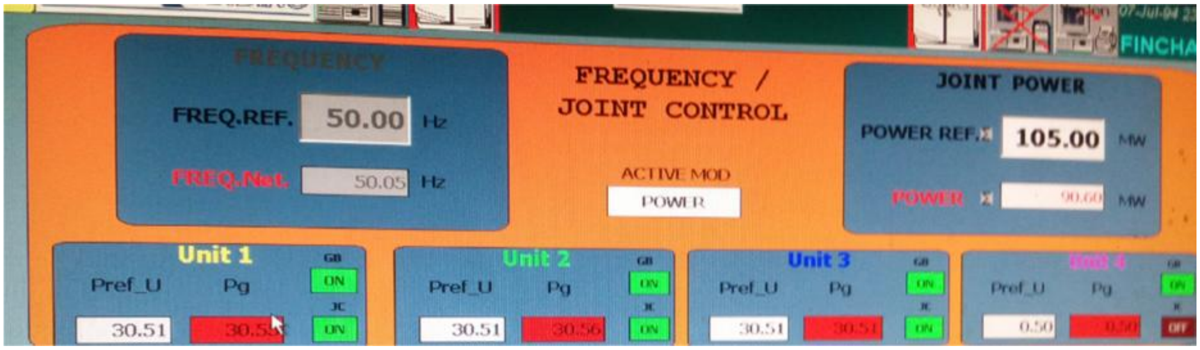
Frequency Control in Parallel Network

Special mode is provided for frequency control in parallel operation. In frequency control the unit regulates the system frequency on the level determined by speed reference set value[10].

Power control in parallel network

Power control is used to keep the power of the unit equal to set value. This kinds of power controller is used to be made certain rate but without overshooting or a slow periodic approaching of preset power.

Survey of power reference and power generated on March 10, 2016 is as shown below where frequency is deviated with 0.05 Hz, total reference from NLDC is 105.0MW and the value of each unit is shown in fig (2:5)



FREQ.REF. 50.00 Hz
FREQ.Net. 50.05 Hz
ACTIVE MOD POWER
POWER REF. 105.00 MW
POWER 90.60 MW
Unit 1 Pref_U 30.51 Pg 30.5
Unit 2 Pref_U 30.51 Pg 30.56
Unit 3 Pref_U 30.51 Pg 30.51
Pref_U 0.50 Pg 0.50 OFF

Figure 2:5 Data of Generating in One Day

2.3.3 Frequency

In order to ensure a working Ethiopian Power Grid, the operating frequency is defined by a standard of 50 hertz. As electric generation and consumption differs, the power transmission grid has to be balanced. There should be the same amount of input and output. Nevertheless changes in the frequency may occur if supply or demand exceeds its counterpart. In case of too much supply the frequency will increase, while in case of too much demand it will decrease. The main task is to keep the frequencies balanced at around the 50 hertz standard to ensure a safe power supply [1] .

2.4 Existing convectional controller

Most common controllers available commercially are the proportional integral (PI) and proportional integral derivative (PID) controller. The PI controllers are used to improve the dynamic response as well as to reduce or eliminate the study state error. PID is made up of three main components i.e. proportional, integral and derivative[13].

2.4.1 Proportional term

The proportional term (sometimes called gain) makes a change to the output that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant K_P, called the proportional gain[13].

2.4.2 Integral term

The contribution from the integral term (sometimes called reset) is proportional to both the magnitude of the error and the duration of the error. The magnitude of the contribution of the integral term to the overall control action is determined by the integral gain, K_i [13].

2.4.3 Derivative term

The rate of change of the process error is calculated by determining the slope of the error over time (i.e., its first derivative with respect to time) and multiplying this rate of change by the derivative gain K_d. The magnitude of the contribution of the derivative term (sometimes called rate) to the overall control action is termed the derivative gain, K_d

2.4.4 Conventional PID controller

A Conventional PID controller is most widely used in industry due to ease in design and inexpensive cost. The PID formulas are simple and can be easily adopted to corresponding to different controlled plants but it can’t yield a good control performance if controlled system is highly order and nonlinear. The PID controller is a combination of the PI and PD controllers. The PD control, as in the case of the lead compensator, improves the transient-response characteristics, improves system stability, and increases the system bandwidth, which implies fast rise time.

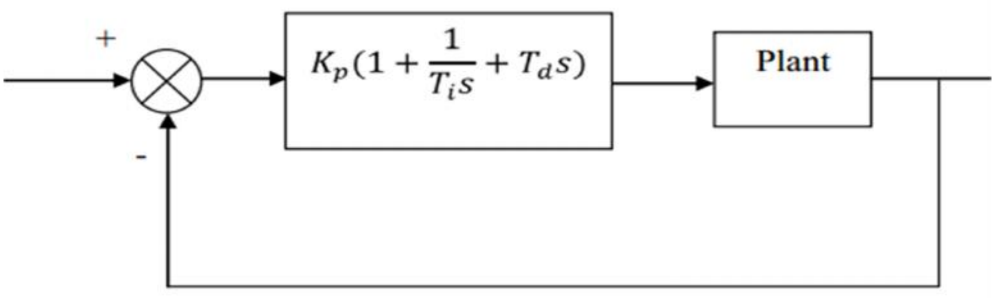


Figure 2:6 PID plant diagram**.**

2.5 Intelligent Fuzzy Logic Controller

According to the oxford dictionary, the word intelligent is derived from intellect, which is the faculty of knowing, reasoning and understanding. Intelligent behavior is therefore the ability to reason, plan and learn, which is in turn requires access to knowledge.

Artificial intelligent is a b**y-**product of the information technology revolution and is an attempt to replace human intelligent with machine intelligence. An artificial intelligent control system combines the techniques from the field of artificial intelligent with those of control engineering to design autonomous system that can sense, reason, and plan, learn and act in an intelligent manner. Such a system should be able to achieve sustained desired behavior under conditions of uncertainty, which include [14].

(1) Uncertainty in plant models
(2) Unpredictable environmental changes
(3) Incomplete, inconsistent or unreliable sensor information
(4) Actuator mal function.

The term ‘‘intelligent control’’ has a more general meaning and addresses more general control problems. That is, it may refer to systems which cannot be adequately described by a differential/difference equations framework but require other mathematical models, as for example, discrete event system models. More often, it treats control problems, where a qualitative model is available and the control strategy is formulated and executed on the basis of a set of linguistic rules. Overall, intelligent control techniques can be applied to ordinary systems and more important to systems whose complexity defies conventional control methods.

There are three basic approaches to intelligent control: knowledge-based expert systems, fuzzy logic, and neural networks. All three approaches are interesting areas of research and development. For this research fuzzy logic controller designed.

2.5.1 Logic

Logic is the science of reasoning. Symbolic or mathematical logic has turned out to be powerful computational paradigm. Not only symbolic logic help in the description of events in the real world but has also turn out to be an effective tool for inferring or deducing information from a given set of facts [14].

2.5.2 Fuzzy versus Crisp

Consider the query “Is water colorless?” The answer to this is a definite yes/true or no/false as warranted by the situation. If “yes/true” is accorded a value of 1 and “no/false” is accorded value of 0, this statement results in a 0/1 type situation. Such a logic which demands a binary (0/1) type of handling is termed crisp in the domain of fuzzy set theory. Thus statement such as “temperature is 32 ^{0}C”, “the running time of program is 4 seconds” are examples of crisp situations [14].

On the other hand consider the statement, “is Abebe honest?” The answers to this query need not to be definite “yes” or “no”. Considering the degree to which one know Abebe, a variety of answers spanning a range such as “extremely honest”, “extremely dishonest”, “honest at times”, “very honest” could be generated. If for instance, “extremely honest” were to be accorded a value of 1, at the high end of spectrum of value “extremely dishonest” a value of 0 at the low end of the spectrum then “honest at the times” and “very honest” could be assigned value of 0.4 and 0.85 respectively. So the situation is that it can accept values between 0 and 1. Such a situation is termed as fuzzy [14].

2.5.3 Fuzzy logic

An objective of fuzzy logic has been to make computers think like people. Fuzzy logic can deal with the vagueness intrinsic to human thinking and natural language and recognizes that its nature is different from randomness. Using fuzzy logic algorithms could enable machines to understand and respond to vague human concepts such as hot, cold, large, small, etc. It also could provide a relatively simple approach to reach definite conclusions from imprecise information.

Fuzzy logic has the advantage of modeling complex, nonlinear problems linguistically rather than mathematically and using natural language processing (computing with words). [15]

2.5.4 Fuzzy Set Theory

Classical sets

A set is defined as a collection of objects that may share certain characteristics. For example, one may define a set of positive integers, a set of students with passing grades, and a set of honest politicians. Each individual object is referred to as an element or member of the set. In a classical set an object x is either a member of a given set A (expressed as $x \in A$) or not a member (expressed as $x \notin A$); partial membership is not allowed.

There are numerous ways to define a set:

■ One may specify the properties of its elements. For example,

A = {x|x is an odd number <10}

■ One may list all the members of the set. For example,

A = {1, 3, 5, 7, 9}

■ One may use a formula to define the set. For example,

A = {xi = xi + 1, i = 1... 5, where xi = 1}

Membership function

■ a membership function, μ, can be used to define a set.

$\mu A(x) = 1$ if $x \in A$, and

$\mu A(x) = 0$ if $x \notin A$ for all values of x.

Let all the numbers under consideration, i.e. the universe of discourse, be defined as

{1, 2, 3, 4, 5, 6, 7, 8, 9, 10}.

Then, the set of odd numbers can be expressed as

{(1,1), (2,0), (3,1), (4,0), (5,1), (6,0), (7,1), (8,0), (9,1), (10,0)}.

Where each member of the universe of discourse is associated with a membership value in the form (#, μ). The numbers 1, 3, 5, 7, and 9 are associated with μ = 1 because they form the set of odd numbers extracted from the universe of discourse. This method of defining a set can be easily extended to define a fuzzy set by allowing partial membership.

Universal Set

The set that consists of all the elements of interest for a particular application (the universe of discourse) is referred to as the universal set. It is the mother of all sets; any set that is not a universal set is a subset. One may write $A \subset I$ to mean that a set A (any set) is actually a subset of the universal set I.

Basic Concepts of Fuzzy Sets

A fuzzy set is a set where degrees of membership between 1 and 0 are allowed; it allows partial membership. Fuzzy sets can thus better reflect the way intelligent people think. For example, an intelligent person will not classify people as either friends or enemies; there is a range between these two extremes. Not recognizing that there are degrees in every trait can lead to erroneous decisions. Vague human expressions such as tall, hot, cold, etc. can be expressed by fuzzy sets of the form

$A = \{(x, \mu A(x))\ x \in X\}$ Where X represents the universe of discourse and μA(x) assumes values in the range from 1 to 0.

Let the values of temperature in °C under consideration be

$T = \{0, 5, 10, 15, 20, 25, 30, 35, 40\}$.

Then, the term hot can be defined by a fuzzy set as follows

$HOT = \{(0, 0), (5, 0.1), (10, 0.3), (15, 0.5), (20, 0.6), (25, 0.7), (30, 0.8), (35, 0.9), (40, 1.0)\}$.

This fuzzy set reflects the point of view that 0 °C is not hot at all, 5, 10, and 15 °C are somewhat hot, and 40 °C is indeed hot. Another person could have defined the set differently.

2.5.5 Fuzzy Sets Properties

Empty fuzzy set

A fuzzy set is referred to as empty if and only if the value of the membership function is zero for all possible members under consideration. $A=\varnothing$ if $\mu A\ (x) = 0\ \forall\ x \in X$.

Universal fuzzy Set

A fuzzy set is universal if and only if the value of the membership function is one for all members under consideration.

2.5.6 Operations on Fuzzy Sets

The three basic logic operations, they are the operations most commonly used in engineering applications

Complement

The absolute complement of a fuzzy set A is denoted by $\bar{A}$ and its membership function is defined by: $\mu \bar{A}\ (x) = 1 - \mu A(x)$ for all $x \in X$.

Union

The union of two fuzzy sets A and B is a fuzzy set whose membership function is defined by

$\mu\, A \cup B\ (x) = \max\, [\mu A(x), \mu B(x)]$

Intersection

The intersection of two fuzzy sets A and B is a fuzzy set whose membership function is defined by $\mu_{A \cap B}(x) = \min[\mu A(x), \mu B(x)]$

2.5.7 Fuzzification

Fuzzification is the operation of transforming a crisp set to a fuzzy set, or a fuzzy set to a fuzzier set. The operation translates crisp input or measured values into linguistic concepts. This, in a way, is similar to what people may do in numerous situations to reach a decision. For example, if one is told that the temperature is going to be 10 °C, one translates this crisp input value into a linguistic concept such as mild, cold, or warm according to one's inclination, then reaches a decision about the need to wear a jacket or not. If one fails to fuzzify (for example, due to lack of familiarity with the Celsius temperature scale) then the decision process cannot continue or a possibly erroneous decision would be reached. So, you have been fuzzifying all along (without knowing it) whenever you made correct decisions.

2.5.8 Classical Reasoning

In classical binary logic, reasoning is based on two complementary mechanisms: deduction (modus ponens) and induction (modus tollens). Deduction is used to obtain conclusions by means of forward inference and induction is used to deduce causes by means of backward inference. The two mechanisms are contrasted in Table 2.1. In that table *A* and *B* are crisp sets and the symbol → means implies

Table 2-1 Deduction and Induction

	Deduction	Induction
Rule	IF x is A → y is B	IF x is A→y is B
Premise	X is A	Y is not B
Conclusion	Y is B	X is not A

In other words, given the rule: IF x is A, THEN y is B and the observation that "x is A", one concludes by deduction that: "y is B". In mathematical shorthand: $(p \wedge (p \rightarrow q)) \rightarrow q$

Given the same rule but the observation that "y is not B", one concludes by induction that: "x is not A". In mathematical shorthand :$(q \wedge (p \rightarrow q)) \rightarrow p$

2.5.9 Fuzzy Reasoning

Fuzzy reasoning is based on inference rules of the form IF <premise>, THEN <consequence> as is the case in classical logic, but fuzzy sets, rather than crisp sets, are used. Fuzzy sets define linguistic variables and hence fuzzy inference rules can model a system linguistically.

Fuzzy algorithms are mathematically equivalent to fuzzy relations and fuzzy inference is equivalent to fuzzy composition.

There are numerous ways that have been put forward to express an inference rule.

A direct, simple inference rule takes the form:

IF x is A, THEN y is B, *Where* A and B are fuzzy sets.

If the number of rules is large it becomes more convenient to employ a fuzzy relations approach. The IF/THEN rules are converted to fuzzy relations, and then fuzzy composition is used to infer conclusions. The conversion from IF/THEN rules to fuzzy relations could be defined in more than one way. A simple method is given by: $R = A \rightarrow B = A \times B$

An inference rule could have more than one proposition. For example, a rule of inference with two propositions would take the form: if x is A, and y is B, then z is C where A, B, and C are fuzzy subsets of X, Y, and Z, respectively.

The rule may be written as: $A \text{ and } B \rightarrow C$

A fuzzy algorithm has several rules, such as

Rule 1: IF x is A_1, THEN y is B_1

Rule 2: IF x is A_2, THEN y is B_2, then up to rule n

Rule n: IF x is An, THEN y is Bn

This n-rule system can be converted to n relations: R_1, R_2... Rn. These relations can be combined into one relation, R, using fuzzy intersection operations or fuzzy union operations depending on how the rules are perceived to be connected.

$R = R_1 \cup R_2 .. \cup R_n$, or

$R1 = R_1 \cap R_2 \ldots \cap R_n$

2.5.10 Fuzzy Logic Controller and Design

Basic block diagram of fuzzy logic controller is as shown under.

