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Study of Synchronous Machine Excitation and Governor Systems in the Power System Stability Using PID and Fuzzy Logic Controller

دراسه نظام الإثارة ونظام الحاكم للماكينه التزامنيه في استقراريه نظام القدره باستخدام وحدة التحكم التناسبي التكاملي التفاضلي ووحدة التحكم المنطق الضبابي

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الآيـــة

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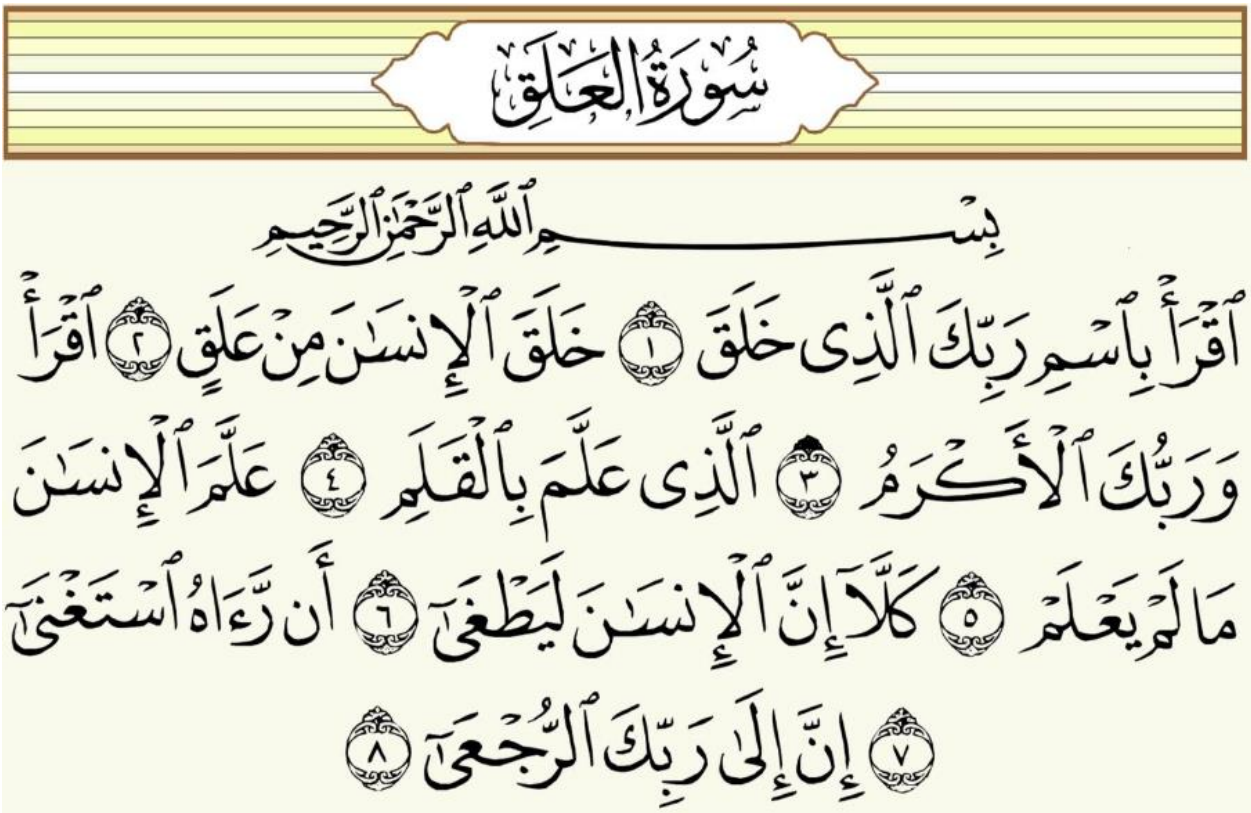
سُورَةُ العَلَق

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صدق الله الهظيم

سورة العلق الايات(1-8)

DEDICATION

THIS RESEARCH IS DEDICATED TO BOTH THOSE WHO SUPPORTS ME AND ESPECIALLY MY FAMILY:

FATHER

MATHER

PRATHER'S

SISTERS

MY WIFE

FRIENDS

ACKNOWLEDGMENT

First and foremost, I wish to appreciate the Almighty God for His amazing grace throughout my academic life. His love and guidance has propelled me to get this far. I extend my appreciation goes to my supervisor Dr. Alfadil Zackaria yahia for ensuring that I had all the necessary guidance and support during the entire period of this project besides being a great mentor. I am grateful to all doctors' in graduate studies for them unwavering support, guidance and motivation towards my understanding, dissection and solving the presented problem in the best way possible. I appreciate my lecturers and non-teaching staff at the University of Sudan for sciences and technology, Department of Electrical and electronic Engineering for their selfless effort that enabled me achieve my academic goals during the entire course of my studies. I am thankful to my entire friend in graduate and undergraduate studies. Their shared knowledge and encouragement was a blessing. My gratitude goes to all my friends and the entire student fraternity not forgetting to Last but not least, I appreciate my family for their invaluable support.

ABSTRACT

Changes in real power affect mainly system frequency, while reactive power is less sensitive to changes in frequency and is mainly dependent on changes in voltage magnitude. Therefore, in a system when the load changes, the voltage and frequency of the system also changes. In this study, automatic generation control system was used, to control the real and reactive power of a power system in order to keep the system in the steady state. MATLAB-SIMULINK simulation software using fuzzy logic controller FLC and proportional integral derivative PID control was used to control the voltage and frequency changes due to some specific load variation for normal and heavy loading conditions to obtain the input output data of the synchronous machine. The mathematical modeling of the system is the first step of controls system analysis and design. Work presented in this thesis has used transfer function (TF) method to develop mathematical model of synchronous generator with exciting system for stability analysis, state space model with linear differential equations for system description is used. In second step we develop the actual mathematical and Simulink models to examine the stability of power system. From the study it was observed that FLC controller model gave shorter settling time and smaller overshoot after specific load variation (perturbation) as compared with the conventional PID controller. Although, most of the earlier works on AGC studied the load frequency controller and automatic voltage regulator loops apart. In this paper however, combined LFC and AVR loops was studied and dynamic response of combined LFC and AVR was also analyzed. Detailed analysis of the results was discussed.

مستخلص

تؤثر التغيرات في القدرة الفعاله بشكل رئيسي على تردد النظام ، في حين أن الطاقة الغيرفعاله أقل حساسية للتغيرات في التردد وتعتمد بشكل رئيسي على التغيرات في حجم الجهد. لذلك ، في نظام القدره عندما يتغير الحمل ، يتغير الجهد والتردد أيضًا. في هذه الدراسه ،استخدم نظام التحكم التلقائي في التوليد ، للتحكم في القدرة الفعاله والقدرة الغيرفعاله لنظام الطاقة من أجل استقراريه النظام للحفاظ على الجهد والتردد حسب القيمة المطلوبة، استخدم برنامج المحاكي (ماتلاب) باستخدام وحدة التحكم التناسبي التكاملي التفاضلي ووحدة التحكم المنطقي الغامض للتحكم في تغيرات الجهد والتردد بسبب تغيرات الحمل في ظروف التحميل العاديه والثقيله للماكينه التزامنيه. النمذجة الرياضية للنظام هي الخطوة الأولى لتحليل وتصميم نظام التحكم للماكينه التزامنيه. في هذا البحث تم استخدام نموذج دالة التحويل للتطوير النمازج الرياضيه للماكينه التزامنيه ونظام الإثارة كما تم استخدام نموذج فضاء الحاله مع المعادلات التفاضليه الخطيه لوصف النظومه. في الخطوه الثانيه تم تطويرالنماذج الرياضيه وتطوير نموذج المحاكي الفعليه لفحص استقراريه نظام القدره. لوحظ ان ان وحدة التحكم المنطقي الغامض اعطي نتائج افضل حيث اعطي زمن استقراريه اقصر وتجاز الحد الاعلي (ادني) اقل بعد تغيرات الحمل المحدد(اضطراب) مقارنة مع النتائج التي تم الحصول عليها بواسطة وحدة التحكم التناسبي التكاملي التفضلي. في معظم البحوث السابقه تم دراسة حلقة وحدة التحكم في تردد الحمل منفصل عن حلقة منظم الجهد التلقائي.في هذا البحث تمت دراستهما بصورة منفصله وبصورة مدمجه ايضا.تمت مناقشة النتائج بصوره مفصله.

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List of symbols

$V_{Ref}(S)$	Reference input voltage
$V_e(S)$	Error voltage signal
$V_R(S)$	Amplifier Voltage
$V_F(S)$	Exciter Voltage
$V_t(S)$	Output Voltage
$V_s(S)$	sensor voltage
K_A	Amplifier gain constant
K_E	Exciter gain constant
K_G	Generator gain constant
K_R	Sensor gain constant
K_F	stabilizer gain constant
τ_A	Amplifier time constant
τ_E	Exciter time constant
τ_G	Generator time constant
τ_R	Sensor time constant
τ_F	stabilizer time constant

H	Inertia constant
ΔP_m	Mechanical power output
ΔP_e	Electrical power output
$\Delta\delta$	Measure of change in frequency successively
ω_s	Synchronous speed

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CHAPTER ONE

ITRODUCTION

1.1 General

The automatic generation control consists of two main loops: load frequency control (LFC) loop and automatic voltage regulator (AVR) loop. The LFC loop controls the real power and frequency, while the AVR loop regulates the reactive power and voltage magnitude, where the main purpose of these controllers is to maintain the frequency and voltage within permissible limits. Hence, the study of automatic generation control is required in the operation of interconnected power system [1-6].

In this project uses Fuzzy logic control FLC and conventional proportional integral Derivative PID control method to control load frequency control loop (LFC) and automatic voltage regulator loop (AVR) of the synchronous generator. Simulation studies were made to determine the degree of improvement that could be gained in AGC dynamic response by the application of FLC controller as compared with the conventional PID controller.

Firstly, the load frequency control (LFC) loop and automatic voltage regulator loop (AVR) were isolated and then studied separately. Secondly, the combined load frequency control loop (LFC) and automatic voltage regulator loop (AVR) was studied. Third MATLAB-SIMULINK simulation software was used to examine the voltage and frequency changes due to some specific load variation. Further simulation studies were carried out using FLC and PID control to obtain the system dynamic response. Lastly, the response obtained using FLC controller was compared with that obtained using conventional PID controller.

1.2 Problem Statement

In the power system when the load changes, the voltage and frequency also changes. The load frequency control (LFC) loop regulates real power and frequency while the automatic voltage regulator (AVR) loop regulates reactive power and voltage magnitude.

1.3 Objectives

This work is aimed at develop and simulate a model for an automation generation control AGC to control of active and reactive power to keep the system in steady state and maintain the voltage and frequency at desired value.

1.4 Methodology

This work studies the automatic generation control AGC by MATLAB-SIMULINK using a conventional controller like PID and FLC to control the system for normal and heavy loading conditions to obtain the input output data of the synchronous machine. The fuzzy logic control FLC and proportional integral derivative PID controllers methods are used to control load frequency control loop (LFC) and automatic voltage regulator loop (AVR) of the synchronous generator to determine the degree of improvement that could be gained in AGC dynamic response.

1.5 Thesis layout

This thesis consists of six chapters

Chapter 1: this chapter represents a general introduction of the automatic generation control, problem Statement, objective and methodology used.

Chapter 2: discusses the literature reviews, proportional integral derivative and fuzzy logic controller.

Chapter 3: discusses the functions of an excitation system, excitation system requirements, elements of an excitation system, types of excitation systems, reactive power and voltage control, modelling of excitation system, state space representation of excitation and test for stability.

Chapter 4: this chapter presents a general introduction of load frequency controller, modelling of LFC, space representation of LFC and test for stability of load frequency controller.

Chapter 5: presents results, discussions, and comparison

Chapter 6: presents the conclusion and the recommendations of the research based on the analysis part.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

The single area and two-area power systems have been considered with a combined model of AGC and AVR for analysis of frequency and voltage deviation. The primary aspect of the design is to keep real power control as to preserve frequency of the system in a prescribed limit. Reactive power control is used to keep the voltage magnitude of synchronous generator at a tolerable limit. The transients produced in dynamic responses are controlled using intelligent and soft-computing technique [22].

Maintaining synchronism between different parts of power system (PS) is getting difficult over time. The fact that growth of interconnected system is a continuous process, also these systems have been extended in different regions. In this research work steady state (SS) and transient stabilities along with swing equation and numerical solution using MATLAB / Simulink are studied. The essential selection criteria of a controller are its proper control performance, maximum speed and its robustness towards the nonlinearity, time varying dynamics, disturbances and other factors. The PID controller has been recommended as a reputed controller in this accord and it also can be used for higher order systems [11- 13].

Classic tuning method is normally used to predict the gain parameters of PID controller. The adaptability of such controllers on the varying load demand and uncertainties are also difficult and thereby quite often impractical for implementation. In response to these challenges so many intelligent approaches shave been introduced for optimal tuning of controllers in AGC [10].

In this project, fuzzy logic control (FLC) was implemented for optimal control in a single area power system AGC. The adequacy of the proposed FLC controller was confirmed by comparing the results with the conventionally tuned PID controller.

2.2 PID controller

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

2.2.1 Proportional term

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

$$P_{out} = K_P e(t) \qquad (2.1)$$

Where

P_{out} = Proportional term of output

K_P = Proportional gain, a tuning parameter

e = error = set value – actual value

t = instantaneous time in sec

2.2.2 Integral term

The contribution from the integral term (sometimes called reset) is proportional to both the magnitude of the error and the duration of the error. Summing the instantaneous error over time (integrating the error) gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain and added to the controller output. The magnitude of the contribution of the integral term to the overall control action is determined by the integral gain K_i.The integral term is given by:

$$I_{out}=K_i \int_0^t e\,(t)d\tau \qquad (2.2)$$

Where

I_{out} = Integral term of output

K_i = Integral gain, a tuning parameter

e = error= set value – actual value

t = instantaneous time in sec

τ = a dummy integration variable

2.2.3 Derivative term

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

$$D_{out}=K_d\frac{d}{dt}e(t) \qquad (2.3)$$

Where

D_{out} =Derivative term of output

K_d = Derivative gain, a tuning parameter

e = error = set value – actual value

t = instantaneous time in

2.3 Fuzzy logic controller

Conventional control methods cannot provide desired results because power system dynamic characteristics are complex and variable. Advanced controller can be replaced with conventional controller to get fast and good dynamic response in load frequency problems. Fuzzy Logic Controller (FLC) as shown in figure 2.1 can be more useful in solving large scale of controlling problems with respect to conventional controller which are slower. Fuzzy logic controller is designed to minimize fluctuation on system outputs. There are many studies on power system with fuzzy logic controller [25].

There are three principal elements to a fuzzy logic controller:

(i) Fuzzification module (Fuzzifier).

(ii) Rule base and Inference engine.

(iii) Defuzzification module (Defuzzifier).

Fuzzy control is based on a logical system called fuzzy logic. It is much close in spirit to human thinking than conventional logical systems. Complexity and Multi-variable nature of power system limits the conventional control method, to provide satisfactory solutions. The FLC is to handle the reliability, robustness and nonlinearities associated with power system controls. Due to this fuzzy logic controller becomes adaptive and nonlinear in nature having a robust performance under parameter variations with the ability to get desired control actions for complex uncertainty, and nonlinear systems without their mathematical models and parameter estimation [26-28].

