CHAPTER 1

Introduction

An electric power system is an energetic and dynamic system. It is always subjected to Disturbances because of which there is change in generator voltage angle. A new suitable steady state of operating condition can be reached, when those disturbances die off. These disturbances do not reach the system to make the condition unstable which is important. These instabilities might be of local mode with frequency range in 0.7-2 Hz or of inter area modes with frequency range of 0.1-0.8 Hz, modern voltage regulators with high gain can cause these swings which are results of poor damping characteristics. Elimination of synchronizing torque has an important effect by high gain regulator through excitation control but this has negative effects on damping torque. Further signals are bring together in feedback loop of voltage regulators for the compensation of unwanted effect of voltage regulators. These addon signals are generally derived from excitation deviation, speed deviation or accelerating power. By injecting stabilizing component into the excitation system voltage reference summing point junction, it could be achieved. This whole device setup is called "power system stabilizer" which measures the improvement in system stability. Excitation control is popularly known as one of the productive ways to intensify the comprehensive stability of electrical power systems. Presently, it constitutes of fast acting AVRs. A high response exciter is helpful in growth of synchronizing torque, and thus enhances the stability temporarily i.e. holding the generator continuously along with power system in an interval of big transient fault condition. Though, it generates a negative damping especially at high values of external system reactance and high generator outputs. Stability of synchronous generators depends upon the number of factors such as arranging of automatic voltage regulators (AVR). A phase gap is introduced by AVR and generator field dynamics so that resulting torque is taken out of phase with both speed deviation and rotor angle. Positive synchronizing torque and negative damping torque frequently result, which can cancel the small inherent positive damping torque available, leading to instability. For improving stability the Generator excitation controls have installed and made faster. PSS has been added to excitation systems for improving the oscillatory instability, it is useful for providing a supplementary signal to excitation system. The basic function of PSS is to prolong the limit of stability by modulating generator excitation to supply the positive damping torque to the power swing modes. The implementation of power system stabilizer

(PSS) is to generate a complementary signal, which is implemented to control loop of the generating unit to produce a positive damping. Conventional PSS is lead-lag PSS which is widely used; here the gain settings are fixed under assured value which is determined under specific operating conditions to result in optimum performance for specific condition. Though, poor performance is given under different synchronous generator loading conditions. A distinctive PSS consists of signal washout stage, phase compensation stage and gain block. For providing damping, PSS must deliver component of an electrical torque on rotor in phase with Angular velocity. PSS input signal comprises generator speed, power and frequency. The transfer function of PSS must compensate gain and phase characteristics of the excitation system, the generator and the power system for the input signal. These together conclude the transfer function from the stabilizer output to component of electrical torque which could be curbed through excitation control. The PSS, while damping the rotor oscillations can be a source for the instability of turbine generator shaft torsional modes. Shaft speed pick-up location and torsional notch filters are selected and are used to reduce frequency signals of the torsional mode. Yet the PSS gain and torsional filter, affect the exciter mode damping ratio adversely. The usage of accelerating power as the input signal for PSS attenuates the shaft torsional modes integrally and alleviates the requirements of filtering in main stabilizing path.

CHAPTER-2

Literature Review

After going through the literature in limited time duration during M.tech work, the various techniques used in power system stabilizer are classical [1]-[12], fuzzy logic [13]-[27], neural network [28]-[41], genetic algorithm [42]-[51], hybrid [52]-[55], swarm intelligence [56]-[57]. The classification of methods is shown in Fig. 2.1.

2.1 CONVENTIONAL PSS

Larsen and Swann [11] gives the overview of power system stabilizer practically from practical point of view. Chow and Sanchez-Gasca [7] proposes a power system stabilizer using pole placement techniques and this work is carried by Yu and Li [4] for a nine bus system. Hsu [12] proposes a proportional integral controller. Cai et al. [5] proposes a lapanov's approach for the design of power system stabilizer and proposed a power system stabilizer with frequency deviation as only input signal and Robak et al. [3] gives the comparison of different control structures. Radman and Smaili [9] proposes the PID based power system stabilizer and Wu and Hsu [8] proposes the self tuning PID power system stabilizer for a multi machine power system.

2.2 FUZZY BASED PSS

Fuzzy set theory is a mathematical concept proposed by Prof. L. A. Zadeh in 1965. Fuzzy logic is a kind of logic using graded or quantified statements rather than ones that are strictly true or false. The fuzzy sets represented by linguistic variables allow objects to have grade of membership from 0 to 1. A fuzzy set F in a universe of discourse U is characterized by a membership μ_f which takes values in the interval[0,1] and can be written as -

$$F = ((u, \mu_F(u))/u \in U$$

The fuzzy logic controller comprises of four principle components: fuzzification, a knowledge base, decision making logic and defuzzification. In fuzzification the value of input variables are measured, scale mapping that transfers the range of values of input variables into corresponding universe of discourse is performed; it performs the function of fuzzification that converts input data into suitable linguistic values which may be viewed as label fuzzy sets. The knowledge base comprises knowledge of application domain and attendant control goals. It consists of a database and linguistic control rule base. The database provides the necessary definitions, which are used to define linguistic control rules and fuzzy data manipulation in an FLC. The rule base characterizes the control goals and control policy of domain experts by means of set of linguistic control rules. The decision making logic has the capability of simulating human decision making based on fuzzy concepts. The defuzzification performs scale mapping, which converts the range of values of output variables into corresponding universe of discourse, it yields a non-fuzzy control action from an inferred control action. The different methods of defuzzification are max criterion method, mean of maxima method and centriod method. Metwally and Malik [18] describes a paper on fuzzy logic power system stabilizer using speed and power output variations as the controller input variables. Hiyama [22] obtained the required information i.e acceleration, speed deviation and phase deviation of generator from measured real power signal. Pasand and Malik [20] discussed fuzzy logic based PSS implement on an intel single board computer iSBC386/21. Majid et al. [23] presented a fuzzy logic controller in which speed deviation and acceleration of rotor synchronous generator were taken as input. Juan et al. [24] compares the fuzzy logic based and rule base power system stabilizer. Gupta et al. [15] proposed a robust PSS based on fuzzy logic. In this speed deviation and acceleration of the rotor of synchronous generator of multi machine power system taken as input to fuzzy logic controller, results a obtained using different defuzzification methods. Moodley et al. [25] investigates the effect of FLPSS in a multimachine environment. Ferreira et al. [26] proposed a fuzzy logic PSS including a fuzzy PI controller to improve steady state behaviour of a system. The PI controller as proposed uses only speed deviation as input and uses triangular membership functions with only small number of rules. Lin [17] proposed a new fuzzy logic control scheme using one input signal which is the linear combination of three signals, i.e. signal, its derivative and its integral.. Park and Lee [21] proposed a self organizing power system stabilizer which doesn't use any reconstructed rule base of an expert or any plant model, with the input-output history. The rules are generated automatically and rule base updated online by self organizing procedure. The proposed stabilizer consists of a conventional lead-lag stabilizer and fuzzy logic based parameter tuner which adjusts the parameters of conventional stabilizer according to real time operating information and knowledge from the rule base prepared offline. Taliyat et al. [27] proposed an augmented fuzzy PSS in which the speed

deviation and acceleration were taken as input to fuzzy logic controller in which an auxiliary stabilizing signal which is a function of accelerating power into the terminal voltage feedback loop is utilized, which is a difference between mechanical and electrical power. Lin [14] proposed a fuzzy logic power system stabilizer which could shorten the tuning process of fuzzy rules and membership functions. The proposed PSS has two stages, first stage develops a proportional derivative type PSS, in the second stage it is transformed into FLPSS. Matsuki et al. [19] described the process of determination of optimal fuzzy control parameters by trial and error. This paper does not concern with improvement of scheme but problems encountered with the practical settings when fuzzy logic controller is introduced. Bandal et al. [16] proposed a PSS based on fuzzy logic and output feedback sliding mode control which is a variable structure control that is designate to
drive and constrain the system to lie within the neighborhood of switching function. Chung et al. [21] proposed the fuzzy PID controller in which three PID parameters of the controller are accurately tuned under a given active and reactive power conditions. Hussein et al. [13] proposed self tuning power system stabilizer in which two tuning parameters are introduced to tune fuzzy logic PSS, these parameters are the output of another fuzzy logic system which gets its input from operating condition of power system. D.K. Sambariya and Rajendra prasad [23] proposed Robust Power System Stabilizer Design for Single Machine Infinite Bus system with Different Membership Functions for Fuzzy Logic Controller Abdelazim and Malik [20] proposed a self learning fuzzy logic power system stabilizer in which for the continuous tracking of system, recursive least squares parameter identification method is used and a forgetting factor is used to discount the importance of older data.

2.3 NEURAL NETWORK BASED PSS

An artificial neural network (ANN) is an information processing paradigm that is inspired by the way biological nervous system, such as brain, process information. It is composed of a large no of highly interconnected processing elements working in unison to solve specific problems ANN like people learn by example. ANN is configured for specific application, such as pattern reorganization or data classification through learning process. Learning involves the adjustment to synaptic connections that exist between neurons. Neural networks with their remarkable ability to derive meaning from complicated or imprecise data, can be used to extract patterns and detect trends that are too complex to be noticed by either human or computer techniques. The neural network based PSS is discussed by various researchers [28]-[34]. Bulic et al. [62] proposed the control of excitation system using neural network, Liu et al. [63] gives the comparison of adaptive neural network based controller and convensional power system stabilizer. Chaturvedi and Malik [66]-[69] proposes a generalized neuron based adaptive PSS. Chusanapiputt et al. [71] proposed a method to tune the parameters of PSS using neural network. Hu Zhijian et al. [72] proposed a PSS using neural network inverse system. Chusanapiputt et al. [75] proposed a hybrid RBF neural network adaptive PSS using tabu search algorithm. Zhang and Malik [78] conducted experimental studies based on neural network based PSS. Shijie cheng et al. [80] proposed the PSS based on neural network by using online learning.

2.4 GENETIC BASED PSS

The genetic algorithm mimics the principle of natural genetics and selection to construct search and optimization procedures. The idea of evolutionary algorithm was introduced in 1960 by I. Rechenberg. Genetic algorithm are good at taking larger, potentially huge, search spaces and navigating them looking for optimal combination of things and solutions which we might not find in life time. Genetic algorithms need design space to be converted into genetic spaces, therefore it work with coding of variables. The advantage of working with coding of variable space is that coding discretizes the search space even though the function is continuous. It uses randomized operators which improve search space in an adaptive manner. Abdel-Magid et al. [51] proposed a method for the stabilization of power systems using GA. Hasanovic and Feliachi [50] proposed a GA based controller design using MATLAB. Rashidi [42] proposed the method for tunning PSS using GA for stabilization of power systems. Huang et al. [44] proposed a sliding mode PSS using GA. Folly [47] proposed a multi machine PSS design based on GA

2.5 HYBRID PSS

Hybrid systems are those for which more than one technology is employed to solve the problem. Combining the above, neuro-fuzzy, neuro-genetic and fuzzy genetic hybrid systems are possible. There are two ways of looking at neuro-fuzzy hybridization. One is to endow neural networks with fuzzy capabilities thereby increasing the networks expressiveness and flexibility to adapt to uncertain environments. The second aspect is to apply neural learning capabilities to fuzzy systems to make the fuzzy systems more adaptive to changing environments. Neuro-genetic Hybrid combined GA-NN also known as GANN have the ability to ability to locate the neighborhood of optimal solution quicker than other search strategies But once in neighbour hood of an optimal solution GANN statergies tends to converge slower than conventional ones. Drawback is that a large amount of memory is required to handle and manipulate chromosomes for a given network Fuzzy systems have been integrated with GA's called fuzzy-genetic Hybrid. The adjustment of system parameters that is called for in the process, so that system output matches the training data, has been tackled using GA. Parsa and Toyoda[52] gives the overview about the implementation of hybrid PSS. Sharaf and Lie [53] proposed a hybrid neuro-fuzzy PSS whearas Abido and Magid [55] proposed the same for a multimachine system. Yuo et al [65] proposed the neuro-fuzzy PSS with self organizing map.

2.6 OBJECTIVE OF THE WORK

In this work a novel power system stabilizer for damping oscillations based on fuzzy logic theory is developed as the controller settings to be inadvertently changed due to nonlinear changes in generators and in transmission-lines operating conditions and the models based on original manufacturer information may not be accurate after few years. The simulation of the power system stabilizer based on fuzzy logic is carried out and its performance is compared using conventional (lead-lag) controller for a single machine infinite bus system when the system is subjected to disturbance.

2.7 ORGANIZATION OF THE THESIS

The thesis is organized into 7 chapters. The 1 chapter is introduction of PSS, The 2 chapter is literature review; identify the objective and organization of thesis. The 3 chapter is study of small signal stability including synchronous machine modeling, saturation effects on system. The chapter 4 dicusses about effect of the excitation system, model of single machine infinite bus system with automatic voltage regulation and exciter, its observation, problem identification. Chapter 5 discusses about the intellingent techniques used with power system stabilizer briefly discusses the theory of compostion of PSS, PID controller, fuzzy control theory and neural network, need for implementing fuzzy controller. It also describes the fuzzy logic based PSS. The results are discussed in chapter 6 having various cases of a single machine to infinite bus system. The system without PSS, with PSS, with fuzzy logic based PSS, Artificial neural network with different various values of gains and damping torque component and also with different overlapping of membership functions in Fuzzy and comparison of their results in tabular form. The conclusion with the recommendation for future work are presented in Chapter 7 followed by the references.

CHAPTER 3

SMALL SIGNAL STABILITY ANALYSIS

3.1 SYSTEM MODELLING:

A general system configuration for the synchronous machine connected to the large system is shown in figure 3.1(a). This general system is used for the study of angle or small signal stability.

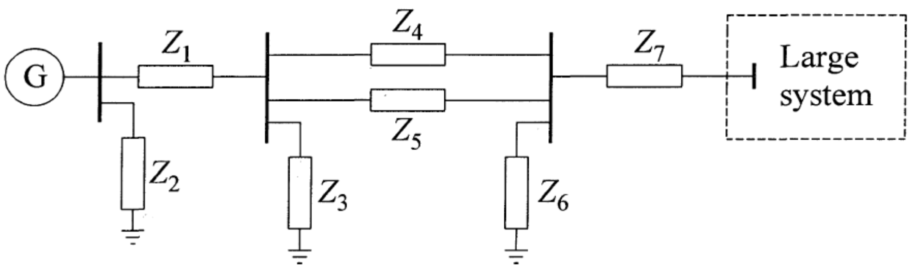

FIGURE-3.1(a) Configuration of single machine connected via transmission line to a large system

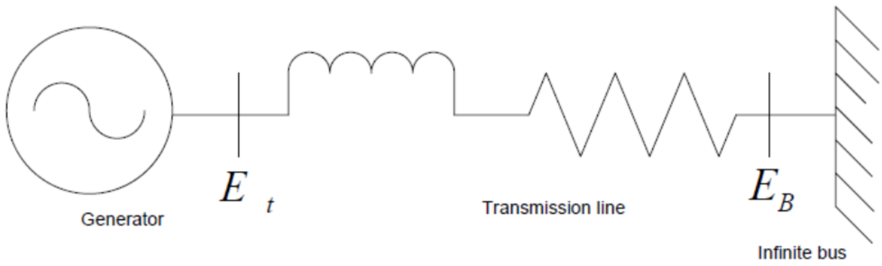

FIGURE-3.1(b) Diagram of single machine connected to an infinite bus

The general system configuration can be reduced to the Thevenin's equivalent circuit shown in above figure. For any given system condition, the magnitude of the infinite bus voltage E_B remain constant when machine is perturbed.

3.2 CLASSICAL MODEL REPRESENTATION

Neglecting all resistances and representing the generator by classical structure, the system represented is shown in Figure 3.3. Here E' is voltage on the other side of X_d'. The magnitude of E' on an presumption remains constant value. Let δ be the angle by which E' leads the infinite bus voltage E_B. As the rotor oscillates δ changes.

The reference phasor taken as E' gives:

$$\check{I}_t = \frac{E'\angle 0° - E_B\angle -\delta}{jX_T}$$

$$= \frac{E' - E_B(\cos\delta - j\sin\delta)}{jX_T} \qquad (3.1)$$

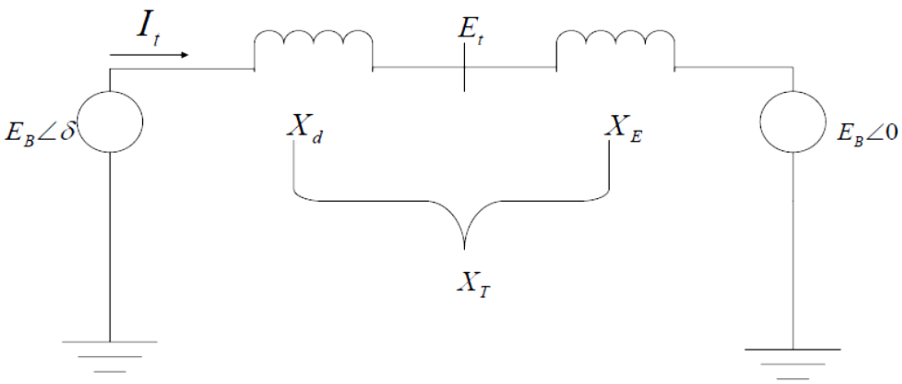

FIGURE-3.2 Classical structure of generator

Behind X_d' complex power is given by :

$$= \frac{E' - E_B\sin\delta}{X_T} + j\frac{E'(E' - E_B\cos\delta)}{X_T} \qquad (3.2)$$

Neglecting stator resistance, air gap power (P_e) becomes equal to terminal power (P_t).

It gives:

$$T_e = P = \frac{E'E_B}{X_T}\sin\delta \tag{3.3}$$

Linearizing about $\delta=\delta_o$ yields

$$\Delta T_e = \frac{\partial T_e}{\partial \delta}\Delta\delta = \frac{E'E_B}{X_T}\cos\delta_o(\Delta\delta) \tag{3.4}$$

Equation of motion in P.U given by:

$$p\Delta\omega_r = \frac{1}{2H}(T_M - T_e - K_D\Delta\omega_r) \tag{3.5}$$

$$p\delta = \omega_o\Delta\omega_r \tag{3.6}$$

After linearizing Equation (3.5) and substituting ΔT from Equation (3.4) we get:

$$p\Delta\omega_r = \frac{1}{2H}(\Delta T_M - K_S\Delta\delta - K_D\Delta\omega_r) \tag{3.7}$$

$$K_S = \frac{E'E_B}{X_T}\cos\delta_o \tag{3.8}$$

After linearizing Equation (3.6), we get

$$p\Delta\delta = \omega_o\Delta\omega_r \tag{3.9}$$

Writing equation 3.5 and 3.6 in matrix form we obtain:

$$\frac{d}{dt}\begin{bmatrix} -K_D & \frac{-K_S}{2H} \\ \omega_o & 0 \end{bmatrix}\begin{bmatrix}\Delta\omega \\ \Delta\delta\end{bmatrix} + \begin{bmatrix}\frac{1}{2H} \\ 0\end{bmatrix}\Delta T_m \tag{3.10}$$

This is of the form $\dot{x} = Ax + Bu$ .Matrix A is state matrix which has elements depending on system Parameters i.e K_D, H, X_T and initial working condition is represented by value of E' and δ_o . Block diagram in figure 3.3 describes small signal performance.

