HAWASSA UNIVERSITY
HAWASSA INSTITUTE OF TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

FREQUENCY CONTROL OF STANDALONE MICRO HYDRO POWER PLANT BASED ON FLOW VALVE CONTROL WITH NEURO FUZZY CONTROLLER

(CASE STUDY:-KERAMO IN BENSA WOREDA)

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN POWER SYSTEM AND ENERGY ENGINEERING

BY
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A thesis submitted to Hawassa University, institute of technology, school of graduate studies, for the partial fulfillment of the requirement for the degree of Master of Science in power system and energy engineering.

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This is to certify that the thesis entitled “FREQUENCY CONTROL OF STANDALONE MICRO HYDRO POWER PLANT BASED ON FLOW VALVE CONTROL WITH NEURO FUZZY CONTROLLER (CASE STUDY:-KERAMO IN BENSA WOREDA)” submitted in partial fulfillment of the requirements for the degree of Masters of Science in Electrical Engineering with specialization in Power system and Energy Engineering, The Graduate Program of the Department of Electrical and Computer Engineering, and has been carried out by Amsale Hankalo ID No- GPPoSyR/005/12 under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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We the under signed Board of examiners of the final open defense by Amsale Hankalo have read and evaluated his thesis entitled “FREQUENCY CONTROL OF STANDALONE MICRO HYDRO POWER PLANT BASED ON FLOW VALVE CONTROL WITH NEURO FUZZY CONTROLLER (CASE STUDY:-KERAMO IN BENSA WOREDA)” and examined the candidate. This is therefore, to certify that the thesis has been accepted in partial fulfilment of the requirements for the degree.

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I, the undersigned, declare that this thesis is my original work, has not been presented for fulfillment of a degree or otherwise in this or any other university, and all sources and materials used for the thesis have been acknowledged. All Advisors' comments are duly incorporated.

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Place: Hawassa, Ethiopia

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

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Abstract

This thesis presents the frequency control of micro hydro power plant based on flow valve control with neuro-fuzzy controller. This was aimed at reducing the frequency deviations which occur during micro hydro power generation. Any mismatch between generation and demand causes the system frequency to deviate from its nominal value. Changes in linked loads are the source of this. As a result, the frequency of the system will fluctuate frequently, which could damage of Generator and electrical equipments.

In this thesis frequency control of standalone micro hydro power plant based on flow valve control with neuro-fuzzy controller designed and simulated by MATLAB/Simulink software. One of the main problems with the synchronous generator of the Keramo Micro-hydro Power Plant (MHPP) is frequency instability. The most often used techniques for MHPP frequency control are servomotor as Flow Control Valve (FCV) with neuro-fuzzy Control (NFC).

A comparison of PID(proportional, integral and derivative) and ANFIS(adaptive neural fuzzy inference system) controllers had been performed under different values of frequency deviations and parameter variations.

It is observed from the simulation results of frequency deviation, gave a response with a settling time of 7.25sec, frequency deviation peak overshoot of 0 p.u, and peak undershoot of 1.8% or 0.018 p.u and based on PID controller gave a response with a settling time of 27.45sec, frequency deviation peak overshoot of 0.18% or 0.0018 p.u, and peak undershoot of 5.25% or 0.0525 p.u. The simulation results show that the ANFIS controller performs better than compared to the PID. The neuro-fuzzy controller not only enhanced performance but also decreased its dependence on the expert system through the fuzzy inference system (FIS).

Key words: - micro hydro power, servomotor, neuro-fuzzy controller, fuzzy logic controller

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ACRONYM

MHPP	micro hydro power plant
KWs	kilowatts
FCV	Flow control valve
ANFIS	Artificial neutral fuzzy inference system
PID	Proportional, integral, derivative
FLC	Fuzzy logic controller
NFC	Neuro-fuzzy controller
SHPP	Small hydro power plant
ANN	Artificial neutral network
HZ	Herz
AGC	Automatic generation control
Tw	water starting time of turbine
D	Damping coefficient
MWs	Megawatts
H	Head
Q	Flow rate
AVR	Automatic voltage regulator
Tm	Mechanical time constant
Te	Electrical time constant
∆F	Frequency deviation
Ta	acceleration torque
MF	Membership functions

CHAPTER ONE

INTRODCTION

1.1 BACKGROUND

Energy is an essential for any country's social and economic development. The existence of an energy system enhances the quality of life for everyone in a community. Additionally, it allows a variety of beneficial actions possible that would be impossible otherwise. Energy shortage is frequently a challenge to achieving a better standard of living in developing countries. Energy is a key requirement in developing nations like Ethiopia for industrialization, improving the standard of living, and economic stability.

Both non-renewable and renewable energy sources are used in power generation. However, because it is a safe and sustainable and environment form of energy, renewable energy is gaining popularity. Renewable energy sources that are available in Ethiopia include solar, wind, biomass, geothermal, and hydropower sources. Hydropower is the most important energy source among them. However, the government's need for energy is not fully satisfied. Specifically those living in Ethiopia's remote regions lack access to electricity. This is based on the fact that extending the main electricity grid to areas lacking electricity is hardly economically neither sustainable nor practical due to these areas' remote areas, low power demand, and inadequate EEP power source [1].

Micro hydro power plants can produce electricity from the water in small rivers. In developing countries, small hydro power is essential to the electrification of remote and isolated areas. There are rivers in Ethiopia's remote areas that are only utilized for agricultural purposes, but these rivers can also be used for small hydropower generation. Mini hydropower plants, micro hydropower plants, and Pico hydropower plants are examples of small hydro generation. Small hydro has a generating capacity of up to 10 megawatts (MWs). The Micro Hydro is often scaled at less than 100 KWs, whereas the Mini Hydro is typically scaled at less than 1000 KWs [2].

Standalone One of the most useful and inexpensive renewable energy sources that can overcome the gap between demand and supply of energy in remote regions is micro-hydro power [3]. In general, communities with run-off rivers will construct micro hydro power plants. Furthermore, MHPP play an essential part in increasing rural electrification in underdeveloped countries [4] while being frequently cut off from grid networks. A widely used technique to maintain frequency stability in Keramo MHPP is to use flow valve control or stepper motors. A flow valve control regulates the flow of water into the turbine to spin the generator. The frequency produced by the generator is directly proportional to the turbine speed [2]. The water flow is controlled by opening the gate valve on the pressure pipe with a stepping motor. To get the proper angle of the gate opening according to the system requirements, we need directed toward alter the rotation angle of the servomotor between the actual value and the frequency setting. Settings are made to minimize the error. This error value and motor response must be minimized by adding the appropriate controller.

1.2 Problem Statement

The issue of frequency reliability is a great concern in Ethiopia. The keramo micro hydropower plant does not resolve the mismatch between load and generation of power caused as a result of increasing demand of hydro power energy and decreasing the level of water from reservoir the time of winter or dry season. To match the supply of electricity produced to the demand, keramo micro-hydro systems use existing base case flow control valves by using servomotor that control the water's flow through the turbines. The results of an analysis of the response frequency control of a standalone Keramo MH power plant based on existing case of a FVC show an increasing frequency deviation with decreasing servomotor performance of the MHPP, which results in a very large frequency deviation. One of the challenges of connected hydropower plants is maintaining their nominal frequency. For a keramo hydropower plant, the primary concern is power generation as changes in load cause a steady-state frequency change depending upon the frequency droop characteristics as well as the sensitivity of the load frequency. Abrupt change in load occurs in any load system because power demand cannot be kept constant in any area. This may vary from time to time. And this abrupt change in load directly has the influence on frequency. Frequency has a particular range in a keramo micro hydro power generation system. Normally this acceptable range is in between -0.05pu (47.5

Hz) to 0.05pu (52.5 Hz) and the expected value is 50Hz. If the value of the frequency goes beyond 52.5 Hz or below 47.5 Hz will cause system component to damage. PID controller is applied to regulate the based on FCV of the hydropower plant. It usually takes in a slow response which makes the system unstable. Therefore, overcome system frequency problems in micro hydro power systems, in this thesis based on FCV with neuro-fuzzy controller is designed**.** The proposed this thesis neuro-fuzzy controller technique reduces frequency deviation, increases system performances and provides a rapid time response to stable steady state error compared to existing case.

1.3 Objectives of the Thesis

1.3.1 General Objective

The general objective of this thesis is to design and simulate Frequency Control of standalone Micro hydro Power Plant Based on Flow Valve Control with neuro-fuzzy Controller.

1.3.2 Specific Objective

The specific objectives of the thesis are:-

- ➢ To find out the main problem of existing system keramo micro hydro power plant.
- ➢ To model standalone MHPP for frequency control.
- ➢ To design FCV with neuro-fuzzy controller for standalone MHPP.
- ➢ To compare the Simulink result of existing system and existing system with neuro-fuzzy controller of standalone MHPP.

1.4 Methodology

To accomplish this thesis work successfully different methodologies have been used as follows:

➢ Literature Review: Published materials about micro hydro power system frequency stability and its controller and frequency stabilizer by using fuzzy logic with PID controller based automatic generation control (AGC) and servomotor with fuzzy have been studied.

➢ Data collection: The data required for keramo micro hydro power systems have been collected from the stakeholder or domestic appliances.

- Data analysis: The keramo hydro power generation system has been analyzed from the collected data using Matlab/Simulink.
- Design and simulation: The keramo micro hydro power frequency control system have been modeled and the simulation have been carried out using Matlab/Simulink.
- Conclusion and recommendations were made based on simulation results.

1.5 Scope of study

This thesis presents frequency control of standalone micro hydropower systems based on flow valve control with neuro fuzzy controller. The simulations have been carried out using MATLAB/SIMULINK software. From the simulation results, comparisons have been made between existing servomotors with neuro-fuzzy controller. As a limitation this thesis work has no hardware implementation and the load disturbances considered are deterministic.

1.6 Organization of the Thesis

This thesis work consists of five chapters. Based on this, chapter one explained the introduction of the thesis, statement of the problem and objective of the study. Chapter two discussed different literatures reviews about the hydropower generation control system. Chapter three discussed Modeling of micro hydro power plant, existing micro hydro power plant based on servomotor or flow control valve and servomotor with neuro-fuzzy controller. Chapter four presented simulation results and discussions by comparing and contrasting of existing system without controller and proposed ANFIS controller.

Finally, the conclusions, recommendation for future work were presented in chapter five.

CHAPTER TWO

LITERATURE REVIEWS

2.1 Introductio*n*

This chapter discusses the generation of micro-hydro power plants, the development of micro hydropower in Ethiopia, and the classification of micro-hydropower plants based to different criteria. This chapter also covers the main parts of MHPPs, frequency control methods for MHPPs, and an extensive model of a micro hydropower plant.

2.2 Micro-Hydro Power Plant

A micro-hydropower system is a small system with capacities of 5-100 KW that can be used to power local mini-grids and small businesses [1]. A "run-of-river design" is the core of the most basic micro hydropower plant, which means it lacks water storage capacity. It might only be able to store a certain quantity of water or it might only be available to produce power when the water is flowing. Despite the fact that these small generators have long been in use, primarily for their mechanical power, recent increases in the cost of electricity and incentive schemes have made the development and installation of micro-hydro power plants a lot more attractive. Micro hydropower plants are the greatest options for electrifying remote communities when connecting to the national grid might not be cost-effective and where an ongoing flow is available [4]. Micro hydropower plants are similar operational principle to large or small hydropower plants, with the exception of their power rating. As a case study, the selection and design of system components uses the same mathematical equations, types of material units, and operating principles as conventional/large hydro power plants [5].

The geography of Ethiopia, which includes many rivers and streams and mountainous regions, makes it suitable for MHPP development. 100 MW is the projected in general potential for micro hydropower (less than 100 kW in size). Only 10 out of every 100 homes (HHs) in Ethiopia, where 85% of the population resides in rural areas, have access to electricity. Technically and financially, expanding the national grid to remote rural villages doesn't seem viable. As a result, micro hydropower facilities may be essential to the electrification of rural areas without access to the grid [1].

Table 2.1 Classification of hydro-electric power plants

TYPE	**CAPACITY**
Large-hydro	More than 100 MW and usually feeding into a large electricity grid
Medium-hydro	15 MW to 100 MW; usually feeding a grid
Small-hydro	1 MW to 15 MW; usually feeding into a grid
Mini-hydro	100 kW to 1 MW; either stand-alone schemes or more often feeding into the grid
Micro-hydro	5 kW to 100 kW; usually provided power for a small community or rural industry in remote areas away from the grid
Pico-hydro	100 W to 5 Kw

2.3 Principal Components of Micro-Hydropower Plant

The principal components of MHPP can be grouped into civil work components and electromechanical components, as shown in Figure 2.1 below. Each component is further classified into different parts which are presented in detail in the following subsections.

2.3.1 Civil Work Components

Intake: is the main method of moving water from the water source in the required amount to the MHPP canals [6]. The trash rack, gate, and intake usually consist of steel, wood, or reinforced concrete.

Canal: - It transports the water to the powerhouse in constructions where the powerhouse is downstream from the intake but not immediately adjacent to it.

Forebay Tank: - The forebay tank, from which the penstock pipe pulls water, is essentially a pool near the headrace canal's terminal. The primary function of the forebay is to reduce air entrance into the penstock pipe, which could otherwise result in cavitation (explosion of trapped air particles under high pressure) in the turbine [7]. Additionally, the forebay's water level must be measured because it influences the micro hydro power plant's engaged head.

A forebay again requires two sets of additional construction. As the water speed is lowered at the forebay, it can cause sedimentation of particles, which requires the construction of spillway. Similarly, installation of trash racks to filter the fine sediments might be required before the water from the forebay gets inside the penstock pipes. Figure 2.1 illustrates a typical fore bay tank in MHPP.

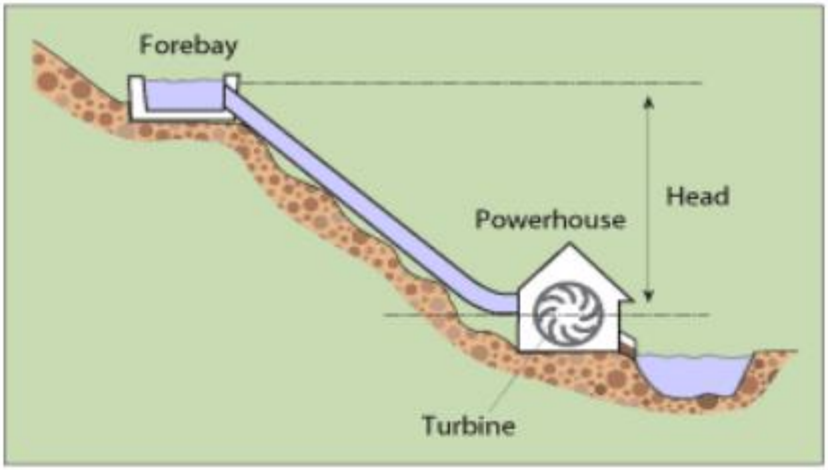


Figure 2.1: Design of a typical forebay[8]

A penstock:- This is pipe that conveys water under high pressure to the turbine wire mesh of reasonable strength should be put in front of the penstock to sieve unsettled sand. It can be installed above/ below the ground excessive template expansion of joints. Gates and valves can be incorporated at the end of the penstock.

A Power House”-This serves as an Engine room. It protects the turbine, generator and other electrical/machinery equipment. It could also have a workshop/office/sanitary and other facilitates

Tail Race:-This is a short, open canal that leads water from power course back to the stream.

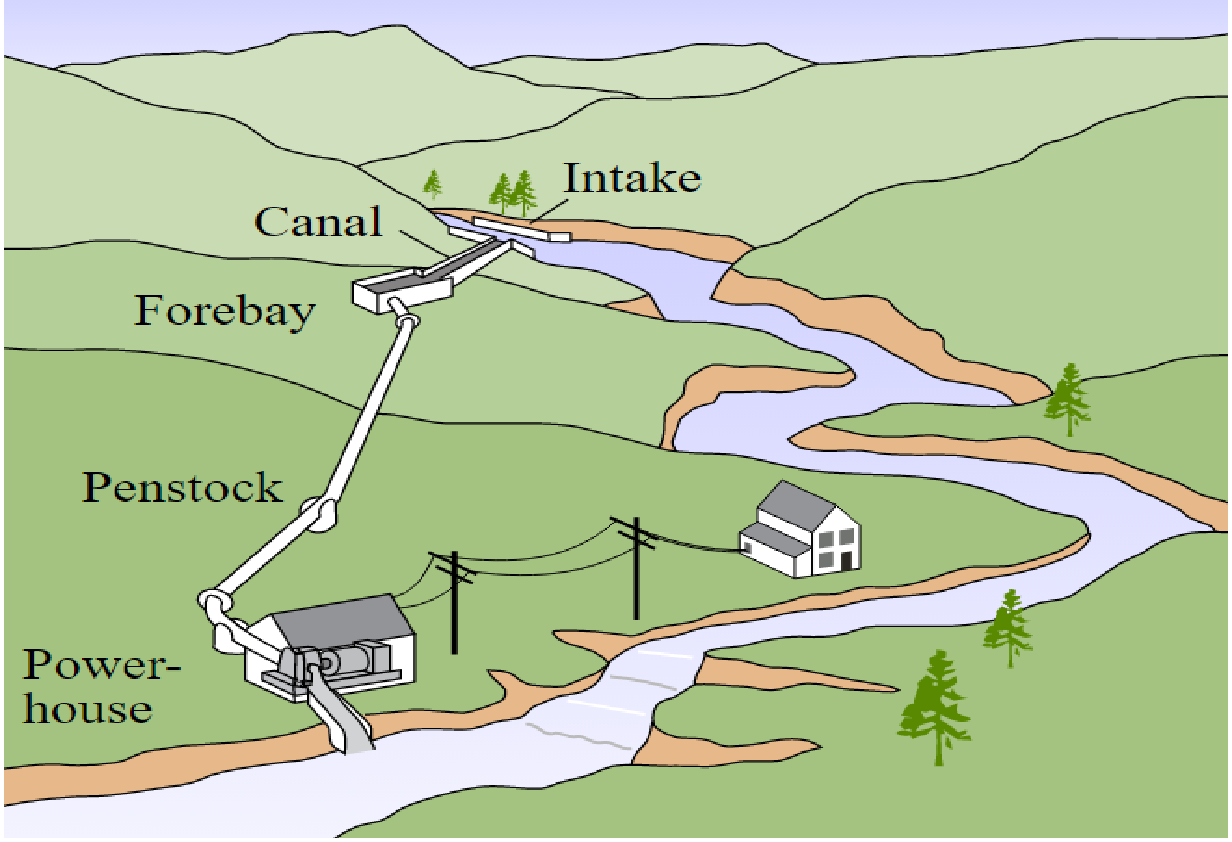


Figure 2.2 Micro hydro-power system [9]

2.3.2 Electro Mechanical Components

Electro Mechanical Components is the powerhouse components of Micro-Hydropower and they are used to convert mechanical energy of water into electrical energy. The principal electro mechanical components of a micro hydro plant are the turbine, valve, generator and drive systems.

2.3.2.1 Turbine

Hydroelectric power is an environmentally friendly and efficient way of supplying the neighboring area with electricity for daily life. Engineers can create mechanisms and environments in which water naturally produces energy, and transfer that energy to generators to produce electricity. One of his methods of generating this water energy is through the use of turbines. A turbine is a mechanism that contains flowing water and contains a wheel or rotor that turns when water hits one of the blades. The faster the water flows, the higher the wheel or rotor frequency. This rotation drives a shaft connected to a generator, which ultimately produces electricity. There are guide vanes and willow gates that can control the flow of water impinging on the rotor blades, ultimately controlling the power output that controls the efficiency of the turbine. All components of hydroelectric power plants revolve around turbines. The turbine converts the hydraulic energy of the water flowing out of the reservoir into mechanical wave energy for the generator. There are various types of water wheels. It can also be used in small hydroelectric power plants. Turbine selection depends on factors such as water column, flow [10]. Turbines are classified into impulse turbines and reaction turbines according to the difference in energy absorption. Axial flow turbine, radial flow turbine, tangential flow turbine, mixed flow turbine, depending on the direction of water flow. Low specific speed turbine, medium specific speed turbine, high specific speed turbine, depending on the specific speed of the turbine. It is also classified into high head and low water flow, medium head and medium flow, low head and high flow according to the head and available water **quality.**

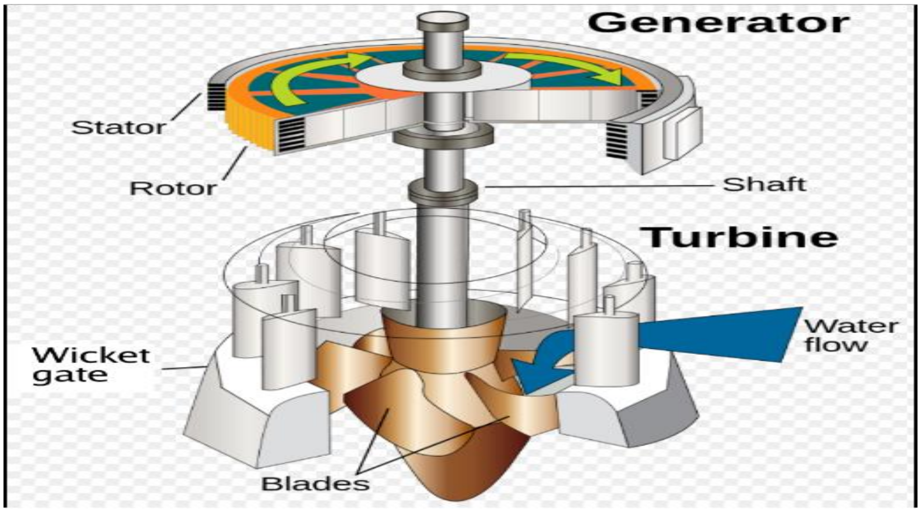


Figure 2.3 Kaplan turbine and electrical generator cur-away view [11]

I, Impulse turbine: As the watery passes through the rotor of the machine, the pressure of the fluid does not change. The total head of entering fluid is transformed into a great velocity head at the exit of the supply nozzle. An example of an impulse turbine is the Pelton turbine.