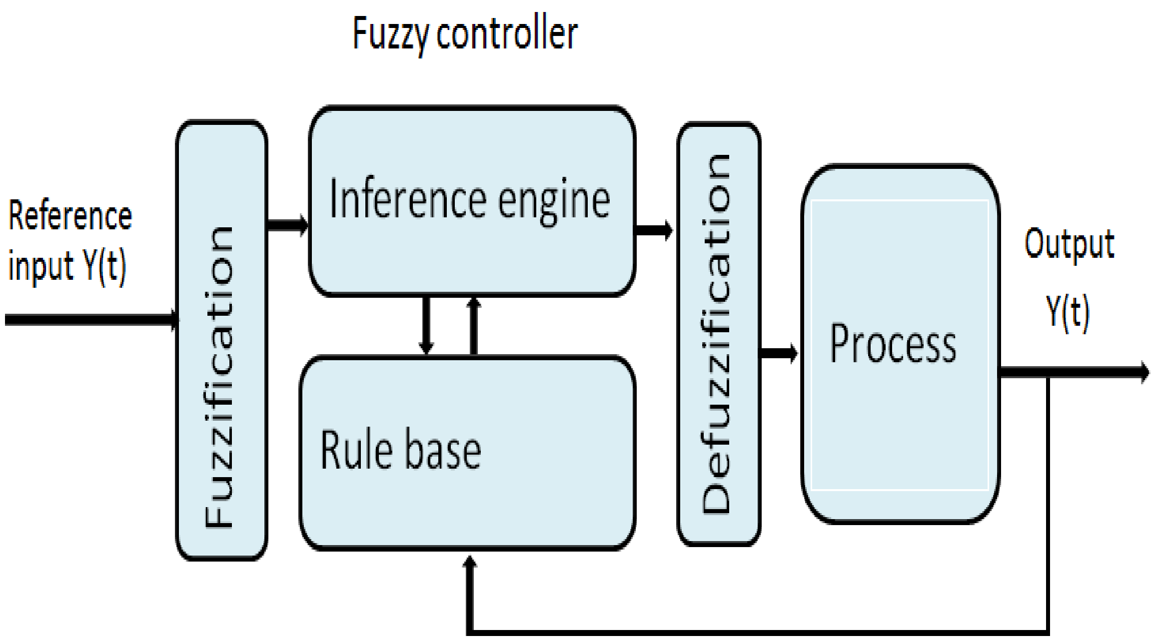

Figure 2.1: fuzzy logic controller

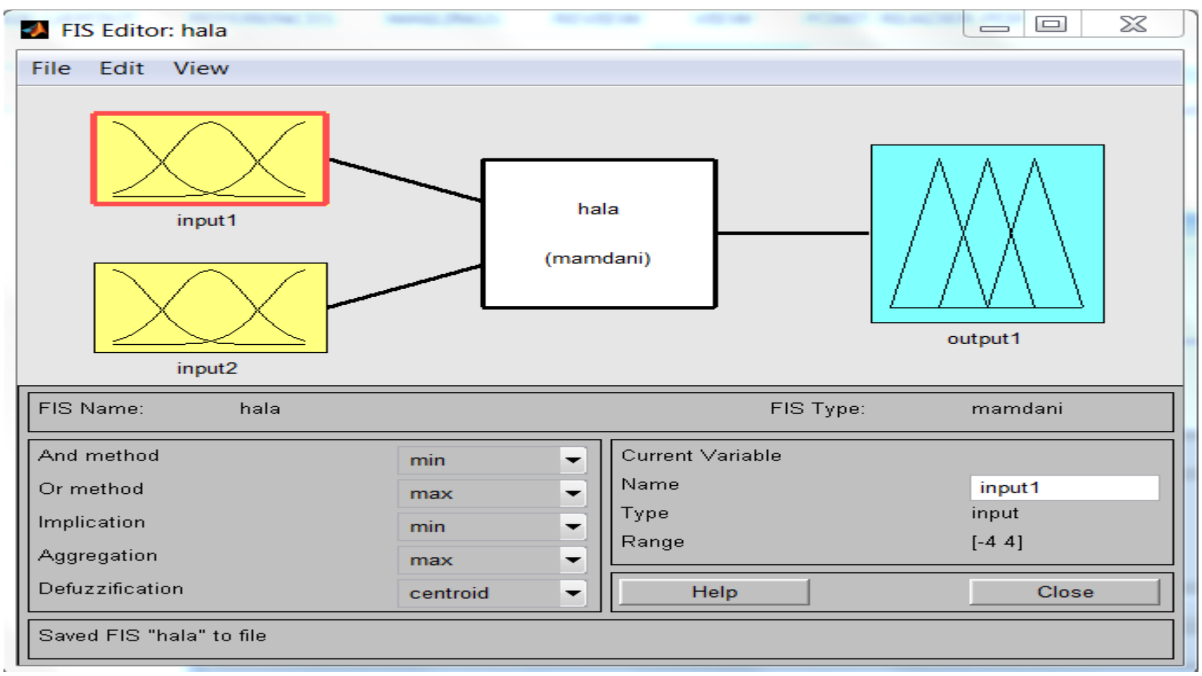

Figure 2.2: Fuzzy inference system (FIS) for FLC

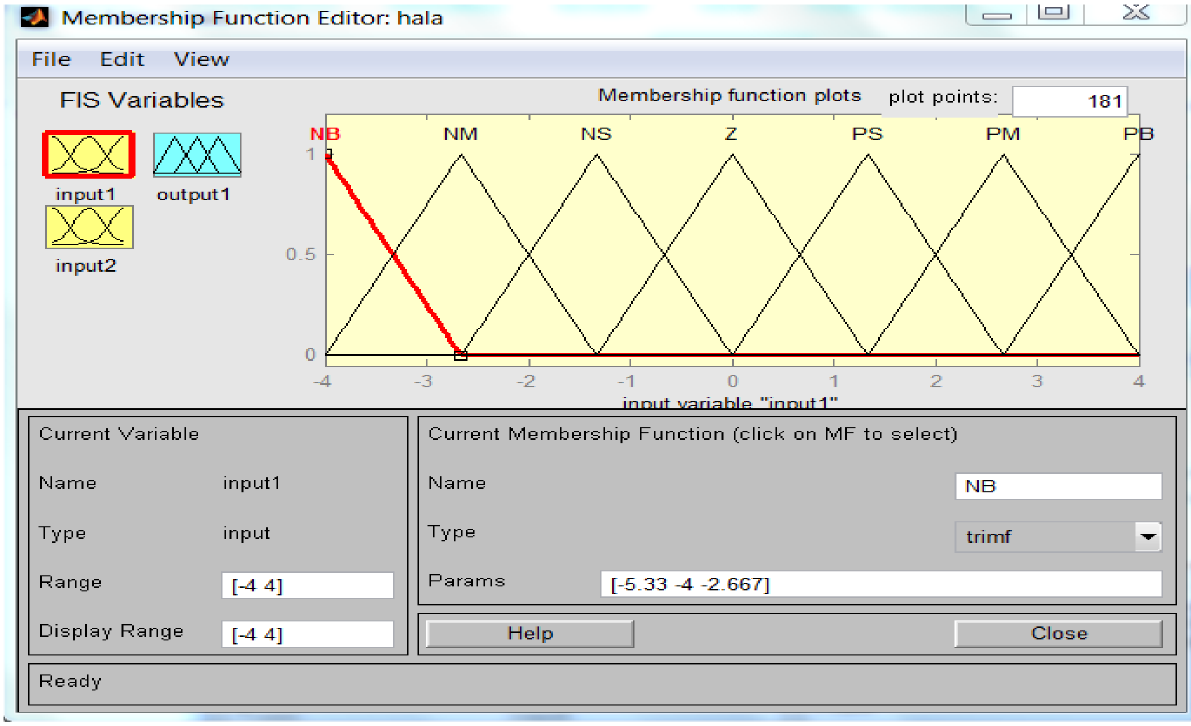

Figure 2.3: Membership function editor for input1 for LFC

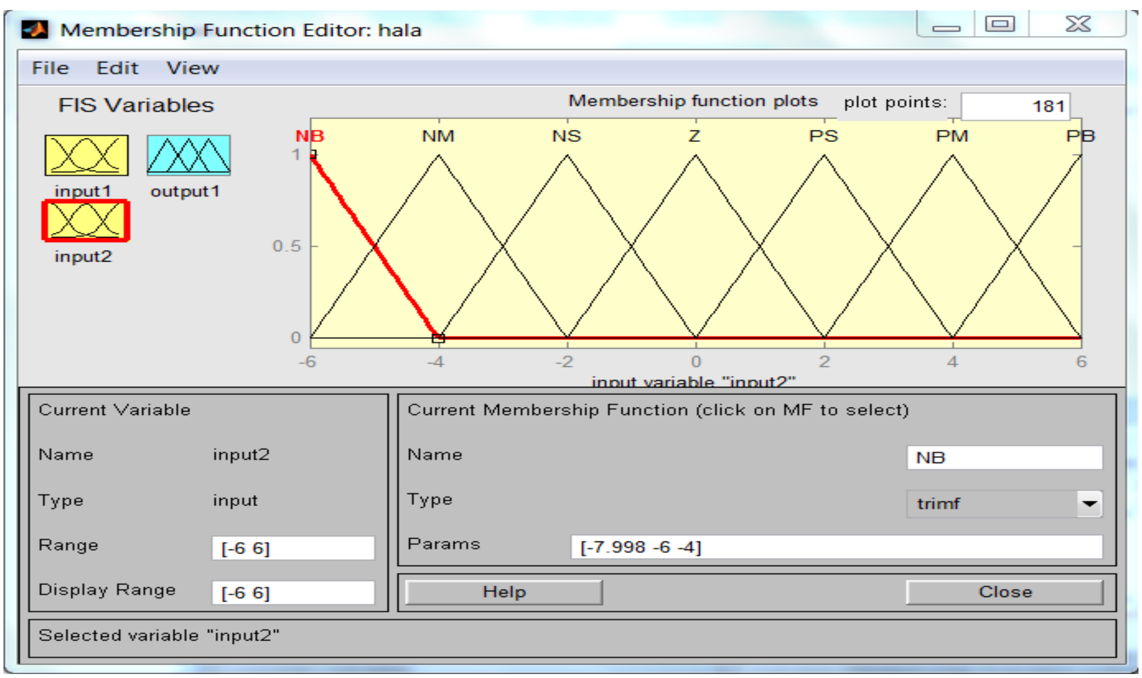

Figure 2.4: Membership function editor for input2 of FLC

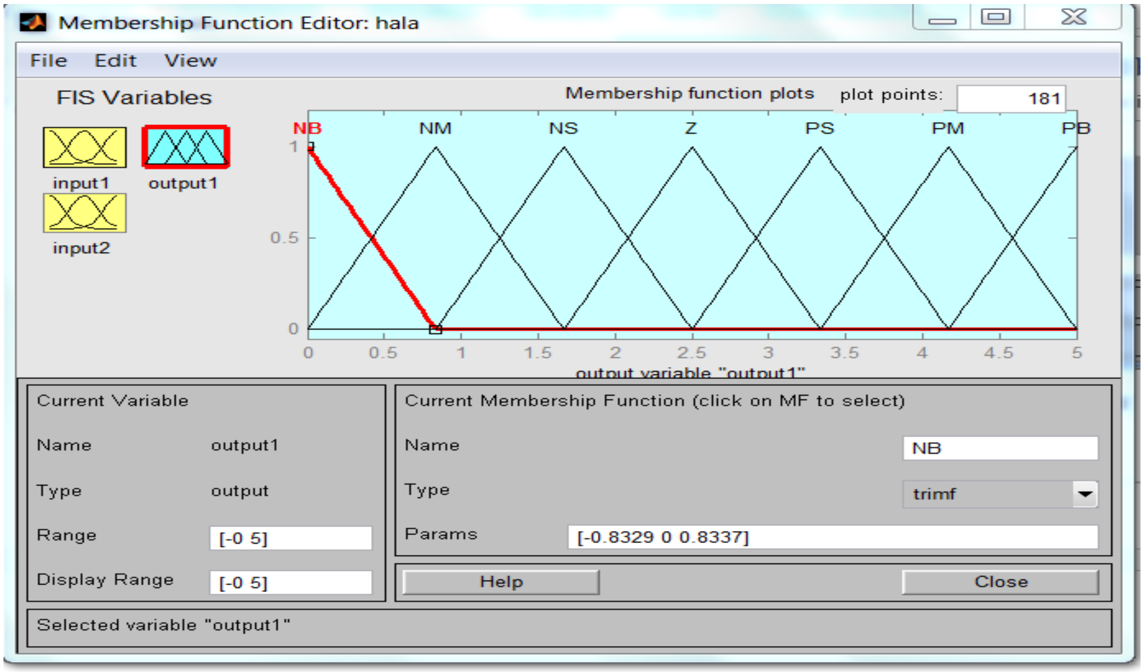

Figure 2.5: Membership function editor for output of FLC

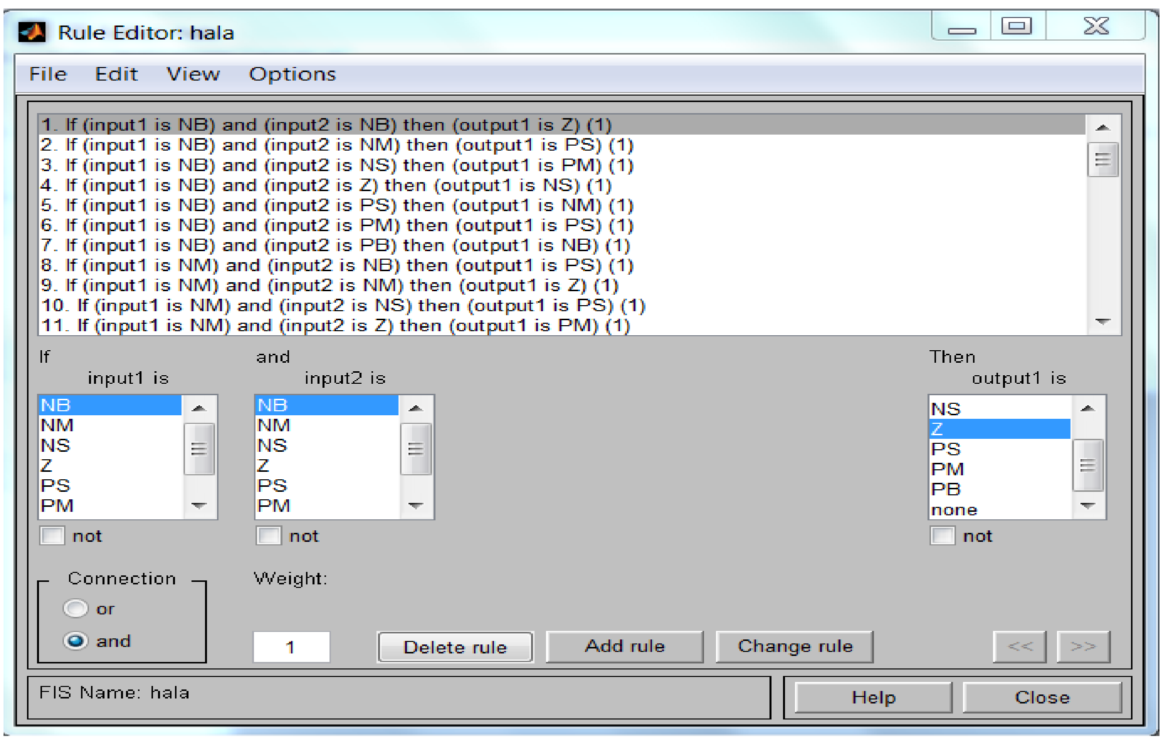

Figure 2.6: Rule editor

Table 2.1: fuzzy rule table for LFC

	NB	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	PB	PB	PB	PB	PM	PM	PS
NM	PB	PM	PM	PM	PS	PS	PS
NS	PM	PM	PS	PS	PS	PS	ZE
ZE	NS	NS	NS	ZE	PS	PS	PS
PS	ZE	NS	NS	NS	NS	NM	NM
PM	NS	NS	NM	NM	NM	NB	NB
PB	NS	NM	NB	NB	NB	NB	NB

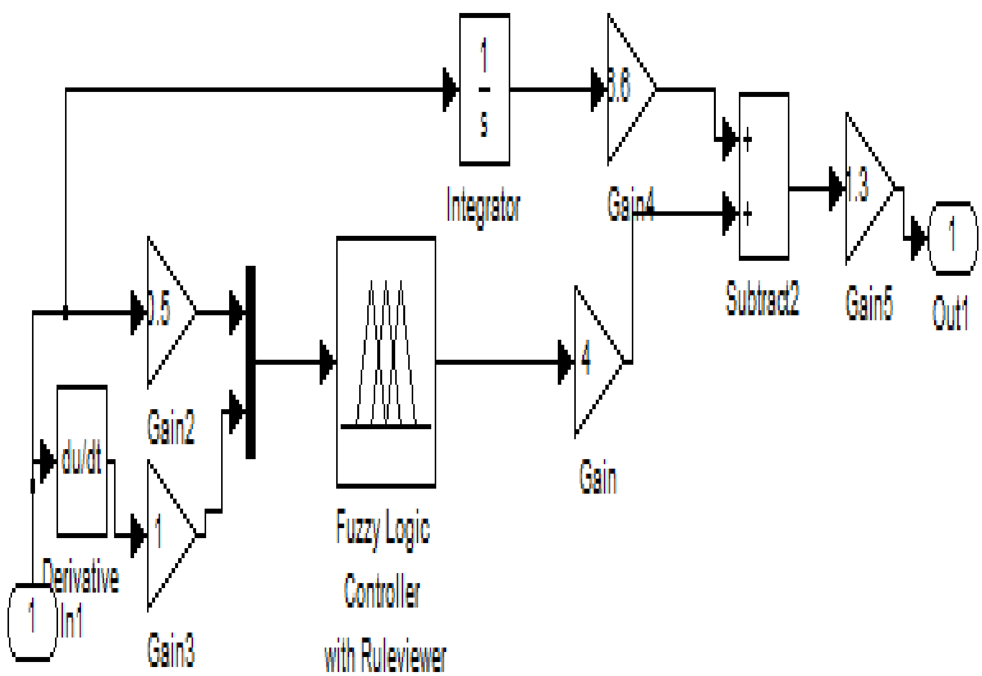

Figure 2.7: FLC Controller

Table 2.2: fuzzy rule table for AVR

	NB	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
NB	Z	PS	PM	NS	NM	PS	NM
NM	PS	Z	PS	PM	NS	NM	PS
NS	PM	PS	Z	PS	PM	PS	PM
Z	PS	PS	PS	Z	NS	NM	PS
PS	PS	PS	PM	NS	Z	NS	NM
PM	NS	PM	NS	NM	NS	Z	NS
PB	NM	NS	NS	NS	NM	NS	Z

CHAPTER THREE

EXCITATION SYSTEM

3.1 The functions of an excitation system

The basic function of an excitation system is to provide direct current to the synchronous machine field winding. In addition, the excitation system performs control and protective functions essential to the satisfactory performance of the power system by controlling the field current. The control functions include the control of voltage and reactive power flow, and enhancement of system stability. The protective functions ensure that the capability limits of the synchronous machine, excitation system, and other equipment are not exceeded [14]

3.2 Excitation system requirements

The performance requirements of the excitation system are determined by [14- 16]

3.2.1 Generator considerations

The basic requirement is that excitation system supply and automatically adjusts the field current of synchronous generator to maintain the terminal voltage as the output varies within the continuous capability of the generator. In addition, the excitation system must be able to respond to transient disturbances with field forcing consistent with the generator instantaneous and short term capabilities. The generator capabilities in this regard are limited by several rotors: rotor insulation failure due to high field voltage, rotor heating due to high field current, stator heating due to high armature current loading, core end heating during under excited operation, and heating due to excess flux (volts/Hz).

3.2.2 Power system considerations

From the power system viewpoint, the excitation system should contribute to effective control of system voltage and improvement of system stability. It should be capable of responding rapidly to a disturbance so as to enhance transient stability.

Historically, the role excitation system in enhancing power system performance has been growing continually. Early excitation systems were controlled manually to maintain desired generator terminal voltage and reactive power loading. When the voltage control was first automated, it was very slow. Greater interest in the design of excitation system developed, and exciter and voltage regulators with faster response were soon introduced to the industry. Modern excitation systems are capable of providing practically instantaneous response with high ceiling voltage.

To fulfil the above roles satisfactorily, excitation systems must satisfy the following requirements:

1 - Meet specified response criteria.

2- Provide limiting and protective functions as required to prevent damage to itself, the generator, and other equipment.

3- Meet specified requirements for operating flexibility.

4- Meet the desired reliability and availability, by incorporating the necessary level of redundancy and internal fault deduction and isolation capability.

3.3 Elements of an excitation system

Figure 3.1, shows the function block diagram of the excitation control system for a large synchronous Generator. The following is a brief description of the various subsystems identified in the figure.

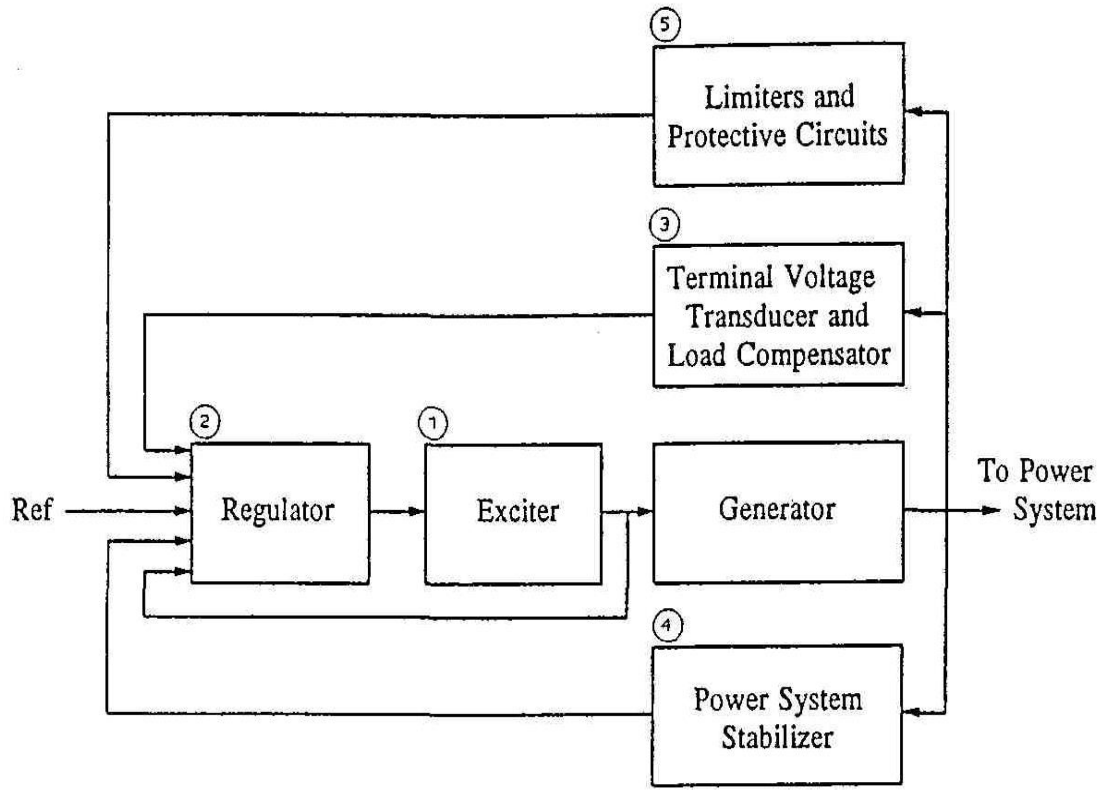

Figure 3.1: Shows the function block diagram synchronous Generator excitation control system

a. **Exciter:** It is a source of dc power that feeds the field winding of the synchronous generator and is called the current of the field, where it controls the amount of magnetic flux and therefore the voltage.

b. **Regulator:** compares the required field current with the existing excitation current and amplifies input control signals to a level and form appropriate for control of the exciter.

c. **Terminal voltage transducer and load compensator:** senses generator terminal voltage, rectifies and filters it to dc voltage quantity and compares with a reference which represents the desired terminal voltage. In additional, load (or line drop or reactive) compensation may be provided if it is desired to hold constant voltage at some point electrically remote from the generator terminal.

d. **Power system stabilizer:** provides an additional input signal to the regulator to damp power system oscillations of the network in transient situations and stabilize the voltage at a given value. Some commonly used input signals are rotor speed deviation, accelerating power, and frequency deviation.

e. ***Limiters and protective circuits*****:** These include a wide array of the control and protective functions which ensure that the capability limits of exciter and synchronous generator are not exceeded. Some of the commonly used functions of field-current limiter, maximum excitation limiter, terminal voltage limiter, volt-per-Hertz regulator and protection, and under excitation limiter.

3.4 Types of excitation systems

The excitation system is a variable source of constant current that provides the generator with a current of the field. Excitation Systems have taken many forms over the years of their evolution. They may be classified into the following three broad categories based on the excitation power source used [14, 17, and 18]:

a. D.C excitation system.
b. AC excitation system.
c. Static excitation system.