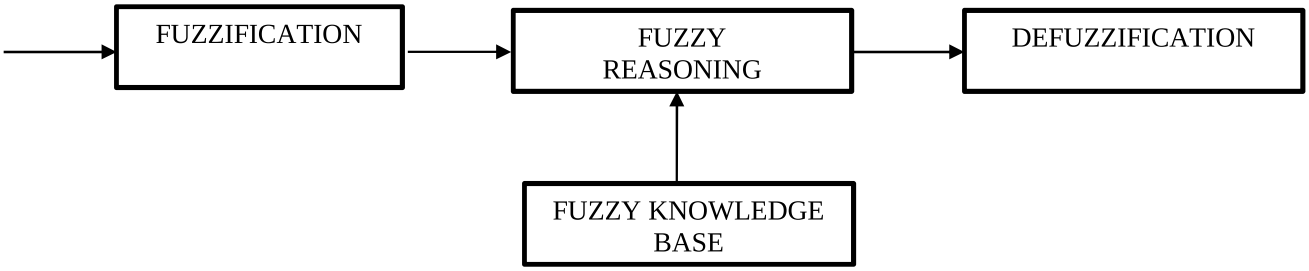


Figure 2:7 Basic structure of fuzzy logic controller.

The main building units of an FLC are a fuzzification unit, a fuzzy logic reasoning unit, a knowledge base, and a defuzzification unit. Defuzzification is the process of converting inferred fuzzy control actions into a crisp control action [16].

In the design of a fuzzy logic control system it is assumed that:

- a solution exists.
- input and output variables can be observed and measured.
- an adequate solution (not necessarily an optimum one) is acceptable.
- a linguistic model can be created based on the knowledge of a human expert.

The basic configuration of Fuzzy Logic Controller (FLC) consists of four main parts

(i) Fuzzification

(ii) Knowledge base

(iii) Decision-Making logic and

(iv) Defuzzification

The functions of the above modules are described below.

(i) The Fuzzification:

(a) Measure the values of input variables

(b) Performs a scale mapping that transforms the range of values of input variables into corresponding universe of discourse.

(c) Performs the function of fuzzification that converts input into suitable linguistic values, which may be, **viewed** labels of fuzzy sets.

(ii) The Knowledge Base:

It consists of data base and linguistic control rule base.

(a) The database provides necessary definitions, which are used to define linguistic control rules and fuzzy data, manipulation in an, FLC.

(b) The rule base characterizes the control goals and control policy of the domain experts by means of set of linguistic control rules.

(iii) The Decision Making Logic:

It is the most important part of FLC; it has the capability of simulating human decision making based on fuzzy concepts and of inferring fuzzy control actions employing fuzzy implication and the rules of inference in fuzzy logic.

(iv) The Defuzzification:

(a) A scale mapping which converts the range of values of input variables into corresponding universe of discourse.

(b) Defuzzification, which yields a non-fuzzy, control action from an inferred fuzzy control action.

There are seven methods used for defuzzifying the fuzzy output functions. They are

1. Max-membership principle,
2. Centroid method,
3. Weighted average method,
4. Mean–max membership,
5. Centre of sums,
6. Bisector of area, and
7. First of maxima or last of maxima

2.6 Previous work related on Modeling and Active Power Control of Hydro Power Plant

Several researches have been conducted on dynamic modeling of a hydro power plant unit and control of power and frequency the different scenario using different control mechanism, among those scholars.

Modeling of hydro power plant with two surge tank at china power plant and the governor uses PID type of a controller on Matlab software at only full load rejection ,use of conventional controller and one operating condition is major draw backs [19]. Power control of a hydro power plant unit only using conventional PID controller and response of active power is simulated on Matlab major drawback plant is not modeled in this thesis, for this scenario all component of hydro power is modeled and customize to Finchaha hydro power plant parameter [12]. Mathematical model of hydro power units, especially the governor system model for different operating conditions, based on software TOPSYS, Case studies are conducted based on one Swedish hydro power plant (HPP) and three Chinese plants. The simulation is for start-up, no-load operation, normal operation, and load rejection in different control modes (frequency, opening, and power feedback). As a result, the model application is simulating different physical quantities of the unit such as guide vane opening, active power, rotation speed, and pressures at volute and draft tube for all by using PID controller, in case conventional controller is major drawback[20-21]. Modeling result of island interconnected and step response of unit 1 Ataturk hydro power plant by Matlab Simulink, using conventional PID controller [22]. Designing speed and active power control of hydro power plant unit using PID controller, use conventional controller and all component of hydro power is not modeled[23]. governor design using neural fuzzy sliding control for hydro power unit at load rejection only at isolated operation using Matlab Simulink, operating mechanism is used in only one operation[24]. Governor design by a reduced-order sliding mode for a hydropower plant with an upstream surge tank, the governing system is comprises tunnel, a surge tank, a penstock, a wicket gate and servomechanism, a governor, a hydro-turbine and a grid, all models are interconnected to simulate the governing system. The control method of reduced-order sliding mode is proposed, where the governor design is based on a reduced-order governing system [25].

Gaps Identified

Following are the gaps identified on modeling and simulation of the hydropower plant as per the literature review:

- ✓ Most of the article are modeled on by neglected tunnel and surge tank of power plant, but in this all component of the power plant is modeled.
- ✓ The control mechanism used in site selection and most researches are using PID control mechanism, but fuzzy logic controller
- ✓ Research conducted for a dynmical model is conducted topsys soft ware, this is by using matlab environment
- ✓ Control used is neural fuzzy sliding control under load rejection only, but this for different operation mode.

CHAPTER THREE

DYNAMIC MODEL OF THE FINCHAHA POWER PLANT

3.1 Introduction

This section presents a Mathematical model of hydro power units, including a model of the turbine governor system improved by this chapter, and the existing models of other components (hydraulic system, turbine, and generator) is modeled and complete Simulink block diagram with all operating mechanism is described.

3.2 Model of the Power Plant

Generating unit of a hydropower plant can be modeled by the superposition of two dependent sub-models, these are [22].

1. The turbine-governor model , this considers;
   - Mechanical dynamics of the generating unit.
   - Maintaining the power output.
2. The generator and excitation system model
   - Maintaining the voltage at the generator terminals. This model is not considered in this thesis.

The model considered here for Finchaha power plant was implemented in SIMULINK / MATLAB software and comprises the following dynamic sub-models:

- Hydraulic System
- Turbine Model
- Hydraulic Actuator
- Turbine Regulator (Fuzzy Logic Controller and PID controller)

The block schemes of the complete model with its sub model is presented in figure (3.1)

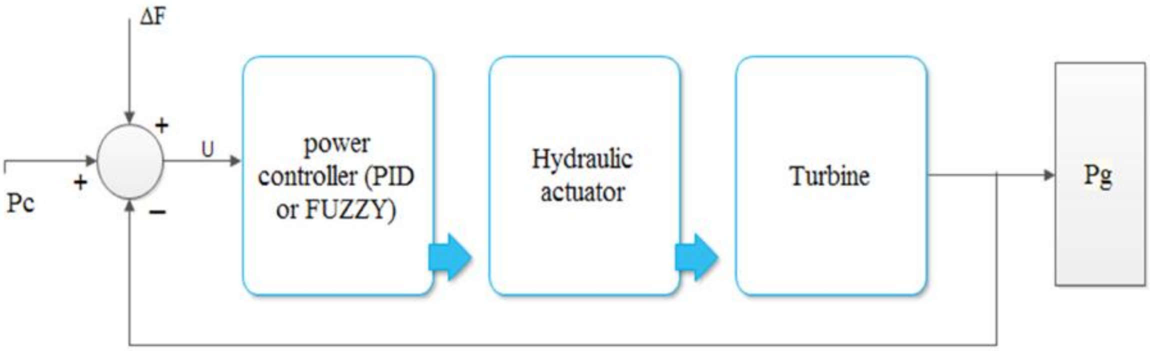


Figure 3:1 General Representation of Sub Model

All is in per unit, i.e. every signal is given in per units (Pu).this simplifies the interface between the parts. This simplifies an interface between the parts and makes algorithm makes for modeling easier. Per unit value is calculated in the following way [24].

$$\text{perunit} = \frac{\text{actual}_{\text{value}}}{\text{base}_{\text{value}}}$$

3.3 Basic Mathematical Models of Typical Hydroelectric Power Plant

A typical layout of a hydroelectric power plant with surge tank is shown in fig (3.3), it consists of reservoir with water level H_R (in meters), tunnel length L_1 (m), tunnel cross-section area A_1 (m^2), head of surge tank H_s (m), cross-section area of the surge tank As (m^2), penstock length L_2 (m), penstock cross-section area A_2 (m2) and tail water head H_0 (m). Both H_R and H_0 are assumed to be constant[25].

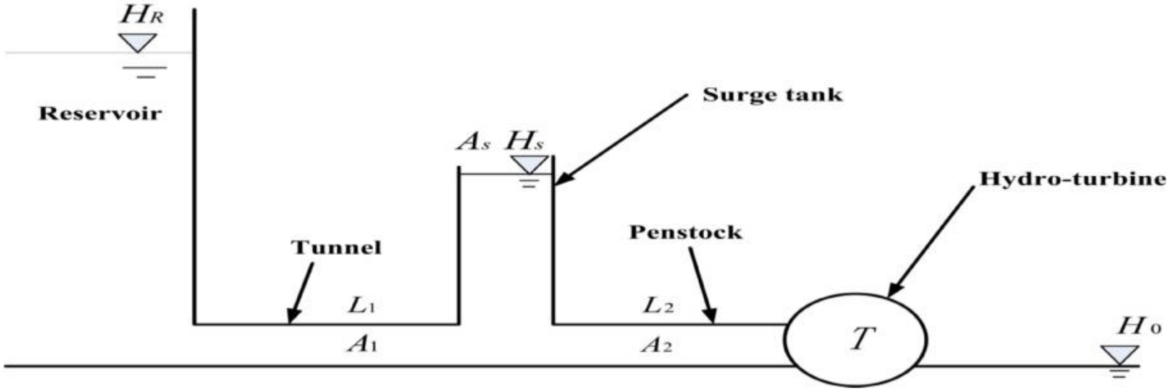


Figure 3:2 Typical Piping Structure of Finchaha Hydro Power Plant

3.3.1Model of the Hydraulic System

In a hydroelectric power plant, stored water flows from a high elevation to the hydro turbine; gravitational potential energy is converted into kinetic energy. Then, the turbine shaft, getting mechanical energy from the conversion, drives the machine to generate electricity. In a turbine, the power is controlled by regulating the flow into the turbine using the position of the gates or nozzles. This regulation is achieved by the turbine governor, which is also called the speed governing system or turbine governing system. The governing system assures turbine-governor speed regulation and therefore frequency and active power, upon detecting load variations[6].

For dynamic stability studies, accurate mathematical modeling of power system components is necessary. The hydraulic system from Finchaha dam to each unit turbine consists commonly for four (4) units comprises:

- Head race tunnel,
- Surge tank,
- Penstock

I. Head Race Tunnel

It joins the reservoir and upstream surge tank together as shown in figure (3.2). Since the inlet of head race tunnel is constant for H and Q during hydrodynamic transients. Therefore, using the equation of continuity flow rate from of head is distributed to a surge tank and turbine admission as equation bellow [4].

$$q_2 = q_1 - q_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where:

- q_1 is per unit flow rate deviation of tunnel
- q_2 is per unit flow rate deviation of penstock
- q_s is per unit flow rate deviation of surge tank.

Dynamics of the Head Race Tunnel is

$$\frac{dq_1}{dt} = \frac{-h_1}{T_{w1}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

$$\frac{h_1(S)}{q_1(S)} = -T_{W1}(S) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3\ )$$

Where:-

- h_1 (per unit) is the head deviation of the tunnel input and output,
- h_{f1} is the hydraulic loss in the tunnel and
- $T_{W1}(S)$ is the water inertia time of the tunnel represented by equation(3.4)[19].

$$T_{w1} = \frac{L_1 Q_r}{A_1 g H_r} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

- Q_r = rated flow rate(29.6)
- H_r = rated head(517m)
- g = acceleration due to gravity

Finchaha hydro power plant parameter is inserted in equation (3.4)

$$T_{w1} = \frac{3523 * 29.6}{7.065 * 9.81 * 517} = 2.91\text{sec}$$

Water inertia time of tunnel is 2.91 sec; in this thesis friction effect is neglected because to reduce complexity of mathematical equation, so transfer function used for tunnel is represented as fig (3:3).

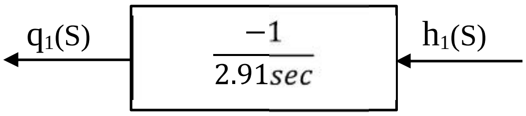


Figure 3:3 Head Race Tunnel Simplified Model

II. Surge Tank

Occurrence of pressure fluctuations, caused when the systems undergoes the changes from one operational steady state to another is water hammer effect. Classical problem to this water hammer is to insert device called surge tank[20], Dynamics of the surge tank can be expressed as equation (3.5).

$$hs = \frac{1}{Ts}\int q_s dt \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

$$\frac{dh_s}{dq_s} = \frac{1}{T_S S} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.6)$$

Where h_s (per unit) is the water head deviation of the surge tank, and Ts (is the filling time of the surge tank), surge tank filling time is represented as equation (3.7) [25].

$$Ts = \frac{AsHr}{Qr} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.7)$$

By inserting the value of Finchaha hydro power plant from **Appendices A** into equation (3.7)

$$Ts = \frac{58.465 * 517}{29.6} = 670.02sec$$

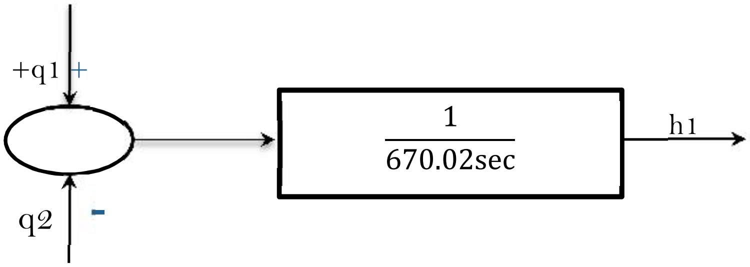


Figure 3:4 Surge Tank Simplified Modeled

III. Penstock

Penstock carry water from surge tank to a turbine, the transfer function of penstock related with incremental head (H) and flow (Q) of penstock with a surge tank. Turbine power is function of head across the turbine and guide vane opening, in the model the travelling effects are represented by an equation, then penstock friction effect is neglected

$$\frac{h_2}{q_2} = -Zp\tanh(TeS) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.8)$$

Te is wave reflection time , represented by L/a , where “a” is the wave speed substuting equation $Zp = \frac{T_{w2}}{T_e}$ into equation(3.8) gives

$$\frac{h_2}{q_2} = -\frac{T_{w2}}{T}\tanh(TeS\,) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.9)$$

Under assumption of inelastic water hammer effect ,the equation above is represented as tanh(TeS) approximated to TeS, then

$$\frac{h_2(s)}{q_2(s)} = -T_{w2}(s) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.10)$$

Where h_2 is perunit head deviation of penstock and Tw2 is water starting time in penstock is represented by formula of

$$T_{w2} = \frac{L_2Q_R}{A_2gH_R} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.11)$$

Inserting the value of finchaha hydro power plant from **AppendicesA** into equation(3.3) ,give

$$T_{w2} = \frac{558 * 29.6}{3.462 * 9.81 * 517} = \frac{16151.8}{17558.47} = 0.92\text{sec}$$

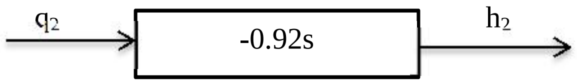


Figure 3:5 Penstocks Simplified Modeled

Then hydraulic system is the modeled by interconnected head race tunnel, surge shaft and penstock, the complete block diagram of hydraulic system modeled is represented as fig (3.6)

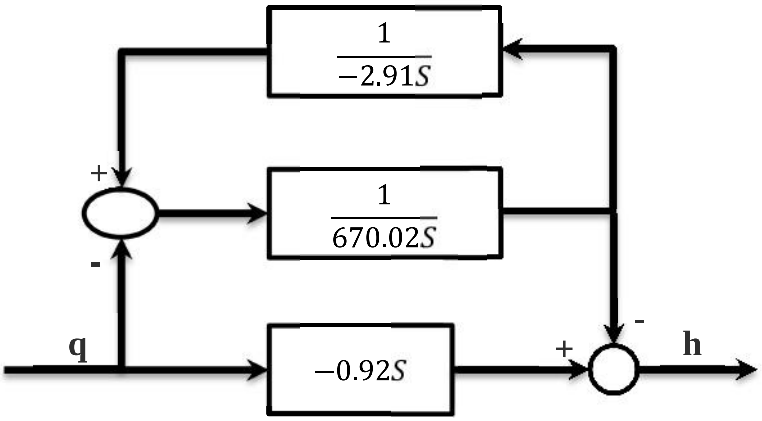


Figure 3:6 Complete Dynamic Block diagram of Hydraulic System

Where q is per unit hydraulic system flow rate deviation and h is per unit hydraulic system head deviation admission to turbine, so power generated in the turbine is as proportional of this two parameter, so next step is to model mechanical system called turbine model .

