CHAPTER 4

TESTING PERFORMANCE OF CONTROLLERS

Chapter deals with parameters used for performance assessment of the controller. It also describes an evaluation of membership functions on a single machine infinite bus (SMIB) system with Power system stabilizers (PSSs). The PSS is added to excitation system to enhance the damping during low frequency oscillations. The speed deviation and acceleration of the rotor of synchronous generator are taken as the input to the fuzzy logic & Neural Network based controller to improve small signal stability by improving damping. The effect of these variables on damping at the generator shaft mechanical oscillations is very significant. The stabilizing signals were computed using the different fuzzy membership functions like triangular, trapezoidal, Gaussian, bell, sigmoid and polynomial types. The performance of the fuzzy logic & Neural Network based PSS is compared with the system Response without PSS and with Conventional PSS (CPSS). The simulation results obtained from the different plants over a wide range of operating conditions indicate the improved performance of ANNPSS over the CPSS& Fuzzy PSS by considering the triangular and Gaussian type of membership functions in the design of fuzzy logic controller.

4.1Introduction

Power system stability is one of the important and challenging concepts. Power system stability is the tendency of a power system to develop restoring forces equal to or greater than the disturbing forces to maintain the state of equilibrium. The instability in a power system mainly depends upon system configuration and operating condition. Power system stability can be classified into three categories:

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

Transient stability is the ability of the power system to maintain synchronism when subjected to a sudden and large disturbance within a small time such as a fault on transmission facilities, loss of generation or loss of a large load [1] [2].

Dynamic stability is a concept used in the study of transient conditions in power systems. Any electrical disturbances in a power system will cause electromechanical transient processes. Besides the electrical transient phenomena produced, the power balance of the generating units is always disturbed, and thereby mechanical oscillations of machine rotors follow the disturbance. A system is said to be dynamically stable if the oscillations do not acquire more than certain amplitude and die out quickly [1] [3].

4.2 Simulation of Conventional power system stabilizer (CPSS)

4.2.1 Single Machine Infinite Bus System

The model used in Simulink to study the response of the Excitation system with AVR is shown below. In this representation the dynamic characteristics of the system are expressed in terms of so called K constants. The analysis is done for three various loading condition and according to that the value of K1 to K6 constant are calculated. And the variation in speed, angular position and the electric torque are analyzed. The value of K1 to K6 is calculated by taking the data given in the appendix.

Table 4. 1The three different operating conditions for SMIB system

CASE	P(p.u)	Q(p.u)	K1	K2	K3	K4	K5	K6
1.	0.5	0.3	0.9339	1.0191	0.3600	1.3044	0.0500	0.4512
2.	1	0.4	1.1053	1.3287	0.3600	1.7008	-0.1001	0.3607
3.	1.5	0.8	0.8894	1.3888	0.3600	1.7776	-0.2697	0.3371

The conventional PSS consists of main three blocks which are stabilizer gain, phase compensation and washout signal. The parameters of CPSS are given below:

Table 4. 2The parameter value of CPSS

PARAMETERS	VALUES
T1	154 msec
T2	33msec
Tw	1400msec
Kstab	9.5

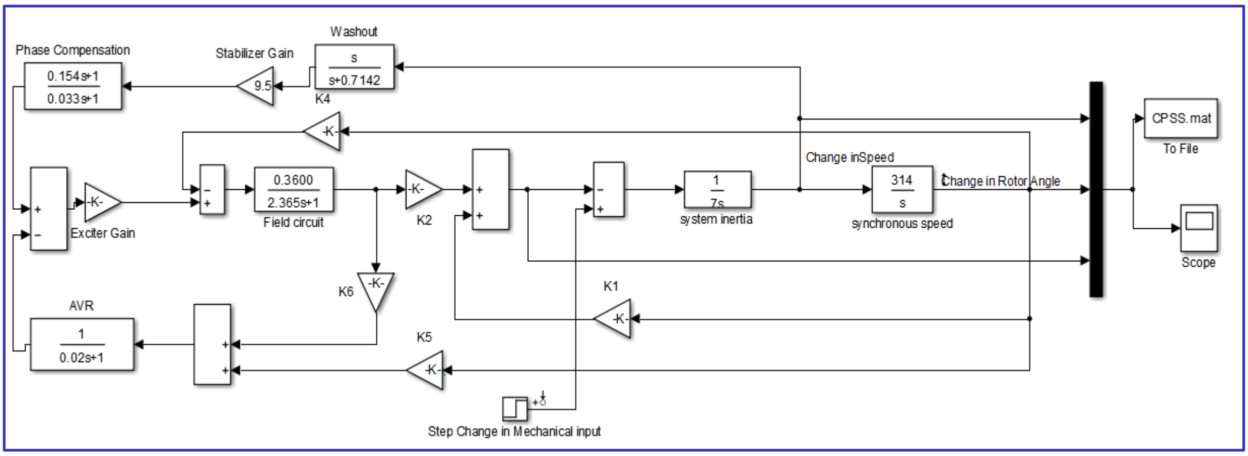

Fig. 4. 1Simulink model for 5% change in mechanical torque input With CPSS

The system response with 0.05 Pu increase in torque for case 1, 2 and 3 is analyzed. The system becomes stable in all cases.

4.2.2 Multimachine System

The Simulink model shown in Fig 4.16 shows multi-machine power system controlled with PSS.

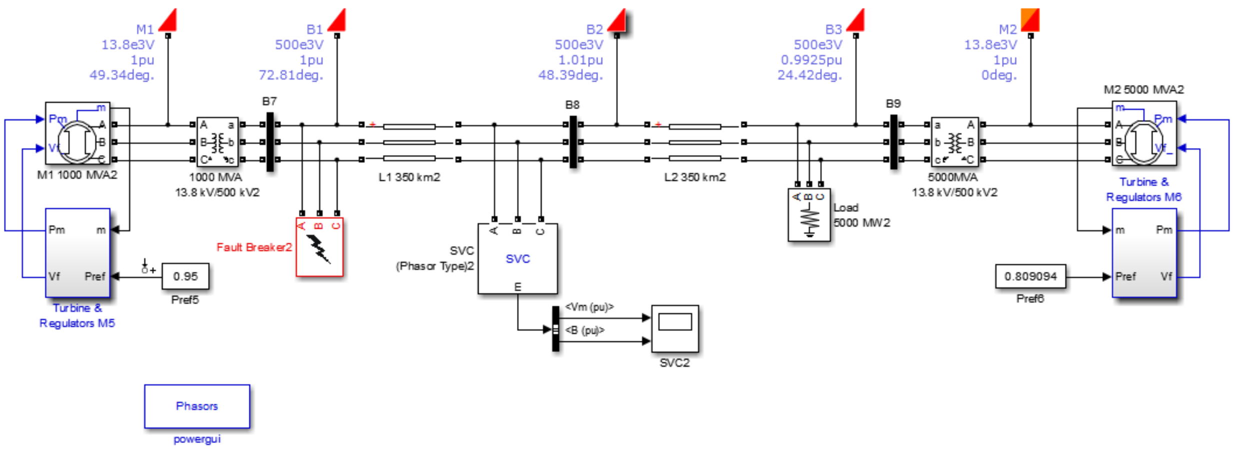

Fig. 4. 2Simulink model Multimachine system with CPSS

Fig. 4.2 system is tested for different loading conditions i.e. 1000 MW load operating condition considered as Light Loading Condition, 3000 MW load operating condition considered as Normal Loading Condition, 5000 MW load operating condition considered as Heavy Loading Condition. Fig. 4.3 shows the location of Power System Stabilizer in multimachine system.

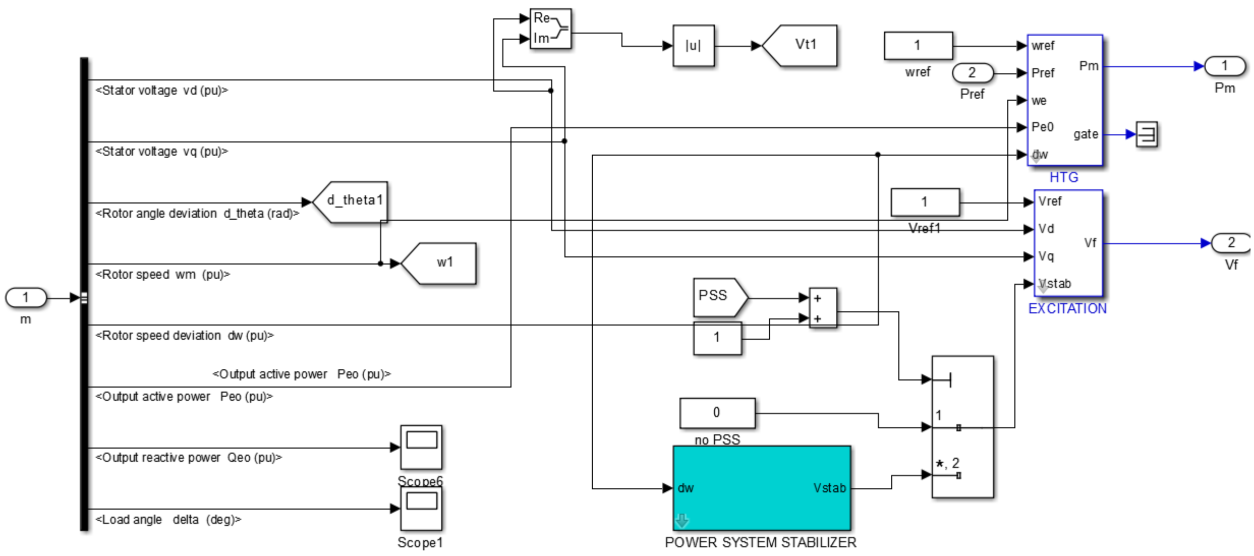

Fig. 4. 3 Location of PSS (Subsystem of Fig 4.2)

As the system is operating on 0.8 power factors, 1000 MVA synchronous machine M1 and 5000 MVA synchronous machine M2. So the maximum capacity of load is ((5000*0.8)+(1000*0.8))=4800 MW. So 5000 MW load considered as Heavy load.