3.5 Reactive power and voltage control

As mentioned earlier a change in reactive power affective mainly the magnitude of the terminal voltage. The excitation system maintains generator voltage and control reactive power flow. The role of automatic voltage regulator (AVR) is to hold the terminal voltage magnitude of synchronous generator at a specified level. An increase in the reactive power load of the generator leads to a drop in the magnitude of the terminal voltage. This drop in the magnitude of the terminal voltage is sensed through a potential transformer **(**PT**),** this voltage is rectified and compared to a dc set point signal. The compared voltage amplified (error signal) is then amplifier and sent to the exciter which controls the exciter field, and increases the exciter terminal voltage, which results in the increase of the generated e.m.f. The reactive power generation is increasing to anew equilibrium, raising the terminal voltage to the desired value. The simple schematic diagram of a simple AVR is as shown in figure 3.2.

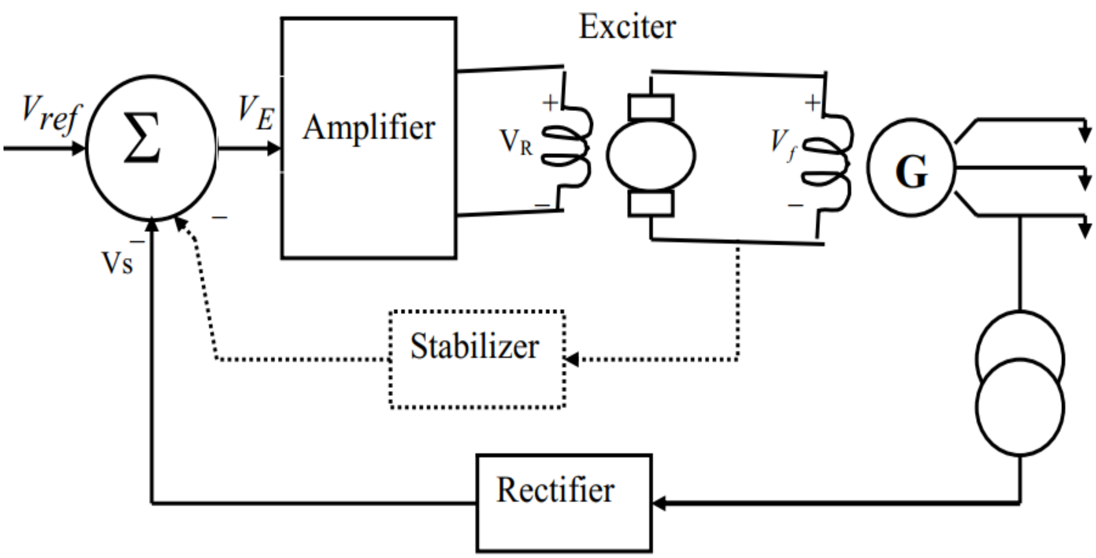

Figure 3.2: Block diagram of automatic voltage regulator

3.6 AVR model

The AVR model is designed through amplifier model, exciter model, generator model, and sensor mode [18].

3.6.1 Amplifier model

The excitation system amplifier may be a magnetic amplifier, rotating amplifier or modern electronic amplifier. The amplifier is represented by a gain $\boldsymbol{K_A}$ and a time constant $\boldsymbol{\tau_A}$and thetransfer function is

$$\frac{V_R(S)}{V_e(s)} = \frac{K_A}{1+\tau_A S} \tag{3.1}$$

$$V_e = V_{ref} - V_s \tag{3.2}$$

Typical values of K_A are in the range of 10 to 400. The amplifier time constant is very small, in the range of 0.02 to 0.1 second, and often is neglected.

3.6.2 Exciter model

There is a variety of different excitation types. However, modern excitation system uses ac power source through solid-state rectifies such as silicon controlled rectifier (SCR). The output voltage of the exciter is a nonlinear function of the voltage because of the saturation effects in the magnetic circuit. Thus, there is no simple relationship between the terminal voltages and the field voltage of the exciter. Many models with various degrees of sophistication have been developed and are available in the IEEE recommendation publications. A reasonable model of a modern exciter is a linearized model, which takes into account the major time constant and ignores the saturation or other nonlinearities. In the simplest form, the transfer function of a model exciter may be represented by a single time constant$\boldsymbol{\tau_E}$and gain K_E

$$\frac{V_F(S)}{V_R(s)} = \frac{K_E}{1+\tau_E S} \tag{3.3}$$

The time constant of modern excitation are very small.

3.6.3 Generator model

The Synchronous machine generated e.m.f is a function of the machine magnetization curve, and its terminal voltage is dependent on the generator load. In the linearized model, the transfer function relating the generator terminal voltage to its field voltage can be represented by a gain $\boldsymbol{K_G}$and a time constant$\tau_G$and the transfer function is

$$\frac{V_t(S)}{V_F(s)} = \frac{K_G}{1+\tau_G S} \qquad (3.4)$$

3.6.4 Sensor model

The voltage is sensed through a potential transformer and in one form; it is rectified through a bridge rectifier. The sensor is modelled by a simple first order transfer function, given by

$$\frac{V_S(S)}{V_t(s)} = \frac{K_R}{1+\tau_R S} \qquad (3.5)$$

τ_RIs very small, and we may assume a range of 0.01 to 0.06 second.

Utilizing the above models results in the AVR block diagram is shown in figure 3.3.

The open loop transfer function of the block diagram in figure 3.3 1s

$$KG(S)H(S) = \frac{K_A K_E K_G K_R}{(1+\tau_A S)(1+\tau_E S)(1+\tau_G S)(1+\tau_R S)} \qquad (3.6)$$

And the close loop transfer function relating the generator terminal voltage $V_t(s)$ to the reference voltage $V_{ref}(s)$ is

$$\frac{\boldsymbol{V_t(S)}}{\boldsymbol{V_{ref}(s)}} = T(S) = \frac{K_A K_E K_G K_R(1+\tau_R S)}{(1+\tau_A S)(1+\tau_E S)(1+\tau_G S)(1+\tau_R S)+K_A K_E K_G K_R} \qquad (3.7)$$

Or

$$V_t(S) = T(S)V_{ref}(S) \qquad (3.8)$$

For a step input $V_{ref}(S) = \frac{1}{S}$, using the final values theorem, the steady state response is

$$V_{t_{ss}} = \lim_{s\to 0} sV_t = \frac{K_A}{1+K_A} \qquad (3.9)$$

And steady state error is

$$V_{ess} = 1 - V_{t_{ss}} = 1 - \frac{K_A}{1+K_A} \qquad (3.10)$$

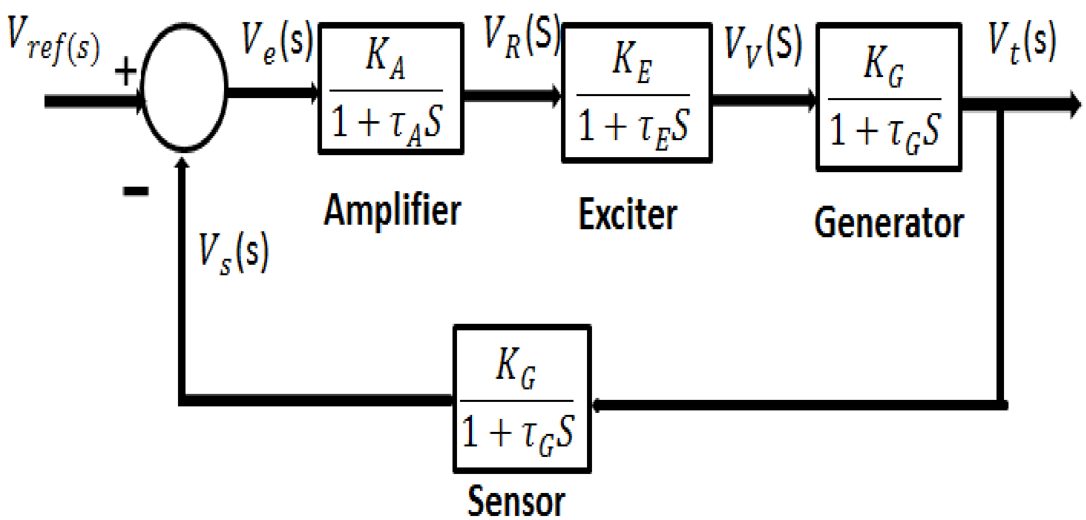

Figure 3.3: A simplified automatic Voltage Regulator (AVR) block diagram

3.7 State space representation

From figure 3.3 State space equations can be written

$$V_R = \frac{K_A}{1+\tau_A S}(V_{ref} - V_S)$$

$$V_R(1+\tau_A S) = K_A(V_{ref} - V_S)$$

$$V_R + \tau_A \frac{dV_R}{dt} = K_A(V_{ref} - V_S)$$

$$\frac{dV_R}{dt} = -\frac{1}{\tau_A}V_R - \frac{K_A}{\tau_A}V_s \quad + \frac{K_A}{\tau_A}V_{ref} \tag{3.11}$$

$$V_F = \frac{K_E}{1 + \tau_E S}V_R$$

$$V_F(1 + \tau_E S) = K_E V_R$$

$$V_F + \tau_E \frac{dV_F}{dt} = K_E V_R$$

$$\frac{dV_F}{dt} = \frac{K_E}{\tau_E}V_R - \frac{1}{\tau_E}V_F \tag{3.12}$$

$$V_s = \frac{K_R}{1 + \tau_R S}V_t$$

$$V_s(1 + \tau_R S) = K_R V_t$$

$$V_s + \tau_R \frac{dV_S}{dt} = K_R V_t$$

$$\frac{dV_s}{dt} = -\frac{1}{\tau_R}V_S + \frac{K_R}{\tau_R}V_t \tag{3.13}$$

$$V_t = \frac{K_G}{1 + \tau_G S}V_F$$

$$V_t(1 + \tau_G S) = K_G V_F$$

$$V_t + \tau_G \frac{dV_t}{dt} = K_G V_F$$

$$\frac{dV_t}{dt} = \frac{K_G}{\tau_G}V_F - \frac{1}{\tau_G}V_t \tag{3.14}$$

$$\frac{d}{dt}\begin{bmatrix} V_R \\ V_F \\ V_S \\ V_t \end{bmatrix} = \begin{bmatrix} -\frac{1}{\tau_A} & 0 & -\frac{K_A}{\tau_A} & 0 \\ \frac{K_E}{\tau_E} & -\frac{1}{\tau_A} & 0 & 0 \\ 0 & 0 & -\frac{1}{\tau_R} & \frac{K_R}{\tau_R} \\ 0 & \frac{K_G}{\tau_G} & 0 & -\frac{1}{\tau_G} \end{bmatrix} \begin{bmatrix} V_R \\ V_F \\ V_S \\ V_t \end{bmatrix} + \begin{bmatrix} \frac{K_A}{\tau_A} \\ 0 \\ 0 \\ 0 \end{bmatrix} V_{ref} \qquad (3.15)$$

The AVR system of generator having the following parameters [18]

$K_E = K_G = K_R = 1, \tau_A = 0.1, \tau_G = 1, \tau_E = 0.4, \tau_R = 0.05$

The Open-loop transfer function of the AVR system is

$$KG(S)H(S) = \frac{K_A(1)(1)(1)}{(1+0.1S)(1+0.4S)(1+S)(1+0.05S)}$$

$$= \frac{500K_A}{(10+S)(2.5+S)(1+S)(20+S)}$$

$$= \frac{500K_A}{s^4 + 33.5s^3 + 307.5s^2 + 775s + 500} \qquad (3.16)$$

The characteristic equation then becomes

$1 + KG(S)H(S) = 0$

$$1 + \frac{500K_A}{s^4 + 33.5s^3 + 307.5s^2 + 775s + 500} = 0 \qquad (3.17)$$

The characteristic polynomial equation becomes

$$s^4 + 33.5s^3 + 307.5s^2 + 775s + 500 + 500K_A = 0 \qquad (3.18)$$

3.8 Stability test

For control stability, the range of K_A is found using the Routh-Hurwits array [18].

s^4	1	33.5	$500 + 500K_A$
s^3	33.5	775	0
s^2	284.365	$500 + 500K_A$	0
s^1	$58.9K_A - 716.1$	0	0
s^0	$500 + 500K_A$	0	0

$58.9K_A - 716.1 \leq 0$

$K_A < 12.16$

3.9 AVR excitation system with stabilizer

The basic function of the excitation system stabilizer is to add damping to the generator power oscillation by controlling its excitation using an auxiliary stabilizing signal [20].

From the analysis above, the AVR step response was not satisfactory even with a small amplifier gain of K_A=10. It's therefore necessary to increase the relative stability of the excitation system by introducing a controller which would add a zero to the AVR open-loop transfer function .A possible way of doing this is by adding a stabilizer feedback to the control as shown in figure 3.4

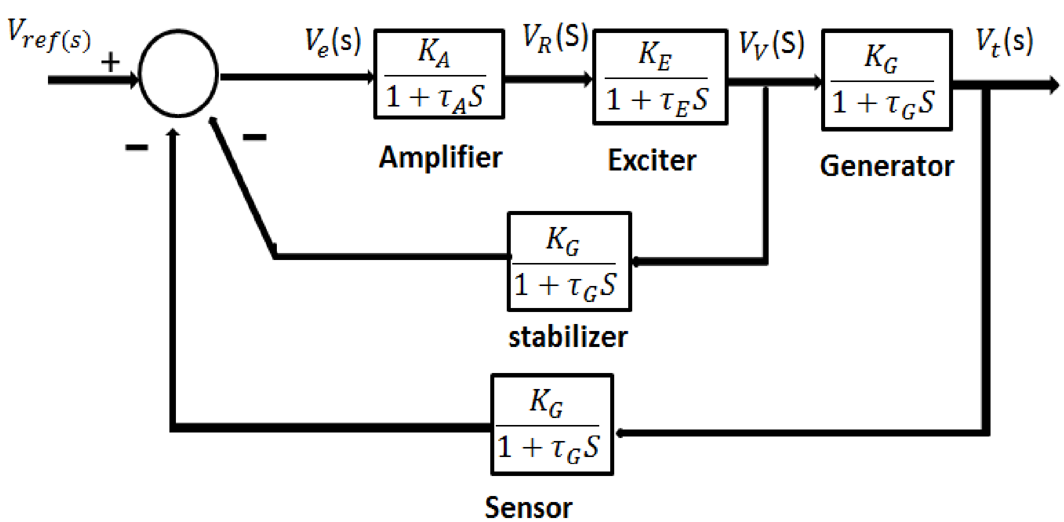

Figure 3.4: Block Diagram of the Compensated AVR System

An improved or satisfactory response of AVR can be obtained by proper adjustment of the stabilizer gain K_F and time constant τ_F

CHAPTER FOUR

LOAD FREQUENCY CONTROLLER

4.1 General

Two main variables that change during transient power load are: area frequency and tie line power interchange. The concept of Load Frequency Control (LFC) is directly related to the aforementioned variables since the task is to minimize this variation. The key thing is to maintain the steady state at null position. In this vein, effective measures like Active Disturbance Rejection Control (ADRC) have been developed that allow practical control.

The main bifurcation between frequency and voltage in power system is on the account of active and reactive power. The dependency of frequency is on active power whereas that of voltage is on the reactive power. The combination of active power and frequency control is generally known as Load Frequency Control.

The major the purposes of the LFC are to:

1. Keep frequency uniform.
2. Divide load between generators.
3. Control tie-line interchange schedules.

4.2 **Modelling of LFC**

The regulation of the frequency in the power system requires the speed control of the prime mover, using the governor. Based on the IEEE proposed standards, suitable mathematical models are developed to integrate the prime mover, governor, and the network [18].

This section presents a brief analysis on the mathematical modelling of the generator, load, prime mover and governor. An isolated electric area, where one generating unit or bunch of generating units, is placed in close vicinity to distribute the electricity in the same area is called single area system. There is no other generating unit which is distant apart is placed. Only the generating unit(s) present in that area is responsible to maintain the desired frequency in normal and abnormal conditions.

For LFC scheme of single generating unit has basically four parts:

1. Generator.
2. Load.
3. Prime Mover.
4. Turbine speed governing system.

4.2.1 Generator model

Swing equation forms the basis for modelling of load frequency control (LFC) loop of the power system. A change in the rotor angle į results in change in real power, which ultimately affects the frequency. Under normal operating conditions, the relative position of the rotor axis and the resultant magnetic field axis are fixed. The angle between these axes is known as the power angle or torque angle. During sudden load disturbance, rotor will decelerate or accelerate with respect to synchronously rotating air gap m.m.f, and a relative motion begins. The equation describing this relative motion is known as swing equation. The swing equation of a synchronous machine is given by:

$$\frac{2Hd^2\Delta\delta}{\omega_s dt^2} = \Delta P_m - \Delta P_e \qquad (4.1)$$

Where

$\Delta P_m - \Delta P_e$ = Increment in power input to the generator

Expressing speed deviation in per unit, Equation (4.1), can be rewritten as:

$$\frac{d\Delta\frac{\omega}{\omega_s}}{dt^2} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \qquad (4.2)$$

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

$$\frac{d\Delta\omega}{dt^2} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \qquad (4.3)$$

Taking Laplace transform of Equations (4.3) and (4.4) is obtained:

$$\Delta\omega(s) = \frac{1}{2H}\left(\Delta P_m(s) - \Delta P_e(s)\right) \qquad (4.4)$$

Figure 4.1, shows the Block Diagram of the generator model.

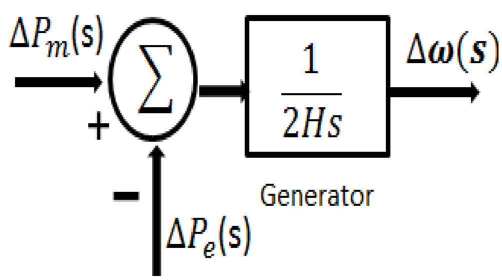

Figure 4.1: Generator block diagram

4.2.2 Load model

The load model on a power system consists of a variety of electrical devices. For resistive loads, such as lighting and heating loads, the electric power is independent of frequency. Motor loads are sensitive to changes in frequency. The speed-load characteristics of a composite load are approximated by

$$\Delta P_e = \Delta P_L + D\Delta\omega \qquad (4.5)$$

WhereΔP_L is the non-frequency sensitive load change, and $D\Delta\omega$ is the frequency sensitive load change, D is expressed as present change in load divided by present change in frequency. Including the load model in the generator block diagram results in the block diagram of figure 4.2.

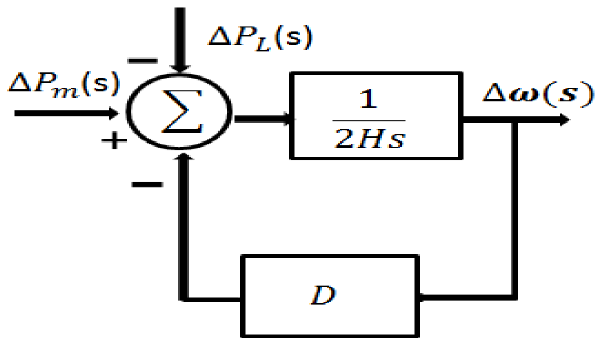

Figure 4.2: Generator and load block diagram

Eliminating the simple feedback loop in figure 4.2, results in the block diagram as shown in figure 4.3.

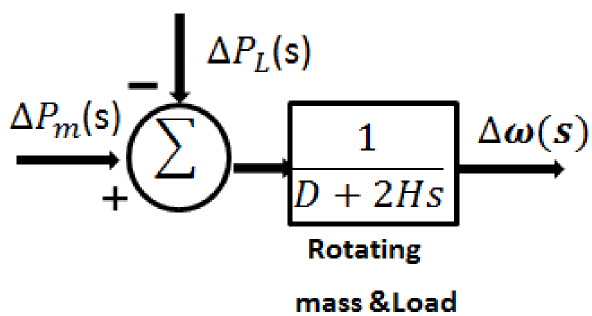

Figure 4.3: Simplified generator and load block diagram

4.2.3 Prime mover model

The source of the mechanical power, commonly known as the prime mover, may be hydraulic turbines at waterfalls, steam turbines whose energy comes from the burning of coal, gas, nuclear and gas turbines. The models for the prime mover must take account of the steam supply and boiler control system characteristics in the case of a steam turbine. The turbine model relates to changes in mechanical power output

ΔPm to changes in a steam valve position ΔP_v. The simplest prime mover model for the non-reheat steam turbine can be approximated with a single time constantτ_T , resulting in the following transfer function.

$$G_T(S) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{1 + \tau_T S} \quad (4.6)$$

The block diagram for a simple turbine is shown in figure 4.4.