3.3.2 Turbine Model

The turbine converts the potential energy of the water into the rotational kinetic energy of the turbine. The turbine used for implementation of Finchaha hydro power plant is the impulse turbine because of high head (558m). As parameters describing the mass transfer and energy transfer in the turbine we will consider the water flow through the turbine Q and the moment M generated by the turbine and that is transmitted to the electrical generator.

These variables can be expressed as non-linear functions of the turbine rotational speed N, the turbine gate position Y, and the net head H of the hydro system.

$$Q = Q(H, N, Y) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.12)$$

$$M = M(H, N, Y) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.13)$$

The above power of turbine is nonlinear, to use simplify method of control mechanism or to reduce complexity of system I can linearize the system at operating system, a better understanding of the model is possible via linearized representation.

Linearization of equation (3.12) and (3.13) around steady value is obtained:

$$\Delta M = \frac{\partial M}{\partial H}\Delta H + \frac{\partial M}{\partial N}\Delta\omega + \frac{\partial M}{\partial Z}\Delta Y \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.14)$$

$$m_t = a_{21}h + a_{22}\omega + a_{23}y$$

$$\Delta Q = \frac{\partial Q}{\partial H}\Delta H + \frac{\partial Q}{\partial N}\Delta\omega + \frac{\partial Q}{\partial Z}\Delta Y \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.15)$$

$$q = a_{11}h + a_{12}\omega + a_{13}y$$

I would substitute turbine coefficient in equation (3.14) and equation (3.15) from the table 3.1

Table 3-1 Turbine Linearized Coeficcient

Turbine linear coefficient	Value of linear coefficient
a_{11}	0.5
a_{22}	0
a_{12}	0
a_{13}	1
a_{21}	1.5
a_{23}	1

substitute the value in table above in the equation of (3.14) and (3.15) the value yield as [12]

$$m_t = 1.5h + 0\omega + y \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.16$$

$$q = 0.5 + 0\omega + y \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.17$$

The corresponding transfer function block diagram is shown bellow

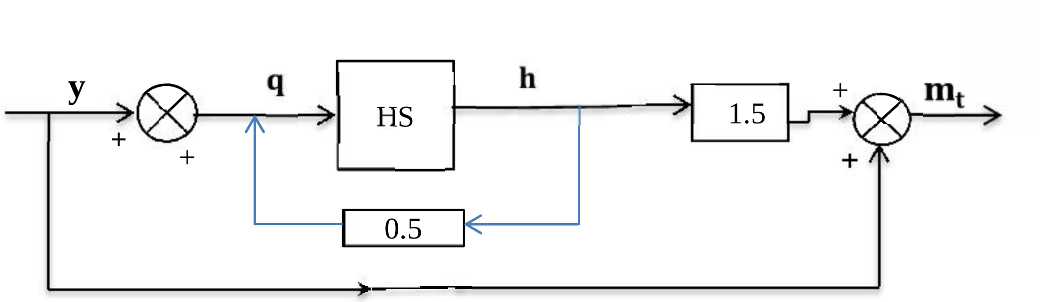


Figure 3:7 Block Diagram Representing Linearized Turbine

From this power generated can be calculated as the product of linearized turbine moment and rated speed [26]

$$P_g = m_t * \omega = m_t * \frac{2\pi}{60} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.18)$$

Inserting the value of rated speed 500RPM, I get the value generated power is as bellow

$$P_g = m_t * \frac{2 * 3.14 * 500}{60} = m_t * 52.33 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.19)$$

Per unit power generated value is represented as, where rated unit of Finchaha is 34.1MW

$$p_g(\mathrm{pu}) = m_t * \frac{52.33}{34.1} = m_t * 1.5$$

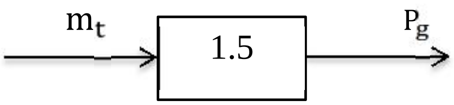


Figure 3:8 Generating Power Simplified Model

3.3.3 Gate Servo Model

Gate movement is driven by the hydraulic system, the relationship between the control signal Y_{ref} and the gate Servomotor stroke Y can be expressed with a first-order equation [27]

$$\frac{y}{yref} = \frac{1}{TaS + 1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.20)$$

T_a is response time of gate servomotor, Subsisting the value time constant for hydraulic actuator for Finchaha hydro power plant (Ta=0.5second) the got, hydraulic actuator transfer function as follows:

$$\frac{y}{yref} = \frac{1}{0.5S + 1}$$

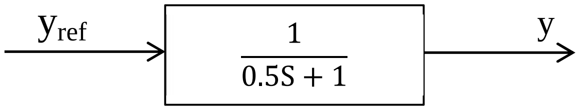


Figure 3:9 Opening gate modeled

3.3.4 Generator Unit and Network

If the generator unit supplies for an isolated load, then the dynamic process of the generator unit considering the load characteristic are represented as equation below [27] , for the isolated operation the equation used is modeled as equation (3.20)

$$\frac{x}{(Mt - Mg)} = \frac{1}{T_a s + e_g} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.20)$$

Where T_a is generator unit mechanical time (in seconds) and m_g is load torque (Pu),Inserted the value of Finchaha hydropower plant, the Finchaha hydro power plant generator unit mechanical time is 6sec and where rotation loss coefficient is neglected (e_g=0) and, inserted the value to the equation (3.20), yield that the transfer function below

$$\frac{x}{(Mt - Mg)} = \frac{1}{5.99s}$$

As well as power generated the product of momentum of turbine and rated speed of turbine, power load is the same as the product of this load momentum and rated speed

3.4 Power and Frequency Control

Power controller is used to keep the power of a unit equal to the set value. This kind of power controller is used to enable power changes to be made with a certain rate. Up to synchronization the frequency control is active.

Power Control Structure

By eliminating speed control, power control may directly drive the guide vanes and perform primary control action. Since the speed control is deactivated, power control settings are tuned to perform satisfactory primary control action

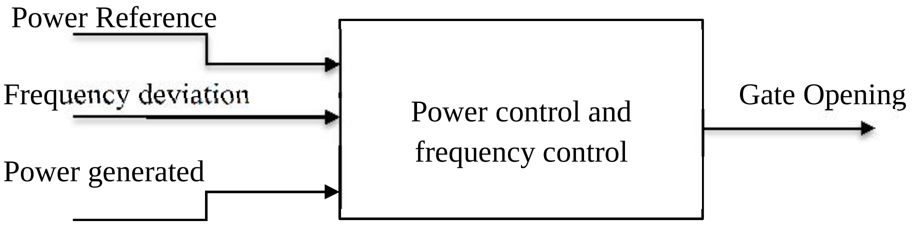


Figure 3:10 Power Control Model block diagram

The controller tries to diminish the error signal generated by three inputs;

- Active power reference
- Output power generated and
- Frequency change
- Speed droop

The active power reference is received from grid or national load dispatch. This signal may be received for each unit or for total generation in a plant. The received reference signal is change by frequency bias. All the variables in the governor system are per unit values. This power control is designed by PID controller and Fuzzy logic controller with a selector switch

Grid connected mode have two control modes

- Power control mode
- Frequency control mode

Isolated mode only in

- Frequency control mode

3.4.1 Speed Drop Control

In case of frequency increase (decrease) in the grid, each power generation unit reduces (adds) a fix percentage of its total rating output power multiplied by the amount of the change in the grid frequency from (to) its output power. The amounts of this power can be calculated from equation (3.21) [18]

$$\frac{\Delta f}{f_n} = -\rho \frac{\Delta p_g}{p_n} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.21)$$

Where: ρ is speed drop, f_n is nominal frequency (1pu), p_n is nominal power (1pu). The speed drop was taken from Finchaha hydro power plant for different operating principle

3.4.2 Existing Conventional PID controller

The PID controller in this thesis regulates the active power production is a response to the variation of load demand, hence frequency of system network at nominal value, By regulating the guiding unit of the impulse wheel, the power regulation is possible. The system of Finchaha hydro power plant is currently use PID controller .A PID controller continuously calculates an error (t) as the difference between a set point (t) and a measured process value (t). The PID controller tries to minimize the error over time by adjusting the control value u(t), in standard for proportional integral derivative control can be expressed as equ(3.22)[18]

$$u(t) = k_p \left(e(t) + \frac{1}{T_i} \int_0^t e(t)dt + T_d \frac{d}{dt} e(t) \right) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 3.22$$

Where u is the control value, Kp is the gain, Ti is the integral time and Td is the derivative time. For this thesis the value of all proportional, integral and derivative coefficients is taken from the manual of Finchaha hydro power plant but, this value of the coefficient is different for different mode of operation.

3.4.3 Fuzzy Logic Controller

It gathers plant output data, compares it to the reference input, and then decides what the plant input should be to ensure that the performance objectives will be met.

We take the speed difference from the measuring system as an input for Fuzzy inference system. Rotor speed is compared with referenced speed to find speed deviation. This speed difference is input for Fuzzy inference system. The output control signal of Fuzzy inference system is a control signal for Gate opening mechanism. The gate opening mechanism comprises servomotor. This control signal drives the servomotor which intern controls the gate opening. It uses error and change in error as input and gate opening as output of the variable, to open and close the guide vane according to the rule given in the rule

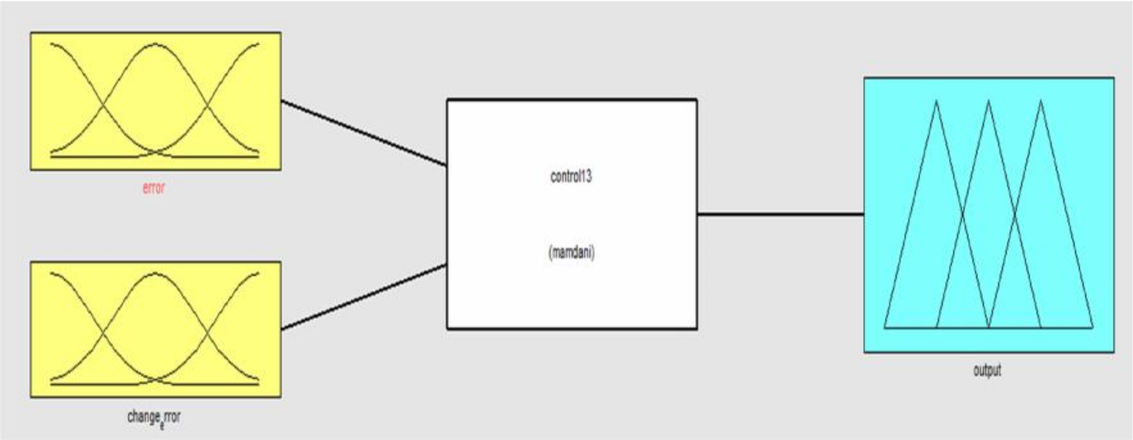


Figure 3:11 Mamdani Fuzzy Logic Controllers

3.5 Operating Principle and Overall Interconnected System

Interconnected all model in one complete block diagram as shown in fig (3:12) and fig (3:13) for different operation mode to get all desired values. My control system is PID or Fuzzy Logic Controller, and all of whole transfer function and block is shown in section above. All value is given as per unit

3.5.1Grid Connected Operation

For simulations in a grid-connected environment, the modeled has be seen in figure (3:12), in the figure (3:12) much of the same signal processing occurs but the regulator loop is power dependent, and the governor regulates towards a power reference and droop characteristics. Changing the value of grid frequency provides a change in the system stability. The system will then automatically regulate the power output from the turbine to the value decided by the droop

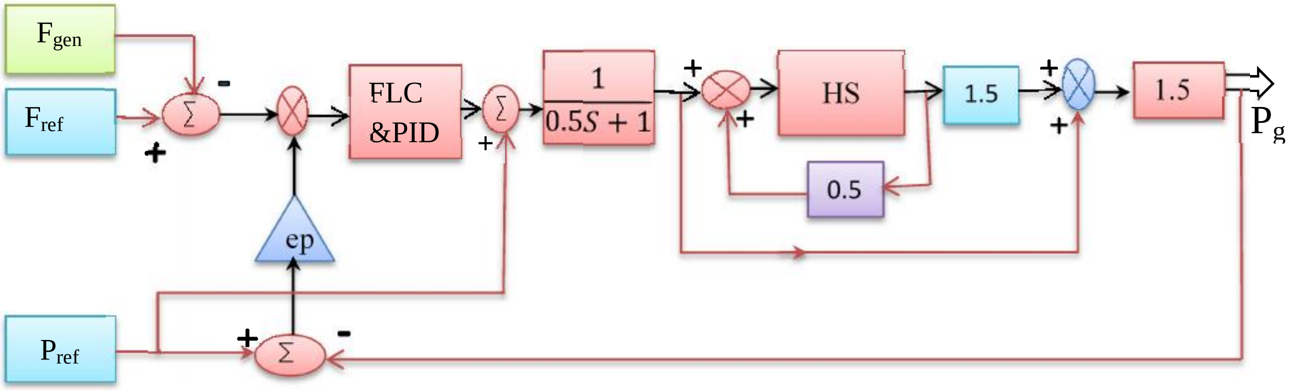


Figure 3:12 Overall Simplified Model of Interconnected Operation

3.5.2 Isolated Operation

The modeled comprise a change in frequency reference value; send the signal to a summation block. The summation block subtracts the process frequency value which becomes e and, sends it into the PID controller and fuzzy logic controller. The controller then transfers the signal into what is then represented as the guide vane opening y. Through turbine dynamics, the amount of flow q is then given by the guide vane opening and sent into the hydraulic system.

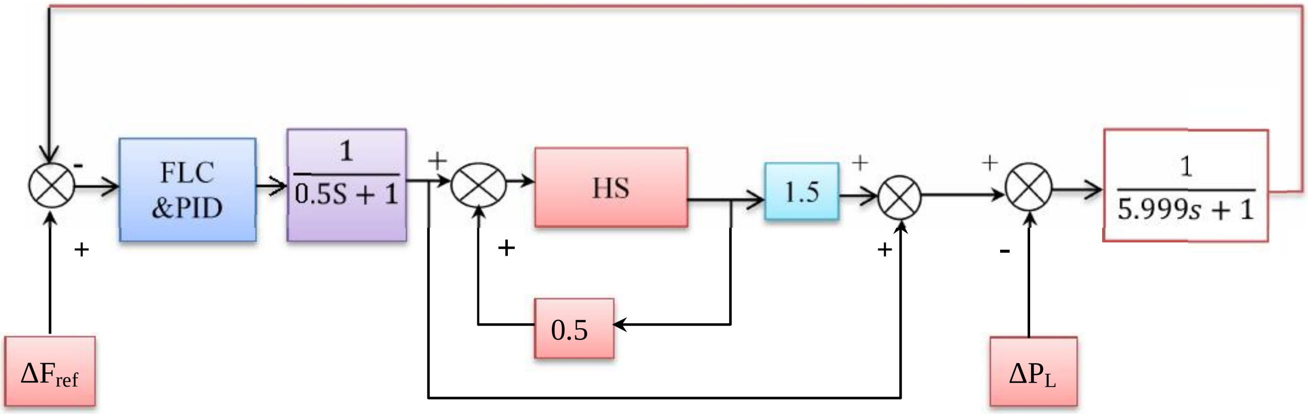


Figure 3:13 Overall Modeled block Diagram for Isolated Operation

The hydraulic system is then transferring the signal into pressure head, h. This pressure is then processed through turbine dynamics one last time giving turbine power as an output that is power generated from turbine. The speed is then represented after the torque (m_t)/power (P_g) signal has gone through the generator dynamics also called electromechanical system. The power provided to the generator is turbine power subtracted with power demands (P_L) giving P. Since the system is in per unit values, the values can easily get converted by multiplying with the base value of power (34.1MW). The same counts for the speed which can be multiplied with both the base value of the grid frequency (50Hz) and the rated generator speed (500rpm).the general block modeled is as a shown in fig (3:13).

