DEVELOPMENT OF POWER SYSTEM STABILIZER FOR SINGLE MACHINE INFINITE BUS (SMIB) USING GENETIC ALGORITHM

BY

ALIYU IBRAHIM USMAN

(SPS/16/MEE/00035)

M. ENG. ELECTRICAL

A DISSERTATION SUBMITTED TO THE DEPARTMENT OF ELECTRICAL ENGINEERING, BAYERO UNIVERSITY, KANO, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE MASTER OF ENGINEERING (M.ENG) (CONTROL AND INTRUMENTATION) DEGREE.

JANUARY, 2020

DECLARATION

I hereby declare that I carried out the work reported in this dissertation in the department of Electrical Engineering, Bayero University, Kano, under the supervision of Engr. Prof. NuraddeenMagaji. I also solemnly declare that to the best of my knowledge, no part of this dissertation has been submitted here or elsewhere in a previous application for award of a degree. All sources of knowledge used have been duly acknowledged.

Engr. Aliyu Ibrahim Usman

SPS/16/MEE/00035

CERTIFICATION

This is to certify that the dissertation entitled **"Development of Power System Stabilizer for Single Machine Infinite Bus (SMIB) using Genetic Algorithm"** submitted by Aliyu Ibrahim Usman **(SPS/16/MEE/00035)** in partial fulfillment of the requirement for Master degree (M.Eng) in Electrical Engineering (Control and Instrumentation), Bayero University Kano, Electrical Engineering Department, is an Authentic work carried out by me under my supervisor. To the best of my knowledge the matter embodied in the Dissertation has not been submitted to any other university/institute for the award of any degree or diploma.

Signature and date---

Supervisor: Engr. Prof. NuraddeenMagaji.

Signature and date--

Head of Department (H.O.D): Engr. Prof. NuraddeenMagaji.

APPROVAL

This dissertation has been examined and approved for the award of the degree of Master in Engineering (Electrical Control and Instrumentation).

Signature and Date --
External Examiner: Engr. Prof. M. B. Muazu

Signature and Date --
Internal Examiner: Engr. Prof. S. B. Ibrahim

Signature and Date --
Supervisor: Engr. Prof. NuraddeenMagaji

Signature and Date --
Head of department (H.O.D): Engr. Prof. NuraddeenMagaji.

Signature and Date --
SPS Representative: Dr. A.A. Adamu

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to the Almighty Allah who is above everything (Alhamdulillah) for giving me the health, strength and ability to accomplish this research work.

My thanks and sincere appreciation go to my supervisor and motivator Engr. Prof. NuraddeenMagaji, Electrical Engineering Department, Bayero University, Kano for his invaluable guidance and co-operation, and for providing the necessary facilities and sources during the entire period of this dissertation. The facilities and co-operation received from Engr. Dr. Hassan Bashir of the Electrical Engineering Department who was always there for me when needed is thankfully acknowledged. I also want to acknowledge the contribution of the entire staff of the Electrical Engineering Department Particularly my internal examiner, Engr. Prof. S. B. Ibrahim. I will like to thank the authors of various research articles and books that were referred to during the course of this Research.

Aliyu Ibrahim Usman

DEDICATION

This Research is dedicated to my late father Alhaji Ibrahim Usman and my late sister Fatima Ibrahim Usman may their souls rest in perfect peace ameen.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This study presents a development of Power System Stabilizer (PSS) design methodology for a single machine infinite bus system (SMIB). The power system oscillation is a major concern in power system stability. Power system stability is the ability to maintain a stationary state in an electrical system after a disturbance has occurred. This disturbance can for instance be loss of generation, change in power demand or faults on the line. The PSS introduces a signal that optimally results in damping electrical torque at the rotor. PSS is used to address such challenges in this dissertation. The SMIB system is the model used to analyze and tune the PSS controller to enhance the dynamic stability of the generator through the excitation control system. A dual input power system stabilizer (PSS4B) is designed and analyzed base on two inputs feedback signals, and its performance is compared with the conventional single input PSS (CPSS) over a wide range of operating conditions. The optimal parameters of both CPSS and PSS4B are obtained by minimizing the bode plot of the transient model of SMIB with help of genetic algorithm (GA). The proposed PSS is evaluated against the Conventional Power System Stabilizer (CPSS) at a SMIB considering system parametric uncertainties. Simulation results show that the proposed PSS provides a better performance in minimizing error by 22% than the conventionalPSS, in terms of settling time proposed PSS has contributed a better result with reduction of time from 5.6 second to 2.5 second as compared to CPSS.

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background

Energy is the basic necessity for the economic development of a country. Many present-day activities will grind to a halt when the supply of energy stops. It is practically complex to estimate the actual magnitude of the role that energy has played in the building up of present-day civilization.

The availability of huge amount of energy in the modern times has resulted in a shorter working day, higher agricultural and industrial production, a healthier and more balanced diet and better transportation facilities. As a matter of fact, there is a close relationship between the energy used per person and the standard of living. The greater the per capita consumption of energy in a country, the higher is the standard of living of its people[1]. Energy exists in different forms in nature but the most important form is the electrical energy. The modern society is so much dependent upon the use of electrical energy that has become a part and parcel of our life[2]. One of the most important stability problems arising from large scale electric power system interconnections is the low-frequency oscillations of interconnected systems [3].

The application of power system stabilizers (PSS) for improving dynamic stability of power systems and damping out the low frequency oscillations due to disturbances is used for many years. The conventional PSS (CPSS) comprising a cascade connected lead-lag network with rotor speed deviation as input has made great contribution in enhancing system stability. However, the performance of the CPSS becomes sub-optimal following variations in system parameters and loading conditions [1]. Power system is a highly nonlinear system and it is difficult to obtain exact mathematical model of the system. In recent years, adaptive self-tuning, variable structure, artificial neural network based PSS and fuzzy logic based PSS have been proposed to provide optimum damping to the system oscillations under wide variations in operating conditions and system parameters. PSS acts through the generator excitation system which produces a component of electrical torque according to the speed deviationin addition to the damping torque [4].

The requirement for improved damping has arisen from a number of factors, including the development of high speed excitation systems, the use of long high voltage transmission lines, and improvements in the cooling of turbo-alternators. The use of high-speed excitation systems has long been recognized as an effective method of increasing stability limits. Static excitation systems appear to offer the practical ultimate in high-speed performance thereby providing a gain in stability limits. Unfortunately, the high speed and gains that give them this capability also result in poor system damping under certain conditions of loading [5]. To offset this effect and to improve the system damping, stabilizing signals are introduced in the excitation systems through fixed parameters lead/lag PSSs [6].

The parameters of the PSS are normally fixed at certain values which are determined under a particular operating condition. It is important to recognize that Machine parameters change with loading, making the dynamic behavior of the machine quite different at different operating points [7]. So a set of PSS parameters that stabilizes the system under a certain operating condition may no longer yield good results when there is a change in the operating point. In daily operation of a power system, the operating condition changes as a result of load changes. The power system under various loading conditions can be considered as a finite number of plants[8]. The parameters of the PSS that can stabilize this set of plants can be determined using a genetic algorithm and an objective function based on the system eigenvalue.

As evident from the literature[9] that reviewed on PSO, SA and GA techniques, GA usually gives the best results based on the value for objective function, since its convergence is sure and asymptotic[9]. Genetic algorithms are used as parameter search techniques, which utilize the genetic operators to find near optimal solutions[10]. The advantage of the GA technique is that it is independent of the complexity of the performance index considered[8]. The PSS designed in this manner will perform well under various loading conditions and stability of the system is guaranteed. However, because of their simple structure, flexibility and ease of implementation, conventional PSS of the lead-Lag compensation type have been adopted by most utility companies[11]. But the performance of these stabilizers can be considerably degraded with the changes in the operating condition during normal operation. Since power systems are highly nonlinear, conventional fixed-parameter PSSs cannot cope with great changes in the operating conditions [12].

1.2 Motivation

Due to presents difficulties for designing theFlexible AC Transmission System (FACTS) controllers in that, the controllers designed to provide desired performance at small signal condition do not guarantee acceptable performance in the event of major disturbances [3]. Traditionally, for the small signal stability studies of a single-machine infinite-bus (SMIB) power system, the linear model of Phillips-Heffron has been used for years, providing reliable results [1]. A systematic procedure for optimal tuning of PSScontroller and simulation of a SMIB power system was presented where the MATLAB/SIMULINK based model was developed and Genetic Algorithm (GA) was employed to tun the PSS controller.It has also been successfully used for designing and tuning the classical power system stabilizers (PSS).

1.3 Significance of the Research

Improvement of power system stability can simply be achieved using PSS. This controller remain an engineer's preferred choice because of their structural simplicity, reliability, and the favorable ratio between performance and cost. Beyond these benefits, this controller also offer simplified dynamic modeling, lower user-skill requirements, and minimal development effort, which are issues of substantial importance to engineering practice [13]. In this research, a comparative study of the Genetic Algorithm based PSS controller design was presented

1.4 Problem Statement

The power system oscillation is a major concern in power system stability, and is usually addressed by several techniques that include addition of flexible alternating current transmission system(FACTS) devices and power system stabilizer (PSS). The later has attracted a lot of attention, where speed deviation are used as PSS input as in [1], [13], [14]… Dual inputs PSS has been used as remarked by [9] in this research, and an intelligent based power system stabilizer (Genetic algorithm based PSS) has been developed for the improvement of power system stability.

1.5 Aim and Objectives

The aim of this work is to develop a power system stabilizer for damping oscillations of SMIB based on genetic algorithm technique. This aim will be achieved through the following objectives:

1. To develop the transient model from the adapted SMIB model for tuning leading and lagging time constants of the PSS.
2. To find the optimal values of the PSS parameters (Time-constants)using Genetic Algorithm solver in the MATLAB Optimization Toolbox.
3. To perform dynamic performance analysis of the system with the proposed GA based power system stabilizer (GAPSS) over a wide range of operating conditions and to compare the performance of the proposed GAPSS with CPSS.
4. To validate the performance of the developed GAPSS with that of[1].

1.6 Scope

This research will deal with simulation based design approach of CPSS and GAPSS for power system stabilizer parameter tuning of an adopted single-machine infinite bus system.

1.7 Methodology

1. To develop the transient model from the adapted SMIB model for tuning leading and lagging time constants of the PSS, the following methods shall be applied:

a) For the purpose of PSS tuning, some modifications are made to the model of Figure 2.5, in order to make it suitable to analyze the phase compensation that the PSS should provide to the system.

b) To determine the phase shift, and to calculate the frequency response between the excitation system input and the electrical torque.

c) The block diagram of the modified model,(*Transient Model)*for system phase analysis is to be used for investigating the phase lag in the system.

d) Plot the Bode Diagram and calculate the phase margin and corresponding frequency.

2. To find the optimal values of the PSS parameters using Genetic Algorithm solver in the MATLAB Optimization Toolbox, the following method shall be applied:

a) The relationship between the phase and time-constant (Equation) is written in the MATLAB script and minimized using GA solver to find optimal value of Tn and Td.The step-by-step method employed in this dissertation for optimizing the time constants of the PSS using GA is as follows:

i). An initial population of 50 individuals is generated using a random number generator that uniformly distributes numbers in the desired range.

ii). Find the objective function value. The objective function considered for optimization of the time constants is as equation (1.1).

$$J = \int_0^t t\left[\Delta\omega(t)\right]^2 dt \qquad (1.1)$$

where, $\Delta\omega(t)$ is the speed deviation of theSynchronous generator for a given time step.

iii). If the value of J obtained is minimum, then set time constants equal to those obtained in the current generation otherwise proceed to step 4.

iv). Regenerate the 50 individuals from parents using reproduction techniques. Go to step2.

v). The optimal value ofJ is found after 15 consecutive generations.

3. To perform dynamic performance analysis of the system with the proposed GA based power system stabilizer (GAPSS) over a wide range of operating conditions and to compare the performance of the proposed GAPSS with CPSS, the following method shall be applied:

a) The Simulink model of the system is simulated when single or dual inputs PSS is used and when the system has been perturbed with different signals. The results and the corresponding comparative response of both proposed GAPSS and CPSS is plotted using MATLAB commands as well as the performances of both.

4. To validate the performance of the developed GAPSS with that of [1], the following method shall be applied:

a) [1]is developed using method 1. Above. The result is compared with proposed technique and was found to be very similar.

Details of this methodology is presented in subsection 3.3.1.

Figure 1.1 [5] shows the Flow chart for Tuning PSS Parameter using Genetic Algorithm

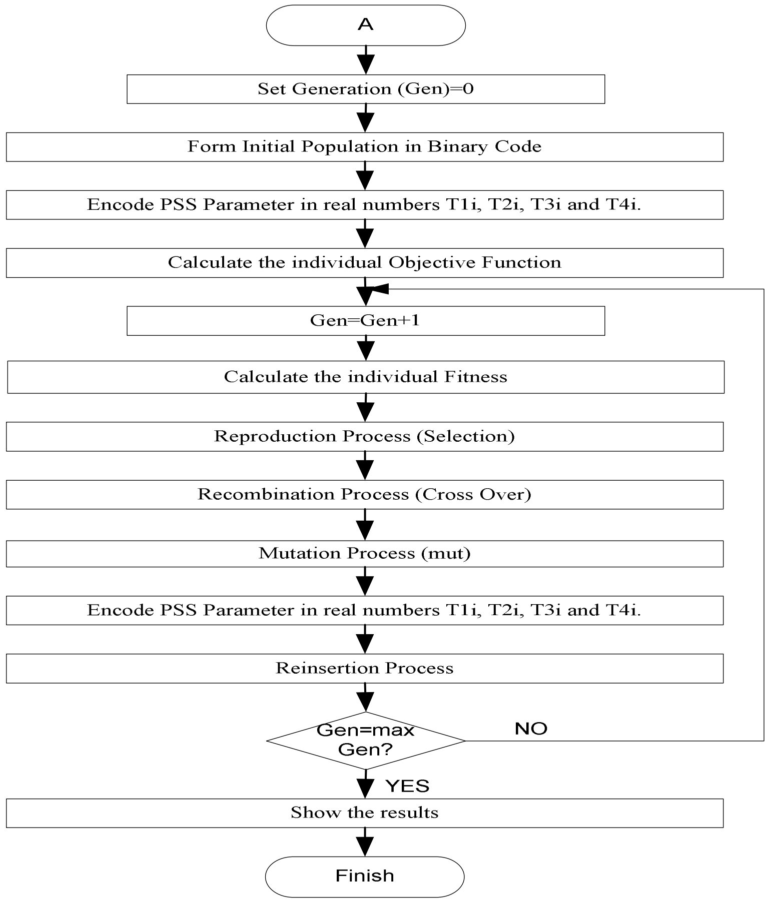

Figure 1.1: Flow chart for Tuning PSS Parameter using Genetic Algorithm [5]

1.8 Report Organization

The report is organized as follows: chapter one covers general introduction, problem statement, aim and objectives, scope, methodology and report organization. Chapter two presents the review of related works and theoretical background of the important components of the research, and chapter three covers the design of PSS using both proposed technique and conventional approach. Chapter four presents the results and its discussions. Finally, the conclusion, contribution andrecommendations for further study were presented in chapter five.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The literature review is categorized into two sections, the review of fundamental concepts (research works) and the review of similar works which include review of some related journals, conference proceedings and books.

