LOAD FREQUENCY CONTROL USING FUZZY LOGIC BASED CONTROLLER IN TWO AREA POWER SYSTEM

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Certificate of Approval

I hereby state that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Dedication

We want to dedicate this thesis book to our family members and all who have stood by our side during our entire lives, bearing witness to both our successes and defeats, and who has always remained by our side, particularly during the difficult times.

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Declaration of Authorship

This is to confirm that the thesis outlined in this study is the result of research and testing conducted by Asif Hasan Sami, Sadat Bin Haque and Tamjid Rahman under the supervision of Md Mehedi Hasan Galib, Assistant Professor, Department of Electrical and Electronic Engineering, Islamic University of Technology (IUT), Gazipur, Bangladesh. It is also stated that this thesis has not been applied to any other university or institution for a degree or diploma. The text acknowledges information obtained from others' published and unpublished work, and a list of references is included.

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Abstract

At the present time, when we are concerned about frequency variation of the power systems, especially the interconnected systems one. In an interconnected grid system, the load and power flow in tie-line are changing abruptly. Hence, a proper control system is needed for an interconnected system to mitigate this frequency variation, which can be attained by the help of *Proportional Integral* PI controller, *Proportional Integral Derivative controller* (PID) controller, fuzzy logic controller and other usual controllers as found in state-of-art literature. However, since the real system deals with variable load values, the fuzzy logic based controller works most efficiently in order to mitigate this frequency variations and attain the steady state value quickly. Hence, in this work, we consider fuzzy based controller and concentrate on triangular membership functions to prepare the rule base for our study system, and then, we validate our findings through Matlab/simulink simulations.

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Nomenclature

The next list describes several symbols & abbreviation that will be later used within the body of the document

ACE Area Control Error

AGC Automatic Generation Control

FLC Fuzzy Logic Controller

LFC Load Frequency Control

MF Membership Function

NB Negative Big

NM Negative Medium

NS Negative Small

PB Positive Big

PM Positive Medium

PS Positive Small

ZO Zero

Chapter 1

Introduction

Frequency is a significant measure of a power system's control. Power system frequency is essentially affected by the load change in an interconnected system. Change in frequency must be maintained around 50Hz to keep the generating units safe. However, the power stability can be restored, the steady state after a contingency is marked by a frequency difference compared to the corresponding reference frequency. [1] When we work with power equations we mainly focus on two components.

1. Real power

2. Reactive power

Reactive power is the one that primarily depends on the change of system voltage. On the other hand, real power relies on the system frequency. So these two components are managed independently in the power system. Load frequency control is focused on controlling the frequency and change of true power in permitted level while the voltage control focuses on reactive power change in the permitted level. The foundation of a large number of developed theories for wide-ranging power system management is load frequency control.

In the face of uncertainties, shifting operating points in which the mathematical model is developed, and worn-out device elements, these methods have trouble achieving design goals. Applications of intelligent technology including fuzzy systems, artificial neural networks, also genetic algorithms have been studied to address these limits [2]. Various types of LFC schemes have been proposed recently in references [3] [4] [5]. A study of various LFC control techniques and automatic generation control (AGC) techniques can be found [6]. The study provides a single PID LFC controller tuning using internal model control. Based on the highest peak resonance specification, a new comprehensive tuning approach with a new framework for designing a robust PID load frequency controller for multimachine power generation is introduced [7].

The controls for the system are always directed at providing quality operation in the power grid since the loading in an interconnected system is not steady or constant. AGC regulates the power flow as well the frequency of the system. The AGC's key target is to maintain the system's frequency stable and more or less insensitive to disruptions. In AGC, two things are typically checked: voltage and frequency. These two entities have different and independent system loops. Fuzzy Logic Controller with a decision-making unit is applied in place of conventional integral controllers [8]

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The secondary majors are achieving a zero steady state error and securing optimum transient activity inside the interconnected Areas, in addition to monitoring the frequency.

1.1 Background and Motivation

Frequent circuit breaker tripping in interconnected grid systems due to overload resulting in damage of equipment, increasing cost and wastage of time has led us to pursue our interest in the aforementioned topic. Circuit tripping is quite a common phenomena in any power generation system or grid system due to various reasons. Among these reasons change in frequency for variable load is the principal one.

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. Suppose, in a certain area, demand at peak load time and at other times will definitely not be the same. Also power demand i.e load for the generation system can change at any moment. And this abrupt change in load directly has the influence on frequency. Frequency has a particular band in a generation system. Normally this band is in between 47.5 Hz to 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 circuit tripping will be a must case. Therefore, if the load changes which is a very common phenomena for any power system will cause frequent circuit tripping. But a convenient load frequency controller can mitigate this issue quite efficiently. Here, in this paper we proposed a load frequency controller based on fuzzy logic. Nowadays, fuzzy logic is one of the most enthralling topics among the researchers. The application of fuzzy logic is that the plan of action can be formulated in terms that human operators can fully comprehend, so that their knowledge could be used in construction of the controller. This makes things simpler to automate tasks that humans can already complete successfully. Fuzzy Logic Controller is still relatively new compared to other controllers. Despite the advantages of this controller, there are areas to improvement to make it more accurate. We were thrilled to learn about this controller and it kept us motivated throughout our thesis to explore the different properties of the controller. In short the motivation of our work, we can say-

1. This research will help to save valuable equipments of power generation and maintain smooth power supply to consumers.

2. We want to apply Fuzzy Logic Controller in multi-area power system to achieve a better system stability.

Chapter 2

Literature Review

Previously, many researches were done on load frequency control in interconnected power systems. In some research, numerous control procedures are used based on traditional linear control methods. Several authors have stated that stability of a system is controlled by a flexible control system [9]–[11]. However, some dataset is needed for system conditions which are unavailable to us.