CHAPTER FOUR

CONTROLLER DESIGN

4.1 Introduction

This chapter presents the design and analysis of the proposed control system for a hydropower plant. Existing PID conventional controller and fuzzy logic controller designed in Matlab environment

4.2 Existing PID controller

The electrical power and the mechanical turbine rotor speed have been compared as the model is simulated in per unit (Pu) form. Figure (4:1) shows the structure of error acquisition system to get the error signal which is the input of PID controller.

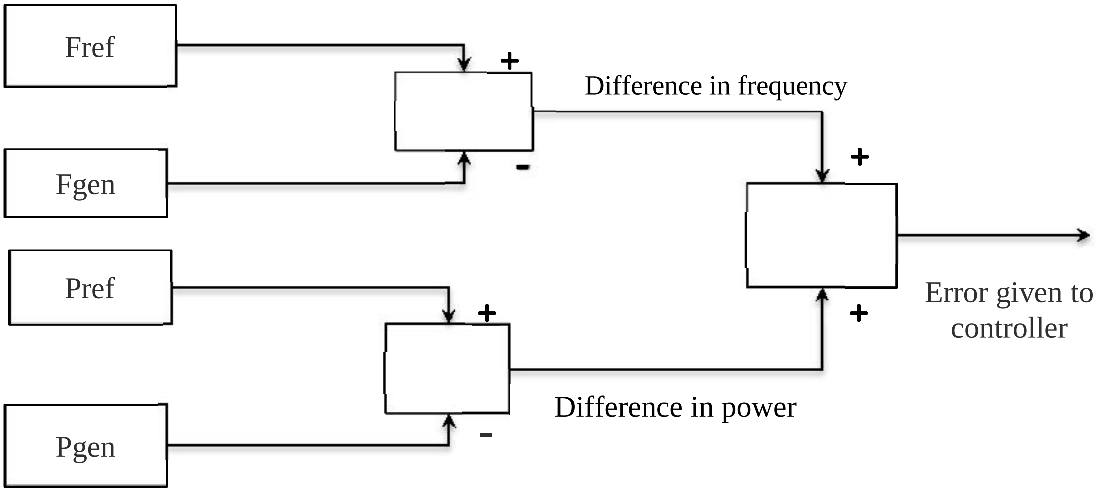


Figure 4:1 Structure of Error Acquisition System

The difference of frequency can be got by comparing the reference frequency and actual generator frequency. The comparison of reference power and a generator output active power provides the difference of power. The error from the difference of frequency and the difference of power sum up and given to controller. In stable situations, the error should be zero thus; the divergence of frequency and power is fed into PID controller to take corrective action maintaining the stabilization of the power generation system.

A PID controller tries to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action that can adjust the process accordingly and rapidly, to keep the error minimal. The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative value determines the reaction based on the sum of recent errors, and the derivative value determines the reaction based on the rate at which the error has been changing, by tuning the three constants in the PID controller algorithm, the controller can provide a control action designed for specific process requirements. Note that the use of PID algorithm for control does not guarantee optimal control of the system or system stability. To design PID Controller, the value of Kp, Ki; and Kd was determined by using trial and error method. The input for PID controller for all case in Finchaha hydro power plant is taken from Finchaha hydro power plant manual and tuned at some operation

Table 4-1 Value of PID controller for Isolated Operation

Parameter	Value
Kp	15
Ki	10
Kd	0.5

Table 4-2 Value of PID Controller for Grid Connected Operation

Parameter	Value
Kp	5
Ki	15
Kd	0.01

4.3 Fuzzy Logic Controller Design

Present thesis describes Fuzzy logic control system for Finchaha hydro power plant is to establish turbine governor. We take the frequency difference and power difference as an input for fuzzy interference system. Frequency deviation and power deviation, this sum is input for Fuzzy inference system, the output control signal of Fuzzy is control signal for Gate opening mechanism. This control signal drives the servomotor which intern controls the gate opening [28].

The following steps are applied to design the fuzzy logic controller.

- First all the information about the system is collected.
- The control elements are identified to apply fuzzy logic.
- Input and output variables for the fuzzy logic controller are identified.
- Universe of discourse is defined for input and output.
- The fuzzy sets and the corresponding membership function shape are determined.
- The rule table is defined.
- The system is simulated with the defined fuzzy controller under different conditions of operation.

4.3.1 Input Variables

For load frequency changes, the process operator is assumed to respond to variables such as sum of power error and frequency error called error (e) and the rate of change of error de (t) they are the inputs to the fuzzy logic controller. These input variables are mathematically represented by the equation bellow.

$$e(t) = r(t) - y(t) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4.2)$$

$$de(t) = e(t) - e(t-1) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4.3)$$

Where r (t) is the desired output value and y (t) is the output of the controller, and e(t) and de(t) are the two fuzzy sets defined for fuzzification.

Change in error is shown in Matlab error minus error multiply with transport delay[9].type of membership function used in this thesis is triangular because of simplicity to understand

Then the following seven triangular membership functions have been identified and applied.

The linguistic variables assigned to Mamdani type fuzzy logic controller are**:**

Table 4-3 Membership of Fuzzy Logic Controller

NEGATIVE BIG	NB
NEGATIVE MEDIUM	NM
NEGATIVE SMALL	NS
ZERO	Z
POSITIVE SMALL	PS
POSITIVE MEDIUM	PM
POSITIVE BIG	PB

The range of fuzzy logic controller is determined from the reference Finchaha hydro power generation unit. Where speed droop (ρ) = 0.02 for isolated operation and 0.05 for grid connected operation, the range of error and change in error as per formula of equation (3.1) for both operation

a) Isolated System

At no load (Pl =0) the change in frequency is zero and

At full load rejection (full load added) change in frequency is 0.02pu.

This means the system is in isolated the frequency of Finchaha varies from 49 to 51 or in per unit varies from (-0.02 to 0.02), so the discourse of fuzzy logic controller for error and change in error in isolated operation of Finchaha is [-0.02 0.02].

b) Grid Connected Operation

For grid connected in Finchaha hydro power plant value of speed droop is five percent i.e. 0.05pu. Range of frequency is deviated by 0.05pu. Range of frequency is 47.5 to 52.5, so the universe of discourse for error and change in error in grid connected operation is [-0.05 0.05].

I. Membership Function of Error (e)

The limits of the power system frequency error (Δf) and power error (Δp) were decided based on the variation of the system frequency of the existing power system, and power fluctuation This is shown in Figure (4:3).

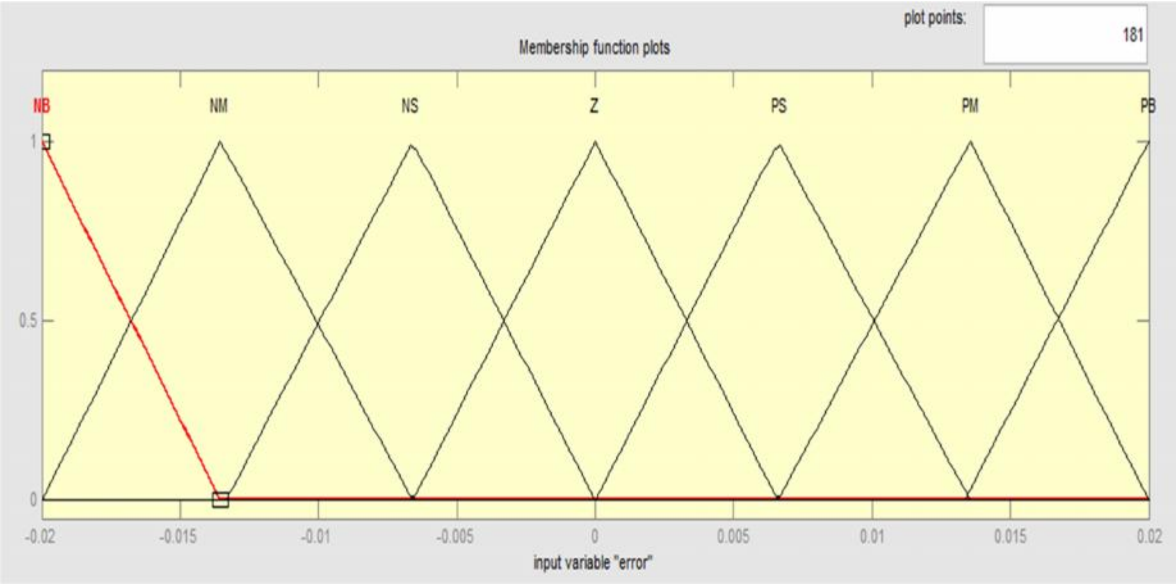


Figure 4:2 Error Input Fuzzy membership isolated system

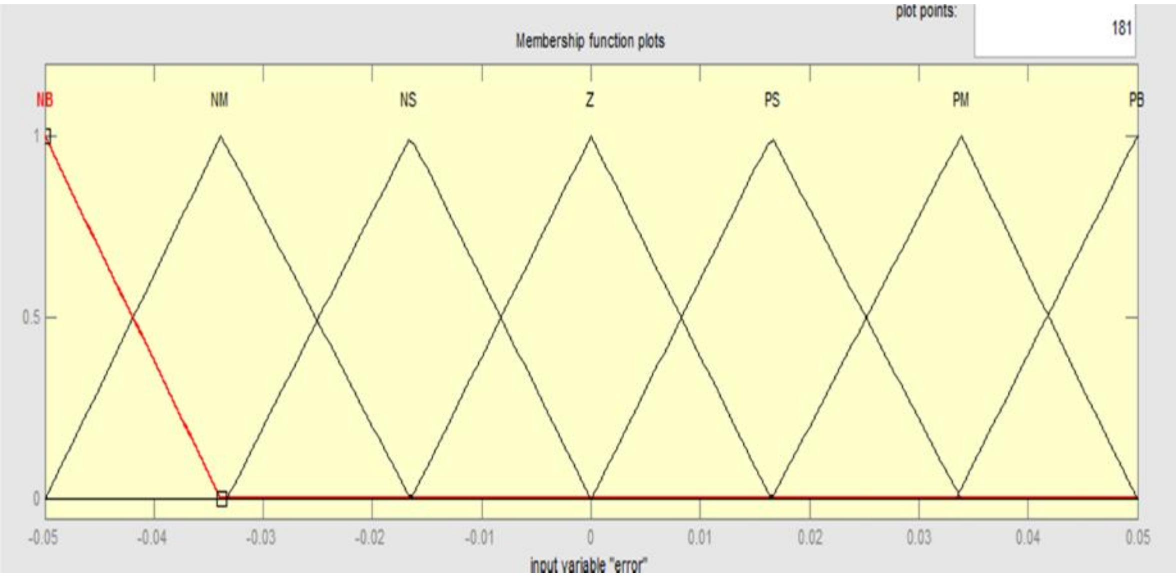


Figure 4:3 Error input membership for grid connected

II. Membership Function for Rate Change of Error (*d*e(t))

Here, a derivative has to be used to predict the error in future, based on the current slope of the error. The limits of membership values are used to reflect the frequency error (Δ**f**) and power error exactly**.** The universe of discourse here too is selected from -0.02 to 0.02 as shown in Figure (4:4).

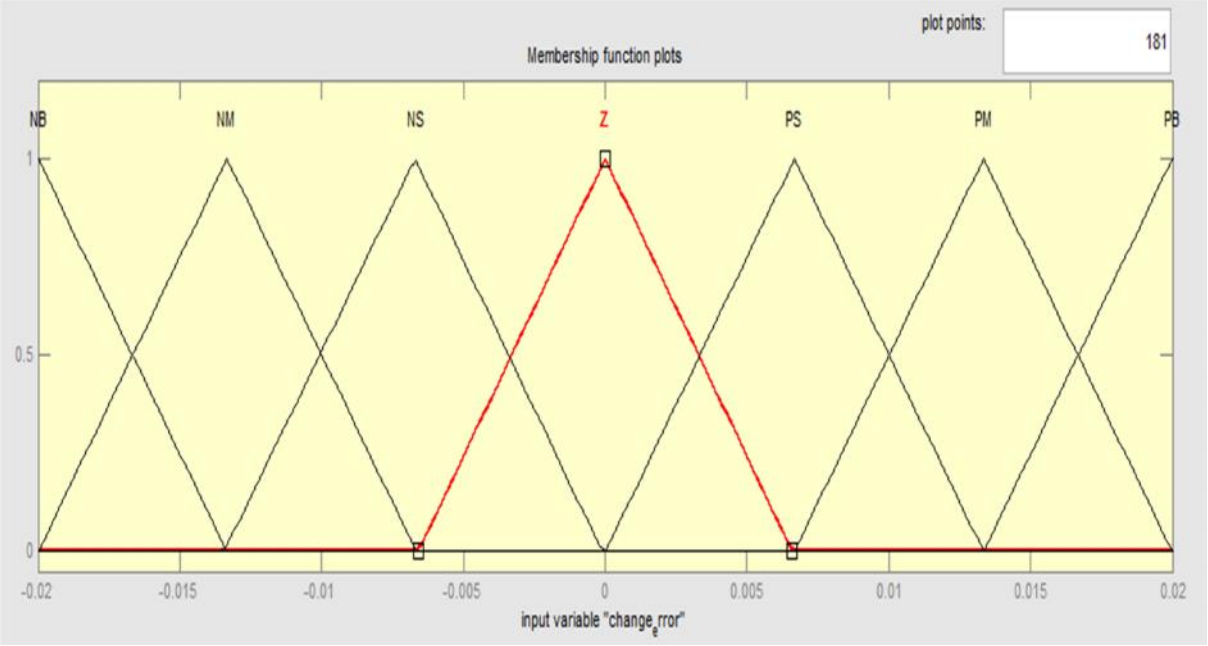


Figure 4:4 Changes in Error Input Membership isolated

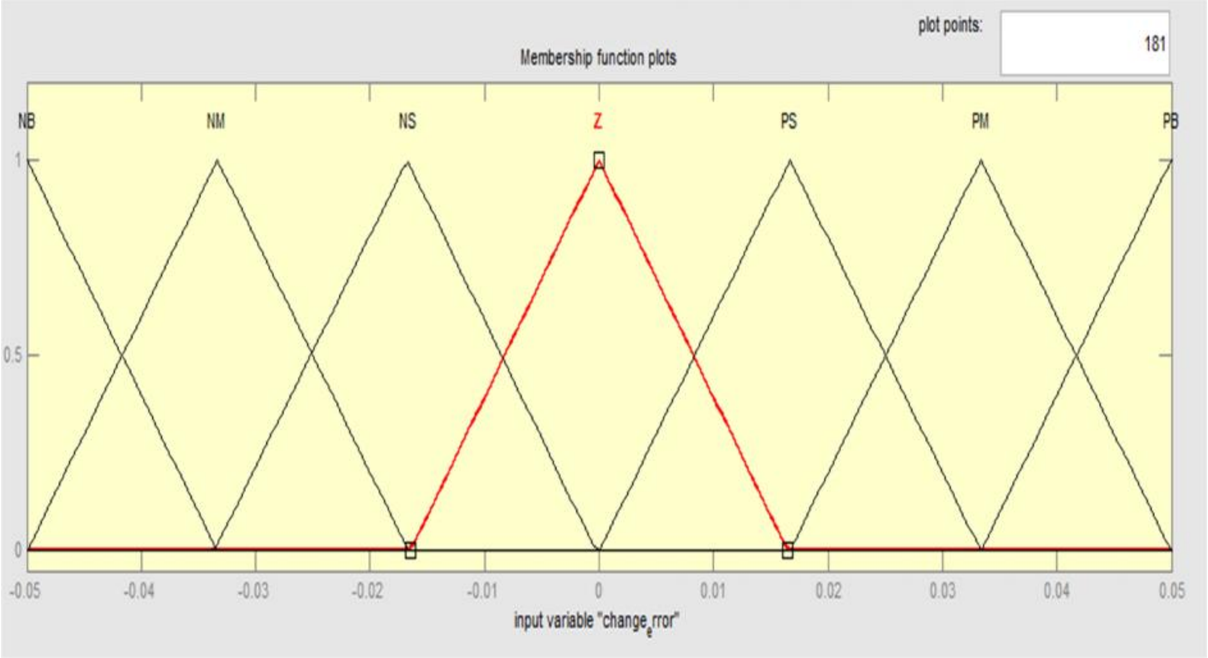


Figure 4:5 Change in Error input for interconnected operation

4.3.2 Output Variable

The output variable identified here is the reference gate opening (Δy)