II, Reaction turbine: As the fluid flows through the rotor of the machine, the pressure of the fluid changes. The change in velocity of the fluid and its drop in pressure produce a reaction on the turbine blades. This is understood to be the source of the name reaction turbine. The Francis and Kaplan turbines are examples of reaction turbines. There are two types of energy conversion in reaction turbines. First, the turbine is completely submerged; producing a pressure drop between the inlet and outlet that translates into axial force (also called reaction section). Second, the change in velocity vector of water as it flows between turbine blades creates momentum forces. The design speed of a turbine is primarily determined by the lift at which it operates. Turbines can be classified as high-, medium-, and low-lift machines. They are also distinguished by their principle of operation and can be either impulse turbines or reaction turbines. The basic turbine classification is shown in the table below.

Table 2.2 Types of turbines

Types of turbine	**High head**	**Medium head**	**Low head**
Impulse turbines	Pelton Turgo	Cros-flow Multi-jet pelton Turgo	Cros-flow
Reaction turbines		Francis	Propeller Kaplan

A. TURBINE SELECTIONS

Choosing the right turbine is determined in large part by the available head, and to a lesser extent, the available flow rate. In general, impulse turbines are used for high-head sites and reaction turbines for low-head sites. Variable-pitch Kaplan turbines can achieve peak efficiency over a wide range of flow conditions, making them suitable for a variety of flow and head ranges. The selection of the most suitable turbine for a particular stand-alone micro-hydro site depends on the characteristics of the site. The decisive factor is the heads available and the power required. The choice also depends on the speed at which the generator or other equipment operates loading a generator.

Table 2.3 Classification of hydro turbines according to head, flow rate and power output

S/NO	Classification	Turbine type	Head(m)	Flow rate (m^3/sec)	Power outside(KW)
1	Impulse turbine	Pelton	50-1000	0.2-3	50-1500
		Turgo	30-200	0.2-5	20-5000
		Cros-flow	2-50	0.01-2	0.1-600
2	Reaction turbine	Kaplan	3-40	3-20	50-5000
		Propeller	3-40	3-20	50-500
		Francis radial flow	40-200	1-20	500-1500
		Francis mixed flow	10-40	0.7-10	100-5000

Turbine type, dimensions and design are basically governed by the following criteria:

- Net head
- Variation of flow discharge through the turbine
- Rotational speed
- Cavitation problems (quality of water available from penstock)
- Cost

The main criterion when choosing a turbine is the net head. The diagram above (Turbine Application Table) shows the range of operating altitudes for each type of turbine. The diagram above and table below show some overlap so that more than one turbine type can be used for a given head.

B. TURBINE EFFICIENCY

Efficiency is defined as the level of performance that describes a process that uses the smallest amount of input to produce the maximum amount of output. In hydroelectric power generation, plant efficiency and performance are primarily determined by the type of turbine used. The choice of turbine depends on the size of the hydroelectric power plant and the location of the turbine. Efficiency is affected by head (H), flow rate (Q), water density (ρ), and gravitational constant. A comparison is made between a small number of turbines to determine the higher power turbine. The important point is that Pelton and Kaplan turbines can maintain very high efficiency even when operating below their design flow. In contrast, the efficiency of cross-flow and Francis turbines drops even further when operated at less than half the normal flow rate. Most fixed pitch turbines perform poorly except above 80% of full flow.

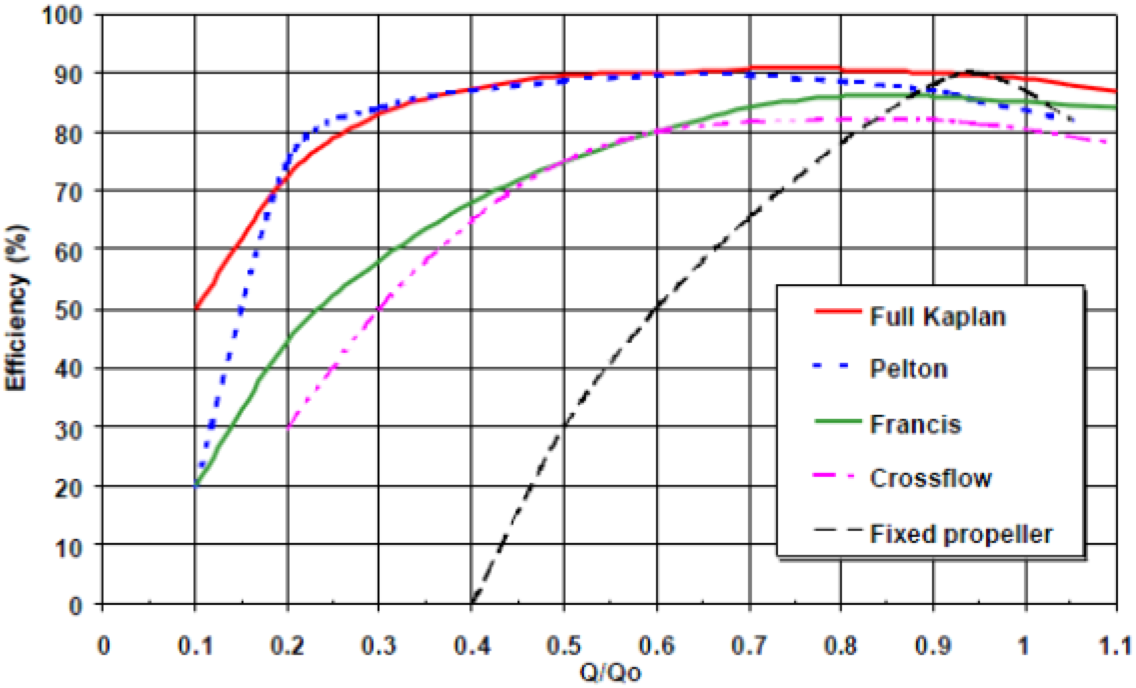


Figure 2.4 Turbine efficiency

Drive systems

A energy system transfers power from a turbine shaft to a generator shaft or a shaft that drives another piece of equipment through a coupling device. It is also useful for changing the speed from one shaft to another when the turbine speed is different from the required speed of the generator or equipment. The following options are mainly used for small hydropower plants.

1. Direct drive,
2. Flat belt and pulleys,
3. V or wedge belt and pulleys,
4. Chain and sprocket, and
5. Gearbox.

1. Direct drive

A direct drive, as the name suggests, uses a flexible coupling to directly connect two shafts and is therefore only used when the shaft speeds of the turbine and generator or equipment are the same. The advantages are low maintenance, high efficiency (over 98%) and low cost. The only drawback of the direct drive configuration is that the alignment of the two shafts is very critical, unlike the indirect drive system.

2. Flat belt and pulley

Modern flat belts operate under high tension and consist of a strong inner band coated with a high-friction material such as rubber. They are more efficient and run cleaner (i.e. less rubber dust) than V-belt drives. The pulley must have a slightly convex "crown" profile. This ensures proper alignment and keeps the tape in place both vertically and horizontally. The main drawback of this configuration is that it requires a higher voltage than other drives, which puts a higher load on the bearings, possibly necessitating the use of additional heavier bearings on standard generators. There is Also, in some areas, it may not be as affordable as a V-belt drive system. Flat belts typically require narrower pulleys than comparable V-ribbed belts, offering cost benefits and less overhang. .

3. "V" or wedge belts and pulleys

This is the most commonly used mechanism for small hydropower plants up to 100 kW. The big advantage is that these belts are very well known and widely used as they are widely used in all kinds of small industrial machines. V-belts differ from flat belts in that the wedging action of the belt sidewalls in the grooves of the pulleys creates a frictional grip on the pulleys. Therefore, less tension is required to maintain the support, resulting in less radial stress on the shaft and bearings. Several V-belts are usually guided side by side in multi-control belt pulleys. A matching set of belts is required to evenly distribute the tension. In some countries, it may be difficult to obtain this fee. With higher horsepower and torque, it can become cumbersome to install multiple V-belts with 8 or more large belts and very wide pulleys.

Generator

A generator converts mechanical energy generated by a turbine into electrical energy using the principle of electromagnetic induction. There are two basic types of generators suitable for MHPP. These include synchronous generators and induction generators. Synchronous generators require the ability to operate in an isolated grid area, are readily available on the market, do not require excitation capacitors to supply reactive power, are highly efficient, and have an automatic voltage regulator to regulate the voltage. There are other advantages over induction generators, such as the built-in, ELC and synchronous generator can be used to achieve good frequency control. However, they are more expensive than induction generators [12]. Induction generators require an external excitation to generate the required magnetic field. It induces a current in the windings to start it. This is achieved by using Properly sized capacitors. Nevertheless, induction generators are generally the cheapest option for MHPPs. Induction motors are widely available in the market, cheap, can be simply reversed as induction generators, and work effectively even in isolated grid areas. However, for more advanced applications, excitation capacitors become more expensive, making synchronous generators more attractive Option [13].

2.4 Design Parameters of Micro Hydro Power Plant

2.4.1 Head

Head is defined as the vertical height (in meters) from the level at which water enters the penstock to the level at which it exits the turbine casing. For example, suppose a river is flowing next to a waterfall. Head is an important parameter in hydropower. Head affects flow velocity. Flow height can be determined by measuring the flow from the highest point to the lowest point of the water. The unit of lifting height is meter (m). Total head (H) is defined as the maximum height available for water to fall vertically. The actual head of the turbine is slightly smaller than the gross head. This is due to the losses that occur when hydropower is fed into or removed from the grid.

2.4.2 Flow Rate

Flow is the quantity of water moving past a given point over a set time period (expressed as volume in gallons per minute (gpm) or cubic meters per second (m3/s). More water falling through the turbine will produce more power. The amount of water available depends on the volume of water at the source. Power is also ‘directly proportional’ to river flow, or flow volume. The flow rate is the product of volume and area. This method will calculate the cross section area (S) as the product of width and average deep of the river. Then, flow rate can be found by multiplying cross section area with water speed flow. Flow rate (Q) is equal to average speed of water flow (Vavg) and the cross section area of the media (S). This method can be formulated as follows [14].

$$Q = Vavg \; x \; S \text{ (L/s)} \qquad (2.\ 1)$$

2.4.3 Power and energy

The amount of energy available from a micro hydrogenator system is directly related to flow rate, head and gravity. The theoretical amount of energy available from a micro-hydro system is directly related to flow (Q), head (H), and gravity (g) as shown below.

$$Pth = Q * H * G \qquad (2.2)$$

To calculate the actual power output (Pact) of a micro-hydro plant, we need to consider penstock friction losses and turbine and generator efficiencies. Generally, the overall efficiency of power generation systems varies between 50-70%, with higher head systems having higher overall efficiency. Therefore, to get a realistic power output, the theoretical power should be multiplied by an efficiency factor of 0.5 to 0.7, depending on capacity and type of installation, as shown below.

$$Pact = Q * Hd * g * e \qquad (2.3)$$

Where e=efficiency factor (0.5 to 0.7).

$$Phydraulic = V^{\bullet} * \rho * g * Hd \qquad (2.4)$$

Where Phydraulic=hydraulic potential in(Kw).

$V^{\bullet}$=volume flow in $\left(m^3/_s\right)$

ρ =density $\left(Kg/_m 3\right)$

g=gravitational constant: 9.8 $\left\lfloor m/_{s^2} \right\rfloor$

Hd=head in [m]

2.5 Control Systems of Micro Hydropower Plants

In power grids, loads require uninterruptible power at rated frequency and rated voltage. Therefore, in CHP, voltage and frequency control are key factors in power quality. If these parameters are not controlled, the quality of electrical energy will be adversely affected.

Voltage regulation is done by controlling the generator excitation [15] [16]. Most often this is accomplished using an automatic voltage regulator (AVR). The main function of the AVR is to control and maintain the terminal voltage of the generator by automatically adjusting the field or excitation current within certain limits despite the different load conditions of the generator. is[17][18].

AVR works by comparing the alternator terminal voltage to a target voltage. If the generator terminal voltage is lower than the reference voltage, the AVR increases the DC voltage in the generator field to the point where the generator terminal voltage equals the commanded voltage. This control action of the AVR keeps the terminal voltage of the generator constant whenever the voltage changes. Most synchronous generators used in MHPPs have built-in AVRs to control the terminal voltage, so voltage control is not a big issue. The frequency of the power supply is controlled by eliminating the difference between the generated power and the consumed power [19] [20]. For proper and effective frequency control, the generator mechanical power (Pm) and power (Pe) must be balanced. If the mechanical power consumption of the turbine is greater than the electrical load connected to the generator, the generator will accelerate resulting in an increase in frequency. The opposite is also true. Therefore, in a real power system, power consumers have different power demands and the load changes continuously and randomly, resulting in an imbalance between the power generated and the power consumed. These operations will always cause frequency variations and therefore require frequency adjustment.

All electrical equipment is designed to operate within a specific frequency range. Failure to operate this device at the specified frequency may result in severe damage or reduced device life [21] [22]. For example, rotating machines such as AC electric motors are designed to operate at a constant speed or frequency and tolerate very small frequency variations in order to operate safely, effectively and efficiently. Increasing the motor frequency beyond the permissible limits can lead to motor damage due to overheating of the windings, increased vibration and wear of the mechanical bearings. Similarly, when power turbines operate at frequencies below 50 Hz, the rotors vibrate excessively, which can also lead to turbine damage. In independent hydro plants, the speed of small hydro generators can be changed as loads are added or removed from the electrical system. The frequency of the generated voltage and the speed of the generator shaft are related.

$$F = \frac{P \times N}{120} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.5$$

By eliminating the mismatch between the generator and the load, the system frequency can be kept constant. A flow control valve or governor is used to control the speed of the shaft depending on the load requirements. Flow control valves control the flow of water to the turbine according to load requirements. Conventional regulators or flow control valves can be classified as mechanical hydraulic regulators, electrohydraulic regulators, or mechanical regulators. Mechanical-hydraulic governors are large, sophisticated devices commonly used in large hydroelectric power systems. Requires a lot of maintenance and is expensive to install It is uneconomical to use in small hydroelectric power plants. Electro-hydraulic regulators are complex devices that require precision engineering and are expensive. These require an elaborate set of intricate guide vanes, intake valves and jet deflectors. Another type of controller used to control water flow to a turbine in a small hydroelectric plant includes spear valves and servo motors that receive control signals from a PID controller. Spear valves are used for continuous flow control. A servo motor is used as the controller to actuate the spear valve and control the flow rate. The controller compares the frequency signal obtained from the generator output with a reference frequency signal to control the spear valve. A spear valve controls the flow of water to the turbine. Conventional control systems are therefore not ideally suited for stand-alone off-grid small hydro plants due to their cost and complexity [23]. Therefore, the latest trend is towards load-side control [24].

2.6 Types of Controller

2.6.1 Proportional Controller

Proportional controllers are mainly used in first-order processes with discrete energy storage to stabilize unstable processes. The main purpose of the P controller is to reduce the steady-state error of the system. As the proportional gain K increases, the steady-state error of the system decreases. However, despite this reduction, P control never succeeds in eliminating the steady-state error of the system. Increasing the proportional gain reduces amplitude and phase headroom, resulting in faster dynamics for a wider frequency band and increased sensitivity to noise. This controller can only be used if the system can tolerate a constant steady-state error.

Furthermore, application of the P-controller reduces the rise time, and beyond a certain steady-state error reduction value, increasing K only causes an overshoot of the system response. P control will also oscillate if it is aggressive enough and there is lag or dead time. The more delays (higher order), the bigger the problem. Furthermore, it directly amplifies the process noise [25].

2.6.2 P-I Controller

P-I controllers are primarily used to remove steady-state errors caused by P controllers. However, this adversely affects reaction speed and overall system stability. This controller is primarily used in areas where system speed is not critical. P-I controllers cannot predict future system failures, so they cannot reduce rise time or eliminate vibration. When applied, setpoint overshoot is guaranteed regardless of the amount of I [25].

2.6.3 P-D Controller

The purpose of using a P-D controller is to improve control and increase system stability because of its ability to predict future errors in system response. To avoid the effects of sudden changes in the value of the error signal, the derivative is formed from the output response of the system variable instead of the error signal. Therefore, the D-mode is designed to be proportional to the change in the output variable to prevent sudden changes in the control output due to sudden changes in the error signal. Furthermore, pure D control is not used because D directly amplifies the process noise [25].

2.6.4 PID Controller

A PID (proportional-integral-derivative) controller is a closed-loop feedback controller used in control systems. The proportional term is responsible for the desired setpoint, and the integral and derivative terms are responsible for the accumulation of past error and the rate of change of error in the process. PID controllers attempt to minimize the error by calculating the error value as the difference between the measured process variable and the desired setpoint, and using the manipulated variable to tune the process. A basic block diagram of a PID controller is shown in Figure 2.5.

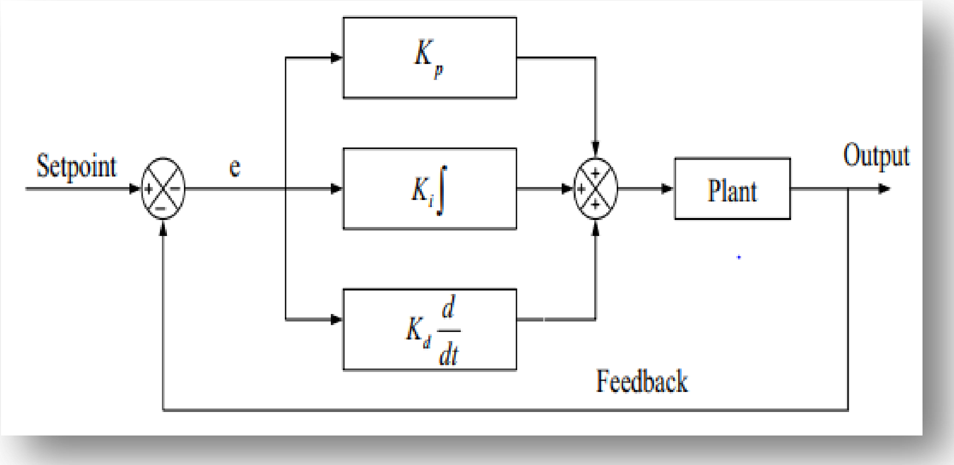


Figure 2.5 Block diagram of classical PID controller

PID controllers are often used in the process industry. This is due to various advantages such as:Easy to understand for plant operators, with near-optimal performance and broad applicability. PID controllers can be tuned using the Ziegler-Nichols method. In the Ziegler-Nichols tuning method, the Ki and Kd gains are initially set to zero. The Kp gain is then increased from zero to a critical value at which sustained oscillations occur. Ki is then increased until the offset is corrected. Finally, after a load disturbance, Kd is increased until the loop reaches the reference value quickly enough. However, the drawbacks of using PID controllers are that they require frequent tuning and suffer from poor performance in highly nonlinear and disturbance-sensitive systems [63].

The general formula for a PID controller is

$$G(s) = Kp + \frac{Ki}{S} + KdS \qquad 2.$$

2.7 Intelligent Techniques for Frequency control in micro hydro power system

Modern power systems require advanced intelligence technology and flexibility in control and optimization to ensure performance to maintain generation load balance after severe disturbances. Today, with the increasing number of renewable energy systems, this issue is becoming more and more important. Classical frequency-controlled controllers for micro-hydro power systems cannot be seen in real systems due to their nonlinear characteristics, yield limitation, and saturation [26]. Therefore, a control technology that can solve this problem is needed. In such cases, soft computing/artificial intelligence (AI) techniques such as fuzzy, neural networks, genetic algorithms, and hybrids are more suitable. Developed by Lotfi Zadeh in 1969, the concept of fuzzy logic addresses the uncertainty and imprecision that pervade engineering problems. The concept of FC is a significant departure from traditional control theory. H. It is primarily based on mathematical models of controlled processes.

Mathematical modeling of fuzzy: - How to describe system properties using fuzzy inference rules. A feature of this method is the ability to describe complex nonlinear systems linguistically. However, it is very difficult to identify the rules and tune the membership functions of the fuzzy arguments. Commonly constructed fuzzy controllers Use fuzzy rules. These fuzzy rules are obtained by review from domain experts or experts familiar with the actual use of this control. Fuzzy set membership functions are determined using information available to subject matter experts. You'll need to adjust the structure of such rules and membership functions. This means that you should measure your controller's performance and adjust your membership functions and rules based on that performance. The modern era of artificial neural networks (ANNs) began in 1943 with pioneering work by McCulloch and Pitts using the famous McCulloch-Pitts model. ANN usually refers to neural networks. It was driven by the realization that the human brain performs certain tasks much more efficiently than traditional digital computers, and in a very different way. They are non-linear in nature and have good properties such as problem tolerance and self-learning, which makes them robust and suitable for parallel processing. ANN inherits the functionality of nonlinear mapping. If the input dataset corresponds to a certain signal pattern, the network can be trained to output the corresponding desired pattern. The ANN technique is relatively easy to implement and does not require prior knowledge of the system model [27]. Concepts of fuzzy logic have been integrated into neural networks to enable systems to cope with cognitive uncertainty better than humans. The resulting hybrid system is called a neural fuzzy, fuzzy neural, fuzzy neuro, or neuro fuzzy network.

2.7.1 Fuzzy Logic Control

The concept of fuzzy logic (FL) was first introduced by Zadeh (1965) to define the logic of human thought. It addresses the engineering problem as a computing mode that allows membership in a subset rather than membership or non-membership in a distinct set by providing some degree of certainty in the answer to a logical question. increase. In contrast to classical logic, which is based on distinct sets of "true and false", fuzzy logic views problems as degrees of "truth", or "fuzzy sets of true and false". It provides an easy way to reach unequivocal conclusions and can be safely programmed without the need for accurate, noise-free information. FL output control is a frictionless control function for a wide range of input data. [28-30].