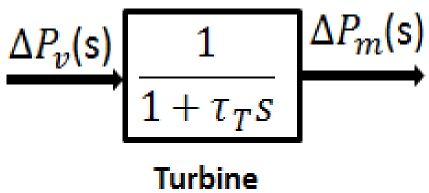

Figure 4.4: Block diagram for a simple non-reheat steam turbine

The time constantτ_T is in the range of 0.2 sec to 2.0 seconds.

4.2.4 Governing model

When the generator electrical load is suddenly increased, the generated power also increases to satisfy the load demand, which in turns exceeds the mechanical power input. This mechanical power deficiency is supplied by the kinetic energy stored in the rotating system. The reduction in kinetic energy causes the reduction in turbine speed and consequently, the generator frequency falls. The change in speed is sensed by the turbine governor which acts to adjust the turbine input by adjusting valve position to change the mechanical power output to bring the speed to a new steady-state. The earliest governors were the Watt governors which sense the speed by means of rotating fly-balls and provide mechanical motion in response to speed changes. There are some inherent drawbacks and limitations of Watt type governor such as problem of backlash, dead band and other nonlinearities etc. These governors are mechanical type and hence slow in their operation. However, most modern governors use electronic means to sense speed changes and its control. Figure 4.5, shows schematically the essential elements of a conventional watt governor which consists of the following major parts:

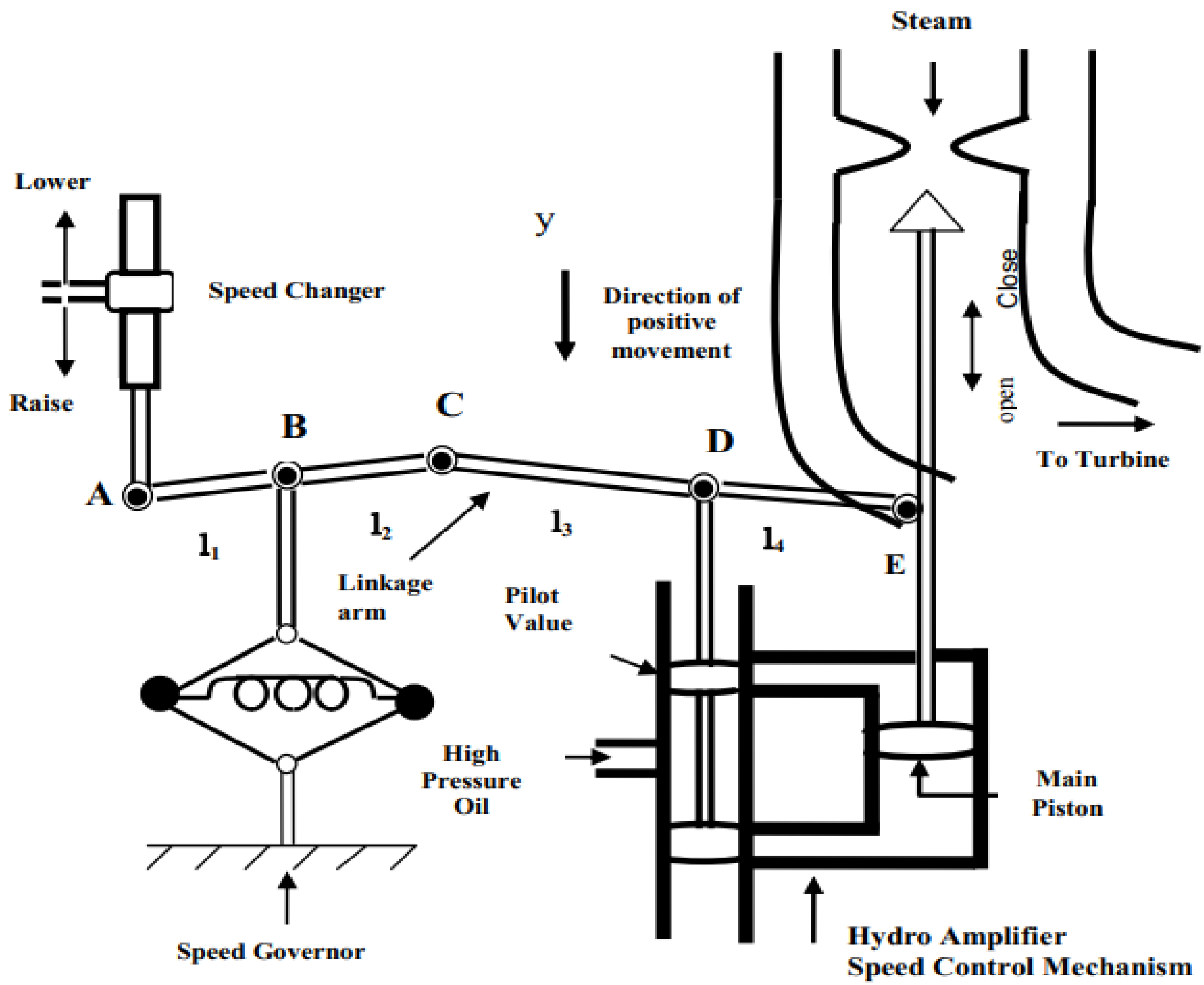

Figure 4.5: Block diagram of speed governing model

a. **Speed Governor:** The essential parts are centrifugal fly balls driven directly or through gearing by the turbine shaft. The mechanism provides upward and downward vertical movements proportional to the change in speed.

b. **Linkage Mechanism:** These are links for transforming the fly balls movement to the turbine valve through a hydraulic amplifier and providing a feedback from the turbine valve movement.

c. **Hydraulic Amplifier:** Very large mechanical forces are needed to operate the steam valve. Therefore, the governor movements are transformed into high power forces via several stages of hydraulic amplifiers.

d. **Speed Changer:** The speed changer consists of a servomotor which can be operated manually or automatically for scheduling load at a nominal frequency. By adjusting this set point, a desired load dispatches can be scheduled at a nominal frequency.

For stable operation, the governors are designed to permit the speed to drop as the load is increased. The speed governor mechanism acts as a comparator whose output ΔPg is the difference between the reference set power ΔPref and the power $\frac{1}{R}\Delta\omega$ in Equation (4.7)

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta\omega \qquad (4.7)$$

Taking Laplace transform of Equation (4.7), we get

$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta\omega(S) \qquad (4.8)$$

The command ΔPg is transformed through the hydraulic amplifier to the steam valve position command ΔPv. Assuming a linear relationship and considering a simple time constant $\Delta\tau_T$, s as follows.

$$\frac{\Delta P_v(s)}{\Delta P_g(s)} = \frac{1}{1 + \tau_g S} \qquad (4.9)$$

Equations 4.8 and 4.9 are represented by the block diagram shown in figure 4.6.

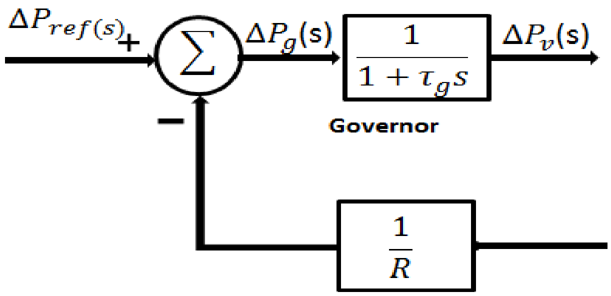

Figure 4.6: Block diagram for speed governing system of steam turbine

Combining the block diagrams of figures 4.3, 4.4 and 4.6 results in the complete block diagram of the load frequency control of an isolated power station are shown in figure 4.7.

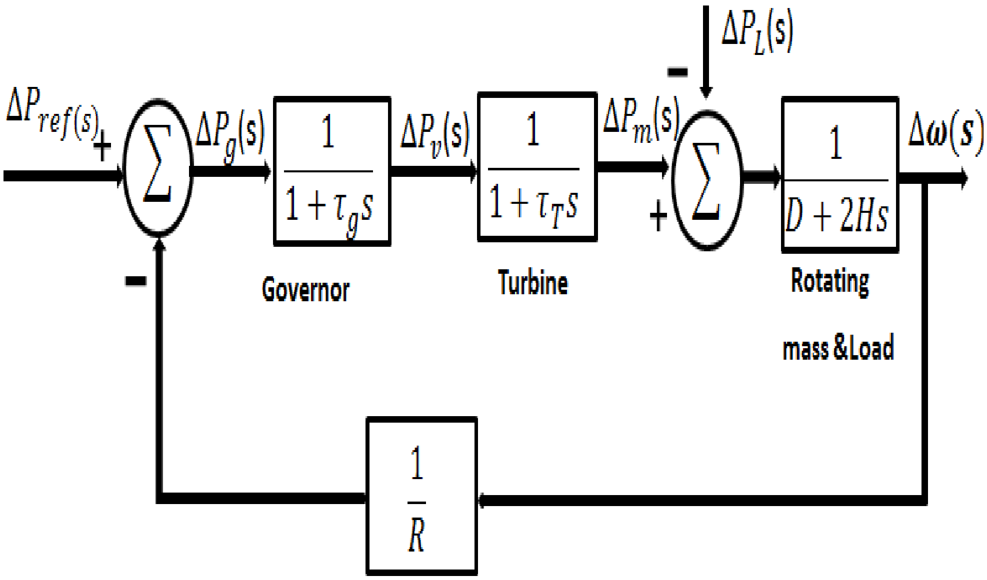

Figure 4.7: LFC block diagram of an isolated power system

The open-loop transfer function

$$KG(S)H(S) = \frac{1}{R(1+\tau_g S)(1+\tau_T S)(D+2HS)} \qquad (4.10)$$

And the close loop transfer function relating the load change ΔPL to the frequency deviation is

$$\frac{\Delta\omega(S)}{\Delta P_L(s)} = \frac{(1+\tau_g S)(1+\tau_T S)}{(2HS+D)\big(1+\tau_g S\big)(1+\tau_T S)+\frac{1}{R}} \qquad (4.11)$$

The load change is a step input

$$\Delta P_L(s) = \frac{\Delta P_L}{S} \tag{4.12}$$

The steady-state value of $\Delta\omega$ is

$$\Delta\omega_{ss} = \lim_{s\to 0} s\,\Delta\omega(S) = -\frac{\Delta P_L}{D+\frac{1}{R}} \tag{4.13}$$

The steady state speed deviation depends on the governor speed regulation. When generators operating in parallel, the composite frequency power characteristics are depend on the combined effect of the droops of all the generator speed governors.

4.3 State space representation

From figure 4.7 State space equations can be written

$$\Delta\omega = \frac{1}{D + 2HS}(\Delta P_m - \Delta P_L)$$

$$\Delta\omega(D + 2HS) = (\Delta P_m - \Delta P_L)$$

$$D\Delta\omega + 2H\frac{d\Delta\omega}{dt} = (\Delta P_m - \Delta P_L)$$

$$\frac{d\Delta\omega}{dt} = -\frac{D}{2H}\Delta\omega + \frac{1}{2H}\Delta P_m - \frac{1}{2H}\Delta P_L \tag{4.14}$$

$$\Delta P_m = \frac{1}{1 + \tau_T S}\Delta P_v$$

$$\Delta P_m(1 + \tau_T S) = \Delta P_v$$

$$\Delta P_m + \tau_T\frac{d\Delta P_m}{dt} = \Delta P_v$$

$$\frac{d\Delta P_m}{dt} = -\frac{1}{\tau_T}\Delta P_m + \frac{1}{\tau_T}\Delta P_v \tag{4.15}$$

$$\Delta P_v = \frac{1}{1 + \tau_g S}(\Delta P_{ref} - \frac{1}{R}\Delta\omega)$$

$$\Delta P_v\left(1 + \tau_g S\right) = (\Delta P_{ref} - \frac{1}{R}\Delta\omega)$$

$$\Delta P_v + \tau_g \frac{d\Delta P_v}{dt} = (\Delta P_{ref} - \frac{1}{R}\ \Delta\omega)$$

$$\frac{d\Delta P_v}{dt} = -\frac{1}{\tau_g R}\Delta\omega - \frac{1}{\tau_g}\Delta P_v\ + \frac{1}{\tau_g}\Delta P_{ref} \qquad (4.16)$$

$$\frac{d}{dt}\begin{bmatrix} \frac{\Delta\omega}{dt} \\ \frac{\Delta P_m}{dt} \\ \frac{\Delta P_v}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{D}{2H} & \frac{1}{2H} & 0 \\ 0 & -\frac{1}{\tau_T} & \frac{1}{\tau_T} \\ -\frac{1}{\tau_g R} & 0 & -\frac{1}{\tau_g} \end{bmatrix} \begin{bmatrix} \Delta\omega \\ \Delta P_m \\ \Delta P_v \end{bmatrix} + \begin{bmatrix} -\frac{1}{2H} & 0 \\ 0 & 0 \\ 0 & \frac{1}{\tau_g} \end{bmatrix} \begin{bmatrix} \Delta P_L \\ \Delta P_{ref} \end{bmatrix} \qquad (4.17)$$

The LFC system of generator having the following parameters [18]

$\tau_T = 0.5sec,\ \tau_g = 0.2sec,\ \ H = 5sec,\ D = 0.8,\ R = 0.05, \Delta P_L = 0.2$

The open-loop transfer function

$$KG(S)H(S) = \frac{K}{(1 + 0.2S)(1 + 0.5S)(0.8 + 10S)}$$

$$= \frac{K}{s^3 + 7.08s^2 + 10.56s + 0.8} \qquad (4.18)$$

$$K = \frac{1}{R}$$

The characteristic equation then becomes

$$1 + KG(S)H(S) = 1 + \frac{K}{s^3 + 7.08s^2 + 10.56s + 0.8} = 0 \quad (4.19)$$

The characteristic polynomial equation becomes

$$s^3 + 7.08s^2 + 10.56s + 0.8 + K = 0 \qquad (4.20)$$

4.4 Stability test:

The Routh-Hurwits array for this polynomial

$$\begin{array}{c|ll} s^3 & 1 & 10.56 \\ s^2 & 7.08 & 0.8+k \\ s^1 & 10.447-0.1412429k & 0 \\ s^0 & 0.8+k & 0 \end{array}$$

$$k < 73.965$$

$$R = \frac{1}{k}$$

$$R > \frac{1}{73.965} \quad or \;\; R > 0.0135$$

CHAPTER FIVE

SIMULITION RESULTS AND DISCUSSION

5.1 Simulation results

Three different cases were used to simulation of synchronous generator.

1. Without control loop.
2. With PID controller.
3. With fuzzy logic controller.

5.1.1 Excitation system

The synchronous generator with automatic voltage regulators in the table below (AVR) has the following parameters. **(**From, Hadi *Sadat, Power System Analysis) [18]*.

Table 5.1: Parameters required for the simulation of SG with AVR

parameter	K_A	K_E	K_G	K_R	τ_A	τ_E	τ_G	τ_R
value	10	1	1	1	0.1	0.4	1	0.05

a. (AVR) without controller

Simulation of synchronous generator with automatic voltage regulator (AVR) without control loop is shown in figure 5.1.

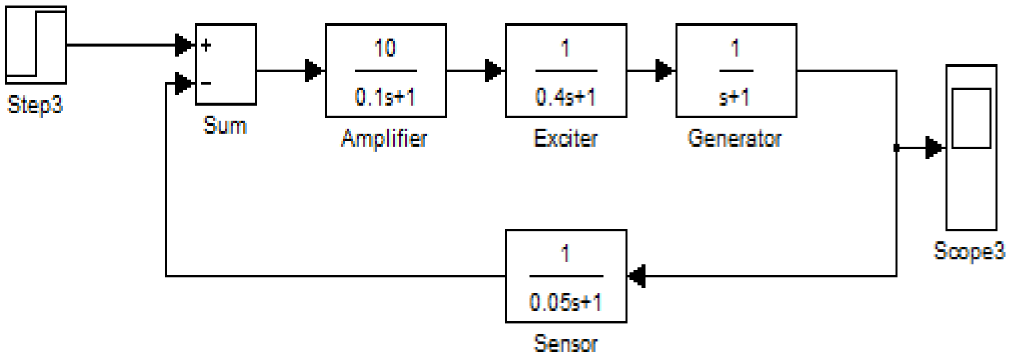

Figure 5.1: Simulation block diagram of (SG) with (AVR) without control loop

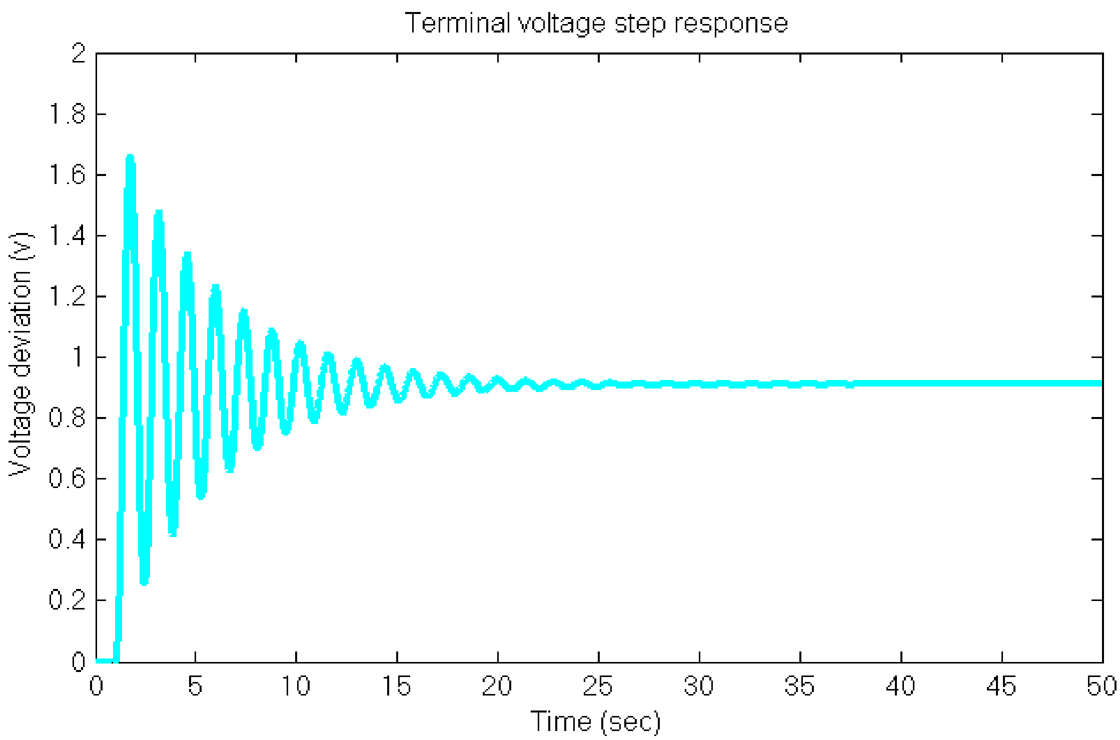

Figure 5.2: Terminal voltage step response of (SG) with (AVR) without control loop

Table 5.2: Terminal voltage response results of (SG) with (AVR) without control loop

results	Settling time (sec)	Overshoot (voltage)	Steady state response (voltage)	Steady state error (voltage)
value	25	0.7	0.909	0.091

From the terminal voltage response, it is seen that the system has a large overshoot and along settling time with oscillatory response and steady state error than 0.09.

b. (AVR) excitation with PID controller

Simulation of synchronous generator with automatic voltage regulator (AVR) with PID control loop is shown in figure 5.3.