Finchaha hydropower plant gate opening for both interconnected operation and isolated operation is: Minimum gate opening = 0.01pu (1%) and Maximum gate opening =0.975pu (97.5**%)**, from this change in gate opening in fuzzy universe discourse is [-0.975 0.975] this shown in fig (4:7)

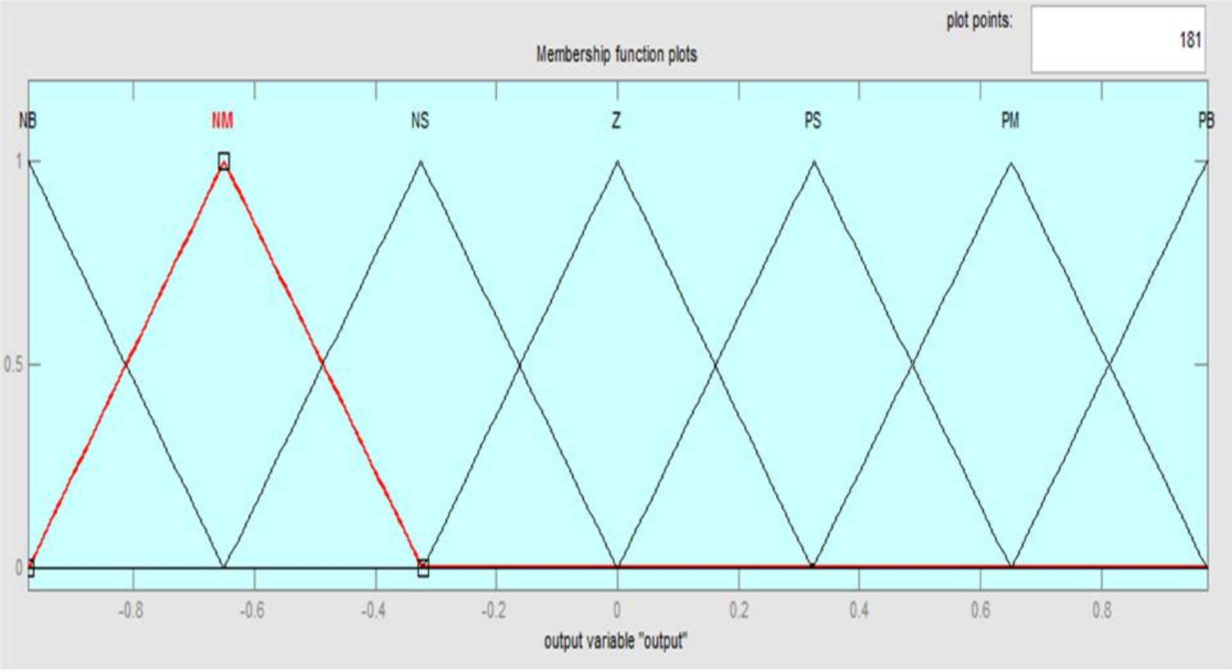


Figure 4:6 Output Membership functions

4.3.3 Fuzzy Control Rules

Fuzzy control rules can be considered as the knowledge of an expert in any related field of application. The fuzzy rule is represented by a sequence of if-then, leading to algorithms describing what action or output should be taken in terms of the currently observed information, which includes both inputs and feedback if a closed-loop control system is applied

Fuzzy Inference Rule for the Proposed Controller

In this study, input and output membership functions are same and seven segment triangular membership functions are used as stated earlier. Since each input has seven membership functions, the number of fuzzy based rules is forty nine and they are presented in Table (4-2) it consists of 49 rules Working of fuzzy logic controller is based on 49 rules. The fuzzy rules are generally IF and THEN statements combined by AND aggregation. These rules can be placed in form of table below here error and cumulative error are two inputs of fuzzy logic controller**.**

Table 4-4 Rule Base of Fuzzy Membership

		Error change						
Error		NB	NM	NS	Z	PS	PM	PB
	NB	NB	NB	NM	NB	NM	NS	Z
	NM	NB	NB	NM	NM	NS	Z	PS
	NS	NB	NM	NM	NS	Z	PS	PM
	Z	NM	NM	NS	Z	PS	PM	PM
	PS	NM	NS	Z	PS	PM	PM	PB
	PM	NS	Z	PS	PM	PM	PB	PB
	PB	Z	PS	PM	PB	PB	PB	PB

I wrote 49 rules for Grid connected and Isolated operation mode, as follows

If error is NB and the change error is NB, then output is NB

If error is NB and the change error is NM, then output is NB

If error is NB and the change error is NS, then output is NM

If error is NB and the change error is Z, then output is NB

If error is NB and the change error is PS, then output is NM

If error is NB and the change error is PM, then output is NS

If error is NB and the change error is PB, then output is Z

If error is NM and the change error is NB, then output is NB

If error is NM and the change error is NM, then output is NB

If error is NM and the change error is NS, then output is NM

If error is NM and the change error is Z, then output is NM

If error is NM and the change error is PS, then output is NS

If error is NM and the change error is PP, then output is Z

If error is NM and the change error is PB, then output is PS

If error is NS and the change error is NB, then output is NB

If error is NS and the change error is NM, then output is NM

If error is NS and the change error is NS, then output is NM

If error is NS and the change error is Z, then output is NS

If error is NS and the change error is PS, then output is Z

If error is NM and the change error is PM, then output is PS

If error is NM and the change error is PB, then output is PM

If error is Z and the change error is NB, then output is NM

If error is Z and the change error is NM, then output is NM

If error is Z and the change error is NS, then output is NS

If error is Z and the change error is Z, then output is Z

If error is Z and the change error is PS, then output is PS

If error is Z and the change error is PM, then output is PM

If error is Z and the change error is PB, then output is PM

If error is PS and the change error is NB, then output is NM

If error is PS and the change error is NM, then output is NS

If error is PS and the change error is NS, then output is Z

If error is PS and the change error is Z, then output is PS

If error is PS and the change error is PS, then output is MM

If error is PS and the change error is PM, then output is PM

If error is PS and the change error is PB, then output is PB

If error is PM and the change error is NB, then output is NS

If error is PM and the change error is NM, then output is Z

If error is PM and the change error is NS, then output is PS

If error is PM and the change error is Z, then output is PM

If error is PM and the change error is PS, then output is PM

If error is PM and the change error is PM, then output is PB

If error is PM and the change error is PB, then output is PB

If error is PB and the change error is NB, then output is Z

If error is PB and the change error is NM, then output is PS

If error is PB and the change error is NS, then output is PM

If error is PB and the change error is Z, then output is PB

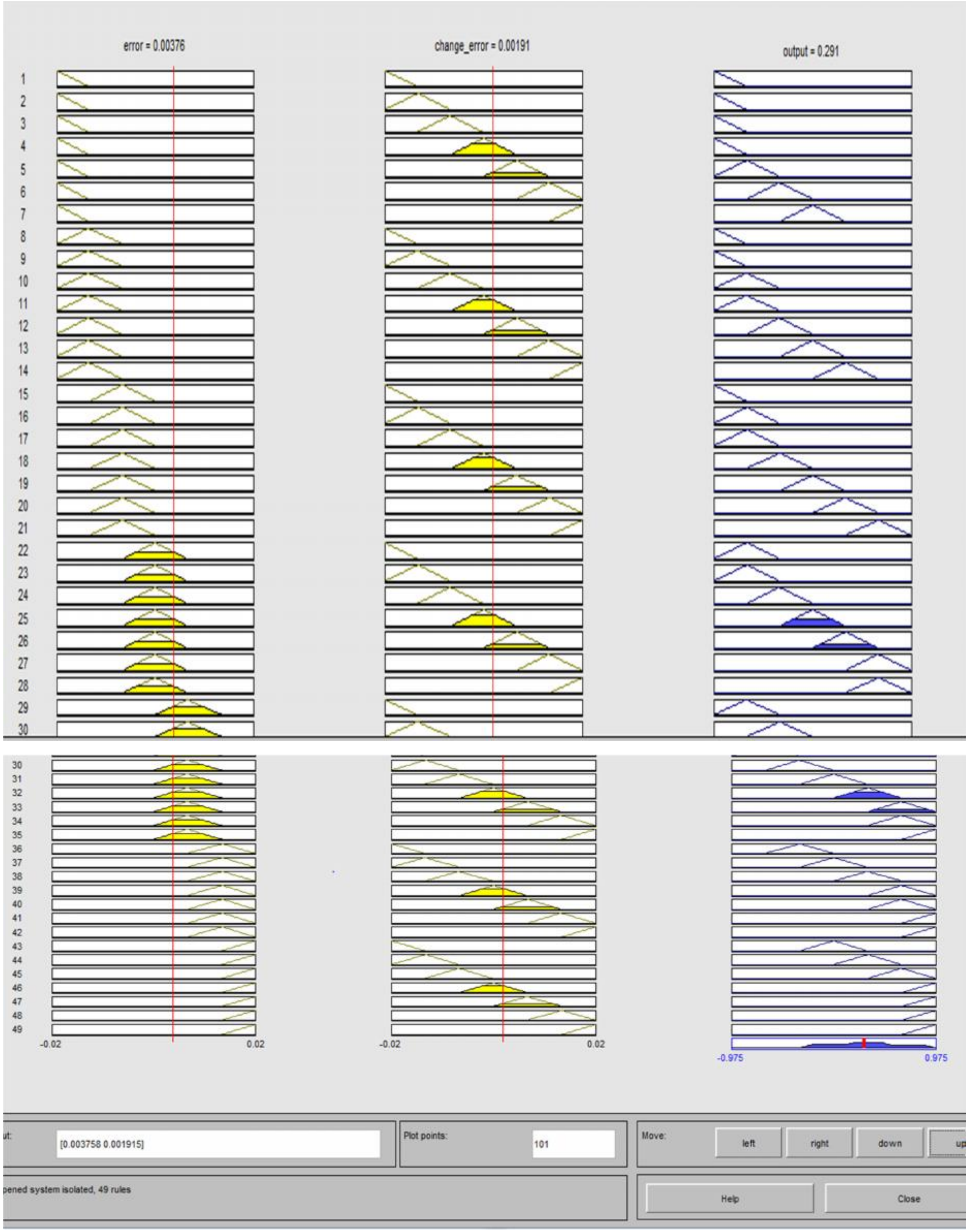
If error is PB and the change error is PS, then output is PB

If error is PB and the change error is PM, then output is PB

If error is PB and the change error is PB, then output is PB

Rule viewer from Matlab

All rules was written in Matlab and the view of all rule is shown in fig (3:8)



ut: [0.003758 0.001915]

Plot points: 101

pened system isolated, 49 rules

Figure 4:7 Rule viewer for Finchaha hydro power plant for isolated

4.3.4 Defuzzification

A Defuzzification is the process of producing the crisp control action from the output of the fuzzy control action**.** The last step in the fuzzy inference process is defuzzification; the final output of a fuzzy system has to be a crisp number. The input for the defuzzification process is the aggregate output fuzzy set and the output is a single number; Defuzzification method used in this proposed model is Centre of Area (COA) method.

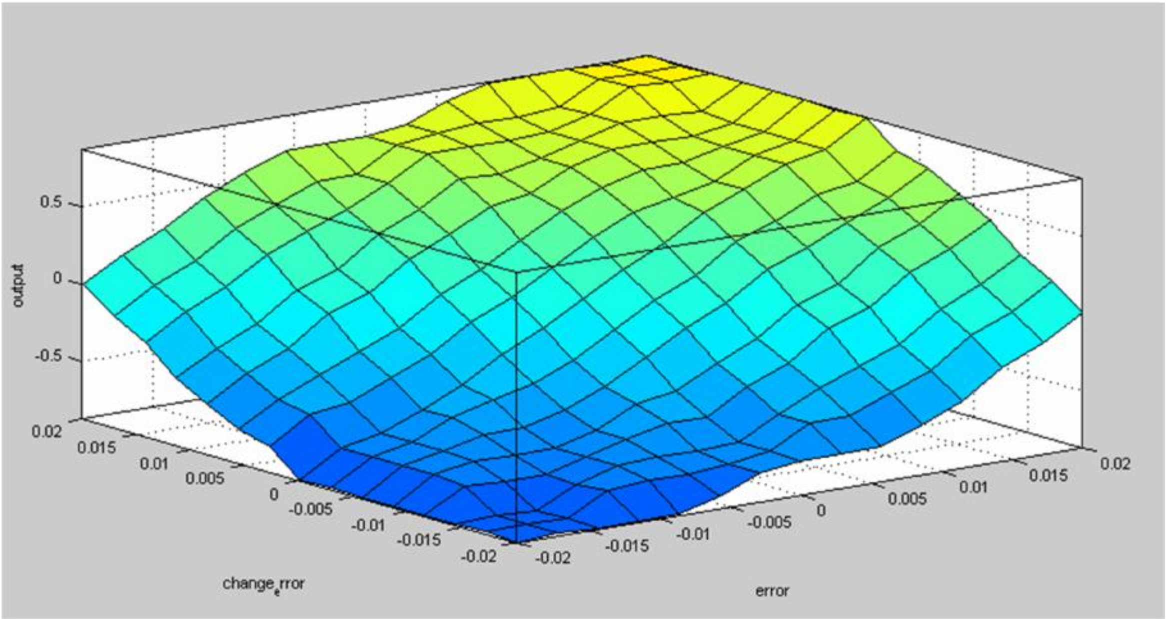


Figure 4:8 Surface viewers for Isolated

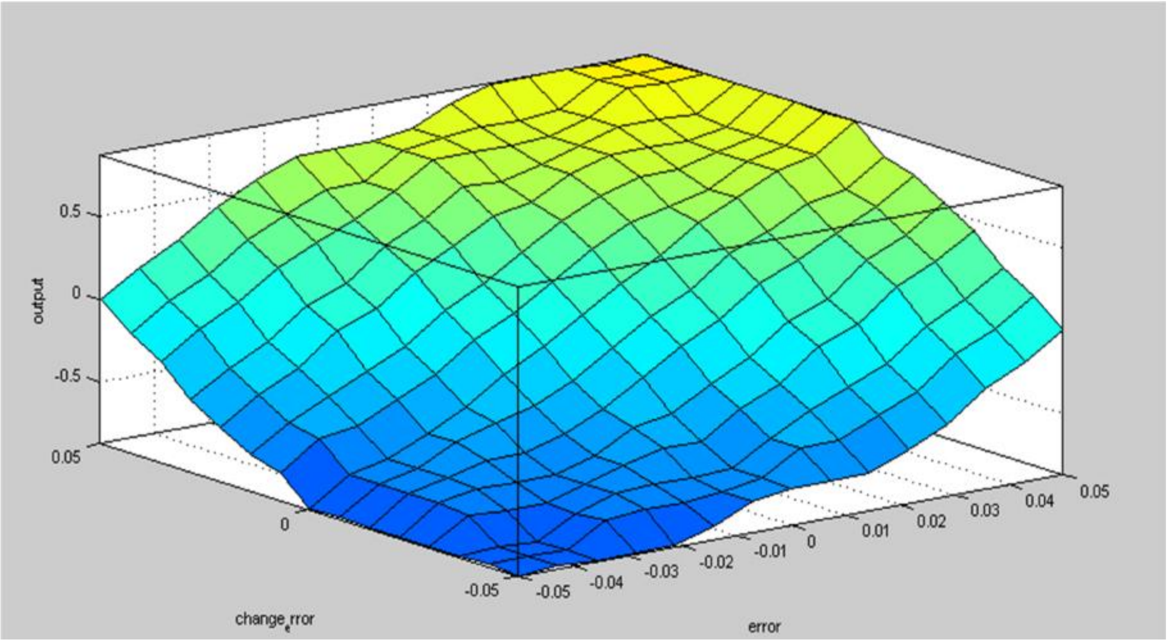


Figure 4:9 Surface viewers for Grid connected

CHAPTER FIVE

SIMULATION RESULT AND DISCUSSION

5.1 Introduction

This chapter presents simulation results got from tests performed on the Finchaha hydropower plant using Matlab Simulink with a different type of controller. The Simulink model shown in the bellow is used to carry out simulation studies and analyze the performance of controlled by comparing simulation of existing PID controller and fuzzy logic controller.