2.1 Review of Fundamental Concepts

In this section, various theoretical frame works and concepts relevant to this research, which include Electric power systems, power system stabilizers as well as techniques used for their design are highlighted.

2.1.1 Electric power systems

The electric power system is one of the largest and most complexinfrastructures and it is critical to the operation of society and other infrastructures. The power system is undergoing deep changes which result in new monitoring and control challenges in its own operation, and in unprecedented coupling with other infrastructures, in particular communications and the other energy grids[15].

Power systems have been operating for years using the same fundamental principles. Technology has, so far, allowed an improvement of their performance, but it has not revolutionized the basic principles[15]. One fundamental law of physics has been driving the process: because the electrical grid has (nearly) no structural way to store energy, it is necessary that at every instant the amount of power generated to be equal to the power absorbed by the loads[16]. In fact, some energy is naturally stored in the inertia of large generators. This is enough to compensate for small unbalances, which continuously occur and cause small variations of frequency and voltage (remaining within rather restrictive limits). Beyond these, violation of balance leads to voltage perturbation, large frequency variations, and electromechanical oscillations. If corrective measures are not applied in a timely manner, the system may collapse, resulting in widespread blackouts. In this context, automation is the way to determine and actuate these measures via the control of the generators[15].

The loads are predictable only in a statistical sense, hence the automation is designed following a demand-driven approach. Based on the prediction of the load, the bulk of generation is scheduled[17]. At run-time, unexpected deviations are actively compensated, reaching the due balance of generation and demand. Such a principle works very well under some clear assumptions:

a) Generation is controllable and predictable, so that the correction in the power balance can always be applied to the generation side of the balance
b) Generation is concentrated as much as possible in large plants, simplifying the problem of scheduling[18].

The conversion of energy available in different forms in nature into electrical energy is known as generation of electrical energy[19].Energy is available in various forms from different natural sources such as pressure head of water, chemical energy of fuels, nuclear energy of radioactive substances etc. All these forms of energy can be converted into electrical energy by the use of suitable arrangements. The arrangement essentially employs (see Figure. 2.1) [1], an alternator coupled to a prime mover. The prime mover is driven by the energy obtained from various sources.

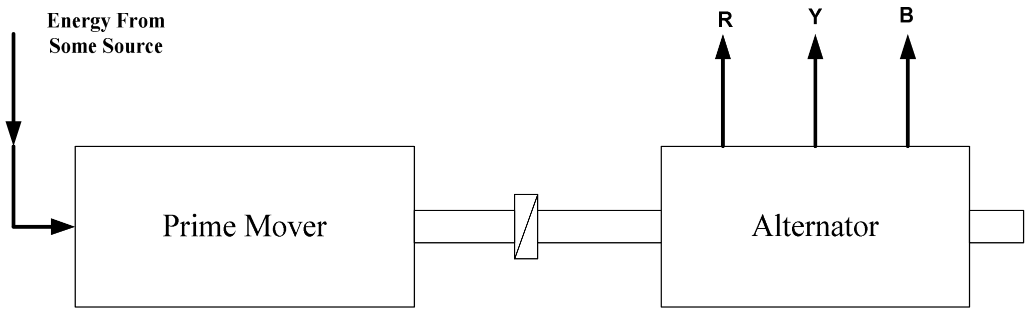

Figure 2.1: Power Plant [1]

2.1.2 Single Machine Infinite Bus (SMIB) System

The model which was used for the design of the final PSS consists of a "single-machine infinite bus". It consists of a single generator that delivers electrical power P_e to the infinite bus. It has been modeled taking into consideration sub transient effects[3]. The schematic diagram of the model is shown in Figure 2.2 [4].

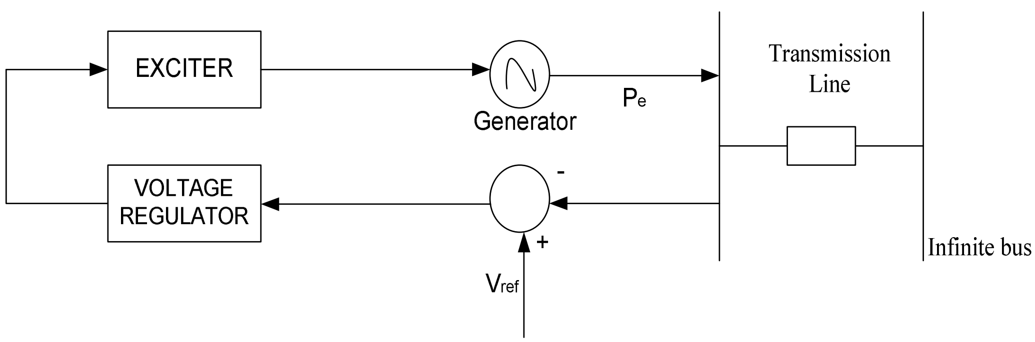

Figure 2.2: Excitation System Control Model [4]

A single machine infinite bus (SMIB) system with synchronous generator provided with IEEE Type-ST1 static excitation system is considered (Fig.2.3) [15]. The synchronous machine is connected to the infinite bus through a transmission system represented by a transformer and a line with reactances and resistancesX_t, X_L, R_t and R_L respectively)[13].

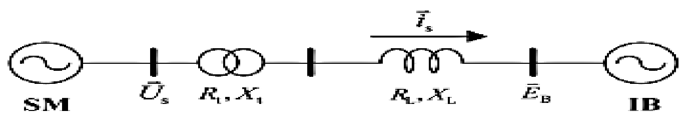

Figure 2.3: Diagram of the Single Machine Infinite Bus System [15]

The SMIB system can be considered as a theoretical simple system that allows the study of electromechanical interaction between a single generator and the power system [20]. The SMIB system model is also the basis to analyze and to tune the PSS controller to enhance the dynamic stability of the generator through the excitation control system. The linearized model will be a suitable model for PSS tuning while the complete one will allow testing the results reached fromthe PSS tuning process and from the application of other control structures to damp power oscillations in the power system[21].

The single machine infinite bus (SMIB) is described by Heffron- Philips model. The relations in the block diagram when using derivative power stabilizer is shown in Figure 2.4 [15] applied to two-axis machine representation with a field circuit in the direct axis but without damper windings. The interaction between the speed and voltage control of the machine is expressed in terms of six constants K1-K6 as seen in Figure 2.4. These constants with the exception of K3 which is only a function of the ratio of the impedance, depend on the actual real and reactive power loading as well as the excitation system in the machine [22].

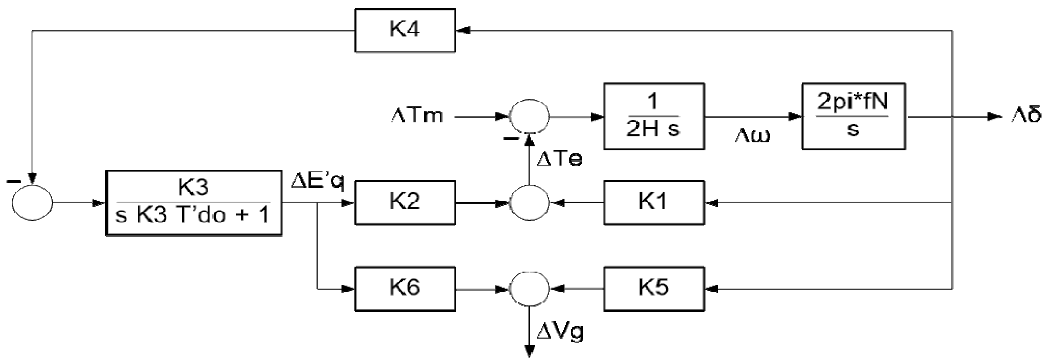

Figure 2.4:Heffron- Philips model of a Single Machine Infinite Bus [15]

2.1.3 Power System Stabilizers

Power System Stabilizer (PSS) is a device that improves the damping of the generator electromechanical oscillations[3].PSS is a feedback controller, part of the control system for a synchronous generator, which act through the excitation system, adding a signal to modulate the field voltage[22].The main reason for implementing PSS in the voltage regulator is to improve the small signal stability properties of the system.When the generator was operated at a high load and connected to a weak external grid, the voltage regulator created a negative damping torque and gave rise to oscillations and instability. An external stabilizing signal was therefore introduced as an input to the voltage regulator. This signal improved the damping of the rotor oscillations and the device was called power system stabilizer (PSS). The PSS introduces a signal that optimally results in damping electrical torque at the rotor. This torque acts opposite of the rotor speed [23].

One of the several methods to stabilize power system oscillation is to use a single input PSS through the generator's excitation system. In real world practical applications, the PSS has been a very effective device for improving generator's oscillation.

Conventional PSS is designed using single generator connected to infinite bus system, andit is tuned for the local mode whose frequency is around 1.0-2.0Hz. Moreover, when designing the PSS, only one operating condition is considered. The inter-area mode is a complex phenomenon which arises from all of the generator dynamics. Therefore, the conventional PSS must be improved to be a more robust controller. In order to improve the performance of PSSs, numerous techniques have been proposed for designing them[24].

The theoretical basis for a PSS may be illustrated with the aid of the block diagram shown in Figure 2.5 [21]. This is an extension of the block diagram of Figure 2.4 and includes the effect of a PSS.

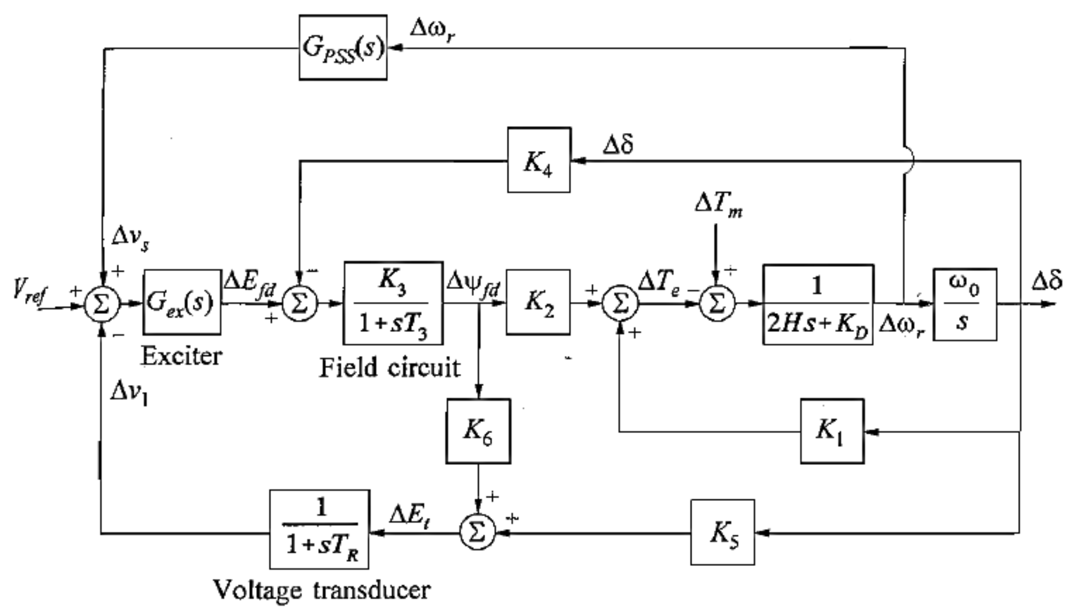

Figure 2.5: Block Diagram Representation SMIB with A VR and PSS [21]

where T_R and T_3 are the time constants of the voltage transducer and field circuit respectively.

Since T_R is very small in comparison to T_3, its effect will be neglected in examining the PSS performance. This simplifies the analysis without loss of accuracy.From the block diagram of Figure 2.5, with T_R neglected, $\Delta\psi_{fd}$ due to PSS is given by

$$\Delta\psi_{fd} = \frac{K_3 K_A}{1+sT_3}\left(-K_6 \Delta\psi_{fd} + \Delta v_s\right) \tag{2.1}$$

$$\frac{\Delta\psi_{fd}}{\Delta v_s} = \frac{K_3 K_A}{sT_3 + 1 + K_3 K_6 K_A} \tag{2.2}$$

Substituting the values of the constants equation (2.2) becomes

$$\frac{\Delta\psi_{fd}}{\Delta v_s} = \frac{1.5 \times 66.66}{21 + j1.91} \tag{2.3}$$

$$\Delta T_{pss} = \Delta T_e \text{ due to PSS} = K_2 \ (\Delta\psi_{fd} \text{ due to PSS})$$

Therefore, at a frequency of 10 rad/s,

$$\frac{\Delta\psi_{fd}}{\Delta v_s} = \frac{1.5 \times 66.66}{21 + j19.1} \tag{2.4}$$

Discussions of Different Parts of the Model

1. Reference voltage **(**V_{ref}**)** signal is a step voltage of 0.1 V. the final aim is to maintain the voltage at a constant level without oscillations.

2. Voltage regulator (AVR**)** - The excitation of the alternator can be controlled by varying the main exciter output voltage which is controlled by the AVR. The actual AVR contains:

1. Power magnetic amplifier
2. Voltage correctors
3. Bias circuit
4. Feedback circuit
5. Matching circuit etc.

3. Power System Model

A state space model of the power system having 7 state variables, an input and 3 output variables for single machine was adopted.

