Power System Dynamic Stability Enhancement Using Fuzzy Logic Based PSS

Major Project Report

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IN

ELECTRICAL ENGINEERING
(Electrical Power System)

By

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Undertaking for Originality of the Work

I **Mr.KASHYAP DUBEY**, **Roll.No.12MEEE09**, give undertaking that the Major Project entitled **"POWER SYSTEM DYNAMIC STABILITY ENHANCEMENT USING FUZZY LOGIC BASED PSS"**, submitted by me, towards the partial fulfillment of the requirements or the degree of Master of Technology in **Electrical Engineering (Electrical Power System)** of Nirma University, Ahmedabad,is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Certificate

This is to certify that the Major Project entitled **"POWER SYSTEM DYNAMIC STABILITY ENHANCEMENT USING FUZZY LOGIC BASED PSS"** submitted by **Mr. KASHYAP DUBEY (12MEEE09)** towards the partial fulfillment of the requirements for the award of degree in Master of Technology (Electrical Engineering) in the field of **Electrical Power Systems** of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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Abstract

Power system are subjected to low fequency disturbances which cause loss of synchronism and an eventual brekdown the entire system.Power system stabilizer(PSS) are use to generate supplementry control signals for the excitation system in order to damp out low fequency power system oscillations. But due to used of lead-lag compensation in Power system stabilizer gives poor performance under different operating conditions.To over come these Fuzzy logic technique have been proposed optimum damping to system oscillation under wide variation condition and reduce computational time in degin process.The Multi-machine Power System model has been taken.

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Abbreviations

AVR .... Automatic Voltage Regulator
CPSS .... Conventinal Power System Stabilizer
FLPSS .... Fuzzy Logic Power System Stabilzer
FLC .... Fuzzy Logic Controller
LFO .... Low Fequency Oscillation
MF .... Membership Function
MISO .... Multi Machine Single Output
PSS .... Power System Stabilizer
NB .... Negative Big
NM .... Negative Medium
NS .... Negative Small
PS .... Postive Small
PM .... Postive Medium
PB .... Postive Big
SMIB .... Single Machine Infinite Bus System
ZE .... Zero

Nomenclature

E_t	Terminal Voltage
E_b	Infinite bus voltage
K_A	voltage regulator gain
V_s	Stabilizer output
T_w	Washout time constant
T_A	Voltage regulator time constant
T_1, T_2	PSS time constant
δ	Torque angle
V_{ref}	Reference input voltage
T_m	Mechanical input torque
K_{STAB}	PSS gain
H	Inertia constant
D	Damping factor
w_r	Rated angular speed

Contents

Chapter 1

Introduction

1.1 Power System Stability

Power system stability is the tendency of a power system to develop restoring forces equal to or greater than the disturbing forces to maintain the state of equilibrium. Since power systems rely on synchronous machines for generation of electrical power a necessary condition for satisfactory system operation is that all synchronous machines remain in synchronism. This aspect of stability is influenced by the dynamics of generator rotor angles and power angle relationships.

The power system is a dynamic system. The electrical power systems today are no longer operated as isolated systems, but as interconnected systems which may include thousands of electric elements and be spread over vast geographical areas.

Power system stability can be classified into three categories:

1. Steady-state stability : Steady-state stability analysis is the study of power system and its gener- ators in strictly steady state conditions and trying to answer the question of what is the maximum possible generator load that can be transmitted without loss of synchronism of any one generator. The maximum power is called the steady-state stability limit.

2. Transient stability : Transient stability is the ability of the power system to maintain syn- chronism when subjected to a sudden and large disturbance within a small time such as a fault on transmission facilities, loss of generation or loss of a large load.The system response to such disturbances involves large excursions of generator rotor angles, power flows, bus voltages etc.It is a fast phenomenon usually occurring within 1 second for a generator close to the cause of disturbance such as 3-phase to ground fault, line to ground fault etc.

3. Dynamic Stability : A system is said to be dynamically stable if the oscillations do not acquire more than certain amplitude and die out quickly. Dynamic stability is a concept used in the study of transient conditions in power systems. Any electrical disturbances in a power system will cause electromechanical transient processes. Besides the electrical transient phenomena produced, the power balance of the generating units is always disturbed, and thereby mechanical oscillations of machine rotors follow the disturbance.

1.1.1 Types of Oscillations

1. Inter-unit Oscillations :- These oscillations involve typically two or more synchronous machines at a power plant or nearby power plants. The machines swing against each other, with the frequency of the power oscillation ranging between 1.5 to 3Hz.

2. Local Mode Oscillations :- These oscillations generally involve one or more synchronous machines at a power station swinging together against a comparatively large power system or load center. The frequency of oscillation is in the range of 0.7 Hertz to 2 Hertz. These oscillations become troublesome when the plant is at high load with a high reactance transmission system.

3. Inter-area Oscillations :- These oscillations usually involve combinations of many machines on one part of a power system swinging against machines on another part of the power system. Inter-area oscillations are normally in the frequency range of less than 0.5 Hz.

1.2 Literature Survey

E.V Larsen and D.A. Swann have presented in their 3 part paper titled Applying Power system Stabilizer I, II and III the history of power system stabilizer and its role in a power system. They recommended that the objective of the most appropriate stabilizer tuning criterion is to provide an adequate amount of damping to local mode of oscillations and inter area modes of oscillations [1].

F.P. De Mello and C. Concordia in their paper Concepts of synchronous machine stability as affected by excitation control have explored the phenomenon of stability of synchronous machines under small perturbations by examining the case of single machine connected to an infinite bus [2].

Prabha Kundur has discussed in his publication Power System Stability and Control, the stability criterion with respect to synchronous equilibrium.The mathematical model presented for small scale stability state is a set of linear time in variant differential equations [3].

M. Anderson and A.A. Fouad, had mentioned in their publication Power System Control and Stability Volume-I, the stability under the condition of small load changes has been called steady state stability. Trends in design of power system components have resulted in lower stability and led to increased reliance on the use of excitation control to improve stability [4].

IEEE Committee Report (1981), the working group of IEEE on computer modeling of excitation systems, in their report has discussed excitation system models suitable for use in large scale stability studies [5].

M. Sharaf, T. T. Lie and H. B. Gooi in their paper Neural Network Based Power System Stabilizers discussed the two ANN-PSS designs are driven by the speed error and its rate of change [6].

In his work Fuzzy logic and neural controller the author Insop Song has designed Fuzzy Logic Controller (FLC) and Artificial Neural Network Controller (ANNC) to control a flexible robotic arm. Both FLC and ANNC are well-known and industry-proven for their effectiveness and good performance[7] .

Michael J. Basler Richard C. Schaefer in their paper titled Understanding power system stability discusses power system instability and the importance of fast fault clearing performance to aid in reliable production of power [8].

N.Nallathambi and P.N.Neelakantan in their paper, Fuzzy logic based power system stabilizer presents a study of fuzzy logic power system stabilizer for stability enhancement of a two-area four machine system. In order to accomplish the stability enhancement, speed deviation and active power deviation of the rotor synchronous generator were taken as the inputs to the fuzzy logic controller [9].

1.3 Problem Identification

Power transactions are increasing day by day in restructured power systems. Restructured power system is therefore, expected to be operated at a greater variety of operating points and closer to their operating constraints. The low frequency oscillations is one of the operational constraints which limit bulk power transmission through power network. In such scenario, power system controls plays significant role. Power system controls can contribute either positive or negative damping. Generation control and particularly the generator voltage regulation can be significant sources of negative damping. High gain in the generator voltage regulation can lead to poor or negative damping of the oscillation. This problem has lead to the implementation of Power System Stabilizer (PSS) to damp out the oscillations.