Fuzzy controllers are used to control industrial processes such as cement kilns, subways, and robots, as well as consumer products such as washing machines, video cameras, and rice cookers. Fuzzy control is a control method based on fuzzy logic. Similarly, fuzzy logic can be simply described as "calculating using words instead of numbers." A simple explanation of fuzzy control is "control using sentences instead of formulas". The fuzzy controller is It contains rules of thumb and is especially useful in operator control systems. Today, control systems are usually described by mathematical models that obey the following laws: A model derived from physics, probabilistic models, or mathematical logic.

General the difficulty with models constructed in this way is how to move from a given problem to a real problem mathematical model. No doubt today's advanced computer technology makes this possible.

However, managing such systems is still too complex. These complex systems can be simplified by using an appropriate level of tolerance for imprecision, ambiguity and uncertainty during the modeling stage. As a result, the system is far from perfect. Still, most of the time it can solve the problem adequately over there. Even with missing input information, knowledge-based systems have already proven sufficient. Fuzzy logic reduces complexity by making intelligent use of imperfect information. It can be implemented in hardware, software, or a combination of both. In other words, the fuzzy logic approach to problem control mimics how humans make decisions, but much faster. In a control system the input to the system is the error and the change is the error. A feedback loop during which the output is a controlling action. The general architecture of a fuzzy controller is shown in Figure 2.7.

The following steps are required to implement the fuzzy logic technique in a real application.

Fuzzification - Convert classic or clear data to fuzzy data or membership function (MF).

Membership functions - indicate the degree to which a particular input corresponds to a particular set or is linguistically related to a controlling concept.

Knowledgebase - contains databases and rule bases. Database contains data about the plant, and the rule base contains quantified fuzzy logic explanations from experts on how to achieve the desired control.

Fuzzy inference Process - This emulates the decision making process of an expert who interprets and applies knowledge about how best to control the plant. During operation, the inference engine determines how relevant the rules are to the current control requirements and makes inferences about the current inputs and rules that fire the rules and determine the state of the outputs. Combining membership functions and control rules to derive fuzzy outputs.

Defuzzification – transforming the fuzzy outputs (conclusions) from the fuzzy inference engine into unambiguous outputs that serve as the actual inputs to the controlled process, using various methods to compute each relevant output. to insert into the table. Search. Capture the output from a lookup table based on the current inputs in your application.

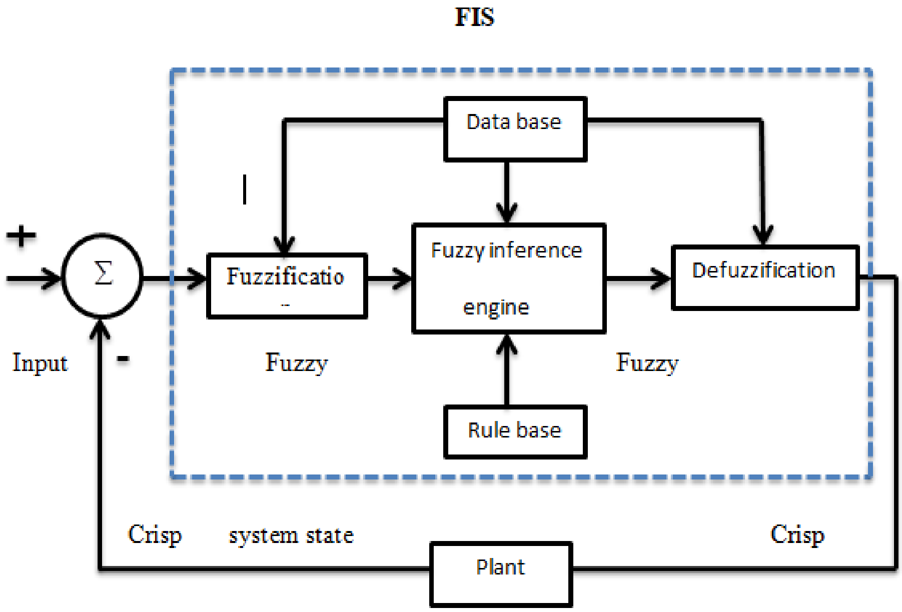


Figure 2.6 Fuzzy Logic Controller [27]

2.7.2 Fuzzification

Fuzzification converts the actual input values into fuzzy set values, and these inputs are assigned degrees associated with each corresponding fuzzy set. Fuzzification is done by characterizing the fuzzy inputs of the membership functions. The membership function classifies the input elements in the set as either discrete or continuous. Graphically, membership functions can take many forms. Triangular, Trapezoidal, Bell-shaped, Gaussian. These membership functions are available depending on how your system works. However, in engineering applications, triangular and trapezoidal membership functions are often used. Figure 7 shows the triangular membership functions of the input (frequency error) to the fuzzy logic controller.

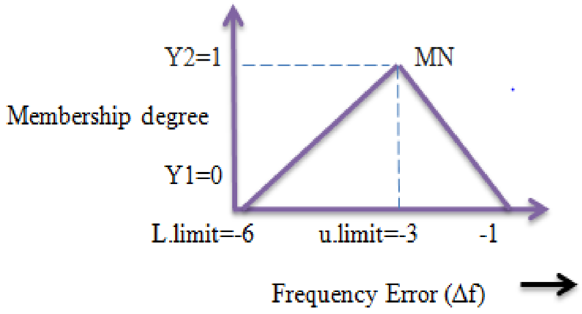


Figure 2.7 Membership function MN

A membership function essentially embodies all the fuzziness of a given fuzzy set, so: The description is the essence of the ambiguous property or operation. Just as there are an infinite number of ways to characterize blur, there are an infinite number of ways to graph membership functions that describe that blur. The most common forms of membership functions are normal, monotonic, and symmetric. The "shape" of membership features is important, so much attention has been given to developing these features. The membership function assigns a weighting factor to each input value and valid rule. These weighting factors determine the impact or membership level (DOM) of each active rule. A set of fuzzy output response sizes is generated by computing the intersection of the membership weights for each active rule. All that remains is to combine and defuzzify these output responses [31].

2.7.3 **Rule Base**

A rule base is essentially a control strategy for a system. This is usually derived from expertise or heuristics and expressed as a set of IF-THEN rules. Rules are based on the concept of fuzzy inference, where antecedents and consequences are associated with linguistic variables. In rules, he uses three variables in both the conditions and conclusions of the rules. For simplicity, this section assumes that the purpose of control is to adjust some aspect of process performance around a given set point or criterion. The representation is therefore limited to single-circuit control.

If error is NB and change in error is NB then Valve gate position is NB
If error is NB and change in error is Ns then Valve gate position PS.
If error is PM and change in error is PB then Valve gate position NM.
If error is Z and change in error is Z then Valve gate position Z.

2.7.3.1 **De-fuzzification**

De-fuzzification is carried out to convert the fuzzy linguistic variable into real crisp values. Without de-fuzzification, results of fuzzy logic generated cannot be used in applications. De-fuzzification is carried out through various methods such as; centre of gravity, weighted average and maximum mean methods.

2.7.4 Adaptive Neuro Fuzzy controller (ANFIS)

An intelligent neuro-fuzzy method called Adaptive Neuro-Fuzzy Inference System "ANFIS" has been developed. It was first proposed by Jang in 1993 [32]. We combine a fuzzy inference system (FIS) and an artificial neural network (ANN) to develop a neurofuzzy technique (FIS). Both Fuzzy and ANN outperform AFIS [32, 33]. We tune the parameters of fuzzy inference systems by implementing different modes of operation and consequently combining the learning power of neural networks with the information processing of fuzzy logic.

2.7.5 Advantages and Disadvantages of Neuro-fuzzy (ANFIS) system

ADVANTAGES	DISADVANTAGES
✚ It can handle any kind of information (numeric, linguistic, logical, etc.) ✚ It can manage imprecise, partial and unclear imperfect information. ✚ It has self-learning, self-organizing and self-tuning capabilities. ✚ It doesn't need prior knowledge of relationship of data. ✚ Mimic human decision making process. ✚ Ability to perform many-to-many maps.	✚ Difficult to develop a model from a fuzzy system ✚ Membership values findings for a fuzzy system. ✚ Training data constraint for Neural network (NN).

2.8 Previous Works on Frequency Control of MHPP

The scientific community has a strong interest in the modeling and control of renewable energy systems, especially hydropower plants and micro-hydropower plants. Various studies have been conducted on the control mechanism of frequency control in small hydroelectric power plants. Different researchers have used different approaches to control the frequency of MHPP. Based on this, some approaches are described in the next section.

Table 2.4 Overall summary of references, related to this thesis work

No .s	Researcher (authors) Name	Years	Different Tittles (approaches) related to this thesis work
1	Pratibha Srivastav, Manojjha, M.F. Qureshi	2014	Proposed research on the theme of "Cooperative Neuro-Fuzzy Inference System for Stability Induction and Excitation Control of Energy Systems". In our research, we use neural fuzzy theory to coordinate control and excitation control to compensate control inputs in the event of an error. To characterize the vibration magnitude, the generator angular velocity ( ), acceleration (Pm - Pc) and terminal voltage (V1) are observed. The compensation has been observed to be robust against various system errors. If there is a disturbance in the sliding system, the original control will dampen the vibration of the system if the disturbance is small, due to the compensation, and will not cause large vibrations. If only the output is added to tune the controller, the first swing is better, but the swing after the first swing is worse than the swing in the uncompensated case, which is the limitation observed in the system. It seems [34].
2	Jagatheesan and k. Anand	2014	Three wide-area hydrothermal power generation systems with electrical and mechanical controllers have been proposed to control the load frequency. The AGC performance shows that the electric governor outperforms the mechanical governor with and without the generator speed limit. When the integral and PI controllers are

			applied to AGC, the results show that the PI controller gives the smallest damped oscillation with good settling time compared to the integral controller (I) with and without considering the nonlinearity. I understand from These controllers have good dynamic behavior and are easy to implement, but they are not efficient in uncertain and complex systems. In addition, most of the water's constituents are lost as the electric regulator heats the water. Therefore, this water cannot be used for other purposes such as irrigation or fish production[35].
3	In Chahar and Panwar	2016	A fuzzy tuned PID controller was proposed for thermal power plants. The results show that the controller achieves a better performance as compared to the conventional controllers. The authors also observed that the system was not capable of adapting to variations in system behavior [36].
4	Chaudhary, R., Singh, A.P	2017	An intelligent controller was applied for an AGC of an interconnected hydropower plant. Both FLC and ANN were compared with the conventional controller. The results show better performance of ANN and FLC as compared to the PID controller [37].
5	In Xiomara and Soares	2017	An optimal controller concept was applied for large power plants with the aim of improving the performance of the plant. The authors stated that the realization of the controller was difficult, cumbersome, as well as expensive because of the feedback parts of the optimal controller are expressed completely in terms of the function of the state vector of the plant [38].
5	Rajendra Fagna	2017	Has studied Load Frequency Control of Single Area Thermal Power Plant Using Type 1 Fuzzy Logic Controller. In this paper, a type 1 Fuzzy controller is composed for solving change in load frequency problem of single area thermal power system. The performances of type 1 fuzzy controller have been demonstrated for

			comparing the performances of other published paper PID controller such as Ziegler Nichols method [39].
6	In Leu	2018	The performance of two regional hydropower plants for AGC was studied using different controllers such as PID, FLC and ANN for optimal control. For a single-region hydropower plant, the performance of AGC with FLC was better compared to AGC with PID control. Additionally, an ANN was trained using the data generated from the results of the optimal controller simulation, and the trained ANN model was used to track the optimal performance of the hydroelectric power plant. A trained ANN model has long settling times and steady-state errors. Furthermore, the authors did not compare fuzzy logic and ANN models and their combined effects [40].
7	M. K. D. Manjit Bahadur Singh	2019	Have presented Design and Application of PID-PID Dual Loop Controller for Load Frequency Control. Spider Monkey Optimization (SMO) tuned PID-PID dual loop controller is proposed for Load Frequency Control (LFC) for dual area power systems in this paper [41].
8	Alireza Sina et al	2019	We have developed load frequency control for multi-band connected power systems using a differential evolution algorithm. Simulation results show that the controller designed with the differential evolution algorithm is insensitive to load changes, disturbances, or changes in system parameters. The proposed algorithm was compared with other load frequency control algorithms and this method showed better response and satisfactory performance [42].
9	Suman Machavarapu et al	2020	Design of load frequency controller for multi-area system using AI techniques. The three-area, two-area, and single area systems are considered as the test systems and response of all the test systems is observed without and with PI, fuzzy, and neural network controller. From the results, we observed that the neural network controller is

			outperforming in damping the variation in the frequency due to the disturbances [43].
10	Deepak Kumar Gupta et al	2021	Proposal of load frequency control using hybrid intelligent optimization techniques for multi-source power systems. A two-tier power system consisting of a thermal power plant and a hydroelectric power plant was designed using MATLAB/Simulink tools. The performance of the system was studied considering the domain change of the step load due to the disturbance and the simulation of the test system affected by the step due to the disturbance. Stresses were performed to evaluate the performance and robustness of the proposed algorithm in terms of peak overshoot and transient time performance indicators. The article suggests that two or more areas of his power system can be designed to test regulators, and in addition to these different values of load conditions and changes in system parameters, they also need to be applied. suggests that there are [44].
11	Honelign Demie	2022	Design of fuzzy proportional-integral-derivative load-frequency control for multi-range power systems using particle swarm optimization. This proposed controller offers better settling time, overshoot, and undershoot response to line-to-line power fluctuations compared to the time response. This sensitivity analysis confirms that the robustness of the proposed controller after changing the parameters depends on its nominal values. Variations in settling time, overshoot and undershoot after changing system parameter values from their nominal values have been found to be within considerable limits [45].
In most of the literatures reviewed, it was observed that in some cases AGC using FLC gave better results compared to the AGC using other controllers, and in other cases, the other controllers performed better than the FLC. Most of the literatures reviewed used the old controller (PID, Flc) or old optimization techniques like genetic algorithm and particle swarm optimization algorithm and			

they not compared the obtained result from this optimization algorithm with other optimization to select the best optimization techniques. These reduce the performance of the micro hydro power system.

Therefore, this thesis work presents the frequency control of standalone micro hydro power plant based on flow valve control with Neuro-fuzzy controller (ANFIS) with the aim of reducing the frequency deviations, fast response and less complexity, which occur during MHPP generation and also to improve the controller's performance and they are ideally suited for frequency control of standalone micro hydro power systems where cost is a sensitive issue..

CHAPTER THREE

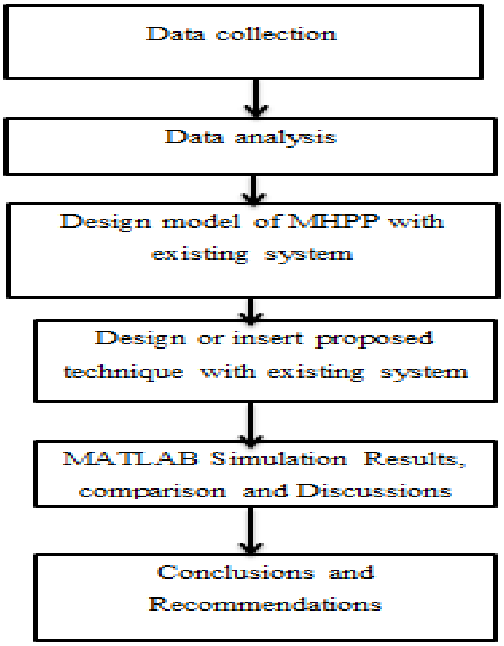
SYSTEM MODELING AND METHODOLOGY

3.1 INTRODUCTION

This section covers data collection and analysis, mathematical modeling of a stand-alone micro-hydro system, and servo motor controller design. Keramo Micro Hydropower Station is used as frequency control system design. The interconnection of these power plants was used to model the frequency control system. The servomotor, turbine and synchronous generator blocks are properly connected to allow self-contained frequency control based on FVC as a servomotor. The existing frequency control system of Keramo Small Hydro Power Station is FCV, which is installed as the main frequency control mechanism. A frequency controller (FC) can minimize transient deviations by maintaining the system's actual frequency and desired output power.

3.2 *METHODS*

The generally to accomplish this thesis work the following procedures have been applied.



3.3 DATA COLLECTION

Various data were collected from various sources for this graduation thesis on the self-contained micro-hydro power system in Keramo. This data falls into two main parts of this: One for primary data and one for secondary data. The primary data are those collected by the Keramo micro hydropower system in Bensa Woreda. This includes collecting information by directly observing the Keramo small hydroelectric power station. Secondary data, on the other hand, are the result of research by others in the same problem area. This includes the study of documents and archival records, websites and other historical and documentary records relevant to the study. The data required for this thesis are collected from various sources by conducting interviews with individual personnel of small hydropower systems. This data collection was conducted as part of a study to study small hydropower on the Keramo River. Performance can be determined by measuring the river flow velocity, and the measurements were made using the velocity area method. Multiplying this gives a river discharge of approximately 0.212 to 0.421 m3/s.

Table 3.1 Households daily energy demand

Sr. No	**Appliances**	**Rating(Watt)**	**Quantity**	**No. of houses**	**Total watts**	**Daily use/hour**	**Daily energy consumed[Wh]**
1	Fan	70	3	3 churches	630	6	3780
2	Fridge	200	1	6	1200	12	14400
3	Stove	1200	1	12	14400	2	28800
4	TV	70	1	15	1050	6	6300
5	LED Lamps	11	3	181	5973	12	71676
6	Fluorescent lamps, in school	18	2	20 classes	720	4	2880
7	water pump machine for irrigation purpose	1000	1	---------	1000	8 Total= 42hrs/day	8000
	TOTAL (	Total=201 houses				135836Wh/day or	

	IN Watts)	25000Watt or 25KW	135.836Kwh/day

3.4 Micro Hydro Power System Modeling

The first step in analyzing and designing a control system for small hydropower plants is to model the various components. System transfer function models are used in the design of control systems. After appropriate assumptions and approximations are made to linearize the differential equations describing the components of the MHPP, the transfer functions representing each component are obtained. Therefore, a transfer function model of a micro hydro power plant for load control and flow control is developed. The block diagram in figure 8 shows the different components of a micro hydroelectric power plant.

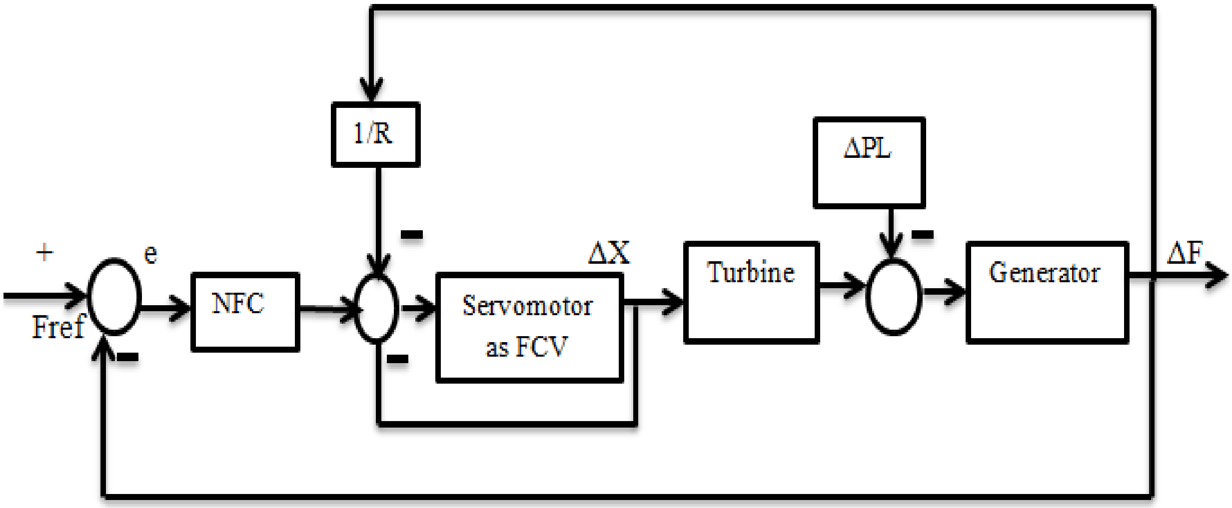


Figure 3.1 Components of a Micro Hydropower Plant

3.4.1 Hydro-electric Servo motor modeling

An electric servomotor is a precision electric motor with the ability to induce motion in the form of rotary or linear motion in proportion to an applied electrical command signal. The controlled variable here is the turbine output. The motor servo inside the FCV controls the gate valve according to the signal from the controller and controls the speed of the water flow so that the set value is maintained. The position of the turbine gate is controlled by a servo motor, adjusting the water flow according to the connected load to generate electricity. Electric servo motors are simple in design, require less maintenance and are cheaper than traditional controllers [46]. In the proposed control system, an electric servomotor is used as an actuator that acts on the gate opening to control the water flow. A hydroelectric servo system is shown in Figure 3.2.

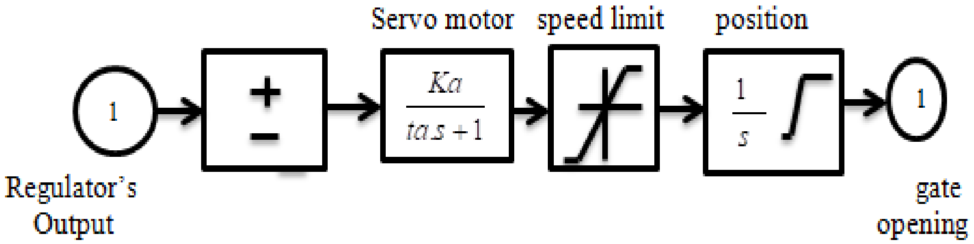


Figure 3.2 Hydroelectric servo systems

The approximate transfer function for the servo motor with driver is considered for the analysis and is given by [37]

$$G(V)=\frac{1}{(TeS+1)}*\frac{1}{(TmS+1)} \qquad 3.1$$

Here *Tm* (s) is mechanical time constant; *Te* (s) is electrical time constant. In addition, unity gain is applied as a feedback to depict the closed-loop armature control of this servomotor. At last, the transfer function of this component is given as

$$\frac{\Delta X(S)}{\Delta Pc(S)-\frac{1}{R}\Delta F(S)}=\frac{Gv(s)}{1+Gv(s)} \qquad 3.2$$

Here *R* (Hz/p.u.kW) is a constant of steady state speed regulation, Δ*X* (per unit) is gate position deviation, Δ*F* (Hz) is frequency deviation, Δ*Pc* (per unit kW) is incremental speed changer position.