5.2 Simulation Result

To show the effectiveness of the proposed method, simulation is carried out using Matlab Simulink.

The following active power output got when the system has in different of operation modes as defined in literature part, optimum settings for the PID controller and design of a fuzzy logic controller for machines at Finchaha hydro power plant

There are performed two types of simulation

- Machine Grid Connected Operation
- Machine Isolated Operation

5.2.1 Machine Operating In an Interconnected Mode

The model made in a described manner was verified after a connection of the sub models in one complete power plant model

The overall **Matlab** block diagram for a power regulated turbine connected to a system network or grid for existing PID controller and fuzzy logic controller seen in figure (5:1) and figure (5:2) respectively. With this model, grid frequency is set as an input, as well is power and frequency references to the turbine too. The simulations are done with a step in grid frequency.

Fig (5:1) show that the Simulink model of Finchaha hydro power unit when the system is connected to grid and controlled by designed fuzzy logic controller.

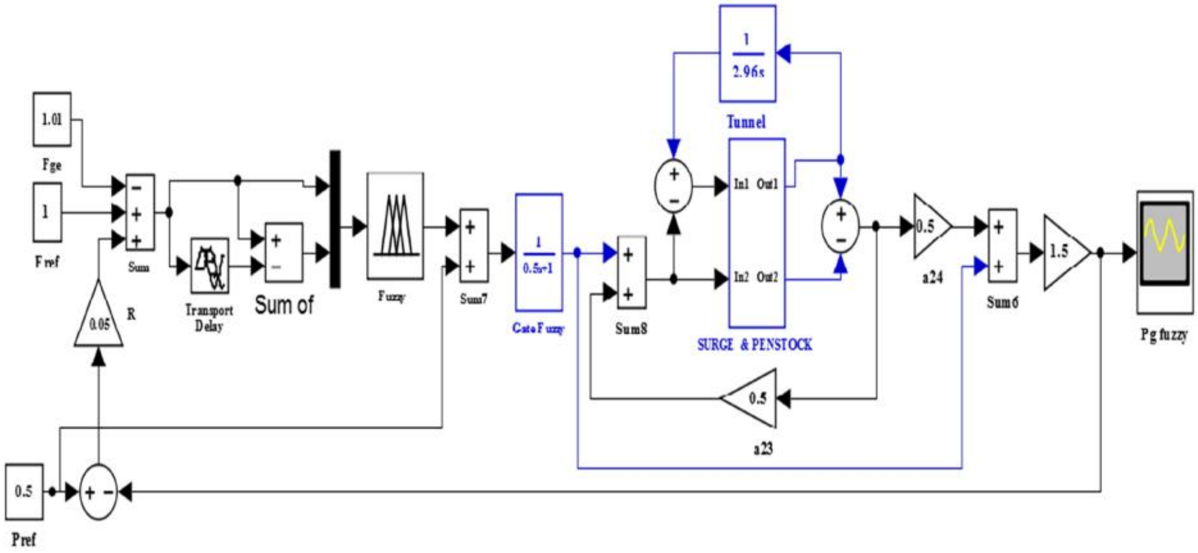


Figure 5:1 Matlab Simulink Modeled of Interconnected Fuzzy Logic Controller

Fig (5:2) Simulink diagram show that system connected to grid, controlled by PID controller.

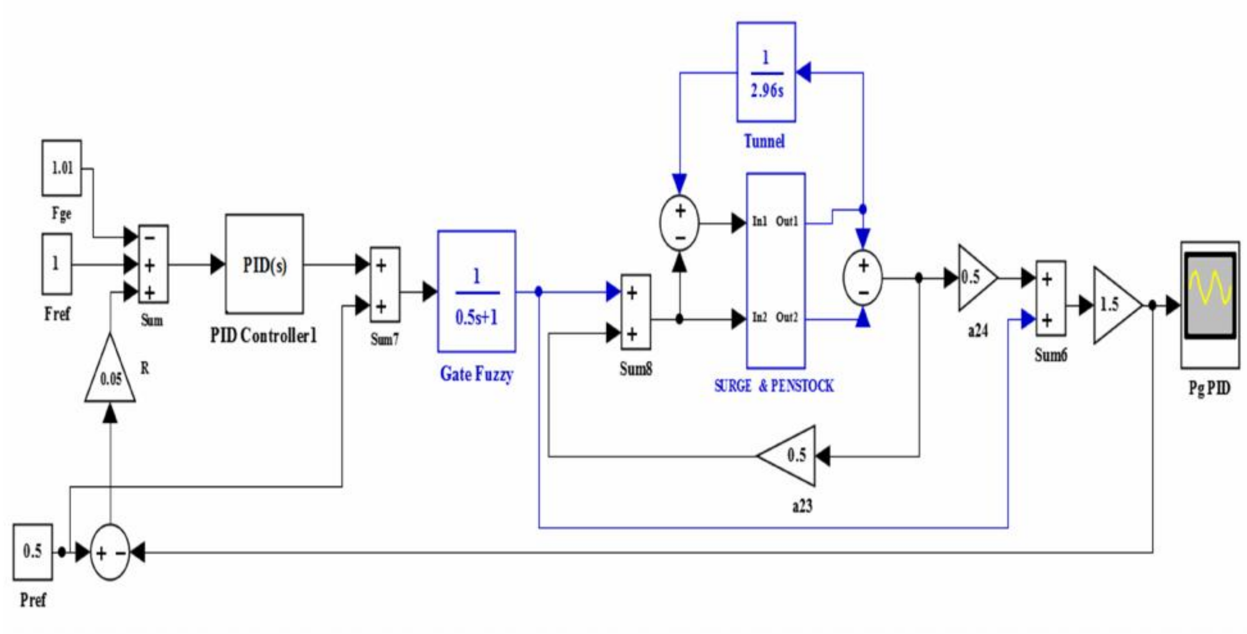


Figure 5:2 Matlab Simulink Model of Interconnected PID controller

The input for the connected system is Frequency difference (from 47.5 to 52.5) for interconnected operation & Reference power (0MW to 34.1MW).then power generated Matlab Simulink is displayed by using scope for two control mechanism, those are

- Frequency Control Mode
- Power Control Mode

A. Frequency Control Mode

This frequency control system is operated automatically depend on irrespective of change in load, when load in system increase frequency drop and when load in system decrease frequency increase, so depending on this open deflector valve open and close on change of frequency value given from grid but for simplicity I would give frequency in form of set point value from, In this control mode, the feedback signal contains not only the frequency value but also the power as shown on Simulink model of fig (5:1) and fig (5:2).

In this model of control system the unit power production was controlled at when frequency of a grid is deviated from set point, the simulation resulted show that at frequency deviation depend on speed drop rated for hydro power plant. For simulation of this thesis I have been discussed two cases:

I. One Percent Increase in Frequency of network

When one percent in frequency is an increase, the load is droop from the system network; the power generated is a decrease as per speed drop calculation, and the result is a decrease in power production of 0.2pu, equivalent to 6.82MW from the rated power of 34.1MW.

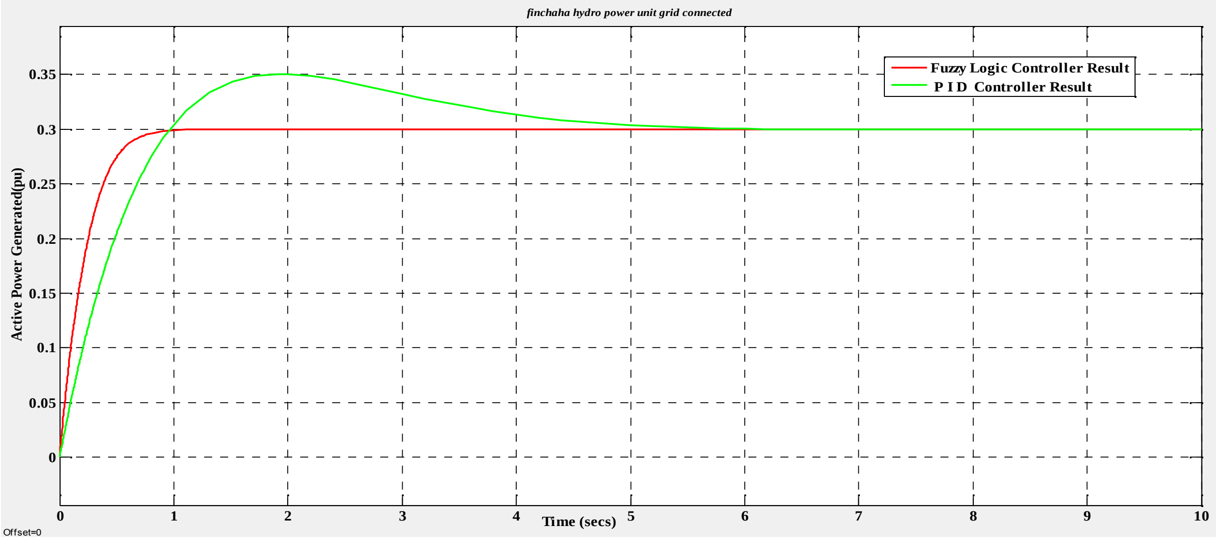


Figure 5:3 Result of One Percent Increase in Frequency

Equation found in (3.21), shows the mathematical relationship between changes in generated power as a function of change in frequency.

$$\Delta P_g = \frac{P_1 * \Delta f}{f_n * \rho} = \frac{1pu * 0.01pu}{1pu * 0.05pu} = 0.2pu$$

So power set point given to the prodution of unit by operator is 0.5pu or 17.05MW , so the power generated after the 0.01pu increase of frequency is 0.3pu to made load balance again

From the graph in fig (5:3) fuzzy logic controller was showed performance difference when compared with existed PID controller, the performance evaluation is shown in table (5-1).

Table 5-1 Control characterics for One Percent Increase Frequency

Control type	**Settling time**	**Overshoot**	**Rise time**
With Pid controller	**5.81sec**	**17.059%**	**717.643ms**
Fuzzy logic controller	**2.8sec**	**0.505%**	**439.153ms**

II. One Percent Drop In Frequency of Network

Frequency of a system is decreased when the amount of power demand is greater than amount power produced to synchronize the network, the amount of power generated to be increased as per formula of speed drop, so power generated increased by 0.2pu and the change in power generated is 0.7pu, the figure (5:4) show that the response of existing PID controller and fuzzy logic controller.

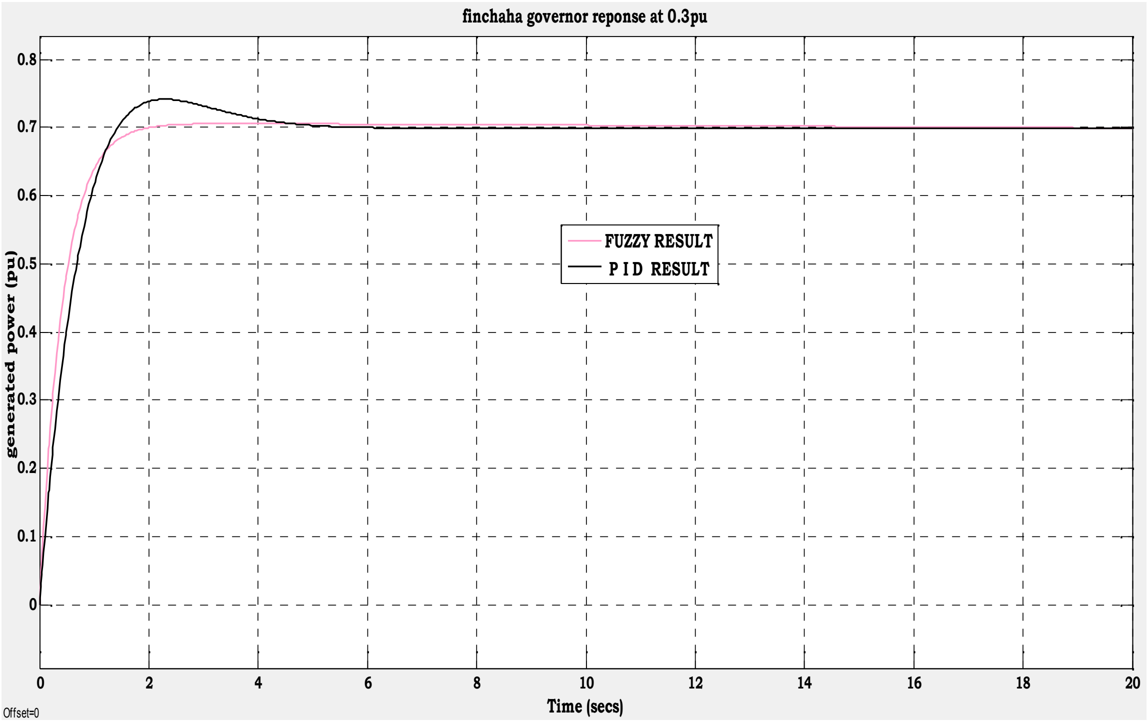


Figure 5:4 Results of One Percent Drops in Frequency

The result is an increase in power production of 0.2pu, equivalent to 6.82MW the rated turbine of unit 34.1MW, the value corresponds well to theory, the result of graph show that the fuzzy logic controller is good transient response compared to PID controller, the control characterics is shown in table (5-2).

Table 5-2 Performance of Controller for One Percent Drop of Frequency

Control type	Settling time	Overshoot	Rise time	Slew rate
PID controller	**4.21sec**	**6.250%**	**960.998ms**	**543.205V/ks**
Fuzzy logic controller	**3.02sec**	**0.505%**	**912.62ms**	**612.412V/ks**

B. Power Control Mode

In the power control mode, the governor controls the opening according to power signals, leading the power output to achieve the given value, is used to keep the power of a unit equal to a set value. The unit generated the power reference this implies the power generated cannot vary with load demand or didn't depend on frequency variation if the system is in power control mode, and so generated power is always reference power signal. The result of a fuzzy logic controller and PID controller for power control at reference power of 0.9pu or 30.69MW is given for unit one of Finchaha hydro power plant is given by an operator for a unit.

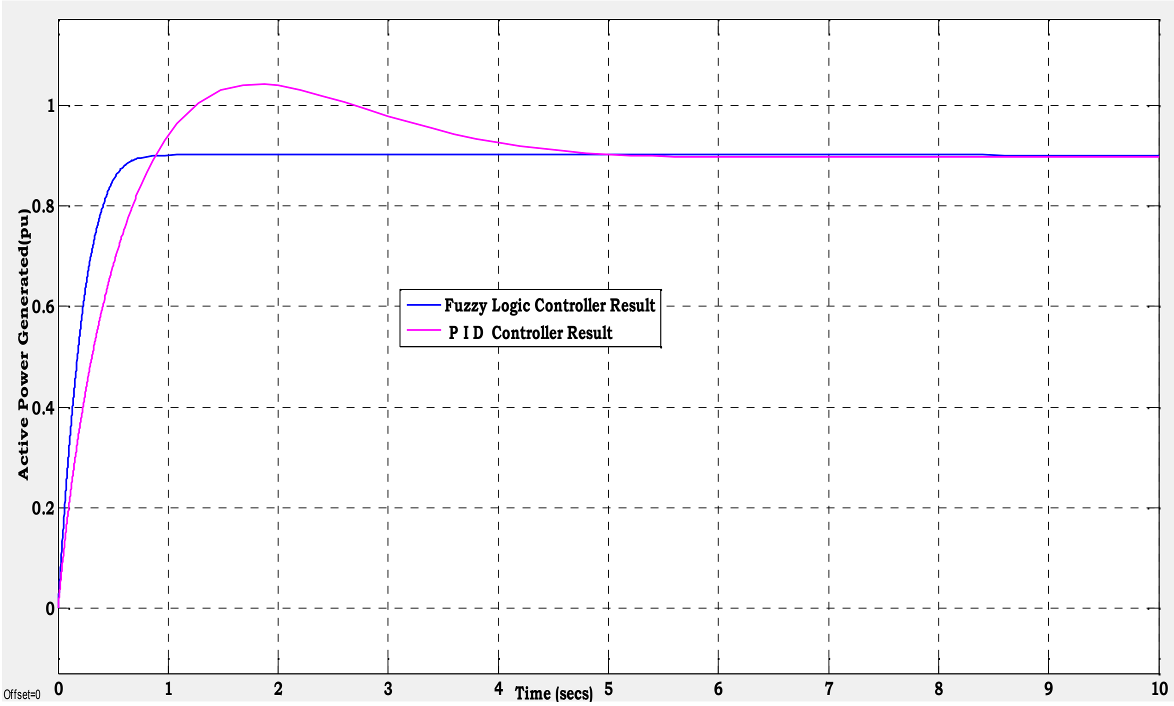


Figure 5:5 Result of Power Control at 0.9 Value of Power Input

From the graph in fig (5:5) fuzzy logic controller was showed performance difference when compared with existed PID controller, the performance evaluation is shown in table (5-3) is comparison of fuzzy logic controller and PID controller.