4. Washout Filter

The output $\Delta\omega$ is fed back through a sign inverter to the washout filter which is a high pass filter having a dc gain of 10. In the simulation, the filter is represented as a transfer function of equation.

$$\mathrm{F}(s) = \frac{10s}{10s+1} \tag{2.5}$$

5. Torsional Filter

This block filters out the high frequency oscillations due to the torsional interactions of the alternator. In the simulation, the transfer function model of this filter was taken.

$$Tor(s) = \frac{1}{1+0.06\mathrm{s}+0.0017s^2} \tag{2.6}$$

The parameters to be optimized using GA in the PSS design problem are PSS gain ($K_{STAB}i$) chosen as 9.8 and phase compensator time constants T_{1i}, T_{2i}, T_{3i} and T_{4i}. 10 is chosen as T_{wi} in order to ensure that the phase-shift and gain contributed by the wash-out block, for the range of oscillation frequencies normally encountered (0.1 to 2.0Hz) is negligible. A low value of 0.0120 s is chosen for both T_{2i} and T_{4i} from the consideration of physical realization. Considering two identical cascade connected phase lead compensator networks for the PSS, i.e. T_{1i} and T_{3i} equal to0.033 both as presented in Table 3.2, the problem reduces to optimization of K_{STAB} and T_{1i} for each generator in the system considered. Thus, the optimization problem to be solved using GA is formulated as follows:

Minimization of the integral of sum of the squares of the speed deviation signal $\Delta\omega$ is considered as the objective function as in (1.1). The objective function J is minimized considering the following ranges of parameters over which the search process is carried out

Where,

iis PSS number,K_{STABi} is stabilizer gain, T_{wi} is washout time constant, T_{1i} T_{2i} T_{3i} T_{4i} are time constants of the lead lag networks. A stabilizer is designed by suitable selection of time constants T_{wi}, T_{1i}, T_{2i}, T_{3i}, $T_{4i}$and the stabilizer gain K_{STABi}.

The basic function of a power system stabilizer (PSS) is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal(s). To provide damping, the stabilizer must produce a component of electrical torque in phase with the rotor speed deviations.

2.1.3.1 Conventional Power system Stabilize

The Conventional Power System Stabilizer (CPSS) block can be used to add damping to the rotor oscillations of the synchronous machine by controlling its excitation [11]. The disturbances occurring in a power system induce electromechanical oscillations of the electrical generators. These oscillations also called power swings must be effectively damped to maintain the system stability [12]. The output signal of the PSS is used as an additional input (v_{pss}) to the Excitation System. The PSS input signal can be either the machine speed deviation, Δω or its acceleration power [13].

The PSS is modeled by the following nonlinear system (Figure2.6) [23]. The model consists of a low-pass filter, a general gain, a washout high-pass filter, a phase-compensation system and an output limiter [14]. The general gain K determines the amount of damping produced by the stabilizer. The washout high-pass filter eliminates low frequencies that are present in the $\Delta\omega$ signal and allows the PSS to respond only to speed changes. The phase- compensation system is represented by a cascade of two first-order lead-lag transfer functions used to compensate the phase lag between the excitation voltage and the electrical torque of the synchronous machine.

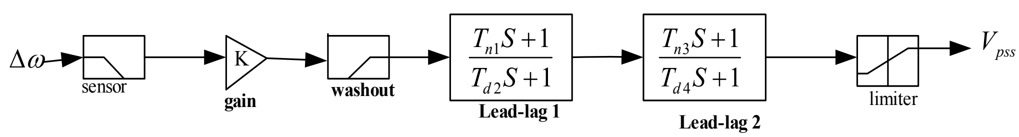

Figure 2.6: Conventional Power System Stabilizer[23]

2.1.3.2 Dual input power system stabilizer (PSS4B)

The $\Delta p + \Delta\omega$ input PSS is shown in Figure 2.7 [23]. Δp and $\Delta\omega$ are generator's local signals which are used as the PSS input. The Δp input PSS and the $\Delta\omega$ input PSS work mainly for local and inter-area oscillation mode [16], respectively. If Δp input PSS and $\Delta\omega$ input PSS are optimized independently and are combined for use as $\Delta p + \Delta\omega$ input PSS, an unexpected unstable oscillation mode may occur [17]. In the proposed method, the parameters of the $\Delta p + \Delta\omega$ input PSS are optimized all together.

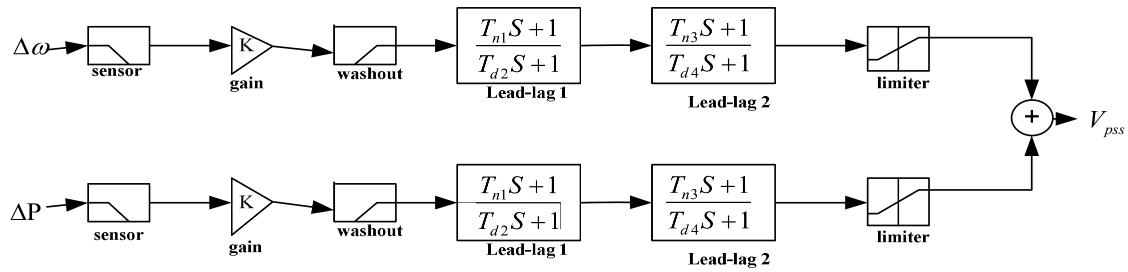

Figure 2.7: Dual Input Power System Stabilizer[23]

2.1.3.3 Categories of PSS Structures

PSS are categorized base on their number of inputs as listed below:

(i) One input PSS

(ii) Two input PSS

(iii) Three dimension PSS

(iv) Multi-band PSS

The input signal for the PSSs in the system is also a point of debate. The signals that have been identified as valuable include deviations in the rotor speed, the frequency, the electrical power and the accelerating power. Since the main action of the PSS is to control the rotor oscillations, the input signal of rotor speed has been the most frequently used in the literature [6]. Controllers based on speed deviation would ideally use a differential-type of regulation and a high gain[25]. Since this is impractical in reality, the previously mentioned lead-lag structure is commonly used[6]. However, one of the limitations of the speedinput PSS is that it may excite torsional oscillatory modes [8]. A power/speed PSS design was proposed as a solution to the torsional interaction problem suffered by the speed-input PSS [10].

The power signal used is the generator electrical power, which has high torsional attenuation. Due to this, the gain of the PSS may be increased without the resultant loss of stability, which leads to greater oscillation damping [11]. A frequency-input controller has been investigated as well. However, it has been found that frequency is highly sensitive to the strength of the transmission system that is, more sensitive when the system is weaker - which may offset the controller action on the electrical torque of the machine [12]. Other limitations include the presence of sudden phase shifts following rapid transients and large signal noise induced by industrial loads [11]. On the other hand, the frequency signal is more sensitive to inter-area oscillations than the speed signal, and may contribute to better oscillation attenuation [6].Some commonly used PSS structures are:

2.1.4 Genetic algorithm

In this study, GA Method is considered for tuning the proposed PSS. Genetic Algorithms (GA) are global search techniques based on the operations observed in natural selection in Genetics. They operate on a population of current approximations of the individuals initially drawn at random from which improvement is sought [16]. Individuals are encoded as strings (Chromosomes) constructed over some particular alphabet, e.g., the binary alphabet {0,1}, so that chromosomes values are uniquely mapped onto the decision variable domain. Once the decision variable domain representation of the current population is calculated, individual performance is assured according to the objective function which characterizes the problem to be solved [18]. It is also possible to use the variable parameters directly to represent the chromosomes in the GA solution. At the reproduction stage, a fitness value is derived from the raw individual performance measure given by the objective function and used to bias the selection process.

Highly fit individuals will have increasing opportunities to pass on genetically important material to successive generations. In this way, the genetic algorithms search from many points in the search space at once and yet continually narrow the focus of the search to the areas of the observed best performance. The selected individuals are then modified through the application of genetic operators [7]. In order to obtain the next generation, genetic operators manipulate the characters (genes) that constitute the chromosomes directly following the assumption that certain genes code on average for fitter individuals than other genes. Genetic operators can be divided into three main categories: Reproduction, crossover and mutation [26].

2.1.4.1 Working mechanism of GA

In nature, a combination of natural selection and procreation permits the development of living species that are highly adapted to their environments. GA is an algorithm that operates on a similar principle. When applied to a problem the standard genetic algorithm proceeds as follows: an initial population of individuals (represented by chromosomes) ‘n’ is generated at random. At every evolutionary step, called as generation, the individuals in the current population are decoded and evaluated according to predefined quality criterion referred to as fitness function. To form a new population (next generation), individuals are selected according to their fitness. Then some or all of the existing members of the current solution pool are replaced with the newly created members. Creation of new members is done by crossover and mutation operators.

a) Selection: According to Darwin's evolution theory the best ones should survive and create new offspring. There are many methods to select the best chromosomes, for example roulette wheel selection, rank selection, steady state selection etc. Roulette wheel selection method has been used in this work to select the chromosomes for crossover because of its simplicity and also the fitness values do not differ very much in this work.

Roulette wheel selection: Parents are selected according to their fitness. The better the chromosomes are, the more chances to be selected they have. A roulette wheel (pie-chart) is considered where all chromosomes in the population are placed according to their normalized fitness. Then a random number is generated which decides the chromosome to be selected

b) Crossover: The main operator working on the parents is crossover, which happens for a selected pair with a crossover probability (pc). Crossover takes two individuals and cuts their chromosome strings at some randomly chosen position, to produce two "head" segments and two "tail" segments. The tail segments are then swapped over to produce two new full-length chromosomes. As a result the two offspring each inherit some genes from each parent. Crossover is not usually applied to all pairs of individuals selected for mating. A random choice is made, where the likelihood of crossover being applied is typically between 0.6 and 1.0. If the crossover is not applied, offspring are produced simply by duplicating the parents. The crossover operation performed on two parents 'A' and 'B' is given below

*Parent A*0 0 **0 0 0 1 0 1**

Parent B **1 1** 1 0 1 0 0 1

Child A 0 0 1 0 1 0 0 1

Child B **1 1 0 0 0 1 0 1**

c) Mutation: Mutation is applied to each child individually after crossover. It randomly alters each gene with a small probability (pm). Mutation provides a small amount of random search and helps ensure that no point in the search space has a zero probability of being examined. The mutation operation performed on two child strings obtained after crossover operation is given below.

Child A 0 1 **0** 1 1

New Child A 0 1 **1** 1 1

These three operators are applied repeatedly until the off springs take over the entire population. When new solution of strings is produced, they are considered as a new generation and they totally replace the parents in order for the evolution to proceed. It is necessary to produce many generations for the population converging to the near optimum or an optimum solution, the number increasing according to the problem complexity.

2.1.5 Control action and controller design

The action of a PSS is to extend the angular stability limits of a power system by providing supplemental damping to the oscillation of synchronous machine rotors through the generator excitation. This damping is provided by an electric torque applied to the rotor that is in phase with the speed variation. A lead-lag PSS structure is shown in

Figure 2.8[6]. The output signal of any PSS is a voltage signal, noted here as VPSS(s), and added as an input signal to the AVR/exciter.

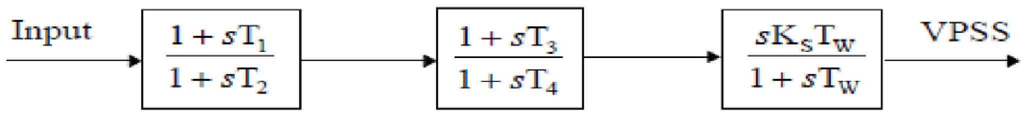

Figure 2.8: Lead-Lag Power System Stabilizer [6]

For the structure shown in Figure 2.8, the output (Vpss) is presented using equation (2.7)

$$VPSS(\mathrm{s}) = \frac{sK_sT_w(1+\mathrm{sT}_1)(1+\mathrm{sT}_3)}{(1+\mathrm{sT}_w)(1+\mathrm{sT}_2)(1+\mathrm{sT}_4)} Input(\mathrm{s}) \qquad (2.7)$$

This particular controller structure contains a washout block, $sK_sT_w / (1+\mathrm{sT}_w)$ used to reduce the over-response of the damping during severe events. Since the PSS must produce a component of electrical torque in phase with the speed deviation, phase lead blocks circuits are used to compensate for the lag (hence, “lead-lag’) between the PSS output and the control action, the electrical torque. The number of lead-lag blocks needed depends on the nature of the system (machine parameters). The PSS gain K_S is an important factor as the damping provided by the PSS increases in proportion to an increase in the gain up to a certain critical gain value, after which the damping begins to decrease. All of the variables (time constants) of the PSS must be determined for each type of generator separately because of the dependence on the machine parameters. The power system dynamics also influence the PSS values. The determination of these values is performed by many different types of tuning methodologies[23].