Table 3.2 A servo motor with the specifications

Parameter	**Value**
Model	43HS2A165-654
Number of teeth (Nr)	50
Rated phase current	6.5A
Phase resistance	0.65ohm
Phase inductance	14Mh
Lead wire	4
Weight	11kg
Holding torque	26.0Nm
Step angle	1.8^o
Inertia constant	0.0013kg-m^2
Torque constant	4 N-m/A
Viscous friction constant(assume)	0.5N-m/rad/sec

The transfer function between the input and output angles of the servomotor is given by

$$T(s)=\frac{KmxIpxNr}{Js^2+\beta s+Km+Ip+Nr}$$

Where Nr is number of rotor teeth, Ip is rated current of the generator, Km is torque constant. From the table rated current 6.5A, steep angle 1.8 degree, number of rotor teeth

$$Nr=\frac{360^0}{p*step\ angle}=\frac{360^0}{1.8^0*4}=50$$

$$T(s)=\frac{50*6.5*0.5}{0.0013s^2+0.5s+162.5}=\frac{162.5}{0.0013s^2+0.5s+162.5}$$

3.4.2 Hydraulic Turbine and Flow control valve (FCV) or Governor Model

Water flow in the turbine is controlled by a flow control valve or regulator. The main purpose of the flow control valve is to regulate the speed of the generator in order to keep the frequency value constant. A flow control valve or governor senses changes in speed and controls a turbine valve for water flow. The FCV and turbine determine the mechanical torque and power applied to the generator. Figure 3.3 shows an overall configuration diagram consisting of a water turbine and FCV.

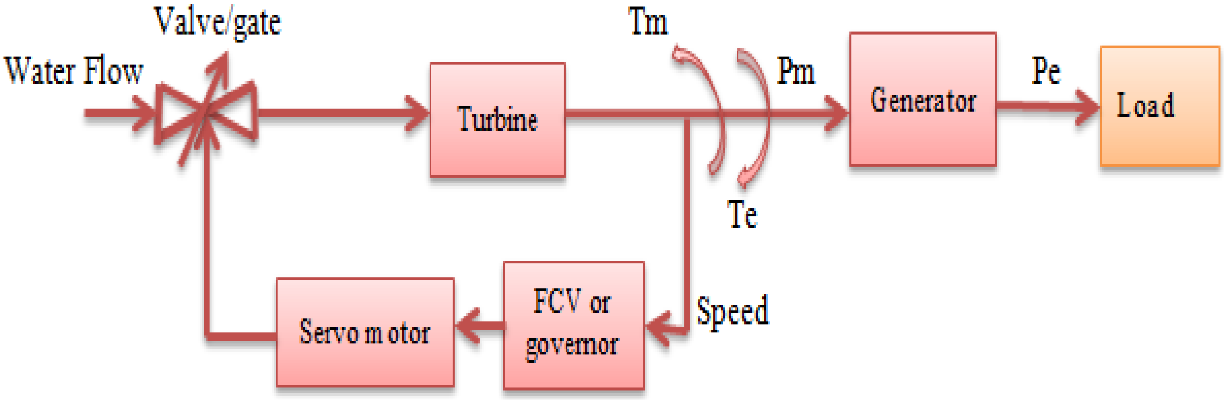


Figure 3.3 Block diagram of turbine speed control with FCV or governor

Hydro turbines produce mechanical energy. This mechanical energy is converted to electrical energy by the force exerted by the water as it falls from the upper reservoir to the lower reservoir. The hydro turbine dynamics model has a great influence on the dynamic stability of the energy system. There are two types of turbines. In this work, the linear turbine model shown below is used. A linear model of a water turbine is modeled based on the following assumptions: The blades of water wheels are considered smooth. H. Their frictional resistance is neglected. Liquids are considered incompressible. The speed of the water in the penstock is directly dependent on the opening of the gate and the water pressure. square root of net head Turbine development power is proportional to the product of water head and water head flow rate. The power produced by a turbine is a function of water flow, runner blade angle, and net head. Flow through the turbine is a function of head, speed, gate opening position, and runner blade angle. The effect of impeller blade movement is used when modeling turbines with fixed blades, such as turbines. B. Francis Turbine not considered.

Impulse turbine flow depends only on the head and nozzle openings. Turbine dynamics relates to generator dynamics through the mechanical power produced by the turbine. The relationship between mechanical power and mechanical torque, expressed in units per unit, is given by:

$$Pm = \frac{n}{\omega s} Mm \qquad 3.3$$

Normally, a simplifying assumption made is that n $= \omega s$ at synchronous speed. This is not the same as saying that the speed is constant, it assumes that speed changes are small and do not have a significant effect. Thus, Equation (3.1) yields [47].

Pm=Mm 3.4

This is because the water flow Q through the turbine and the mechanical power produced by the turbine represent the exchange of matter and the transfer of energy in the turbine system. They are taken into account in turbine modeling. Both variables depend on the parameters gate opening increment Gt, velocity increment ω, and head increment Hd, which are expressed as nonlinear functions as follows:

Q=Q(Hd, ω , Gt) 3.5

Pm=M(Hd, ω , Gt) 3.6

Through linearization of the Equation (3.3) and Equation (3.4) around the steady state values, we obtain:

$$\Delta Q = \frac{\partial Q}{\partial G}\Delta Hd + \frac{\partial Q}{\partial G}\Delta Gt + \frac{\partial Q}{\partial \omega}\Delta\omega \qquad 3.7$$

$$\Delta Pm = \frac{\partial Pm}{\partial G}\Delta Hd + \frac{\partial Pm}{\partial G}\Delta Gt + \frac{\partial Pm}{\partial \omega}\Delta\omega \qquad 3.8$$

Normalizing Equation (3.5) and Equation (3.6) based on rated values; the following expressions that completely describe the turbine features are obtained:

$$\Delta\overline{Q} = a11\Delta\overline{H}d + a12\Delta\overline{G}t + a13\Delta\overline{\omega}$$

$$\Delta\overline{P}m = a21\Delta\overline{H}d + a22\Delta\overline{G}t + a23\Delta\overline{\omega}$$

Where the following notations were used:

$$\Delta\overline{Q} = \frac{\Delta Q}{\Delta Qo}, \quad \Delta\overline{P}m = \frac{\partial Pm}{\partial Pmo}, \ \Delta\overline{H}d = \frac{\partial Hd}{\partial Hdo}, \ \Delta\overline{G}t = \frac{\partial Gt}{\partial Gto}, \quad \Delta\overline{\omega} = \frac{\partial\omega}{\partial\omega o}, \quad a11 = \frac{\partial Q}{Hd}, \ a12 = \frac{\partial Q}{\partial Gt},$$

$$a13 = \frac{\partial Q}{\partial\omega}, \ a21 = \frac{\partial Pm}{\partial Hd}, \ a22 = \frac{\partial Pm}{\partial Gt}, \ a23 = \frac{\partial Pm}{\partial\omega}$$

The partial derivatives of flow rate and mechanical power as a function of head, speed and gate position are called turbine coefficients. The turbine coefficient expresses the nonlinear characteristics of the turbine, and the partial derivative changes depending on the operating conditions of the turbine, such as the gate opening position Gt and the unit speed ω. The effect of turbine coefficients on model accuracy is very important. These values must be measured accurately in the field or obtained from model testing. The partial derivative of mechanical power with respect to gate position $\frac{\partial Pm}{\partial Gt}$ is called turbine gain. Turbine Gain is a critical parameter for an accurate approximation of hydro power plants dynamics, and has to be measured precisely in the field. The partial derivative of flow with respect to rotational speed $\frac{\partial Q}{\partial \omega}$ is usually considered to be negligible. The deviation of mechanical power with rotational speed $\frac{\partial Pm}{\partial \omega}$ is known as turbine self-regulation. The value of the turbine self-regulation is negative with an absolute value usually near unity. In inter connected power system the hydraulic units are synchronized with the system as a result speed vibration $\Delta\omega$ is fairly small and usually neglected. Consequently, the above equation is simplified to the equation below [48].

$$\Delta\overline{Q} = a11\Delta\overline{H}d + a12\Delta\overline{G}t \qquad 3.9$$

$$\Delta\overline{P}m = a21\Delta\overline{H}d + a22\Delta\overline{G}t \qquad 3.10$$

Let’s consider m1, m2... mn the water masses in the pipe zones having the lengths l1,l2,...,ln and cross-sections A1, A2,..., An of the real feed system. The equivalent system will have the length L=l1+l2+……..+ln and cross-section, conveniently chosen. In this case, the mass conservation law in both systems will lead to the equation:

$$A\sum_i^n = 1li = \sum_i^n = 1liA \qquad 3.11$$

Since the water can be considered incompressible, the flow Qi through each pipe segment with cross-section Ai is identical and equal with the flow Q through the equivalent pipe.

$$Q = V * A = Qi = Vi * Ai \text{ For i=1, 2,,,, n} \qquad 3.12$$

Where V is the water speed in the equivalent pipe and Vi is the speed in each segment of the real pipe. From the mass conservation law it results:

$$V = \frac{Q}{A} = \frac{Qi\sum li}{\sum Ai * li} = \frac{\sum li}{\sum li * Ai} * Q \qquad 3.13$$

Through linearization of Equation (3.11) around operation point we obtain:

$$\Delta Q = \frac{\partial Q}{\partial V}\Delta V$$

$$\Delta Q = A\Delta V \qquad 3.14$$

Normalize the above equation by dividing both sides by Qo = AVo which yield

$$\frac{\Delta Q}{Qo} = \frac{A\Delta V}{AVo}$$

$$\Delta \overline{Q} = \Delta \overline{V} \qquad 3.15$$

The velocity of the water in the penstock is given by the formula [49],

$$V = KuG\sqrt{Hd} \qquad 3.16$$

Where V = water velocity Gt= gate position Hd= Hydraulic head at gate

Ku = a constant of proportionality

Through linearization of the Equation (3.14) around the steady state values, we obtain:

$$\Delta V = \frac{\partial V}{\partial H}\Delta Hd + \frac{\partial V}{\partial G}\Delta Gt$$

$$\Delta V = 0.5\Delta Hd + \Delta Gt \qquad 3.17$$

Normalize the above equation by dividing both sides by Vo=kuGto $\sqrt{Hdo}$ which yield

$$\frac{\Delta V}{Vo} = \frac{\Delta Hd}{2Hdo} + \frac{\Delta G}{Go}$$

$$\Delta \overline{V} = 0.5\Delta \overline{Hd} + \Delta \overline{Gt} \qquad 3.18$$

Where the subscript 0 denotes initial steady-state values, the prefix Δ denotes small deviations, and the super bar "-"indicates normalized values based on steady-state operating values.

By Substituting Equation 3.17 in Equation (3.12) we obtain:

$$\Delta \overline{Q} = 0.5\Delta \overline{H}d + \Delta \overline{Gt} \qquad 3.19$$

The acceleration of water column due to a change in head at the turbine, characterized by Newton's second law of motion, is expressed as

$$\Delta HdA\rho ag = -\rho AL\frac{d\Delta V}{dt} \qquad 3.20$$

Where L = length of conduit, A = pipe area. ρ = mass density, ag = acceleration ρAL = mass of water in the conduit, ΔHd ρag = incremental change in pressure at turbine gate t = time in seconds

Dividing both sides of Equation (3.19) by, Aρag HdoV0 the acceleration equation in normalized form becomes

$$\frac{\Delta H}{Hdo} = -\frac{l}{ag}\frac{\Delta H}{Hdo}\frac{d}{dt}\left(\frac{\Delta V}{Vo}\right)$$

$$\Delta\overline{H}d = -\frac{l}{ag}\frac{\Delta V}{Hdo}\frac{d}{dt}\left(\Delta\overline{V}\right)$$

$$\Delta\overline{H}d = -Tw\frac{d}{dt}\left(\Delta\overline{V}\right) \qquad 3.21$$

Where $= \frac{l}{ag}\frac{\Delta V}{Hdo}$

Tw is called the water time constant. It represents the time required by the head H do for the water in the penstock to accelerate from rest to velocity Vo. Note that Tw varies with load. Typically, Tw is between 0.5 and 4.0 s at full load and the water time constant remains constant in load-controlled micro-hydro plants. From Equation 3.18 and Equation 3.20, the relationship between velocity change and gate position change can be expressed as [49]:

$$\mathrm{Tw}\frac{d}{dt}\left(\Delta\overline{V}\right) = 2(\Delta\overline{G}t - \Delta\overline{V}) \qquad 3.22$$

After Laplace transforming and simplifying Equation 3.20 we obtain:

$$\Delta\overline{V} = \frac{\Delta\overline{G}t}{1 + 0.5Tw}$$

Substituting this equation in Equation 3.13 we obtain:

$$\Delta\overline{Q} = \frac{\Delta\overline{Gt}}{1 + 0.5Tw}$$

For an ideal turbine, without losses, the coefficients aij resulted from the partial derivatives in Equation 3.8 and Equation 3.8 have the following values:a11 = 0.5; a12= 1; a21=1.5; a22= 1. After substituting this value in Equation 3.7 and Equation 3.8 we obtain:

$$\Delta\overline{Q} = 0.5\Delta\overline{H}d + \Delta\overline{G}t$$

$$\Delta\overline{Pm} = 1.5\Delta\overline{H}d + \Delta\overline{G}t$$

$$\Delta\overline{Pm} = 1.5(2)(\Delta\overline{Q}t - \Delta\overline{G}t + \Delta\overline{Gt})$$

$$\Delta\overline{Pm} = 3\Delta\overline{Q} - 2\Delta\overline{Gt} \qquad 3.22$$

After substituting Equation 3.21 in Equation 3.22 the transfer function of the turbine is determined as follows: [44]

$$Gt(s) = \frac{\Delta PG(S)}{\Delta X(s)} = \frac{\Delta \overline{P}m}{\Delta \overline{G}t} = \frac{1 - Tw}{1 + 0.5Tw} \qquad 3.23$$

Here Tw (s) is nominal starting time of water in penstock or water starting time and its value varies between 1-4s.Tw is 1 s for low head, 2.2 s for medium head and 4 s for high head, s is Laplace transform complex variable operator, ΔPG (per unit) is incremental power (torque) output of turbine, ΔX (per unit) is incremental power input to the turbine (valve position). Note that water flow in the penstock is subject to the phenomenon of water hammer, which result in a non-minimum phase system. Further, the water-hammer effect means an initial tendency exists for the torque changes in an opposite direction to the water flow changes.

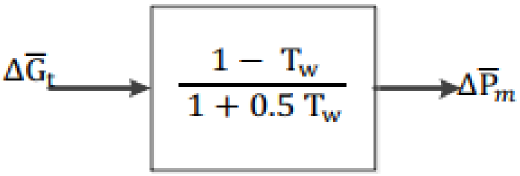


Figure 3.4 Linear turbine model

3.4.3 Generator model

The dynamic behavior of generators is important in energy systems. A generator converts mechanical power into electrical power of appropriate voltage and frequency. Load frequency control is commonly used in power systems because system frequency and active power balance are linked. The generator model is also based on the frequency change response. Equations of motion and vibration are used to set up this model. The electrical model of the generator is known from the mechanical equations and can be obtained using the rotational inertia vibration equations. Therefore, the power generation part is modeled with linear differential equations that can respond quickly to small disturbances. The vibration equation relates the rotor torque angle and acceleration torque of a machine. This is the difference between the shaft torque and the electromagnetic torque. When the mechanical and electrical torques are balanced, the speed of the generator remains constant. An imbalance between torques causes the machine to accelerate or decelerate. The equations of motion for a rotating body are given as follows (Tabakh, 2020; Tiryaki and Gün, 2019; Kundur et al. 1994).

$$Ta = Tm - Te \qquad 3.24$$

Where Ta=acceleration torque in N.m

Tm=mechanical torque in N.m

Te=electromagnetic torque in N.m

The combined inertia of the generator and prime mover is accelerated by the unbalance in the applied torques. Hence the equation of motion is

$$J\frac{dWm}{dt} = Ta = Tm - Te \qquad 3.25$$

Where J=combined moment of inertia of generator and turbine, Kg.m^2

Wm=angular velocity of the rotor, mech, rad/sec

t=times, s

The per unit inertia constant H, defined as the kinetic energy in watt-seconds at rated speed divided by the VA base. Using the

$$H = \frac{1Jwom^2}{2VAbase} \qquad 3.26$$

The moment of inertia J in terms of H is

$$H = \frac{2H}{wom^2}VAbase \qquad 3.27$$

Substituting Equation (3.10) in Equation (3.8) we get

$$\frac{2H}{wom^2}VAbase\frac{dwm}{dt} = Tm - Te \qquad 3.28$$

Rearranging yields

$$2H\frac{d}{dt}\left(\frac{wm}{wom}\right) = \frac{Tm - Te}{VAbase/wom}$$

$$2H\frac{d}{dt}\left(\frac{wm}{wom}\right) = \frac{Tmwom - Tewom}{VAbase}$$

$$2H\frac{d}{dt}\left(\frac{wm}{wom}\right) = \frac{pm - pe}{VAbase} \qquad 3.29$$

Where $pm = Tmwom$ is the mechanical input power to the synchronous generator and

$Pe = Tewom$ is the electrical power generated by the generator.

In per unit the above equation can be rewritten as

$$2H\frac{d}{dt}\overline{wm} = \overline{pm} - \overline{pe} \qquad 3.30$$

$$\overline{wr} = \frac{wm}{wom} = \frac{wr/pf}{wo/pf} = \overline{wm}$$

Where wr=angular velocity of the rotor, electrical. rad/sec

Wo=rated angular velocity of the rotor, electrical. rad/sec

If δ the angular position of the rotor in electrical radians with respect to a synchronously rotating reference and δ is its value at t=0,

$$\delta = Wrt - Wot + \delta o \qquad 3.31$$

Taking the time derivative,

$$\frac{d\delta}{dt} = wo - wr = \Delta wr$$

$$\frac{d^2\delta}{dt^2} = \frac{dwr}{dt} = \frac{d\Delta wr}{dt}$$

$$= wo\frac{d\overline{wr}}{dt} = wo\frac{d\Delta\overline{wr}}{dt}$$

From which

$$\frac{d\overline{wr}}{dt} = \frac{d\Delta\overline{wr}}{dt} = \frac{d\overline{wm}}{dt} \qquad 3.32$$

Substituting Equation (3.31) in Equation (3.29),

$$2H\frac{d}{dt}\Delta\overline{wr} = \Delta\overline{pm} - \Delta\overline{pe}$$

With the Laplace transformation,

$$2Hs\Delta\overline{wr} = \overline{\Delta pm}(s) - \overline{\Delta pe}(s) \qquad 3.34$$

$$\Delta\overline{wr} = \frac{\overline{\Delta pm}(s) - \overline{\Delta pe}(s)}{2Hs} \qquad 3.35$$

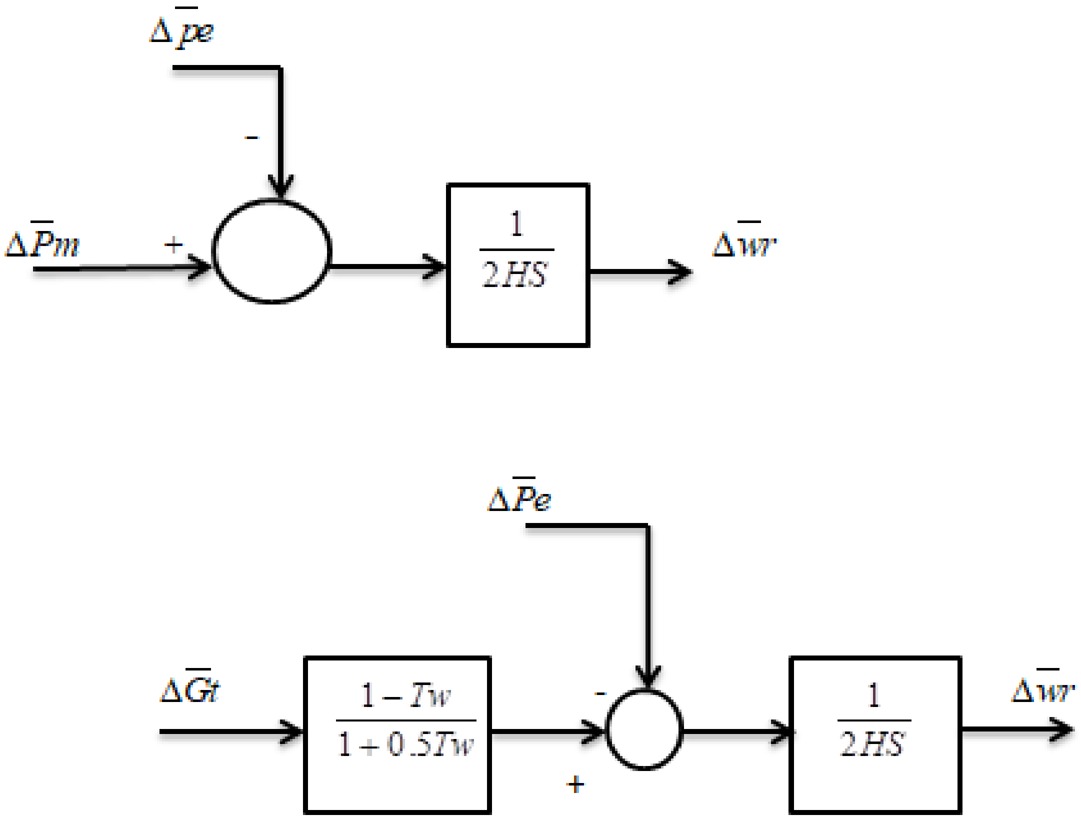


Figure 3.5 Generator model coupled with turbine

Table 3.3 Specifications of 1FC2-283-4 synchronous generator

Parameter	**Value**
Current rating	45.106A
The moment of inertia	2.03 kgm^2
Power factor	0.8
Load damping coefficient	0.8%
Generated power	50KW
Consumed power	25KW
Voltage rating	400 v
Speed	1500rpm

Number of pole	4

3.4.4 Load Modeling

Mains loads are all electrical devices that people want to use in their homes and offices. For resistive loads such as lighting, computers, and heating loads, the power is frequency independent. For engine loads such as fans and pumps, power varies with frequency due to changes in engine speed. The overall frequency dependent properties of the combined load can be expressed as [48].

$$\Delta\overline{pe}(s)=\Delta\overline{P}D(S)=\Delta\overline{psl}(s)-D\Delta\overline{wr}(s) \qquad 3.36$$

Where $\Delta\overline{psl}(s)$ =non-frequency sensitive consumer load change.