However, It needs certain data for device conditions, to which we do not have complete access. According to Ref. [12], PID control systems that have been used aren't going to produce accurate results. The gain forecasting regulator is applied [13]. In case of nonlinear systems, gain forecasting is a controller technique. In this approach control variables are quickly changed so evaluation of variables isn't required. This is much simpler to notice compared to both scheduled updates and differences in the controller parameters. However, due to unpredictability in the function parameters, the transient response can be uneven. Furthermore, accurate linear time invariant designs of variable operation marks are impossible to obtain [14]. Chang and Fu used fuzzy approaches to monitor load-frequency in power systems [13], also by Akalın along with his fellow authors [15]. The pair set several fuzzy rules about the PI gains separately.The result is improved in this study by gain laws that are chosen similarly. Overshoots as well as settling time are more effective in the selected controller compared to other controllers.

2.1 Reasons To Keep Constant Frequency

The speed of synchronous generators is directly connected to frequency in a power grid. Since the difference between mechanical and electrical torques is largely responsible for a generator's acceleration, mechanical input and electrical output power must be continuously balanced to maintain a constant speed. It is widely known that when the frequency deviation reaches a certain threshold, generation and utilization equipment can fail to function properly **unkwown3** There are several reasons to maintain stable frequency in an area which are given below

1. As the frequency is dependent on the speed of alternating current motors on the power supply's frequency. High order consistency of speed is expected in some instances.

2. Synchronous motors drive the electric clocks. Along with frequency, frequency error controls the accuracy of the clocks.

3. The frequency needs to remain in between 47.5Hz to 52.5Hz where 50Hz is the normal frequency. Otherwise, the turbine might be damaged resulting in the generator being stopped.

4. Thermal power plants are severely affected by the fluctuating frequency. Operating in subnormal frequency causes a blast of ID and FD which ultimately reduces the generation of power in the plant. This eventually can cause the total shutdown of power plants unless proper techniques of load shedding are not implied.

2.2 Load Frequency Control

As a lot of loads are connected with the power grid, frequency and speed may differ with the difference in loads and governor characteristics. If there's no requirement of keeping the frequency constant then no chances are needed in the generator setting. However, if there's a need for constant frequency, characteristics of the governor can be varied to adjust the speed of the turbine. Problems may take place if parallel generating stations are dealing with load variation. Load being distributed in both systems depend on the below factors

1. When a tie line connects both generating station, load varies in one of the stations and it is required to continue serving the same frequency, then this is Flat Frequency Regulation

2. Parallel Frequency Regulation is when each of the generating units need to sustain the same frequency

3. If frequency is controlled of a particular area using own generator and also tie-line loading is kept constant then It's known as flat tie-line loading control

4. Selective Frequency control, the system individually controls the change in load and does not require any interfering along with controlling the other one.

2.3 Automatic Generation Control

The goal of Automatic Generation Control is to keep system frequency near to a given nominal value, to keep individual unit generation at the most cost-effective level, and to keep the line power across different control areas at the correct level. Due to time variance and non-linearity properties, there is a shift in expected behavior of dynamic systems [16]. It is important to maintain much greater frequency accuracy than the speed governor can offer. To accomplish this, the action of the speed governor is to be supplemented by the appropriate supplementary action through modifications of speed changer settings with suitable control strategy. AGC has evolved rapidly from the time when the control function was performed manually, through the days of simple analog systems to the present application of sophisticated direct digital control techniques. To achieve the goal, the speed governor's action must be balanced by the necessary supplementary action, which can be done by adjusting the speed changer settings with the appropriate control technique. AGC has progressed steadily from the days where the control function was done manually, through the days of basic analog devices, and now to the implementation of advanced digital control methods. AGC is one of the most critical control issues in the design and operation of integrated power systems. The evolving configuration and rising scale, complexity as well as the functionality of power systems, the gradual development of renewable energy sources, advances in power generation/consumption technology, and environmental restrictions are all adding to its growing importance. [17]

All systems of interconnectivity work together to sustain frequency in Tie-line Load-bias control, regardless of in which the difference is generated. This includes a primary lfc and a tie line plotter for evaluating given power in tie and accurate frequency control. Frequency is reduced suddenly because of slowing down of prime mover. As a prime mover has to balance the power drop, however, this speed is governed by the power generation. Error signal is reduced as soon as the speed is controlled. But as the load varies with time the speed cannot be kept to a fixed value.

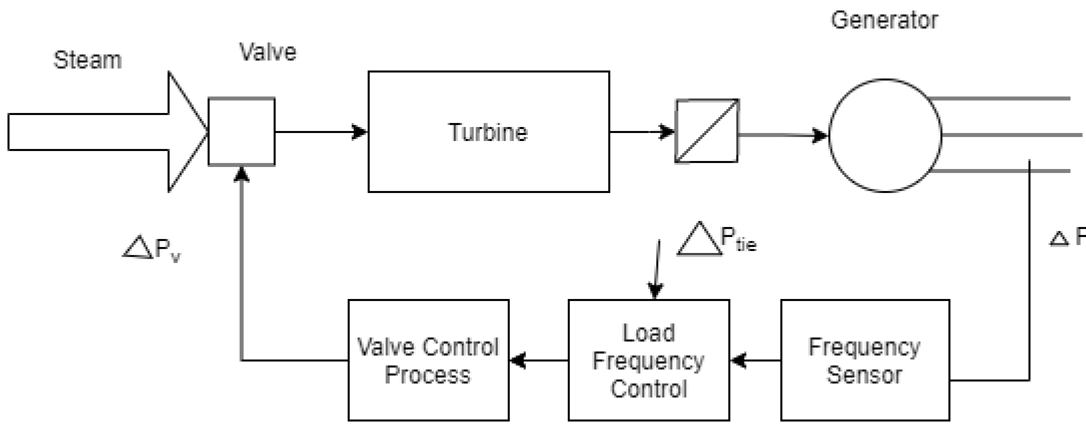

Figure 2.1: Load Frequency Control without controller

For this varying load an integrator is used with the control system. Therefore control systems can scrutinize the change and make the necessary correction as soon as possible. This capability of correcting the changed value to a normal value is called reset point. To make the frequency value to the stated value automatically AGC scheme (fig: 2.1) is used. AGC is made up of a governor mechanism that sends a signal to the turbine to change its speed in order to keep the frequency constant.