2.1.5.1 PSS Designing methods

Many advanced methods have been successfully investigated, to design a high performance PSS. The most commonly used methods are as follows:

1 Optimization and intelligence methods

2 Robust methods

3 Adaptive methods

4 Nonlinear methods

1. Optimization Methods

Many optimization methods have been used to design PSS. In optimization techniques, the PSS designing isused as an optimization problem, and then solved by using an optimization methods. Some of the optimization methods are:

(i) Artificial neural networks

(ii) Ant colony

(iii) Immune algorithm

(iv) Chaos

(v) Differential evolution

(vi) Fuzzy and expert system

(vii) Frog leaping algorithm

(viii) Genetic algorithms

(ix) PSO

(x) Simulated annealing

(xi) Tabu search

(xii) Harmony search

2. *RobustMethods*

Robust control methods have been widely used to design PSS. The most commonly used robust methods for the design of PSSs are as follows:

(i) Robust feedback technique

(ii) Quantitative feedback theory

(iii) Linear matrix inequalities

(iv) Robust H-infinity

(v) Interval matrixes

3. Adaptive Methods

Adaptive control methods have been widely used to design PSS. The most commonly used adaptive PSSs are as follows:

(i) Adaptive Nero-Fuzzy

(ii) Adaptive sliding mode

(iii) Dynamic back-propagation

(iv) Adaptive Fuzzy logic

(v) Adaptive model reference approach

4. Nonlinear Methods

Nonlinear methods have not been adequately investigated to design PSS. The nonlinear methods for PSS design are as follows:

(i) Reaction Mass Pendulum (RMP) model

(ii) Synergetic control theory

2.1.6 Performance Indices

These are some standard criteria used to explain the behavior of system response curves. These include:

2.1.6.1 Settling time (t_s)

Settling time is defined as the time for the response to reach, and stay within the specified range (2% to 5%) of its final value [11].

$$t_s = \frac{C}{\xi w_n} \tag{2.8}$$

where ξ is a damping factor, ω_n is a natural frequency of oscillation and C is a constant value and given as 4 for an under damped second order system

2.1.6.2 Rise time (t_r)

The time required for the waveform to go from 0.1 to 0.9 of the final value for over-damped systems and 0 to 1 for under-damped system [11].

$$t_r = \frac{\pi - \tan^{-1}\left(\frac{\sqrt{1-\xi^2}}{\xi}\right)}{\omega_n\sqrt{1-\xi^2}} \tag{2.9}$$

where ξ is damping factor and ω_n is natural frequency of oscillation

2.1.6.3 Overshoot (M_p)

This is the amount by which the waveform overshoots (rises above) the steady-state, or final value at the peak time [11].

$$M_p = e^{-\frac{\pi\xi}{\sqrt{1-\xi^2}}} \tag{2.10}$$

where ξ is damping factor

2.1.6.4 Steady state error (e_{ss})

This is the difference between the input and the output for a prescribed test input as time tends to infinity [11].

$$e_{ss} = \lim_{t\to\infty}\left[r(t) - c(t)\right] \tag{2.11}$$

where: $r(t)$ is reference input and $c(t)$ is actual output

2.2 Review of Existing Similar Works

Many different PSS designing methods were investigated and introduced. Optimization and intelligent methods, robust methods, adaptive methods and nonlinear methods are the general methods which were introduced. The review results showed that application of optimization and intelligent methods are more used by researchers[24].

[27]Investigated the Simultaneous Tuning of Power System Damping Controllers Using Genetic Algorithms.Simultaneous tuning of multiple power system controllers using Genetic Algorithms (GA's). Damping controller structures are assumed to be fixed consisting basically of lead-lag filters. The tuning method takes robustness into consideration as it guarantees system stabilization over a pre-specified set of operating conditions. Modified GA operators are used in the simultaneous optimization of both phase compensations and gain settings for the stabilizers.The results of this work showed that in a multi-machine system, fixed-structure damping controllers can be tuned to provide satisfactory damping performance over a pre-specified set of operating conditions. The GA-based tuning process has shown robustness in achieving controllers satisfying the design criteria in a large-scale realistic power system.Generator shaft speed is used as the stabilizing feed-back signal. It is remarkable that other signals or combination of signals could have been employed in the proposed approach.One of the great advantages of using the proposed tuning method is that after each run there will be many different solutions to the problem. It is possible that the best solution does not satisfy all the practical control design requirements. A fine search among the solutions may be required by an expert. How-ever, in future developments, human expertise can be captured and readily implemented in a more elaborate fitness function.

Power system stabilizer tuning in multimachine power system based on agenetic algorithm and minimum phase control loop method was Proposed by[28], An intelligent method using a genetic algorithm (GA) and the incorporated use of an analytical method so called minimum phase control loop has been proposed in this paper for an off-line power system stabilizers (PSS) tuning in a multimachine power system. First, selecting

PSS parameter problem is converted to an optimization problem. Then, the problem will be solved by a micro- genetic algorithm (micro-GA) with the small population and reinitialization process combined with a hierarchical genetic algorithm (HGA). The concept of HGA is applied for automatically identifying the appropriate choice of PSS locations.It is proposed using the concept of HGA for automatically identifying the PSS locations. Participation factor, which may lead to the incorrect numbers of PSSs when considering the overall damping performance, is not essential in this work. This is a benefit compared to other works that fix the PSS locations before the optimization. It has been shown that the proposed tuning approach gives better result for the minimum damping requirement since the interaction among stabilizers is taken into consideration. It is also proposed the application of a micro-GA with the selected initial solution from the database which may be obtained from other calculation methods or user's experiences. The minimum phase control loop method which is easy to implement was selected as a reasonable choice of initial solution. The results show that the combination of these features can speed up the GA calculation timesignificantly. An excellent improvement in the damping for every contingency has been achieved with one set of PSS parameters.

Tuning of Power System Stabilizers via Genetic Algorithm for Stabilization of Power SystemsProposed by[22]. The power system operating at various conditions is considered as a finite set of plants. The problem of setting parameters of power system stabilizers is converted as a simple optimization problem that is solved by a genetic algorithm and an eigenvalue-based objective function. Single machine infinite bus system and multi-machine system are considered to test the suggested technique.A PSS tuned using this procedure is robust at different operating conditions and structure changes of the system.It was shown that it is possible to select a single set of the PSS parameters to ensure the stabilization of the system for the entire loading range. The suggested technique was also applied on a multi-machine system, the results of time domain simulation showed that the designed PSSs have good performance in the system and work coordinately. It is clear that if the results of genetic algorithm lead to a very small Ki (the gain of PSS for ithmachine) it means that the PSS shall not be mounted on i_{th} generator, and simultaneous placement and tuning of power system stabilizers is achieved.Till date numerous PSS designs have been suggested. Using various input parameters such as speed, electrical power, rotor frequency several PSS models have been designed. For the speed input PSS, at least m parameters must be optimized more than power input PSS and the computation time increases in this case and the optimization problem may not converge. By analyzing behavior of system when different PSSs exist, it is understood that either power PSS or speed PSS have special advantages and disadvantages so the use of a combined PSS using both power and speed signals as input is recommended.

PSS designed with the use MATLAB/SIMULINK Based Model of Single-Machine Infinite-Bus and TCSC for Stability Studies and Tuning Employing GA was Proposed by[1]. A systematic procedure for modelling and simulation of a single-machine infinite-bus power system installed with a thyristor controlled series compensator (TCSC) is presented where the parameters of the TCSC controller are optimized using genetic algorithm.The MATLAB/SIMULINK model of a single-machine infinite-bus power system with a TCSC controller presented in the paper provides a means for carrying out power system stability analysis and for explaining the generator dynamic behavior as effected by a TCSC. This model is far more realistic compared to the model available in open literature, since the synchronous generator with field circuit and one equivalent damper on q-axis is considered. Further, for the TCSC controller design problem, a parameter-constrained, time-domain based, objective function, is developed to improve the performance of power system subjected to a disturbance. Then, GA is employed to search for the optimal TCSC controller parameters. The controller is tested on power system subjected to various large and small disturbances. The simulation results show that, the genetically tuned TCSC controller improves the stability performance of the power system and power system oscillations are effectively damped out. Hence, it is concluded that the proposed model is suitable for carrying out power system stability studies in cases where the dynamic interactions of a synchronous generator and a TCSC are the main concern.

Optimal Design of Multi-Machine Power System Stabilizer Using Genetic Algorithm was Investigated by[26].The stabilizers are tuned to simultaneously shift the lightly damped and undamped electromechanical modes of all plants to a prescribed zone in the s-plane. A multiobjective problem is formulated to optimize a composite set of objective functions comprising the damping factor, and the damping ratio of the lightly damped electromechanical modes. The performance of the proposed PSSs under different disturbances, loading conditions, and system configurations is investigated for different multi-machine power systems.The performance of proposed GAPSS is compared with conventional speed-based lead-lag PSS.The problem of tuning the parameters of the power system stabilizers is converted to an optimization problem which is solved by GA with the eigen value-based multi-objective function. Eigen value analysis under different operating conditions reveals that undamped and lightly damped oscillation modes are shifted to a specific stable zone in the s-plane.These results show the potential of GA algorithm for optimal settings of PSS parameters. The nonlinear time-domain simulation results show that the proposed PSSs work effectively over a wide range of loading conditions and system configurations.

[29] Proposed the Design of Power System Stabilizer for Power System Damping Improvement with Multiple Design Requirements.The design requirements are considered as both time domain and frequency domain specifications which are initially specified before designing the PSS. The optimization based linear control design technique is used to determine the optimal controller parameters.The proposed design of power system stabilizer is tested for various disturbance conditions for damping of oscillations while satisfying the design requirements.Different types of optimization algorithms are used to determine the optimum parameters of stabilizer for damping of oscillations.The performance of different algorithm is compared, based on the settling time genetic algorithm performs better than other algorithm, based on phase margin pattern Nelder-Mead method perform better than other algorithm. By this simple compensator design technique the oscillations are damped out quickly and the stability is improved from marginally stable to completely stable system. Time domain and frequency domain requirements are satisfied with overall improvement in stability.

[12] Investigated on theRobust tuning of power system stabilizers using a Lyapunov method based genetic algorithm,A method of tuning of power system stabilizers using genetic algorithms has been presented. The scheme involved measuring

the quality of system dynamics for each individual of a population of possible solutions and eliminating the less fit ones. Robustness of parameter setting was built into the problem's mathematical formulation, and the final solution is considered to be globally optimal in the operating domain chosen for the purpose. By virtue of this being a simultaneous search process, the problem of eigenvalue drift characteristic to sequential types of tuning is overcome.

The proposed method has been tested on two different PSS structures: the lead-lag and the derivative PSS, and two different system models: the single machine connected to an infinite bus and a multi-machine model. Investigations reveal that the lead-lag PSS provides performance superior to the derivative PSS. The dynamic responses were satisfactory for large variations in system operating load and even for large faults. Interestingly, it was seen that the operating range for which the system with the proposed GA based PSS withstands small perturbations is much bigger than the range considered within the objective function.

Investigation of theTuning of Power System Stabilizer in Single Machine Infinite Bus (SMIB) using Genetic Algorithm and Power Factory Modal Analysis made by[13].In this paper tuning of parameters of a Conventional Power System Stabilizer in a Single Machine Infinite Bus (SMIB) using Genetic Algorithm (GA) is proposed. The power system is modelled in Power Factory and the optimization is done through MATLAB optimization toolbox. The cost function is to maximize the damping ratio which is calculated using Power Factory Modal Analysis. The problem of tuning the parameters is converted to an optimization problem which is solved to maximize the damping ratio of dominant oscillatory modes. A real time data exchange between MATLAB and Power

Factory is established using DIgSILENT Programming Language in form of executable script in Power Factory. The result of simulation shows the effectiveness of tuning process. The proposed technique could be easily adapted to be used for multi machine power systems with many mode of oscillation by changing the codes in MATLAB and PowerFactory scripts. The result of simulation proves the effectiveness of optimization process.

[9]Presents a method for designing Power System Stabilizer (PSS) using particle swarm optimization(PSO), GA and simulated Annealing (SA) methods. The tuning of lead-leg PSS parameters is accomplished by formulating an optimization problem. Solution to the formulated problem is then obtained by three meta-heuristic techniques to achieve an optimal global stability. It is shown from the simulation results that these algorithms in terms of damping characteristics and dynamic stability of an electric power system are robust and effective. A comparison of the three techniques shows that GA performs better in terms of PSSs parameter tuning. In terms of time convergence, PSO has the best score. Elsewhere, SA algorithm is simpler to implement. But, the GA usually gives the best results based on the objective function value, since its convergence is sure and asymptotic.

Design of Genetic Algorithms Based Fuzzy Logic Power System Stabilizers in Multimachine Power System was Proposed by[14].This paper presents a method for the design of fuzzy logic power system stabilizers in a multimachine power system using genetic algorithm. A systematic approach for tuning the parameters of fuzzy logic power system stabilizer using ISTSE technique has been presented. The design algorithm for simultaneous tuning of fuzzy logic power system stabilizers has been tested for multimachine model. The performance of the FLPSS can be significantly improved by incorporating the genetic-based learning mechanism for tuning of parameters of fuzzy logic power system stabilizer. Simulation results reveal that the dynamic performance of the system enhances with genetic based fuzzy logic power system stabilizer. Investigations reveal the performance of simultaneously tuned genetic algorithm based fuzzy power system stabilizers in a multi-machine system is quite robust under wide variations in loading conditions both for small and large disturbance for local as well as inter-area mode.

2.3 Review Summary

The review results showed that application of optimization and intelligence methods is more used by researchers.GA usually gives the best results based on the value for objective function, since its convergence is sure and asymptotic. It is understood that either power input PSS or speed input PSS have special advantages and disadvantages, thus it is recommended that the combination of both signals could have been employed in thisresearch work.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter presentssome of the materials used in this dissertation, with detailed design of both lead-lag and GA based power system stabilizer. The model in [13] is adopted in this research.

3.2 Materials

This section presentssome of the materials used in this dissertation.

3.2.1 MATLAB/ Simulink

MATLAB is a programming language developed by MathWorks, which stands for MATrixLABoratory. It is mathematical software package that is used extensively in both academia and industry. It is an interactive program for numerical computation and data visualization that along with its programming capabilities provides a very useful tool for almost all areas of science and engineering. Unlike other mathematical packages, such as MAPLE or MATHEMATICA, MATLAB cannot perform symbolic manipulations without the use of additional Toolboxes. It remains however, one of the leading software packages for numerical computation. As you might guess from its name, MATLAB deals mainly with matrices. A scalar is a 1-by-1 matrix and a row vector of length say 5, is a 1-by-5 matrix. One of the many advantages of MATLAB is the natural notation used. It looks a lot like the notation that you encounter in a linear algebra course. This makes the use of the program especially easy and it is what makes MATLAB a natural choice for numerical computations. Some of the futures and uses of MATLAB are presented as follows:

3.2.1.1 Features of MATLAB

Following are the basic features of MATLAB:

a) It is a high-level language for numerical computation, visualization and application development.
b) It also provides an interactive environment for iterative exploration, design and problem solving.
c) It provides vast library of mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, numerical integration and solving ordinary differential equations.
d) It provides built-in graphics for visualizing data and tools for creating custom plots.
e) MATLAB's programming interface gives development tools for improving code quality, maintainability, and maximizing performance.
f) It provides tools for building applications with custom graphical interfaces.
g) It provides functions for integrating MATLAB based algorithms with external applications and languages such as C, Java, .NET and Microsoft Excel.