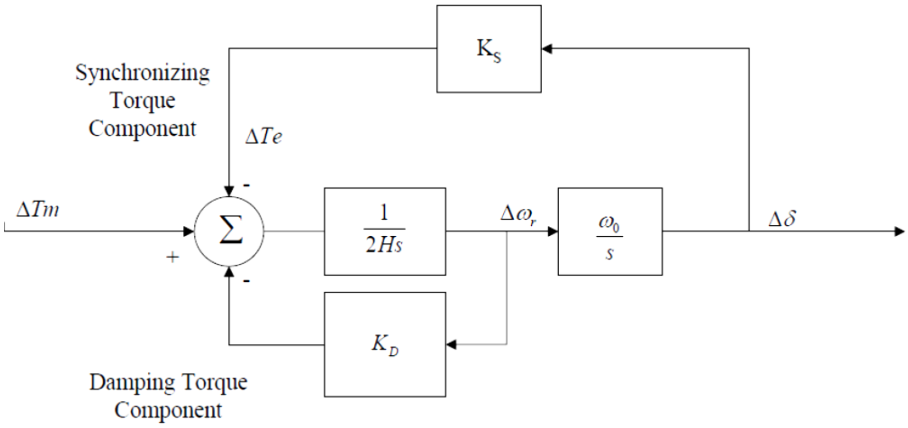

FIGURE-3.3Block model of SMIB with structure of generator

The above diagram we get,

$$\Delta\delta = \frac{\omega_o}{s}\left[\frac{1}{2Hs}(-K_S\Delta\delta - K_D\Delta\omega_r + \Delta T_m)\right]$$

$$= \frac{\omega_o}{s}\left[\frac{1}{2Hs}(-K_S\Delta\delta - K_D s\frac{\Delta\delta}{\omega_o} + \Delta T_m)\right] \tag{3.11}$$

Solving the above diagram the characteristic equation becomes:

$$s^2 + \frac{K_D}{2H} + \frac{K_S\omega_o}{2H} = 0 \tag{3.12}$$

When compared to general form, undamped natural frequency becomes:

$$\omega_n = \sqrt{K_S\frac{\omega_o}{2H}} \tag{3.13}$$

Also damping ratio becomes:

$$\xi = \frac{1}{2}\frac{K_D}{\sqrt{K_S 2H\omega_o}} \tag{3.14}$$

3.3 EFFECT OF FIELD CIRCUIT DYNAMICS

Under field circuit dynamics the state space model of system is developed by reducing the equations of synchronous machine to a proper form and then their combination with network equations.

The equation of acceleration of generator model is given by:

$$p\Delta\omega_r = \frac{1}{2H}(\Delta T_M - T_e - K_D\Delta\omega_r) \tag{3.15}$$

The field circuit equations of synchronous generator are :

$$p\Delta\delta = \omega_o\Delta\omega_r \tag{3.16}$$

$$p\psi_{fd} = \omega_o(E_{fd} - R_{fd}i_{fd}) \tag{3.17}$$

E_{fd} = Exciter output voltage.

$$= \omega_o \frac{R_{fd}}{L_{adu}} E_{fd} - \omega_o R_{fd} i_{fd} \tag{3.18}$$

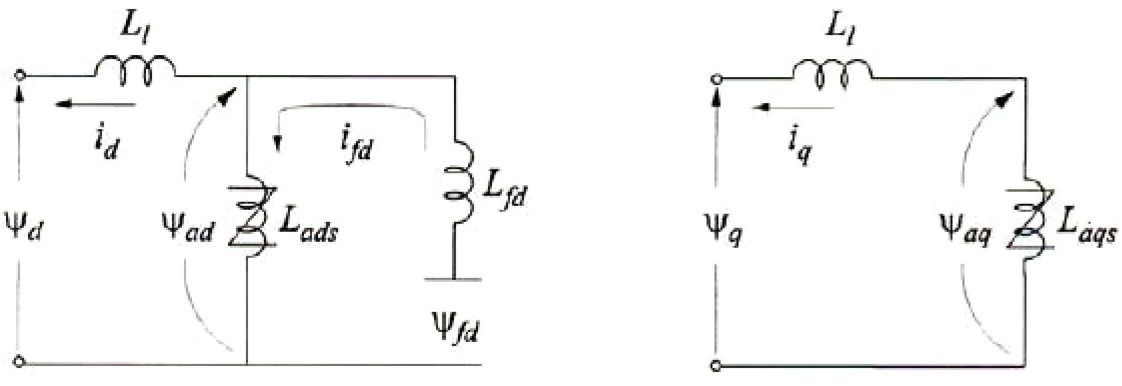

FIGURE-3.4 Machine and current equivalent circuit for flux linkage

Rotor and Stator flux linkage are:

$$\psi_d = -L_l i_d + L_{ads}(-i_d + i_{fd}) = -L_l i_d + \psi_{ad} \tag{3.19}$$

$$\psi_q = -L_l i_q + L_{aqs}(-i_q) = -L_l i_q + \psi_{aq} \tag{3.20}$$

$$\psi_{fd} = L_{ads}(-i_d + i_{fd}) + L_{fd}i_{fd} = \psi_{ad} + L_{fd}i_{fd} \quad (3.21)$$

From the above equation, field circuit is given by:

$$i_{fd} = \frac{\psi_{fd} - \psi_{ad}}{L_{fd}} \quad (3.22)$$

The mutual flux linkage at d-axis including $\psi_{fd}$and i_d becomes:

$$\psi_{ad} = -L_{ads}i_d + L_{ads}i_{fd} \quad (3.23)$$

$$= -L_{ads}i_d + \frac{L_{ads}}{L_{fd}}(\psi_{fd} - \psi_{ad}) \quad (3.24)$$

$$= L'_{ads}\left(-i_d + \frac{\psi_{fd}}{L_{fd}}\right) \quad (3.25)$$

It is known that

$$L'_{ads} = \frac{1}{\frac{1}{L_{ads}} + \frac{1}{L_{fd}}} \quad (3.26)$$

Not Considering rotor circuits in q-axis, mutual flux linkage is defined by:

$$\psi_{aq} = -L_{aqs}i_q \quad (3.27)$$

The air gap torque is defined by:

$$T_e = \psi_d i_q - \psi_q i_d = \psi_{ad} i_q - \psi_{aq} i_d \quad (3.28)$$

Neglecting speed variation and terms, stator voltage equation becomes:

$$e_d = -R_a i_d - \psi_q = -R_a i_d - \left(L_l i_q - \psi_{aq}\right) \quad (3.29)$$

$$e_q = -R_a i_q - \psi_d = -R_a i_q - \left(L_l i_d - \psi_{ad}\right) \tag{3.30}$$

Expressing infinite bus and machine terminal voltage in terms of q-axis and d-axis components as follows:

$$\breve{E}_t = e_d + je_q \tag{3.31}$$

$$\breve{E}_B = E_{Bd} + jE_{Bq} \tag{3.32}$$

The network constraint equation for system in fig. 3.2 is given by:

$$\breve{E}_t = \breve{E}_B + (R_E + jX_E)\breve{I}_t \tag{3.33}$$

$$\left(e_d + je_q\right) = \left(E_{Bd} + jE_{Bq}\right) + (R_E + jX_E)\left(i_d + ji_q\right) \tag{3.34}$$

Resolving the above equation into q and d components gives:

$$e_d = R_E i_d - X_E i_q + E_{Bq} \tag{3.35}$$

$$e_q = R_E i_q - X_E i_d + E_{Bq} \tag{3.36}$$

Also,

$$E_{Bd} = E_B \sin\delta$$

$$E_{Bq} = E_B \cos\delta$$

Eliminating E_d and E_q by using equations 3.29 and 3.30 gives:

$$i_d = \frac{X_{Tq}\left[\psi_{fd}\left(\frac{L_{ads}}{L_{ads} + L_{fd}}\right) - E_B\cos\delta\right] - R_T E_B \sin\delta}{D} \tag{3.37}$$

$$i_q = \frac{R_T\left[\psi_{fd}\left(\frac{L_{ads}}{L_{ads} + L_{fd}}\right) - E_B\cos\delta\right] + X_{Td} E_B \sin\delta}{D} \tag{3.38}$$

Also,

$R_T = R_a + R_E$

$$X_{Tq} = X_E + \left(L_{aqs} + L_l\right) = X_E + X_{qs} \tag{3.39}$$

$$X_{Td} = X_E + (L'_{ads} + L_l) = X_E + X'_{ds} \tag{3.40}$$

$$D = {R_T}^2 + X_{Tq}X_{Td}$$

Equations 3.25, 3.27, 3.37 and 3.38 used for eliminating i_{fd} *and* T_e from equations 3.15, 3.16, 3.18 and are linearised given below.

Equation 3.37 and 3.38 are linearised to give:

$$\Delta i_d = m_1\Delta\delta + m_2\Delta\psi_{fd} \tag{3.40}$$

$$\Delta i_q = n_1\Delta\delta + n_2\Delta\psi_{fd} \tag{3.41}$$

It is known that:

$$m_1 = \frac{E_B(X_{Tq}\sin\delta_o - R_T\cos\delta_o)}{D}$$

$$n_1 = \frac{E_B(R_T\sin\delta_o - X_{Td}\cos\delta_o)}{D}$$

$$m_2 = \frac{X_{Tq}}{D}\frac{L_{ads}}{(L_{ads} + L_{fd})}$$

$$n_2 = \frac{R_T}{D}\frac{L_{ads}}{(L_{ads} + L_{fd})}$$

Linearizing the equations 3.24 and 3.27 of flux linkages:

$$\Delta\psi_{ad} = L'_{ads}\left(-\Delta i_d + \frac{\Delta\psi_{fd}}{L_{fd}}\right) \tag{3.42. a}$$

$$= \left(\frac{1}{L_{fd}} - m_2\right) L'_{ads}\Delta\psi_{fd} - m_1 L'_{ads}\Delta\delta \qquad (3.42.b)$$

$$\Delta\psi_{aq} = -L_{aqs}\Delta i_q$$

$$= -n_2 L_{aqs}\Delta\psi_{fd} - n_1 L_{aqs}\Delta\delta \qquad (3.43)$$

Linearising eaquation 3.22 and substituting for $\Delta\psi_{ad}$ from 3.42.a equation gives:

$$\Delta i_{fd} = \frac{\Delta\psi_{fd} - \Delta\psi_{ad}}{L_{fd}}$$

$$= \frac{1}{L_{fd}}\left(1 - \frac{L'_{ads}}{L_{fd}} + m_2 L'_{ads}\right)\Delta\psi_{fd} + \frac{1}{L_{fd}} m_1 L'_{ads}\Delta\delta \qquad (3.44)$$

Linearized torque equation is given by:

$$\Delta T_e = \psi_{ado}\Delta i_q + i_{qo}\Delta\psi_{ad} - \psi_{aqo}\Delta i_d - i_{do}\Delta\psi_{aq} \qquad (3.45)$$

Where by putting $\Delta i_q,\ \Delta i_d, \psi_{ad}, \psi_{aq}$ from above equation gives:

$$\Delta T_e = K_1\Delta\delta + K_2\Delta\delta\psi_{fd} \qquad (3.46)$$

$$K_1 = n_1(\psi_{ado} + L_{aqs} i_{do}) - m_1\left(\psi_{aqo} + L'_{aqs} i_{qo}\right) \qquad (3.47)$$

$$K_2 = n_2(\psi_{ado} + L_{aqs} i_{do}) - m_2\left(\psi_{aqo} + L'_{aqs} i_{qo}\right) + \frac{L'_{aqs}}{L_{fd}} i_{qo} \qquad (3.48)$$

Expressing in the desired matrix form by linearising equation 3.17 to 3.19 and 3.45, 3.46 gives.:

$$\begin{bmatrix} \Delta\dot{\omega} \\ \Delta\dot{\delta} \\ \Delta\dot{\psi}_{fd} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & 0 & 0 \\ 0 & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} \Delta\omega \\ \Delta\delta \\ \Delta\psi_{fd} \end{bmatrix} + \begin{bmatrix} b_{11} & 0 \\ 0 & 0 \\ 0 & b_{32} \end{bmatrix} \begin{bmatrix} \Delta T_m \\ \Delta E_{fd} \end{bmatrix} \qquad (3.49)$$

It is known that:

$$a_{11} = -\frac{K_D}{2H}$$

$$a_{12} = -\frac{K_1}{2H}$$

$$a_{13} = -\frac{K_3}{2H}$$

$$a_{21} = \omega_o = 2\pi f_o$$

$$a_{32} = -\frac{\omega_o R_{fd}}{L_{fd}} m_1 L'_{ads}$$

$$a_{33} = -\frac{\omega_o R_{fd}}{L_{fd}} \left[1 - \frac{L'_{ads}}{L_{fd}} + m_2 L'_{ads}\right]$$

$$b_{11} = \frac{1}{2H}$$

$$b_{32} = -\frac{\omega_o R_{fd}}{L_{adu}}$$

ΔE_{fd} and ΔT_m depends upon excitation controls and prime mover. Also mechanical input torque being constant $\Delta T_m = 0$ and exciter output voltage being constant $\Delta E_{fd} = 0$.

3.4 REPRESENTATION OF SATURATION IN STABILITY STUDIES

While representing magnetic saturation for stability analysis the usual assumption made are:

a) The leakage inductances are independent of saturation. The leakages fluxes are in air for a considerable portion of their paths so that they are not significantly affected by saturation of the iron portion. As a result, the only elements that saturate are the mutual inductances L_{ad} and L_{aq} .

b) The leakage fluxes do not contribute to the iron saturation. The leakage fluxes are usually small and their paths coincide with that of the main flux for only a small part of its path. By this assumption, saturation is determined by the air-gap flux linkage.

(c) The saturation relationship between the resultant air-gap flux and the mmf under loaded conditions is the same as under no-load conditions. This allows the - saturation characteristics to be represented by the open-circuit saturation curve, which is usually the only saturation data readily available.

(d) There is no magnetic coupling between the d- and q-axes as a result of nonlinearities introduced by saturation; i.e., currents in the windings of one axis do not produce flux that link with the windings of the other axis.

With the above assumptions, the effects of saturation may be represented as

$$L_{ad} = K_{sd} L_{adu}$$

$$L_{aq} = K_{sq} L_{aqu}$$

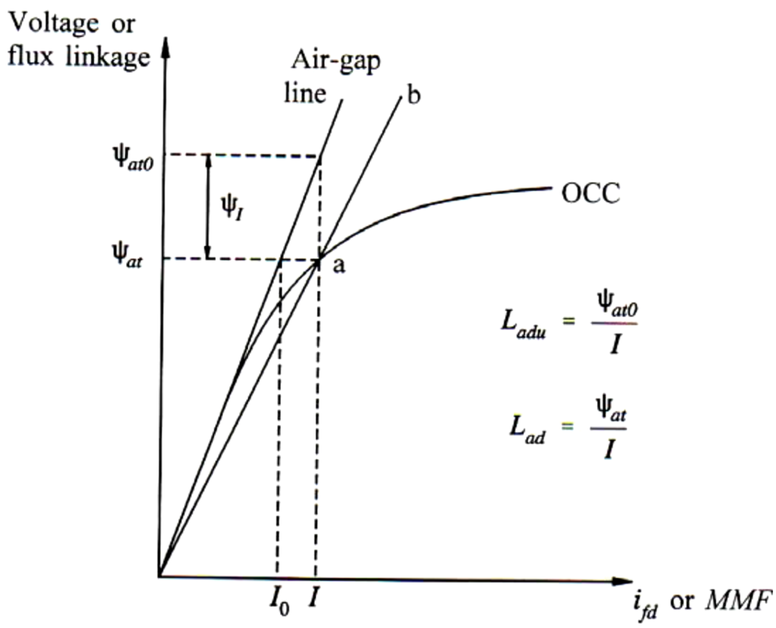

Figure 3.5 Saturation effects on open circuit characteristics

Where L_{adu} and L_{aqu} are the unsaturated values of L_{ad} and L_{aq}. The saturation factor K_{sd} and K_{sq} identifies the degrees of saturation in the d-axis and q-axis respectively.

The saturation curve may be divided into three segments:

I. Unsaturated segment

II. Nonlinear segment

III. Fully saturated linear segment.

The threshold values ψ_{T1} and ψ_{T2} defines the boundaries of the three segments as shown in figure 3.6.

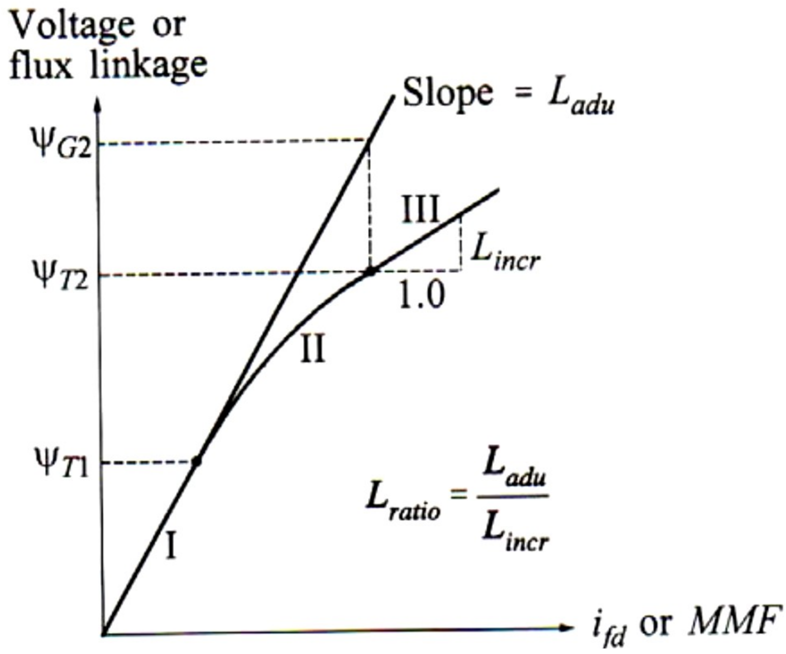

Figure 3.6 Representing saturation effects

Since we are expressing small-signal performance in terms of perturbation values of flux linkage and currents, a distinction has to be made between total saturation and incremental saturation.

Total saturation is associated with total values of flux linkages and currents. Incremental saturation is associated with perturbed values of flux linkages and currents. Therefore the incremental slope of the saturation curve is used in computing the incremental saturation as shown in Figure 3.10.

Denoting the incremental saturation factor $K_{sd(incr)}$:

$$L_{ads(incr)} = K_{sd(incr)} L_{adu} \tag{3.50}$$

Also ,

$$K_{sd(incr)} = \frac{1}{1 + B_{sat}A_{sat}e^{B_{sat}(\psi_{aT0}-\psi_{T1}}} \tag{3.51}$$

Where A_{sat} and B_{sat} are saturation constants depending on the saturation characteristics in the segment II portion in figure 3.7.

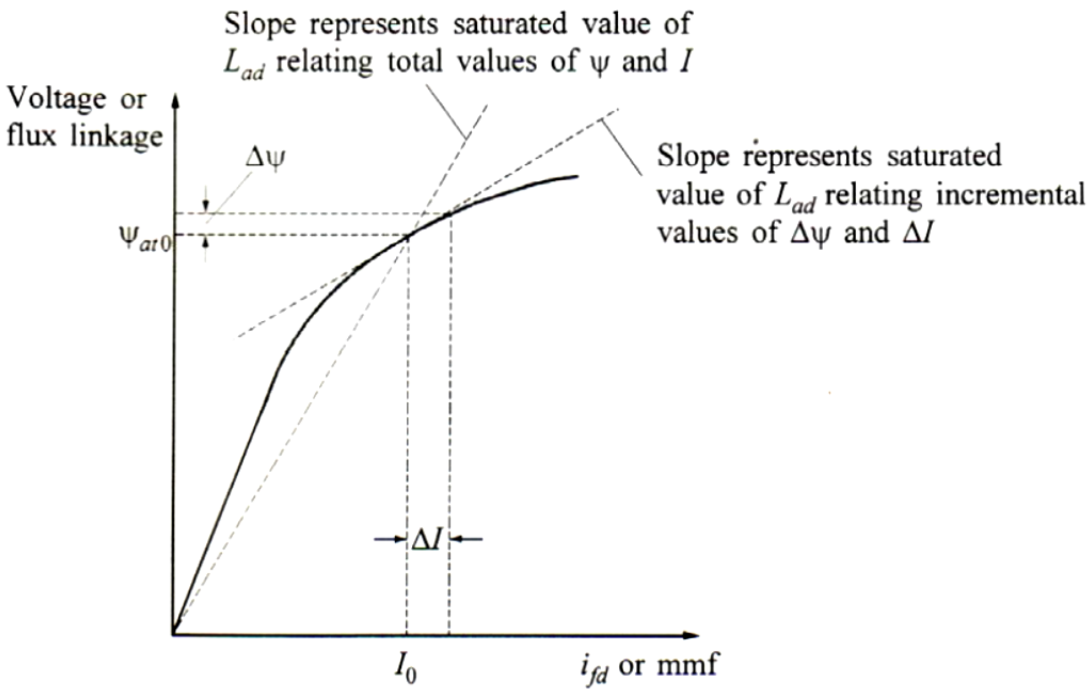

Figure 3.7 Difference between total and incremental saturation

For computing the initial values of system variable (dipicted by 'o' subscript), total saturation has been used. For relating the perturbed values, the incremental saturation factor is used. Figure 3.8 shows the block diagram representation of the small signal performance of the system.