Chapter 3

Background Study

3.1 Two Area Interconnected Power System

A large power system can be separated into multiple load frequency control areas that are joined together by tie-lines. Assume a two-area connected by a single tie-line as shown in Fig 3.1. Multiple power systems are usually connected to save money and ensure continuous power supply. Both generators for every control area are considered to form a single group. The control stress is related to random magnitude and length local variations. As a result, each control area's frequency and tie-line power differences must be monitored. The difference among area generation and area load is the total interchange of power across the tie lines of a n area along with losses.[18]

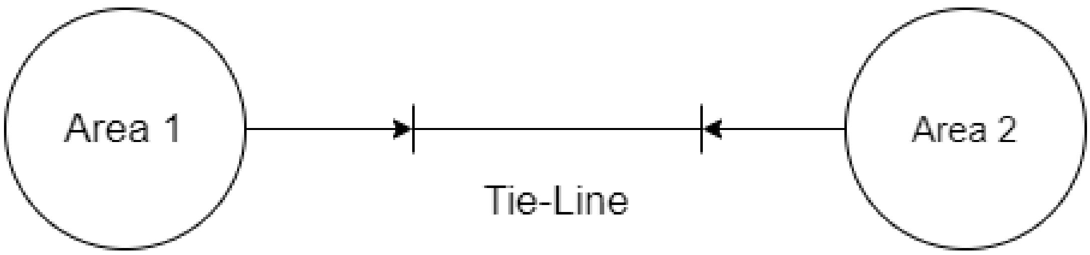

Figure 3.1: Two Area Connection with Tie-Line

Power networks, in general, necessitate hybrid and multi-variable configurations, as well as multiple non-minimum or nonlinear phase systems. Generators must maintain synchronization with the given tie line. In integrated power systems, there are essentially two kinds of frequency control mechanisms.

1. Primary Speed Controller

2. Secondary Speed Controller

In case of first speed modulation results in a tentative rough modification of the frequency. The generators keep track of the load variations and distribute it to themselves based on individual ratings. Typically, the primary loop reacts in 2–18 seconds. The second speed modulation matches the well-altered frequency by using an intrinsic control action to reduce the frequency errors to null. By adjusting a set point input, the relationship between load and speed can be established. Any division's output frequency can be just modified while changing load property, which tends adjusting the speed-droop feature fluctuate. This process is slow and activates just after the primary speed control has completed its task. The frequency is controlled by the speed-governing process. The isochronous governor adjusts the turbine valve/door to restore the frequency to the nominal or scheduled speed. Afterwards an unchanging state opinion circle around the integrator may be used to obtain the speed-droop or control trademark

The whole mechanism is represented as a multi-parameterized method.With arrangement of Equation (1)

$x' = A(x) + Bu(t) + Ld(t)$

Here A,B and L represents system matrix, input and disorder dispersal matrices respectively. Besides, x(t), u(t) and d(t) stand for the state vector , control vector and load changes disturbance vector respectively.

$x(t) = [\Delta f1 \;\; \Delta p_{g1} \;\; \Delta p_{v1} \;\; \Delta p_{tie12} \;\; \Delta f2 \;\; \Delta p_{g2} \;\; \Delta p_{v2}]$

$u(t) = [u1 \;\; u2]^T$

$d(t) = [\Delta Pd1 \;\; \Delta Pd2]^T$

where marks change beginning from the lowest values. u1 and u2 are the controller results . The classification result, which rest on the ACE presented in Fig. 1, is Equation (2)

$Y(t) = [Y1(t); Y2(t)] = [ACE1; ACE2] = Cx(t)$

Equation (3)

$ACE(t) = \Delta P_{tie,i} + bi\Delta f1$

Here , bi defines frequency bias constant. fi denotes the frequency change and Ptie, i stands for variation in tie line power in Area i C equals to result matrix .