1.4 Solution Methodology

Limitations of fixed parameters of conventional PSS have been reduced by using fuzzy logic controllers. Unlike the classical logic approach, which requires a deep understanding of a system, exact equations and precise numeric values, fuzzy logic incorporates an alternative way of thinking which allows one to model complex systems using a higher level of abstraction originated from accumulated knowledge and experience. Fuzzy logic allows one to express the knowledge with subjective concepts such as very tall, too small, moderate and slightly deviated, which are mapped on to numeric ranges.

1.5 Objective of the work

The thesis work on the dyanmic stability analysis of power system.The multi-machine system model used here for the study. The objective of the project are:

- To study about the nature power system stability,excitation system,automatic voltage regulator (AVR) for synchronous generator and power system stabilizer(PSS).

- To develop system without power system stabilzer (PSS) and with conventinal power system stabilizer.

- To develop a fuzzy logic based power system stabilizer (FPSS)which make the system quickly stable when fault occure in the power system.

- Comparison of fuzzy logic based power system stabilizer (FPSS) with conventinal power system stabilizer(CPSS) and without power system stabilizer

1.6 Contribution of the Thesis

Chapter 1: Presents the introduction of power system stability, oscillation types,literature survey and objective of the work.

Chapter 2: Presents the modelling of power system.

Chapter 3: Presents the conventional power system stabilizer.

Chapter 4: Presents brifly the fuzzy logic based power system stabilizer.

Chapter 5: presents results and comparision between without PSS, with conventional PSS and fuzzy logic based PSS.

Chapter 2

Power System Modelling

The mathematical models needed for small signal analysis of synchronous machine, excitation system and the lead-lag power system stabilizer are briefly reviewed.The guidelines for the selection of power system stabilizer parameters are also presented.

2.1 Syncronous Machine Model

The synchronous machine is vital for power system operation.The general system configuration of synchronous machine connected to infinite bus through transmission network can be represented as the Thevenins equivalent circuit shown in fig 2.1

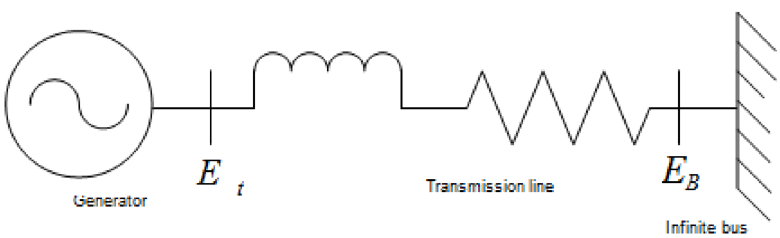

Figure 2.1: The equivalent circuit of synchronous machine connected to infinite bus

2.1.1 Classical Model

The generator is represented as the voltage E' behind Xd' as shown in Fig. 2.2. The magnitude of E' is assumed to remain constant at the pre-disturbance value.Let be the angle by which E' leads the infinite bus voltage EB. The changes with rotor oscillation. The line current is expressed as:

$$I_t = \frac{E'\angle 0' - E_B\angle - \delta}{jX_t} = \frac{E' - (E_B cos\delta - j sin\delta)}{jX_T} \tag{2.1}$$

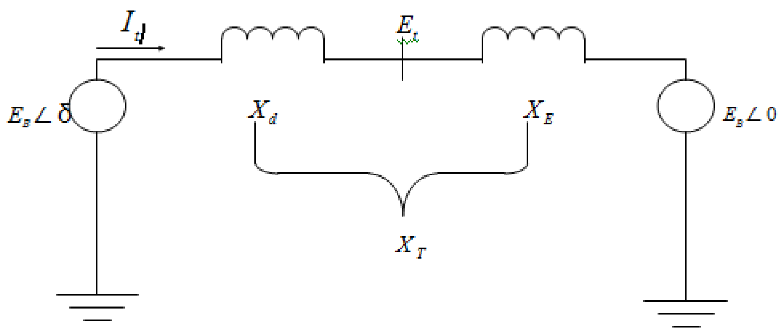

Figure 2.2: Classical model of generator

The complex power behind Xd' is given by:

$$S = P + jQ = \frac{E'E_B sin\delta}{X_t} + j\frac{E'(E' - E_B cos\delta)}{X_t} \tag{2.2}$$

With stator resistance neglected, the air-gap power P_e is equal to the terminal power (P). In per unit, the air-gap torque is equal to the air-gap power. Hence

$$T_e = P = \frac{E'E_B}{X_T} sin\delta \tag{2.3}$$

Linearizing about an initial operating condition represented by $\delta = \delta_0$ yields

$$\Delta T_e = \frac{\partial T_e}{\partial \delta}\Delta\delta = \frac{E'E_B}{X_T}cos\delta_0(\Delta\delta) = K_s(\Delta\delta) \tag{2.4}$$

$$Where, K_s = \frac{E'E_B}{X_T}cos\delta_0 \tag{2.5}$$

The equations of motion in per unit are:

$$p\Delta\omega_r = \frac{1}{2H}(T_M - T_e - K_D\Delta\ \omega_r) \tag{2.6}$$

$$p\delta = \omega_0\Delta\omega_r \tag{2.7}$$

Linearizing equation and substituting for ΔT_e given by results into:

$$p\Delta\omega_r = \frac{1}{2H}(T_M - K_s\Delta\delta - K_D\Delta\omega_r)p\Delta\delta = \omega_0\Delta\omega_r \tag{2.8}$$

The equation is of the form of x= Ax+Bu The elements of the state matrix A are seen to be dependent on the system parameters K_D, H, X_T and the initial operating condition represented by the value of E' and δ_0. The equation to describe small-signal performance is represented in block diagram as Fig.2.3.

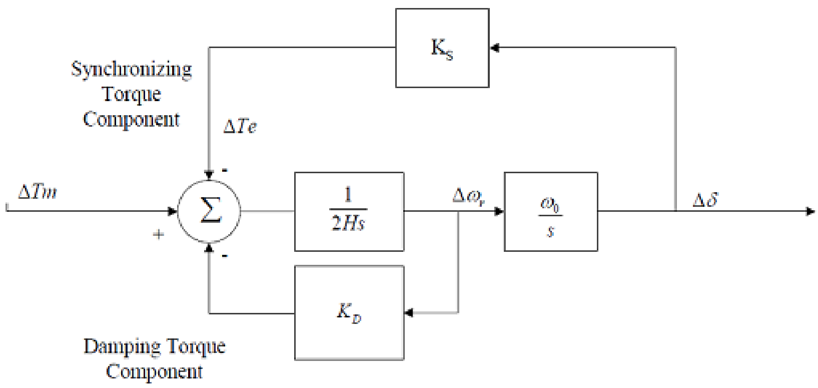

Figure 2.3: Block diagram of single machine infinite bus system with classsical model

$$\Delta\delta = \frac{\omega_0}{s}(\frac{1}{2Hs}(-K_s\Delta\delta - K_D\Delta\omega_r + \Delta T_M)) \tag{2.9}$$

$$\Delta\delta = \frac{\omega_0}{s}(\frac{1}{2Hs}(-K_s\Delta\delta - K_D\frac{\Delta\delta}{\omega_0}s + \Delta T_M)) \tag{2.10}$$

Solving the block diagram we get the characteristic equation:

$$S^2 + \frac{K_D}{2H}S + \frac{K_S\omega_0}{2H} = 0 \tag{2.11}$$

Comparing it with general form, the undamped natural frequency ω_n and damping ratio ζ are expressed as -

$$\omega_n = \sqrt{\frac{K_S\omega_0}{2H}(2.12)}$$

$$\zeta = \frac{1}{2}\frac{K_S}{\sqrt{K_S 2H\omega_0}} \tag{2.13}$$

2.2 Excitation System

From the power system viewpoint, the excitation system should contribute to effective control of voltage and enhancement of system stability. It should be capable of responding rapidly to a disturbance so as to enhance transient stability, and of modulating the generator field so as to enhance small-scale stability. In this dissertation, excitation control has been assumed for the purpose of analysis. Fundamentally, simplest excitation system consists of an exciter only. The duty of an exciter is to provide necessary field current in rotor windings of alternator. When the excitation system also performs the task of maintaining the terminal voltage of alternator constant, under varying load conditions, it incorporates voltage regulator also.Figure 2.4 shows the functional block diagram of a typical control system for a large synchronous generator.