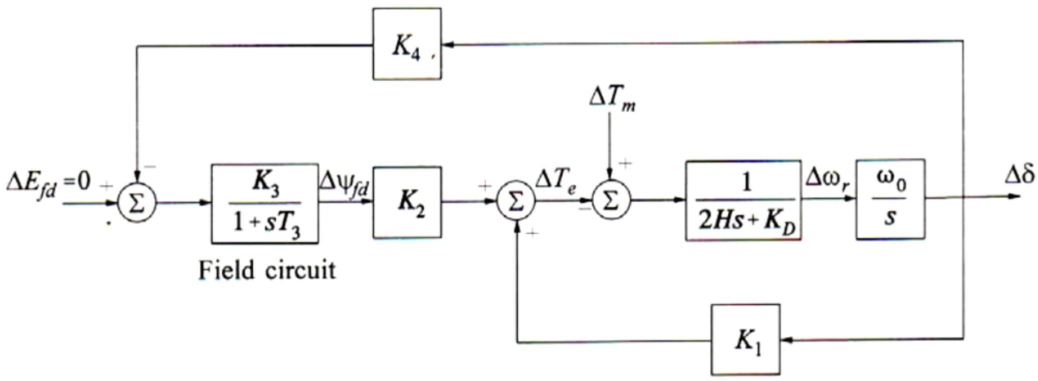

Figure 3.8 Model with Constant E_{fd}

From above schematic diagram the system with dynamic characteristics have been expressed in the form of K constants.

From equation 3.46, it can be understood that

$$\Delta T_e = K_1\Delta\delta + K_2\Delta\psi_{fd}$$

Also, $K_1 = \frac{\Delta T_e}{\Delta\delta}$; ψ_{fd} constant

$$K_2 = \frac{\Delta T_e}{\Delta\psi_{fd}};\ \Delta\delta \text{ constant}$$

$K_1\Delta\delta$ represents the synchronizing torque component while $K_2\Delta\psi_{fd}$ is the other component of torque.

The variation of $\Delta\psi_{fd}$ can be determined by

$$p\Delta\psi_{fd} = a_{32}\Delta\delta + a_{33}\psi_{fd} + b_{32}\Delta E_{fd} \quad (3.52)$$

Rearranging and grouping terms having $\Delta\psi_{fd}$, it gives:

$$\Delta\psi_{fd} = \frac{K_3}{1 + pT_3}[\Delta E_{fd} - K_4\Delta\delta] \quad (3.53)$$

$$K_3 = -\frac{b_{32}}{a_{33}}$$

$$K_4 = -\frac{a_{32}}{b_{32}} \quad (3.54)$$

$$T_3 = -\frac{1}{a_{33}}$$

CHAPTER 4

EFFECT OF EXCITATION SYSTEM

Block diagram from previous section is extended by combining it with excitation system whose effect on stability performance of SMIB is considered. The terminal voltage of generator E_t is normally the specific control signal to excitation system. E_t is expressed in the form:

$\check{E}_t = e_d + je_q$

Applying a small perturbation gives:

$$(E_{t0} + \Delta E_t)^2 = (e_{d0} + e_d)^2 + (e_{q0} + \Delta e_q)^2 \tag{4.50}$$

The above equation reduces to:

$$E_{t0}\Delta E_t = e_{d0}\Delta e_d + e_{q0}\Delta e_q \tag{4.51}$$

Hence,

$$\Delta E_t = \frac{e_{d0}}{E_{t0}}\Delta e_{d0} + \frac{e_{q0}}{E_{t0}}\Delta e_{d0} \tag{4.52}$$

With perturbed values from equations equations 3.29 and 3.30 :

$$\Delta e_d = -R_a\Delta i_d - \left(L_l\Delta i_q - \Delta\psi_{aq}\right) \tag{4.53}$$

$$\Delta e_q = -R_a\Delta i_q - (L_l\Delta i_d - \Delta\psi_{ad}) \tag{4.54}$$

Eliminating inconstants $\Delta i_d, \Delta i_q, \Delta\psi_{ad}, \Delta\psi_{aq}$ from all above equations in regard of state variables and replacing the values gives:

$$\Delta E_t = K_5\Delta\delta + K_6\Delta\psi_{fd} \tag{4.55}$$

Also,

$$K_5 = \frac{e_{d0}}{E_{t0}}\left[-R_a m_1 + L_1 n_1 + L_{aqs}n_1\right] + \frac{e_{q0}}{E_{t0}}[-R_a n_1 + L_1 m_1 + L'_{ads}m_1 \tag{4.56}$$

$$K_6 = \frac{e_{d0}}{E_{t0}}\left[-R_a m_2 + L_l n_2 + L_{aqs} n_2\right] + \frac{e_{q0}}{E_{t0}}\left[-R_a n_2 + L_l m_2 + L'_{ads}(\frac{1}{L_{fd}} - m_2)\right] \quad (4.57)$$

The effect on small signal stability is considered by including the excitation structure shown in Figure 4.1. It presents a thyristor excitation part. The structure shown in Figure 4.1, simplifies to take in only the elements which are necessary in presenting a specific system. The exciter gain used is high, without reducing derivative feedback or transient gain.

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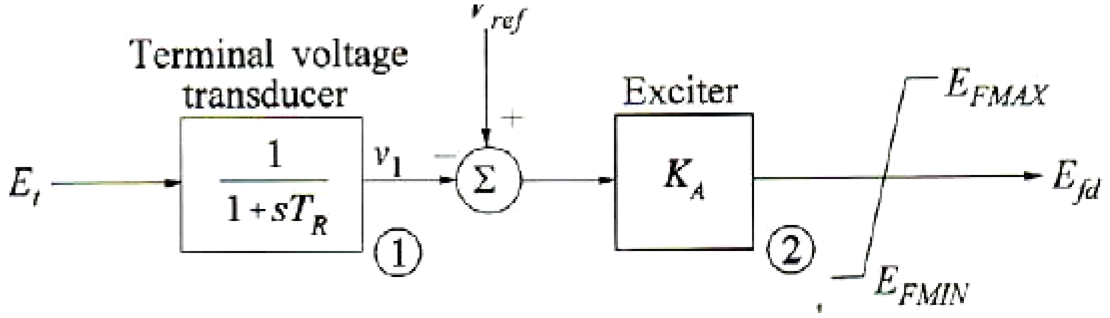

FIGURE-4.1 AVR with thyristor excitation system

T_r = transducer time constant of terminal voltage

From above block of Fig. 4.1, using perturbed values, the equation becomes:

$$\Delta v_1 = \frac{1}{1 + pT_r}\Delta E_t \quad (4.58)$$

Therefore,

$$p\Delta v_1 = \frac{1}{T_r}(\Delta E_t - \Delta v_1) \quad (4.59)$$

Substituting for ΔE_t from equation 4.4 gives:

$$p\Delta v_1 = \frac{1}{T_r}(K_5 \Delta\delta + K_6 \Delta\psi_{fd} - \Delta v_1 \quad (4.60)$$

From block 2 of Fig. 4.1 it gives:

$$E_{fd} = K_A(V_{ref} - v_1) \quad (4.61)$$

In terms of perturbed values it gives:

$\Delta E_{fd} = K_A(-v_1)$

The field circuit dynamic equation shown in equation 3.52 becomes:

$$p\psi_{fd} = a_{31}\Delta\omega_r + a_{32}\Delta\delta + a_{33}\Delta\psi_{fd} + a_{34}\Delta v_1 \qquad (4.62)$$

Where,

$$a_{34} = -b_{32}K_A = -\frac{\omega_o R_{fd}}{L_{adu}}K_A$$

The expressions for a_{31}, a_{32} and a_{33} remain unchanged as before and since we have a first order-order model for the exciter, the order of the overall system is increased by 1; the new state variable added is Δv_1

$$\Delta v_1 = a_{41}\Delta\omega_r + a_{42}\Delta\delta + a_{43}\Delta\psi_{fd} + a_{44}\Delta v_1$$

$$a_{41} = 0$$

$$a_{42} = \frac{K_5}{T_r}$$

$$a_{43} = \frac{K_6}{T_r}$$

$$a_{44} = -\frac{1}{T_r}$$

The complete state-space structure inclusive of excitation system has the following form:

$$\begin{bmatrix} \Delta\dot{\omega}_r \\ \Delta\dot{\delta} \\ \Delta\dot{\psi}_{fd} \\ \Delta\dot{v}_1 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 \\ a_{21} & 0 & 0 & 0 \\ 0 & a_{32} & a_{33} & a_{34} \\ 0 & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{bmatrix} \Delta\omega_r \\ \Delta\delta \\ \Delta\psi_{fd} \\ \Delta v_1 \end{bmatrix} + \begin{bmatrix} \Delta\omega_r \\ \Delta\delta \\ \Delta\psi_{fd} \\ \Delta v_1 \end{bmatrix} \Delta T_m \qquad (4.63)$$

The terminal voltage error signal, which forms the input to the voltage transducer block is given by -

$\Delta E_t = K_5 \Delta\delta + K_6 \Delta\psi_{fd}$ (4.64)

For mechanical torque input to be constant $\Delta T_m = 0$

4.1 MODEL REPRESENTATION

Fig. 2.7 depicts the model formed by combining of Exciter block and voltage transducer. This representation can be applied to various type of exciters, with $G_{ex}(S)$ depicting the transfer function of exciter and AVR.

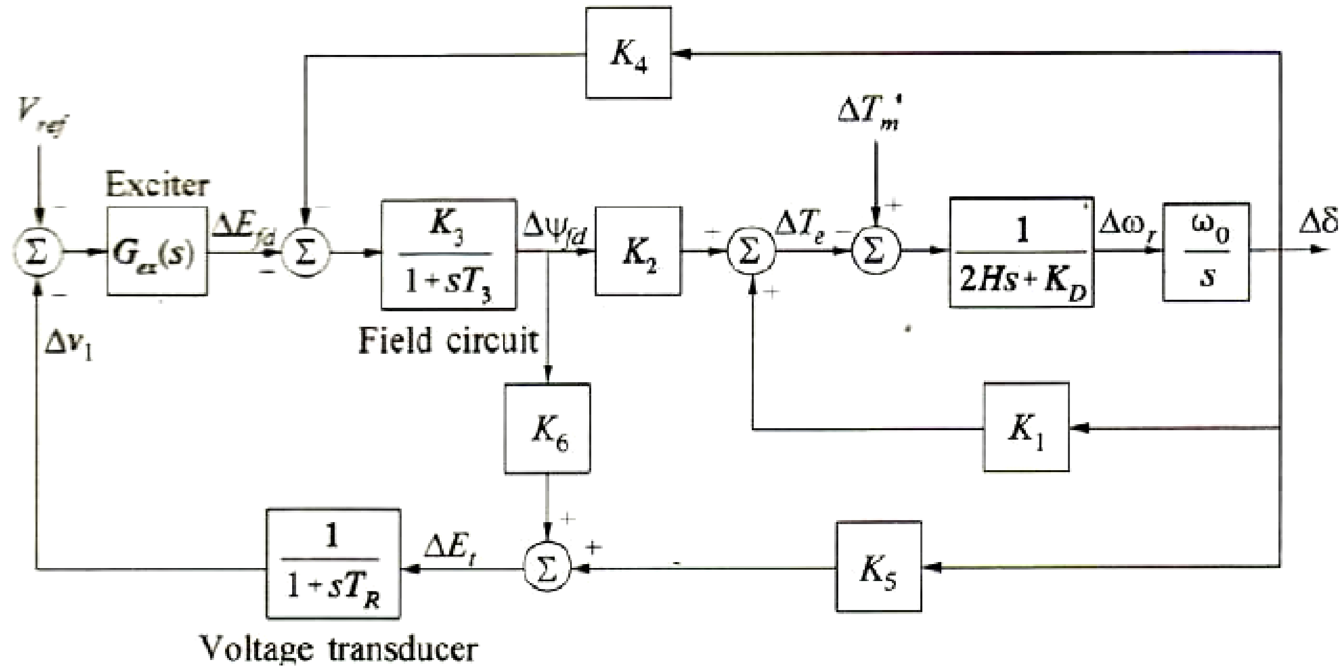

FIGURE-4.2 AVR and exciter block model

Depending upon the operating conditions the coefficient K_5 can be negative or positive and coefficient K_6 is inevitably positive. K_5 value has a notable effect on AVR influence on damping system oscillations.

4.2 IMPACT OF AVR ON SYNCHRONIZING AND DAMPING TORQUE ELEMENTS

It is ordinarily keen on the exhibitions of excitation frameworks with moderate or high reactions. For such excitation frameworks, it can be mention about accompanying general objective facts with respect to the impacts of AVR:

• With K_5 positive, the impact of the AVR is to present a negative synchronizing torque and a positive damping torque segment. The steady K_5 is certain for low estimations of outer framework reactance and low generator yields. The diminishment in $K_S$because of AVR activity in such cases is as a rule of no specific concern, in light of the fact that K_1 is high to 8the point that the net K_S is altogether more prominent than zero. Part and a negative damping torque segment. This impact is more declared as the exciter reaction increments

• With K_5 negative, the AVR activity presents a positive synchronizing torque. For high estimations of outside framework reactance and high generator yields K_5 is negative. By and by, the circumstance where K_5 is negative are generally experienced. For such cases, a high reaction exciter is advantageous in expanding synchronizing torque. On the other hand, in this manner it presents negative damping. We therefore have clashing prerequisites concerning exciter reaction. One conceivable plan of action is to strike a trade off and set the exciter reaction with the goal that it brings about adequate synchronizing and damping torque segments for the normal scope of framework working conditions. This may not generally be conceivable. It might be important to utilize a high-reaction exciter to give the obliged synchronizing torque and transient stability execution. With a high outer framework reactance, even with low exciter reaction the net damping torque coefficient may be negative.

4.3 OBSERVATIONS WITH EXCITER AND AVR

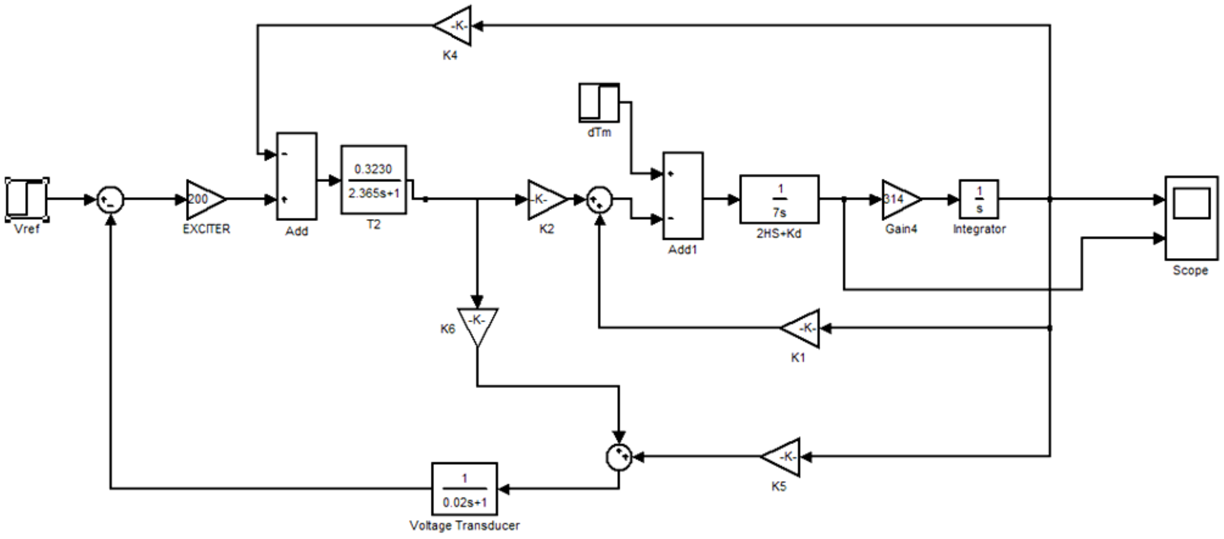

Figure 4.3 Model of simulink for AVR and SMIB

The values taken have been discussed in the last chapter.

For 5% step input change the system gives result as:

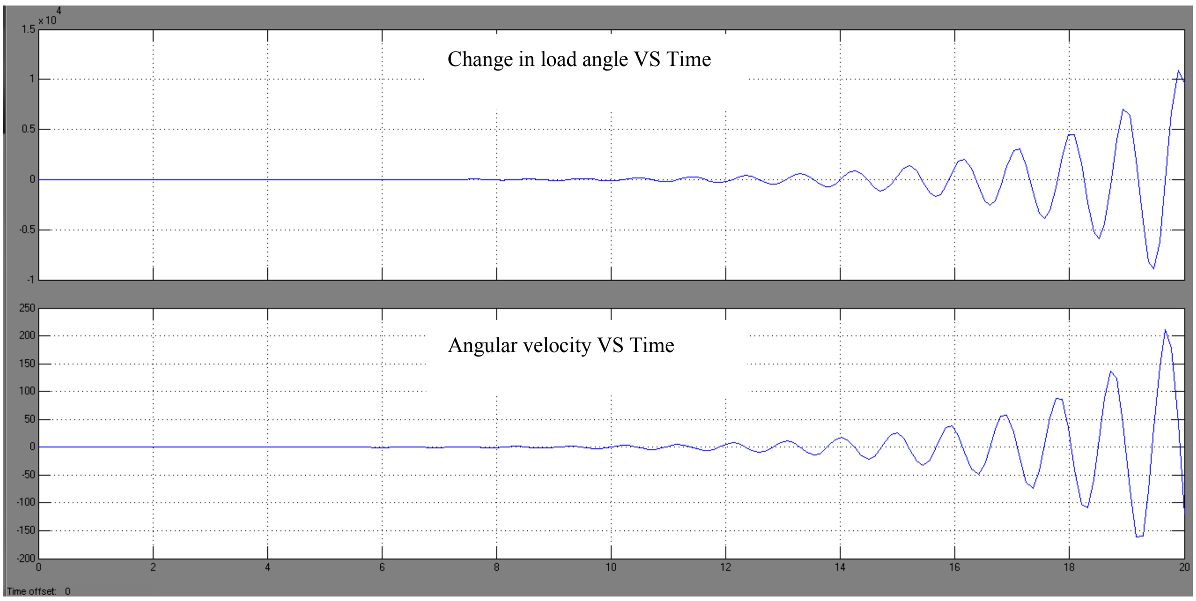

Figure 4.4 Response of 5% step input change in ΔT_m

4.4 Problem identification

Constant K_5 with AVR can have either positive or negative values which influences synchronizing torque and damping torque coefficient in figure shown below.