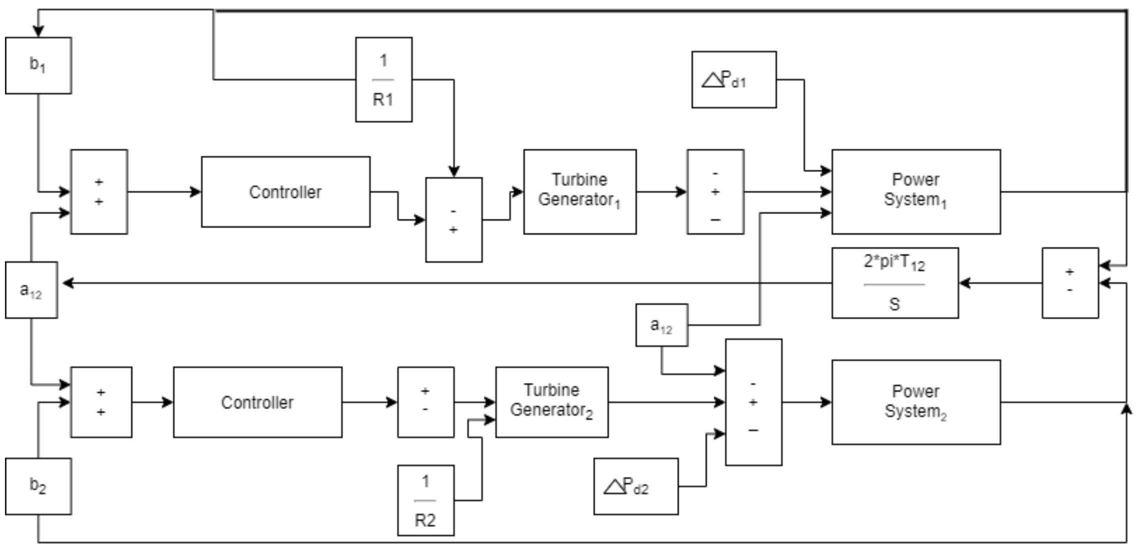

Figure 3.2: Two Area Interconnected Power System with Controller

3.2 Fuzzy Logic in Power System

The fuzzy controller is based on a structure known as fuzzy rationale, and is far closer in terms of human intelligence and standard dialect than conventional automated systems. It was first introduced by Zadeh [19] and Mamdani [19] first implemented it in power systems.The use of fuzzy sets creates a foundation for a well-organized route for requesting unspecified and ambiguous prototypes.Since the basis functions can be generated from either numerical data as well as linguistic information, each of which can be cast into the form of IF-THEN laws, the fuzzy basis function expansion is extremely strong [2]. In today's world, fuzzy logic is seen in almost every aspect of manufacturing and technology. LFC is one of them. The main purpose of LFC in linked power systems is to ensure that handling and use are in sync. Conventional controller solutions may not have sufficient outcomes due to the power system's complex and nuanced structure with multi-parameterized phases. Fuzzy controllers, on the other hand, are useful in grasping a wide range of control problems due to their power and consistency. Fuzzification section, a fuzzy reasoning part, a knowledge base, and a defuzzification unit are the basic building units of a Fuzzy Logic Controller. It's the process of converting a set of optimistic fuzzy control activities into a new set of control movements.

3.3 Architecture of Fuzzy Logic Controller

A fuzzy logic controller's basic building block consists of four key structures mentioned below:

1. Fuzzification

2. Fuzzy Inference

3. Fuzzy Set Rules

4. Defuzzification

3.3.1 Fuzzification

This is the process where input crisp values are decomposed into fuzzy sets. Change in data manipulation in a fuzzy logic controller is based on fuzzy set theory, which requires fuzzification at an earlier level [20]. In Fuzzification, input variables values are measured and then does a scale mapping that converts the set of input variable values into a universe or discourse. Fuzzification is a function that transforms input into appropriate linguistic values that can be interpreted as fuzzy sets labels [21].

3.3.2 Fuzzy Inference

Then performs the fuzzy knowledge base block which defines all variables and parameters. It is a fuzzy logic-based method of converting an input space to an output space [22].

3.3.3 Fuzzy Set Rules

Fuzzification is followed by the fuzzy reasoning which compares the inputs with the given rule base. A FLC's knowledge base is made up of two elements, one of them is database and the other one is rule base. The basic purpose of a database is to provide details for the Fuzzification, Rule Base, and Defuzzification to function properly. The database contains information on fuzzy sets that reflect the context of the process' linguistic values and control output variables [23].

3.3.4 Defuzzification

The defuzzification block is the final block, and its key purpose is to transform fuzzy outputs to definite crisp values. The fuzzy output range is converted to a crisp number during defuzzification. The centroid as well as maximum methods are two widely used approaches. One of the variable values at which the fuzzy set has its highest truth value is selected as the crisp value in the output variable in the maximum method [24].

Membership function (MF) represents a curve which specifies how every value present in the input space is converted to a membership value (or degree of membership) ranging from 0 to 1. Membership functions can be of several types. The simplest of them is the triangular membership function.

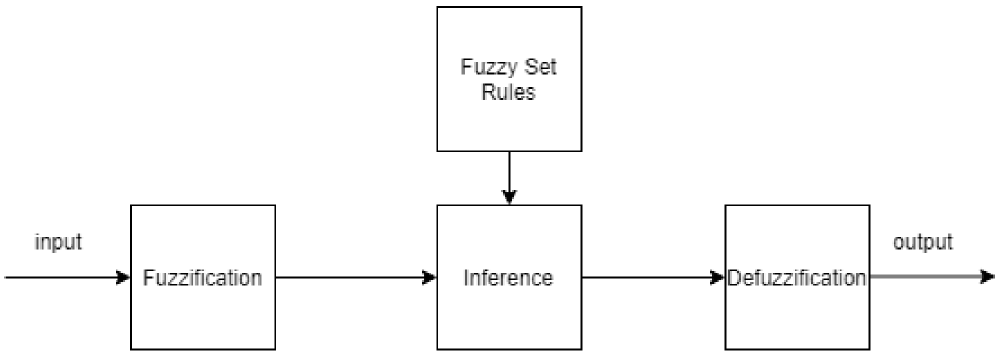

Figure 3.3: Block Diagram of Fuzzy Logic Controller

In the LFC scheme, following assumptions are made.

1. It is possible to see and quantify the input and output variables.

2. A satisfactory outcome is one that is appropriate, but not necessarily the best.

3. A linguistic design based on the facts of a human expert may be developed.

4. Based on his expertise, the human analyst assists in the simulation of the linguistic prototype.

Chapter 4

Simulation

Using all the values and transfer functions a two area interconnected system was implemented in MATLAB SIMULINK. Using a transfer function block diagram we can represent the models of governor, turbine and generator load. No controller was used in the first case. Then frequency of both area 1 and area 2 were determined without any controller(Fig. 4.1 Fig. 4.2). After that different controllers were used and the comparison between the controllers for controlling the load frequency is shown in Fig. 4.6 and 4.7.

4.0.1 For Load Increase in Area

A load is applied at Area 1 firstly. After that area frequency F1 and F2 are shown in Fig. 4.1, Fig. 4.2 . From the Figures, it can be said that without any controller the desired frequency can not be achieved.