(1) Exciter: Provides dc power to the synchronous machine field winding, constituting the power angle of the excitation system.

(2) Regulator: processes and amplifies input control signal to a level and form appropriate for control of the exciter.

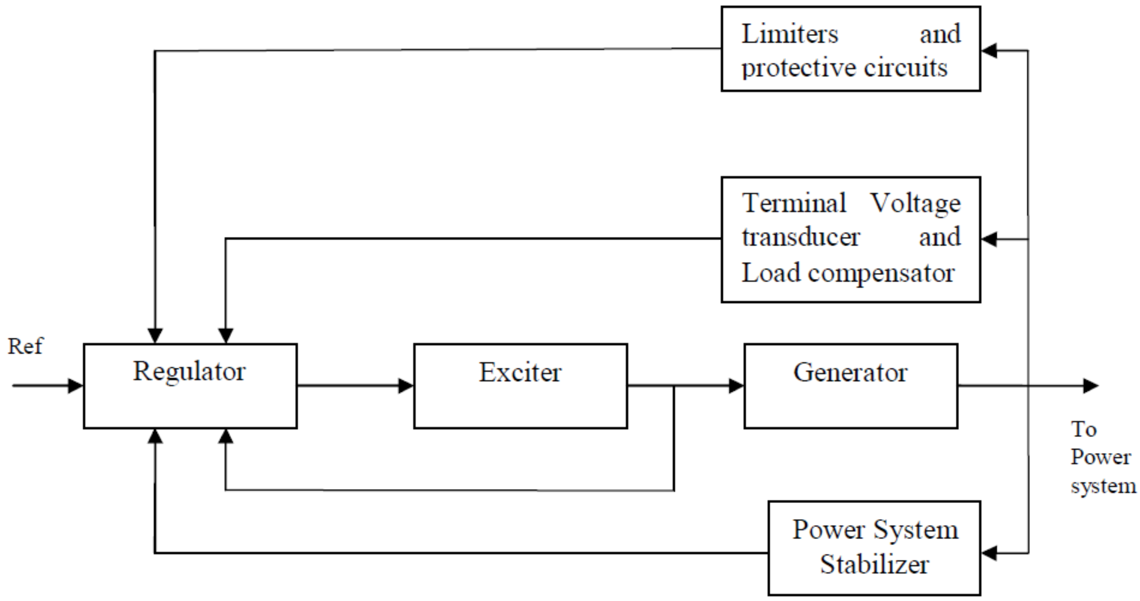

Figure 2.4: Block diagram of a synchronous generator excitation system

(3) Terminal voltage transducer and load compensator: senses generator terminal voltage, rectifies and filters it to dc quantity and compares it with a reference which represents the desired terminal voltage. In addition load compensation can be provided.

(4) Power system stabilizer: provides an additional input signal to the regulator to damp power system oscillation. Some commonly used input signals are rotor speed deviation, accelerating power and frequency deviation.

(5) Limiter and protective circuits: these include a wide array of control and protective functions which ensure that the capability limits of exciter and generator are not exceeded. Common functions are field-current limiter, maximum excitation limiter, under excitation limiter etc.

Different types of excitation system are as below: -

a) DC Excitation System: - The system which utilize a direct current generator with a commutator as the source of excitation system power.

b) AC Excitation System: - The system which uses an alternator and either stationary or rotating rectifiers to produce direct current needed for generator field.

c) ST Excitation System: -The system in which excitation power is supplied through transformer and rectifiers.

Chapter 3

Power System Stabilizer

3.1 Introduction

Since the later 1950's and early 1960's most generating units were being fitted with continuously acting voltage regulators.With these regulators and the increasing size of the power system networks,these networks were begin operated closer to their stability limits,particularly during periods of prolonged low fequency power oscillation,which were being noticed in power systems around the world. Research revealed that continuous supplementary control of excitation system could be used to improve system stability and was rigorously investigated by [DEMELLO] and many others.From this type of research the power system stabilizer was developed to help evolved and has become almost commonplace in most large power system networks.Various techniques for designing and tuning such power system stabilizer have been developed.

The term conventional power system stabilizer is used to differentiate the between power system stabilizer tuned by classical linear control techniques and those utilising fuzzy logic techniques.

3.2 Fundamental Theory

The basic function of power system stabilizer is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signals.To provide damping, the stabilizer must produce a component of electrical torque in phase with rotor speed deviations. The theoretical basis for PSS may be illustrated with the aid of block diagram as shown in Fig.3.1

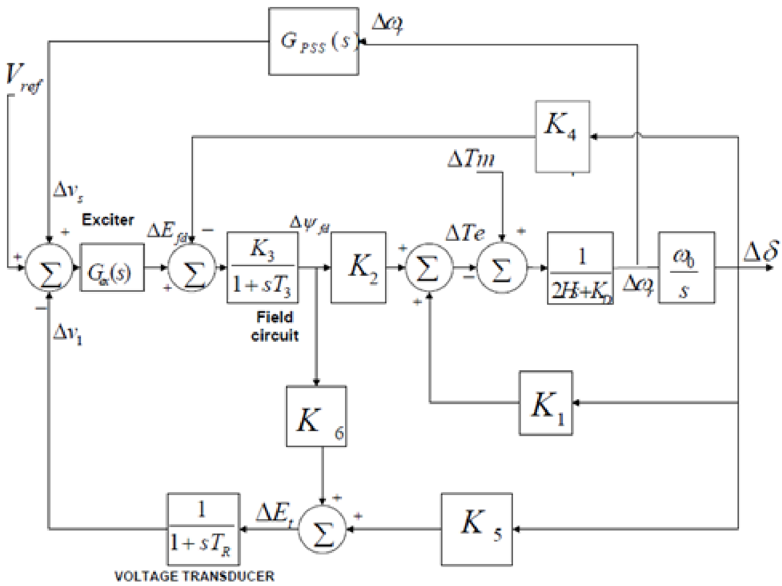

Figure 3.1: Block diagram representation with AVR and PSS

Since the purpose of PSS is to introduce a damping torque component.A logical signal to use for controlling generator excitation is the speed deviation $\Delta\omega_r$.The PSS transfer function, GPSS(s), should have appropriate phase compensation circuits to compensate for the phase lag between exciter input and electrical torque. The following is a brief description of the basis for the PSS configuration and consideration in selection of parameters.