$D\Delta\overline{wr}(s)$=frequency sensitive load changes.

D is expressed as % change in load divided by % change in frequency.

Typical values of D are 1 to 2 percent. Substituting Equation (3.35) in Equation (3.35),

$$\Delta\overline{wr}(s)=\frac{\Delta\overline{pm}(s)-\Delta\overline{psl}(s)-D\Delta\overline{wr}(s)}{2HS}$$

$$\Delta\overline{wr}(s)\;2HS=\Delta\overline{pm}(s)-\Delta\overline{psl}(s)-D\Delta\overline{wr}(s)$$

$$\Delta\overline{wr}(s)(2HS+D)=\Delta\overline{pm}(s)-\Delta\overline{psl}(s)$$

$$\Delta\overline{wr}(s)=\frac{\Delta\overline{pm}(s)-\Delta\overline{psl}(s)}{(2HS+D)} \qquad 3.37$$

According to the load frequency characteristic, a load damping term is employed to describe the swing equation of a synchronous generator. By taking Laplace transform for the equation, the generator dynamics is able to be gotten as

$$Gp(s)=\frac{\Delta F(s)}{\Delta PG(s)-\Delta PL(s)}=\frac{Kp}{TpS+1} \qquad 3.38$$

Here ΔPL (per unit kW) is step function load disturbance, Kp is generator gain constant, defined by $Kp = \frac{1}{D} = \frac{1}{\partial PL / \partial F}$, TP (s) is generator time constant, defined by $Tp = \frac{2H}{f^{o} D}$, where H is inertia constant of synchronous generator, f^{0} (Hz) is nominal system frequency.

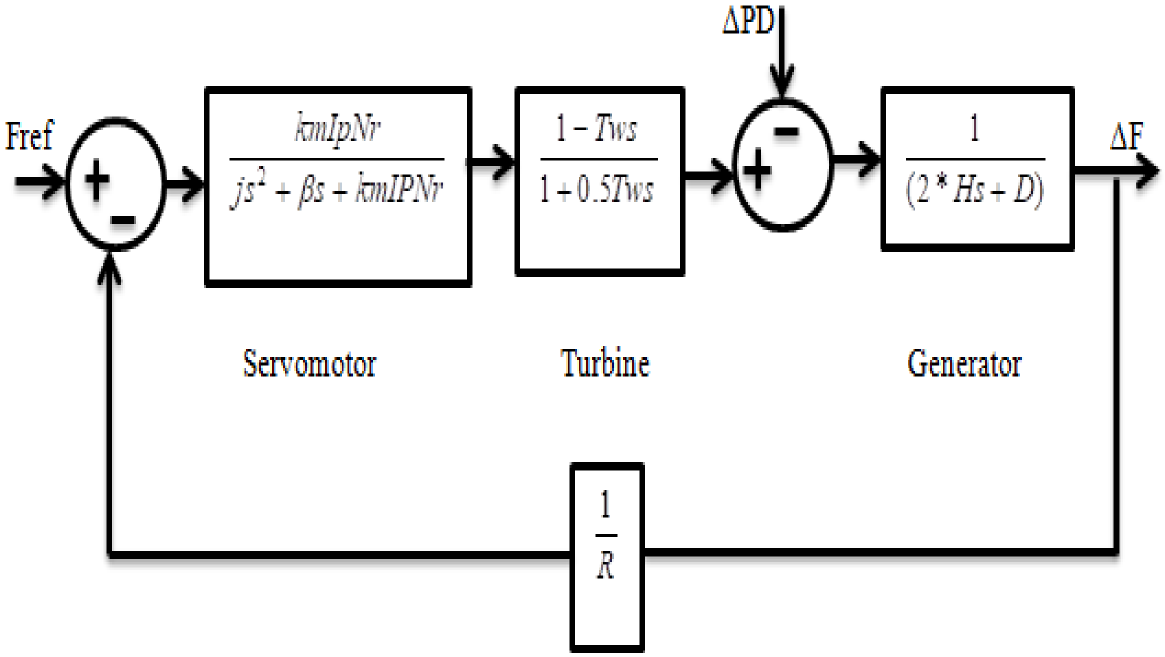


Figure 3.6 The overall block diagram of frequency control of keramo MHPP

3.5 Conventional PID controller

Frequency control in hydropower plants is mainly used in conventional PID control systems (Saha and Saikia, 2018)[50]. An error value is calculated as the difference between the measured process variable (actual plant performance) and the desired set point. Frequency and effective power can be adjusted by adjusting the guide part of the waveguide wheel. In addition, an attempt is made to reduce the deviation by adjusting the manipulated variable. Generally, it is mainly used in industrial processes because it has many advantages such as: B. Easy operation by plant operators, near-optimal performance and wide range of applications. PID controllers try to minimize the error over time by adjusting the control value U(t). This is common in proportional-integral-derivative control. Mathematically, frequency control in a hydroelectric system can be expressed as an equation. (3.39).

$$U(t) = kp(e(t) + \frac{1}{Ti}\int_0^T e(t).dt + Td\,\frac{d}{dt}e(t)) \qquad 3.39$$

Where U is the control value, Kp is the gain, Ti is the integral time and Td is the derivative time.

Parameter	kp	ki	Kd
Values	0.613	0.104	0.002

3.6 Artificial Intelligent Controller

Power system performance must be managed to maintain frequency and control the quality of power generated by the system. Therefore, energy systems, especially small independent hydropower plants, require control systems [51]. In this thesis, two different intelligent controllers of his, a fuzzy logic controller and an adaptive neurofuzzy controller, were used to control the frequency of a stand-alone micro-hydro system.

3.6.1 Fuzzy Logic Controller

Fuzzy logic is a type of reasoning or problem-solving control used in the development of control systems to control systems whose inputs are incorrect or wholly absent [52]. The block diagram and structure of the fuzzy logic controller are shown in the figure. The two input variables used by the LFC member unit are the frequency error f and its derivative. Input is given by:

$$e(t)=r(t)-y(t) \tag{3.39}$$

$$de\,(t)=e(t)-e(t-1) \tag{3.40}$$

The design of fuzzy controllers relies on information about the behavior of the system or the experience of human experts. The level of fuzzification is determined by the selection of range, shape, and number of membership functions. The input and output membership function bounds are chosen in [-2.5 Hz, +2.5 Hz]. According to the IEC 60034 standard, the normal frequency variation of the power system should be within 5% of the reference frequency. For power grids with a standard frequency of 50 Hz, this means that the controller should not tolerate frequency variations below -2.5 Hz and above +2.5 Hz. Frequency outputs in this range are classified as interference by the control technology used and ultimately trigger electrical protection in small hydropower plants as a reaction to such interference. As shown in Figure 3.8, the constant gain blocks are used as scaling factors Ke, Kec, and Ku, respectively, to create the normalized input and output of the fuzzy logic controller.

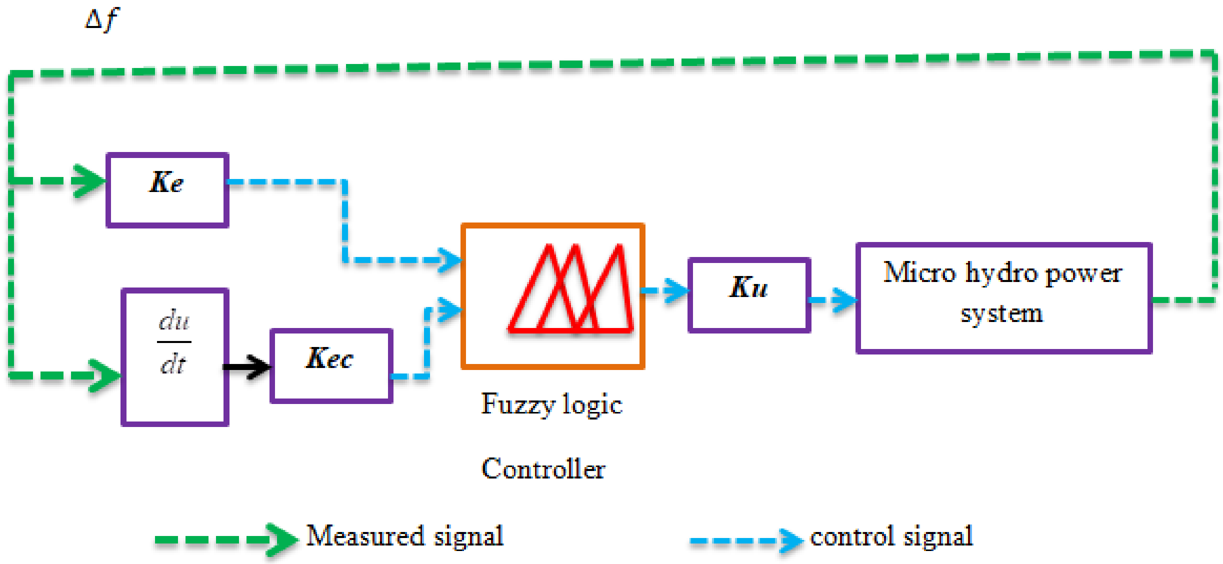


Figure 3.7 Block diagram of Fuzzy logic controller

Two known inference systems based on fuzzy rules are the Mamdani fuzzy method and the Tagaki-Sugeno (T-S) fuzzy method. Mamdani's fuzzy inference system has the following advantages: It is intuitive, widely accepted, and amenable to human perception. The Mamdani fuzzy inference system has shown advantages in output representation and is also used in this work [53].

3.7 Adaptive Neuro Fuzzy controller (ANFIS)

ANFIS is a multilayer adaptive fuzzy inference system based on neural networks [54]. In order to learn and optimize the parameters of the fuzzy inference system, or "FIS," the ANFIS algorithm implements several node functions using fuzzy logic and a five-layer neural network applying an integrated learning approach for structuring. A least-squares error estimation method is used in the forward pass of training with fixed assumptions to update the sequence parameters and transfer the error to the backward pass. Gradient descent is used to update the assumed parameters during the backward pass of training while the sequence parameters are fixed. Membership function (MF) and FIS premise and result parameters are found by successive forward and backward passes. Fuzzy Sugeno models are incorporated into the architecture of adaptive systems to help in learning and adaptation, and these systems are known as adaptive neuro fuzzy inference systems [54]. A structure like this makes FLC more organized and less specialized. The fuzzy inference system in this study has two sets of inputs Δf, $\Delta^{\bullet} f$ and one output (U). Consider a rule base with two fuzzily defined if-then rules of the Takagi and Sugeno types.

Rule 1: If Δf is X1 and $\Delta^{\bullet} f$ is Y1, then $u1 = p1\Delta f + q1\Delta f + r1$

Rule 2: if Δf is X2 and $\Delta^{\bullet} f$ is Y1, then u2=p2Δf+q2Δf+r2

where *Δf* and $\Delta^{\bullet} f$ are the inputs, Ui are the outputs within the fuzzy region specified by the fuzzy rule, pi, qi and ri are the design parameters that are determined during the training process. Out of the five layers, the first and the fourth layers consist of adaptive nodes while the second, third and fifth layers consist of fixed nodes.

The adaptive nodes are associated with their respective parameters, get duly updated with each subsequent iteration while the fixed nodes are devoid of any parameters. The ANFIS architecture to implement these two rules is shown in Fig. 3.8.

Layer 1: This layer is an adaptive node and also known as fuzzification layer. The values of parameters of this layer are changes according to the error signal and generate the proper value of each membership function, each node denoted as i, and adaptive with a node function, as shown;

$0i^{1} = \mu xi(\Delta f)$ for i=1, 2,……………………………………………………………….3.41

$0i^{1} = \mu y1 - 2(\Delta^{\bullet} f)$ for i=3,4………………………………………………………….3.42

Where, Δf (or $\Delta^{\bullet} f$) is input at node i, while Xi (or Yi) is a linguistic label (fuzzy sets: Big, Small, …) μxi and μyi represents the member ship functions of each nodes. The parameters in this layer the basic parameters or named as precondition parameters.

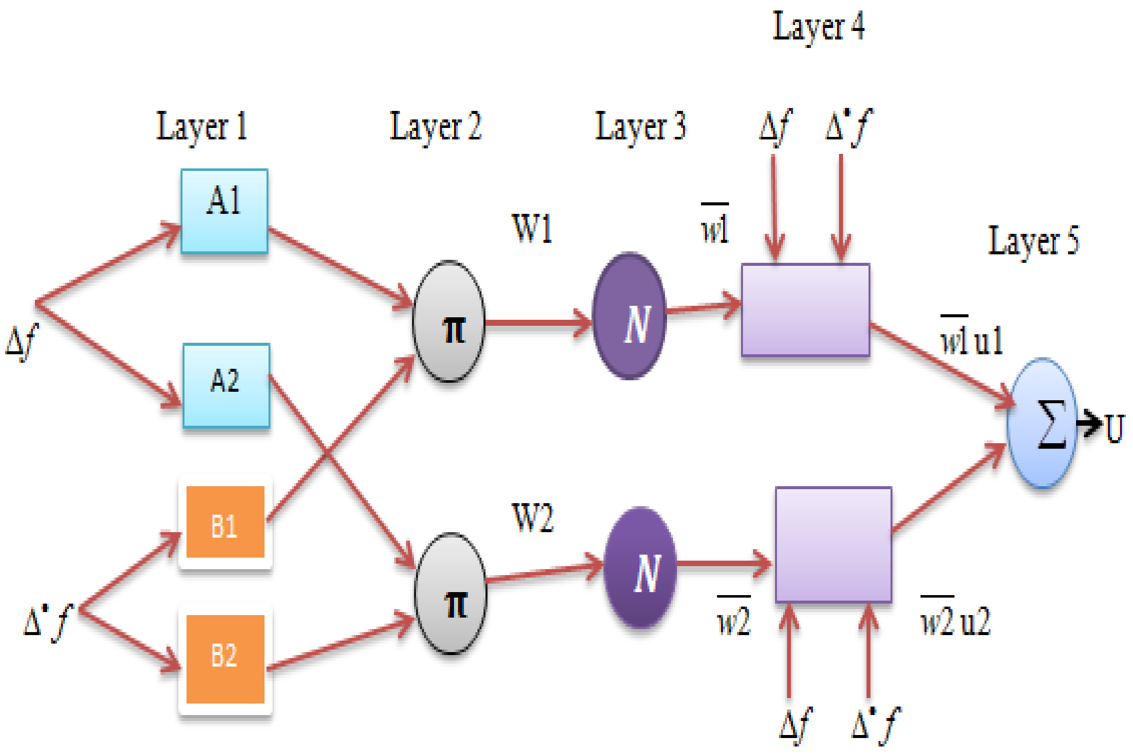


Figure 3.8 Architecture of ANFIS

Layer 2: In this layer, the outputs of the first layer are multiplies with each other and forwards it to the next layer. The node in this layer is a fixed node and labeled Π (AND or multiplication), which is used to calculate the degree of activation or (firing strength) wi of a rule. The output obtained from each node of this layer is given by;

$0i^2 = wi = \mu xi(\Delta f)\times \mu yi(\Delta^{\bullet} f)$ for i=1, 2…………………………………………………………..3.43

Layer 3: This layer calculates the normalized firing strength of each rule and labeled as N (Normalization). Each node in this layer is also a fixed [55].The output of this layer is the normalized firing strength of each node which is calculated as the ratio of the ith rule's firing strength to the sum of firing strengths of all the rules, the output from the it^{h} node is the normalized firing strength $(\overline{wi})$ and is given by ;

$oi^3 = \overline{wi} = \dfrac{wi}{w1+w2}$ for i=1,2…………………………………………………………………3.44

Layer 4: Each node in this layer is an adaptive node and the output obtained from this layer is given as follows;

$Oi^{4} = \overline{Wi}Ui = \overline{Wi}\left(pi\Delta f + qi\Delta^{\bullet} f + ri\right)$ for i=1,2……………………………………………….....3.45

Where, $\overline{wi}$ is the output of the third layer and {pi, qi, ri} is the parameter set of this node. The parameters in this layer are referred to as consequent parameter.

Layer 5: This layer is the last layer of ANFIS architecture which result the output U and labeled as ∑, which computes the overall output as a summation of all incoming signals to the node which is given by;

$$Oi^{5} = U = \sum \overline{Wi}Ui = \frac{\sum wiui}{\sum wi} \text{ ……………………………………………………….3.46}$$

3.8 NEURO-FUZZY CONTROLLER

In this section a control strategy that was developed using the principles of the ANFIS control system to control the frequency deviation of a standalone micro hydro power system is provided. In order to create a model that utilizes fuzzy theory to represent knowledge in an understandable way and a neural network's ability for learning to optimize its parameters, the neuro-fuzzy method combines the benefits of neural networks with fuzzy theory. The suggested thesis controller integrates a fuzzy logic algorithm with a five-layer ANN structure to combine the advantages of both techniques. ANFIS is a particular method to creating neuro-fuzzy systems that first appeared by Jang [54]. First, the ANFIS scheme is used to design the controller. The Takagi-Sugeno Fuzzy inference model is the base of the model under discussion. The suggested ANFIS-based Neuro-Fuzzy controller for micro hydro power system is illustrated in Fig. 3:10 as a block diagram with four components: fuzzification, knowledge base, neural network, and the de-fuzzification sections.

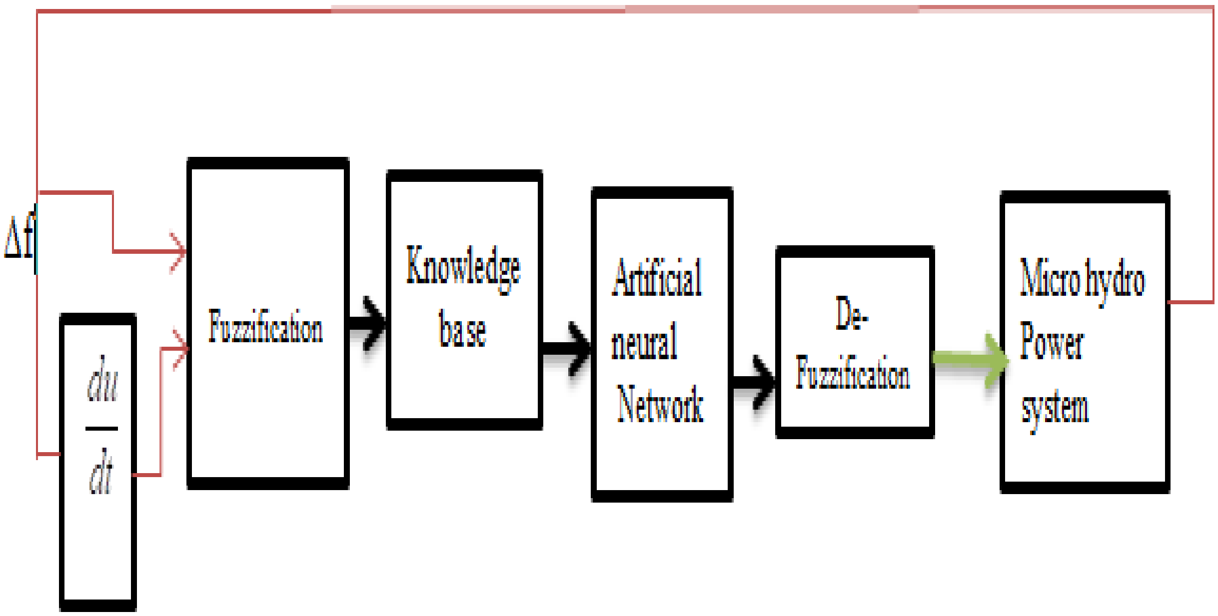


Figure 3.9 Block diagram of ANFIS based Neuro-Fuzzy Controller

→ Control signals → measured signals

In order to determine the resulting parameters of fuzzy inference frameworks of the Sugeno type, ANFIS implements a hybrid learning technique. The membership work parameters for the fuzzy inference system have been developed using a combination of the least squares strategy and the back propagation gradient reduction strategy for replicating the training data set. The fuzzy inference system under consideration has two inputs. In the proposed thesis, inputs to the ANFIS considered are error (ΔFs) and change in error (ΔFs)' where as the output is the corresponding signal to the gate opening.

Steps to design the Neuro-Fuzzy Controller are as given below:

1. Draw the Simulink model with FLC (Takagi-Sugeno inference model) and simulate it with 7 membership functions for the two inputs (error (ΔFs) and change in error (ΔFs)' and with the given rule base.
2. Collect the training data while simulating with FLC to design the Neuro-Fuzzy controller.
3. The two inputs, i.e., error (ΔFs) and change in error (ΔFs) and the output signal give the training data.
4. Use „anfisedit‟ to create the Neuro-Fuzzy FIS file.