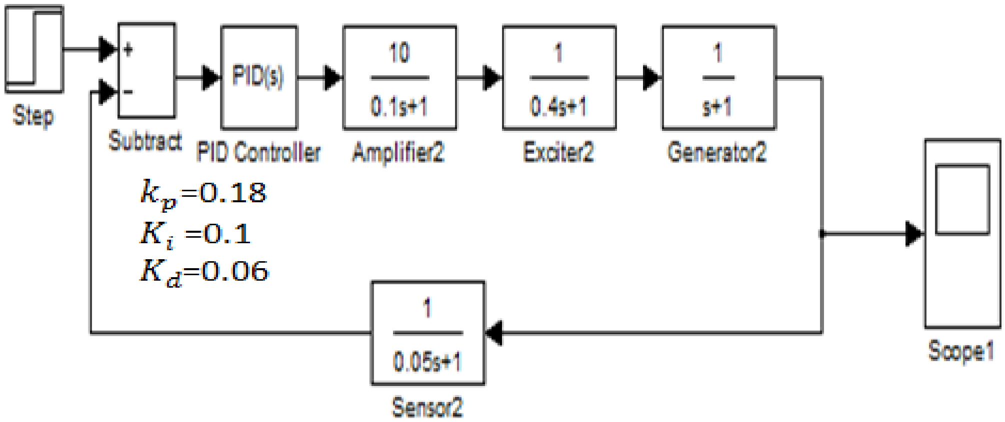

Figure 5.3: Simulation block diagram of (SG) with (AVR) with PID controller

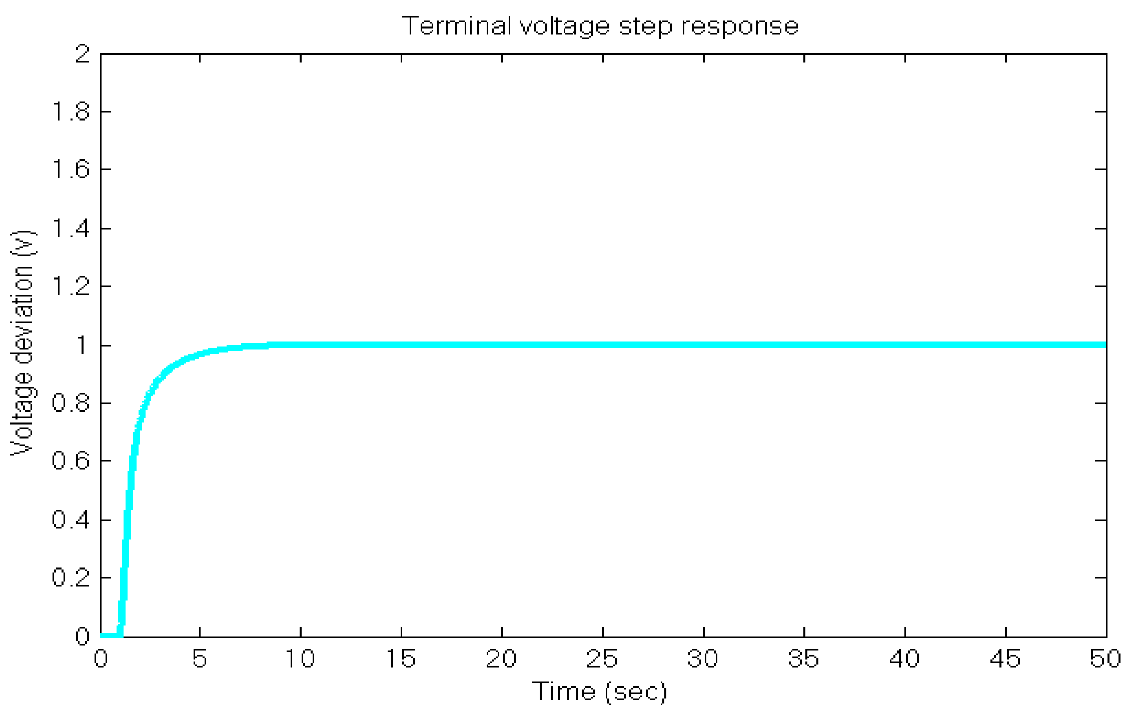

Figure 5.4: Terminal voltage step response of (SG) with (AVR) with PID controller

Table 5.3: Terminal voltage response results of (SG) with (AVR) with PID control loop

case	K_p	K_i	K_d	Settling time (sec)	Overshoot (voltage)	Steady state response (voltage)	Steady state error (voltage)
1	0.18	0.05	0.03	23	-	1	0
2	0.18	0.06	0.4	18	-	1	0
3	0.18	0.8	0.05	13	-	1	0
4	0.18	0.09	0.06	11.5	-	1	0
5	0.18	0.1	0.06	8	-	1	0

From Table (5.3), the best response of the AVR loop occurs when the gain $K_p, K_i, and K_d$ are equal 0.18, 0.1 and 0.06 respectively. This implies that case 5 gives the best tradeoff between overshoot/undershoot and settling time. Case 5 of the AVR loop was simulated in figure 5.3.

c. (AVR) excitation with FLC controller

FLC controller was used to control the generator excitation system and improve the dynamic response as well as reduce or eliminate the steady-state error.

Simulation of synchronous generator with automatic voltage regulator (AVR) with FLC control loop is shown in figure 5.5.

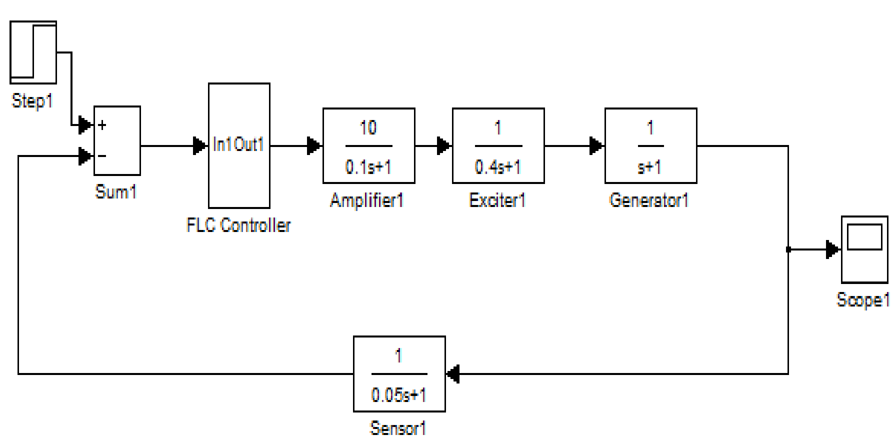

Figure 5.5: Simulation block diagram of (SG) with (AVR) with FLC controller

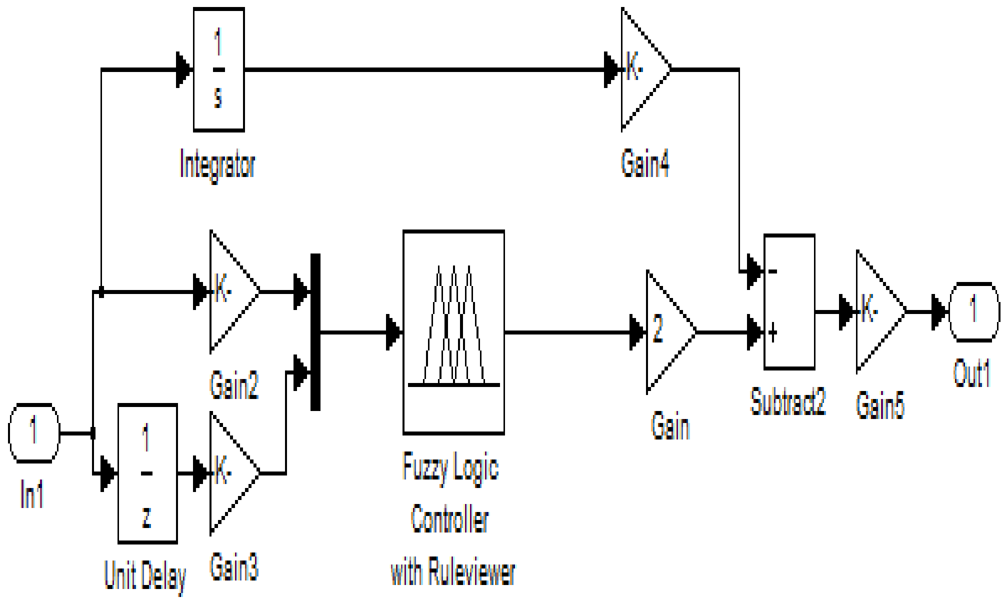

Figure 5.6: FLC controller

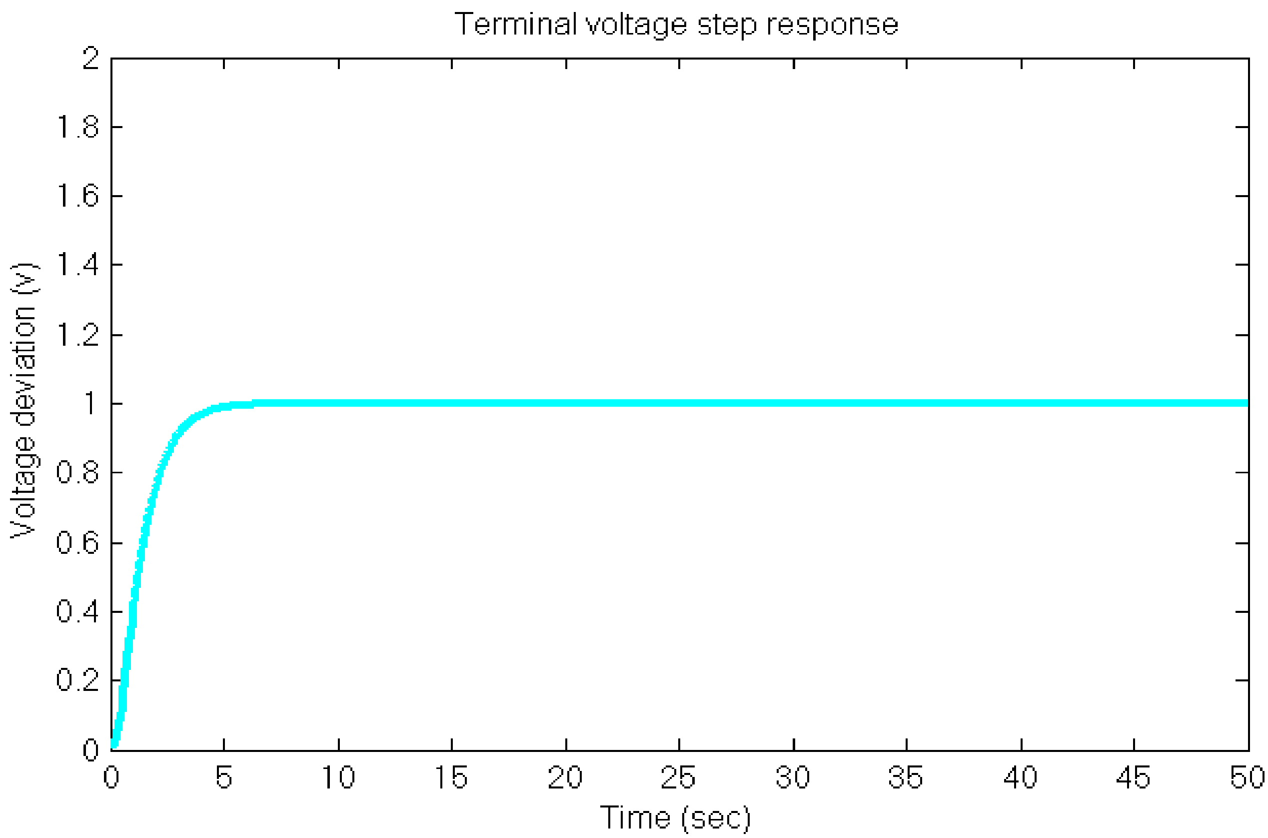

Figure 5.7: Terminal voltage step response of (SG) with (AVR) with FLC controller

Table 5.4: Terminal voltage response results of (SG) with (AVR) with FLC control loop

results	Settling time (sec)	Overshoot (voltage)	Steady state response (voltage)	Steady state error (voltage)
value	6	-	1	0.0

Comparison of AVR loops for all cases

The simulation block diagram the AVR loop using without, PID, and FLC controllers is shown in figure 5.8.

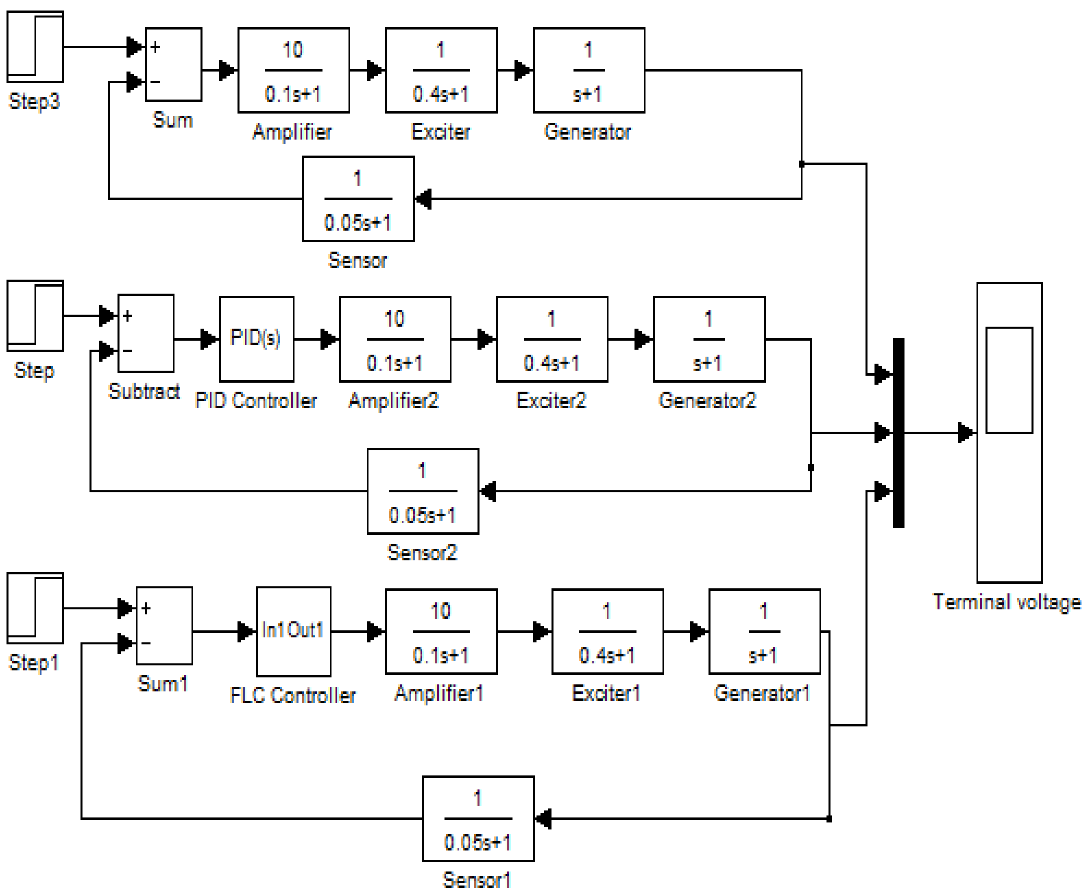

Figure 5.8: Simulation block diagram of (SG) with (AVR) without, PID and FLC controllers

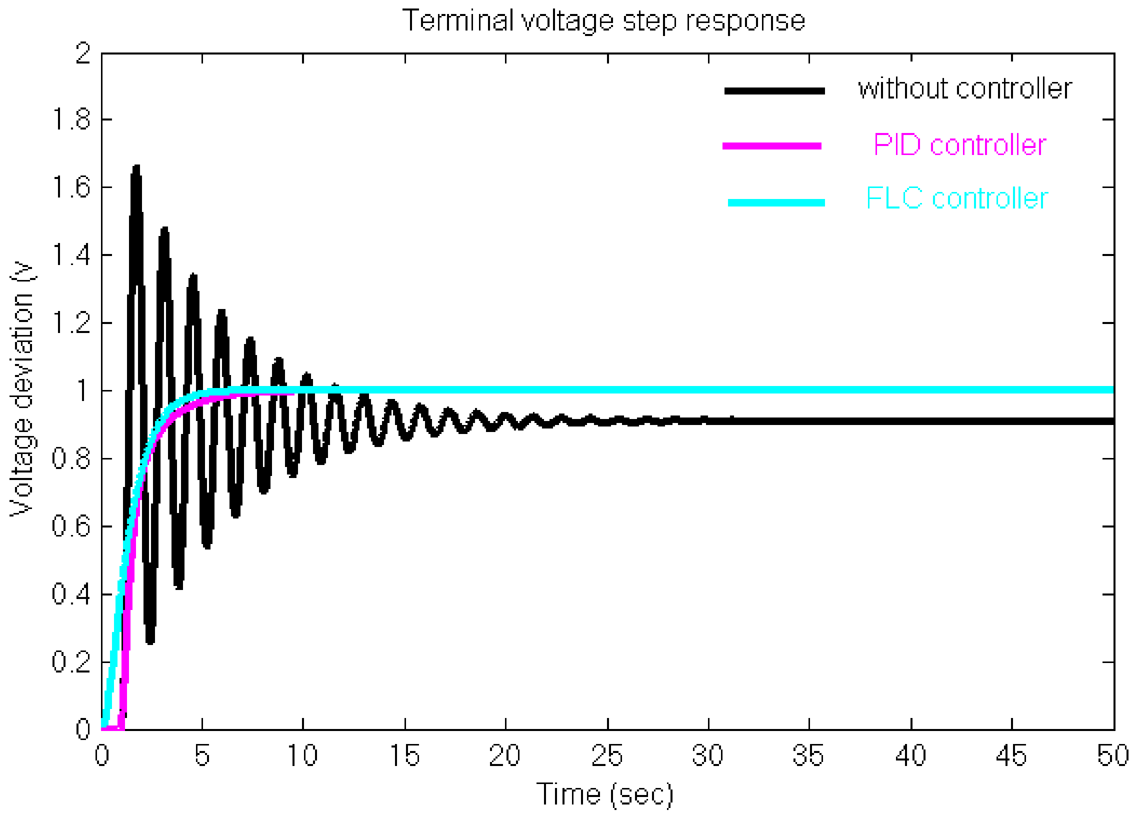

Figure 5.9: Terminal voltage step response of AVR loop using without, PID and FLC controllers

Table 5.5: Terminal voltage results of AVR loop using without, PID and FLC controllers

controller	Settling time (sec)	Overshoot (voltage)	Steady state response (voltage)	Steady state error (voltage)
Without	25	0.7	0.909	0.091
PID	8	-	1	0
FLC	6	-	1	0

Now, comparing the best PID controller result for AVR loop with the result Obtained using FLC controller, significant improvement was observed as shown in figure 5.4 and figure 5.7. Also, the comparison result is tabulated in table 5.5.

5.1.2 Load Frequency Controller

The main specifications of any control system are: the control loop must have a sufficient degree of stability, acceptable transient frequency error response and zero steady state frequency error. If the load on the system is increased, the turbine speed drops before the governor can adjust the input of the steam to the new load.

The nominal system parameters of LFC investigated in this paper are similar to the parameters commonly quoted in most of the research papers [1, 5, 14, and 21].

By adding PID and FLC controller in forward path of FLC loop, the simulation diagram of the AVR with PID and FLC controller can be represented as follow:

a. LFC without control loop

The synchronous generator with load frequency controller (LFC) has the following parameters in the table below. **(**From, Hadi *Sadat*, *Power System Analysis) [18]*.