The phase compensation block provides the appropriate phase lead characteristics to compensate for the phase lag between exciter input and generator electrical torque. The phase compensation may be a single first order block as shown in Fig.3.2 or having two or more first order blocks or second order blocks with complex roots. The signal washout block serves as high pass filter, with time constant T_w high enough to

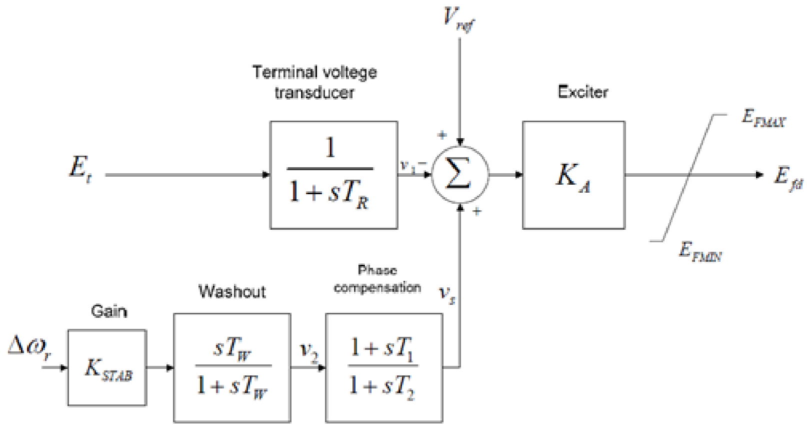

Figure 3.2: Thyristor excitation system with AVR and PSS

allow signals associated with oscillations in ω_r to pass unchanged, which removes d.c. signals. Without it, steady changes in speed would modify the terminal voltage.It allows PSS to respond only to changes in speed. The stabilizer gain K_{STAB} determines the amount of damping introduced by PSS. Ideally, the gain should be set at a value corresponding to maximum damping; however, it is limited by other consideration.

From block 4 of Fig.3.2, using perturbed values, we have

$$\Delta v_1 = \frac{pT_W}{1 + pT_W}(K_{STAB}\Delta\omega_r) \tag{3.1}$$

Hence,

$$p\Delta v_2 = K_{STAB}p\Delta\omega_r - \frac{1}{T_W}\Delta v_2 \tag{3.2}$$

Substituting for $p\Delta\omega_r$ given by Equation , we obtain the following expression for $p\Delta v_2$ in terms of the state variables:

p $\text{v}_2 = K_ST AB[a_{11}\Delta\omega_r + a_{12}\Delta\delta + a_{13}\Delta\psi_f d + \frac{1}{2H}\Delta T_M] - 1T_W v_2$

$$p = a_{51}\Delta\omega_r + a_{52}\Delta\delta + a_{53}\Delta\psi_f d + a_{54}\Delta v_2 + \frac{K_ST AB}{2H}\Delta T_M \tag{3.3}$$

Where,

$a_{51} = K_{STAB}a_{11}$

$a_{52} = K_{STAB}a_{12}$

$a_{53} = K_{STAB} a_{13}$

$a_{54} = \frac{1}{T_W}$

From block 5

$\Delta v_s = \Delta v_2 (\frac{1+p_T 1}{1+p_T 2})$ $\Delta v_s = \frac{T_1}{T_2} p \Delta v_2 + \frac{1}{T_2} \Delta v_2 - \frac{1}{T_2} \Delta v_s$

$Substitution for$ pΔv_2 given by equation,

$$\Delta v_s = a_{61} \Delta\omega_r + a_{62} \Delta\delta + a_{63} \Delta\psi_{fd} + a_{64} \Delta v_1 + a_6 5 \Delta v_2 + a_6 6_s + \frac{T_1}{T_2} \frac{K_S TAB}{2H} \Delta T_M \quad (3.4)$$

Where,

$a_{61} = \frac{T_1}{T_2} a_5 1$

$a_{62} = \frac{T_1}{T_2} a_{52}$

$a_{63} = \frac{T_1}{T_2} a_{53}$

$a_{64} = \frac{T_1}{T_2} a_{55} + 1T_1$

$a_{65} = \frac{-1}{T_2}$

From block 2 we get,

$$\mathrm{E}_{fd} = K_A (\Delta v_S - \Delta v_1)$$

The field circuit equation, with PSS included, becomes

$$p\psi_{fd} = a_{32} \Delta\delta + a_{33} \psi_f d + a_{34} \Delta v_2 + a_{36} \Delta v_2 \quad (3.5)$$

where,

$a_{36} = \frac{\omega_0 R_{fd}}{L_{ad-u}} K_A$

3.3 General Structure of PSS

It consists of gain block, washout circuit, dynamic compensator, and limiter. The functions of each of the components of PSS are given in subsequent sections.

(1) PSS Gain

Stabilizing gain KP SS determines the amount of damping introduced by PSS. Ideally, PSS gain is set to get the maximum damping of the oscillatory modes. However, due to practical considerations, high gain may not be always the best option and may cause excessive amplification of stabilizer input signal. In general, the gain value is set such that it results in satisfactory damping of critical system modes without compromising the stability limits.

(2) Washout Circuit

The washout circuit is provided to eliminate steady state bias in the output of PSS which will modify the generator terminal voltage. The PSS is expected to respond only to transient variations in the input signal, say rotor speed and not to the dc offsets in the signal. The washout circuit acts essentially as a high pass filter and it must pass all frequencies that are of interest. If only the local modes are of interest, the time constant Tw can be chosen in the range of 1 to 2. However,if inter area modes are also to be damped, then Tw must be chosen in the range of 10 to 20. The value of Tw = 10 is necessary to improve damping of the inter area modes. There is also a noticeable improvement in the first swing stability when Tw is increased from 1.5 to 10.The higher value of Tw also improved the overall terminal voltage response during system islanding conditions.

(3) Lead-Lag Compensator

Lead-Lag compensator block provides the suitable phase lead to compensate for the phase lag between the exciter input and generator electrical torque.The dy- namic compensator, used in practice, is made up of several multiple stages of lead-lag compensators depending upon the requirement of phase compensation to be provided.

(4) PSS Output Limits

Stabilizer output voltage is limited between typical maximum and minimum val- ues to restrict the level of generator terminal voltage fluctuation during transient conditions. Large output limits ensure maximum contribution of stabilizers but generator terminal voltage may face large fluctuation.The main objective in selecting the output limits of PSS is to allow maximum forcing capability of stabilizer, while maintaining the terminal voltage within desired limits. Most commonly used value of the maximum limit is between 0.1 to 0.2 p.u., while minimum limit is taken between -0.05 and -0.1 p.u.

(5) Input of PSS

Many signals, like rotor speed deviation, frequency deviation, change in load angle, change in electrical power etc are possible to use as input signal to PSS. However, from practical point of view, the following three types of input signals are most commonly used as input to power system stabilizer:

- Rotor Speed Deviation ($\Delta\omega$)
- Frequency Deviation ($\Delta\ f$)
- Electrical Power Deviation (ΔP)

Chapter 4

Design Of Fuzzy Logic Based PSS

4.1 Introduction

In 1965, Lofty A. Zadeh of the University of California at Berkeley published Fuzzy Sets which laid out the mathematics of fuzzy set theory and, by extension, fuzzy logic. Zadeh had observed that conventional computer logic couldn't manipulate data that represented subjective or vague ideas, so he created fuzzy logic to allow computers to determine the distinctions among data with shades of gray, similar to the process of human reasoning. Fuzzy logic, as its name suggests, is the logic underlying modes of reasoning which are approximate rather than exact.FLCs are very useful when an exact mathematical model of the plant is not available; however, experienced human operators are available for providing qualitative rules to control the system. Fuzzy logic, which is the logic on which fuzzy logic control is based, is much closer in spirit to human thinking and natural language than the traditional logic systems.