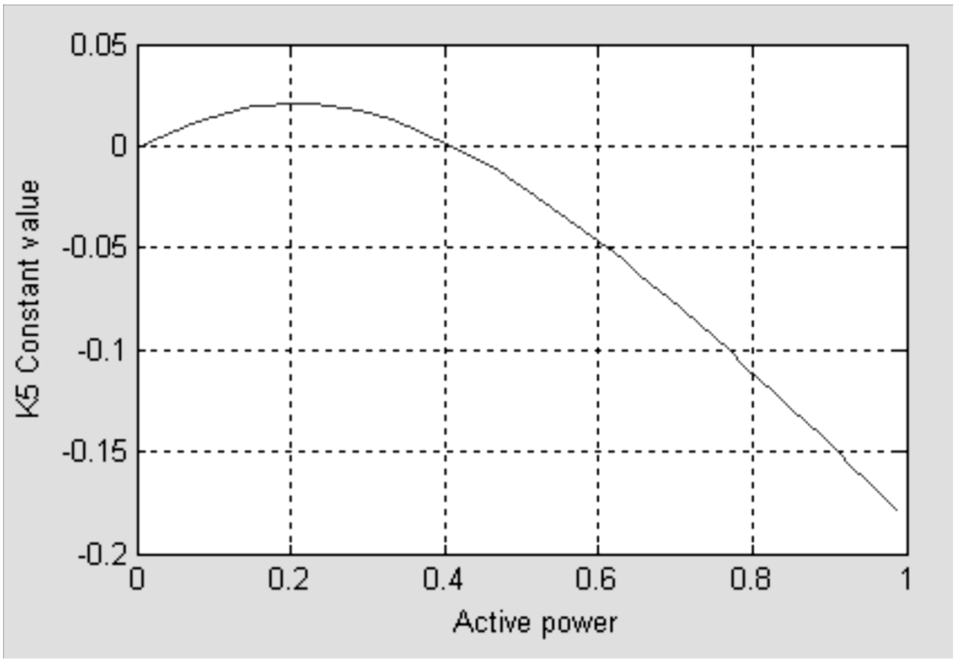

Figure 4.5 Response for K_5 VS Active power in per unit

The AVR introduces negative damping and positive synchronizing coefficient figure 4.6 and 4.7

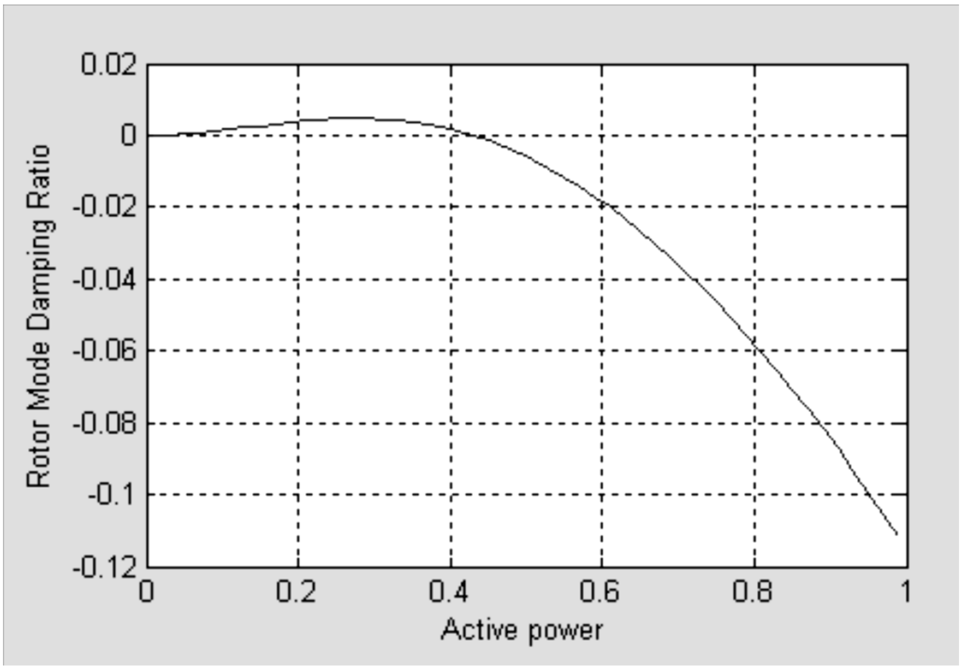

Figure 4.6 Response for Damping Torque Coefficient VS Active power (p.u)

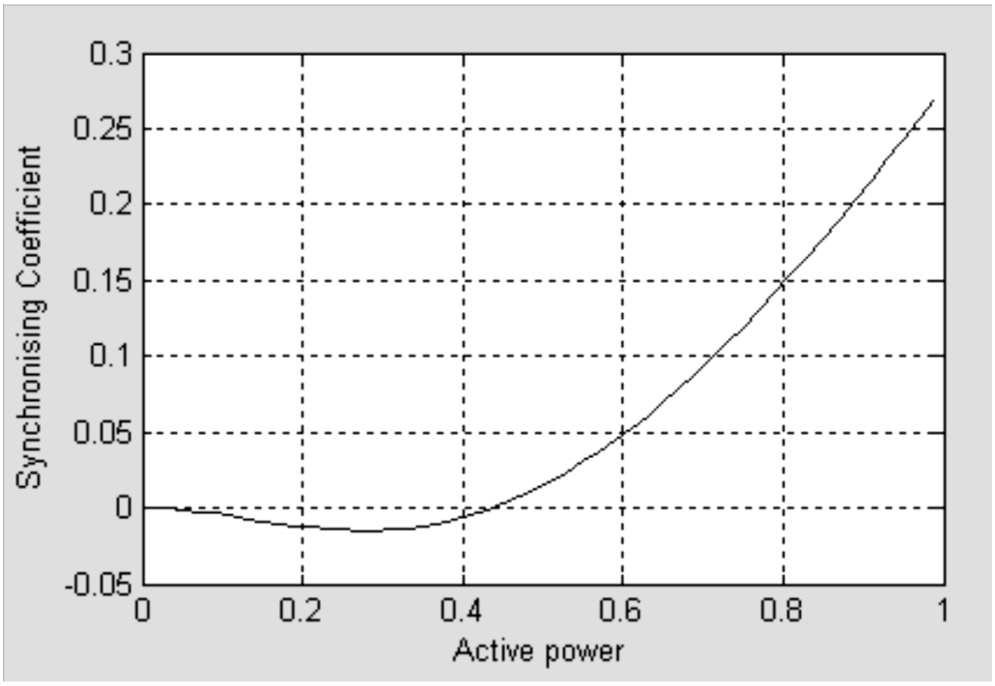

Figure 4.7 Response for Synchronising coefficient VS Active power (p.u)

Presently impact variety in excitation on framework stability will be depicted. Estimation of excitation to the framework is controlled by excitation gain K_A. So K_A will be changing its impact on the synchronizing and damping torque coefficient and will be mulled over. K_5 is autonomous of K_A so its impact won't be considered.

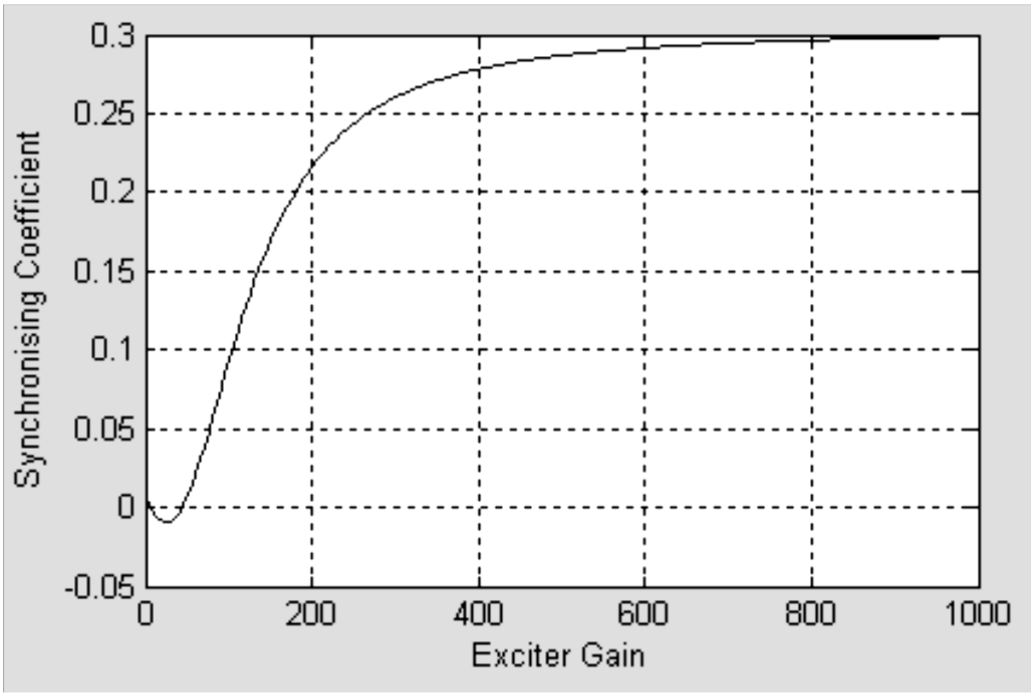

Figure 4.8 Response for Synchronising coefficient VS Exciter gain

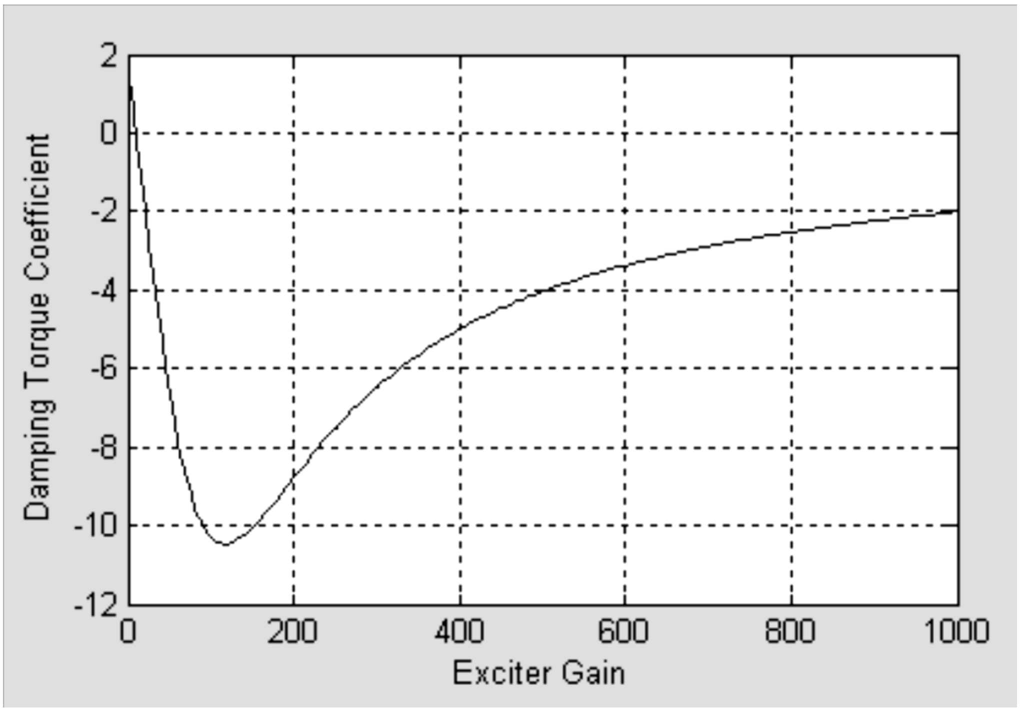

Figure 4.9 Response for Damping Torque coefficient VS Exciter gain

The impact of the variety in exciter addition (K_A) on synchronizing and damping coefficient is demonstrated in figure 4.8 and 4.9. Where, for lower excitation the damping torque coefficient is more negative. The net damping is littlest when (K_A) is 110(approx.) and will increment with expansion in exciter addition. Be that as it may, there is sure point of confinement upto which exciter addition can be expanded. The high reaction exciter is gainful in expanding synchronizing torque yet in doing as such it presents negative damping this is as obvious in figure 4.8 and 4.9.

From the above examination, we presumed that the impact of AVR on damping and synchronizing torque part is consequently fundamentally impact by steady K_5 and exciter addon (K_A). With steady K_5 negative, the AVR activity presents a positive synchronizing torque segment and negative damping torque part. This impact is more maintained as this exciter reaction increments. The fundamental driver of instability of the framework is negative damping coefficient; this antagonistic influence of low damping ought to be uprooted by adding damping to the framework.

CHAPTER 5
INTELLIGENT TECHNIQUES WITH POWER SYSTEM STABILIZER

5.1 POWER SYSTEM STABILIZER

Conventional PSS

The simplest function of power system stabilizer (PSS) is the addition of adequate damping to rotor oscillations of generator by giving auxiliary stabilizing signal(s) to control its excitation. In order to provide damping properly, the stabilizer produces a component or a part of electrical torque which is in phase to Angular velocity of rotor.

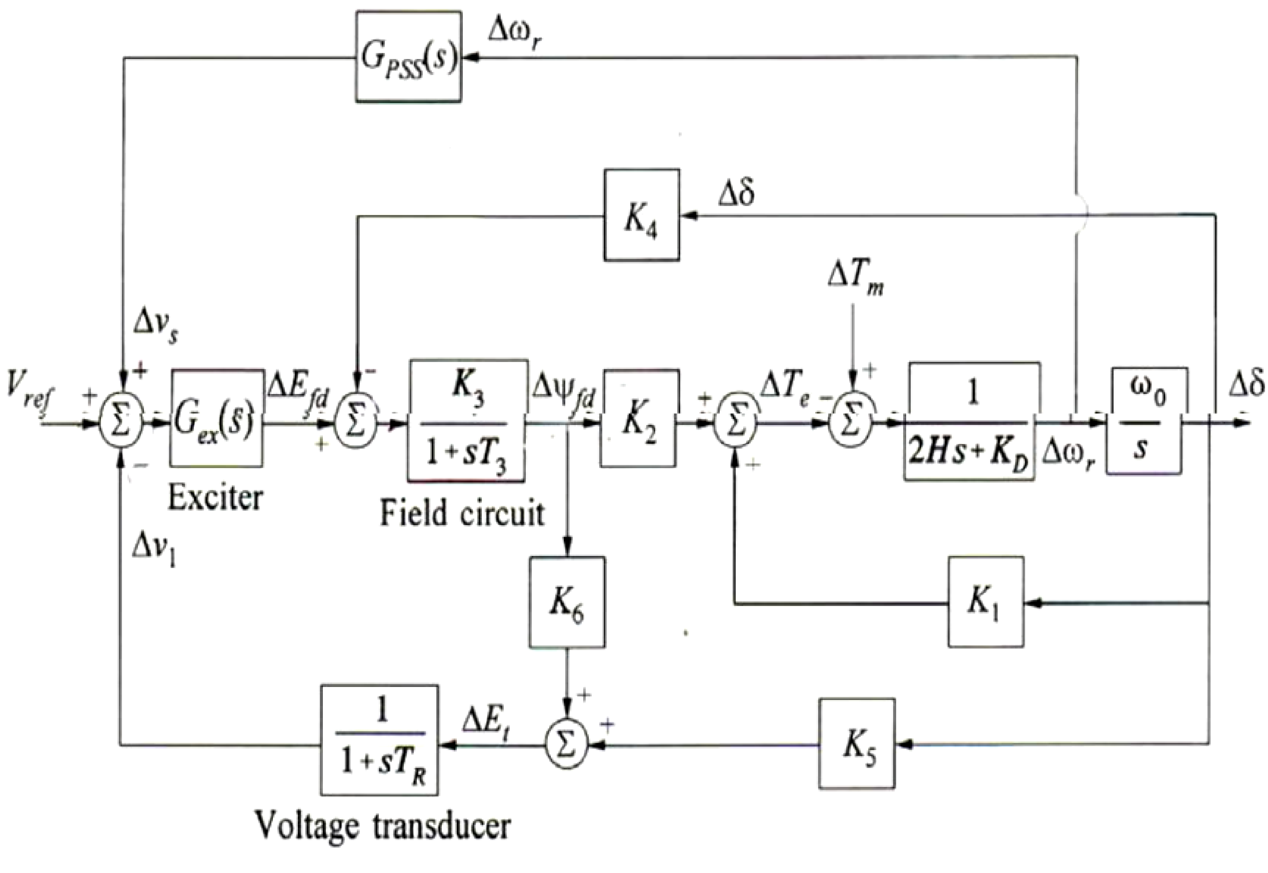

Figure 5.1 Block model of AVR and PSS

Since the principal purpose of PSS is to bring up a damping fundamental of torque. The rotor angle deviations $\Delta\omega_r$ is a probable signal to use for control of generator excitation. A damping torque fundamental would result as a direct reaction of the pure gains between

ΔE_{fd} and ΔT_e of the generator and the exciter transfer function $G_{PSS}(s)$. Although, in normal practice together the exciter and generator (type-dependent) exhibit characteristics based on frequency dependent phase and gain. Hence, the stabilizer transfer function i.e $G_{PSS}(s)$, has an appropriate circuits for phase compensation for phase lag among electrical torque and exciter input. In an optimal case PSS gives a classic damping torque at all frequencies of oscillation although its phase characteristic being inverse to that of generator and exciter phase characteristics for compensation. Following this is a short description on PSS configuration and its selection parameters.

5.2 COMPOSITION OF PSS

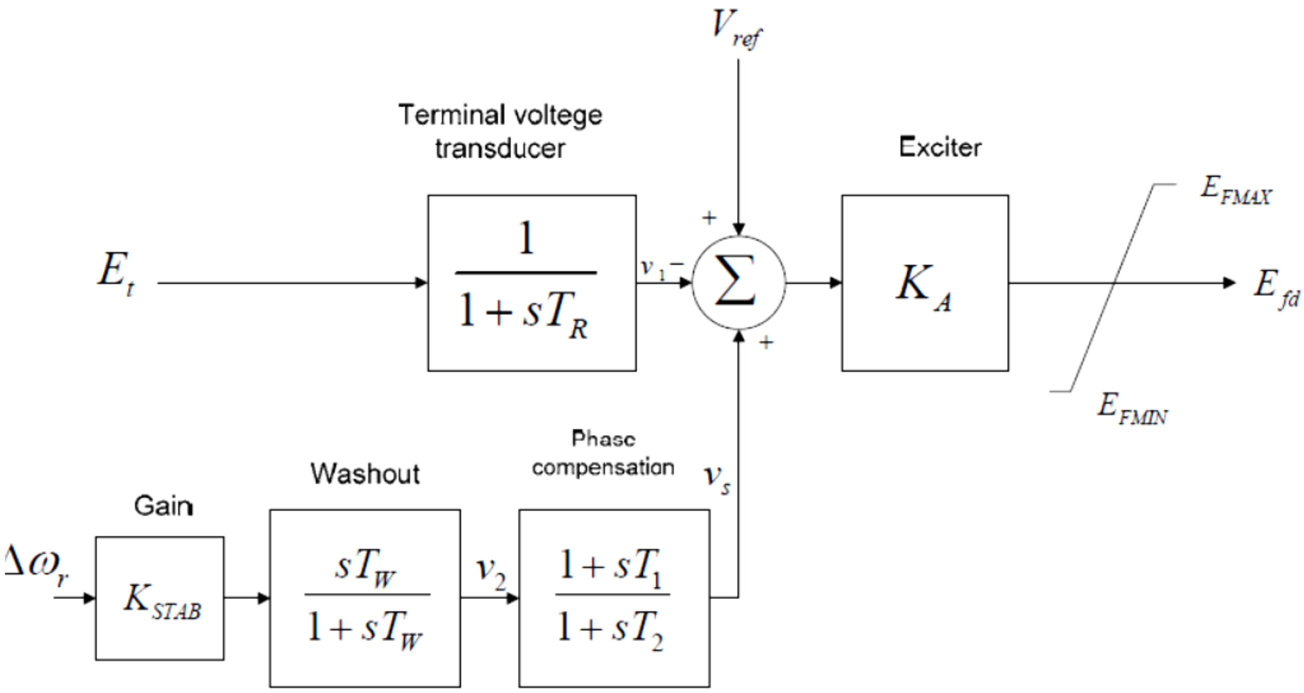

Figure 5.2 PSS and AVR along Thyristor excitation system

A proper phase lead feature is provided by phase compensation part of the PSS for the compensation of phase lag within the generator air gap (electrical) torque and exciter input. The block diagram depicts a first order phase compensation block. In general practice for a suitable phase compensation number of blocks are increased from two to more than two. Also for some cases, complex roots in second order blocks are used. commonly, frequency range taken is between 0.1 - 3.0 Hz, also phase lead system provides compensation on this whole frequency range. The characteristic of phase which will be compensated alters along system conditions. Following this a compromisation is made for unlike system conditions a suitable characteristic is picked. Ordinarily some lower compensation in addition is required for the PSS, to significantly increase damping torque, resulting in small increase of synchronizing torque.

The washout block is used as high-pass filter, having T_W as time constant which is large enough to let signals linked with ω_r oscillations pass unchanged and hence eliminate dc signals. If not used, the steady speed changes will modify terminal voltage. The washout block only allows the PSS to respond to speed changes only. From the viewpoint of the washout function, the value taken for T_W is not critical and can be in range of 1-20 seconds.