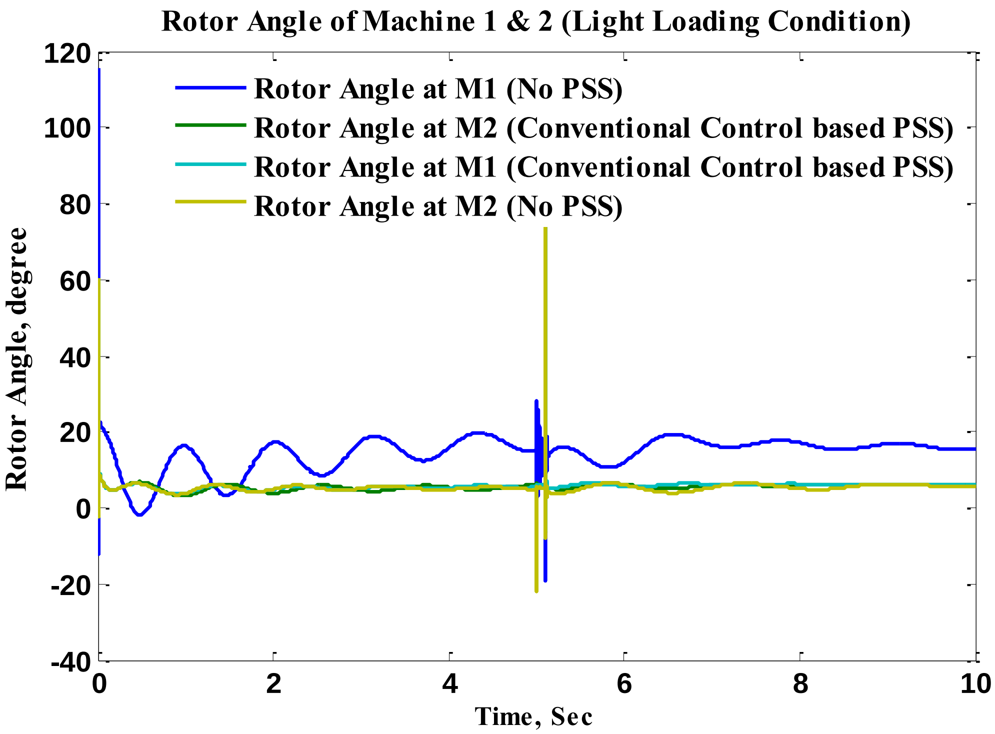

Fig. 4. 4 Rotor Angle Performance of PSS installed in multimachine system for light loading condition

The response of the rotor angle of generators is shown in Fig 4.4. Under light load condition (1000 MW load), Fig 4.5Under Normal load condition (3000 MW load) and Fig 4.6 Under Heavy load (5000 MW load) compared without installation of PSS installed in the system along with Conventional power system stabilizer. It shows that without power system stabilizer installation the rotor angle increases gradually so it is stable by PSS installed in the system.The damping ratio and damping coefficient increases with increase in exciter gain.. Thus, CPSS design performance not proven effective in heavy loading condition. Under light load condition, the average peak overshoot of all the generators reach up to 1.0005 P.Uand the mean settling time of the oscillations are about 30 to 40 seconds.

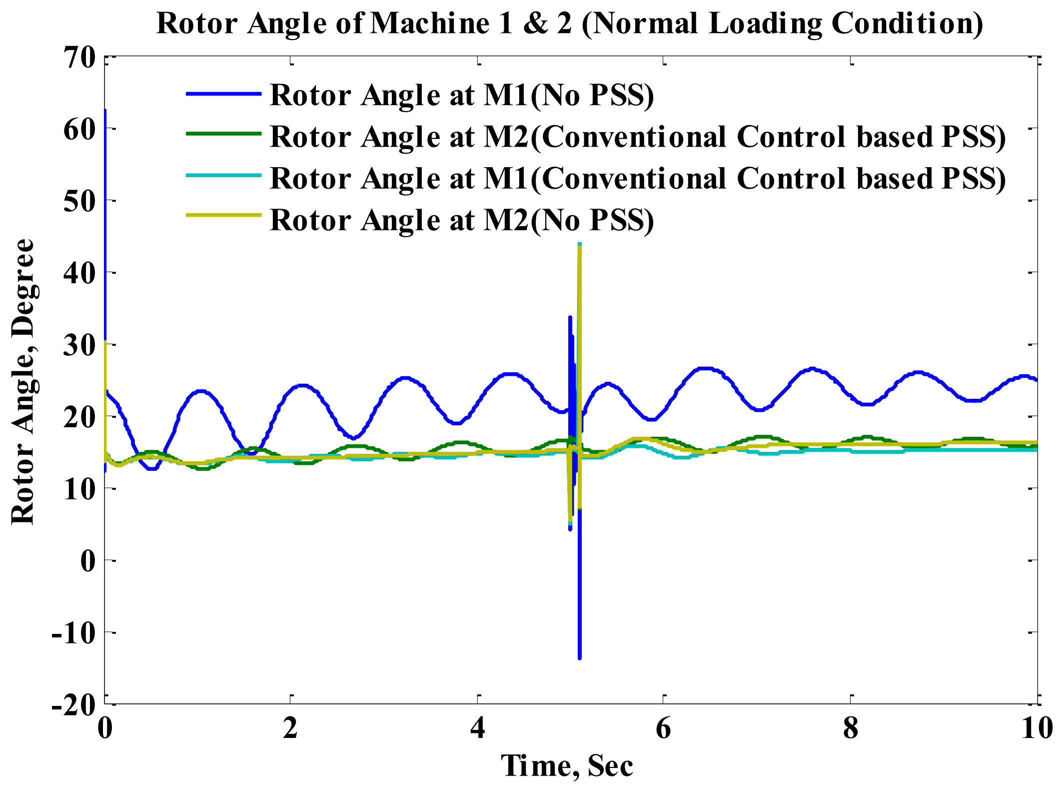

Fig. 4. 5 Rotor Angle Performance of PSS installed in multimachine system for normal loading condition

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(1) Paper entitled, "Design and Analysis of Switched Multiple Model Adaptive Control for Local Controllers" at International Journal of Engineering Associates, ISSN: 2320-0804, Vol. 1 Issue 4, 2012. (http://www.advanceresearchlibrary.com/temp/downloads/ijea/feb2013/rk32.pdf)

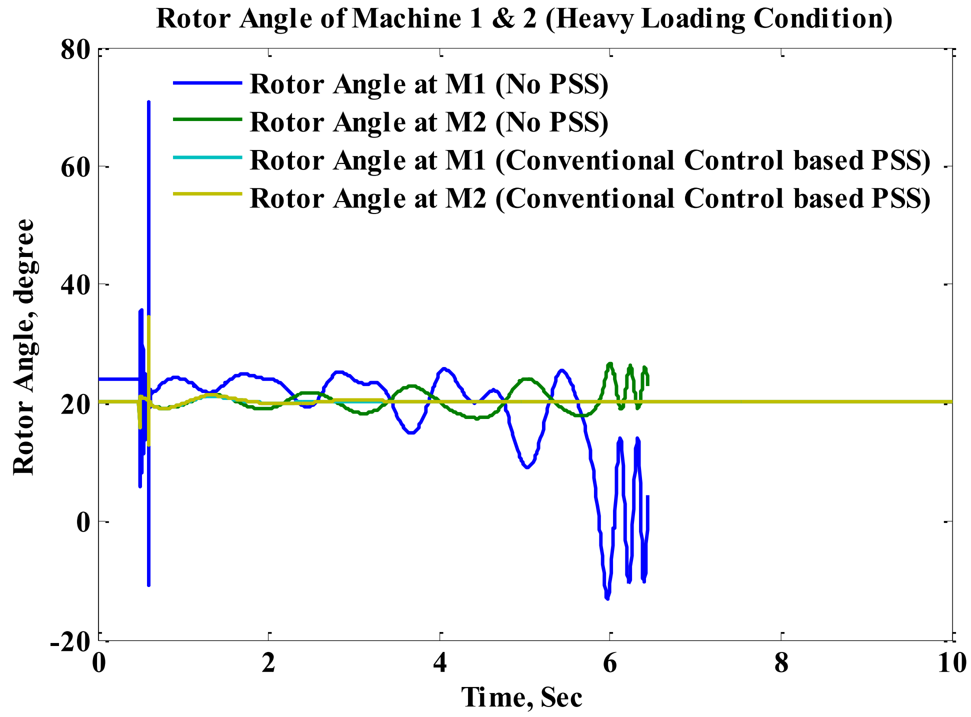


Fig. 4. 6 Rotor Angle Performance of PSS installed in multimachine system for heavy loading condition