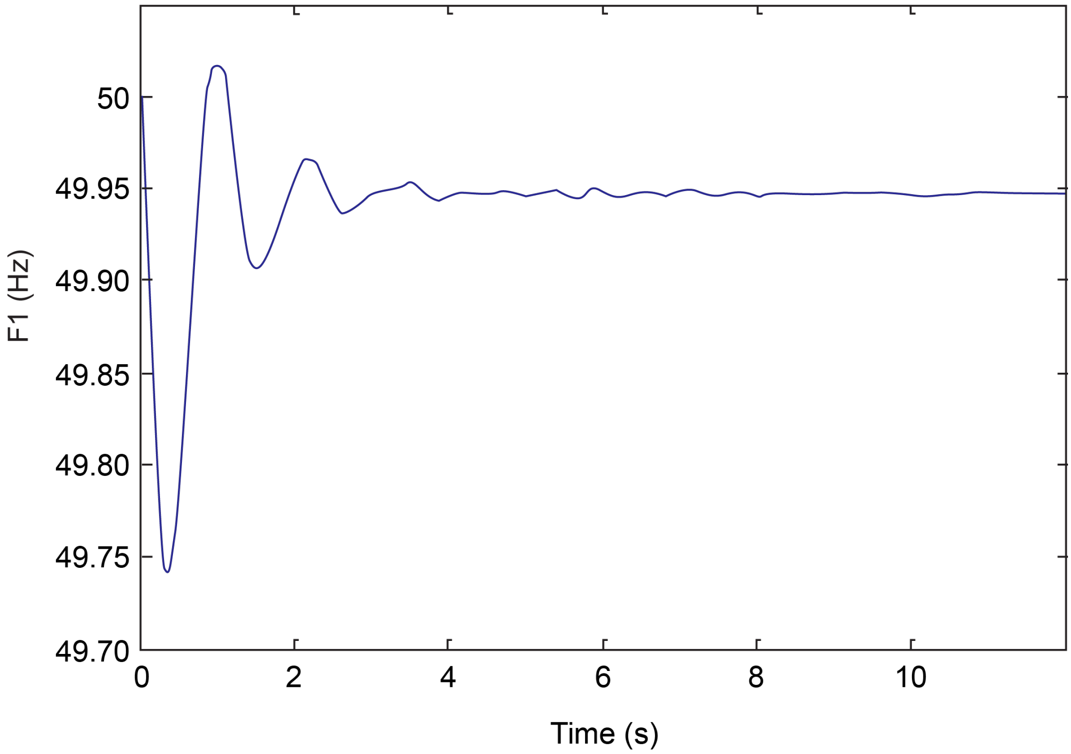

Figure 4.1: Area 1 Frequency with 0.1 PU

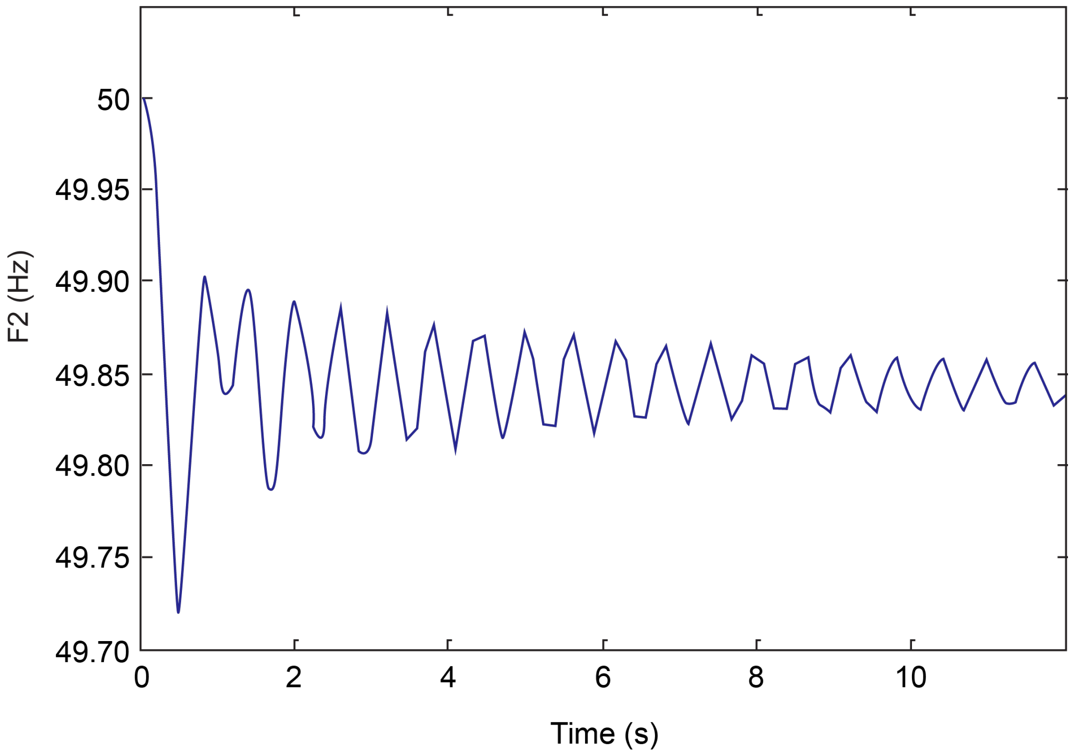

Figure 4.2: Area 2 Frequency with 0.1 PU

4.0.2 Implementation of Fuzzy Controller

The traditional PI controller shows a great overshoot and a long settling period, as seen in the simulation results [25]. In addition, optimization time for control parameters takes a long time. There are several explanations for the current success of fuzzy logic control, according to several scholars. First and foremost, fuzzy logic can be quickly extended to the majority of industrial applications. It also has the ability to manage with inherent variability by altering the controller parameters. Ultimately, this is suitable for fast implementations. As a result, fuzzy logic has been used as a controller in industries. Linguistic variables are created as fuzzy laws by human experts. The rules are derived from step response of process, derivative of time and error signal time derivative experiments [26]. In this method, the fuzzy logic controller is formed. In this project, the controller's gain levels are selected differently than those used in Refs. [27] and [28]. In addition, Chang used two rules and Akalın used five rules for the inference mechanisms of their gains. In another study builds a fuzzy rule base using the change of frequency and its rate as inputs [29]. Seven rules are used to implement the inference process in this article. However, the improvements in both of these experiments were normalized using the same method, and the inference processes of ACE and D ACEs law numbers were taken as seven. In comparison, both of the experiments used the centre of gravity procedure for defuzzification. Proper rules are listed in Table 4.1

Table 4.1: The Fuzzy Rule Set

ACE/DACE	PB	PM	PS	ZO	PS	PM	PB
PB	ZO	PS	PM	PB	PB	PB	PB
PM	NS	ZO	PS	PM	PB	PB	PB
PS	NM	BS	ZO	PS	PM	PB	PB
ZO	NB	NM	NS	ZO	PS	PM	PB
NS	NB	NB	NM	NS	ZO	PS	PM
NM	NB	NB	NB	NM	NS	ZO	PS
NB	NB	NB	NB	NB	NM	NS	ZO

It is possible to apply fuzzy logic more efficiently in LFC to achieve improved performance. The FLC is divided into two phases: one of them is a fuzzy system unit in which the Area control error (ACE) and also the derivative () is defined as input parameters, and afterwards fuzzy rules are generated, with the output being the control operation based on the rules.