K_{STAB} is stabilizer gain block which determines the damping amount to be brought in by PSS. The ideal value of the gain is set to provide maximum damping, nonetheless, it is certainly limited according to other considerations.

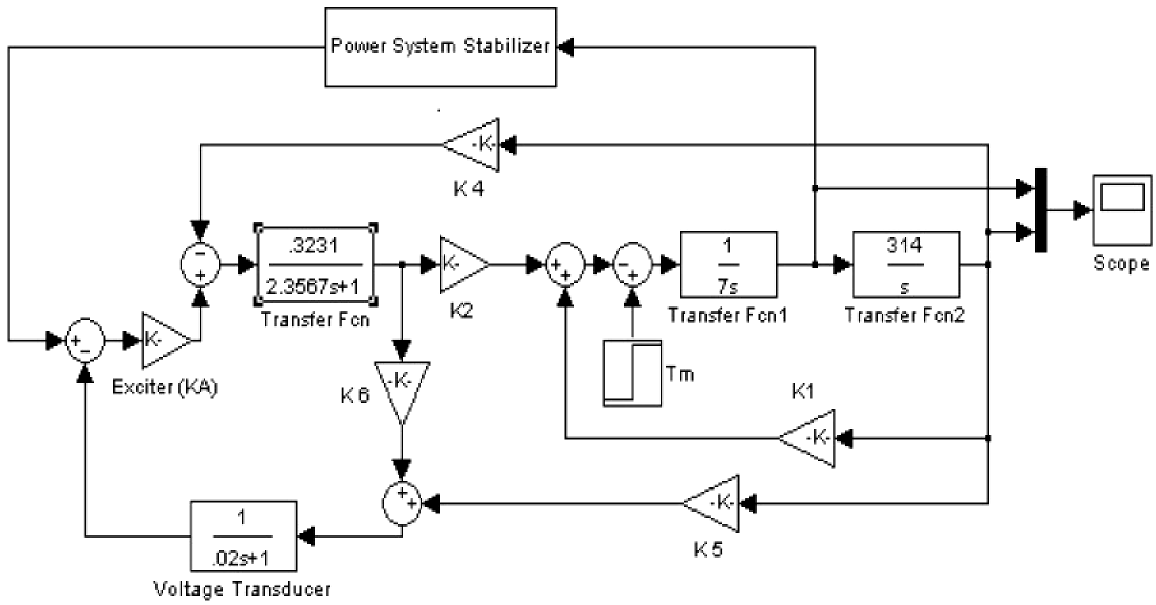

Figure 5.3 Simulink model of AVR and PSS

The Power System Stabilizer has phase compensation block, signal washout block, and gain block.

The Expanded form of PSS model is drawn below:

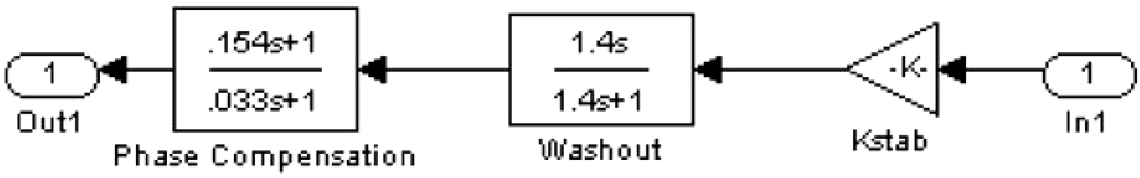

Figure 5.4 PSS block model

5.3 PID CONTROLLER based PSS

Proportional-integral and derivative i.e PID controller is quite difficult to design and tune in normal practice, when multiple objectives like high stability and short transient are needed to achieve. The PID controller can be considered as a compensator for phase lead lag having a pole at origin and other at infinity. Correspondingly PD and PI controllers are known as phase lead and phase lag compensators. Its transfer function is commonly written in parallel form or ideal form as following:-

$$G(s) = K_p + K_i\left(\frac{1}{s}\right) + K_d s$$
$$= K_p(1 + \frac{1}{T_1 s} + T_d s)$$

K_p= proportional gain,

K_i = integral gain,

K_d = derivative gain,

T_1 = integral time constant

By changing the values of K_p, K_i and K_d high stability and short transients can be achieved also while tuning they have mutual dependence.

5.4 Fuzzy Logic - Introduction

Fuzzy logic has derived from customary Boolean logic which likewise executes the linguistic inconstants on persistent and extensive variety of truth qualities to be characterized in the midst of conventional binary. Fuzzy logic gives estimated results in an attractive way, it can be utilized to control non linear framework and to model complex framework having unclearness or uncertainty regular. A methodical fuzzy framework regularly comprises of rule base, fuzzy participation functions and a technique of inference.

SUBSETS IN FUZZY

In traditional set hypothesis, a subset U of set S can be distinguished as mapping from elements of S to elements of subset {0, 1}.

$U: S \rightarrow \{0, 1\}$

The mapping is spoken to as a course of action of asked sets, with accurately one asked for pair present for each part of S. The fundamental part of the asked for pair is a segment of the set S, and second segment is a segment of the set (0, 1). The quality zero is used to speak to non-participation, and worth one is used to speak to finish enrollment. Reality or misdirection of the declaration 'X is in U' is directed by finding the asked for pair whose first segment is X. The declaration is authentic if the second segment of the asked for pair is 1, and the declaration is false in the event that it is 0.

5.4.1 THE BENEFITS OF FUZZY LOGIC IS AS FOLLOWS

1. It is quick and easy.

2. It minimizes pattern involving progress routine.

3. It simplifies design intricacy.

4. Provides altered solution in case of non-linear problems.

5. Also boosts control performance.

6. Also setup is easy.

7. In addition, it decreases hardware price.

Fuzzy control frameworks are tenet based structures in which a game plan of suggested fuzzy standards speak to a control choice component to change the impacts of certain framework jolts. The point of fuzzy control frameworks is regularly to supplant a capable human director with a fuzzy standard based structure. The fuzzy method of reasoning controller gives a number which can change over the etymological control method in view of master learning into a programmed control technique. Figure 14 outlines the fundamental design of a fuzzy logic controller (FLC) which comprises of a fuzzification interface, an information base, choice making logic, and a defuzzification interface.

The fuzzy logic controller when used in PSS has two input and one output signal. It is called as MISO system. Angular velocity and rate of change of Angular velocity are the inputs and voltage signal is the output of a fuzzy logic controller.

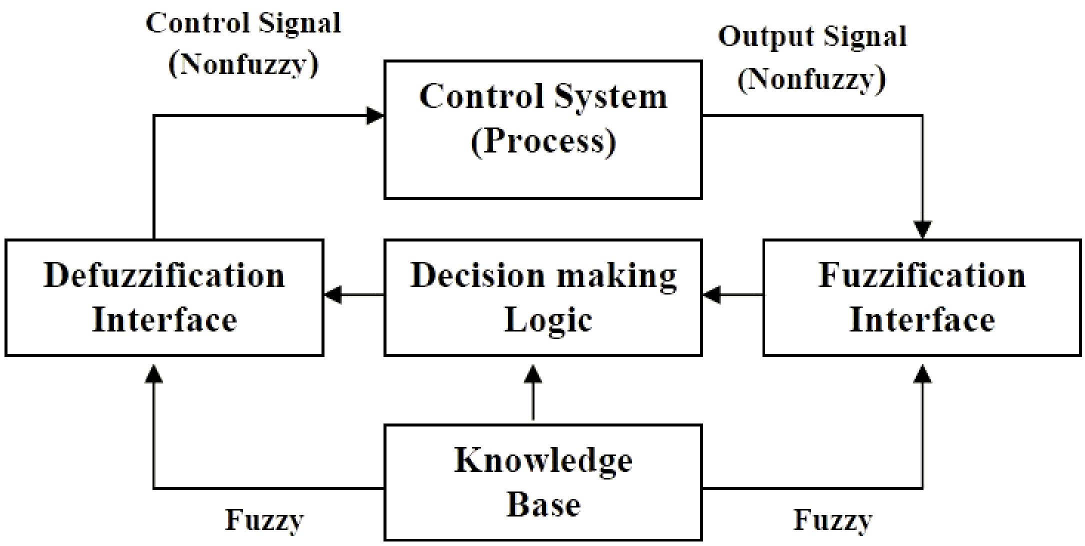

Figure 5.5 The principle Design of fuzzy logic Controller

The IF-THEN rules of fuzzy describes the nature of the unknown plant (e.g. when applying a negative control signal to synchronous machine the shaft acceleration changes to positive direction).

These are the steps to design a fuzzy logic controller (FLC):-

1) Identifying the input and output inconstant.

2) Forming the control rules.

3) Constituting an approach to describe system state in fuzzy sets i.e. constituting fuzzification method and fuzzy membership functions.

4) Selecting the designing rule of inference.

5) Transforming the fuzzy control statement into specific control actions i.e. Defuzzification method

5.4.2 DETERMINATION OF INPUT OUTPUT INCONSTANTS

Characterize information and control variables, figure out which conditions of the procedure ought to be watched and which control activities circular segment to be considered. For FLPSS arrangement, generator speed deviation ($\Delta\omega$) & acceleration ($\Delta\dot{\omega}$) can be watched and have been picked as the data indication of the fuzzy PSS. The dynamic execution of the structure could be surveyed by investigating the response twist of these two inconstants. By and by, just shaft speed ($\Delta\omega$) is promptly accessible. The acceleration sign ($\Delta\dot{\omega}$) can be gotten from the rate signs measured at two progressive examining moments utilizing the accompanying mathematical equation:

$$\Delta\dot{\omega}(\text{k}) = \frac{((\Delta\omega(k) - \Delta\omega(k-1))}{\Delta T}$$

5.4.3 THE MEMBERSHIP FUNCTIONS

Voltage, speed deviation and acceleration are the linguistic inconstants taken for controller. Acceleration and speed deviation are taken as input linguistic inconstants while voltage is taken as output linguistic inconstant. The linguistic inconstant varies with application and normally taken as odd number. So seven is a suitable number. If the number of variables are increased correspondingly the rules are also increased. Each linguistic inconstant has its own fuzzy membership function. The mapping of the crisp values to the fuzzy inconstants is done by this membership function. Triangular membership functions defines degree of membership. This degree of membership is important for designing the fuzzy controller.

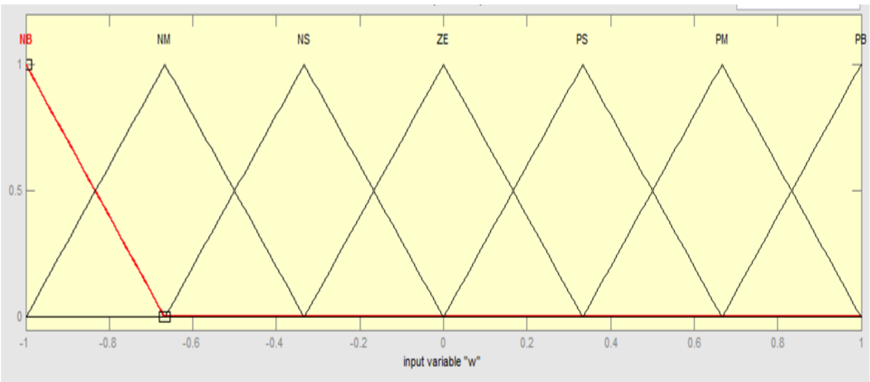

Figure 5.6 Input 1- Angular velocity

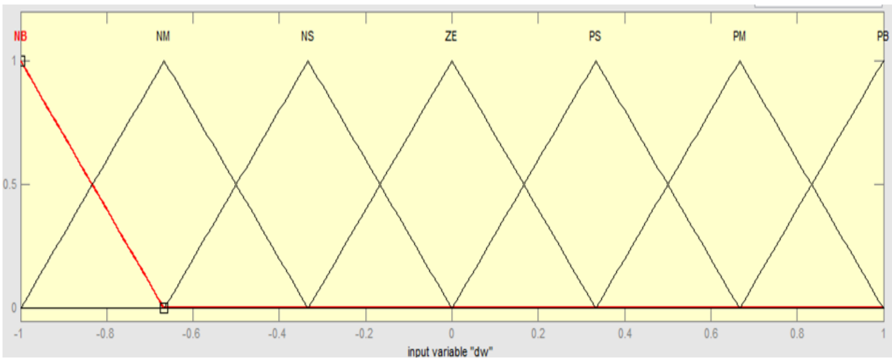

Figure 5.7 Input 2- Angular velocity per unit time

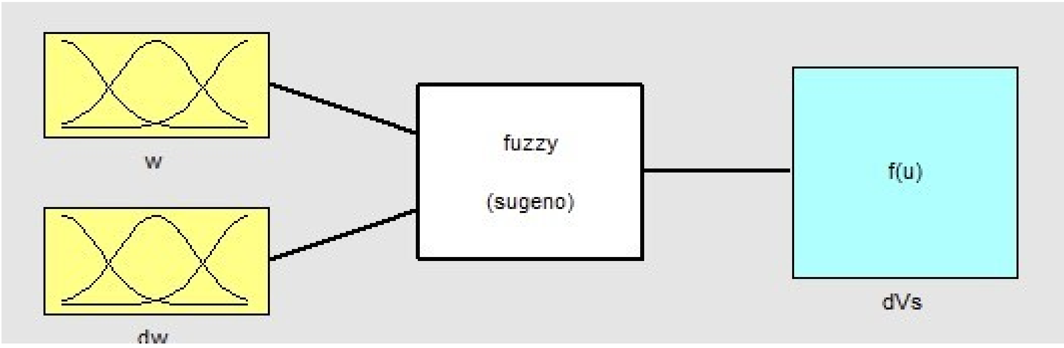

Figure 5.8 Algorithm Inputs and Outputs

5.4.4 FUZZY RULE BASE

For defining relation among input and output set of regulations can be originated using the knowledge available which has been used to design PSS. These regulations are defined by using linguistic inconstants. Speed deviation and acceleration are two inputs which makes 49 rules. The table given below depicts these rules properly with symbols defined in basic fuzzy terminology.

$\Delta\omega/\Delta\dot{\omega}$	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

Table 5.1 Fuzzy Rule Base

CHAPTER 6

RESULTS AND DISCUSSION

6.1 System under consideration

The system represented here is a thermal generating station which consist of four 555 MVA, 24 KV, 60 Hz Units.

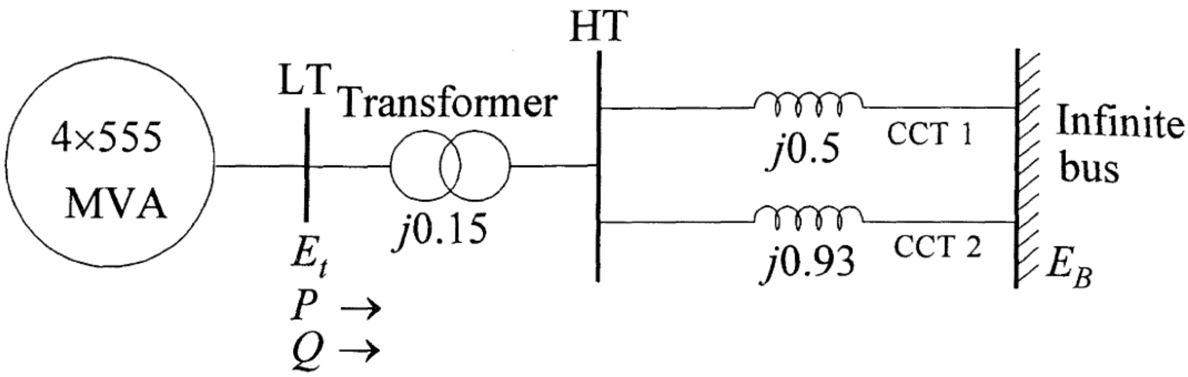

Figure 6.1 SMIB system under study (with circuit 2 lost)

The aim of this case study is to analyze the angle stability characteristics of the system about steady state working condition following with the loss of circuit 2. The post-fault system condition in per unit on the 2220 MVA, 24 KV base is as follows:

System parameters:

H = 3.5 ; $X'_d = 0.3$

Operating condition:

P = 0.9 ; Q = 0.3 ; $E_t = 1.0$

* (All network reactances are in p.u. on 2220 MVA, 22 KV base)
The generators are modeled as a single equivalent generator.

6.1.1 SYSTEM PARAMETERS

System working condition in per unit for 4×555MVA, 24 KV, 50 Hz generating unit on a common 2220MVA, 24 KV base are: $P = 0.9$; $Q = P/3$; $E_t = 1.0$

Thyristor exciter gain: K_A= 200; T_R= 0.02;

Frequency of oscillation is taken as 10 rad/sec.

Values of other parameters f =50; X_d=1.81; X_q=1.76; X_{d1}=0.3; X_L=0.16; X_e = 0.65; R_a=0.003; T_{d01}=8.0; H = 3.5; K_A =200; ω_o=314; ω=10; K_D=0; T_R=0.02; E_T=1.0; E_{Tmag} =1.0; L_{adu} =1.65; L_{aqu} =1.60; L_l =0.16; R_{fd} =0.0006; L_{fd} =0.153; K_{sd} =0.8491; K_{sq}=0.8491; K_{sdI}=0.434; K_{sqI}=0.434;

Saturation Constant used: A_{SAT}= 0.031; B_{SAT} = 6.93; ψ_1 = 0.8.

6.2 Implementation and Results without PSS

A. Implementation

The following figure shows the system implementation of the power system without the use of a controller with positive value of K_5.

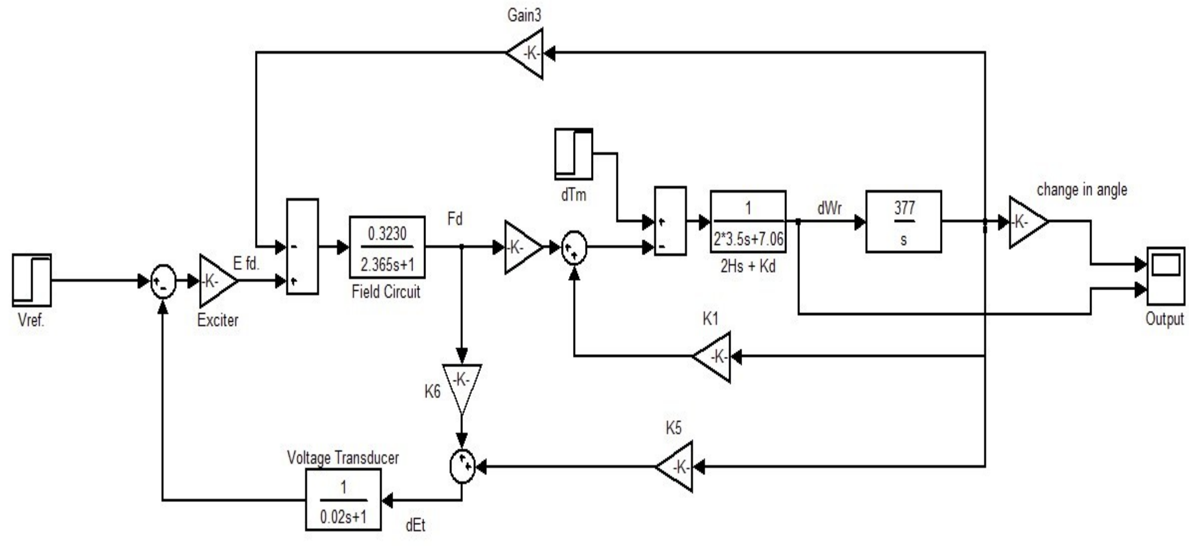

Figure 6.2 Simulink model representing without PSS

B. Results

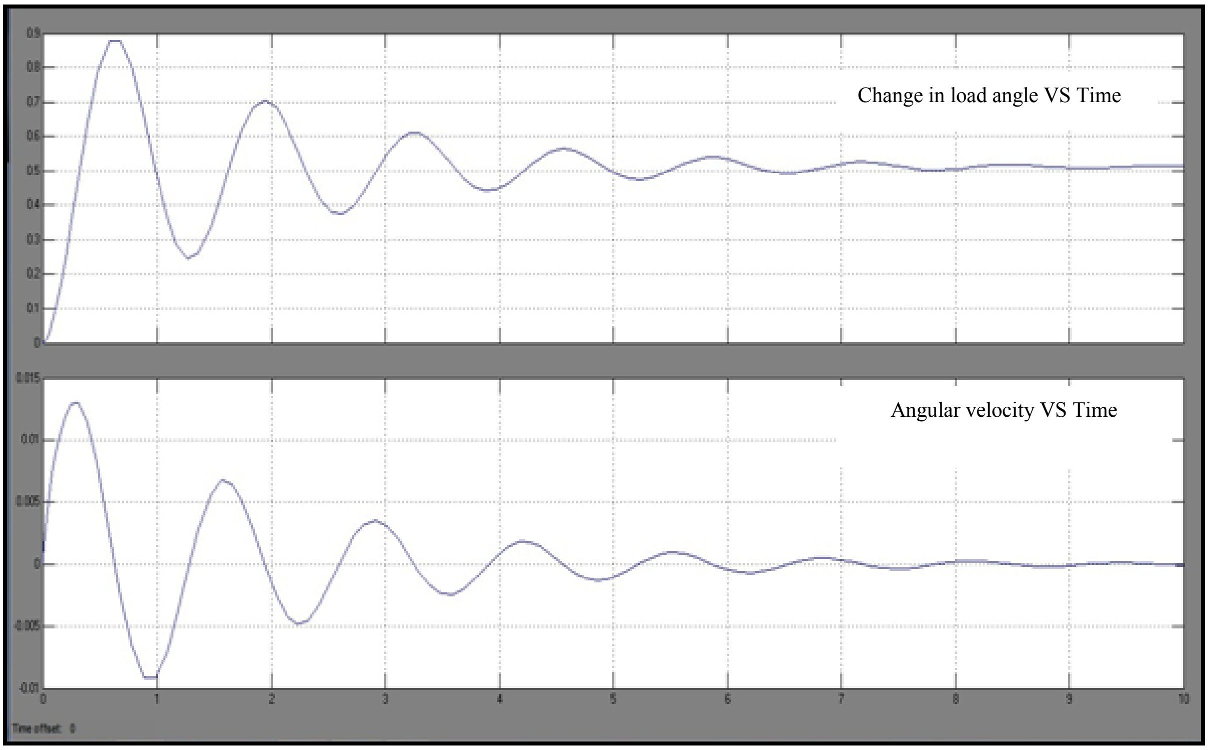

Figure 6.3 Results obtained without PSS

6.3 Implementation and Results with Conventional PSS

A. Implementation with negative value of K_5

The following figure shows the system implementation of the control system required to produce the adequate damping. The controller used is a conventional PSS. The controllerconsists to three parts, namely, gain, washout, phase compensation block.