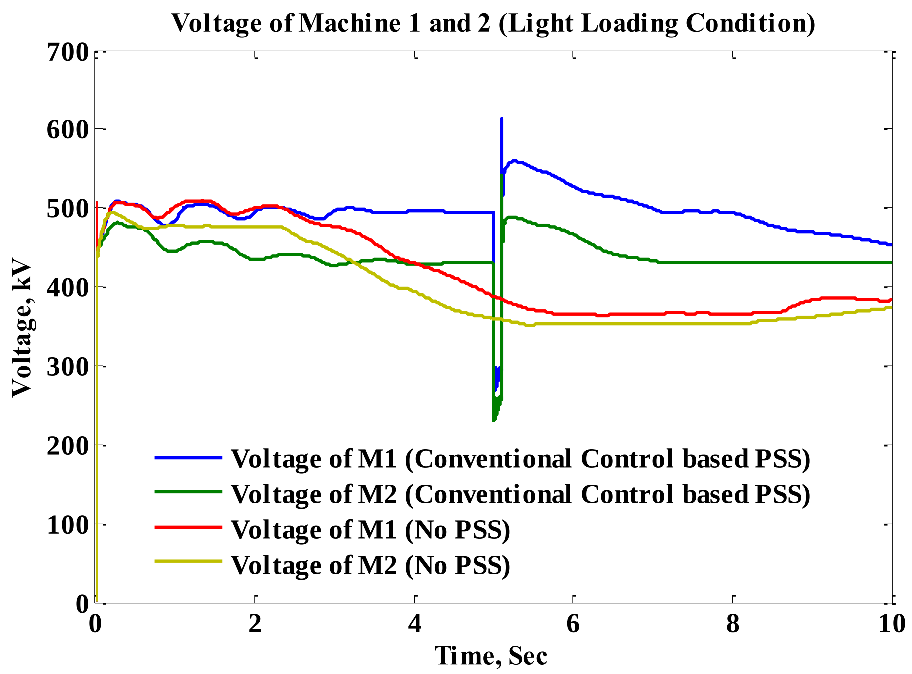


Fig. 4.7Voltage performance of PSS installed in multimachine system for light loading condition

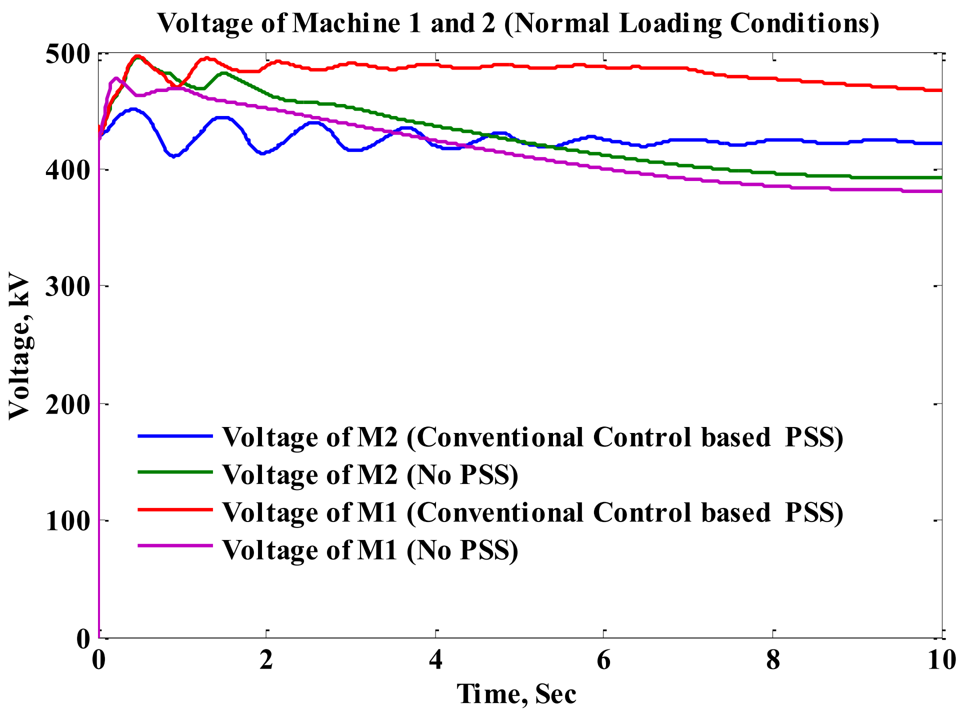


Fig. 4.8Voltage performance of PSS installed in multimachine system for normal loading condition

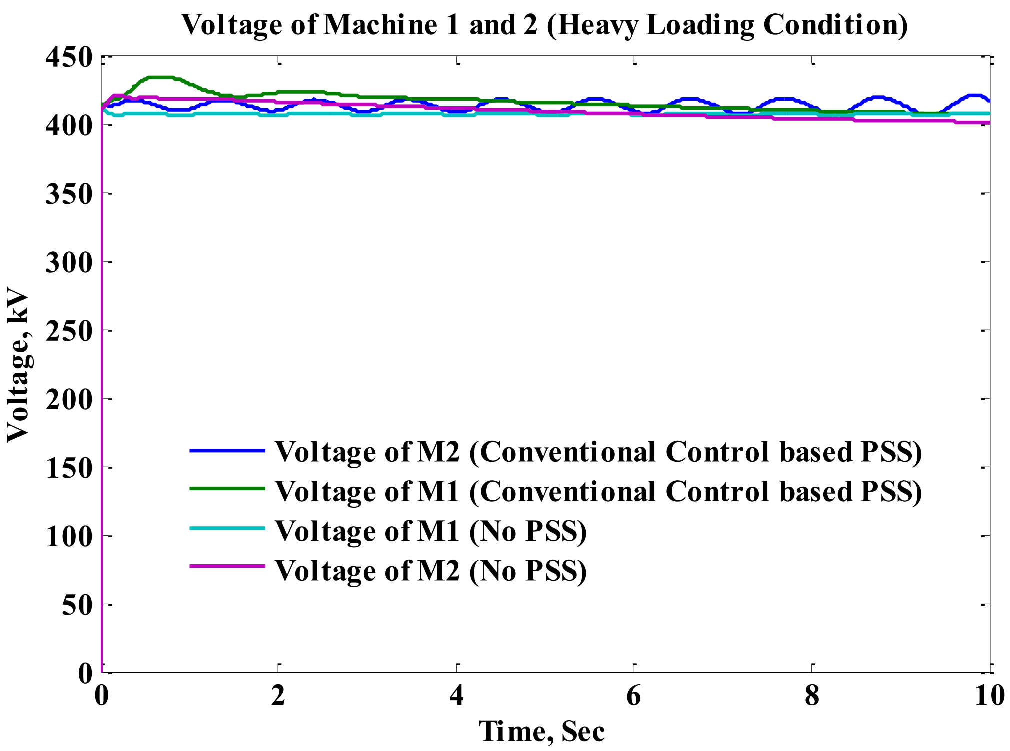


Fig. 4.9Voltage performance of PSS installed in multimachine system for heavy loading condition

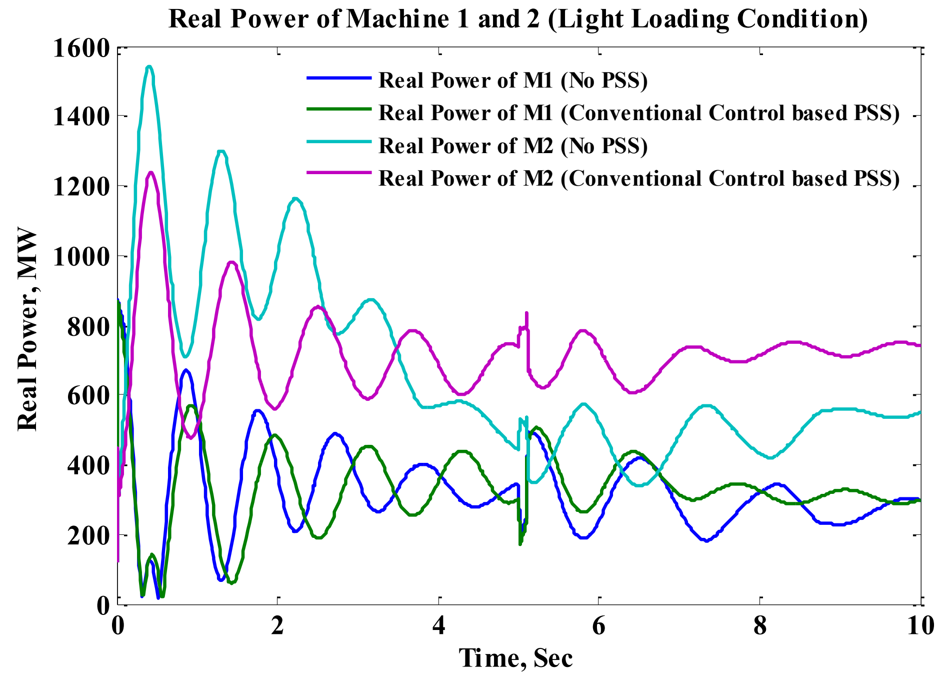


Fig. 4.10Real power performance of PSS installed in multimachine system for light loading condition