3.2.1.2 Uses of MATLAB

MATLAB is widely used as a computational tool in science and engineering encompassing the fields of physics, chemistry, math and all engineering streams. It is used in a range of applications including:

1) Signal processing and Communications
2) Image and video Processing

3) Control systems
4) Test and measurement
5) Computational finance
6) Computational biology

3.2.1.3 Simulink

Simulink is a graphical extension to MATLAB for modeling and simulation of systems. In Simulink, systems are drawn on screen as block diagrams. Many elements of block diagrams are available, such as transfer functions, summing junctions, etc., as well as virtual input and output devices such as function generators and oscilloscopes. These virtual devices will allow you to perform simulations of the models you built. Simulink is integrated with MATLAB and data can be easily transferred between the programs. In this dissertation, we used Simulink to modeled systems, build controllers and simulate the model.

Figure 3.1 shows the Simulink Model of the complete system including the selectable inputs to the PSS (single or dual inputs PSS), i.e modified version of Figure 2.5

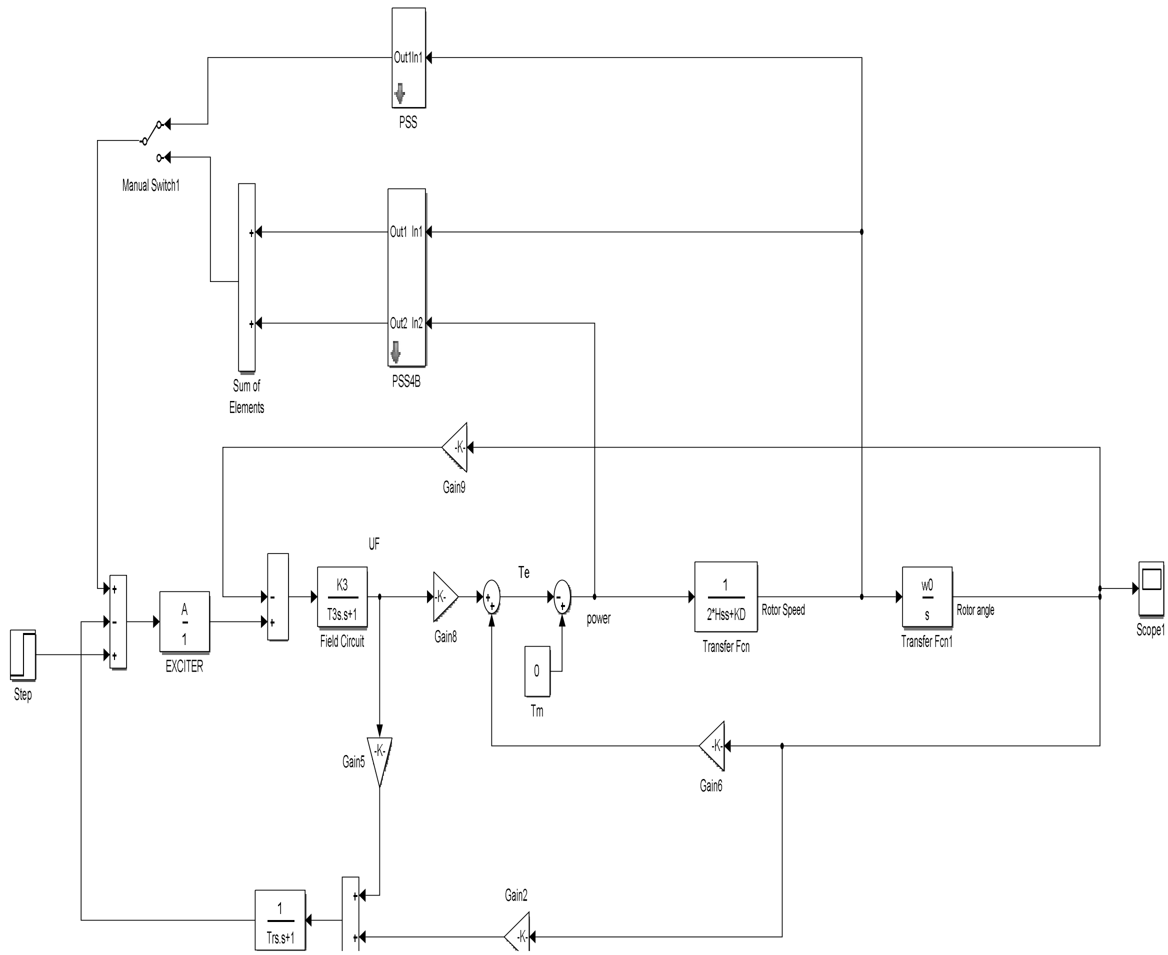

Figure 3.1 System Simulink Block Diagram

3.2.2 Personal Computer

A SAMSUNG computer that has the following specification was used: Windows 8.1 Pro, Processor: Intel(R) Pentium(R) @ 1.8GHz, RAM: 4.00GB, System type: 64-bit Operating System and Hard Disk: 500GB.

3.3Methodologies

This section present a step by step procedure for achieving the stated objectivesTwo common approaches to provide enough damping to the system are minimum phase (frequency response method) and root locus (pole placement method), in the former, the parameters of stabilizer are adjusted to compensate the phase lag using frequency response analysis, while the latter is achieved by modal analysis to find out the position of eigenvalues associated with mode of oscillation. Then the parameters of stabilizer are tuned so that the zeros and poles of the stabilizer are placed in the s-plane in order to shift the eigenvalues to the left as much as possible [13]. The first one is adapted in this work. To achieve the stated objectives the following Methodology is followed:

3.3.1 To develop the transient model from the adapted SMIB model for tuning leading and lagging time constants of the PSS. The following methods shall be applied.

a) For the purpose of PSS tuning, some modifications are made to the model of Figure 3.1 in order to make it suitable to analyze the phase compensation that the PSS should provide to the system. To determine the phase shift, the first step is to calculate the frequency response between the excitation system input and the electrical torque. then, the rotor speed and angle should remain constant due to when the excitation of the generator is modulated, the change that results in the electrical torque causes variations in rotor speed and angle that will affect the electrical torque [30]. Since the purpose of a PSS is to introduce a damping torque component, a logical signal to use for controlling generator excitation is the speed deviation $\Delta\omega$. If the exciter transfer function $G_{ex}(s)$ and the generator transfer function between ΔE_d and ΔTe were pure gains, a direct feedback of $\Delta\omega$ would result in a damping torque component. However, in practice both the generator and the exciter (depending on its type) exhibit frequency dependent gain and phase characteristics [16]. Therefore, the PSS transfer function, $Gpss(s)$, should have appropriate phase compensation circuits to compensate for the phase lag between the exciter input and the electrical torque. In the ideal case, with the phase characteristic of $Gpss(s)$ being an exact inverse of the exciter and generator phase characteristics to be compensated, the PSS would result in a pure damping torque at all oscillating frequencies [16]. As seen in Figure 2.5, the voltage regulator controls the input u equal to V_{ref} to the excitation system which provides the field voltage so as to maintain the generator terminal voltage V_{term} at a desired value V_{ref}. Considering the state –space representation of the system as follows:

There are 7 state variables, 1 input variable and 3 output variables y.

Where state variablesx = $[\delta \ \omega \ E_q \ \psi_d \ E_d \ \psi_q \ V_r]^T$(3.3)

Output variables $y = [V_{term} \omega \ P_e]^T$ (3.4)

Input variable $u = V_{ref}$ (3.5)

Where,

δ is the rotor angle in radian, ω is the angular frequency in radian/sec, ψ_d, E_d is direct axis flux and field voltage, ψ_q, E_q is quadrature axis flux and field voltage, V_t is terminal voltage and P_e is Power delivered to the infinite bus. The state space equations are:

$$\dot{x} = Ax + Bu \quad (3.6)$$

$$y = Cx \quad (3.7)$$

Here, is the adapted model in matrices A, B and C which depends on a wide range of system parameters and operating conditions.

$$A = \begin{bmatrix} 0 & 377.0 & 0 & 0 & 0 & 0 & 0 \\ -0.246 & -0.156 & -0.137 & -0.123 & -0.0124 & -0.0546 & 0 \\ 0.109 & 0.262 & -2.17 & 2.30 & -0.171 & -0.0753 & 1.27 \\ -4.58 & 0 & 30.0 & -34.3 & 0 & 0 & 0 \\ -0.161 & 0 & 0 & 0 & -8.44 & 6.33 & 0 \\ -1.70 & 0 & 0 & 0 & 15.2 & -21.5 & 0 \\ -33.9 & -23.1 & 6.86 & -59.5 & 1.5 & 6.63 & -114 \end{bmatrix} \quad (3.8)$$

$$B = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 16.4 \end{bmatrix} \quad (3.9)$$

$$C = \begin{bmatrix} -0.123 & 1.05 & 0.230 & 0.207 & -0.105 & -0.460 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ -1.42 & 0.9 & 0.787 & 0.708 & 0.0713 & 0.314 & 0 \end{bmatrix} \quad (3.10)$$

b) Therefore, the rotor angle variation effect is eliminated from the model and in that way the rotor speed is kept constant. The block diagram of the modified model (*Transient Model)*for system phase analysis and is used for investigating the phase lag in the system, is presented in Fig. 3.5 [16].

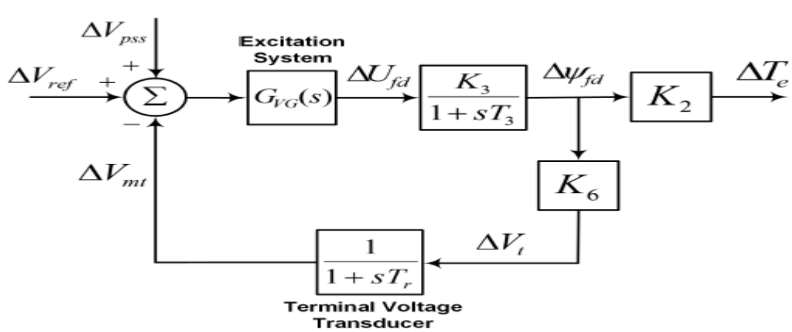

Figure 3.2 Block Diagram SMIB Transient Model[16]

c) The Bode Plot in Figure 3.3, is drawn from the transfer function of Figure 3.2 using MATLAB command, the next step is to compute the phase lag of the system at the frequency of the identified mode. The last is done with the model shown in Figure 3.2 [16] above by plotting the Bode Diagramfrequency response technique. Once the phase shift of the PSS is known, then the parameters of the cascade lead-lag filters stage the PSS structure can be tuned. In this case the parameters are calculated as from equation (3.10).

$$\left.\begin{aligned} N &= \frac{\theta_{pss}}{55^o} = \left\{\begin{array}{l} 1 \rightarrow \theta_{pss} \leq 55^o \\ 2 \rightarrow \theta_{pss} \leq 110^o \\ 3 \rightarrow \theta_{pss} \leq 180^o \end{array}\right\} \\ \sigma &= \frac{1 - \sin\frac{\theta_{pss}}{N}}{1 + \sin\frac{\theta_{pss}}{N}} \\ T_{nl} &= \frac{1}{\omega_{osc}\sqrt{\sigma}} \\ T_{dp} &= \sigma T_{nl} \end{aligned}\right\} \quad (3.10)$$

Where θ_{pss}, given in degrees, is the angle that the PSS should compensate at the oscillation frequency ω_{osc}. N is the number of filters in cascade which are defined according to θ_{pss}. The restriction of 55° compensation per filter is to ensure acceptable phase margin and noise sensitivity at high frequencies [22]. T_{nl} are the lead time constants with l = 1, 3, 10 and T_{dp} are the lag time constants with p = 2, 4, 11. This way of calculation can be applied for lead and for lag compensation effect that depends on the sign of θ_{pss}.

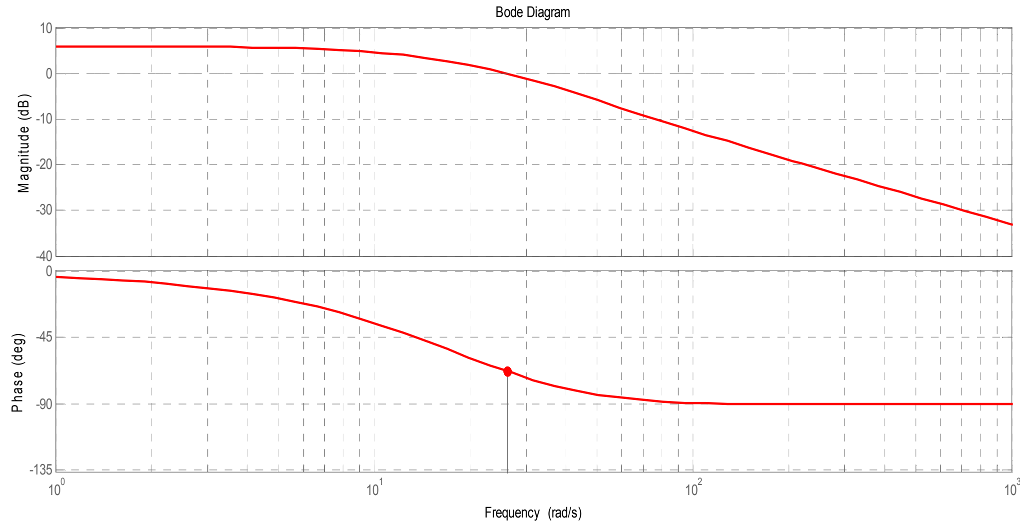

Figure 3.3 Bode Plot of the Transient Model

d) From the transient model bode Plot shown in Figure 3.3 above, the phase Margin θpss is 108^o and corresponding frequency ω_{osc} is $26.1H_Z$, is calculated using MATLAB command, hence from the value of θpss, N should be 2 that is two number of filters in cascade are required. By adjusting the plot new θpss and its corresponding ω_{osc} is tabulated as shown in Table 3.1. Hence, Table 3.1 is used to calculate the time-constants (leading time constant (Tn) and lagging time constant (Td)) at different phase and frequency using the relationship in equation (3.10), and listed in Table 3.2. This is called the conventional approach of tuning PSS.

Table 3.1:Phase Margin and its Corresponding Frequency

θ_{pss}	89.7	85	80	70	60
ω_{osc}	253	260	280	300	320

3.3.2 To find the optimal values of the PSS parameters (time-constants) using Genetic Algorithm solver in the MATLAB Optimization Toolbox.The following methods shall be applied

a) To form the fitness function, there are two variables, phase margin θ_{pss} and corresponding frequency ω_{osc} which can be derived from the Bode plot of the transient model of the system, thus equation (3.10) is written in the script of MATLAB Editor which is minimized using GA solver.Figure 3.4 is the Convergence Characteristics of GA.