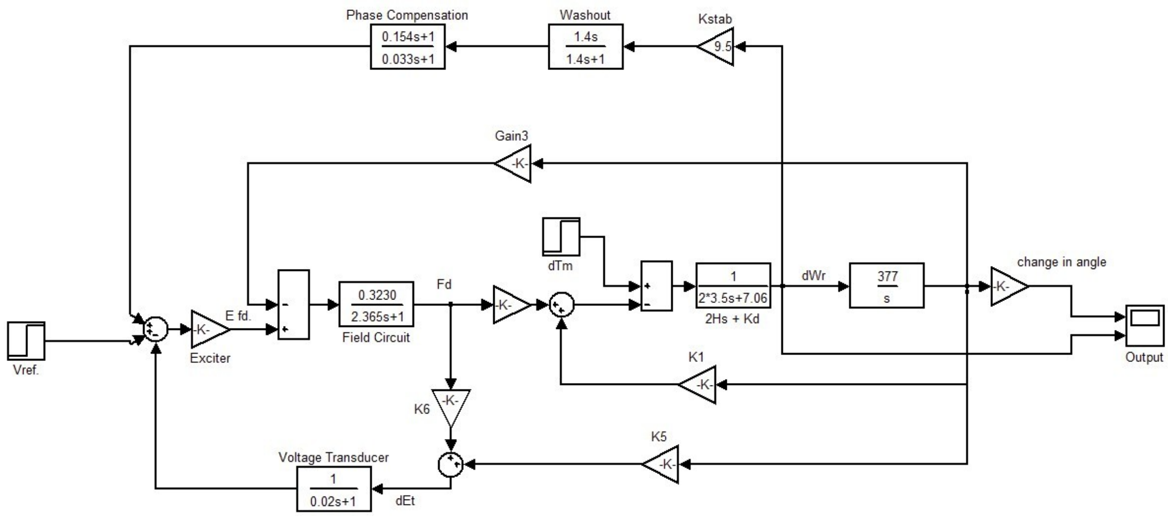

Figure 6.4 Simulink model with PSS

B. Result with negative value of K_5

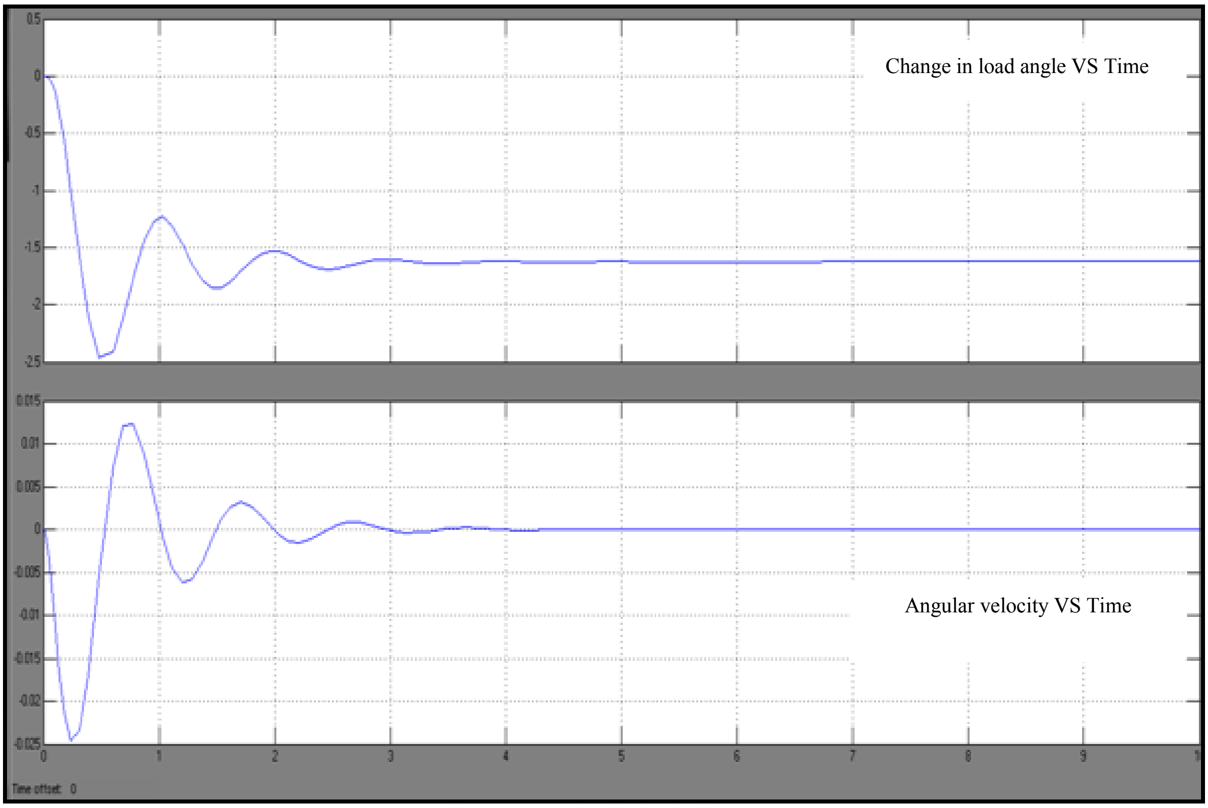

Figure 6.4 Results obtained with PSS

6.4 Implementation and Results with PID based PSS

A. Implementation with negative value of K_5

A PID based PSS contain Two blocks which include a washout block Followed by a PID controller block where the values have been put for the proportional, integral and derivative controller values by trial and error method, tunning or by zeigler Nicholas.

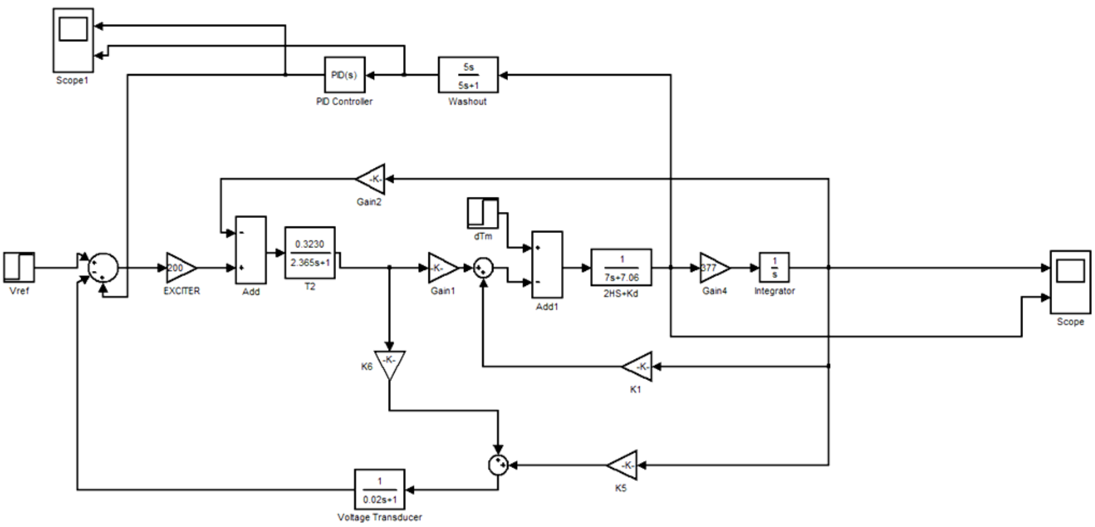

Figure 6.5 Simulink representing PID based PSS

B. Result with negative value of K_5

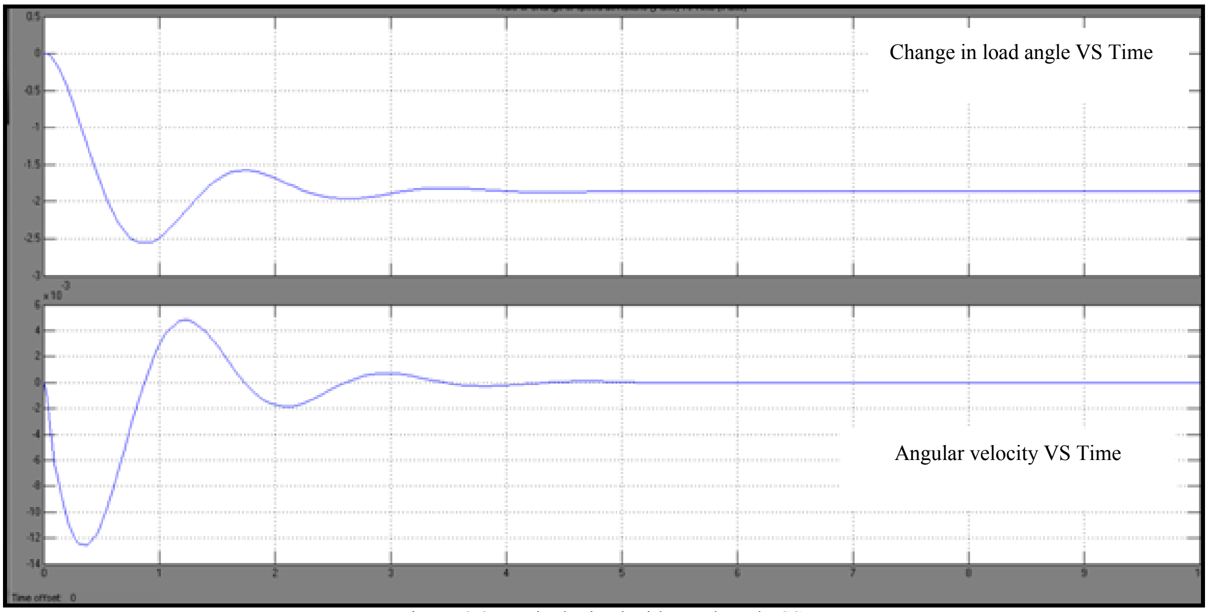

Figure 6.6 Result obtained with PID based PSS

6.5 Implementation and Results with Fuzzy Logic based PSS

A. Implementation with negative value of K_5

The following figure shows the system implementation of the control system required to produce the adequate damping. The values taken for gains are $K_{in1} = 2.491, K_{in2} = 2.491, K_{out} = 30.56$. The controller used is a Fuzzy Logic controller. The controller consists to three parts, namely, the normalizer blocks, the Fuzzy Logic Implementation block, and the proportional block.