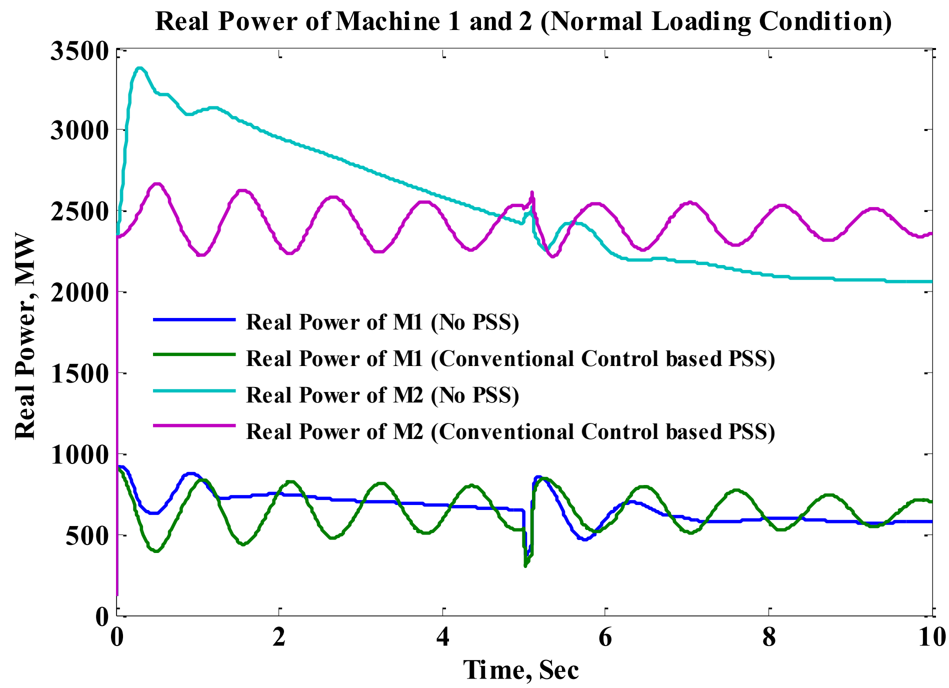


Fig. 4. 11 Real power performance of PSS installed in multimachine system for normalt loading condition

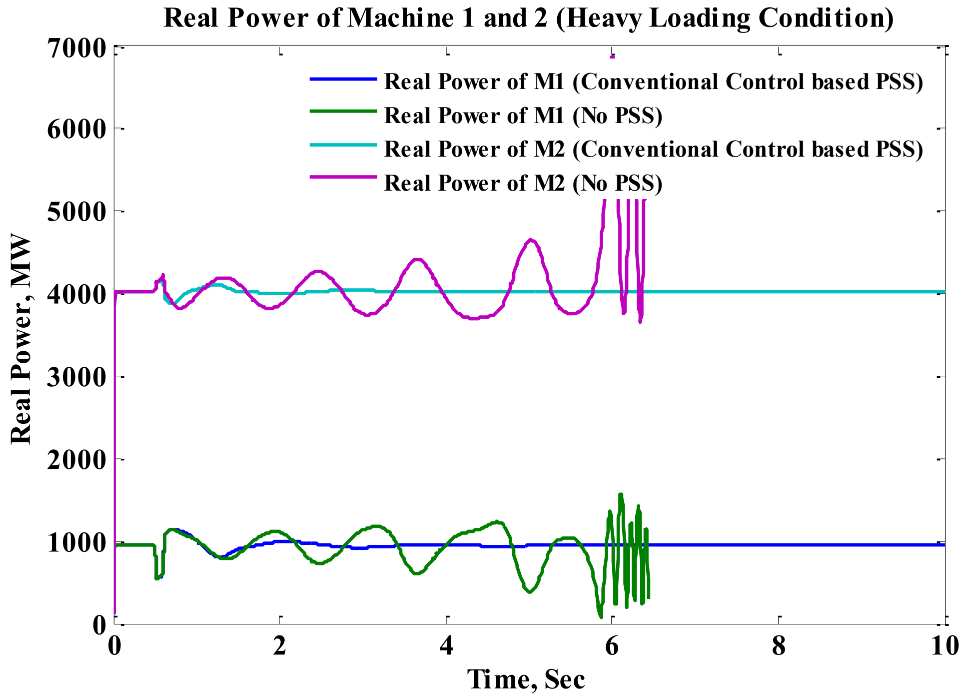


Fig. 4. 12 Real power performance of PSS installed in multimachine system for heavy loading condition

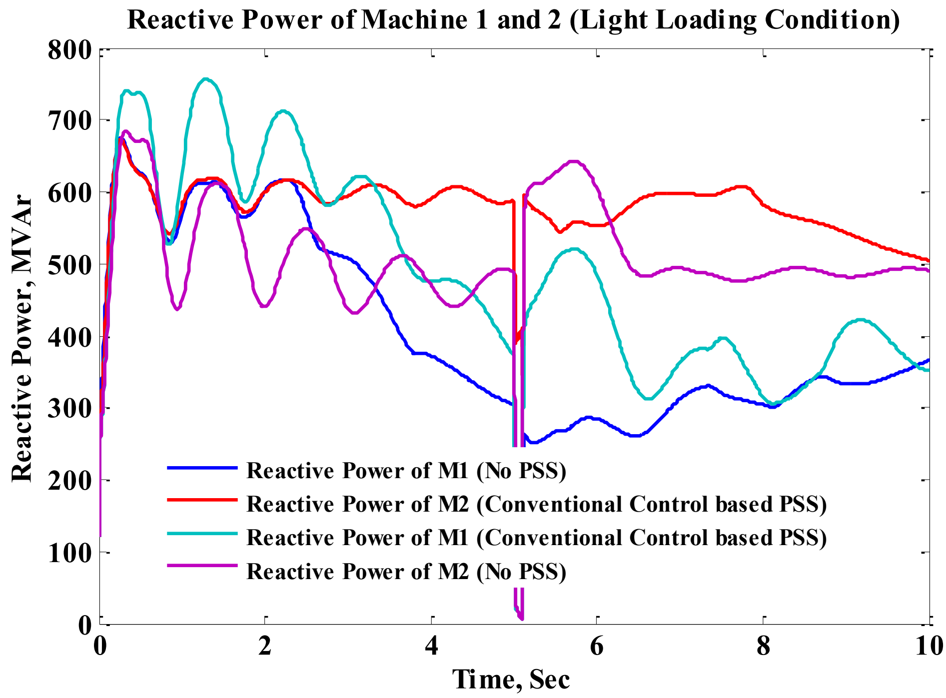


Fig. 4. 13Reactive power performance of PSS installed in multimachine system for light loading condition

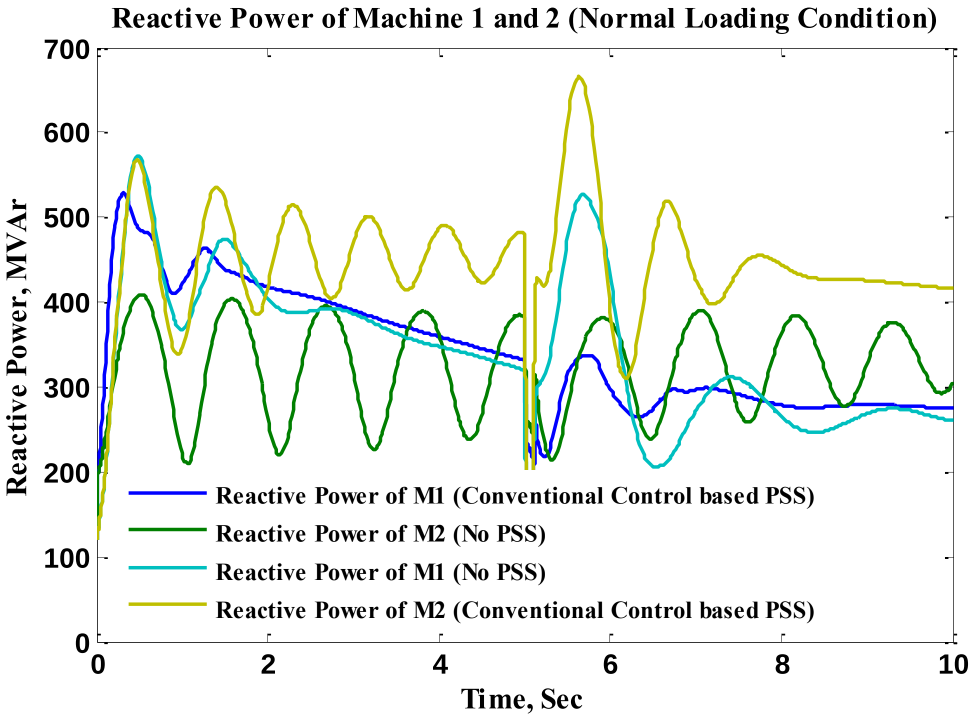


Fig. 4. 14Reactivepower performance of PSS installed in multimachine system for normal loading condition