Mamdani inference is used to write codes applying AND function in MATLAB . The MATLAB file type is fis.file. The rules that are in the above table, depend on the MF highly .

In its membership features, fuzzy logic demonstrates experience and choice. Based on the expertise of researchers, these functions take on various forms [28]. The ACE, DACE, Kp, and Ki functions of membership sets are given in figure 4.3, 4.4 and 4.5.

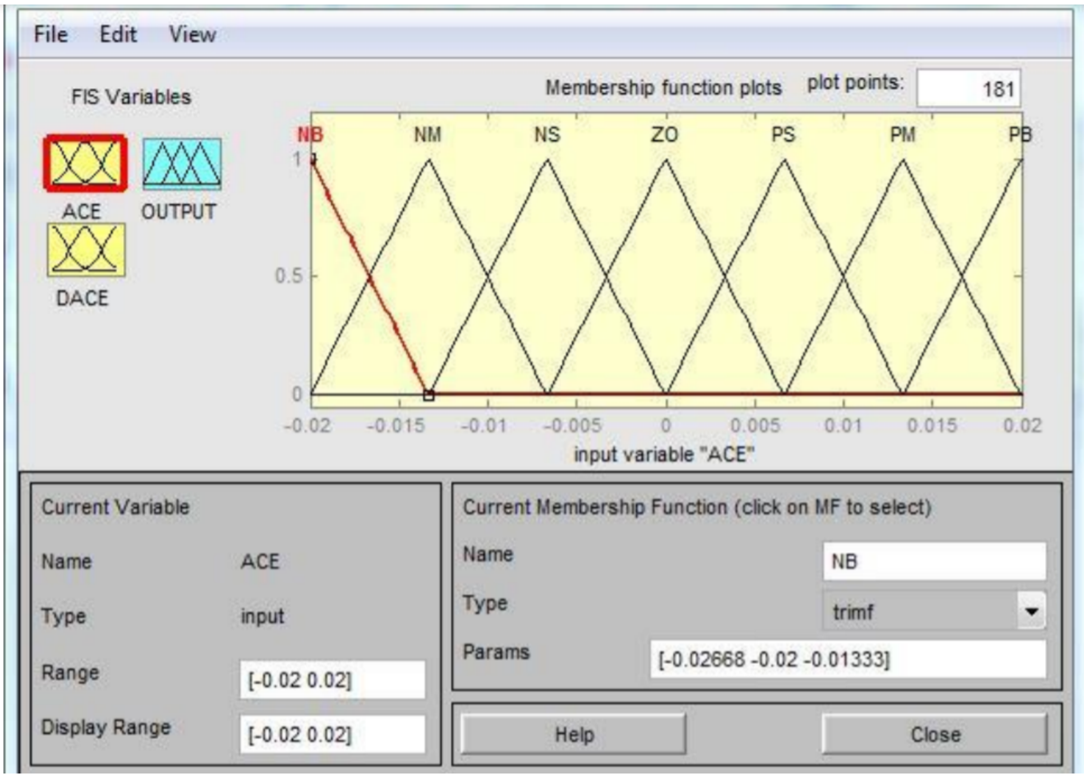

Figure 4.3: MF of input(ACE)

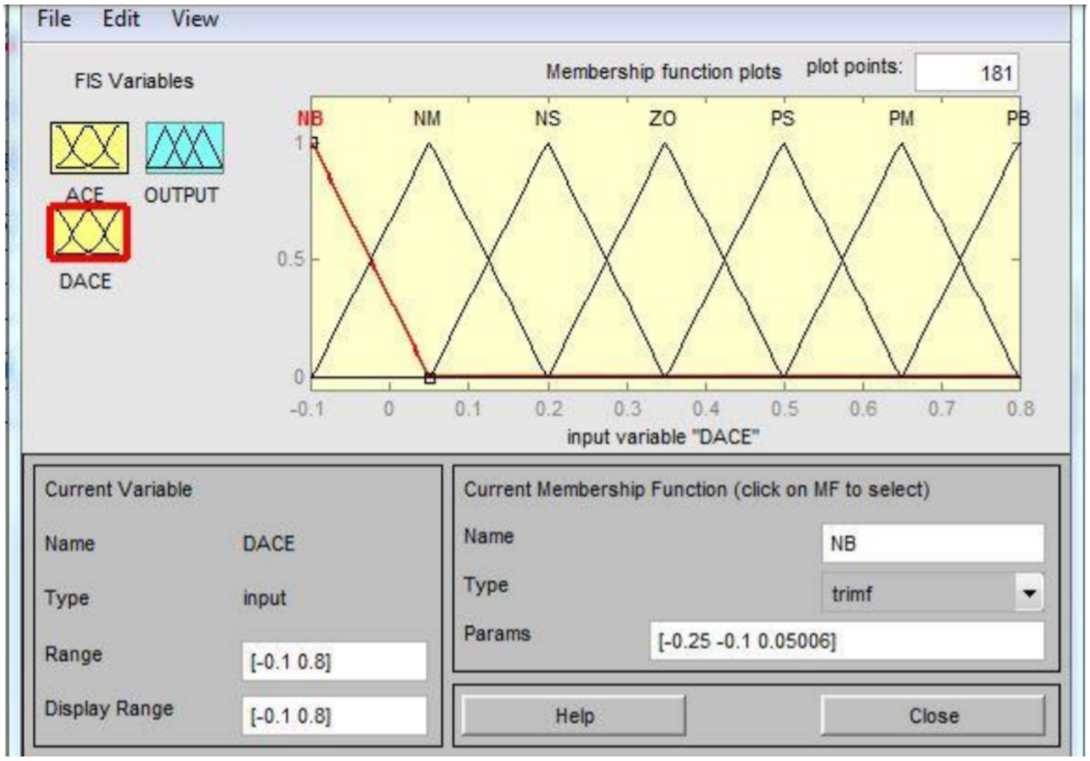

Figure 4.4: MF of input(DACE)