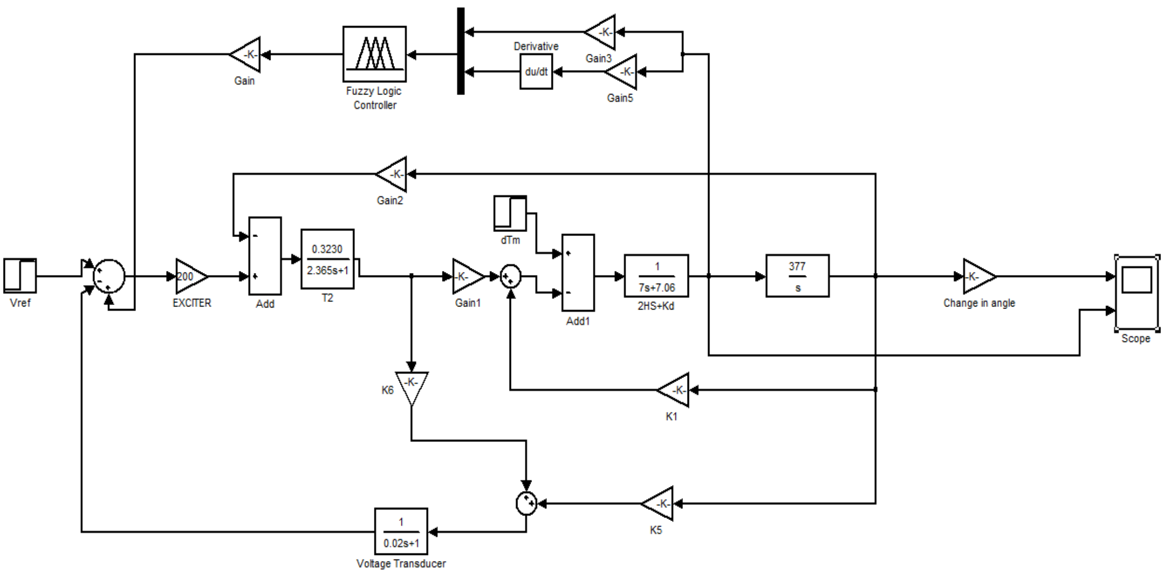

Figure 6.7 Simulink representing Fuzzy logic based PSS

B. Result with negative value of K_5

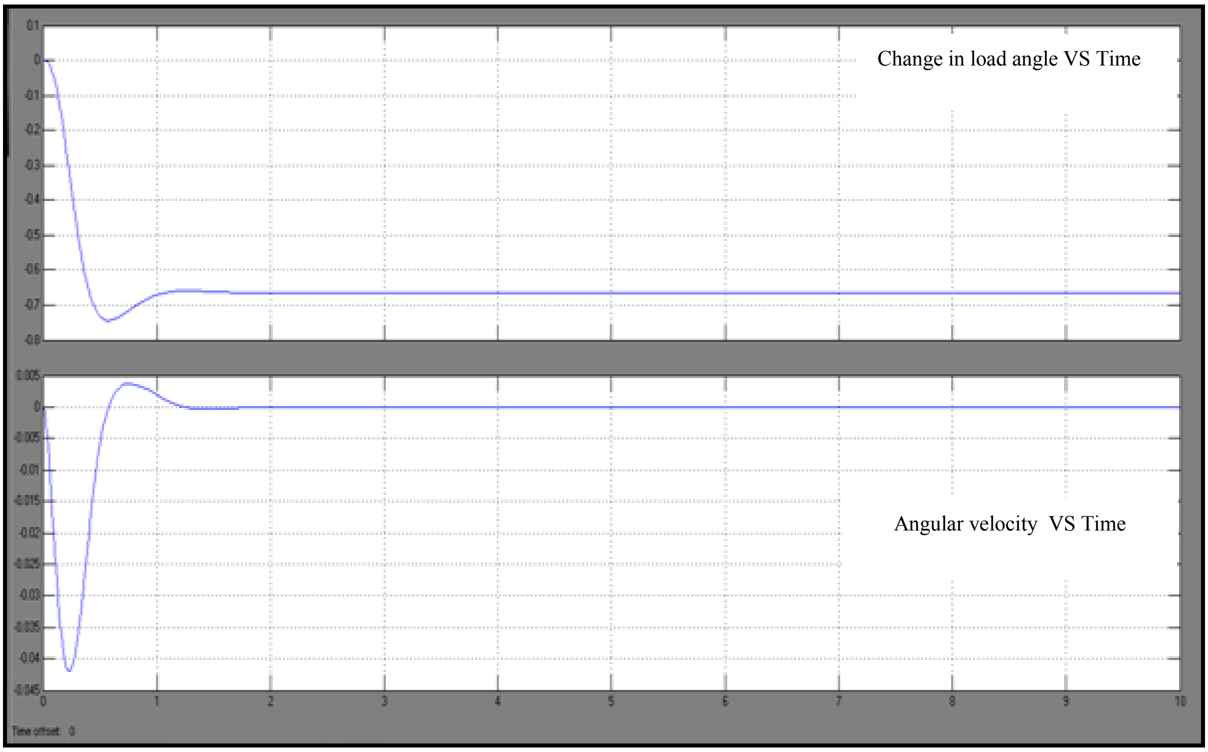

Figure 6.8 Results obtained with Fuzzy logic based PSS

6.6 Results obtained with all techniques for positive value of K_5

For Conventional PSS

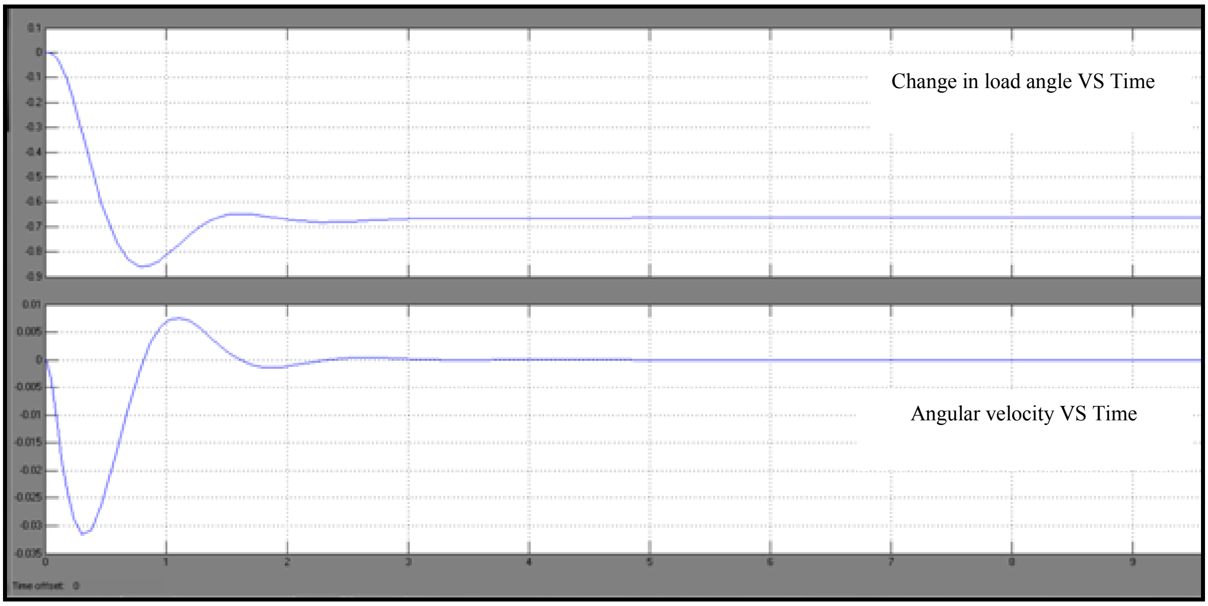

Figure 6.9 Result obtained with Conventional PSS

For PID based PSS

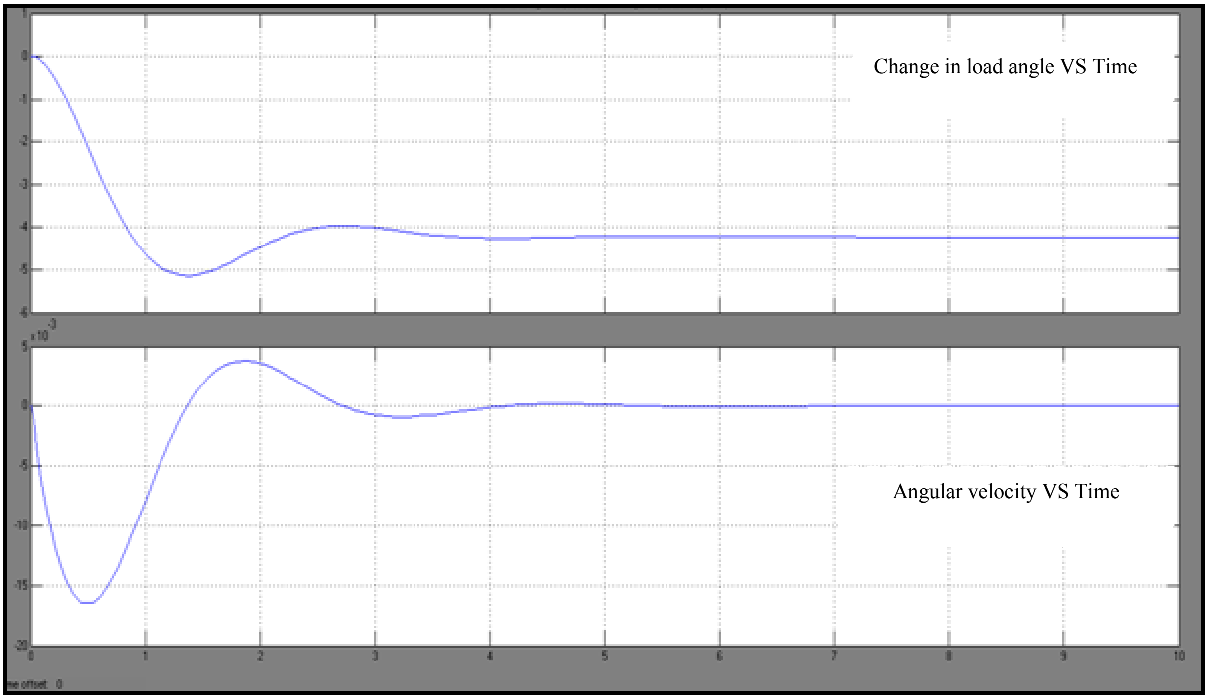

Figure 6.10 Result obtained with PID based PSS

For Fuzzy based PSS

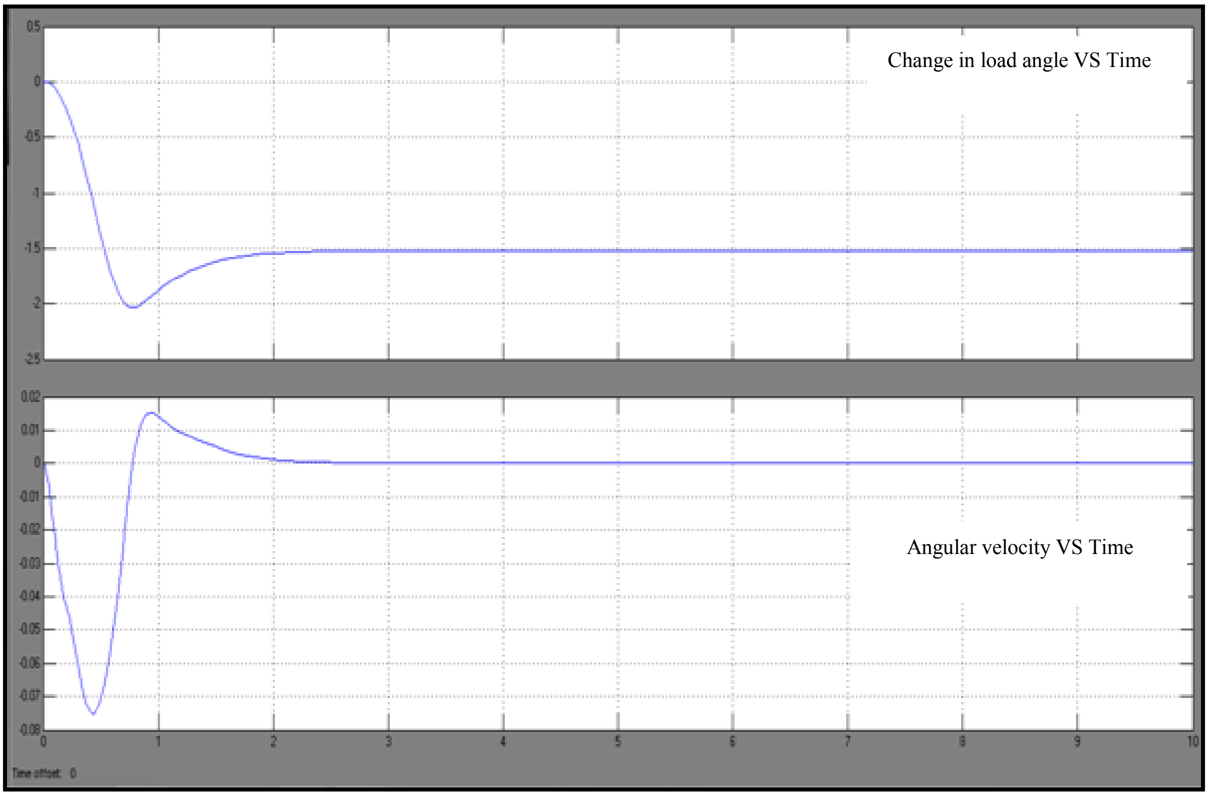

Figure 6.11 Result obtained with Fuzzy logic based PSS

6.7 Results obtained with different values of K_{Stab}

For $K_{Stab} = 30$

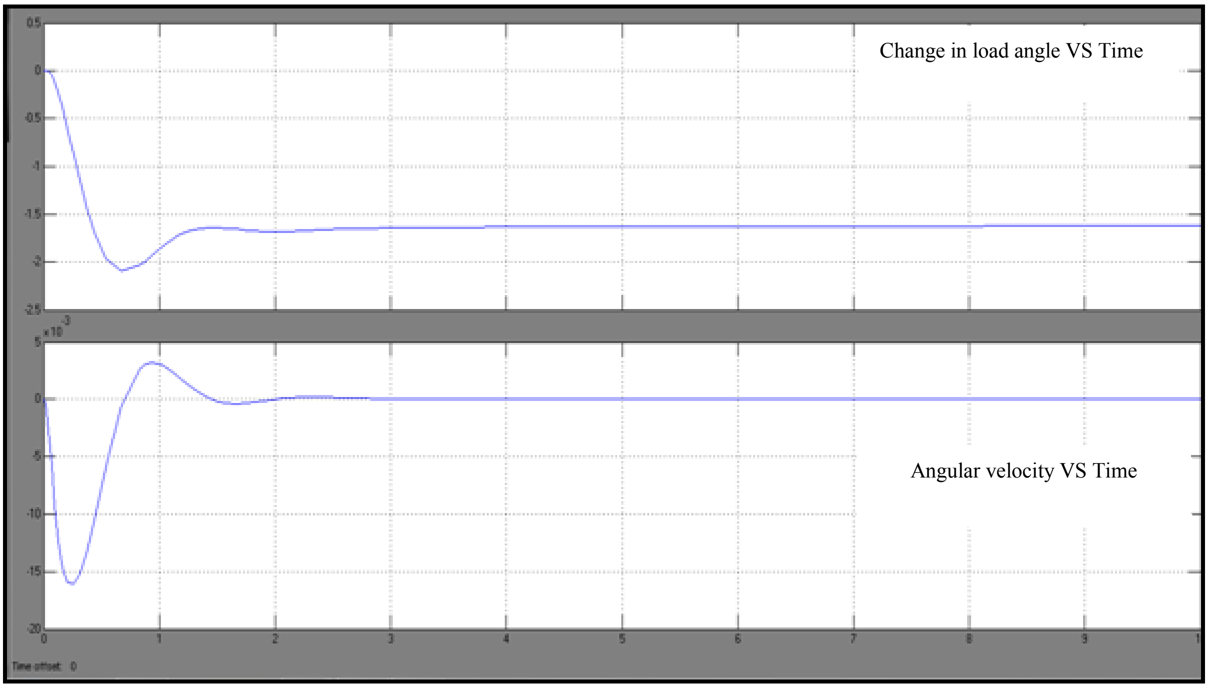

Figure 6.12 Result obtained for conventional PSS

For $K_{Stab} = 60$

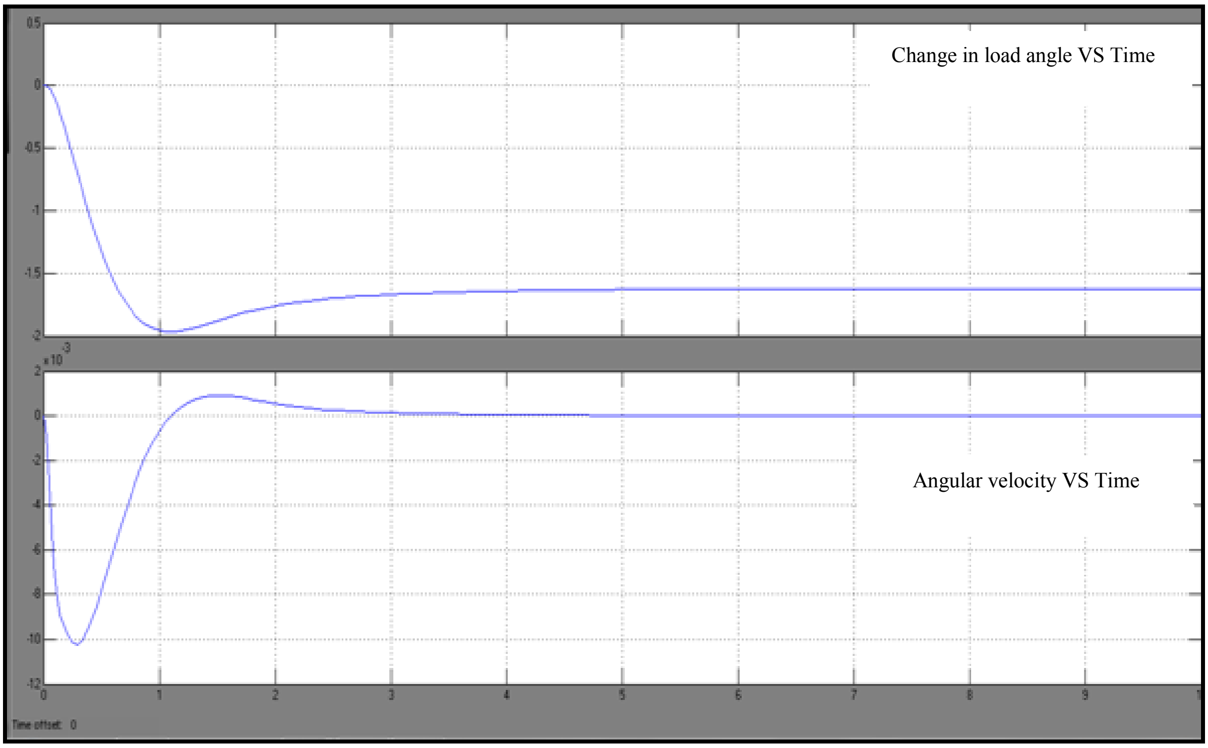

Figure 6.13 Result obtained for conventional PSS

For $K_{Stab} = 80$

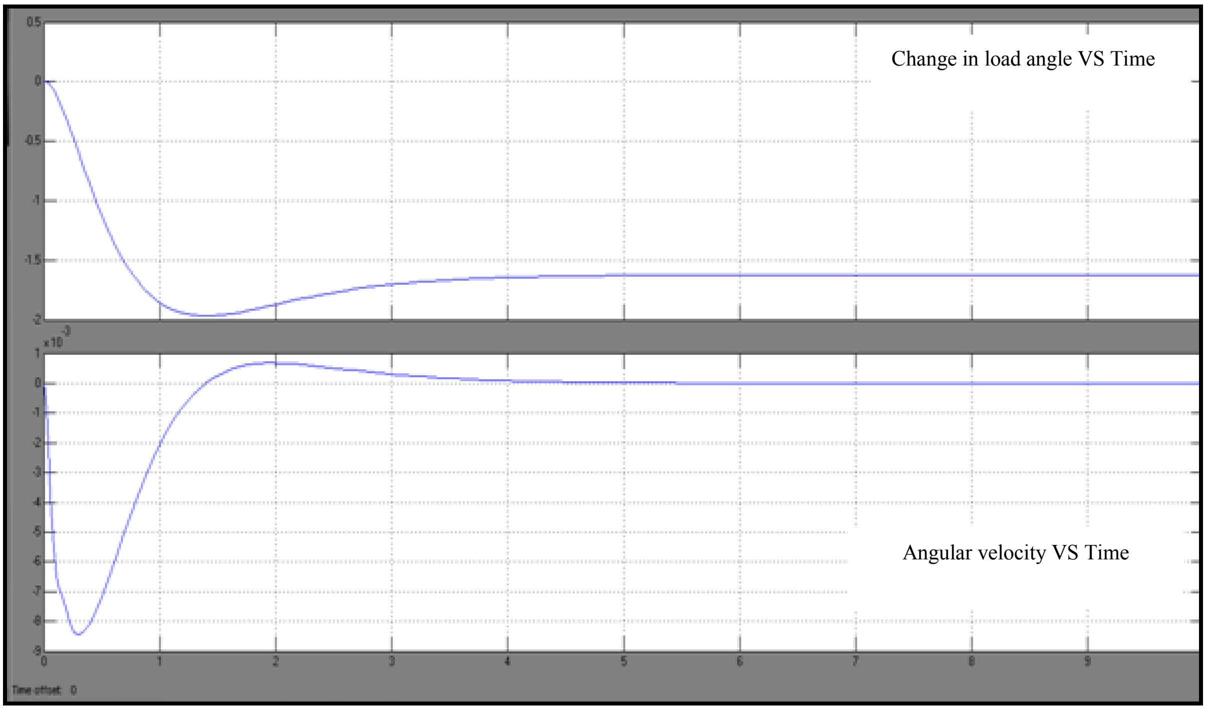

Figure 6.14 Result obtained for conventional PSS

For $K_{Stab} = 120$

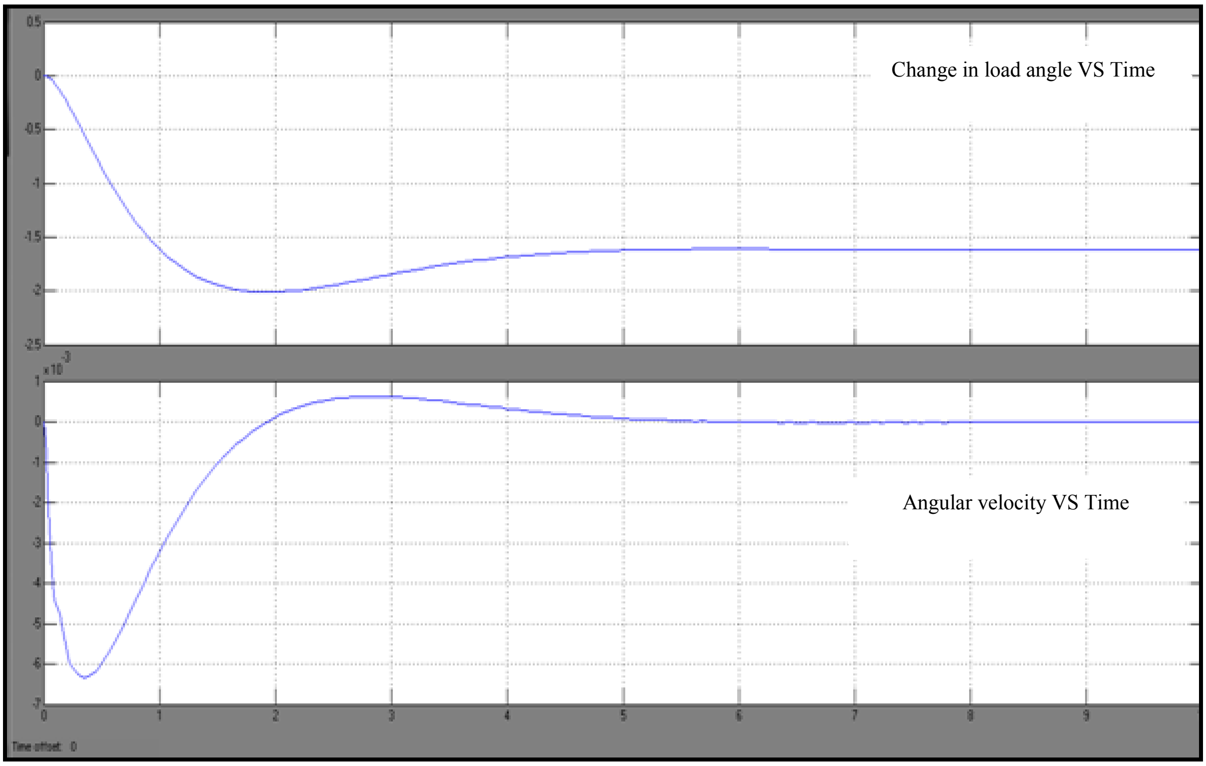

Figure 6.15 Result obtained for conventional PSS

6.8 Results obtained with K_D=0

For Conventional PSS

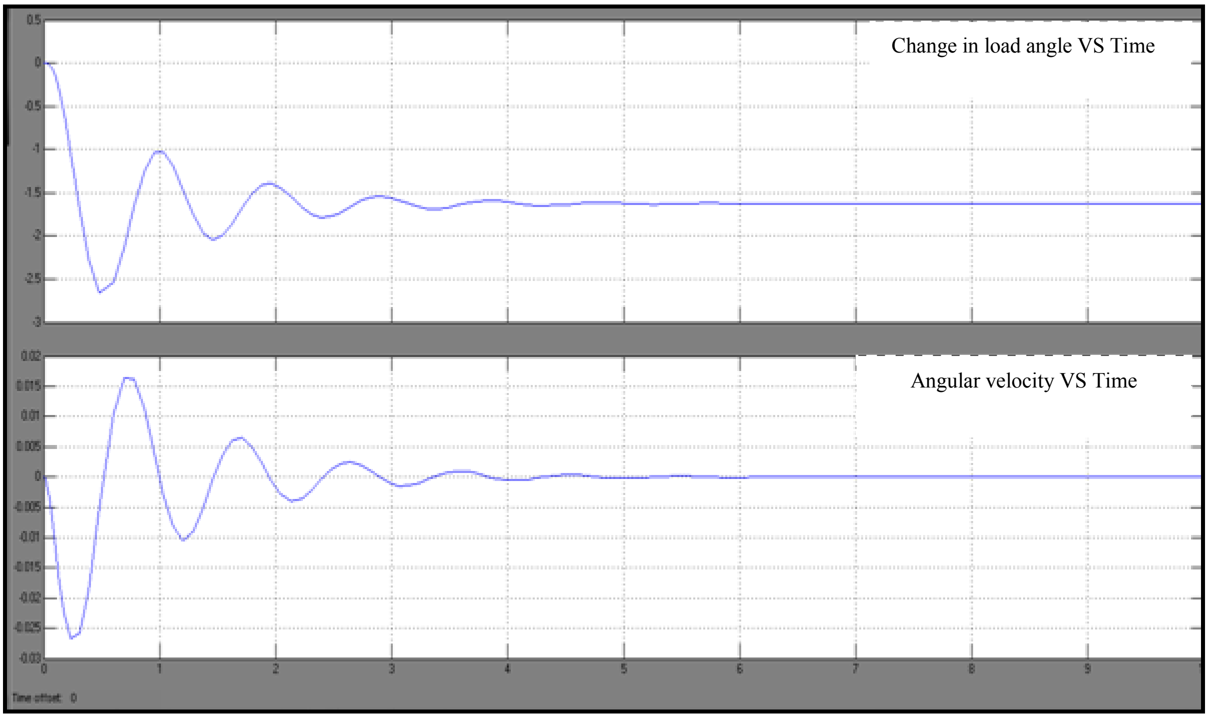

Figure 6.15 Result obtained for conventional PSS

For PID based PSS

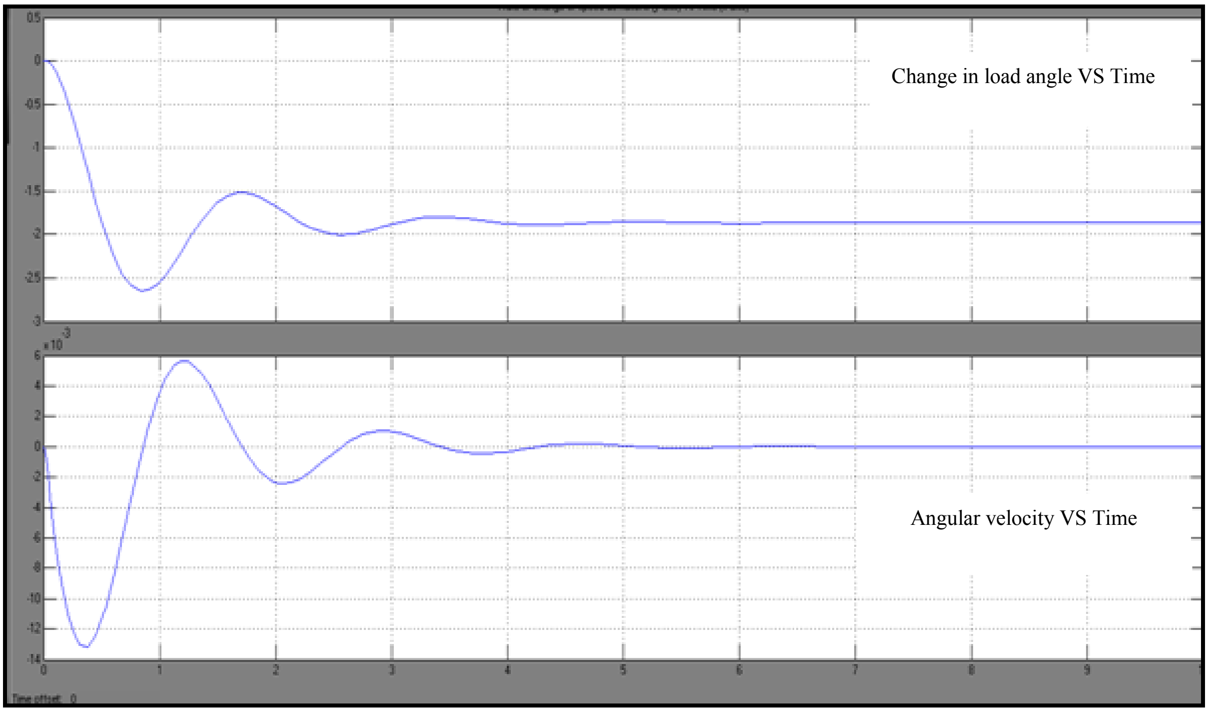

Figure 6.15 Result obtained for PID based PSS

For Fuzzy logic Based PSS

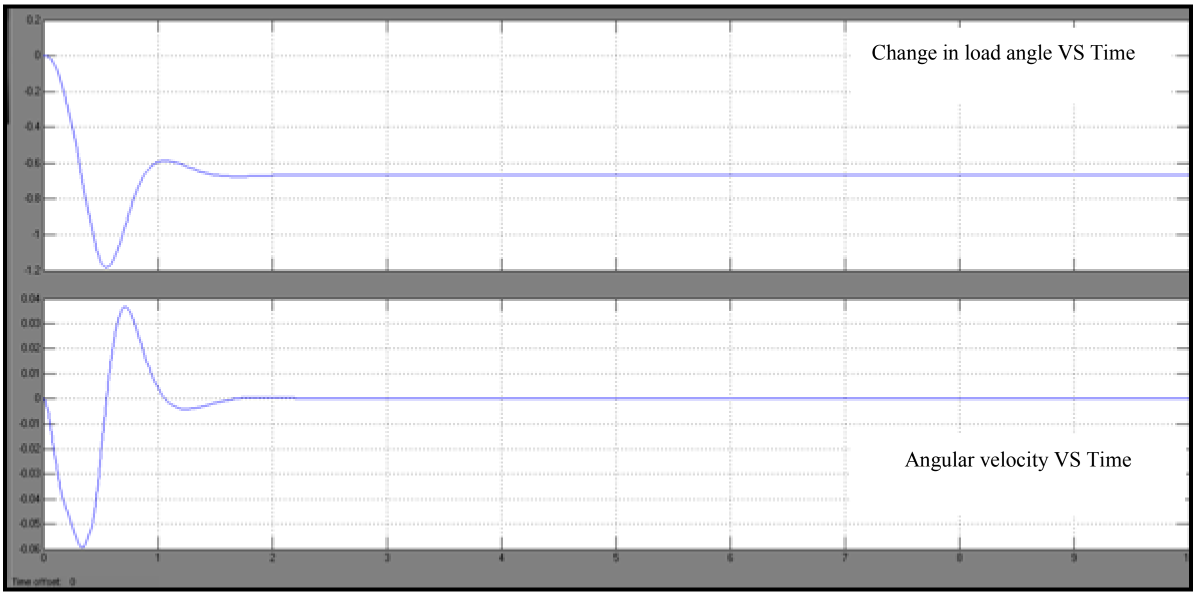

Figure 6.16 Result obtained for Fuzzy logic based PSS

6.9 Fuzzy logic based PSS with change in overlapping

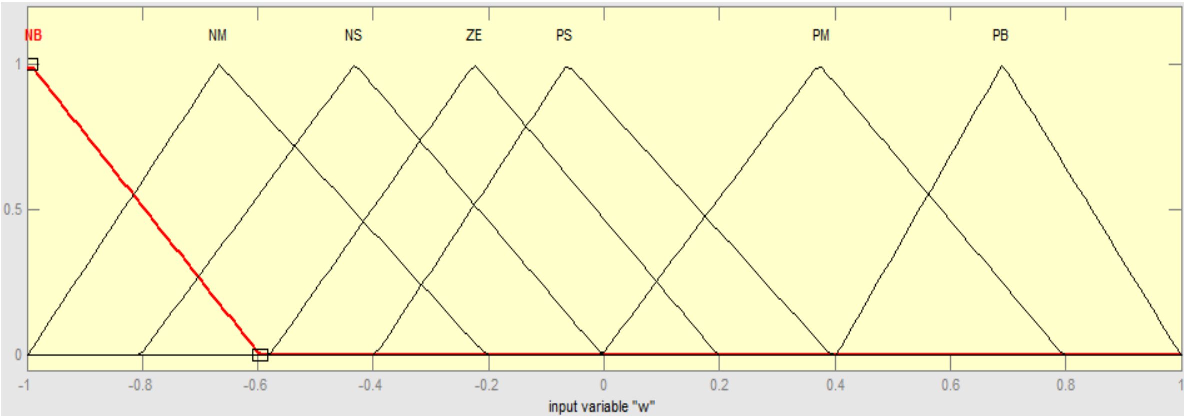

Figure 6.17 1nput 1- Angular velocity

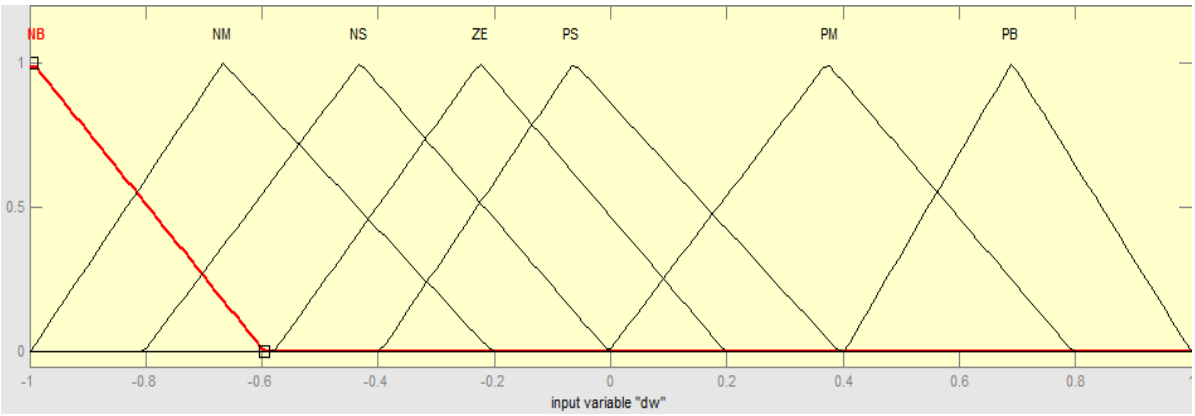

Figure 6.18 input 2-Angular velocity per unit time

The values taken for gains are $K_{in1} = 2.491, K_{in2} = 2.491, K_{out} = 30.56$ are:

Result Obtained –

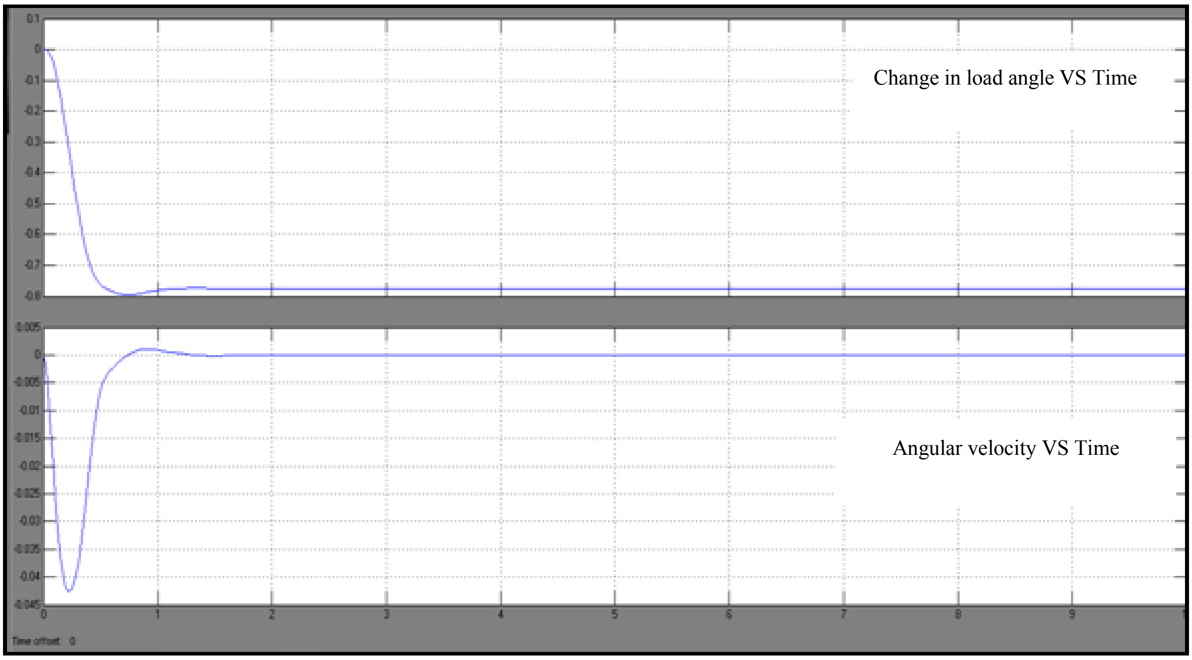

Figure 6.19 Result obtained for changed in overlapping of fuzzy membership function

6.10 Comparative analysis of different controllers

Hence after performing the simulation in simulink each result is compared to each other in terms of T_S = settling time (seconds) and T_p = peak time (seconds) in the form of a table given below.

Analysis of different controllers using negative value of K_5:

	With PSS (In seconds)	**PID-PSS** (In seconds)	**FUZZY PSS** (In seconds)	**FUZZY changed overlap** (In seconds)
T_s (change in load angle)	6.73	4.712	1.645	1.424
T_p (change in load angle)	0.48	0.811	0.575	0.695
T_s (Angular velocity)	4.03	5.119	1.74	1.576
T_p (Angular velocity)	0.24	0.348	0.23	0.223

Table 6.1

Analysis of different controllers using positive value of K_5:

	With PSS (In seconds)	PID-PSS (In seconds)	FUZZY PSS (In seconds)	FUZZY changed overlap (In seconds)
T_s (change in load angle)	4.845	7.187	2.317	2.348
T_p (change in load angle)	0.767	1.345	0.745	0.752
T_s (Angular velocity)	4.855	6.768	2.501	2.641
T_p (Angular velocity)	0.3022	0.423	0.413	0.423

Table 6.2

Analysis of PSS using different values of K_{Stab}:

	PSS with KStab=30 (In seconds)	PSS with KStab=60 (In seconds)	PSS with KStab=80 (In seconds)	PSS with KStab=120 (In seconds)
T_s (change in load angle)	8.198	4.975	4.843	8.197
T_p (change in load angle)	0.678	1.13	1.39	1.77
T_s(Angular velocity)	2.939	5.445	5.436	8.127
T_p (Angular velocity)	0.219	0.283	0.282	0.342

Table 6.3

Analysis of different controllers using $K_D = 0$:

	With PSS (In seconds)	PID-PSS (In seconds)	FUZZY PSS (In seconds)
T_s (change in load angle)	5.815	6.184	2
T_p (change in load angle)	0.492	0.824	0.5402
T_s(Angular velocity)	6.078	6.649	2.185
T_p (Angular velocity)	0.223	0.325	0.323

Table 6.4

1. While analyzing different controllers for negative value of K_5 it is observed that FLC with change in overlapping gives an outstanding result in both the cases i.e for change in load angle and Angular velocity in terms of settling time and peak time when compared to FLC with 50% overlapping of membership functions except in the case

for peak time of change in load angle. Also the damping effect of FLC was better than that of other controllers.

2. In the case positive value of K_5 FLC with 50% overlapping of membership function outstands every other controller both in the terms of settling time and peak time. It also provided sufficient damping when compared to PID-PSS and PSS.

3. While for different values of K_{stab} the PSS with the minimum value of K_{stab}= 30 performed better in terms of settling time and peak time except for settling time in the case of change in load angle which was approximately twice than that of the values for other controllers. The rest of the PSS with different values for K_{stab} could not perform well. The damping was better in case of Angular velocity only while it was better in case of change in load angle for K_{stab}= 80.

4. While taking K_D = 0 for all controllers it was observed that Fuzzy PSS had given better results in the case of settling time with adequate damping effect while PSS gave better result in the case for peak time for the same.

CHAPTER 7
CONCLUSIONS & SCOPE FOR FURTHER WORK

4.1 Conclusions

Based upon the implementation of the PSS using various techniques, and subsequent analysis of the performance of the algorithms at various conditions, it was observed that the Fuzzy algorithm outperformed the rest of the techniques by far. The improvement was observed in terms of both settling time, peak time as well as the damping induced. The settling time improvement over the rest of the two algorithms was significant, and sufficient damping was induced. The performance of the system with Conventional PSS and PID Controller wasn't satisfactory as the time taken to stabilize the system was large by a huge factor when compared to that of the Fuzzy Controller, and the damping wasn't sufficient.