Table 5-3 Performance of Controller for Power Control at 0.9pu

Control type	Settling time	Overshoot	Rise time
PID controller	4.12sec	24.107%	546.733ms
Fuzzy logic controller	1.05sec	0.897%	340.075ms

From table (5-5) fuzzy logic controllers is less percentage of overshot, less settling time and less rise time when compared with existed PID controller , when the system of unit on power control mode

Power control mode at reference value of 0.5pu

For reference value of 0.5pu, the power generated must follow the reference signal as shown in fig (5-6)

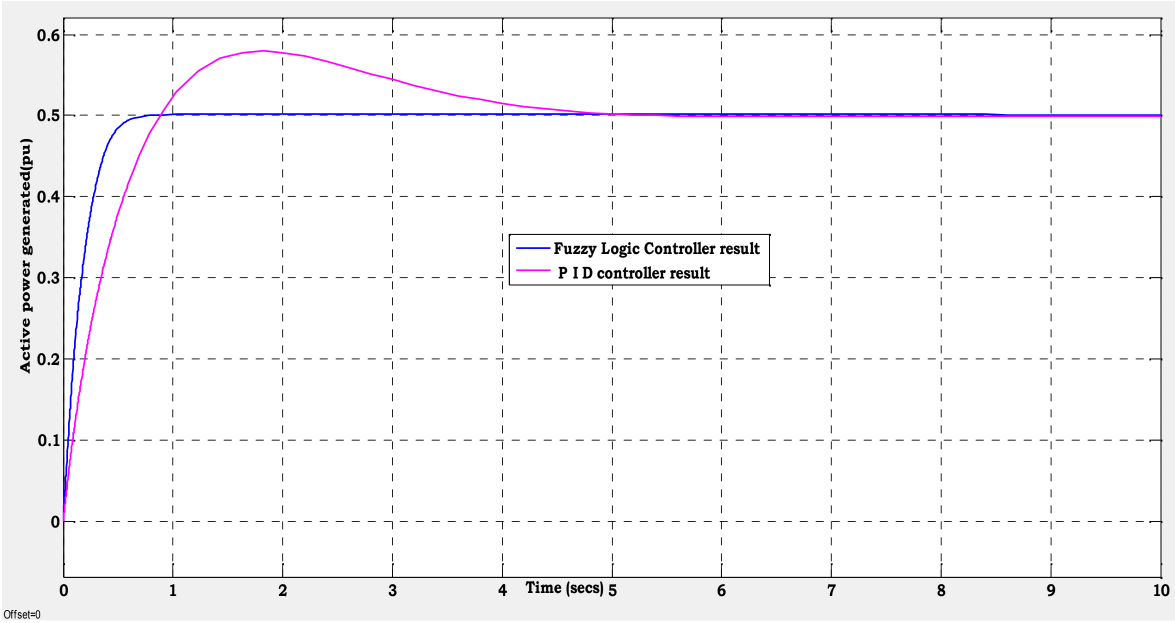


Figure 5:6 Graph of power control at 0.5pu

For small power reference the response of hydro power unit is better than high power reference, fuzzy logic is give fast response in power control mode

Table 5-4 Time-response specifications of power control at 0.5pu

Control type	Settling time	Overshoot	Rise time
PID controller	4.12sec	26.471%	512.854ms
Fuzzy logic controller	1.05sec	0.773%	316.307ms

5.2.2 Machine Operating In an Isolated Mode (Island Operation)

The overall interconnected Matlab Simulink model in figure (5-7) and (5-8) is frequency regulated unit one of Finchaha hydro power in island mode. It is a single machine, single load environment, existing PID controller parameter and designed fuzzy logic controller for Finchaha hydro power plants.

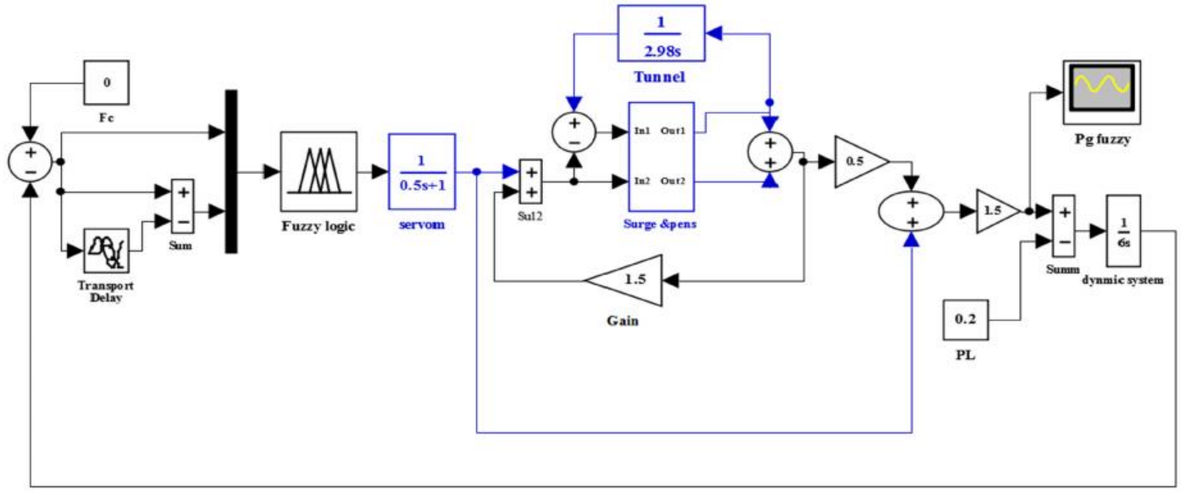


Figure 5:7 Matlab Simulink Modeled of Isolated Fuzzy Logic controller

Matlab Simulink model for isolated by using existing PID controller as shown bellow

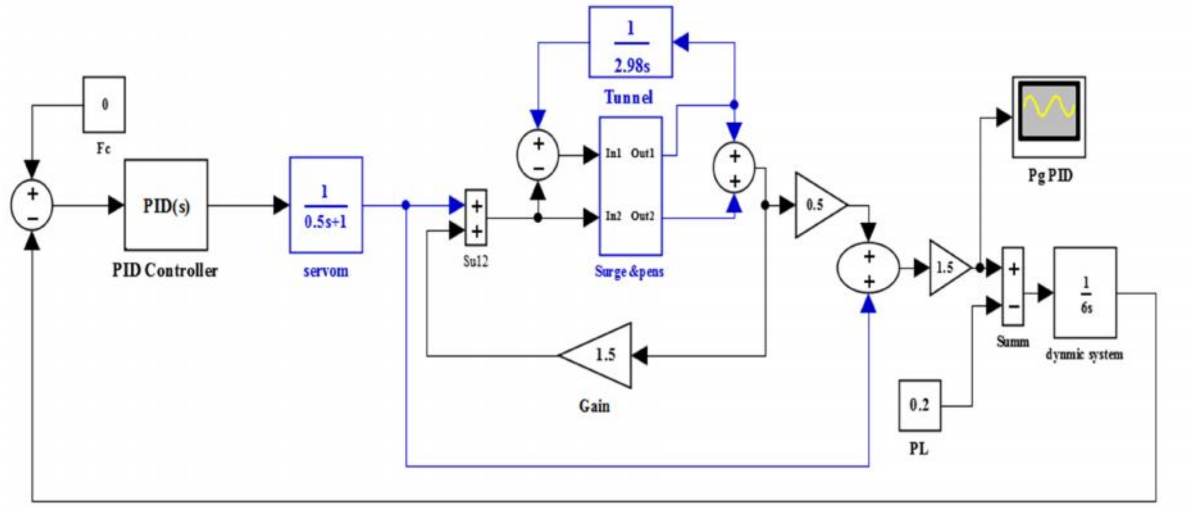


Figure 5:8 Matlab Simulink Model of Isolated PID controller

Input for isolated operation

- Reference frequency deviation

Output for isolated operation

- Generated power deviation

Matlab Simulink model of fig (5:7) & fig (5:8) the generated power is shown at different cases

1. When 0.2 Power of load is added to the Isolated Network

Then the change in power generated is equal with the change in load power added to the system and the frequency of the system is decrease, simulation in fig (5.9) show that the power generated equal to 0.2 per unit value

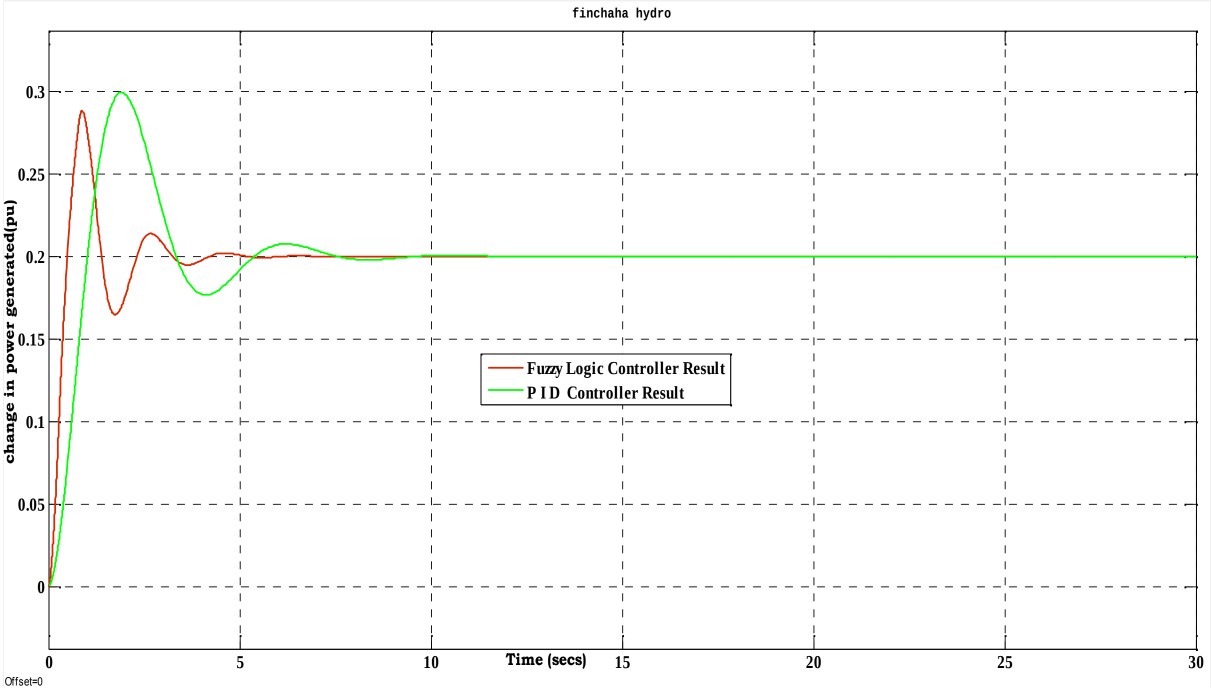


Figure 5:9 Result of fuzzy and PID isolated increase by load 0.2pu

From the fig (5:9) fuzzy logic controller more robust and better transient response than PID controller, for the value of twenty percent load is added to the system, then the change in power generated is increased by twenty percent in order to synchronize the system i.e. Power generated must be equal with power demand.

The system is slowly increase in the power generation at start up, reach the maximum point At 0.876 second value reach peak value at 0.288pu and, decline to the peak value 0.202pu at 4.59, for fuzzy logic controller, the stable the system to 0.2pu.

For PID controller the systems start operation increase to peak value of 0.299pu at 1.99secs, and decline to 0.2006pu at 10.43secs, the control characterics is shown in table (5-5).

Table 5-5 Time Response Specification under 0.2pu power is added

Control type	Settling time	Overshoot	Rise time	Preshoot
PID controller	**5.732sec**	**50.758%**	**696.834ms**	**0.758%**
Fuzzy logic controller	**4.99 sec**	**44.203%**	**340.104ms**	**0.725%**

2. When 0.1pu load is added to the system

At ten percent load is added to the system network, the frequency of system is decreased to normalize frequency change at zero, the Finchaha hydro generation unit generate 10 percent of rated power and, the graph result is shown in fig(5:10).

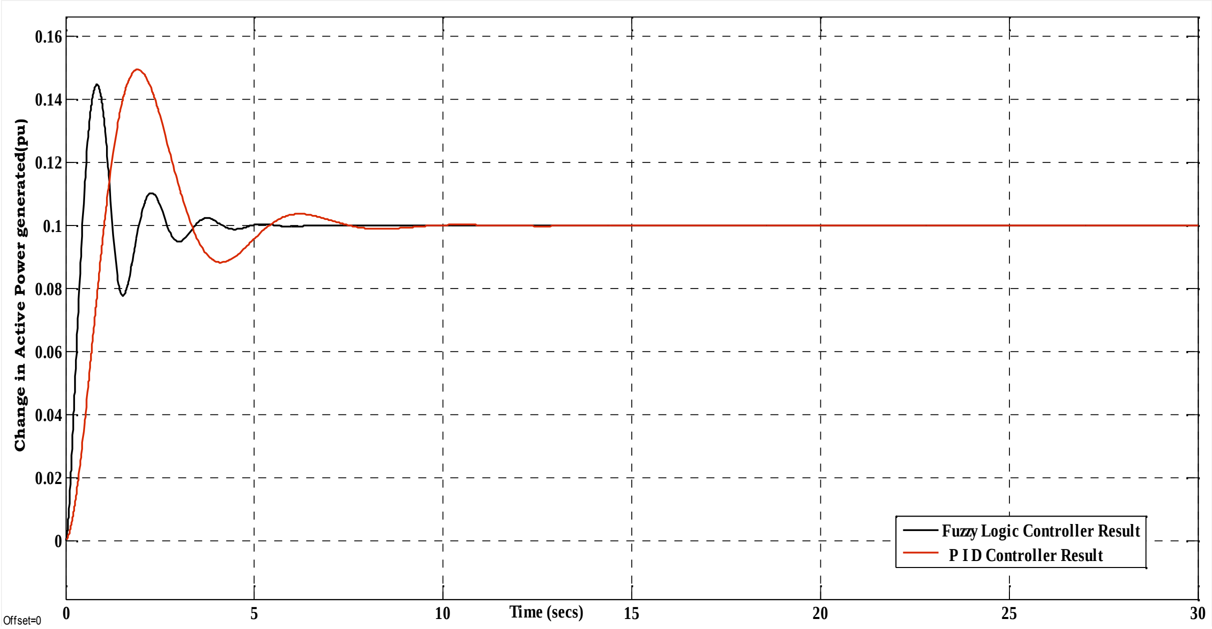


Figure 5:10 Graph power generated at 0.1pu load added

The system time response control specification is as shown in table (5-6).system is improved using fuzzy logic controller

Table 5-6 Time-response specifications of 0.1pu load added

Control type	Settling time	Overshoot	Rise time
PID controller	**5.65sec**	**50.758%**	**696.845ms**
Fuzzy logic controller	**4.99secs**	**44.203%**	**312.423ms**

3. When 0.3pu load is added to isolated unit network

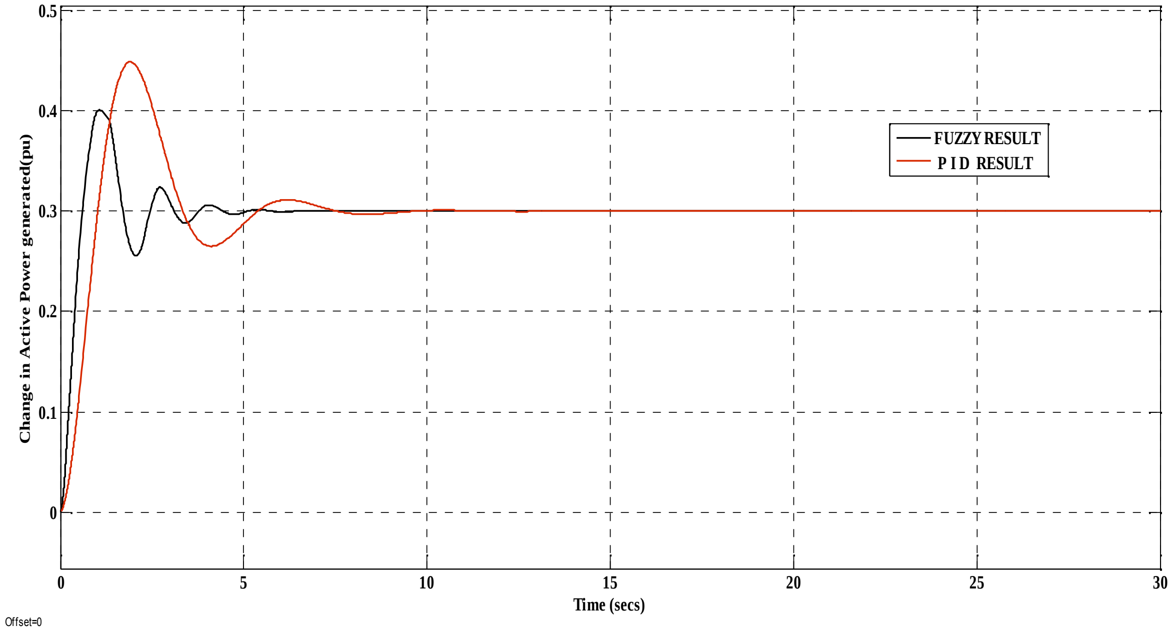


Figure 5:11 Graph of 0.3pu load added to the system

4. Load rejection at 0.2pu power is reduced from load)

Load rejection in an electric power system means a sudden load trip in the system, which causes the generation side to be over frequency, fig(5.12) show illustrates that the comparison of fuzzy logic controller and existing controller under twenty percent load rejection.