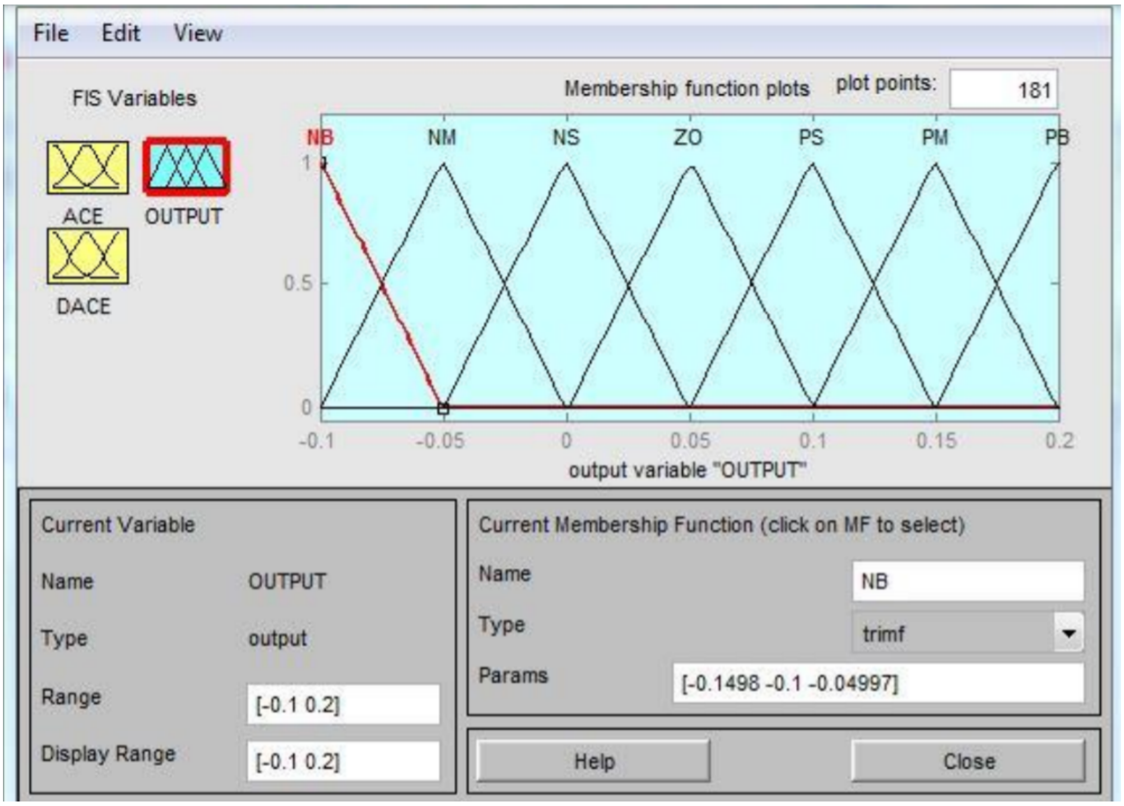

Figure 4.5: MF of output

4.1 Result and Comparison

Changes in the gain in the matlab simulations are shown in Figures. 4.6 and 4.7. The simulations show, the gain values of the proposed controller settles more quickly than the others