Taking into consideration all the factors, it is concluded that the Fuzzy algorithm provided greatest amount of damping and stabilizes the system in the least amount of time, and hence safeguards the system against detrimental operating conditions.

4.2 Scope for Further Work

Although large enough damping was provided by the Fuzzy Controller, there is still a huge scope to boost the performance of the system by employing various algorithmic techniques. Such techniques should be directed at improving the damping to meet the objective of slashing the time required to stabilize the system. Some of the recently developed techniques that may help in achieving the objectives are:

A.) Genetic Algorithm

In the software engineering field of manmade brainpower, genetic algorithm (GA) is a hunt heuristic that mirrors the procedure of common advancement. This heuristic (additionally some of the time called a metaheuristic) is routinely used to create valuable answers for streamlining and hunt issues. Hereditary calculations have a place with the bigger class of evolutionary algorithms (EA), which create answers for improvement issues utilizing strategies propelled by common advancement, for example, inheritance, mutation, selection, and crossover.

B.) Fire-Fly Algorithms

The firefly algorithm (FA) is a metaheuristic algorithm, motivated by the blazing conduct of fireflies. The main role for a firefly's glimmer is to go about as a sign framework to draw in different fireflies. Xin-She Yang figured this firefly algorithm by expecting:

1. All fireflies are unisexual, so that one firefly will be pulled in to every single other firefly;

2. Allure is corresponding to their brilliance, and for any two fireflies, the less splendid one will be pulled in by (and consequently move to) the brighter one; in any case, the splendor can diminish as their separation increments;

3. On the off chance that there are no fireflies brighter than a given firefly, it will move randomly.

C.) ADAPTIVE NEURO FUZZY INFERENCE SYSTEM (ANFIS)

Adaptive neuro fuzzy inference system (ANFIS) is a kind of neural network that is based on Takagi-Sugeno fuzzy inference system. Since it integrates both neural networks and fuzzy logic principles, it has potential to capture the benefits of both in a single framework. Its inference system corresponds to a set of fuzzy IF-THEN rules that have learning capability to approximate nonlinear functions. Hence, ANFIS is considered to be universal estimator. It harnesses the abilities of both fuzzy logic and ANNs. The mathematical properties of ANNs are required for tuning rule based fuzzy systems which approximate the human's way of processing information. Adaptive Neuro-Fuzzy inference system (ANFIS) is a specific approach of Neuro-Fuzzy methodology. The ANFIS approach learns the rules and membership functions from data. ANFIS is an adaptive network. An adaptive network is network of nodes and directional links. Associated with the network is a learning rule - for example back propagation. It's called adaptive because some, or all, of the nodes have parameters which affect the output of the node. These networks are learning a relationship between inputs and outputs. Adaptive networks cover a number of different approaches but the best is proposed by Jang known as ANFIS.

D.) BACTERIAL FORAGING ALGORITHM (BFA)

Bacteria Foraging Optimization Algorithm (BFOA), proposed by Passino, is a new comer to the family of nature-inspired optimization algorithms. For over the last five decades, optimization algorithms like Genetic Algorithms (GAs), Evolutionary Programming (EP), Evolutionary Strategies (ES), which draw their inspiration from evolution and natural genetics, have been dominating the realm of optimization algorithms. Recently natural swarm inspired algorithms like Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) have found their way into this domain and proved their effectiveness. Following the same trend of swarm-based algorithms, Passino proposed the BFOA. Application of group foraging strategy of a swarm of E.coli bacteria in multi-optimal function optimization is the key idea of the new algorithm. Bacteria search for nutrients in a manner to maximize energy obtained per unit time. Individual bacterium also communicates with others by sending signals. A bacterium takes foraging decisions after considering two previous factors. The process, in which a bacterium moves by taking small steps while searching for nutrients, is called chemotaxis and key idea of BFOA is mimicking chemotactic movement of virtual bacteria in the problem search space. During foraging of there all bacteria, locomotion is achieved by a set of tensile flagella. Flagella help E.coli bacterium to tumble or swim, which are two basic operations performed by a bacterium at time of foraging. When they rotate the flagella in the clock wise direction, each flagellum pulls on the cell. That results in the moving of flagella independently and finally the bacterium tumbles with lesser number of tumbling whereas in a harmful place it tumbles frequently to find a nutrient gradient. Moving the flagella in the counterclockwise direction helps the bacterium to swim at a very fast rate. In the above-mentioned algorithm the bacteria undergoes chemotaxis, where they like to move towards a nutrient gradient and avoid noxious environment. Generally the bacteria move for a longer distance in a friendly environment. When they get food in sufficient, they are increased in length and in presence of suitable temperature they break in the middle to from an exact replica of itself. This phenomenon was inspired by Passino.

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