5. Load the training data collected in Step.1 and loads the Neuro-Fuzzy FIS file.

6. Choose the hybrid learning algorithm.

7. Train the collected data with generated FIS up to a particular no. of Epochs.

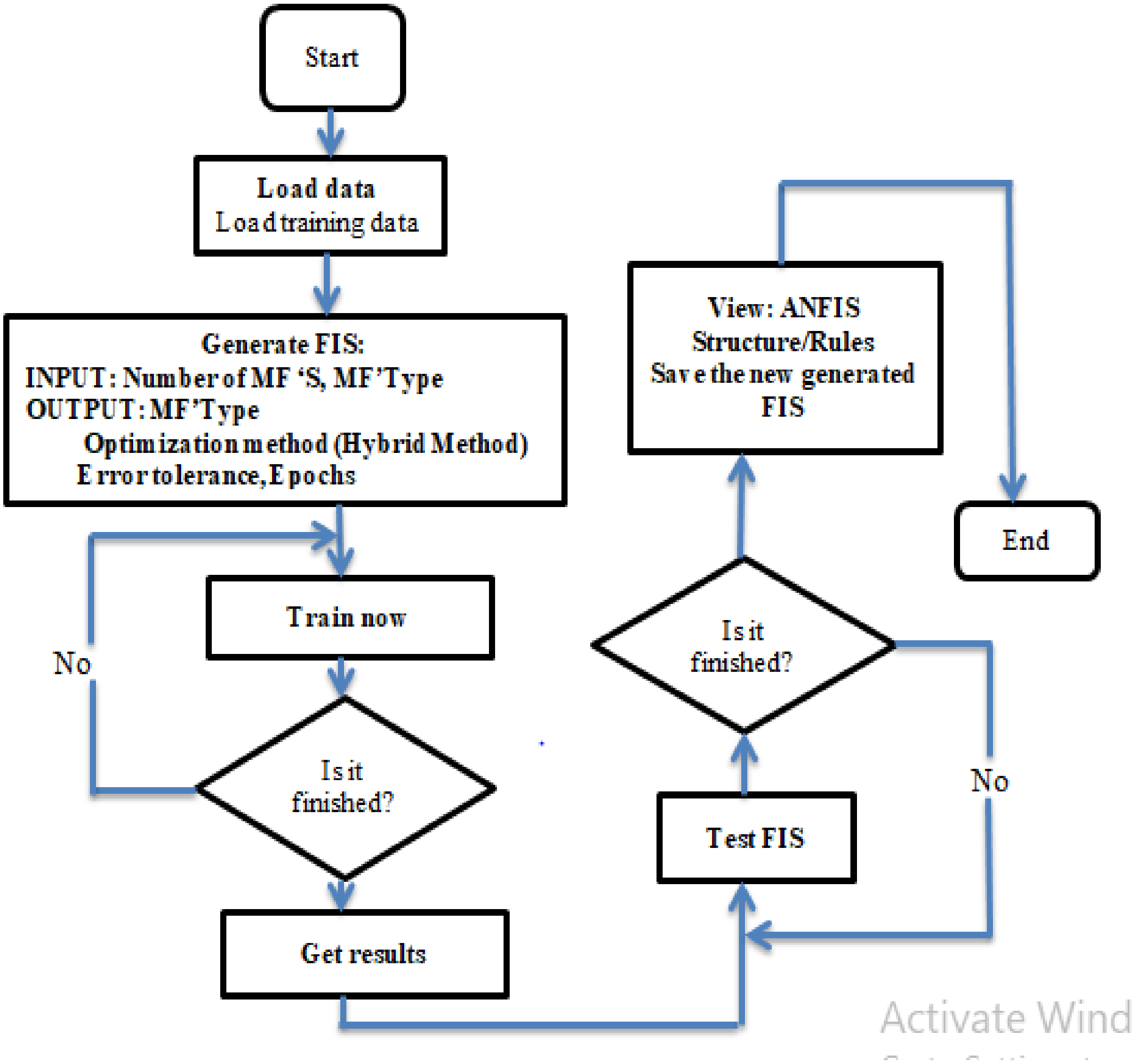


Figure 3. 1 Flow chart of the ANFIS structure

3.9 Over all simulation design of standalone frequency control of micro hydro power plant

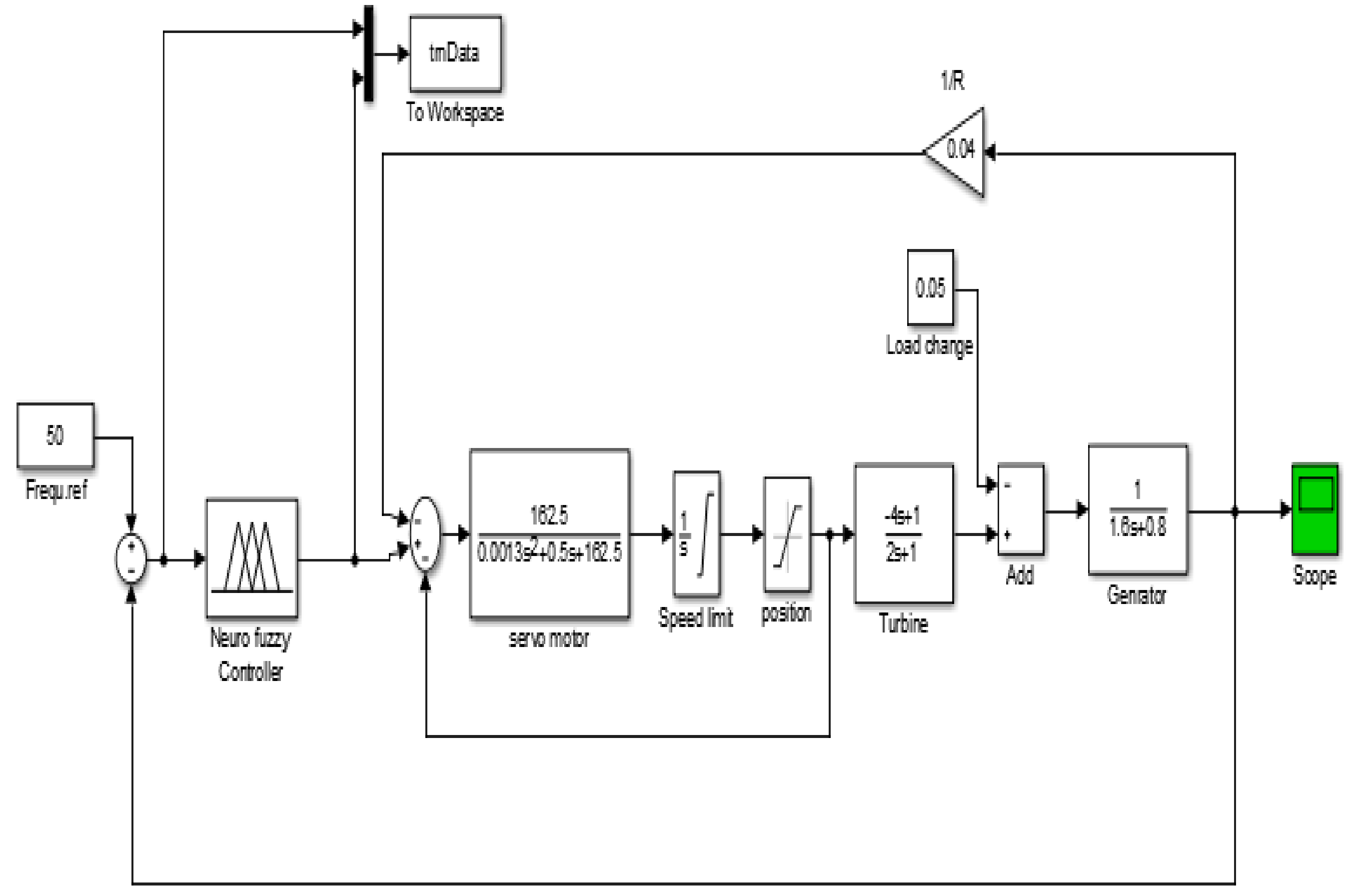


Figure 3.10 over all simulation design of frequency control of MHPP based on FVC with Neuro fuzzy controller

CHAPTER FOUR

RESULT ANALYSIS AND DISCUSSION

4.1 INTRODUCTION

This chapter presents simulation result got from tests performed on the Keramo standalone micro hydro powe plant using Matlab Simulink with a different type of controller. The Simulink model shown in the below is used to carry out simulation studies and analyze the performance of controlled by comparing simulation of existing flow control valve or servomotor device, PID and Neuro-fuzzy controller. The proposed neuro-fuzzy controller changes the states of servomotor as flow valve control (FVC) to control the frequency deviation of micro hydropower plant. This chapter presents the design and analysis of the proposed control system for standalone micro hydropower plant.

The acceptable speed deviation at full load for the synchronous generator 1FC2-283-4 is shown in Table 3.3. Therefore, a steady-state frequency deviation of 5% is set as the desired specification. Calculate the rotor inertia constant (H) of the connected synchronous generator and turbine based on the specifications. The connected efficiency of the turbine and generator become 80%, and the moment of inertia of the synchronous generator rotor and its couple is calculated. Since the mechanical power of the prime mover is 50 kW, the moment of inertia becomes and Sbase=62.5KVA.

First to find synchronous speed (N_s) = $\frac{120f}{p}$ =$\frac{120*50}{4}$ =1500rpm

ω_m =$\frac{2\pi*N_S}{60}$ = $\frac{2\pi*1500}{60}$ = 157rad/sec, $J = \frac{50000}{0.5(157^2)} = 4.057\ kg.m^2$

The inertia constant (H) is found to be H = $\frac{0.5J\omega_m^2}{S_{base}}$ = $\frac{0.5*4.057*(157)^2}{62500}$ =0.800 sec

2*H=2*0.800sec=1.6sec and Load Damping coefficient=0.8

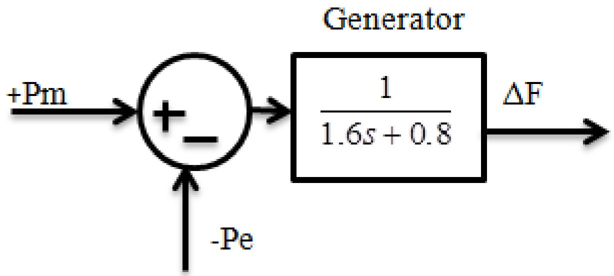


Figure 4.1 generator and load model

The standalone frequency control of micro hydro power plant figure 3.10 R, represents frequency regulation gain HZ/Pu KW with magnitude 0.05 respectively; Tw represents water flow constant through turbine with magnitude of 4sec, and other power system parameters are given in appendix A.

4.2 Proposed neuro-fuzzy (ANFIS) controller procedures

A standalone MHPP system's frequency control receives data on frequency error and frequency error rate of change, and the system's output is a power control control signal. To give the ANFIS model with the necessary training and test data, data was collected through the controller. The ANFIS controller is modeled using: creating I/O data pairs to set the controller's parameter range. The fuzzy MF is then initialized and optimized using the neuro-fuzzy structure. The optimization method was a hybrid learning algorithm, which integrates both the least-squares estimation method and the back propagation algorithm.

Training of the ANFIS model.

The AFIS network learning algorithm is used to tune the adaptive node parameters (premise and outcome parameters) to achieve the desired performance. The training and testing process is an important phase of AFIS modeling as it defines the behavior of the developed model. A test dataset was used to validate the accuracy and validity of the AFIS model. Training is the learning process of the developed model. The model is trained on a suitable dataset and trained until it produces results with minimal error. This means the frequency deviation error and the change in frequency deviation error over the normal case evaluation range (-0.05 to 0.05). This data is very important for proper training and validation.

The output variable identified here is the reference gate opening, and this change in the AFIS universe discourse on gate opening yields values between [-0.975 and 0.975].

Below the table from the frequency deviation error and change of frequency deviation error is formed from the knowledge of the fuzzy inference system. This is applied to train the ANFIS.

Table 4.1Training data of the system to get knowledge of FIS

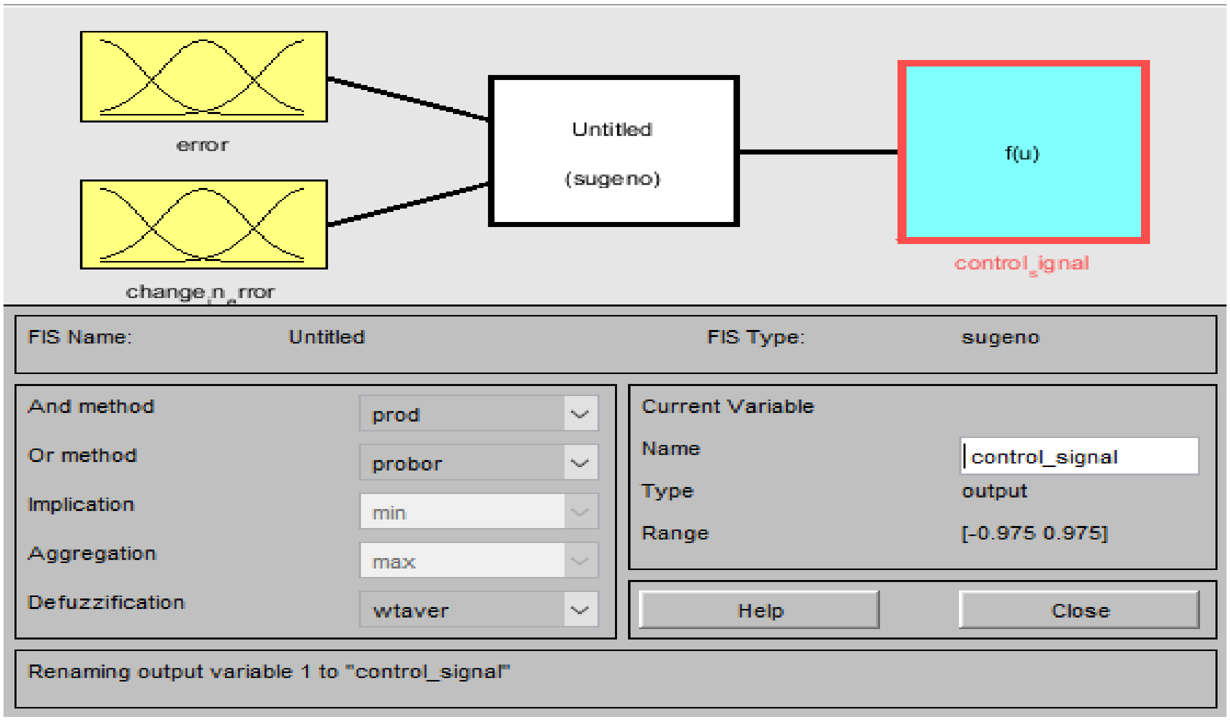
Error deviation	Change of error deviation	Control signal
-0.0500000000000000	-0.0500000000000000	-0.975000000000000
-0.0400000000000000	-0.0350000000000000	-0.775000000000000
-0.0300000000000000	-0.0250000000000000	-0.575000000000000
-0.0200000000000000	-0.0100000000000000	-0.375000000000000
-0.0100000000000000	-0.00500000000000000	-0.175000000000000
0	0	0
0.0100000000000000	0.00500000000000000	0.175000000000000
0.0200000000000000	0.0100000000000000	0.375000000000000
0.0300000000000000	0.0250000000000000	0.575000000000000
0.0400000000000000	0.0350000000000000	0.775000000000000
0.0500000000000000	0.0500000000000000	0.975000000000000

After loading and generating training data or an initial FIS structure, you can start training the FIS. MATLAB ANFIS has two of his learning algorithms, the back propagation algorithm and the hybrid algorithm. In this study, the input/output data were trained using a hybrid algorithm by choosing an appropriate number of epochs with zero error tolerance. A significant advantage of the AFIS design method compared to the fuzzy design method is the smaller number of input and output membership functions (7) shown in Table 4.3, which means the same maximum number of rules. Therefore, the rule base and memory used is much smaller.

Table 4.2 input and output membership functions

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

The frequency deviation and derivative of frequency deviation has been taken with seven numbers of membership functions in the first case, the dynamic response to load disturbance. After the application of fuzzy inference system 49 rule bases have been developed with 49 output membership function, then after application of DE fuzzification has been extracted one output.



FIS Name: Untitled
FIS Type: sugeno
And method: prod
Or method: probor
Implication: min
Aggregation: max
Defuzzification: wtaver
Current Variable
Name: control_signal
Type: output
Range: [-0.975 0.975]
Renaming output variable 1 to "control_signal"

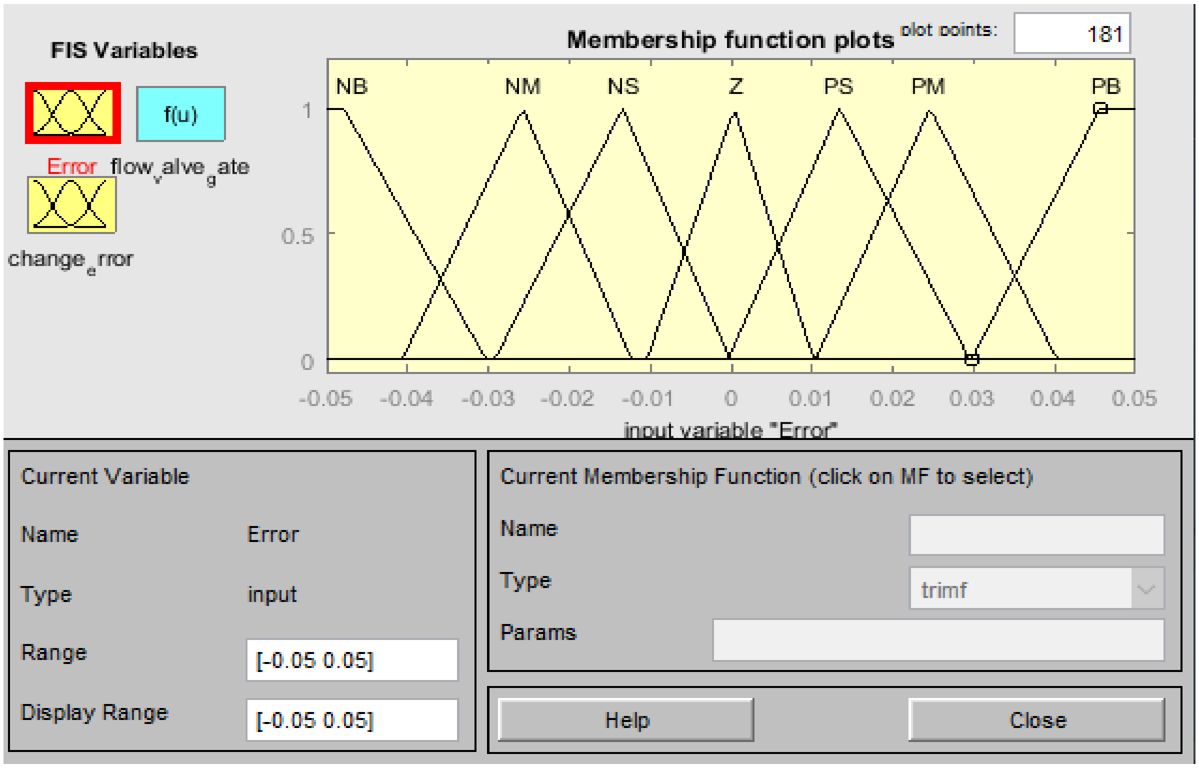
Figure 4.2 FIS editor (Sugeno model) with two inputs and one output.

a) Standalone keramo micro hydro power plant mode

At no load (PL=0) the change of frequency is Zero and at full load rejection (full load added) change in frequency deviation at Keramo MHPP acceptable range is ±5% or 0.05pu and (ΔPL=0.05 or 5%). This means the system is standalone keramo MHPP, frequency varies from 47.5HZ to 52.5HZ or (-2.5HZ to+2.5HZ) or in per unit varies from (-0.05 to 0.05 pu), so the discourse of ANFIS controller for error and change in error in operation of Keramo MHPP is (-2.5HZ to 2.5HZ).

I) Membership Function Error and change in Error

The limits of the keramo micro hydro power system frequency error was decided based on variation of the system frequency of the existing micro hydro power system, the ranges of frequency error in HZ is ±2.5HZ, that shown below the figure 4.3.



plot points: 181

Current Variable

Name Error

Type input

Range [-0.05 0.05]

Display Range [-0.05 0.05]

Current Membership Function (click on MF to select)

Name

Type trimf

Params

Figure 4.3 The frequency deviation Input error and change of error membership function

Figure 4.3 is a graph of the frequency error and change in frequency error fuzzy membership functions. It assigns a crisp value's degree of membership to seven fuzzy linguistic values -- NB, NM, NS, Z, PS, PM, and PB. The fuzzy input membership functions used for error in frequency and change of error in frequency are trapezoidal type for PB and NB and are triangular type for NM, NS Z, PS, and PM.

II) Output variable

The out variable identified here is the reference gate opening. The keramo MHPP gate opening system operation is: Minimum gate opening is 0.01pu (1%) and maximum gate opening =0.975pu (97.5%), from this change in gate opening ANFIS universe discourse is [-0.975 0.975].

Fuzzy inference Rule for the proposed controller

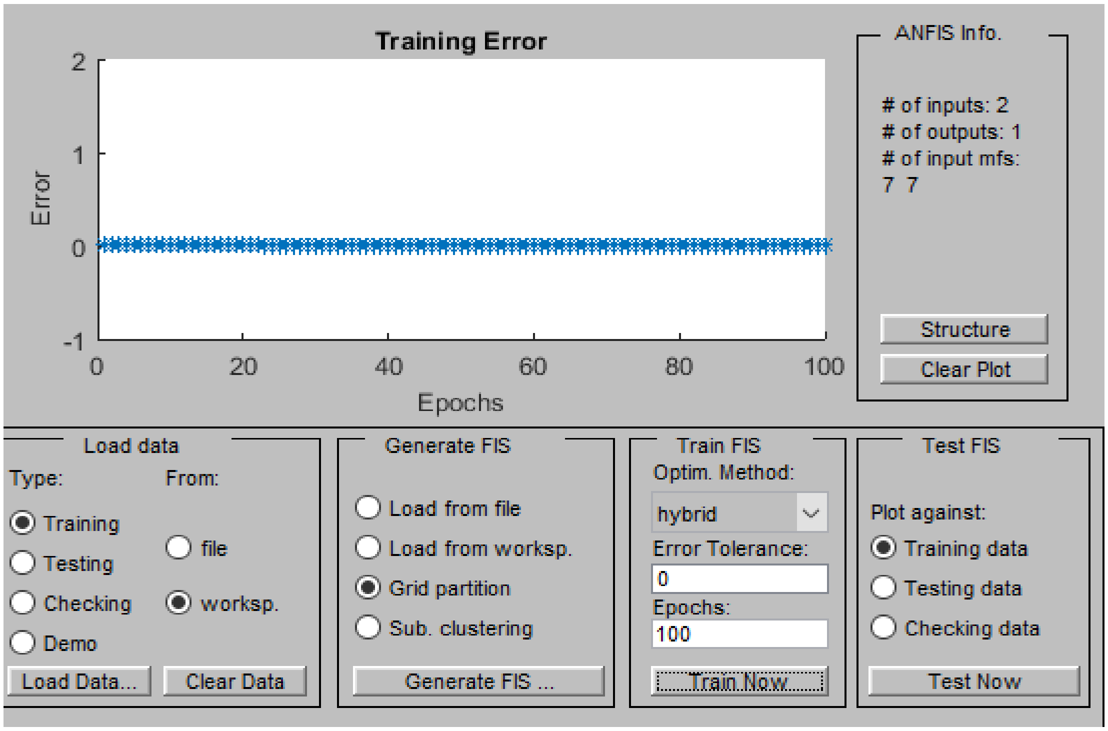
In this study, input and output membership function are same and seven segment both trapezoidal and triangular membership functions are used as stated earlier. Since each input has seven membership functions, the number of fuzzy based rules is 49 and they are presented in Table 4.3.