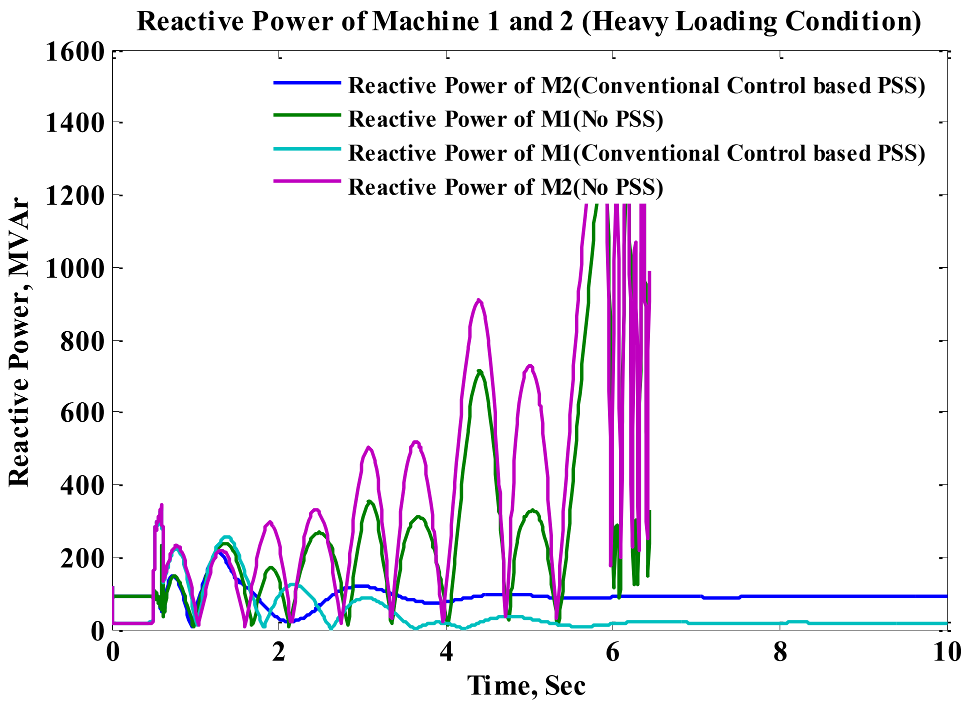


Fig. 4. 15 Reactive power performance of PSS installed in multimachine system for heavy loading condition

Voltage comparisons with and without PSS is shown in Fig. 4.7, 4.8 and 4.9. it shows that the value of voltage is increased by installing power system stabilizer in the multimachine system.

4.3. Simulation of single machine infinite bus system with FPSS

The Simulink model of Fuzzy PSS for damp out small signal oscillations is shown below. Here, two inputs speed deviation and acceleration given to Fuzzy logic controller. And scaling factor is provided for both input and output which determine the extent to which controlling effect is produced by the controller. Kin1= 1.8, Kin2=29.58 and Kout=1.05.

- **Single Machine Infinite Bus System**

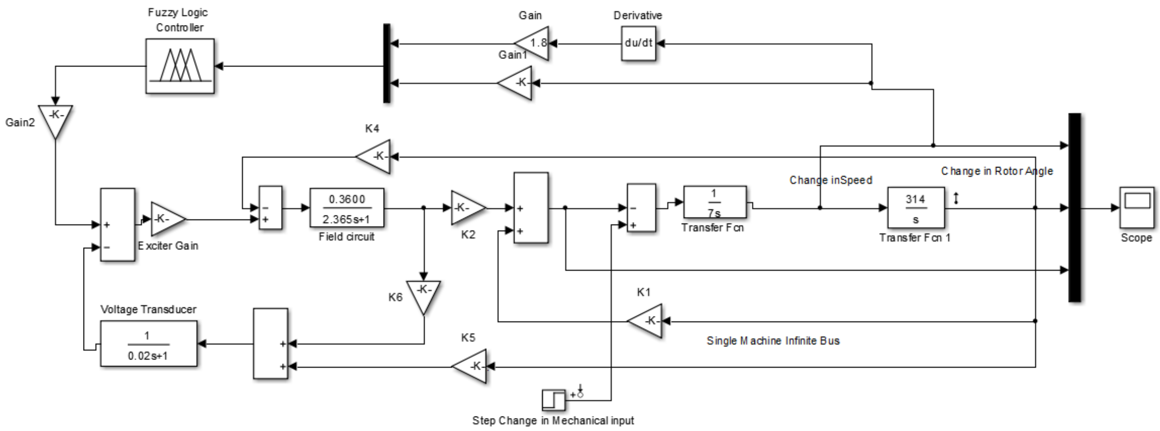


Fig. 4.16Simulink model for 5% change in mechanical torque input With FPSS

The system response for three different cases with Fuzzy based PSS is shown below. It is observed that fuzzy controller provides good damping and has less settling time and overshoot to reach in steady state condition for all operating conditions (7). It improves the dynamics over wide range of operating conditions.

- **Multimachine System**

Fuzzy logic control has emerged as a powerful tool and it start to be used in various power system applications. The application of fuzzy logic control technique appears to be most suitable one whenever a well-defined control objective cannot specified, the system to be controlled is a complex, or its exact mathematical model is not available [1-3]. Most power system stabilizers are used in electric power systems to employ the classical linear control theory approach based on a linear model of a fixed configuration of the power system. Such a fixed-parameter PSS, called a conventional Power System Stabilizer (CPSS). [4, 5] Low -frequency oscillations are a common problem in large power systems. A power system stabilizer (PSS) can provide a supplementary control signal to the excitation system and/or the speed governor system of the electric generating unit to damp these oscillations [6]. Most (PSS) is used in electrical power system employing the classical linear control theory approach based on a linear model of affixed configuration of power system. Such affixed parameter PSS, is also called conventional PSS. It is widely used in power system and has made a great contribution in enhancing power system dynamics.

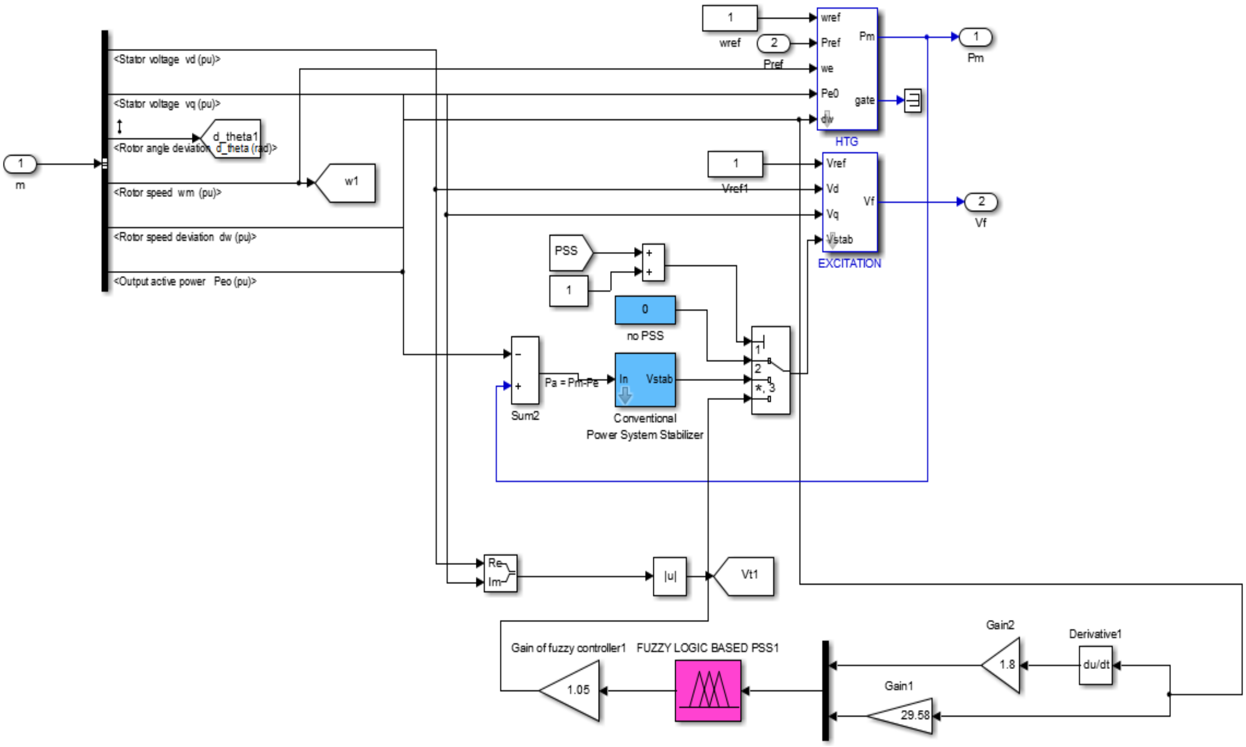


Fig. 4.17Simulink model for multimachine system With FPSS

The parameters of CPSS are determined based on a Linearize model of power system around a nominal operating point. Because power system are highly nonlinear systems, with configurations and parameters that change with time, the (CPSS) design based on the Linearize model of the power system cannot guarantee its performance in a practical operating environment.

4.4. Simulation of ANN based PSS

- **Single Machine Infinite Bus System**

The Simulink model of ANN based PSS for damp out small signal oscillations is shown below. During normal load condition with artificial neural network rise time 1.00 sec, settling time 2.5 sec, peak time 1.11 sec, so settling time is reduced as compared to conventional power system stabilizer and fuzzy based PSS.The stabilizer output is obtained by applying a particular rule expressed in the form of membership functions (7). Finally the output membership function of the rule is calculated. This procedure is carried out for all of the rules and with every rule an output is obtained [24].