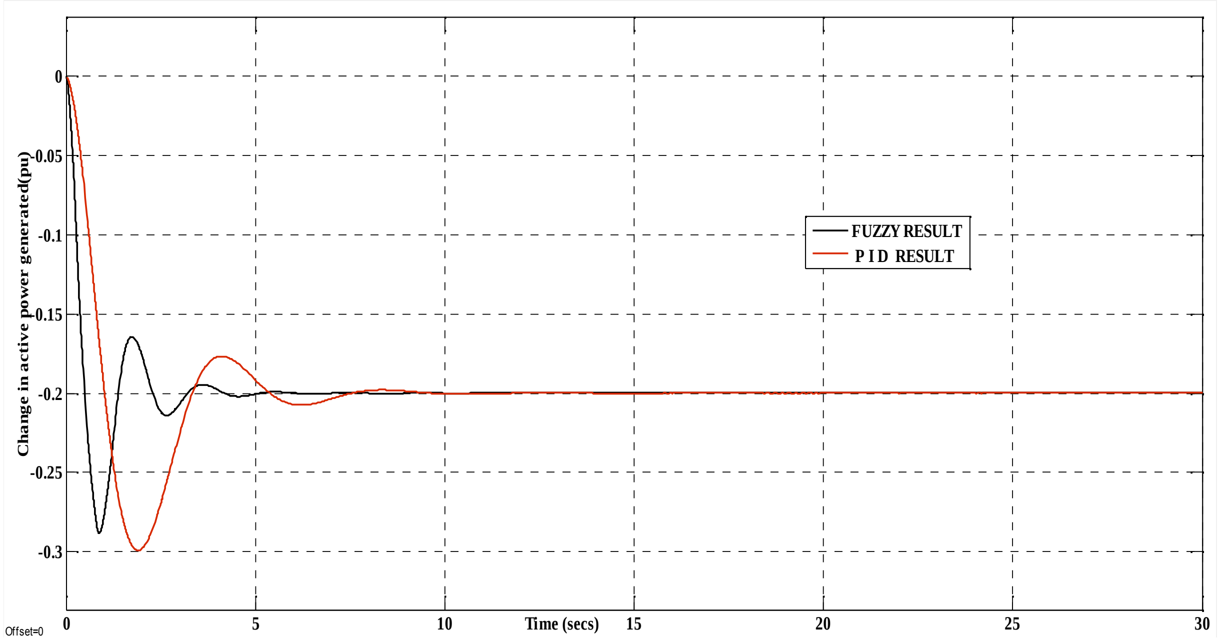


Figure 5:12 Result of fuzzy and PID isolated removed by load 0.2pu

For two percent load is removed from the system the time control specification is shown in table below, fuzzy logic controller small settling time.

Table 5-7 Steady State Performance under 0.2pu Power is Removed

Control type	Settling time	Undershoot	Fall time
PID controller	**4.285sec**	**50.758%**	**696.832msec**
Fuzzy logic controller	**2.03sec**	**44.203%**	**339.284msec**

5.When 0.1PL drop from the system

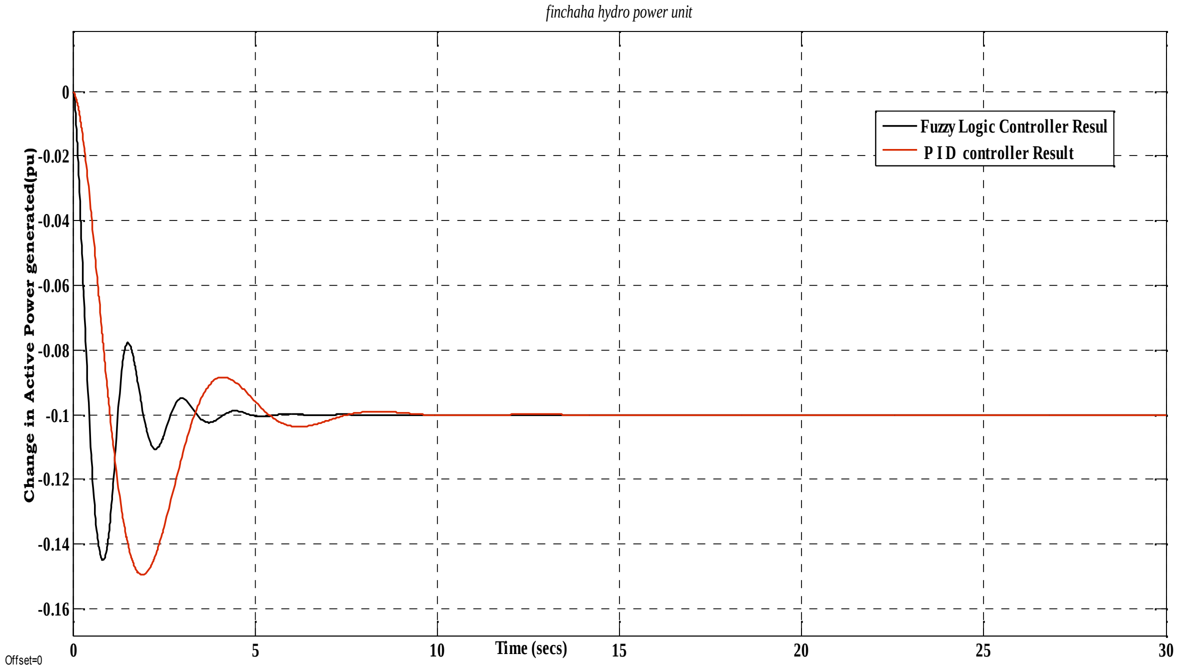


Figure 5:13 Graph of 0.1pu load drop

Table 5-8 Time-response specifications of 0.1pu load dropped

Control type	**Settling time**	**Undershoot**	**Fall time**
PID controller	**8.212Sec**	**50.758%**	**696.819ms**
Fuzzy logic controller	**4.852sec**	**46.321%**	**306.479ms**

6.Isolated operation when 0.3pu load is droop from network

The unit produce 0.3pu power in order to equalize the power generated and power demand , to make the system frequency at nominal value .from the graph bellow, the system is decrease the power generated by 0.3pu, the system is fluctuate up to 0.3pu value , then stabilize at some point.

T= 7.027secs for fuzzy logic controller and T = 10.159sec for PID controller

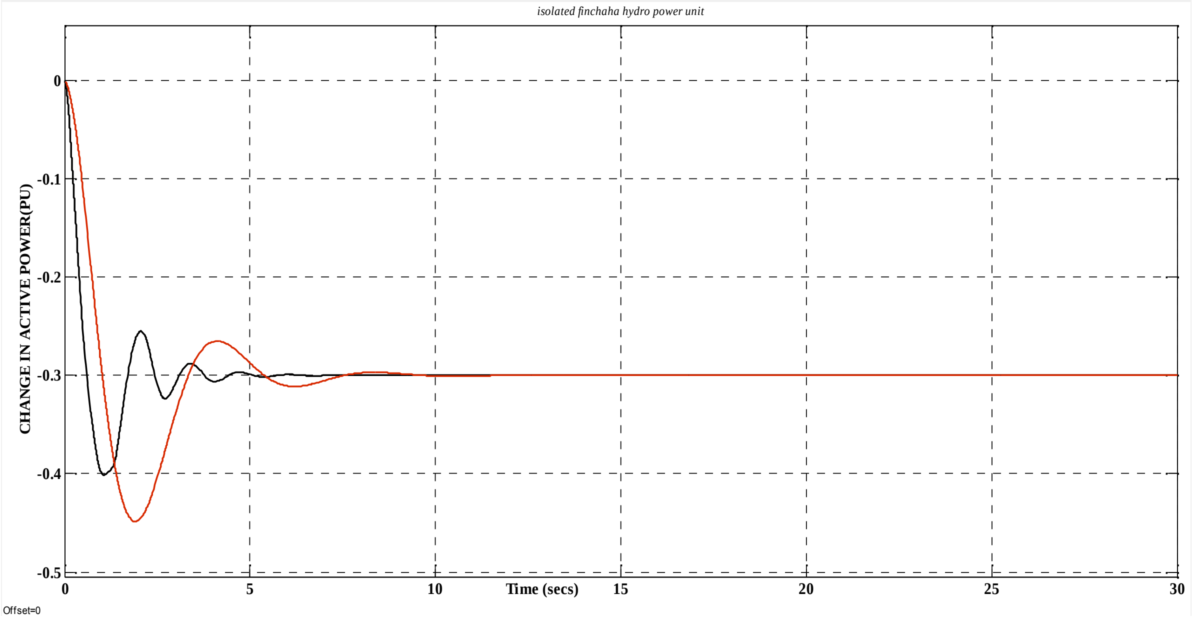


Figure 5:14 Thirty percent load drop isolated operation

Table 5-9 Time-response specifications of 0.3pu load dropped

Control type	Settling time	Undershoot	Fall time
With Pid controller	**6.02sec**	**50.758%**	**696.825ms**
Fuzzy logic controller	**4.852sec**	**34.459%**	**415.848ms**

5.3 Discussion

As main goal of a control system is to get a desired output of the system and to minimize or diminish error between set point given to controller and feedback in the above, all result I was got the different graph at a different set point.

The discussion part is divided in two main parts

5.3.1Grid Connected Operation

Simulation performed in grid connected mode can be seen in the figure (5:3), fig (5:4) and fig (5:5).for frequency and power control respectively at set point value defined, both simulations show power regulation as the frequency droops and increase 0.01pu.

The controller supposed to, increase the production as the frequency drops and decrease power output as the frequency decreases.

Comparing the two controllers, they both behave similar inform of power production value during governing action, and final steady state values. the controlled behave accordingly to theory, and fuzzy logic controller is better transient response and robust than existing PID controller for both power control and frequency of grid connected operation as shown in table (5.1), table (5.2) and table (5.3).

5.3.2 Isolated Operation

The model responded as expected from theory. When the load demand drops, an increase in frequency occurs. Both simulation result responded by changing the guide vane opening (y) and reducing the hydraulic force to the turbine wheel.by doing so, the system speed is getting regulated back to its point of reference, as system speed is proportional to the system frequency: $n = \frac{120f}{p}$

The response can be linked to system frequency and turbine and generator speed. This tendency of regulation can be seen in all simulations done in isolated operation with frequency control.

Two simulation are done with power load drooped and power load added as shown in figure from fig (5.9) to fig (5.14), the model behave as expected; they gave the same result for existing PID controller and designed fuzzy logic controller, but with different transient response, as per table from (5.4) to table (5.5) the simulation result show that fuzzy logic controller is more robust and better transient response when compared with existing PID controller, that is fuzzy logic controller less overshot, fewer settling time and less rise time when compared with existing pid controller.

From all power control is good transient response compared with frequency control of Finchaha hydro power plant.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Introduction

In this chapter writing the conclusion from the result got and writing the recommendation

6.2 Conclusion

This thesis has presented a fuzzy logic controller to control frequency and active power for a Finchaha hydro power plant unit. To achieve this possibility of implementation of digital systems for monitoring and control for power in Finchaha hydro power plant was discussed. Dynamic of Hydraulic system (Tunnel, Surge tank and Penstock), Mechanical System (Linearized turbine) and Electrical system were firstly modeled. The individual component of Finchaha hydro power plant modeled to form hydro power plant and simulated for two operating condition grid connected and isolated operation. For grid connected operation simulate two types of control power and frequency and for isolated operation control frequency of the system using existing conventional controller.

In this work intelligent fuzzy logic controller controls frequency and active power generated under the system is in isolated operation and Grid connected operation, and the result of simulation is compared with existing PID controller. The control performance of a fuzzy logic controller is superior to existing conventional PID controller

The simulation result show that the overall system output performance can be improved using the proposed fuzzy logic governor, the fuzzy logic controller resulted less percentage overshoot (0.505%), less settling time (2.8sec) and less rise time (439.153ms) as compared to 17.059%, 5.81sec and 717.643ms for pid controller under grid operation, for Isolated operation to fuzzy logic controller resulted less percentage overshoot (44.205%), less settling time (4.99sec) and less rise time (312.423ms) as compared to 50.758%,5.65sec and 696.845ms as compared to existing pid controller

With the proposed control technique, Finchaha hydro power plants can contribute significantly to national grid stability through the capabilities governing system using fuzzy logic control.

6.3 Recommendation

As it is shown in the result discussion part, the designed intelligent fuzzy logic control of Finchaha hydro power plant unit have shown a better result as compared to that of the conventional once. This is already validated by simulation only. So any one can take this design and it can be implemented by prototypes.

6.4 Future works

As future works

1. Change controller by integrating fuzzy logic with neural networks for further improvements in the performance of the hydro power plants
2. Stability of hydropower system is depend on active power and reactive power, by considering frequency and voltage respectively at admissible range , active power is controlled in this thesis , Finchaha hydro power plant can be made more accurate and attractive by introducing voltage controller in excitation system.

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APPENDICES A

Parameter value of Finchaha hydro power unit

Parameter value of Pelton Turbine	
Type of turbine	Impulse
Diameter of turbine	2.5m
The equivalent cross-section of the penstock	$3.46 m^2$
Maximum output	4*34.1MW
Maximum discharge	$4*7.42 m^3/s$
Turbine efficiency (η)	0.91
Nominal rotational speed of the turbine	500rpm
Net head	517m
Maximum gross head	594m
Parameter value of Penstock	
Number	1
Diameter	2.1m
Length	558m
Parameter value of Tunnel	
Length	3523m
Diameter	3m
Parameter value of Surge shaft	
Diameter	7m
Height	50m
Parameter value Servomotor	
Servo-motor time Ta	**0.5**

Parameter value of Governor

No	Sign	Units/description	Frequency control	Parallel power control
1	K_P		6.0	3.0
2	K_I	Sec^{-1}	0.2	0.1
3	K_D	Sec	20	0.5
4	e_p	%	1.0	5.0