Table 4.3 Rule base with 49 rules

		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 standalone keramo micro hydro power plant operation mode, as follows

Neuro fuzzy designer



ANFIS Info.

# of inputs: 2
# of outputs: 1
# of input mfs:
7 7

Load data — Type: ● Training ○ Testing ○ Checking ○ Demo; From: ○ file ● worksp.

Generate FIS: ○ Load from file ○ Load from worksp. ● Grid partition ○ Sub. clustering

Train FIS — Optim. Method: hybrid; Error Tolerance: 0; Epochs: 100

Test FIS — Plot against: ● Training data ○ Testing data ○ Checking data

Figure 4.4 Neuro-fuzzy designer training error

Designated epoch numbers reached -> ANFIS training completed at epoch 2.

ANFIS info:

Number of nodes: 131

Number of linear parameters: 49

Number of nonlinear parameters: 42

Total number of parameters: 91

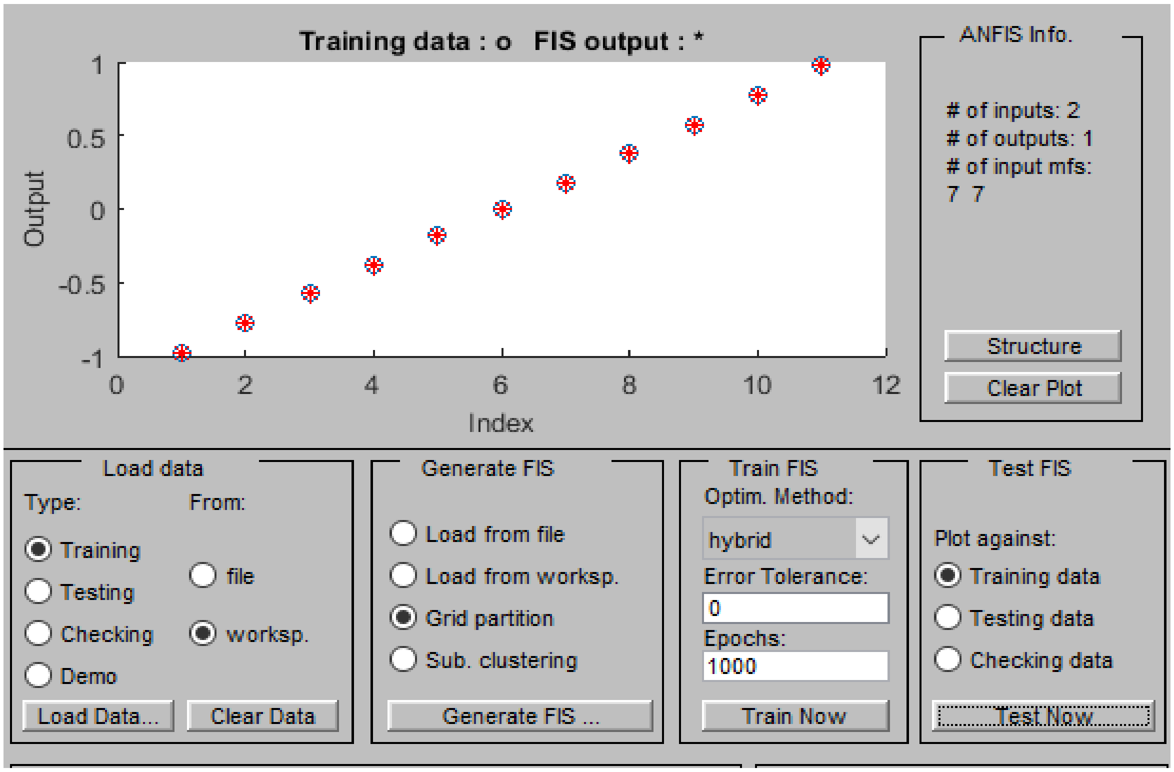
Number of training data pairs: 11

Number of checking data pairs: 0

Number of fuzzy rules: 49

1 3.4324e-07

2 3.4535e-07



# of inputs: 2
# of outputs: 1
# of input mfs:
7 7

Type: ● Training

From: ● worksp.

● Grid partition

Optim. Method: hybrid

Error Tolerance: 0

Epochs: 1000

Plot against: ● Training data

Figure 4.5 ANFIS Designer, training data with hybrid optimization method

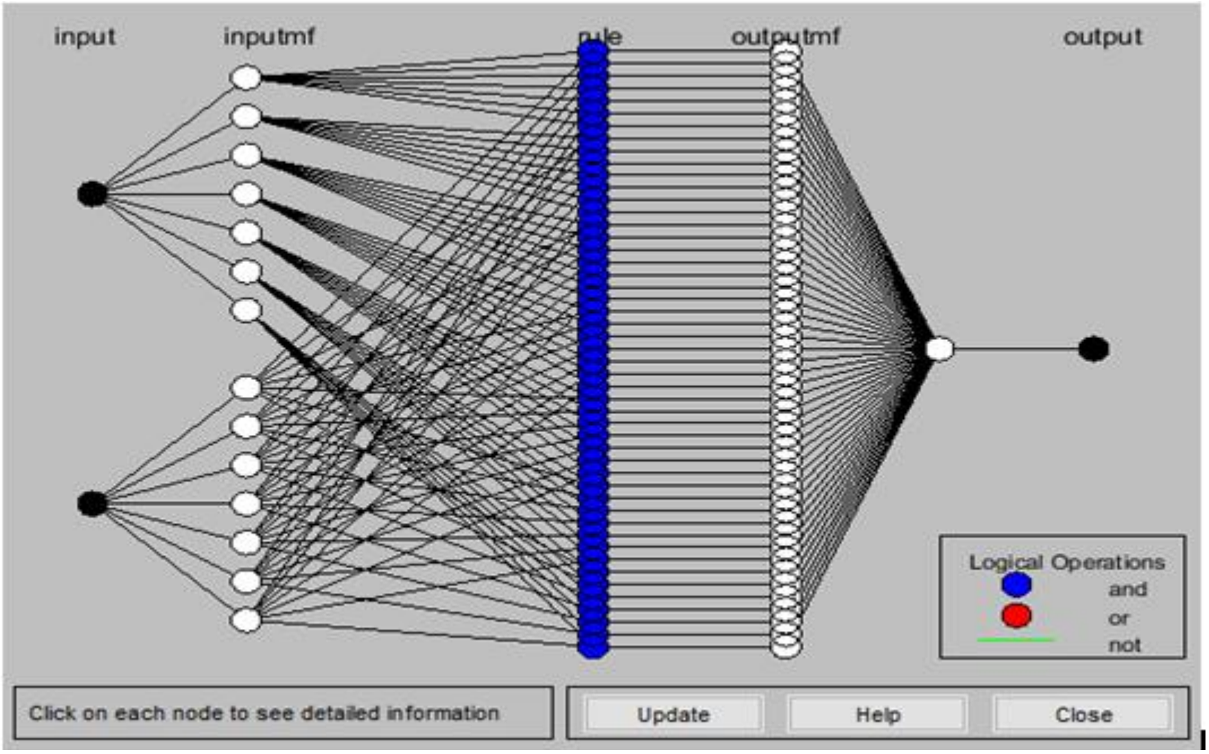


Figure 4.6 ANFIS Model structure


Error = 0.0174

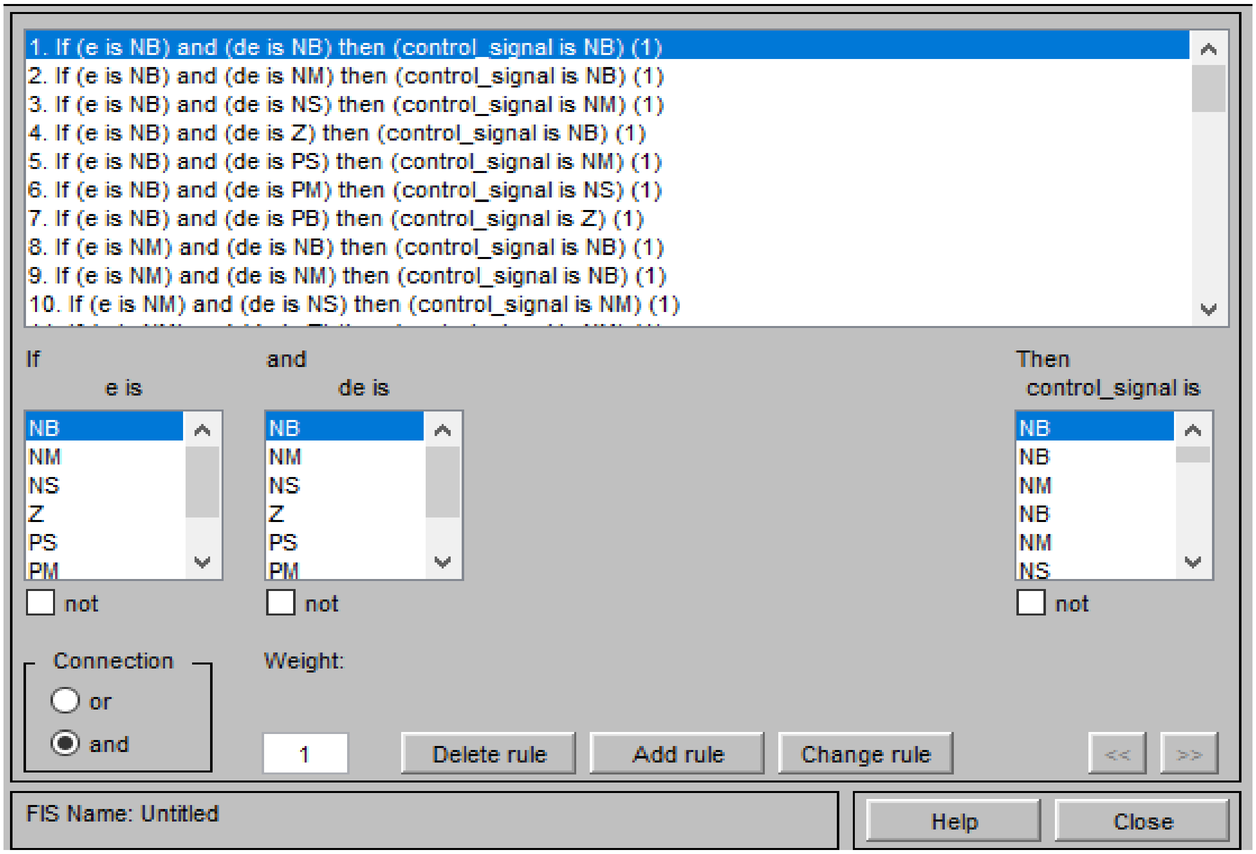
change_error = 0.0123

flow_valve_gate = 0.311

Input: [0.01743;0.01227]

Plot points: 101

Figure 4.7 Rule viewer



1. If (e is NB) and (de is NB) then (control_signal is NB) (1)
2. If (e is NB) and (de is NM) then (control_signal is NB) (1)
3. If (e is NB) and (de is NS) then (control_signal is NM) (1)
4. If (e is NB) and (de is Z) then (control_signal is NB) (1)
5. If (e is NB) and (de is PS) then (control_signal is NM) (1)
6. If (e is NB) and (de is PM) then (control_signal is NS) (1)
7. If (e is NB) and (de is PB) then (control_signal is Z) (1)
8. If (e is NM) and (de is NB) then (control_signal is NB) (1)
9. If (e is NM) and (de is NM) then (control_signal is NB) (1)
10. If (e is NM) and (de is NS) then (control_signal is NM) (1)

If e is: NB, NM, NS, Z, PS, PM — ☐ not

and de is: NB, NM, NS, Z, PS, PM — ☐ not

Then control_signal is: NB, NB, NM, NB, NM, NS — ☐ not

Connection: ○ or ● and

Weight: 1

FIS Name: Untitled

Figure 4.8 ANFIS Rule Editor

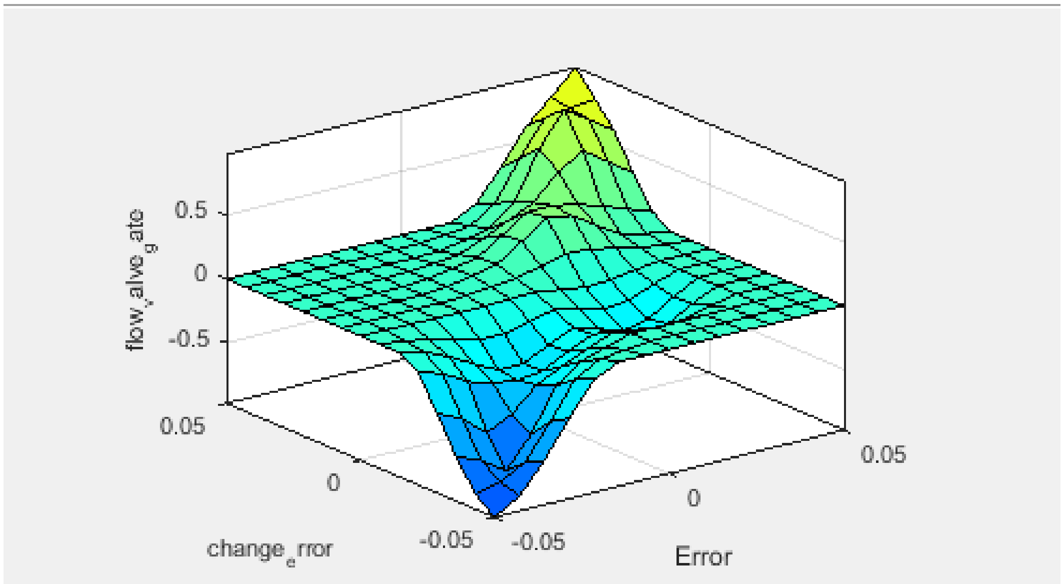


Figure 4.9 Surface viewer

4.3 Simulation results of existing system and proposed technique

The simulation results of at existing system without controller technique, has large frequency deviation in Keramo MHPP. At normal case keramo MHPP acceptable range frequency deviation is **+5% or (+0.05pu).** But frequency deviates 0.67pu or (6.7%) from normal. If this operating condition is allowed to continue, it will affect performance and lead to damage of system components at figure 4.10.

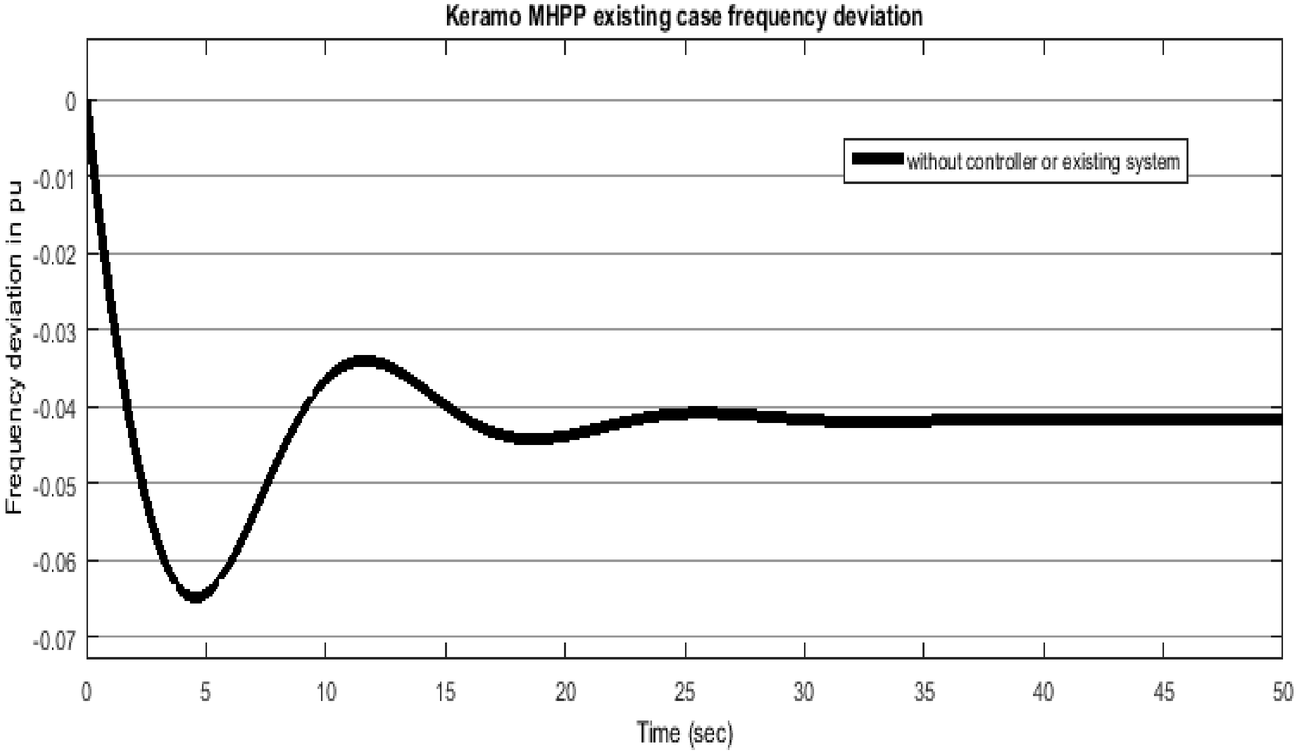


Figure 4.10 frequency deviation of keramo MHPP with existing controller

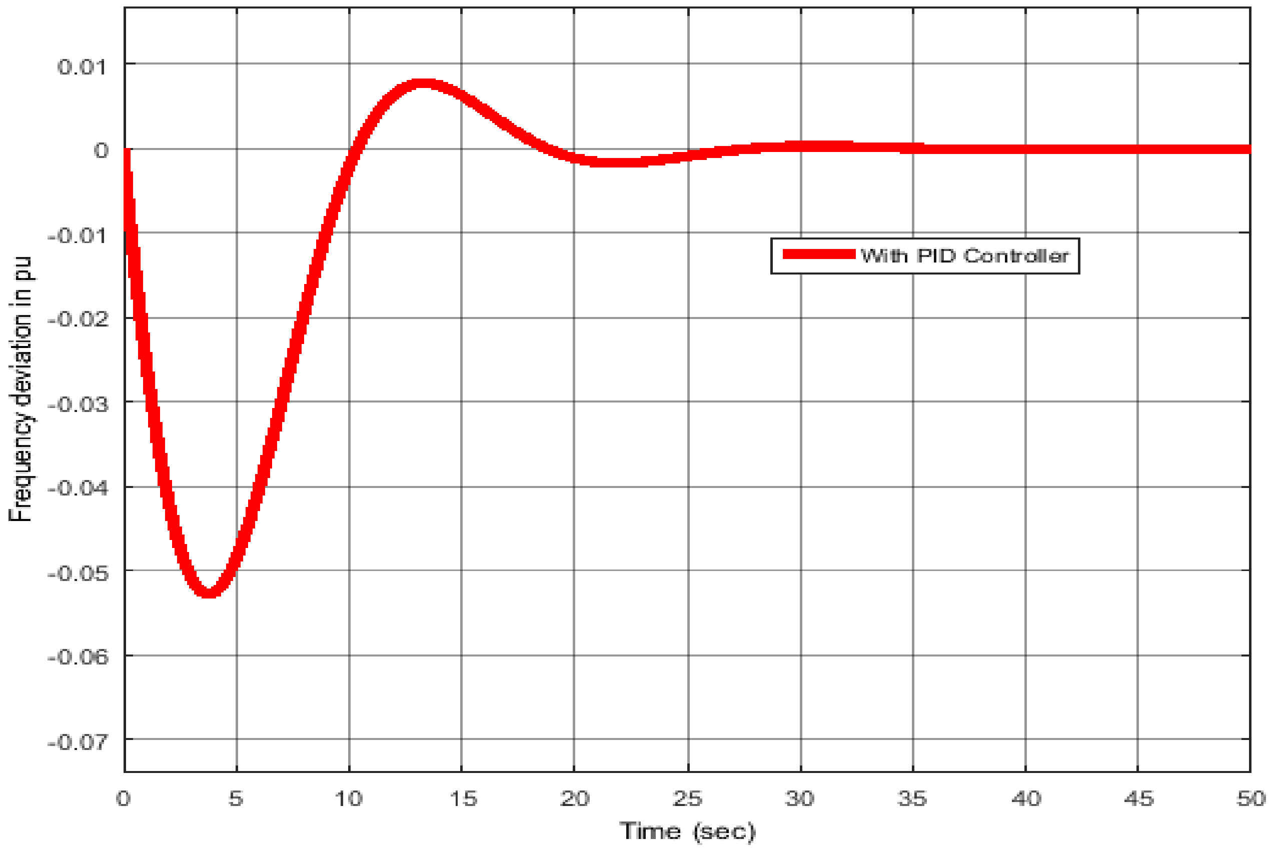


Figure 4.11 PID controller with Servomotor as FCV

The response of PID with existing system at above figure 4.11, there is decreases undershoot of frequency deviation (5.25%), overshoot (0.018%) and stable steady response time 27.45 sec compared to existing system. But, until PID controller frequency deviation is not acceptable range or frequency deviates out of range. As a result this frequency deviation affects system components.