Table 5.6: Parameters required for the simulation of (LFC)

parameter	τ_g	τ_T	H	D	R	ΔP_L
value	0.2	0.5	5	0.8	0.05	0.2

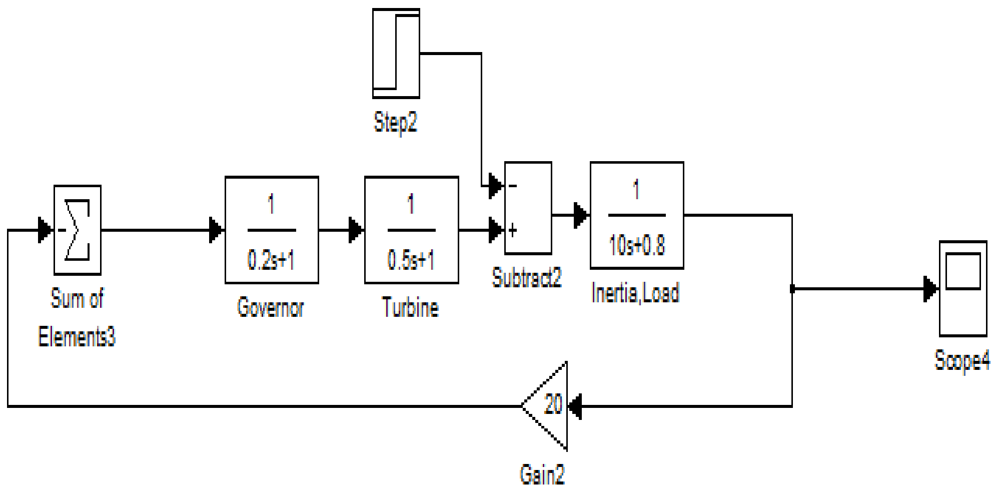

Figure 5.10: Simulation block diagram (LFC) without control loop

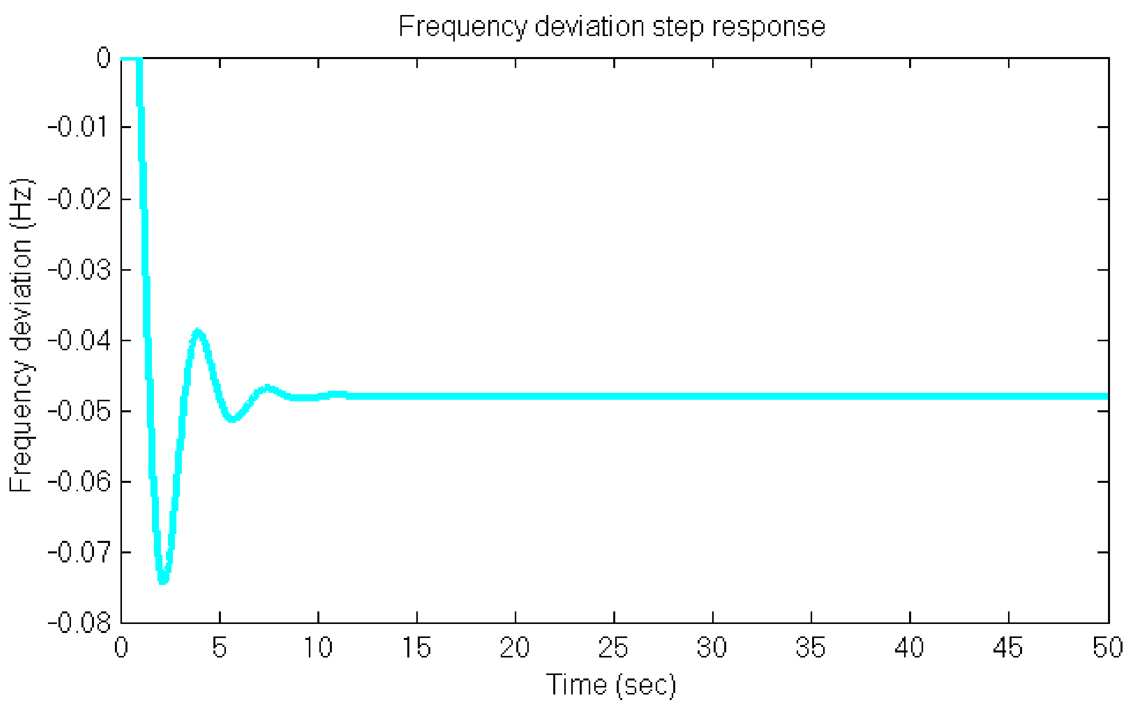

Figure 5.11: Frequency deviation response of (LFC) without control loop

Table 5.7: Frequency deviation response results of (LFC) with PID controller

results	Settling time (sec)	Undershoot (Hz)
value	10	0.075

From the figure 5.11 the frequency deviation response, it is seen that the system has a large overshoot and along settling time

b. LFC with PID controller

Simulation of (LFC) with PID control loop is shown in figure 5.12.

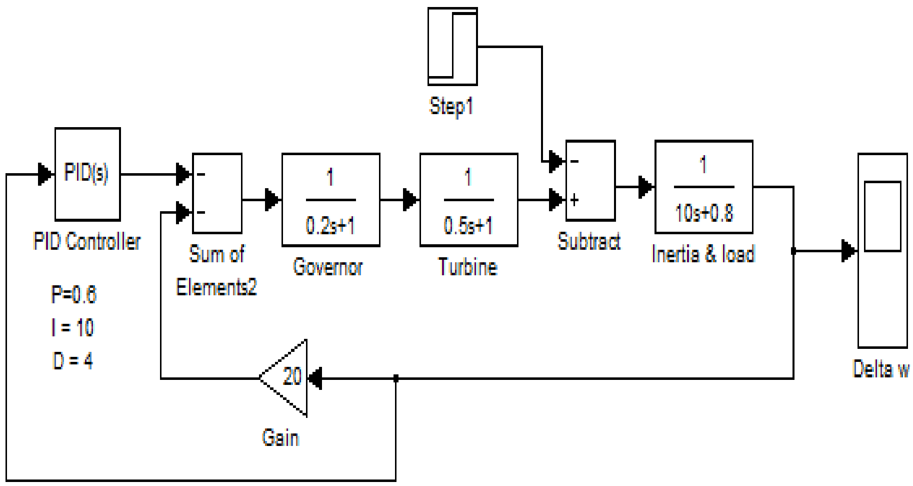

Figure 5.12: Simulation block diagram (LFC) with PID control loop

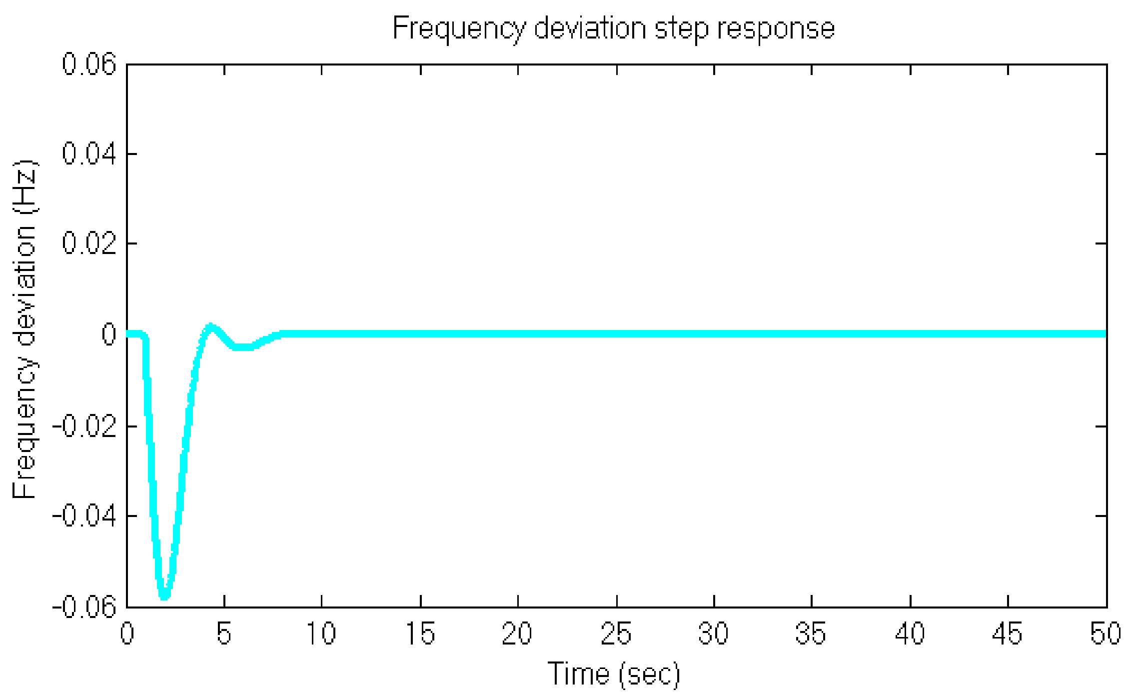

Figure 5.13: Frequency deviation step response of (LFC) with PID control loop

Table 5.8: Frequency deviation response results of (LFC) with PID controller

results	Settling time (sec)	Undershoot (Hz)
value	8	0.059

The best response of the LFC loop occurs when the gain $K_p, K_i, and K_d$ are equal 0.6, 10 and 4 respectively.

c. LFC with FLC controller

Simulation of (LFC) with FLC control loop is shown in figure 5.14.

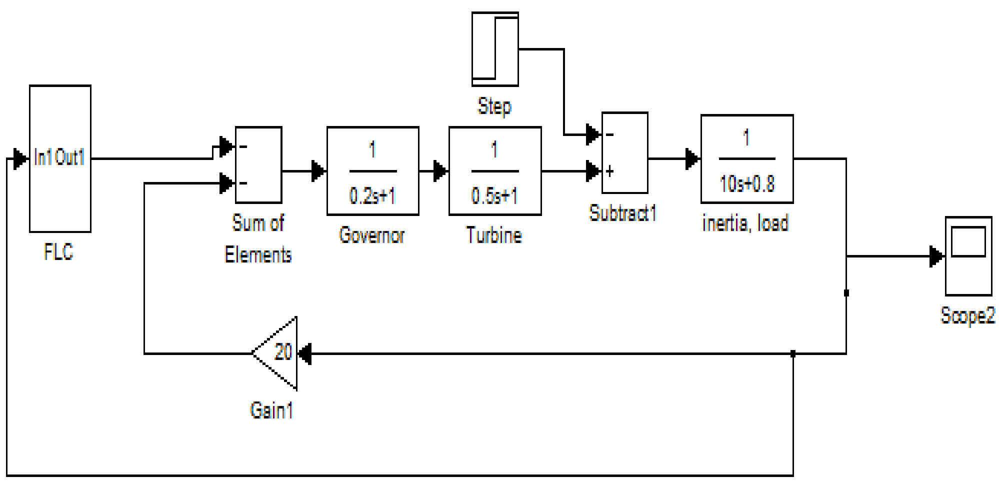

Figure 5.14: Simulation block diagram (LFC) with FLC controller

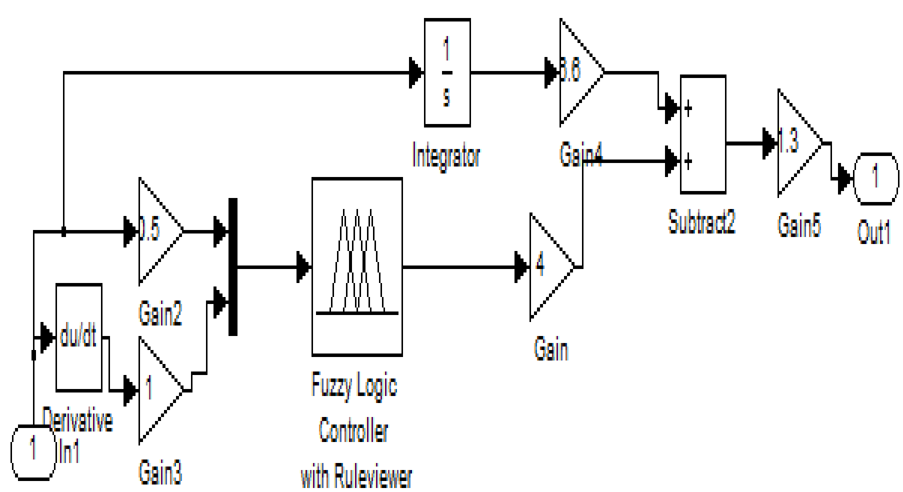

Figure 5.15: FLC Controller

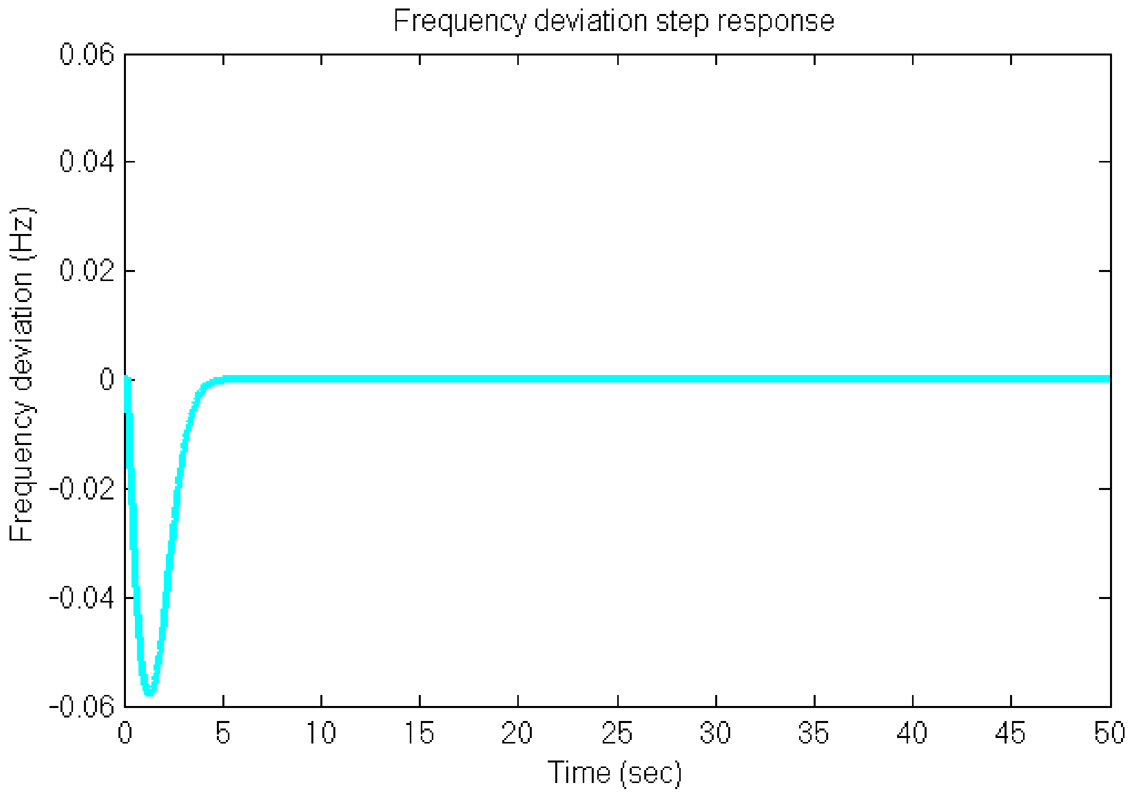

Fig 5.16: Frequency deviation step response of (LFC) with FLC controller

Table 5.9: Frequency deviation response results of (LFC) with FLC controller

result	Settling time (sec)	Undershoot (Hz)
value	4.5	0.058

Comparison of LFC loops for all cases

The simulation block diagram of the load frequency controller loop using without, PID and FLC controllers is shown in figure 5.17.

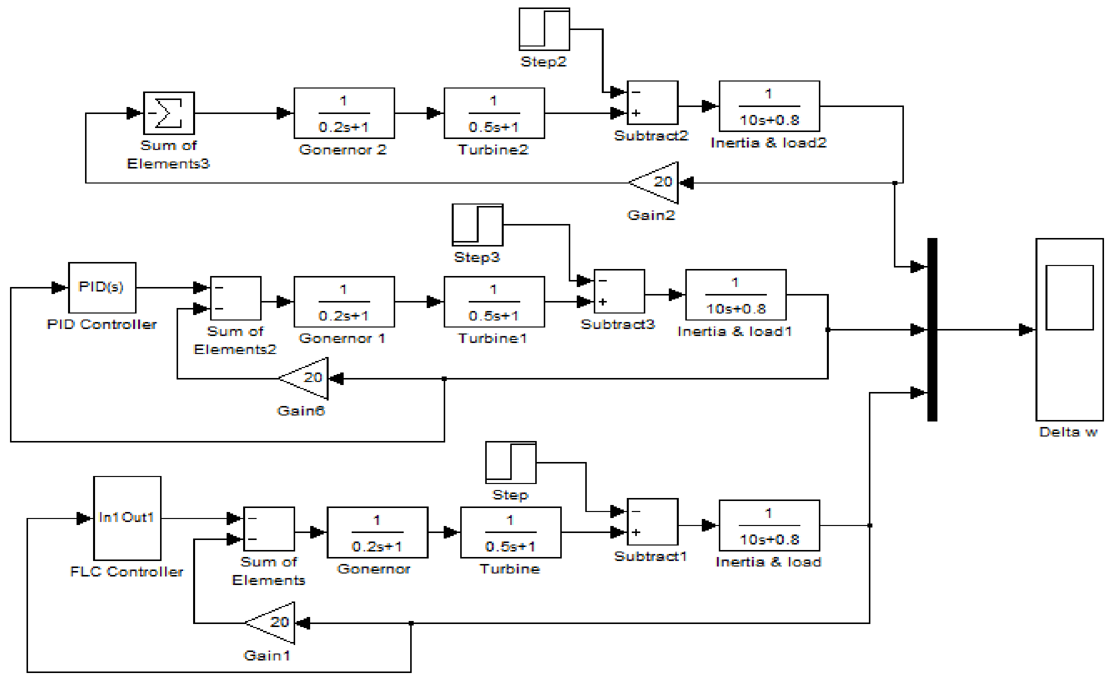

Figure 5.17: Frequency deviation step response of AVR loop using without, PID and FLC controllers

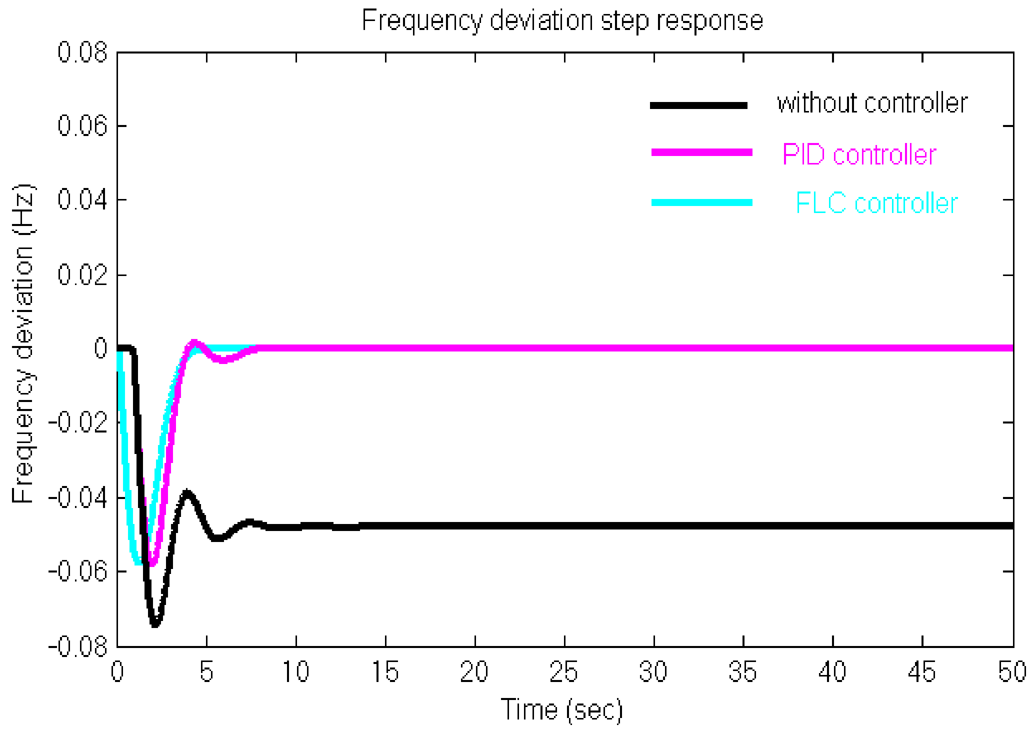

Figure 5.18: Frequency deviation step response of the LFC loops using three cases

Table 5.10: Frequency deviation results of LFC loop using without, PID and FLC controllers

results	Settling time (sec)	Overshoot (Hz)
Without controller	10	0.075
PID controller	8	0.059
FLC controller	4.5	0.058

Comparing the PID controller result for LFC loop with the result Obtained using FLC controller, significant improvement was observed as shown in figure 5.13 and figure 6.16. Also, the comparison result is tabulated in table 5.9.

5.1.3 AGC Including excitation system

Due to the weak coupling relationship between the LFC and AVR systems, the frequency and voltage were controlled separately. We can study the coupling effect by extending the linearized automatic generation control (AGC) system to include the excitation system. The coupling effects show as a small change in the electrical powerΔP_e, which is product of the synchronizing power coefficient P_S and the change in the power angle$\Delta \delta_e$. If we include the small effect of voltage upon real power, we obtain the flowing linearized equation is obtained [5, 14, 21, 18].

$$\Delta P_e = P_S \Delta \delta + K_2 \acute{E} \qquad (5.1)$$

Where

K2 is the change in the electrical power for a small change in the stator emf. Also, including the small effect of rotor angle upon the generator terminal voltage we may write as [5, 14, 18, and 21]

$$\Delta V_t = K_3 \Delta \delta + K_4 \acute{E} \qquad (5.2)$$

Where

K3 is the change in terminal voltage for a small change in rotor angle at constant stator emf, and K4 is the change in terminal voltage for a small change in the stator emf at constant rotor angle.