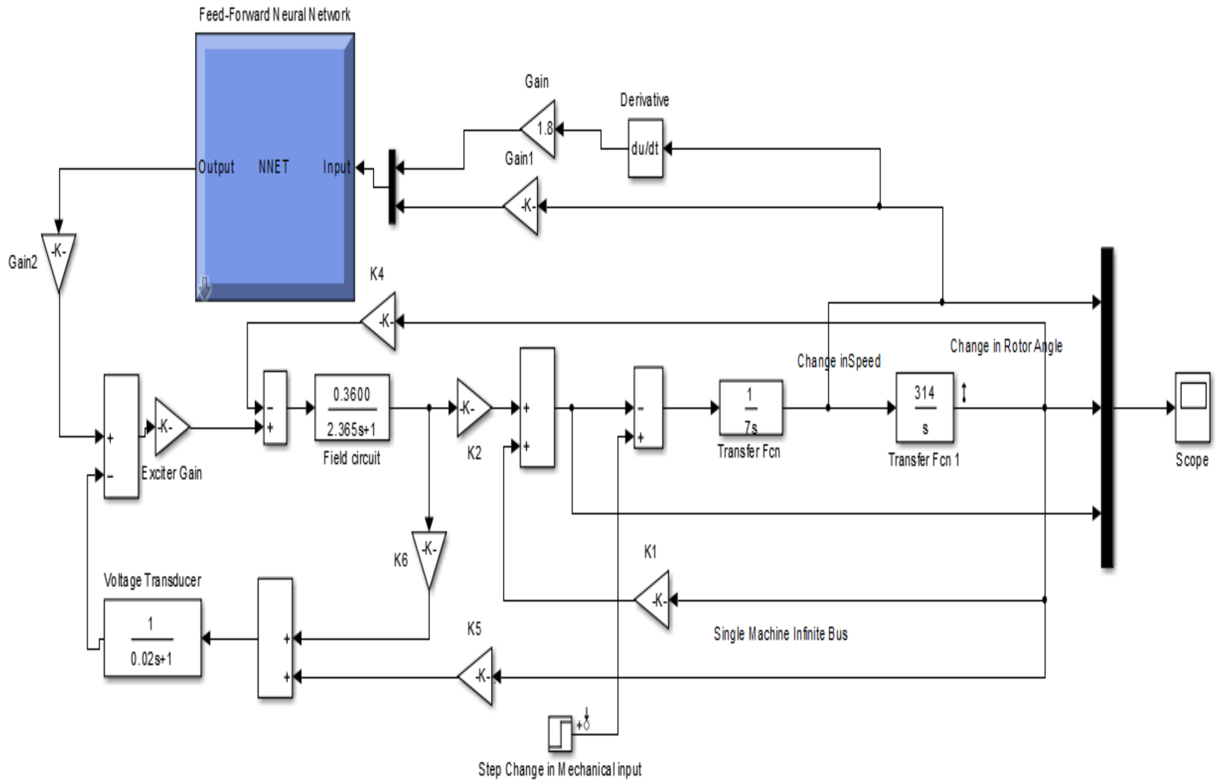


Fig. 4.18Simulink model for 5% change in mechanical torque input With ANNPSS

- **Multimachine System**

Training of neural network has important role in stabilizer design based on neural network. Training must contain extend area of generator operating point. The Simulink model of

Multimachine system with ANN based PSS for damp out small signal oscillations is shown below [25] [26].

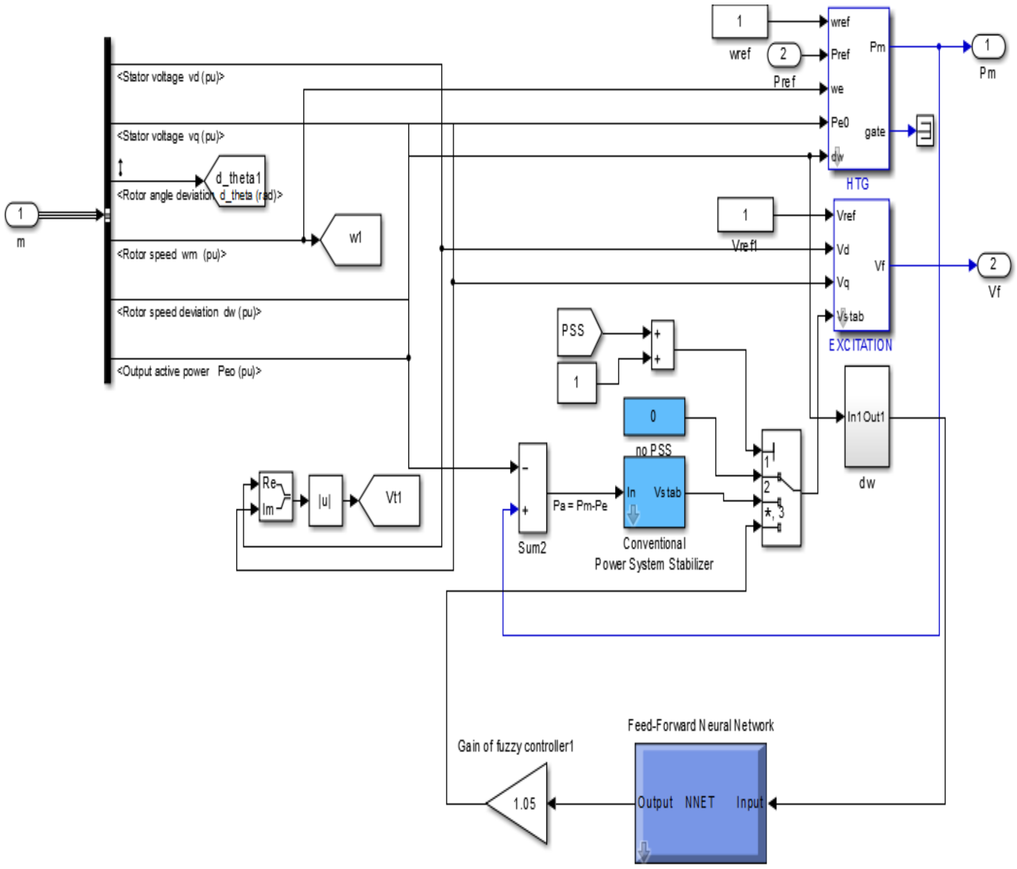


Fig. 4.19Simulink model for Multimachine system with ANNPSS

The stabilizer output is obtained by applying a particular rule expressed in the form of membership functions. Finally the output membership function of the rule is calculated. This procedure is carried out for all of the rules and with every rule an output is obtained.

4.5 Comparative assessment of Intelligent and smart controller performance

4.5.1 Comparison of various controller design for SMIB system

In order to investigate the performance of single machine infinite bus system has been studied with Conventional PSS, Intelligent control based PSSand Smart control based PSS cases are

(7) Paper entitled "Improvement of Transient stability of SMIB system using Fuzzy & ANFIS based STATCOM damping stabilizer", Target -2014, Institution of electrical and electronics engineers, Vadodara, March 8th 2014.

compared with each other. These results are presented for the rotor speed, torquevariations and Angular Position of the system.As the system is stable with both positive and negative K5, the limitations of PSS are taken care by applying power system stabilizer. With Power system stabilizer the rotor mode damping ratio and damping coefficient increases with increase in exciter gain. It depicts that angular speed and angular position stabilizes to a particular value with very few oscillations by using Smart control of PSS. By comparative analysis ANN proves improved performance against Conventional control &intelligent control.

4.5.2 Comparison of control parameters of SMIB system

The performance of different PSS is compared, based on the settling time, peak time & rise time. By this type of controller PSS design technique the oscillations are damped out quickly and the stability is improved from marginally stable to completely stable system. Time domain requirements are satisfied with overall improvement in stability. However, this scheme involves updating controller parameters in real time using a system identifier which can be complicated and expensive.

Table 4. 3Comparison of control parameters of SMIB system

System	Performance parameters	Controller Techniques	Tr	tp	ts
SMIB system	Torque variation	Conventional control	1.22 s	1.47 s	5.2 s
		Intelligent control	1.21 s	1.45 s	2.8 s
		Smart control	1.20 s	1.40 s	2.2 s
	Rotor angle	Conventional control	1.28 s	1.6 s	5.5 s
		Intelligent control	1.26 s	1.56 s	3.5 s
		Smart control	1.23 s	1.5 s	2.4 s
	Change in speed	Conventional control	1.11 s	1.24 s	4.8 s
		Intelligent control	1.02 s	1.14 s	3.2 s
		Smart control	1.0 s	1.12 s	2.7 s

From the simulation it is observed that real time power system stabilizer the system can be stabilize up to certain limit and maintain the synchronism between the inter connected area and protect the whole power system from cascade tripping which is very serious matter.