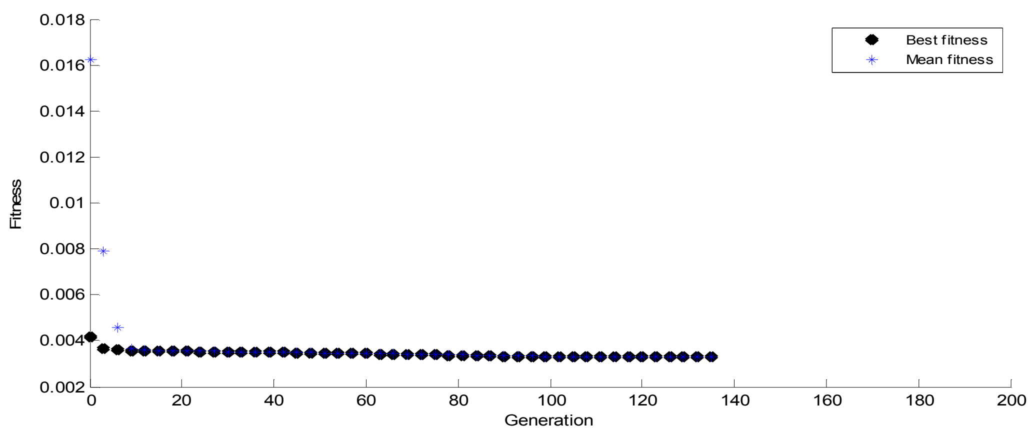

Figure 3.4 Convergence Characteristics of GA

b) To compute the optimum parameter values, a 0.1 step change in the reference mechanical torque (ΔTm) is assumed. The optimal values of T_n and T_d of the parameters are achievedby optimizing equation (3.10) using GA Tool on MATLAB platform, and listed in the Table 3.2.

Table 3.2:Parameters of CPSS and GAPSS

Parameter	T_{n1}	T_{d2}	T_{n3}	T_{d4}
CPSS	0.0035	0.0013	0.0035	0.0013
GAPSS	0.0333	0.0120	0.0333	0.0120

3.3.3 To perform dynamic performance analysis of the system with the proposed GA based power system stabilizer (GAPSS) over a wide range of operating conditions andto compare the performance of the proposed GAPSS with CPSS, the following method shall be applied:

a) The Simulink model of the system is simulated when single or dual inputs PSS is used and when the system has been perturbed with different signals. The results and the corresponding comparative response of both proposed GAPSS and CPSS is plotted using MATLAB commands as well as the performances of both.

b) The performance index is the Integral of the Time multiplied Square value of the Error (ITSE), and the performance index is considered as in equation (1.1), i.e. by taking integral of the square value of the Error ($\Delta\omega$) multiplied by time.

c) Different performances: ITSE, ISE, ITAE and IAE are found and tabulated in Table 3.3, and used the one that minimized error the most, which is ITSE. Section 4.4 presented the details of the various operating conditions based on the type of PSS inputs used, Particularly Figure 4.12.

Table 3.3: Performance Index

Operating conditions	CPSS	CPSS4B	GAPSS	GAPSS4B
ITSE	6.945×10^{-4}	1.381×10^{-4}	4.083×10^{-4}	1.076×10^{-4}

ISE	8.198×10^{-4}	3.165×10^{-4}	5.736×10^{-4}	2.464×10^{-4}
ITAE	6.736×10^{-2}	1.305×10^{-2}	4.224×10^{-2}	1.171×10^{-2}
IAE	4.500×10^{-2}	1.910×10^{-2}	3.426×10^{-2}	1.697×10^{-2}

where:

CPSS is Conventional Single Input PSS, CPSS4B is Conventional Dual Input PSS, GAPSS is Genetic Algorithm based Single Input PSS, GAPSS4B is Genetic Algorithm based Dual Input PSS

3.3.4 To validate the performance of the proposed method with [1].the following method shall be applied:[1] is developed using method 1. Above. The result is compared with proposed technique and was found to be very similar.

a) Performances comparison is carried out for method 1 and 2 above, and depicted the result in Figure 4.11 and Table 4.5 using MATLAB toolbox.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the simulation results obtained from various simulations carried out on Figure 3.1 under the following cases: When only AVR is connected to the system; when conventional PSS is connected; when a GA based PSS is connected; when only Speed is taken as input to the PSS; when only power is taken as input to the PSS; when both power and Speed are simultaneously taken as the PSS input and comparison of each. The responses wereplotted in the figures 4.1 to 4.13.

4.2 Single Machine Infinite Bus with and without PSS

The response in Figure 4.1 shows the result obtained when the system was simulated withAVR only, i.e before any of the methods is applied. The result show that AVR introduces low frequency oscillation when a step input of 0.1 was applied, but after the PSS is introduced, as describe in method 3.3.1, the oscillation was damped as shown in Figure 4.2. The Simulink block shown in Figure 2.5 was used.

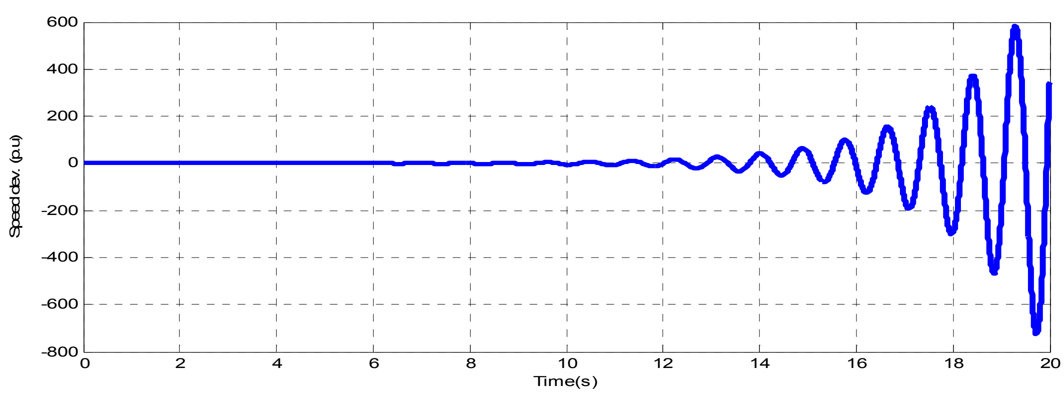

Figure 4.1 Rotor Angle Deviation (NO PSS)

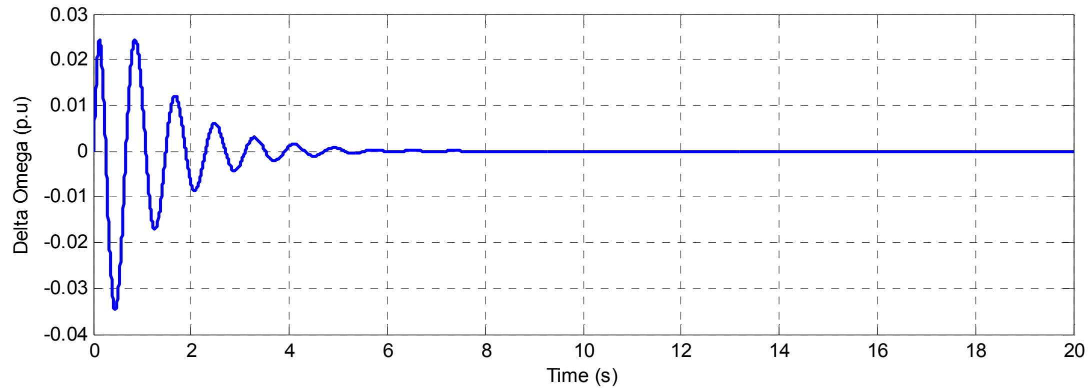

Figure 4.2: Rotor Speed (ω) as Input to CPSS(Validating Signal)

4.3 Single Machine Infinite Bus with Different PSS Inputs

This section is divided into three different cases based on the input to the PSS, and each case was simulated with both conventional PSS and GA based PSS, as presented in method 3.3.1. The results obtained were presented in the Figures 4.3 to 4.6:

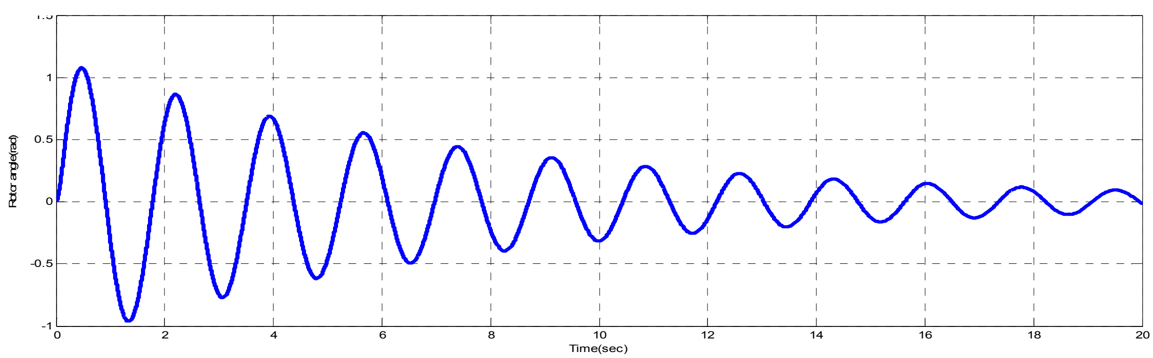

Figure 4.3: Power (P) as Input to (CPSS)

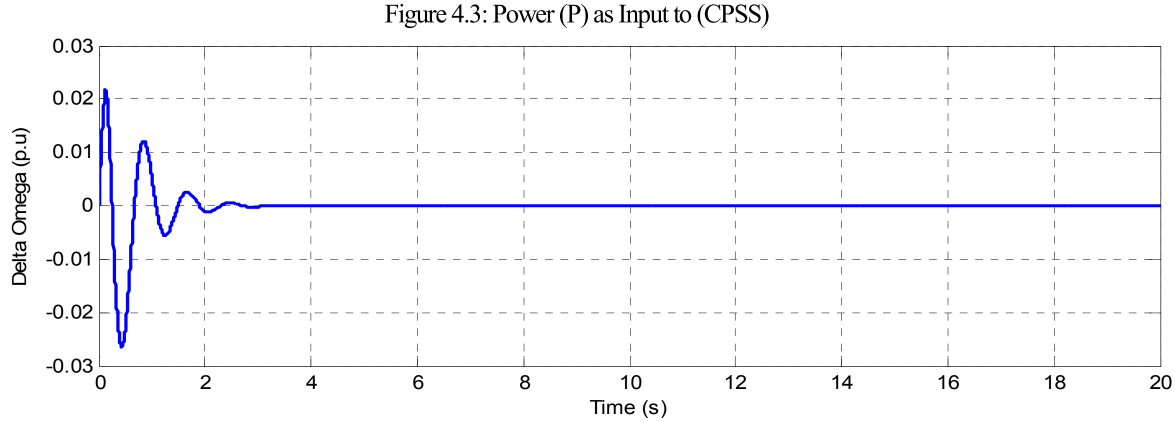

Figure 4.4: Dual Input P+ω (CPSS2B)

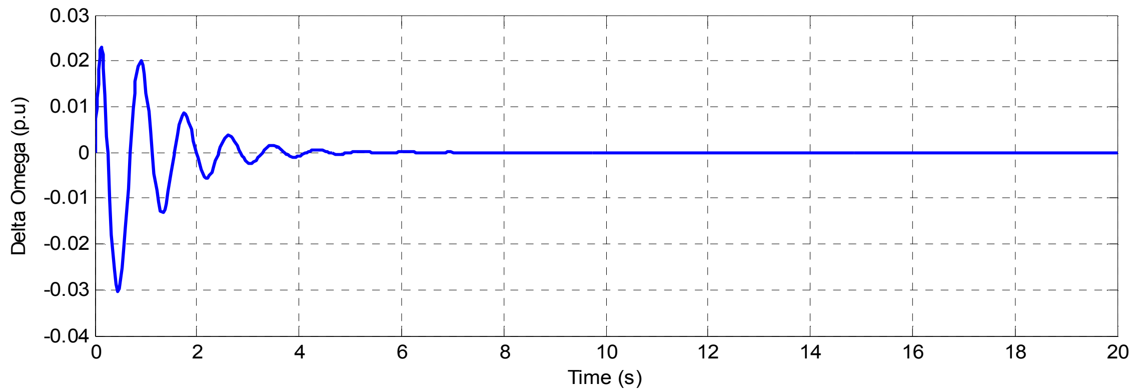

Figure 4.5: Rotor Speed (ω) as Input to (GAPSS)

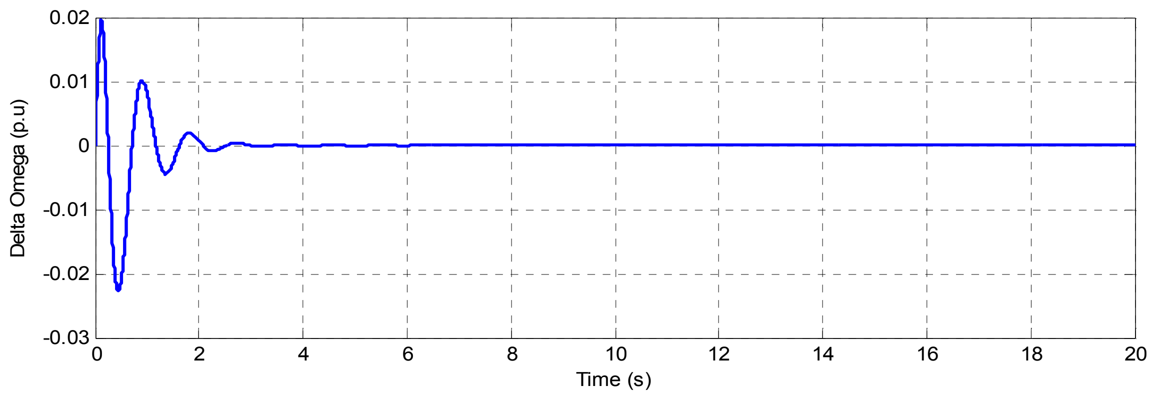

Figure 4.6: Dual Input (GAPSS4B)

Figure 4.3 shows the simulation result when power is used as PSS input, and the rotor oscillations decayed slowly. But when speed is used as input, the oscillations is damped faster as shown in Figure 4.5, a significant improvement was experienced when both power and speed is used as input to the manually tuned PSS shown in Figure 4.4. A look at Figure 4.6 reveals how fast the oscillation is damped, which is achieved by using the dual input PSS and tuned by GA, as presented in method 3.3.2.