By modifying the generator field transfer function to include the effect of rotor angle δ, we may express the stator emf as [5, 14, 18, and 21].

$$E^{\prime} = \frac{K_G}{1+\tau_G}\left(V_f - K_5 \Delta\delta\right) \qquad (5.3)$$

The above constants depend upon the network parameters and the operating condition. For the stable system, P_S positive, Also K_2, K_5 and K_4 are positive, but K_3may be negative.

By considering the combining effect discussed above and combining the LFC and AVR loops, the simulation diagram of the LFC and AVR loops can be represented as follow:

To restore the speed an integrator is added (rest action). Adding the integrator (delay) to the blocks, the simulation diagram of the LFC loop can be represented in figure 5.19.

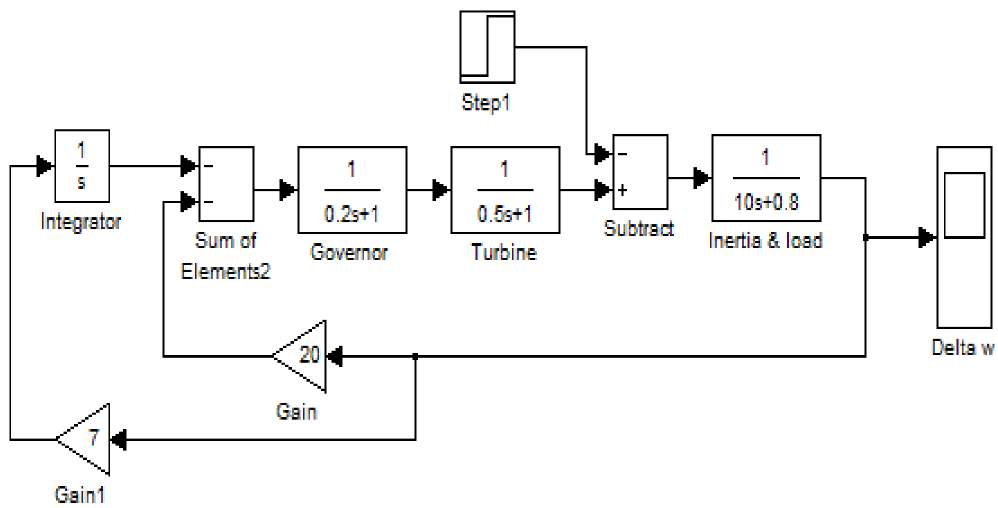

Figure 5.19: Simulink diagram for LFC loop with integrator (Rest Action)

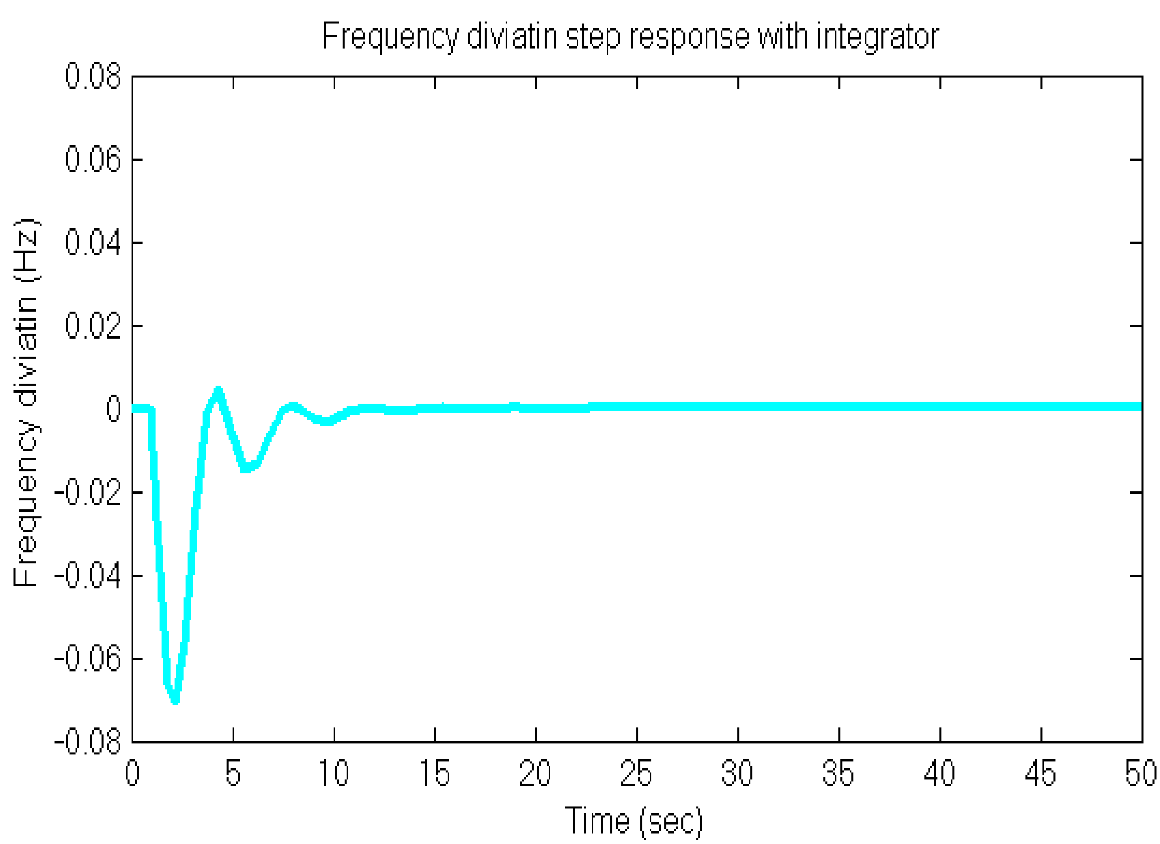

Figure 5.20: Frequency deviation step response of LFC with integrator

Table 5.11: Comparison of results for LFC loop

Case	K1	Overshoot (Hz)	Settling time (sec)	Steady State Response (Hz)	Steady state error (Hz)
1	3	0.072	32	1	0
2	5	0.072	18	1	0
3	7	0.0708	12	1	0
4	9	0.0698	17	1	0
5	11	0.068	21	1	0

From table 5.10, the best response of the LFC loop occurs when gain KI was 7. This implies that case 3 gives the best tradeoff between overshoot/undershoot and settling time. Case 3 of the LFC loop was simulated in figure 5.20.

a. AGC Including excitation system without control loop

There is a weak coupling between LFC and AVR Simulation of AGC including excitation system without control loops shown in figure 6.21.

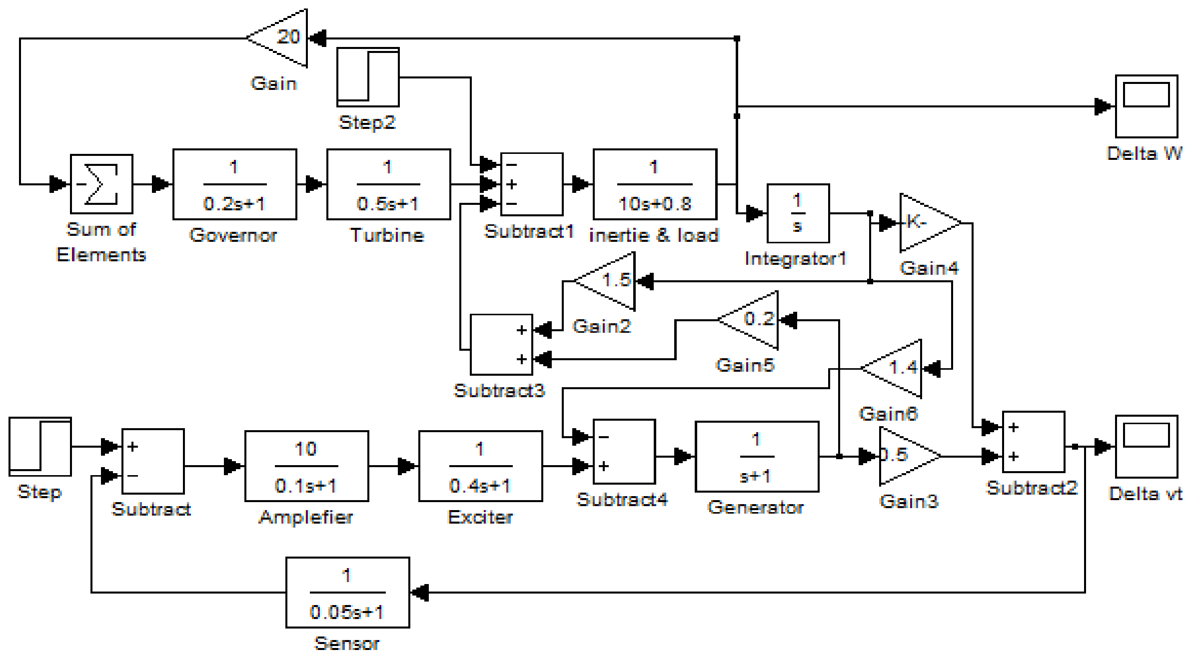

Figure 5.21: Simulation block diagram of AGC including excitation system without controller

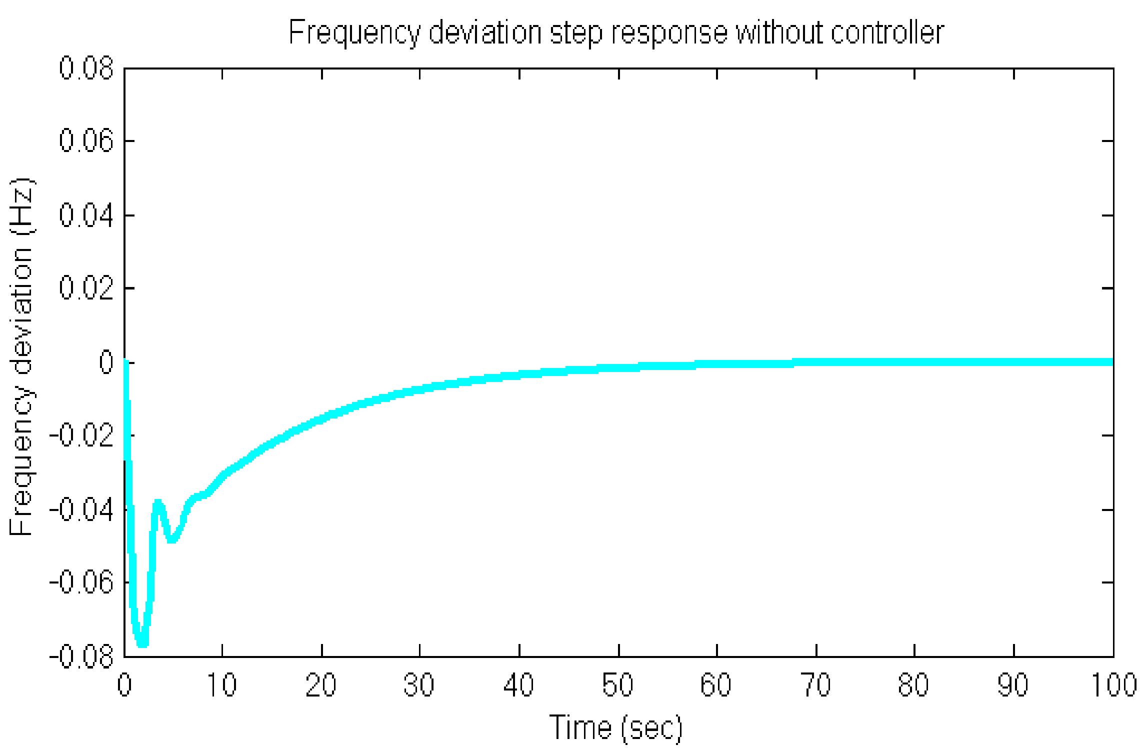

Figure 5.22: Frequency deviation step response of AGC including excitation system without control loop

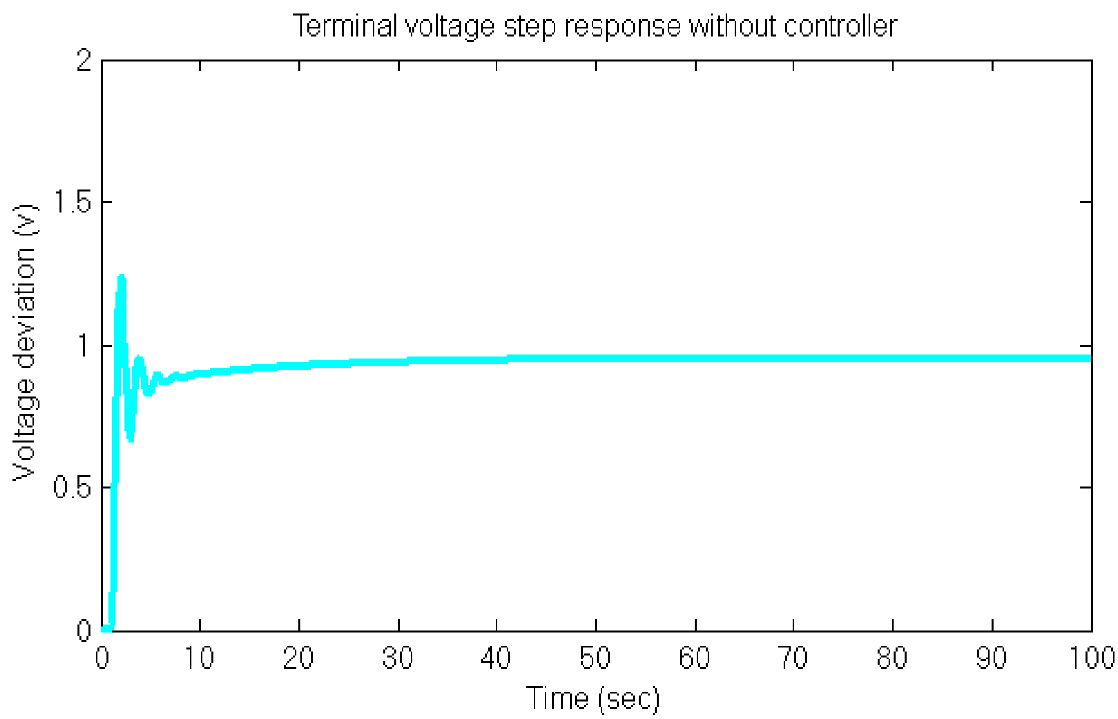

Figure 5.23: Terminal voltage step response of AGC including excitation system without controller

Table 5.12: terminal voltage and frequency deviation results of AGC including excitation system without control loop

results	Settling time	Overshoot	Steady state response	Steady state error
$\Delta\omega$	54 (sec)	0.068 (Hz)	-	-
V_t	41 (sec)	0.22 (V)	0.875 (V)	0.125 (V)

The system has a large overshoot and very along settling time for terminal voltage and frequency deviation.

b. AGC including excitation system with PID controller

Simulation of AGC including excitation system with PID controller is shown in figure 5.24.

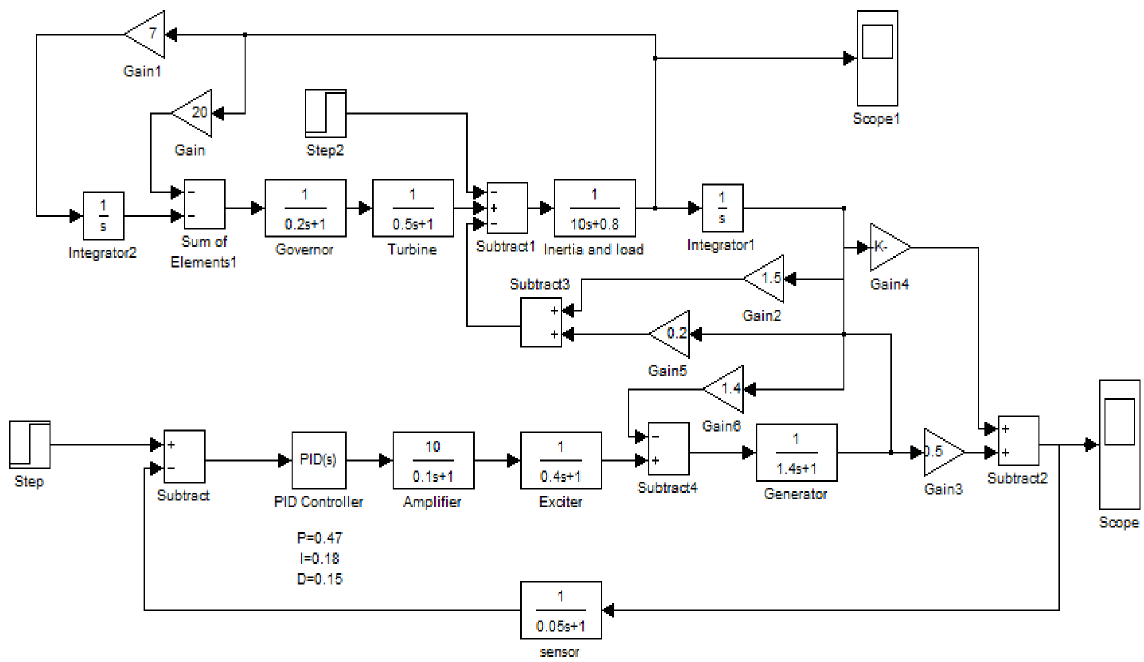

Figure 5.24: Simulation block diagram of AGC including excitation system with PID controller

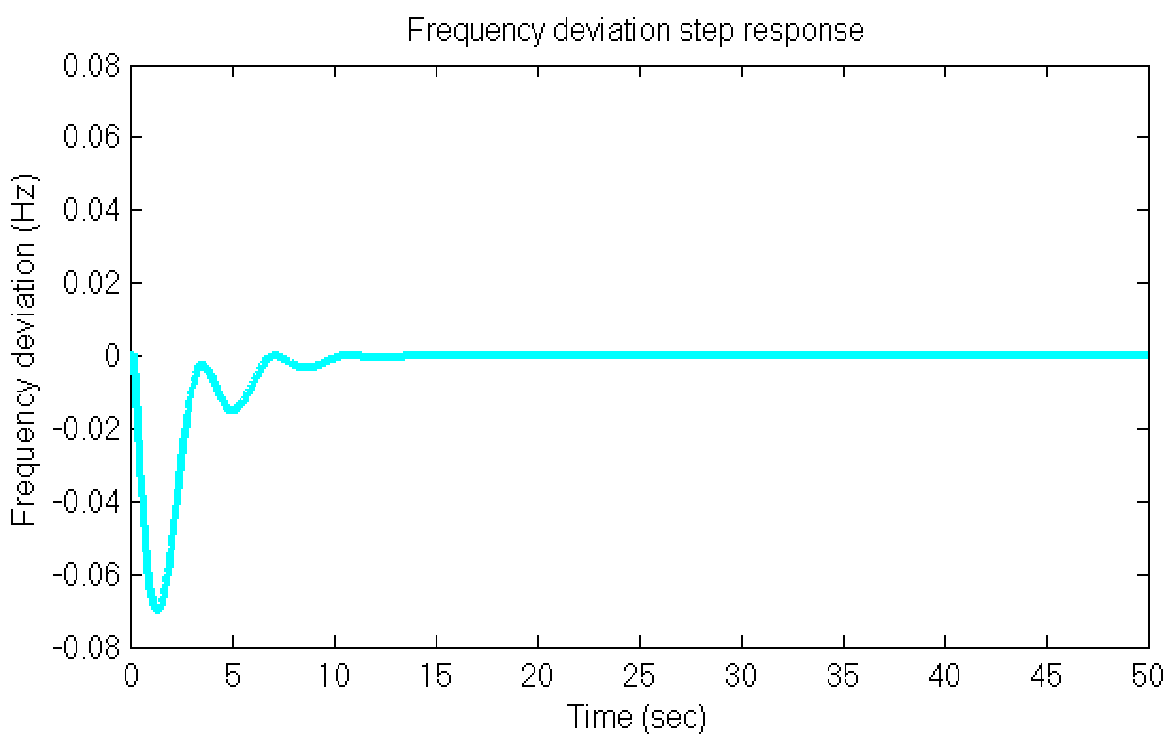

Figure (5.25): Frequency deviation step response of AGC including excitation system with integrator controller