4.5.3 Comparison of controller design for Multimachine system

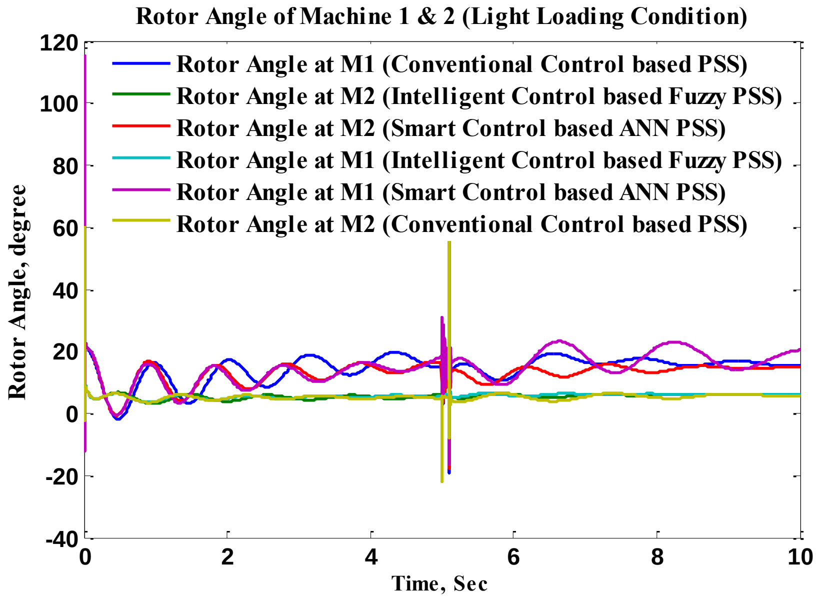


Fig. 4.20Rotor angle comparisons for multimachine system (Light Loading Condition)

Power transferred from the rotor to the stator through the magnetic field depends on the sine of the angle between the rotor magnetic field and that developed in the stator. When the two are in alignment, no power is transferred, and when the angle is 90 degrees with the rotor leading, the power transfer is a maximum.

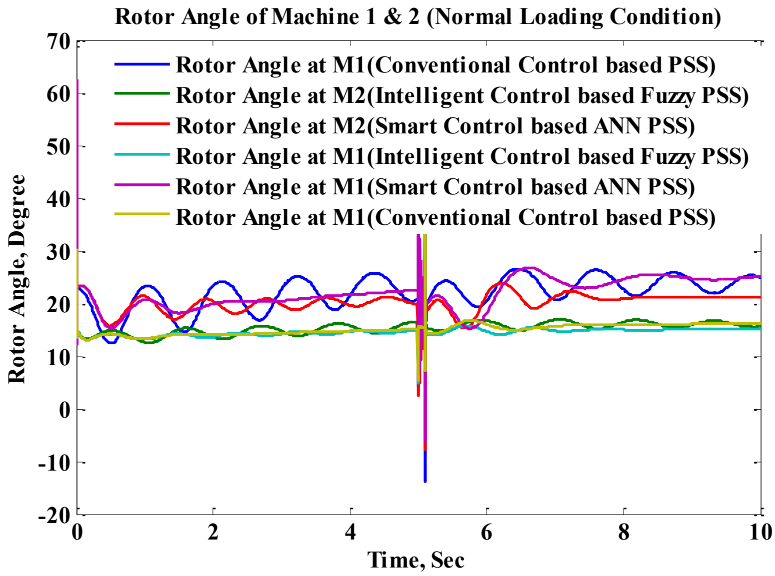


Fig. 4.21Rotor angle comparisons for multimachine system (Normal Loading Condition)

The measurements of rotor Angle for different loading conditions of Machine 1 & Machine 2 as shown in Fig. 4.20, Fig. 4.21 and Fig. 4.22.

When synchronised to an external grid, the stator field is related to the terminal voltage and rotates at a speed set by the entire electrical system. At any load between the two, the angle will remain constant as long as the power drawn from the alternator matches the power supplied by the turbine. If the turbine power increases slightly, the imbalance increases the energy in the rotor, and this causes it to speed up very slightly. As a result, the rotor moves a little ahead of the stator field, and the angle between the two fields increases. In turn, the electrical power delivered to the alternator increases and the balance is restored.

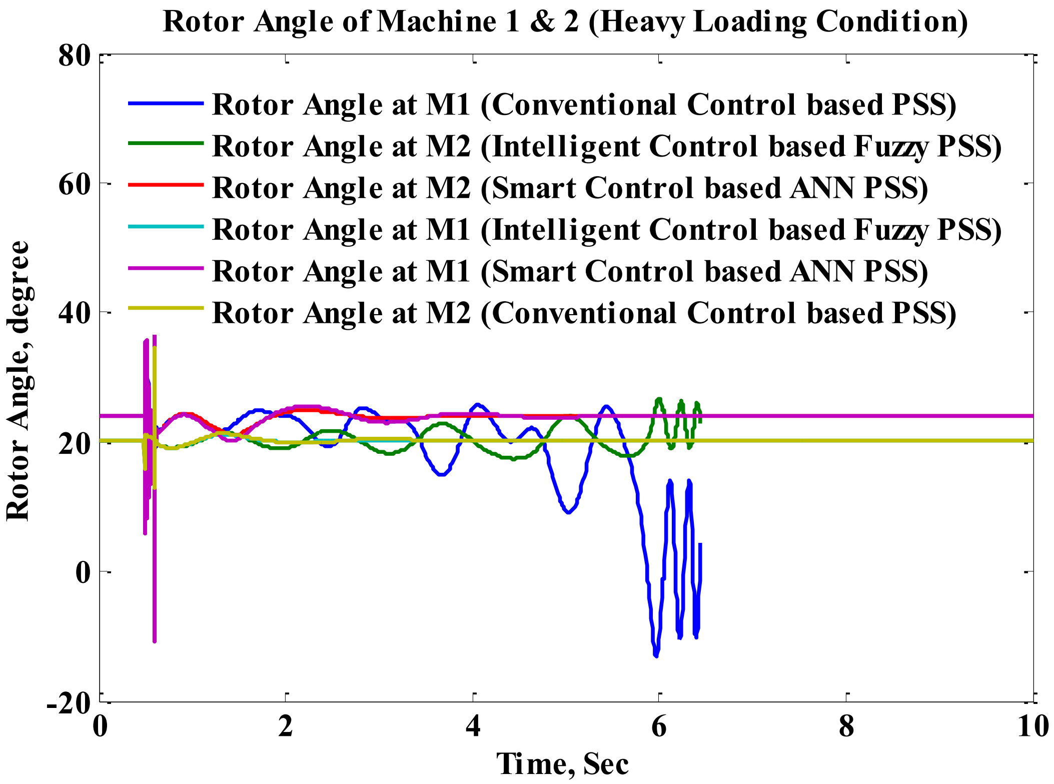


Fig. 4.22Rotor angle comparisons for multimachine system (Heavy Loading Condition)

In the new balance condition, the rotor goes back to synchronous speed but at an increased angle. If electrical load increases slightly, the extra power is drawn in the first instance from the rotor which slows it down, decreasing the load angle and restoring the balance.The change is a dynamic process, and if either the mechanical load increases by a relatively large amount or (more commonly) the electrical load should fall suddenly, the rotor angle will oscillate before stabilizing. Under these conditions it is possible for the rotor angle to exceed 90 degrees, and the electrical power out will then start to fall. The result will be noisy and possibly quite violent as the alternator goes into pole-slipping

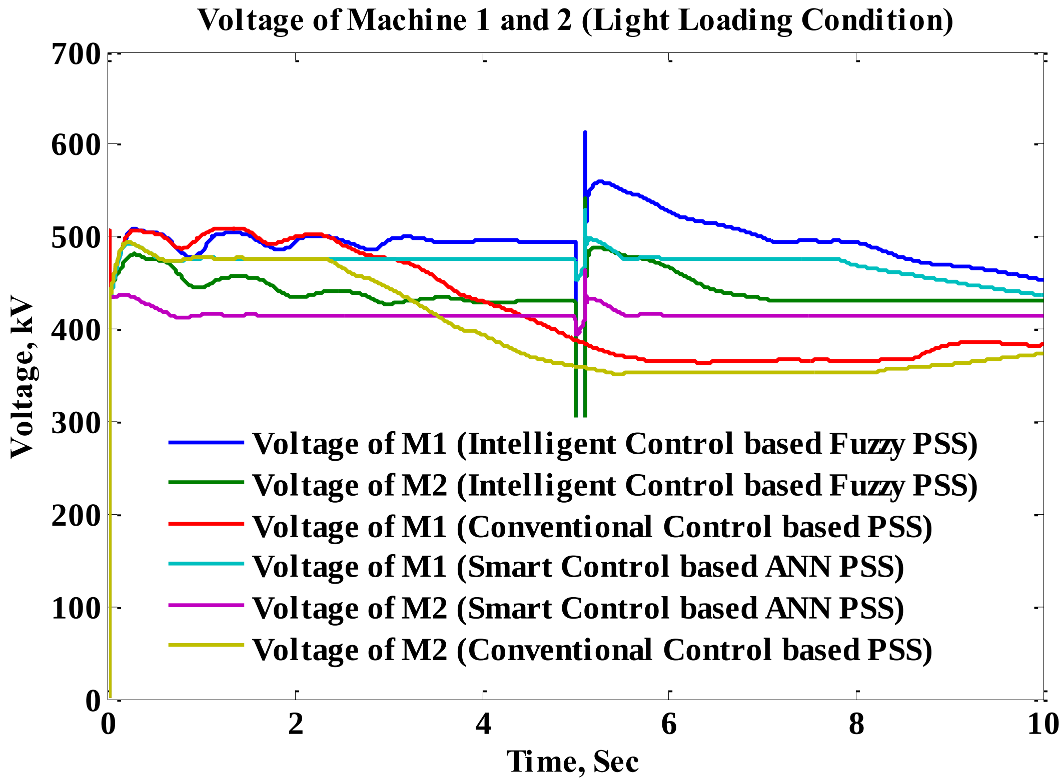


Fig. 4.23Voltagecomparisons for multimachine system(Light Loading Condition)

Voltage stability depends on the balance of reactive power demand and generation in the system.The line capacity is 500 kV. V2 is affected mainly by changes in Q and less affected by changes in P. So the value of voltage at Breaker 1 > Voltage at Breaker 2. The comparison of without PSS and with PSS indicates that by using power system stabilizer the value voltage is maintained. All the results comparisons of voltages as shown in Fig. 4.23 to Fig. 4.25.