Fuzzy logic is a derivative from classical Boolean logic and implements soft linguistic variables on a continuous range of truth values to be defined between conventional binary i.e. [0, 1]. It can often be considered a subset of conventional set theory. The fuzzy logic is capable to handle approximate information in a systematic way and therefore it is suited for controlling non- linear systems and for modelling complex systems where an inexact model exists or systems where ambiguity or vagueness is common [10].

As compared to the conventional PSS, the Fuzzy Logic Controller (FLC) has some advantages such as:

1) A simpler and faster methodology.

2) It does not need any exact system mathematical model.

3) It can handle nonlinearity of arbitrary complexity.

4) It is based on the linguistic rules with an IF-THEN general structure.

5) It is more robust than conventional nonlinear controllers.

6) Reduce hardware cost

4.2 Fuzzy Sets

Fuzzy set, as the name implies, is a set without a crisp boundary.The transition from belong to a set to not belong to a set is gradual, and this smooth transition is characterized by membership functions. The fuzzy set theory is based on fuzzy logic, where a particular object has a degree of membership in a given set that may be anywhere in the range of 0 to 1. On the other hand, classical set theory is based on Boolean logic, where a particular object or variable is either a member of a given set (logic 1), or it is not (logic 0).

4.3 Fuzzy System

The fuzzy inference system or fuzzy system is a popular computing framework based on the concept of fuzzy set theory, fuzzy if-then rules, and fuzzy reasoning. The fuzzy inference system basically consists of a formulation of the mapping from a given input set to an output set using FL as shown in Figure 4.1. The mapping process provides the basis from which the inference or conclu- sion can be made. The basic structure of fuzzy inference system consists of three conceptual components: a rule base, which contains a selection of fuzzy rules; a data base, which defines the membership functions used in the fuzzy rules; and a reasoning mechanism which performs the inference procedure upon the rules and given facts to derive a reasonable output or conclusion [10].

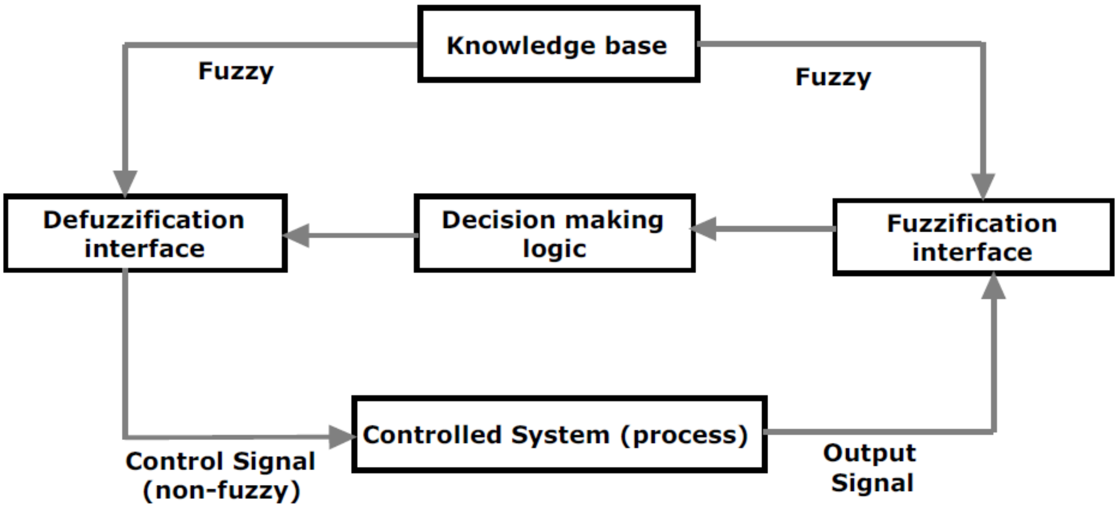

Figure 4.1: Block diagram of fuzzy logic controller

The fuzzy logic controller comprises four principle components: fuzzification interface, knowledge base, decision making logic, and defuzzification interface.

i) Fuzzification: In fuzzification, the values of input variables are measured i.e. it converts the input data into suitable linguistic values.

ii) Knowledge base: The knowledge base consists of a database and linguistic control rule base. The database provides the necessary definitions, which are used to define the linguistic control rules and fuzzy data manipulation in an FLC. The rule base characterizes the control policy of domain experts by means of set of linguistic control rules.

iii) Decision making logic: The decision making logic has the capability of stimulating human decision making based on fuzzy concepts.

iv) Defuzzification: The defuzzification performs scale mapping, which con- verts the range of values of output variables into corresponding universe of discourse. If the output from the defuzzifier is a control action for a process, then the system is a non-fuzzy logic decision system. There are different techniques for defuzzification such as maximum method, height method, centroid method etc.

4.4 Membership Function of FPSS

The variables chosen for this controller are speed deviation, acceleration and voltage. In this, the speed deviation and acceleration are the input variables and voltage is the output variable. The number of linguistic variables describing the fuzzy subsets of a variable varies according to the application. Usually an odd number is used. A reasonable number is seven. However, increasing the number of fuzzy subsets results in a corresponding increase in the number of rules. Each linguistic variable has its fuzzy membership function. The membership function maps the crisp values into fuzzy variables. The triangular membership functions are used to define the degree of membership. It is important to note that the degree of membership plays an important role in designing a fuzzy controller [11],[12].

Each of the input and output fuzzy variables is assigned seven linguistic fuzzy subsets varying from negative big (NB) to positive big (PB). Each subset is associated with a triangular membership function to form a set of seven membership functions for each fuzzy variable.

4.5 Design of Fuzzy Logic PSS

The basic structure of the fuzzy logic controller is shown in Figure 5.2. Here the inputs to the fuzzy logic controller are the normalized values of error $'e'$ and change of error $'ce'$.Normalization is done to limit the universe of discourse of the inputs between -1 to 1 such that the controller can be successfully operated within a wide range of input variation. Here $'K_e'$ and $'K_{ce}'$ are the normalization factors for error input and change of error input respectively. For this fuzzy logic controller design, the normalization factors are taken as constants. The output of the fuzzy logic controller is then multiplied with a gain $'K_0'$ to give the appropriate control signal $'U'$. The output gain is also taken as a constant for this fuzzy logic controller.

The fuzzy controller used in power system stabilizer is normally a two input and a single output component. It is usually a MISO system. The two inputs are change

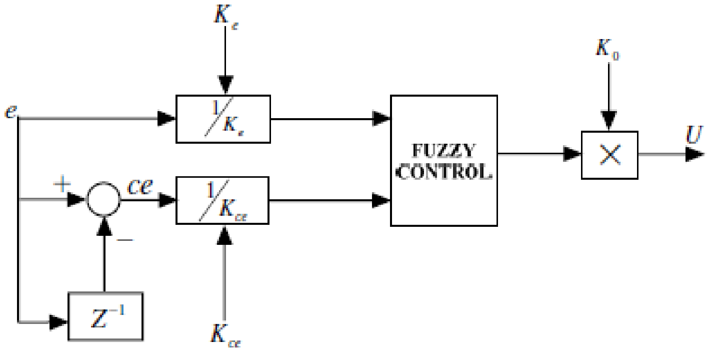

Figure 4.2: Basic structure of fuzzy logic controller

in angular speed and rate of change of angular speed whereas output of fuzzy logic controller is a voltage signal.