4.4 Comparison of the Results

This section is divided into six different cases based on the input to the PSS, and in each case the system is simulated with both conventional PSS and GA based PSS. The results obtained were presented on the same graph for comparison.

4.4.1 Case 1: Dual Input PSS (Angular Speed and Active Power as Input)

This section considered the simulation of the system with both GA based PSS and conventional PSS as presented in Method 3.3.2, with angular rotor speed and electrical power taken as the input to the PSS.

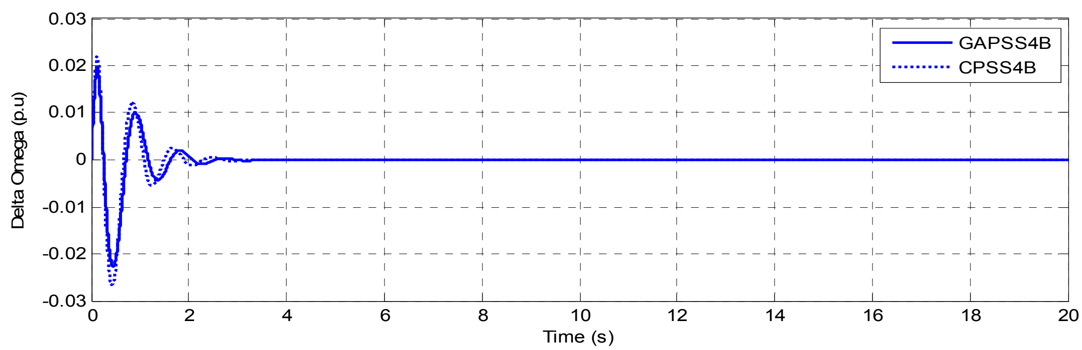

Figure 4.7: Comparison of Dual Input GAPSS and Dual Input CPSS

Figure 4.7 Shows response with both GAPSS4B and the CPSS4B on the same graph. Tables 4.1 and 4.3 was obtained from the responses, they compare the performance indices of both GAPSS4B and the CPSS4B.

Table 4.1 Performance Index for both GAPSS4B and the CPSS4B.

PERFORMANCE INDEX	CPSS4B	GAPSS4B
SETTLING TIME	2.5555 seconds	2.4677 seconds
RISE TIME	0.0026 seconds	0.0021 seconds
% OVERSHOOT	132.8632	75.5632

4.4.2 Case 2: Single Input PSS (Angular Speed as Input)

As explained in method 3.3.4, this section considered the simulation of the system with both GA based PSS and conventional PSS when angular rotor speed was taken as the input to the PSS. The response in Figure 4.8 shows the result obtained when the system is simulated with both Conventional and GA based PSS. The result shows that both the PSS were able to damped the oscillation, the GA based PSS performs much better as can be seen in the detail description of the response characteristic shown in Tables 4.2 and 3.3.

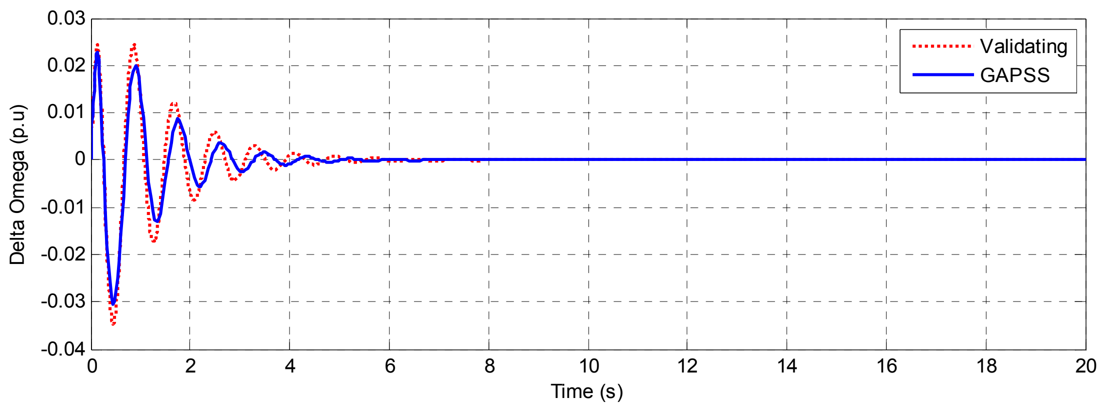

Figure 4.8: Comparison of Single Input CPSS/Validating and Single Input GAPSS

Table 4.2 Response with Angular Speed as the Input to PSS

PERFORMANCE INDEX	CONVENTIONAL PSS	GA BASED PSS
SETTLING TIME	5.5718 sec	4.6733 sec
RISE TIME	0.0025 sec	0.0026 sec
%OVERSHOOT	151.3694	130.6646

4.4.3 Case 3: PSS Comparison between dual and Single input GAPSS

This section considered the simulation of the system for only GA based PSS when the active power and speed were taken as the input and when only Speed was taken as input to the PSS. The response in Figure 4.9 shows the result obtained when the system is simulated. The result shows that both conditions are able to dampen the oscillation as expected however, the Dual input GAPSS outperforms the Single input GAPSS, as can be seen in the detail description of the response characteristic shown in Tables 4.3 and 3.3.

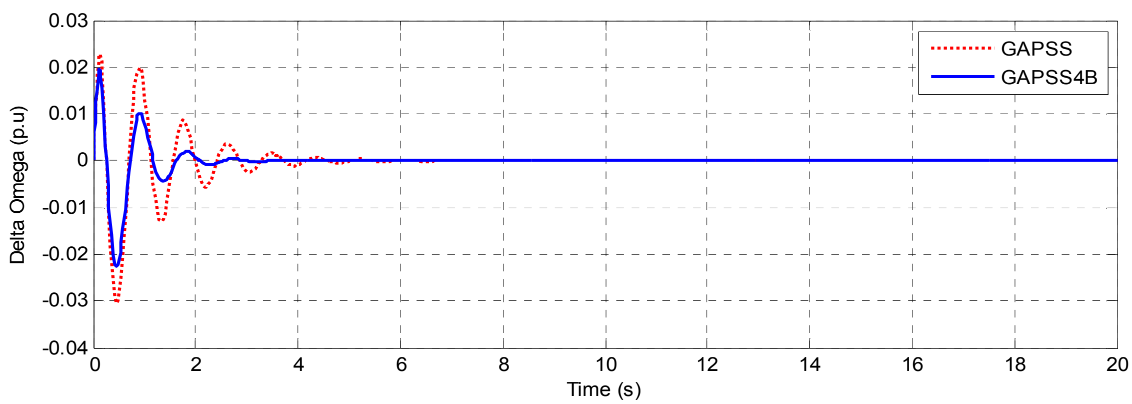

Figure 4.9: Comparison of Dual and Single Input GAPSS

Table 4.3 Comparison of GAPSS and GAPSS4B with Speed Inputs to the PSS

PERFORMANCE INDEX	GAPSS	GAPSS4B
SETTLING TIME	19.9656 sec	2.4677 sec
RISE TIME	16.7671 sec	0.0021 sec
OVERSHOOT	80.6543	79.3393

4.4.4 Case 4: Comparison between Dual input CPSS and Single input CPSS

This section considered the simulation of the system for only conventional PSS when the active power and speed were taken as the input and when only Speed was taken as input to the PSS. The response in Figure 4.10 shows the result obtained when the system is simulated. As explained in method 3.3.3. The result shows that both conditions are able to dampen the oscillation as expected however, the Dual input CPSS performs better than the Single input CPSS, as can be seen in the detail description of the response characteristic shown in Table 4.4 and 3.3.

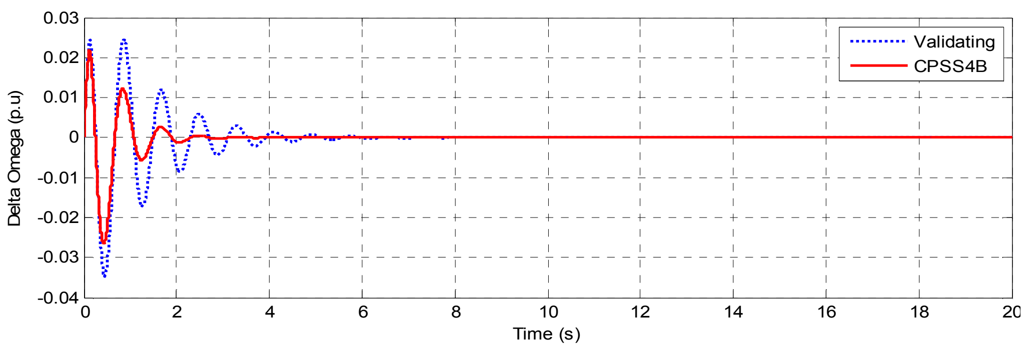

Figure 4.10: Comparison of Dual Input CPSS and Single Input CPSS/Validating

Table 4.4 Comparison of CPSS and CPSS4B with Speed as Inputs

PERFORMANCE INDEX	CPSS	CPSS4B
SETTLING TIME	5.5718 sec	2.5555 sec
RISE TIME	0.0025 sec	0.0026 sec
%OVERSHOOT	151.3694	88.7371

4.4.5 Case 5: Comparison between proposed dual input GAPSS4B and Single input CPSS

This section considered the simulation of the system when the PSS parameter was optimized with GA, and both power and speed were considered as input and when speed input manually tuned PSS. The response in Figure 4.11 shows the result obtained when the system is simulated. The result shows that both conditions were able to dampen the oscillations as expected, however, the Dual input GAPSS performs wonderfully better than the Single input CPSS, as can be seen in the detail description of the response characteristic shown in Tables 4.5 and 3.3.

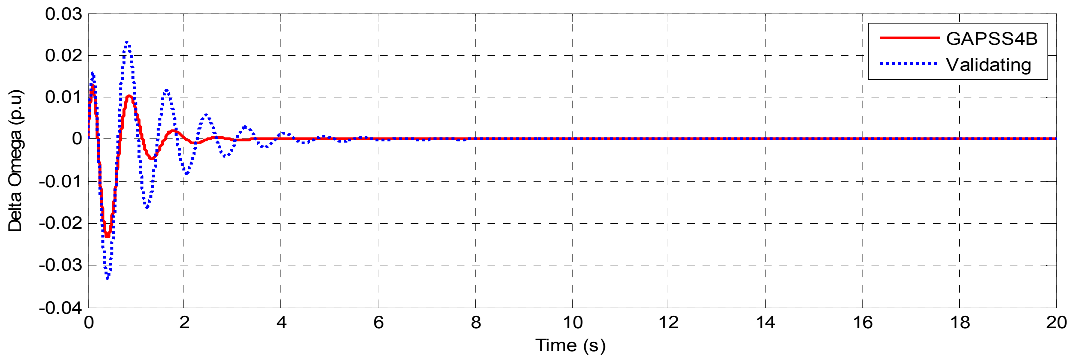

Figure 4.11:GAPSS4B and the Validating Signal Performance

Table 4.5 Comparison of CPSS and GAPSS4B with Speed as Inputs

PERFORMANCE INDEX	CPSS	GAPSS4B
SETTLING TIME	5.5718 sec	2.4677 sec
RISE TIME	0.0025 sec	0.0021 sec
OVERSHOOT	151.3694	79.3393

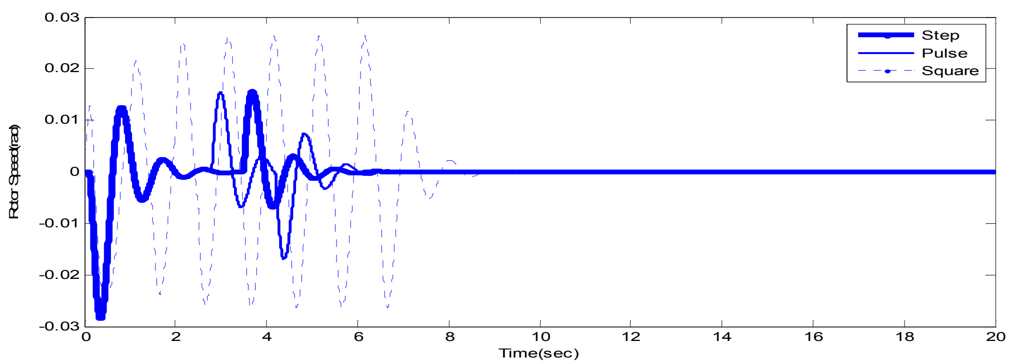

Figure 4.12:GAPSS4B Perturbed with Step, Pulse and Triangular Signals

4.4.6 Case 6: Transient response of the dual input GAPSS4B and Single input CPSS

As presented in method 3.3.3, simulation results and the corresponding comparative transient response for both GAPSS4B and GAPSS are shown in Figure 4.12 and 4.13. To show the robustness of the proposed technique, the system is perturbed with different signals such as step & pulse and in each case, the proposed technique was able to damp out the rotor oscillations as shown in Figure 4.12. A look into Figure 4.13 reveals that after the creation of the fault the PSS4B based response recovers from this abnormal situation with much lesser fluctuation in angular speed as compared to that of CPSS based one. The result shows the robustness of the proposed technique GAPSS4B.