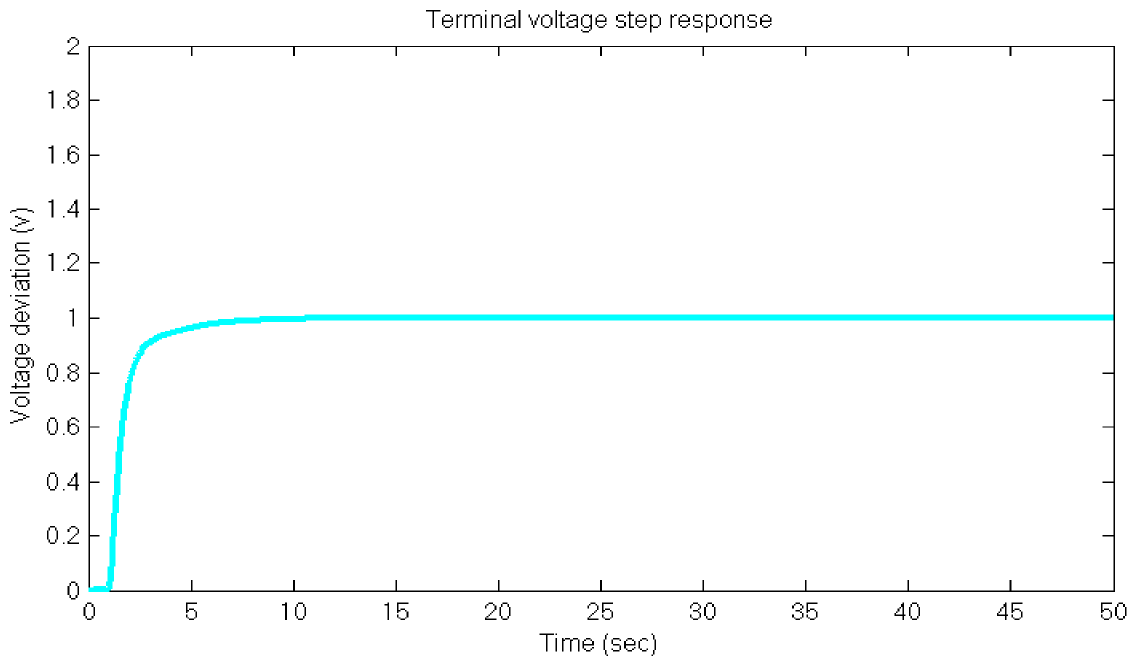

Figure (5.26): Terminal voltage step response of AGC including excitation system with PID controller

Table 5.13: Frequency deviation and terminal voltage results of AGC including excitation system with PID and integrator controller

Case	Settling time	Overshoot	Steady state response	Steady state error
$\Delta\omega$	12 (sec)	0.070 (Hz)		
V_t	7(sec)	-	1 (V)	0 (V)

From table 5.12, settling time for LFC is *12sec* and undershoot is *0.070*. Also, settling time for AGC using PID is 10 sec.

c. AGC including excitation system with FLC controller

Simulation of AGC including excitation system with fuzzy logic controller is shown in figure 5.28.

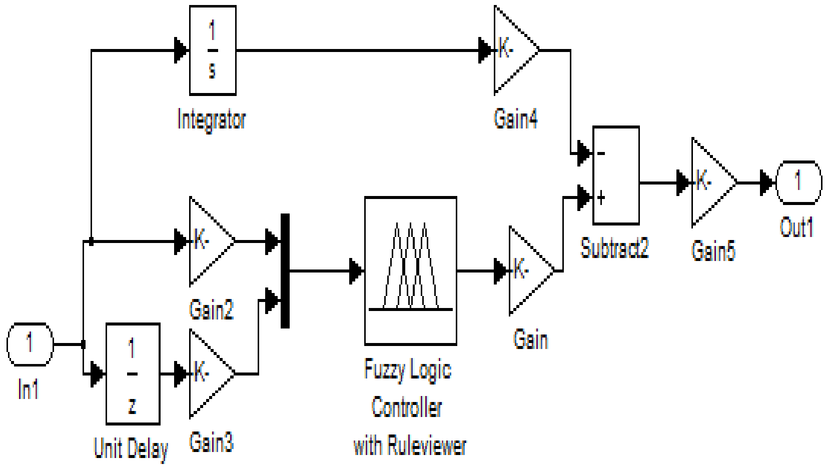

Figure 5.27: Fuzzy logic Controller

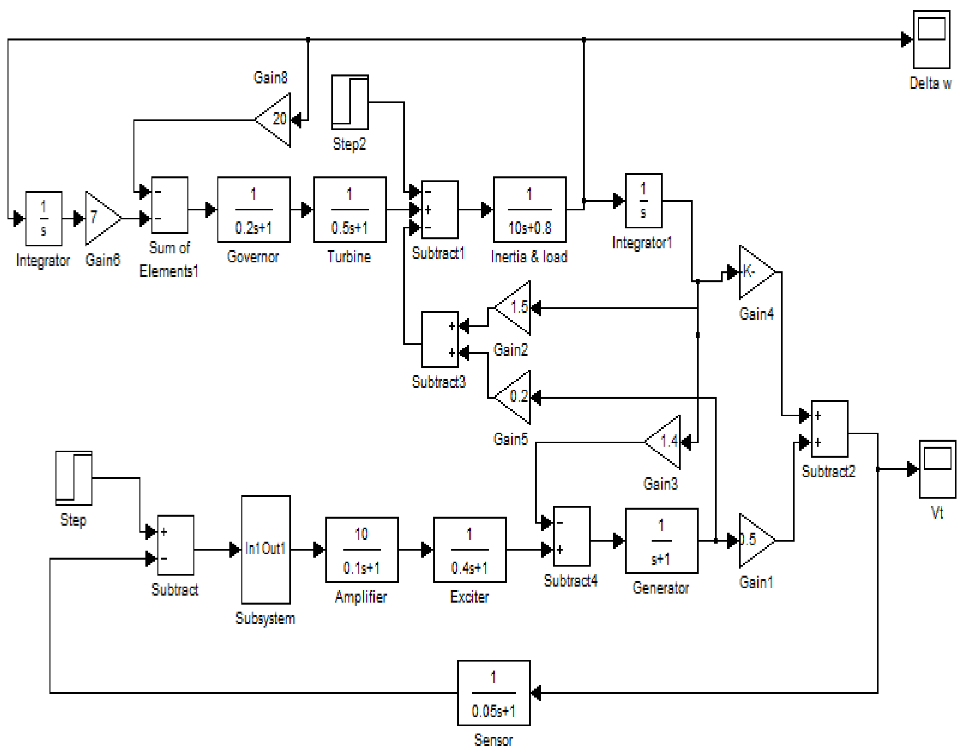

Figure 5.28: Simulation block diagram of AGC including excitation system with FLC.

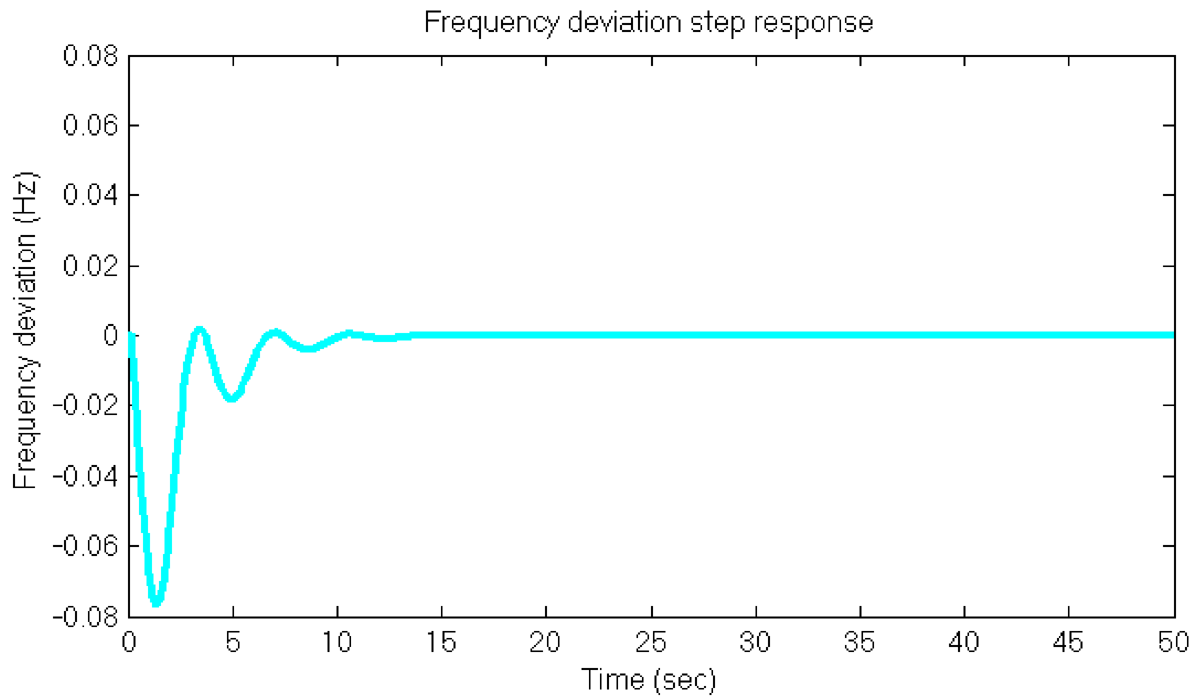

Figure 5.29: Frequency deviation step response of AGC including excitation system with FLC

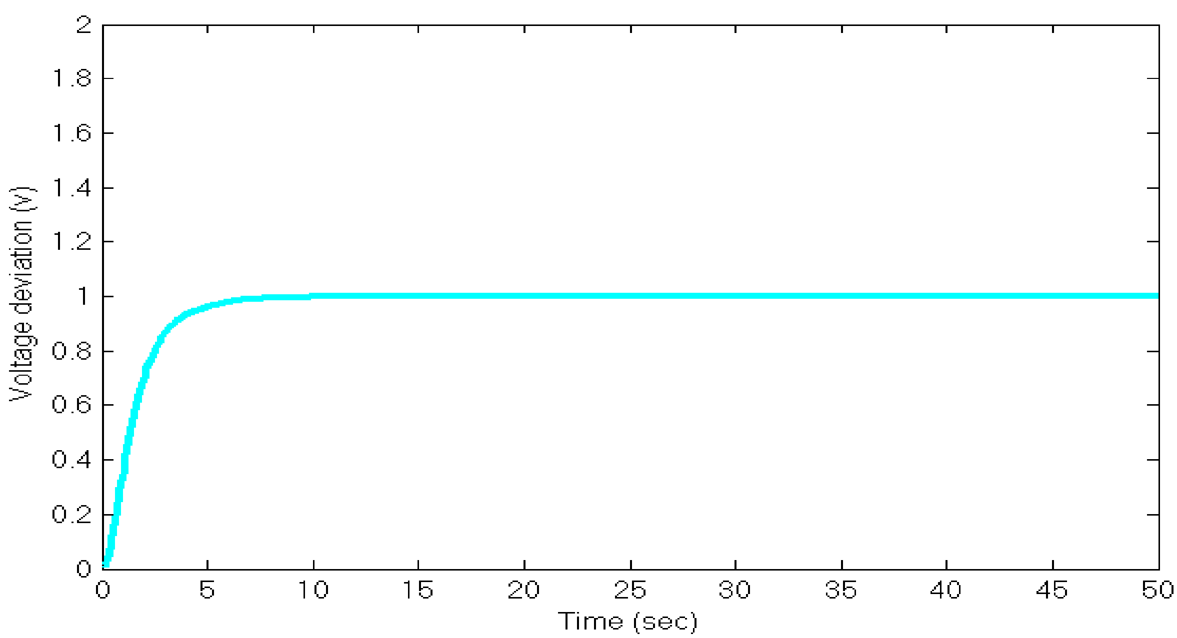

Figure 5.30: Terminal voltage response of AGC including excitation system with FLC

Table 5.14: terminal voltage and Frequency deviation results of AGC including excitation system with FLC

Case	Settling time	Overshoot	Steady state response	Steady state error
$\Delta\omega$	12 (sec)	0.068(Hz)	-	-
V_t	7 (sec)	-	1(V)	0 (V)

From table 5.13, settling time for LFC is *12sec* and undershoot is *0.0680*. Also, settling time for AGC using PID is 6 sec.

Comparison of AGC including excitation system for all cases

The simulation block diagram the AVR loop using without, PID and FLC Controllers is shown in figure 5.31.

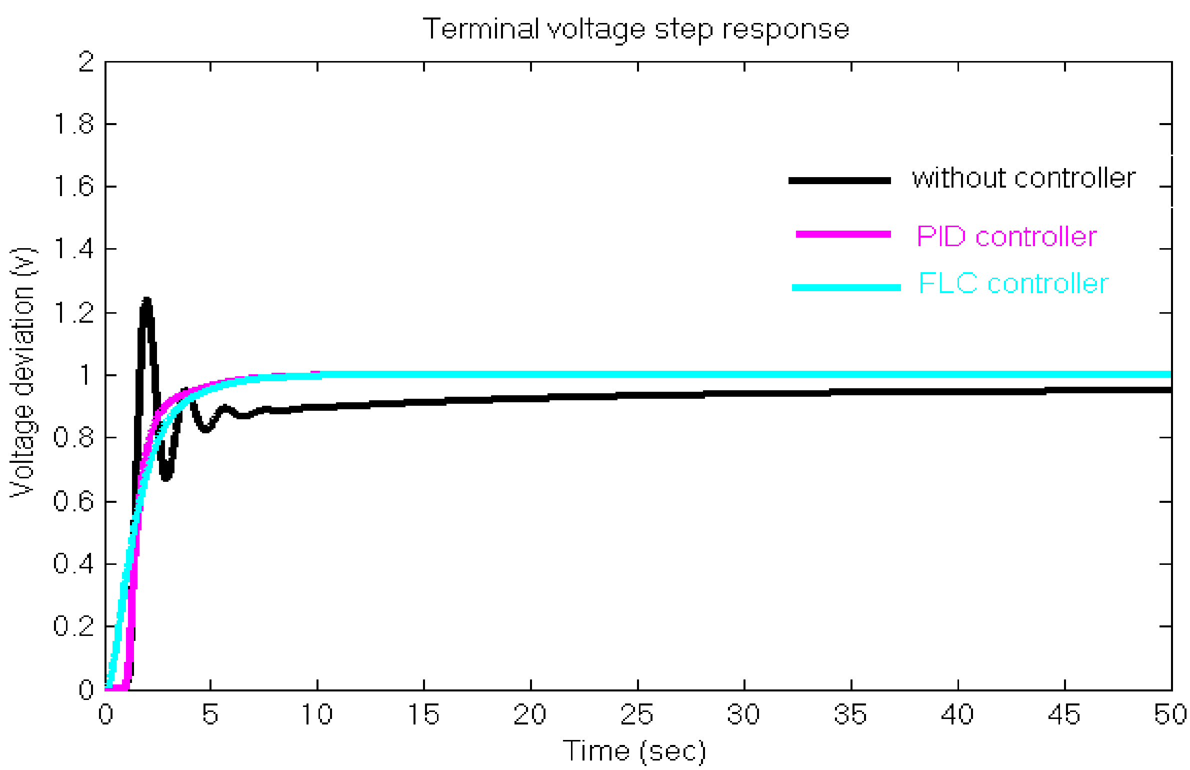

Figure 5.31: Terminal voltage response of AGC including excitation system for the AGC including excitation system loop using without, PID and FLC controllers

Table 5.15: Terminal voltage results for the including excitation system using without, PID and FLC controllers

controller	Settling time (sec)	Overshoot (voltage)	Steady state response (voltage)	Steady state error (voltage)
Without	11	-	0.909	0.091
PID	7	-	1	0
FLC	7	-	1	0

Comparing the PID controller result for AGC including excitation system with the result Obtained using FLC controller, significant improvement was observed as shown in figure 5.26 and figure 5.30. Also, the comparison result is tabulated in table 5.15.

5.2 Discussion:

The result obtained from PID and FLC controllers are detailed below. The proportional integral PI controller in the LFC loop is required to minimize frequency deviation due to the applied step load/disturbance to zero as fast as possible. From figure 5.2 the terminal voltage response, it is seen that the system has a large overshoot and along settling time with oscillatory response and steady state error than 0.09.From figure 5.4 the settling time for AVR using PID is 8sec in the case 5. Also, from figure 5.7 the settling time for the AVR with FLC is 6sec. Comparing the result of the AVR which was obtained using PID and FLC it clear that significant improvements were observed in the dynamic response of the AVR model when FLC controller was employed as shown in table 5.5 and figure 5.9. FLC controller model gave shorter settling time and smaller overshoot as compared with conventional PID controller after specific load variation (perturbation/disturbance). From the figure 5.11 the frequency deviation response, it is seen that the system has a large overshoot and along settling time. From figure 5.13 the settling time for LFC using PID is 8sec and overshoot 0.059. Also, from figure 5.16 the settling time for the LFC with FLC is 4.5sec overshoot 0.058. Comparing the result of the LFC which was obtained using PID and FLC it is clear that significant improvements were observed in the dynamic response of the LFC model when FLC controller was employed as shown in table 5.10 and figure 5.18. FLC controller model gave shorter settling time and smaller overshoot as compared with conventional PID controller.

From figure 5.20, the best value of the integrator gain for the LFC loop is K1=7. Settling time for LFC is 12sec and undershoot is 0.0708. The obtained value of settling time and undershoot for the PI controller in load frequency control is typically satisfactory and desirable, because too fast controller action can easily hasten the wear and tear of the synchronous generator. From figure 5.26 the settling time for AGC using PID is 7sec for terminal voltage response. Also, from figure 5.30 the settling time for the AGC with FLC is 7sec for terminal voltage response. Comparing the result of the AGC which was obtained using PID and FLC as shown in Table 5.14 and figure 5.31 Short settling time and small/negligible overshoot are highly desirable characteristic of a controller model in Automatic Generation Control.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions:

In the power system when the load changes, the voltage and frequency also changes. The load frequency control (LFC) loop regulates real power and frequency while the automatic voltage regulator (AVR) loop regulates reactive power and voltage magnitude.

This work is aimed at develop and simulate a model for an automation generation control AGC to control of active and reactive power to keep the system in steady state and maintain the voltage and frequency at desired value.

This work studies the automatic generation control AGC by MATLAB-SIMULINK using a conventional controller like PID and FLC to control the system for normal and heavy loading conditions to obtain the input output data of the synchronous machine. The fuzzy logic control FLC and proportional integral derivative PID controllers methods are used to control load frequency control loop (LFC) and automatic voltage regulator loop (AVR) of the synchronous generator to determine the degree of improvement that could be gained in AGC dynamic response.

The mathematical modelling of the system is the first step of controls system analysis and design. Commonly used methods are transfer function (TF) method and state variable approach (SVA) method. Work presented in this thesis has used transfer function (TF) method to develop mathematical model of synchronous generator with exciting system for stability analysis, state space model with linear differential equations for system description is used. The total system mainly contains exciter, synchronous machine and transmission line in AVR, and governor, load, prime mover and turbine in LFC. All of the state equations are achieved as first order differential equations with proper state variable identification. It is through the Mat lab/Simulink that the replacing of steady space equation to the transfer function is carried out.

In second method we develop the actual mathematical and Simulink models to examine the stability of power system. The problem of automatic generation control (AGC) was studied with the interaction of the LFC and AVR systems. The isolated LFC and AVR loops were also studied and analysed. Comparison was made between the results obtained using FLC controller and conventional PID controller. The aim is to demonstrate the potential advantages of these relatively new techniques for adaptive approach to controller design and simulation, while highlighting some of the limitations and areas of potential difficulty for practical application. From the study it was observed that FLC controller model gave shorter settling time and smaller overshoot after specific load variation (perturbation) as compared with the conventional PID controller. Although, most of the earlier works on AGC studied the LFC and AVR loops apart. In this paper however, combined LFC and AVR loops was studied and dynamic response of combined LFC and AVR was also analysed. Detailed analysis of the results was discussed.

6.2 Recommendations:

The other control methods such as model predictive control (MPC) and Neuro Fuzzy Control (NFLC) are also recommended for the better dynamic response.

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