4.5.1 Input Output Variables

The design starts with assigning the mapped variables inputs output of the fuzzy logic controller (FLC). The first input variable to the FLC is the generator speed deviation and the second is acceleration. The output variable to the FLC is the voltage.

choosing proper variables as input and output of fuzzy controller, it is required to decide on the linguistic variables. These variables transform the numerical values of the input of the fuzzy controller to fuzzy quantities. The number of linguistic variables describing the fuzzy subsets of a variable varies according to the application. Here seven linguistic variables for each of the input and output variables are used to describe them. Table-I shows the Membership functions for fuzzy variables.

The membership function maps the crisp values into fuzzy variables. The triangular membership functions are used to define the degree of membership. Here for each input variable, seven labels are defined namely, NB, NM, NS, ZE, PS, PM and PB. Each subset is associated with a triangular membership function to form a set of seven membership functions for each fuzzy variable.

Table I: Membership function for fuzzy variables

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

4.5.2 Fuzzy Rule Base

A set of rules which define the relation between the input and output of fuzzy controller can be found using the available knowledge in the area of designing PSS. These rules are defined using the linguistic variables. The two inputs, speed and acceleration, result in 49 rules for each machine. The typical rules are having the following structure [10]:

Table II: Decision Table

Speed Deviation	**Acceleration**					
	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NM	NS
NM	NB	NM	NM	NM	NS	NS	ZE
NS	NM	NM	NS	NS	ZE	ZE	PS
ZE	NM	NS	NS	ZE	PS	PS	PM
PS	NS	ZE	ZE	PS	PS	PM	PM
PM	ZE	PS	PS	PM	PM	PM	PB
PB	PS	PM	PM	PB	PB	PB	PB

Rule 1: If speed deviation is NM (negative medium) AND acceleration is PS (positive small) then voltage (output of fuzzy PSS) is NS (negative small).

Rule: 2 If speed deviation is NB (negative big) AND acceleration is NB (negative big) then voltage (output of fuzzy PSS) is NB (negative big).

Rule: 3 If speed deviation is NS (positive small) AND acceleration is PS (positive small) then voltage (output of fuzzy PSS) is PS (positive small).

Rule: 4 If speed deviation is ZE (positive small) AND acceleration is PS (positive small) then voltage (output of fuzzy PSS) is PS (negative small).

Rule: 5 If speed deviation is PS (negative small) AND acceleration is PS (negative small) then voltage (output of fuzzy PSS) is PS (positive small). And so on.

All the 49 rules governing the mechanism are explained where all the symbols are defined in the basic fuzzy logic terminology [10].

Chapter 5

Simulation Results

The system under study is Three machine and nine bus system. Base MVA is 100 and system frequency is 60Hz.