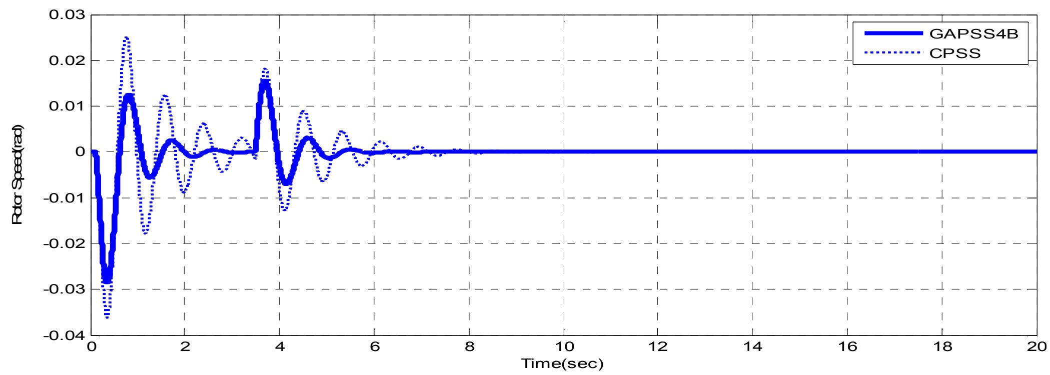

Figure 4.13: Comparison of Transient Responses of both the PSS

4.5 Conclusion

This chapter has considered the responses, obtained from the simulation of both single input PSS and Dual Input PSS under various operating conditions. From the result, it can be seen that PSS damped oscillation introduced by AVR on both the conventional and GA based PSS. Performance index was calculated and tabulated, however, the GAPSS4B outperforms the conventional based PSS in the entire scenario or situation considered so far in this research.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This work has considered the design of both conventional and GA based PSS for a single-machine infinite bus system. It was observed that the conventional PSS designed approach was cumbersome and time consuming. This will however, not yield a good result in addition to the difficulties in the model derivation.

From the results obtained, dual input GA based PSS was able to perform much better than the conventional PSS with less difficulty in design. From the result also, it was observed that AVR connected to the system introduces electromechanical oscillation to the system.In view of this, an intelligent based power system stabilizer (Genetic algorithm based PSS) was developed for possible improvement of power system stability. Damping the oscillation requires PSS as it was shown in the results presented in chapter four of this report.Also, the result obtained from the simulation of the system with both conventional PSS and GA based PSS shows that the developed GA based PSS (GAPSS) gives a better performance as compared with CPSS especially when both angular speed and active power were used as input to the PSS. Also, from synchronism investigation, it was observed that the response from speed deviation of the machine damped to zero as expected.

Therefore, it can be concluded that from the MATLAB/Simulink platform simulation results, shows the proposed PSS based performed better in terms of error minimization, settling time and percentage overshoot, than the performance of the conventional PSS (CPSS), the comparative analysis shows the robustness of proposed technique.

5.2 Contributions

1. This dissertation has investigated the performance of CPSS and the proposed PSS in damping electromechanical oscillation for single Machine infinite bus, Table 3.3 shows that GA based dual input PSS outperforms conventional dual input PSS by 22% in minimizing error (ITSE).
2. Performance based on maximum overshoot, 47.6% improvement was achieved by the proposed PSSas compared to CPSS as seen in Table 4.3.
3. In terms of settling time GAPSS4B has contributed a better result with reduction of time from 5.6 second to 2.5 second as compared to CPSS.
4. Validation was done by comparing the result of [1] with the proposed approach.

5.3 Recommendations for Further Studies

The following research points are recommended for further study:

1. The use of different combination of signal as input to the dual input PSS is recommended, as seen from the result in all the above conditions investigated dual input PSS performs better then single input PSS.
2. Practical implementation of the Proposed PSS will add more insight in the understanding of the proposed technique. Automatic tuning of the PSS parameter will add simplicity in the design of the GA based PSS.

REFERENCES:

[1] S. Panda and N. P. Padhy, "MATLAB / SIMULINK Based Model of Single-Machine Infinite-Bus with TCSC for Stability Studies and Tuning Employing GA," vol. 1, no. 3, pp. 552–561, 2007.

[2] V. K. Mehta, *principls of power system*, 4th Edition. S. CHAND, 1998.

[3] N. Magaji and B. Umar, "Application of Power System Stabilizer on Stability Studies," *Appl. Mech. Mater. Trans Tech Publ.*, vol. 793, pp. 149–153, 2015.

[4] M. Beza and M. Bongiorno, "An adaptive power oscillation damping controller by STATCOM with energy storage," *IEEE Trans. Power Syst.*, 2015.

[5] S. M. Abd Elazim and E. S. Ali, "Optimal Power System Stabilizers design via Cuckoo Search algorithm," *Int. J. Electr. Power Energy Syst.*, vol. 75, pp. 99–107, 2016.

[6] Y. Yu, S. Grijalva, J. J. Thomas, L. Xiong, P. Ju, and Y. Min, "Oscillation Energy Analysis of Inter-Area Low-Frequency Oscillations in Power Systems," *IEEE Trans. Power Syst.*, vol. 31, no. 2, 2016.

[7] M. G. Jolfaei, A. M. Sharaf, S. M. Shariatmadar, and M. B. Poudeh, "A hybrid PSS-SSSC GA-stabilization scheme for damping power system small signal oscillations," *Int. J. Electr. Power Energy Syst.*, 2016.

[8] L. H. Hassan, M. Moghavvemi, H. A. F. Almurib, and K. M. Muttaqi, "A coordinated design of PSSs and UPFC-based stabilizer using genetic algorithm," *IEEE Trans. Ind. Appl.*, 2014.

[9] I. K. Okakwu, E. A. Ogujor, and A. E. Airoboman, "Enhancement of Power System Transient Stability - A Review," vol. 12, no. 3, pp. 32–36, 2017.

[10] R. K. Khadanga and J. K. Satapathy, "A new hybrid GA-GSA algorithm for tuning damping controller parameters for a unified power flow controller," *Int. J. Electr. Power Energy Syst.*, 2015.

[11] K. Tang and G. K. Venayagamoorthy, "Adaptive inter-area oscillation damping controller for multi-machine power systems," *Electr. Power Syst. Res.*, 2016.

[12] A. Andreoiu and K. Bhattachawa, "Robust tuning of power system stabilisers using a Lyapunov method based genetic algorithm," vol. 11, pp. 30–36, 2015.

[13] A. Kharrazi and A. Kharrazi, "Tuning of power system stabilizer in Single Machine Infinite Bus (SMIB) using genetic algorithm and Power Factory Modal Analysi," vol. 6, pp. 22–29, 2016.

[14] M. Dubey and N. E. Mastorakis, "Design of Genetic Algorithms Based Fuzzy Logic Power System Stabilizers in Multimachine Power System 3 Design Methodology," vol. 7, pp. 193–202, 2018.

[15] A. Monti and F. Ponci, *Electric Power Systems*. 2015.

[16] P. Kundur, “Power System Stability and Control”, McGraw-Hill, 1994

[17] M. Derafshian and N. Amjady, “Optimal design of power system stabilizer for power systems including doubly fed induction generator wind turbines,” *Energy*, vol. 84, 2015.

[18] S. Vijaykumar, B. Vijeta, P. Vishal, B. Jagadish, and J. Kittur, “Modeling of Synchronous generator connected to,” pp. 56–63.

[19] P. M. Anderson and A. A. Fouad, *Power System Control and Stability*, Second Edi. San Diego, California: A JOHNWILEY & SONS, 1999.

[20] A. A. (Department of E. and E. D. of E. P. E. C. U. O. T. ZEA, “Power System Stabilizers for The Synchronous Generator,” *J. Electr. power Eng.*, vol. 12, pp. 44–56, 2013.

[21] V. S. Rao and B. V. S. Ram, “A Comprehensive Review of Power System Stabilizer Modeling , Analysis and Control Strategy,” vol. 2055, no. 6, pp. 80–91, 2014.

[22] F. Rashidi and M. Rashidi, “Tuning of Power System Stabilizers via Genetic Algorithm for Stabilization of Power Systems,” pp. 1210–1219, 2004.

[23] S. Shakerinia, “The Power System Stabilizer (PSS) Types And Its Models,” vol. 4, no. 3, pp. 154–159, 2016.

[24] H. F. Boroujeni and B. Branch, “Review of Power System Stabilizer Designing Methods,” vol. 1, no. 3, pp. 77–83, 2012.

[25] D. K. Sambariya and R. Prasad, “Robust tuning of power system stabilizer for small signal stability enhancement using metaheuristic bat algorithm,” *Int. J. Electr. Power Energy Syst.*, 2014.

[26] G. N. Corresponding, “Optimal Design of Multi-Machine Power System Stabilizer Using Genetic Algorithm,” vol. 2, no. 4, pp. 138–154, 2011.

[27] N. Glauco and M. Djalma, “Simultaneous Tuning of Power System Damping Controllers Using Genetic Algorithms T-,” vol. 895, no. I, 2000.

[28] K. Hongesombut, Y. Mitani, and K. Tsuji, “System Based on a Minimum Phase Control Loop Method,” vol. 3, no. June, pp. 24–28, 2002.

[29] G. Y. R. Vikhram and S. Latha, “Design of Power System Stabilizer for Power System Damping Improvement with Multiple Design Requirements,” no. 5, pp. 43–48, 2012.

[30] R. Kamdar, M. Kumar, and G. Agnihotri, “Transient Stability Analysis and Enhancement of IEEE- 9 Bus System,” vol. 3, no. 2, pp. 41–51, 2014.

APPENDIX

Here, we provide some of the MATLAB™ scripts used in the design and the simulation process:

1. To convert the power system model into transfer function:

```
% this function converts the power system
% model from state space to transfer function.
% A,B,C,D are the state parameters
% PS0 refers to transfer function matrix having 3 outputs
% PS refers to transfer function with output=w
% PS1 refers to transfer function with output=Vterm
% all coeff having very small values are approximated
% to zero in the saved variables
clc
clear
A=[0, 377.0, 0, 0, 0, 0, 0; -0.246, -0.156, -0.137, -0.123, -
0.0124, -0.0546, 0; 0.109, 0.262, -2.17, 2.30, -0.0171, -
0.0753,
1.27; -4.58, 0, 30.0, -34.3, 0, 0, 0; -0.161, 0, 0, 0, -
8.44,
6.33, 0; -1.70, 0, 0, 0, 15.2, -21.5, 0; -33.9, -23.1,
6.86, -
59.5, 1.50, 6.63, -114];
B=[0; 0; 0; 0; 0; 0; 16.4];
C=[-0.123, 1.05, 0.230, 0.207, -0.105, -0.460, 0; 0, 1, 0,
0, 0,
0, 0; 1.42, 0.900, 0.787, 0.708, 0.0713, 0.314, 0];
D=[0; 0; 0];
[numPS0,denPS0]=ss2tf(A,B,C,D);
numPS=numPS0(2,:);
denPS=denPS0;
numPS1=numPS0(1,:);
denPS1=denPS0;
save 'tf_ps.mat' % saves the workspace variables to
tf_ps.mat

clc
clear
closeall
globalsys_controlled
global time
globalsysrl
%_________________________________________________________________________
den1=[1 0.2098 12.45 -0.0001176];
num1=[-0.03448,0.002624,- 1.62e-006];
sysrl=tf(num1,den1);
%_________________________________________________________________________
%Initialising the genetic algorithm
```

```
populationSize=50;
variableBounds=[0 50;0 50;0 50;0 50;0 50];
evalFN='LEADLAG_objfun_ISE';
evalOps=[];
options=[1e-6 1];
initPop=initializega(populationSize,variableBounds,evalFN,...
evalOps,options);
%_____________________________________________________________________
%Setting the parameters for the genetic algorithm
bounds=[-50 50;-50 50;-50 50;-50 50;-50 50];
evalFN='LEADLAG_objfun_ISE';
evalOps=[];
startPop=initPop;
opts=[1e-6 1 0];
termFN='maxGenTerm';
termOps=220;
selectFN='normGeomSelect';
selectOps=0.08;
xOverFNs='arithXover';
xOverOps=6;
mutFNs='unifMutation';
%mutFNs='nonUnifMutation';
mutOps=8;
%_____________________________________________________________________
%Iterating the genetic algorithm
[x,endPop,bPop,traceInfo]=ga(bounds,evalFN,evalOps,startPop,opts,...
termFN,termOps,selectFN,selectOps,xOverFNs,xOverOps,mutFNs,mutOps);
%_____________________________________________________________________
%Plotting Genetic algorithm controller Vs Root locus controller
%den1=[1 5.21 48 12.13];
%num1=[215,-346.1,406.7];
%sysrl=tf(num1,den1);
%Transfer function of the Root Locus LEADLAG controller
%den_LEADLAG=[1 0];
%num_LEADLAG=[4.74 6 1.91]; %KdKp Ki
%rl_LEADLAG=tf(num_LEADLAG,den_LEADLAG);
%Placing LEADLAG controller in unity feedback system with 'sysrl'
%sys1=series(rl_LEADLAG,sysrl);
%rl_sys=feedback(sys1,[1]);
%Creating the optimal LEADLAG controller from GA results
ga_ldlg=tf(x(1)*conv([x(1),1],[x(3),1]), conv([x(4),1],[x(2),1]));
ga_ldlg1=series(ga_ldlg,tf([1,0],[4,1]))
ga_ldlg2=series(ga_ldlg1,tf([0,1],[.04,1]));
ga_sys=feedback(series(ga_ldlg2,sysrl),1);
figure(1)
holdon;
step(ga_sys,sysrl,'g',0:0.03:50);%Green-genetic algorithm
%legend('GA Controlled Sys','ZN Controlled Sys',2);

%_____________________________________________________________________
%Printing to screen the LEADLAG values and
%comparing them to the Zeigler Nichols values
fprintf(' Genetic Algorithm values : T1 = %7.5f  T2 = %7.5f  T3 = %7.4f
T4 = %7.5f  K = %7.4f',x(1),x(2),x(3),x(4),x(5));
%disp( x );
%_____________________________________________________________________
%Plotting best population progress
```

```
figure(2)
subplot(4,1,1),plot(bPop(:,1),bPop(:,3)),...
title('T1 Value'),, ylabel('Time');
subplot(4,1,2),plot(bPop(:,1),bPop(:,4)),...
title('T2 Value'),, ylabel('Time constant');
subplot(4,1,3),plot(bPop(:,1),bPop(:,2)),...
title('T3 Value'),xlabel('Time'), ylabel('Time constant')
subplot(4,1,4),plot(bPop(:,1),bPop(:,2)),...
title('T4 Value'),xlabel('Time constant'), ylabel('Time constant');

function [T_n,T_d]=myfitness(x)
R=((pi*x(1))/360);
T_n=(sqrt((1+sin(R))/(1-sin(R))))/x(2);
T_d=1/(x(2)*sqrt((1+sin(R))/(1-sin(R))));
rad2deg(R);
end
```