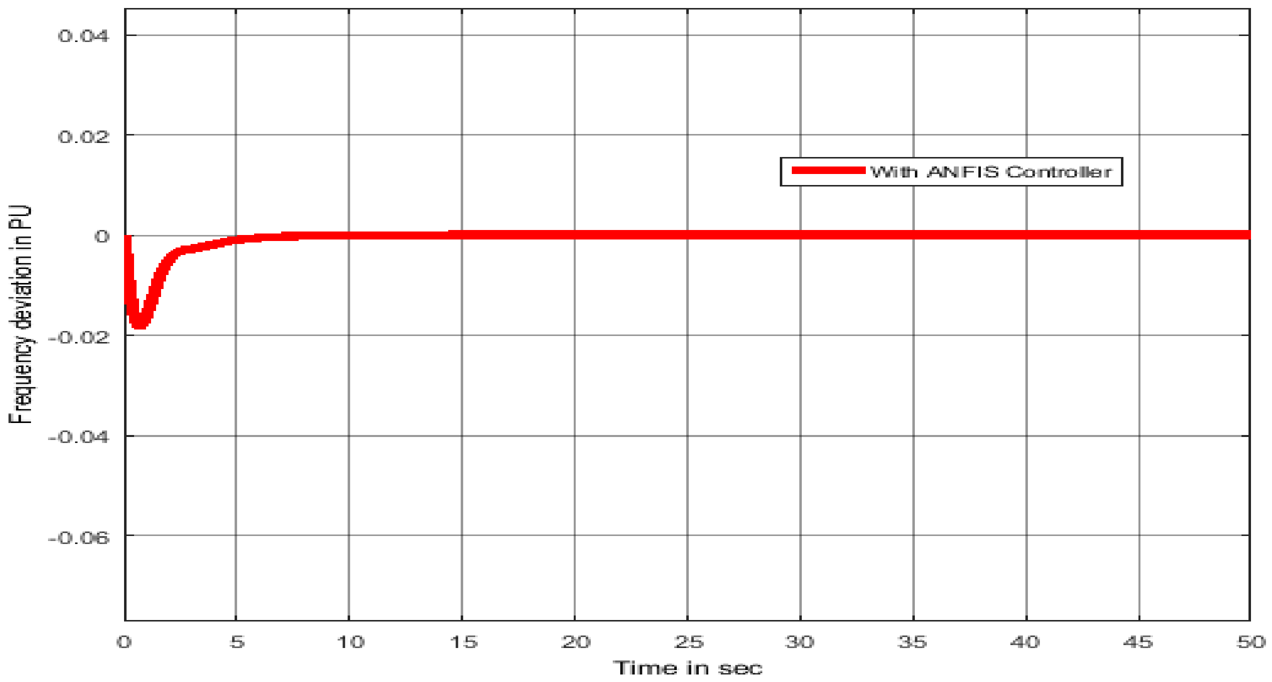


Figure 4.12 frequency control with ANFIS controller

The response of the FCV or servomotor with the ANFIS controller was decreases or minimizes error of frequency deviation compared to PID controller and that of when the servomotor as FCV was used only. The application of FCV with the ANFIS controller achieved at a figure 30 a settling time of 7.25sec, frequency deviation come to judged or acceptable range (0.0185pu or 1.85%.) above figure 4.12. Therefore, ANFIS has been proven to be an effective tool for tuning the membership functions of fuzzy inference system.

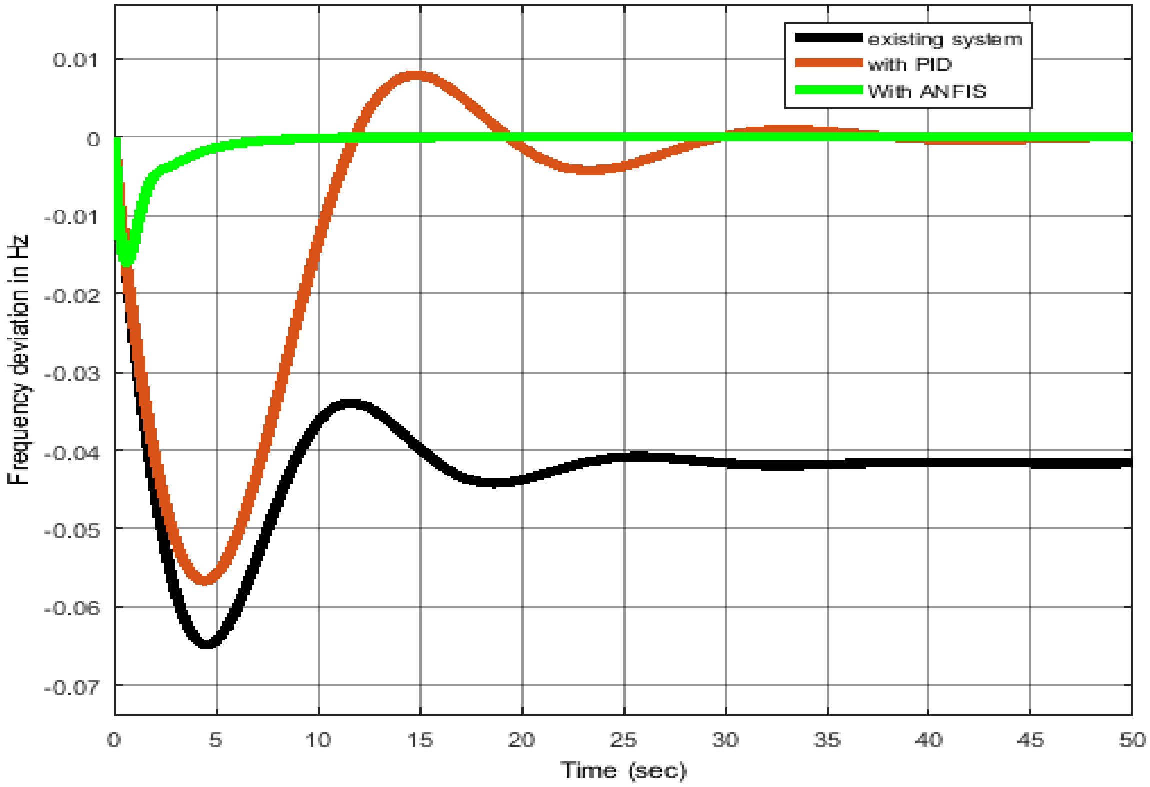


Figure 4.13 Frequency control of keramo MHPP based on servomotor with PID and ANFIS

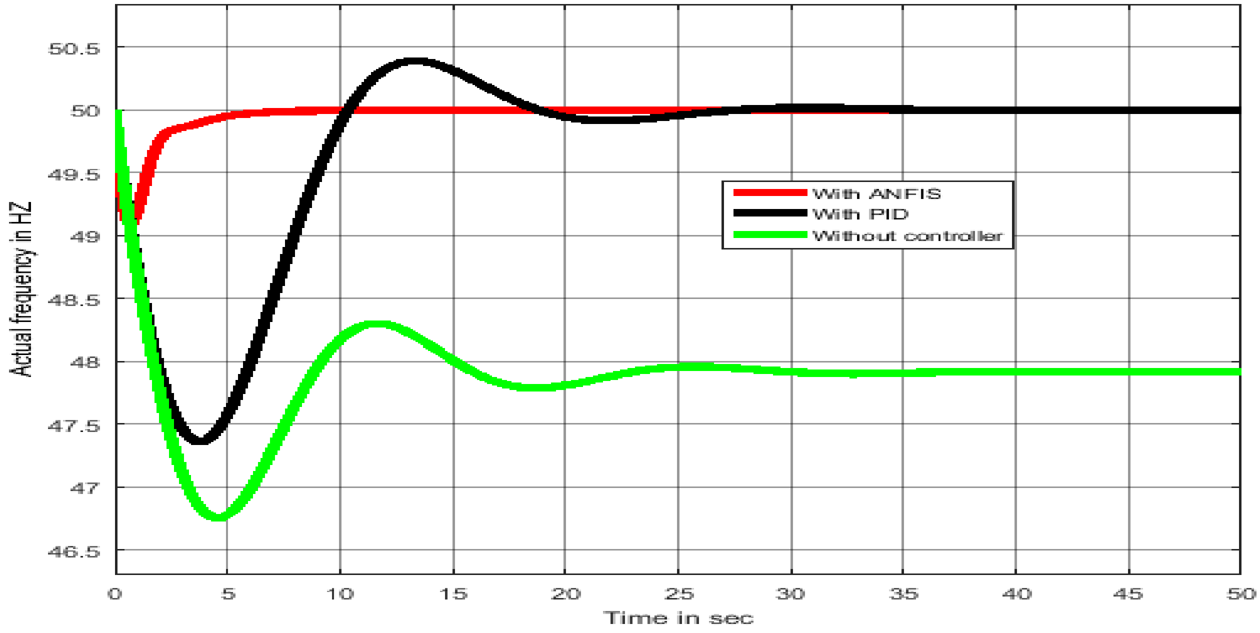


Figure 4.14 Comparative measured frequency of karamu MHPP with existing, PID and ANFIS

4.4 Discussions

Standalone micro hydro power plant presented in this thesis work. The performance of the frequency control of micro hydro power system based on flow control valve or servomotor was tested with PID and Adaptive Neuro Fuzzy inference system (ANFIS) controllers, the simulations were performed using MATLAB software. The response frequency deviation standalone Keramo micro hydro power plant with existing controller is shown in Fig.4.10. The results show an increased frequency deviation with decreased performance of the standalone keramo MHPP with servomotor controller leading to a very large steady state error. The acceptable tolerance of frequency deviation of Keramo micro hydro power plant occurs when the deviation is between ±5% or ±0.05 Pu at Fig.4.3. The error in frequency deviation obtained for the standalone micro hydro power plant with flow control valve action or servomotor is 0.067 p.u at Fig 4.10. while the actual frequency is 3.35 Hz deviated from the normal. If this operating condition is allowed to continue, it will not only affect performance, but will lead to damage of system components.

To solve this challenge and to generate a stable power supply, other controllers such as PID and ANFIS were also used. The response of the flow control valve controller with the PID controller was improved compared to that of when the existing controller of servomotor was used only.

Table 4.4 Comparative analysis for frequency deviation responses after applying load.

Controllers	Performance Parameters	ΔF
Without controller or existing system	Peak overshoot (P.U)	0
	Peak undershoot (P.U)	0.067P.U 0r 6.7%
	Setting time (sec)	------
PID	Peak overshoot (P.U)	0.0018 or 0.18%
	Peak undershoot (P.U)	0.0525 or 5.25%
	Setting time (sec)	27.45 sec
ANFIS	Peak overshoot (P.U)	0
	Peak undershoot (P.U)	0.0185 or 1.85%
	Setting time (sec)	7.25sec

The application of servomotor controller with the PID controller achieved a settling time of 27.45 sec, an peak overshoot of 0.18%, peak undershoot 0.0525% and frequency deviation error of -0.0525 p.u. The performance of servomotor of the keramo micro hydropower plant in the standalone area with ANFIS achieved a settling time of 7.25 s, peak overshoot of 0, peak undershoot 1.85% and a frequency deviation of 0.0185 p.u.

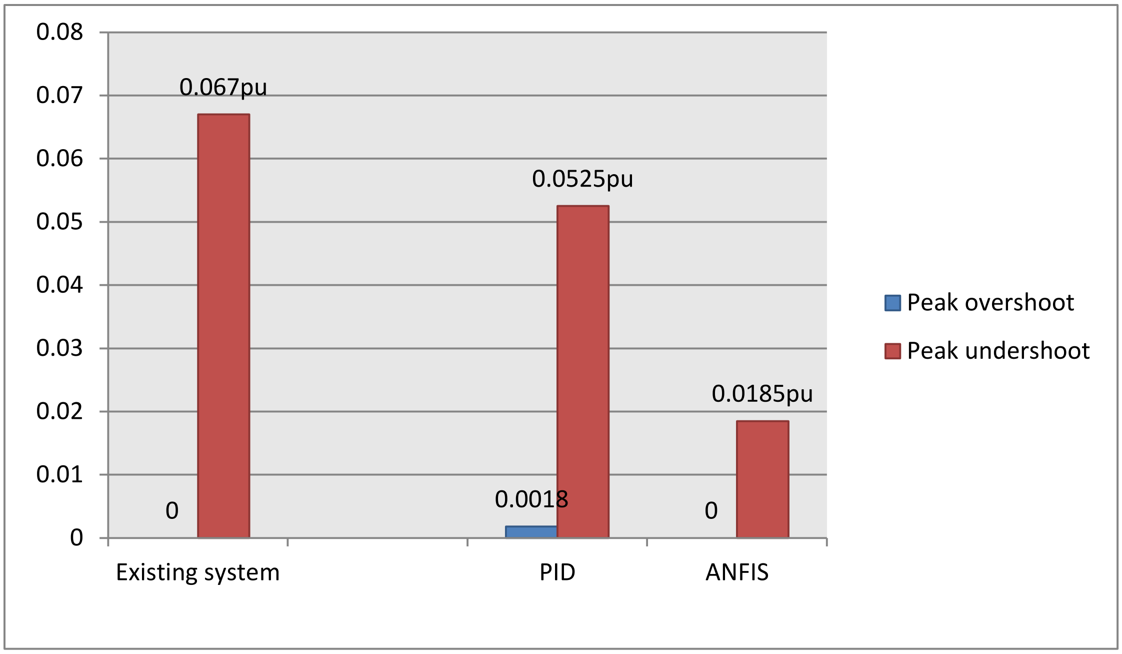


Figure 4.15 Frequency deviation in terms of undershoot and overshoot

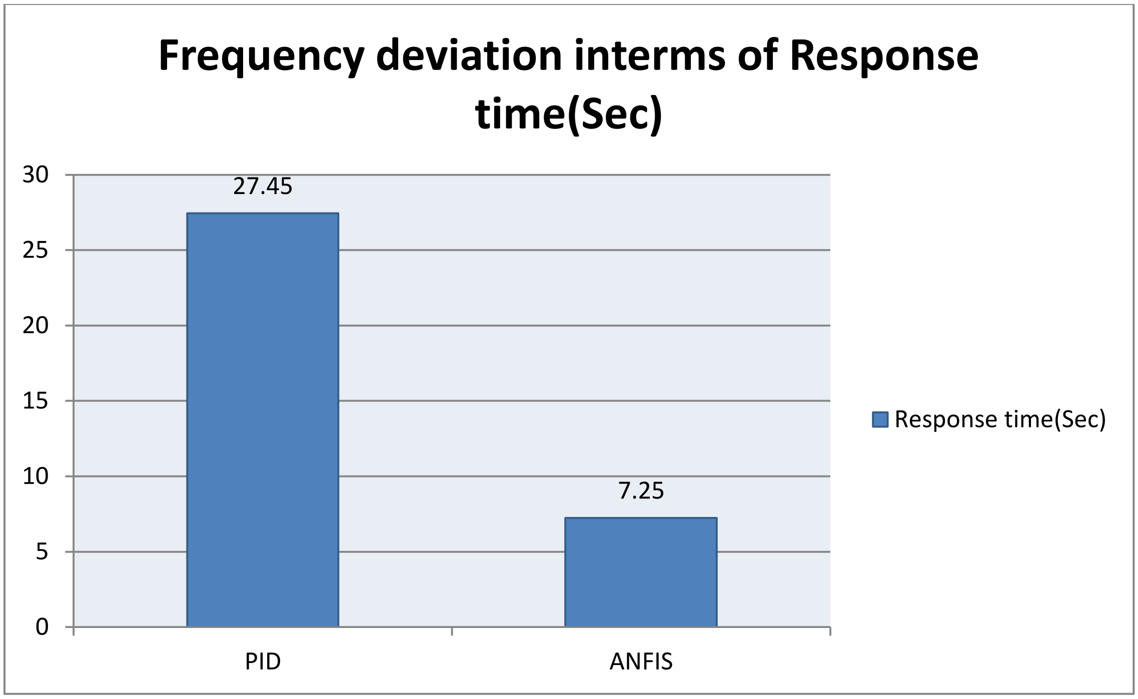


Figure 4.16 Frequency deviation interms of Response setting times

The results show that the ANFIS is stable with the application of servomotor compared to that of servomotor or FCV with the PID controller. When existing system is applied, it maintains an actual frequency deviates value of about 46.65 Hz.

It was observed that the frequency control of standalone micro hydro power plant without applying a controller gives an increase in frequency deviation of about 3.35 Hz. This is not an acceptable frequency error or frequency deviation is far from the standard operating range; such operating range of frequency with the application of frequency control with existing system not only affects performance of the keramo micro hydropower plant, but is also harmful to components of the system. The application of frequency control of keramo micro hydro power plant based on servomotor with ANFIS gives a better performance when compared to other existing system and PID controllers in the standalone micro hydropower plant.

CHAPTER FIVE

Conclusion and Recommendation

5.1 CONCLUSION

This thesis investigated the frequency control of standalone micro hydro power plant based on flow valve control with neuro-fuzzy controller. In addition to this, PID controller has been also designed for comparing the performance of the proposed controller. The comparison study was performed using MATLAB software to test the performance of the controllers. The performance of each controller was investigated with servomotor as FCV based on the frequency deviation of standalone micro hydropower plant. The behavior of frequency deviation at keramo micro hydro power studied.

The performances of existing case, PID and neuro-fuzzy controllers have been compared in terms of settling time, peak overshoot, and peak undershoot values. The simulation results of the different controllers were obtained for the frequency deviations or step load disturbance of the micro hydropower plant. The simulation results show that neuro-fuzzy controller (or ANFIS) based controller gave a response with a settling time of 7.25sec, frequency deviation peak overshoot of 0 p.u, and peak undershoot of 1.8% or 0.018 p.u and based on PID controller gave a response with a settling time of 27.45sec, frequency deviation peak overshoot of 0.18% 0r 0.0018 p.u, and peak undershoot of 5.25% or 0.0525 p.u.

In general, the results show that the ANFIS achieved a superior performance compared to other controllers. Therefore, we can conclude that the ANFIS controller is better compared to the existing system and PID controllers. The frequency control of micro hydro power plant was only introduced for small perturbation

5.2 RECOMMENDATIONS

Even though hydro-power is a main electric generation in Ethiopia, there are almost no micro hydro power generation in the country. As a recommendation, considering the situation where many villages still live without electricity, especially those in mountains, but still have the resource for micro hydro-power generation; the government should give attention for the exploitation of MHPP.

Therefore, in this thesis work recommended that Keramo micro hydroelectric power systems should use neuro-fuzzy controller based on flow controller and AVR to maintain the steady frequency or speed, generator terminal voltage and connecting to grid line power and use PSS to damp the oscillation of the synchronous generator and finally it enables to reduce the settling time of the system to increase the life span of generation units and minimize the cost of generation and distribution system.

5.3 FUTURE WORK

Only standalone MHPP is considered in this thesis, though there are different renewable energies which may be relevant for rural electrification. Such as solar and wind energy generation. Therefore the performances of neuro-fuzzy controller can be investigated on this type of energy generation. In additional future thesis hope to compare the performance of the frequency control micro hydro power plant or Automatic generation control (AGC) with ANFIS controller and automatic voltage regulators (AVR), since their frequency and voltage can be decoupled and studied for very small perturbation.

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Appendix A

Table 3.3 Keramo MHPP, Specifications of 1FC2-283-4 synchronous generator.

Parameter	Value
Current rating	45.106A
The moment of inertia	2.03 kgm^2
Power factor	0.8
Load damping coefficient	0.8%
Power rating	50KW
Voltage rating	400 v
Speed	1500rpm
Number of pole	4

Table 3.2 A servo motor with the specifications

Parameter	Value
Model	43HS2A165-654
Number of teeth (Nr)	50
Rated phase current	6.5A
Phase resistance	0.65ohm
Phase inductance	14Mh
Lead wire	4
Weight	11kg
Holding torque	26.0Nm
Step angle	1.8^o
Inertia constant	$0.0013kg\text{-}m^2$
Torque constant	4 N-m/A
Viscous friction constant(assume)	0.5N-m/rad/sec

APPENDEX B

```
%% Train ANFIS with Custom Number of Training Epochs
% Create two-input-single-output training data.
% Copyright 2015 The MathWorks, Inc
x=(-0.05:0.01:0.05)';
y=(-0.05:0.015:0.05)';
Error=(x-y)'k=(x-y)./x
z=(x error k);
trnData=[x y z];
% Define an FIS structure with seven triangular input membership functions.
numMFs = 7;
mfType = 'Trianmf';
in_fis = genfis1(trnData,numMFs,mfType);
% Train the FIS using 1000 training epochs. Suppress the Command Window
% display.
epoch_n = 1000;
dispOpt = zeros(1,100);
out_fis = anfis(trnData,in_fis,1000,dispOpt);
% Compare the ANFIS output with the training data.
plot(x,y,x,evalfis(x,out_fis))
legend('Training Data','ANVLFIS Output')
%% Train ANFIS with Custom Number of Training Epochs
% Create two-input-single-output training data.

% Copyright 2015 The MathWorks, Inc

x=(47.5:0.01:52.5)';
y=(-2.5:0.015:2.5)';
Error=(x-y)'k=(x-y)./x
z=(x error k);
trnData=[x y z];
% Define an FIS structure with seven triangular input membership functions.
```

```
numMFs = 7;
mfType = 'Trianmf';
in_fis = genfis1(trnData,numMFs,mfType);
% Train the FIS using 1000 training epochs. Suppress the Command Window
% display.
epoch_n = 1000;
dispOpt = zeros(1,100);
out_fis = anfis(trnData,in_fis,1000,dispOpt);
% Compare the ANFIS output with the training data.
plot(x,y,x,evalfis(x,out_fis))
legend('Training Data','ANVLFIS Output')
```