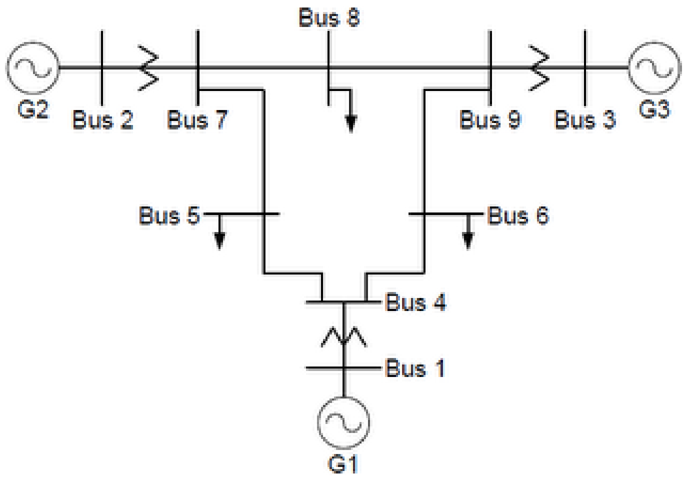

Figure 5.1: Single line diagram of 3 machine 9 bus system

5.1 Performance without Conventional PSS

5.2 Performance with Conventional PSS

5.3 Performance with Fuzzy Logic based PSS

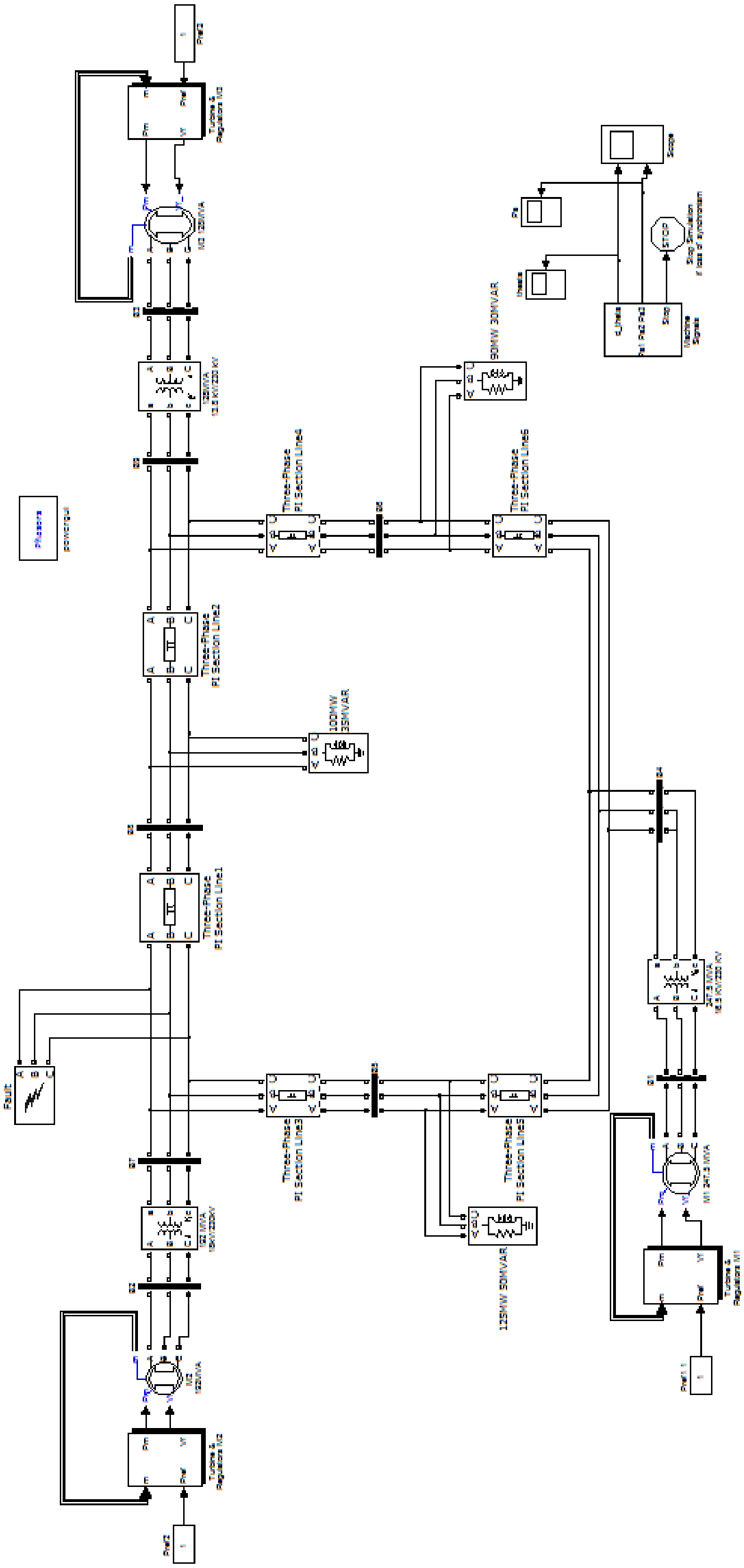

Figure 5.2: 3 machine 9 bus system simulink model

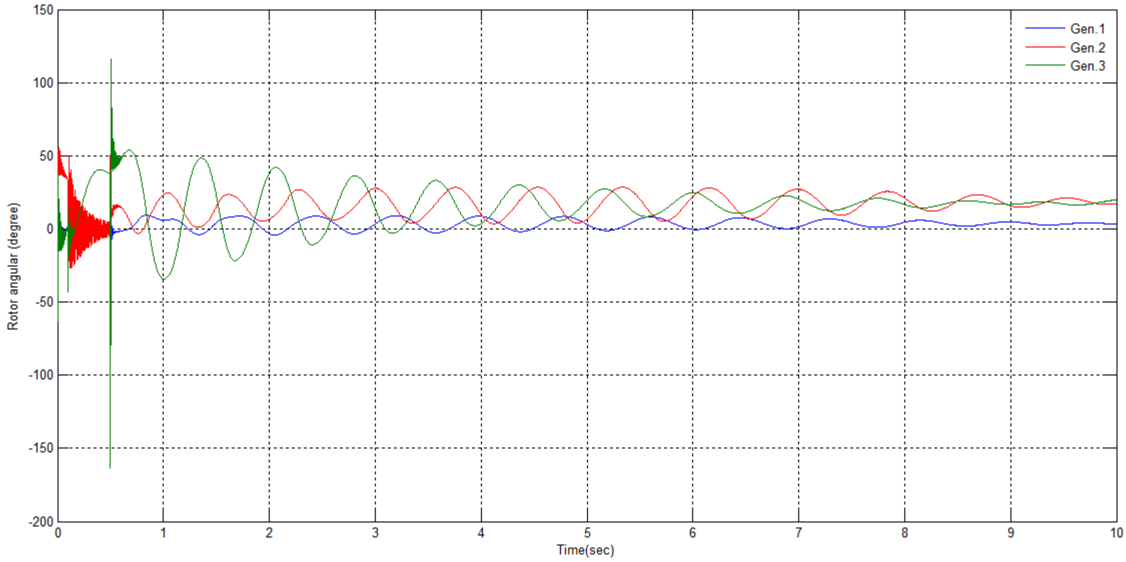

Figure 5.3: Waveform of Rotor anlge(degree) versus Time(sec)

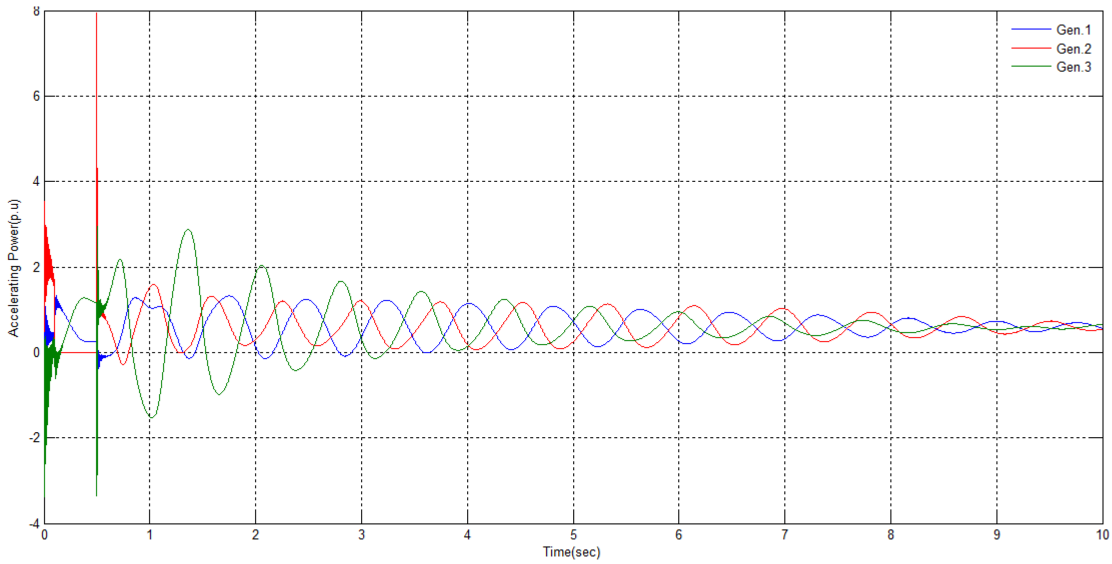

Figure 5.4: Waveform of Accelerating power(p.u) versus Time(sec)

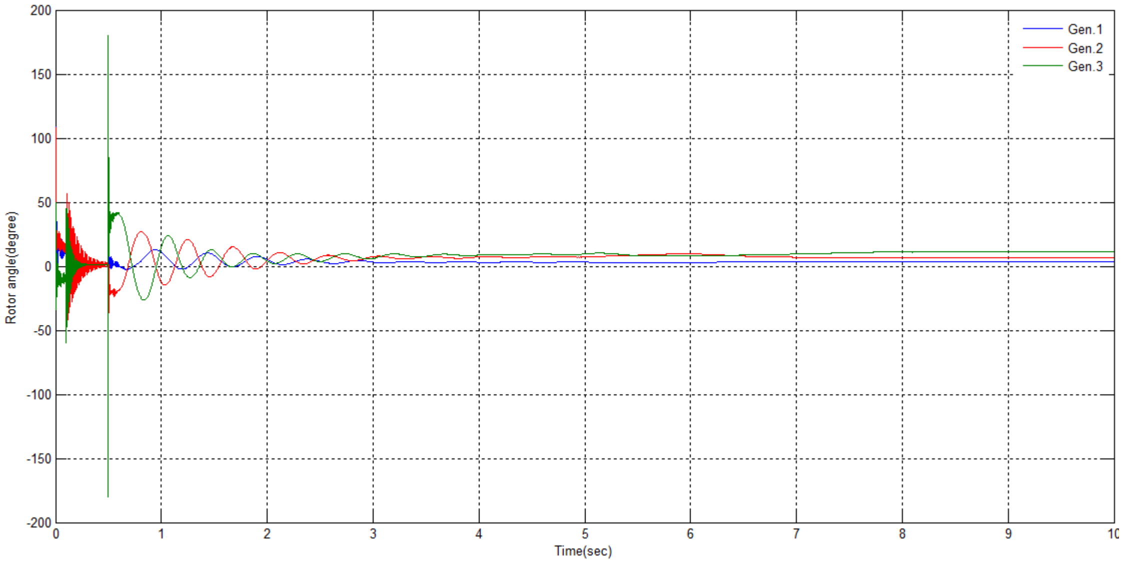

Figure 5.5: Waveform of Rotor anlge(degree) versus Time(sec)