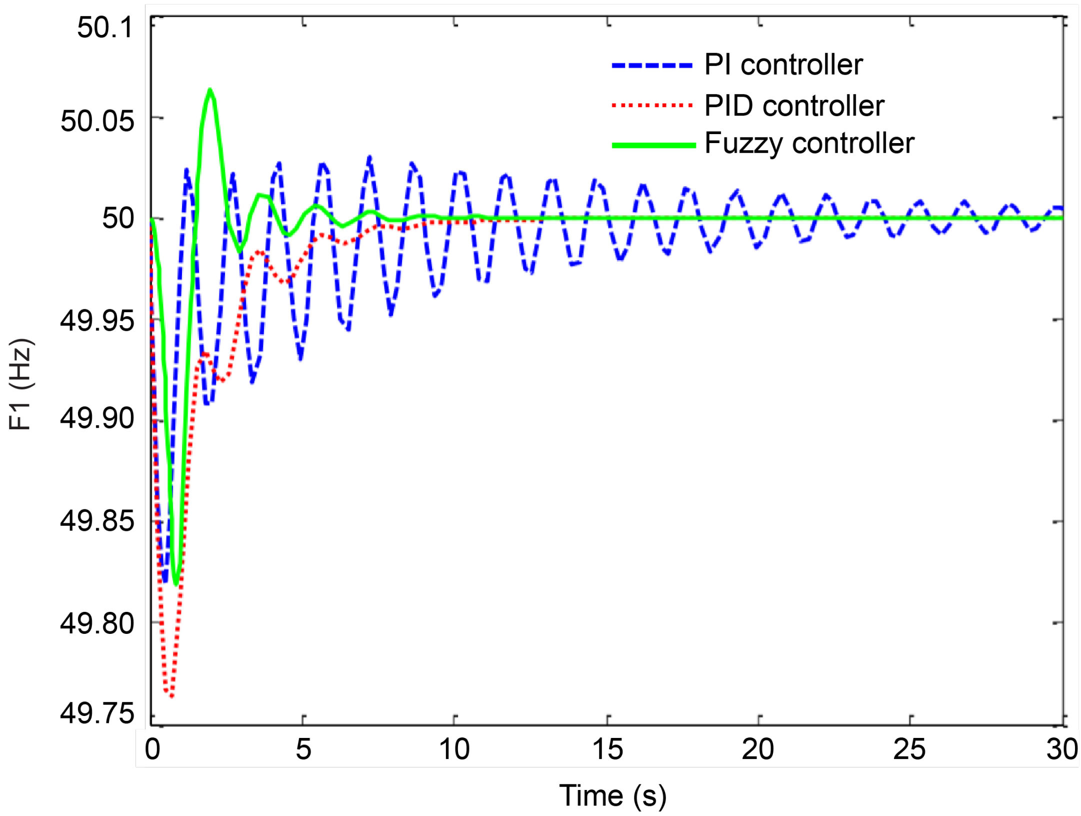

Figure 4.6: Performance of different controllers for 0.1 pu (Area 1)

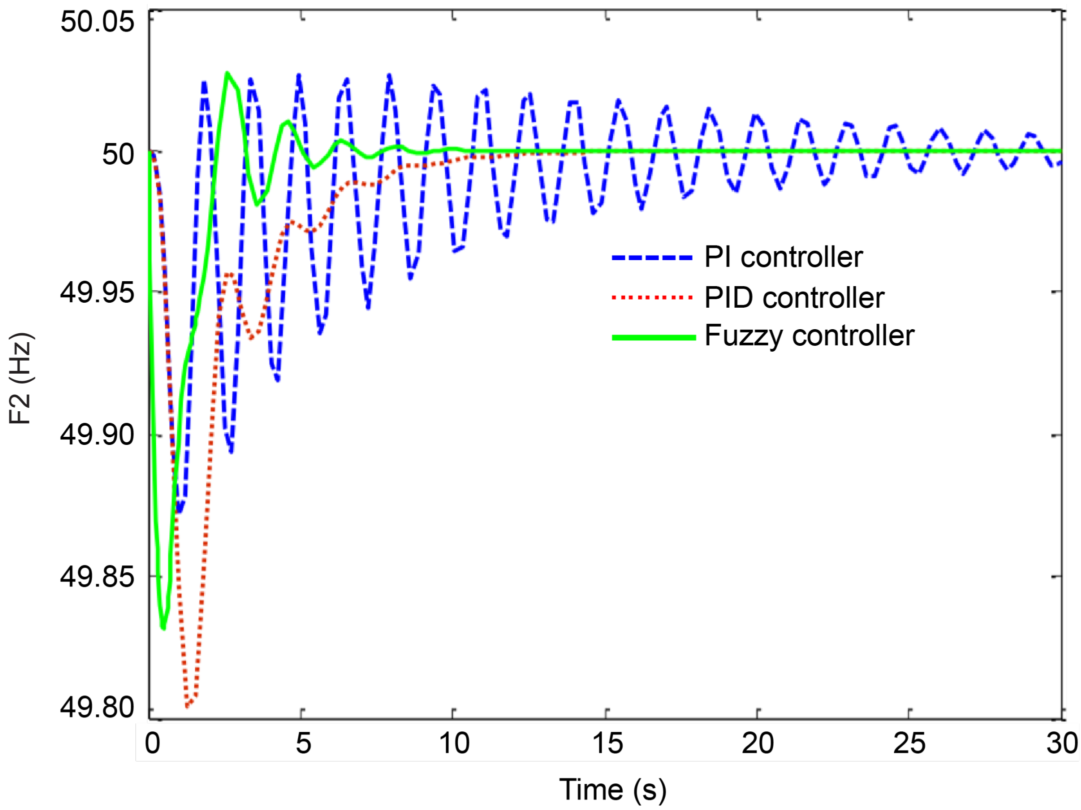

Figure 4.7: Performance of different controllers for 0.1 pu (Area 2)

The figures show the comparative performance of PI,PID fuzzy logic controller. Among the controllers the fuzzy controller performance has a better response over PI and PID. The settling time is lowest during fuzzy controller .

The proposed controller's output compared to that of other controllers shows the system output with the suggested controller has almost equivalent overshoots but a much shorter settling period. Simulations were run including a variety of immediate load adjustments, and all showed effective results. The complex efficiency of the machine is enhanced by applying variable values for the proportional and integral improvements in the controller unit.Table 4.2 lists different settling times of different controllers for better understanding.

There is significant improvement in settling time of LFC Controllers than the other controllers which increases the system stability and is essential to run a two-area interconnected system..

Table 4.2: Settling time for different controllers

	Settling time of area 1	Settling time of area 2
PI	29.5280	29.3708
PID	9.8627	9.6189
FUZZY	5.2583	5.4901

Chapter 5

Conclusion and Future Work

5.1 Conclusion

The research implies the case of load frequency control of a two area power system using FLC that can withstand the frequent change of input parameters. It has been observed in unregulated experiments where load variation increases, area control faults increase as well. When LFC is used in both areas of Area 1 for a phase load transition, the differences in f1, f2, and Ptie become fully non-oscillatory. In case of similar phase load shifts in both areas with LFC in area 1, comparable deduction may be drawn. LFC is used in both Areas to produce the retorts. When LFCs are put in both regions, anomalies are minimal, and oscillations fade away quickly. When opposed to traditional and GA PI controllers, the fuzzy controller has a better overall performance. The time it takes to settle and grow has drastically decreased. The transient is quickly settling. The suggested controller has been shown to be effective and increases system performance greatly. It can mitigate the losses caused by the frequent change of load to a minimum level and save an enormous sums of money and time. In addition, there is a lot of room for progress in this field, as it is possible to expand power system analysis towards a multi-area system that ensures closed loop system reliability.

5.2 Future Plans

1. Further improvement of the controller to apply in multi-area systems that ensures closed loop system stability.

2. To strengthen the result further through an integral-fuzzy controller.

3. To establish the controller more robust for complex control system simulation.

4. Including production control along with governor dead band to make the whole structure more realistic and linear.

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