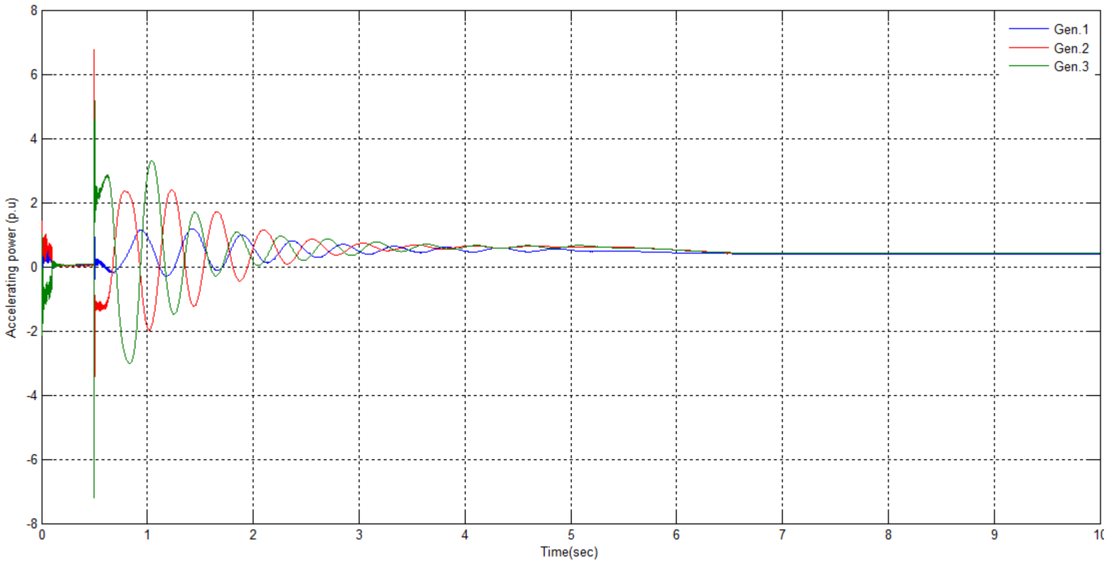

Figure 5.6: Waveform of Accelerating power(p.u) versus Time(sec)

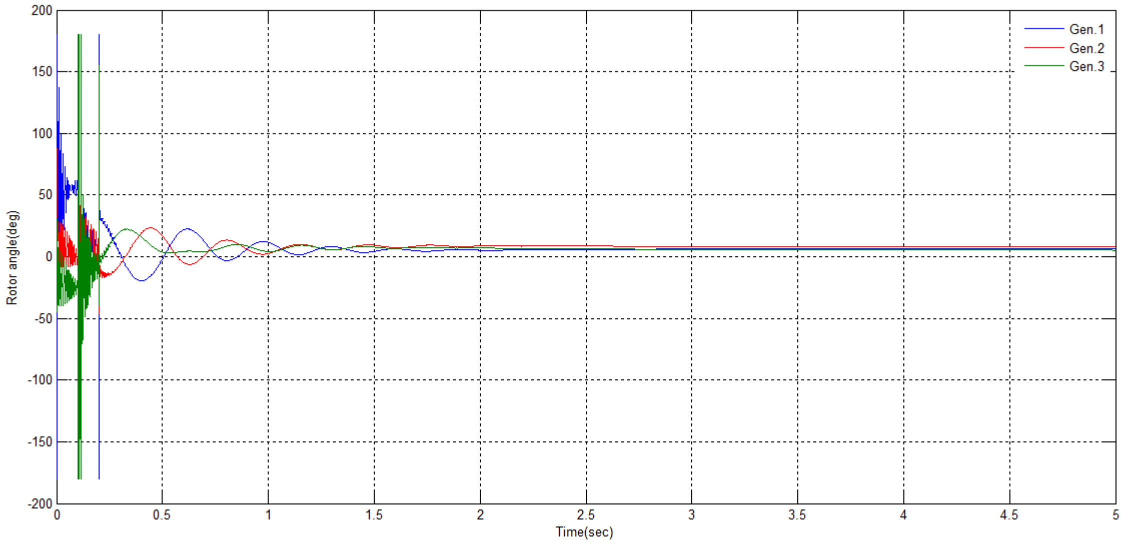

Figure 5.7: Waveform of Rotor anlge(degree) versus Time(sec)

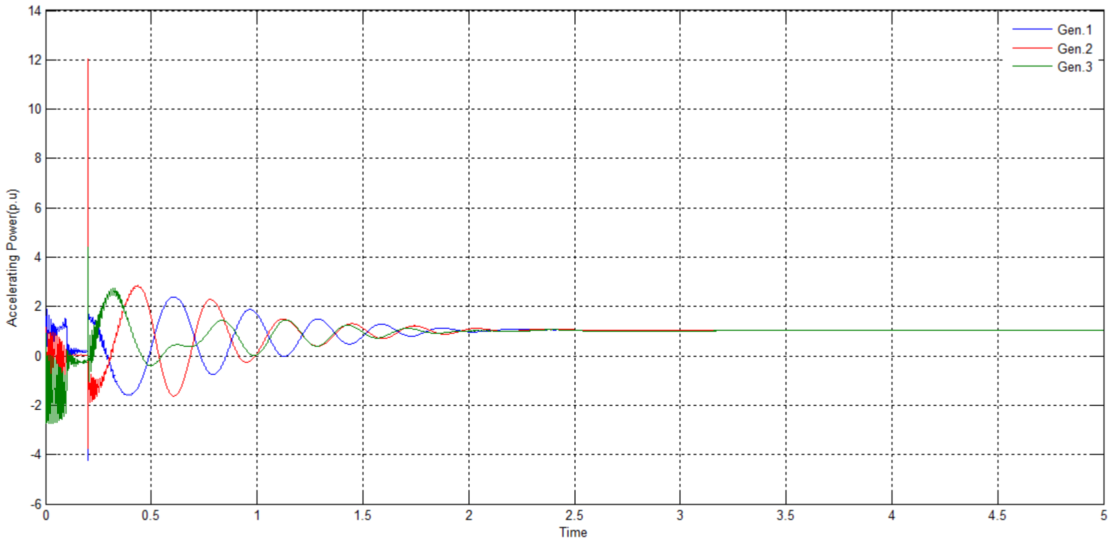

Figure 5.8: Waveform of Accelerating power(p.u) versus Time(sec)

Chapter 6

Conclusion Future work

6.1 Conclusion

In the present work a comparative analysis of various types of power system stabilizers is performed, while applied to a Multi Machine power System. For the same set of conditions the fuzzy logic power system stabilizer (FLPSS) has increased the damping of the system causing it to settle back to steady state in much less time than the conventional power system stabilizer (CPSS) and it also decreases the peak value. The FLPSS, though rather basic in its control proves that it is indeed a good controller due to its simplicity.

6.2 Future work

(1) The fuzzy logic based PSS with frequency as input parameter can be investigated because the frequency is highly sensitive in weak system, which may offset the controller action on the electrical torque of the machine.
(2) Testing using more complex network models can be carried out.

Appendix A

Appendix: Multi Machine System Parameters

Table I: Generator Data

Generator	**1**	**2**	**3**
Rated MVA	247.5	192	128
KV	16.5	18	13.8
X_d	0.146	0.8958	1.3125
X'_d	0.0608	0.1198	0.1813
X_q	0.0969	0.8645	1.2578
X'_q	0.0969	0.1969	0.25
X_l	0.0336	0.0521	0.0742
T'_{d0}	8.96	6.00	5.89
T'_{q0}	0.31	0.535	0.6

Table II: Exciter Data

Exciter	**1**	**2**	**3**
K_A	20	20	20
$T_A(sec)$	0.2	0.2	0.2
K_E	1.0	1.0	1.0
$T_E(sec)$	0.314	0.314	0.314
T_A	0.063	0.063	0.063
$T_A(sec)$	0.35	0.35	0.35

Table III: Line parameters

Line	**Resistance(p.u)**	**Reactance(p.u)**	**Susceptance(p.u)**
$1-4$	0.0000	0.0576	0.0000
$4-5$	0.0170	0.0920	0.1580
$5-6$	0.0390	0.1700	1.3580
$3-6$	0.0000	0.0586	0.0000
$6-7$	0.0119	0.1008	0.2090
$7-8$	0.00085	0.0720	0.1490
$8-2$	0.0000	0.0625	0.0000
$8-9$	0.0320	0.1610	0.3060
$9-4$	0.0100	0.0850	0.1760

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