(4) Paper entitled, "Design of fuzzy logic power system stabilizers in a multimachine power system using Particle swarm optimization based optimal control algorithm", Discovery International Daily journal ISSN 2278 – 5469.

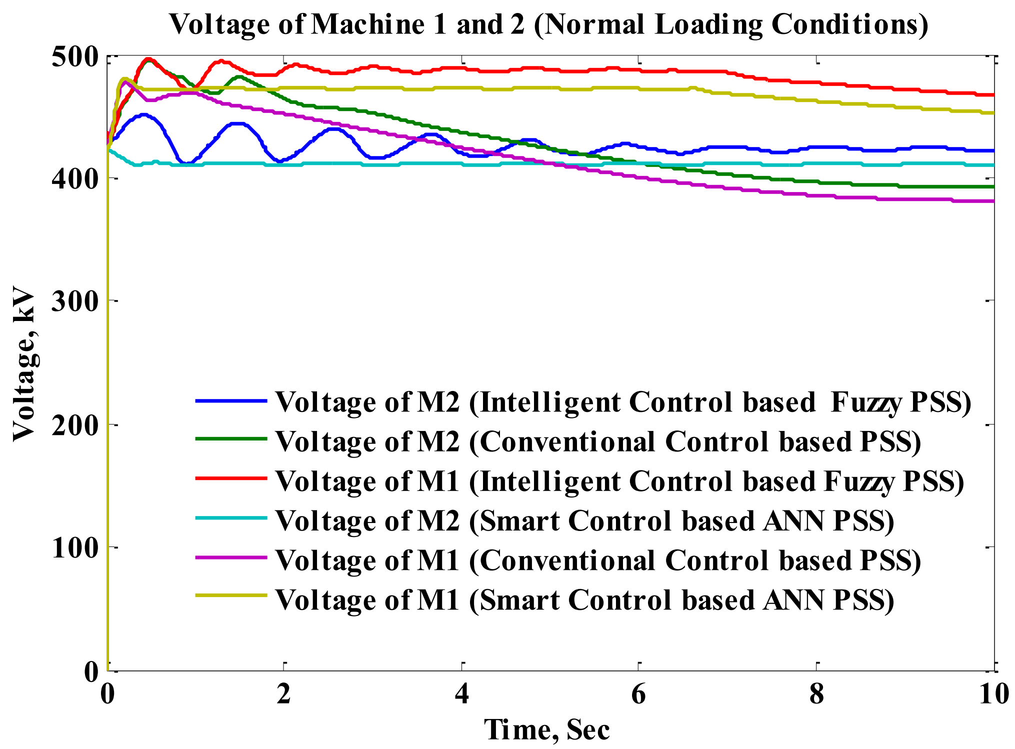


Fig. 4.24Voltagecomparisons for multimachine system (Normal Loading Condition)

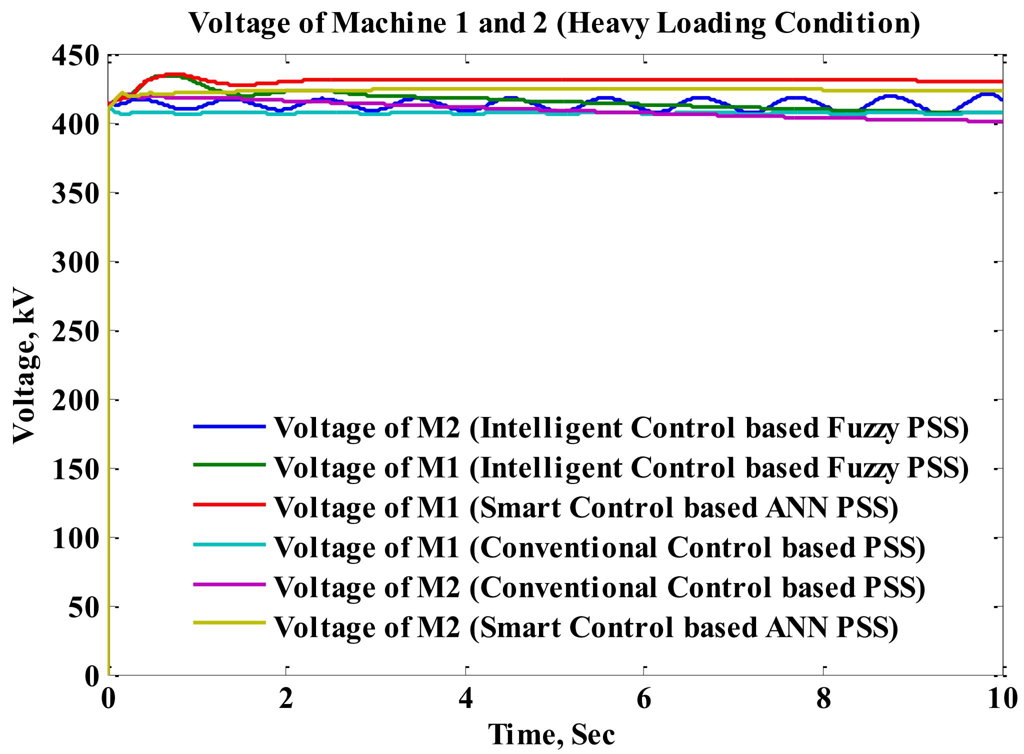


Fig. 4.25Voltagecomparisons for multimachine system (Heavy Loading Condition)

Table 4. 4 Voltage measurement under different loading conditions

Load MW	Voltage kV					
	Conventional PSS	Intelligent Control PSS	Smart Control PSS	Conventional PSS	Intelligent Control PSS	Smart Control PSS
	V at M1	V at M1	V at M1	V at M2	V at M2	V at M2
1000	436	463	473	430	451	460
3000	423	459	467	410	442	452
5000	392	445	458	380	425	430

Above table shows that as the value of load is increase, voltage will goes on decrease. Also By using Smart Control with PSS Voltage is stabilized up to certain limit.

The rotor angle oscillations are responsible for real power oscillations in the system. So the Fig 4.26, Fig 4.27 and Fig. 4.28 shows the performance comparisons for the real power measurements for different loading conditions at Machine 1 and Machine 2.

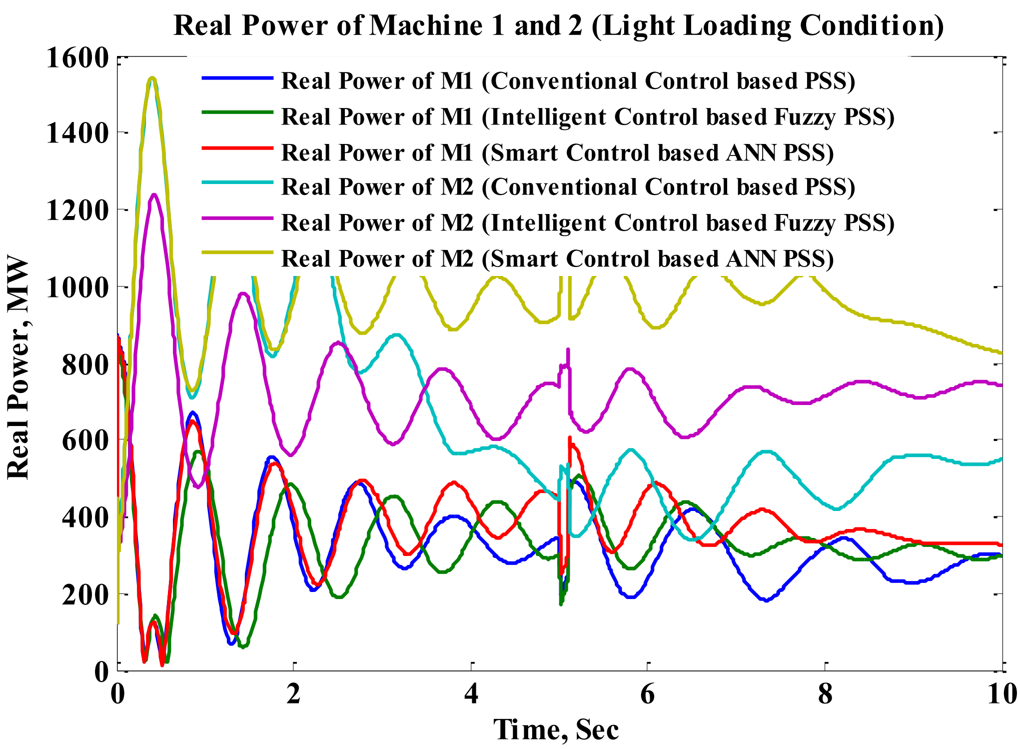


Fig. 4.26Real power comparisons for multimachine system (Light Loading Condition)

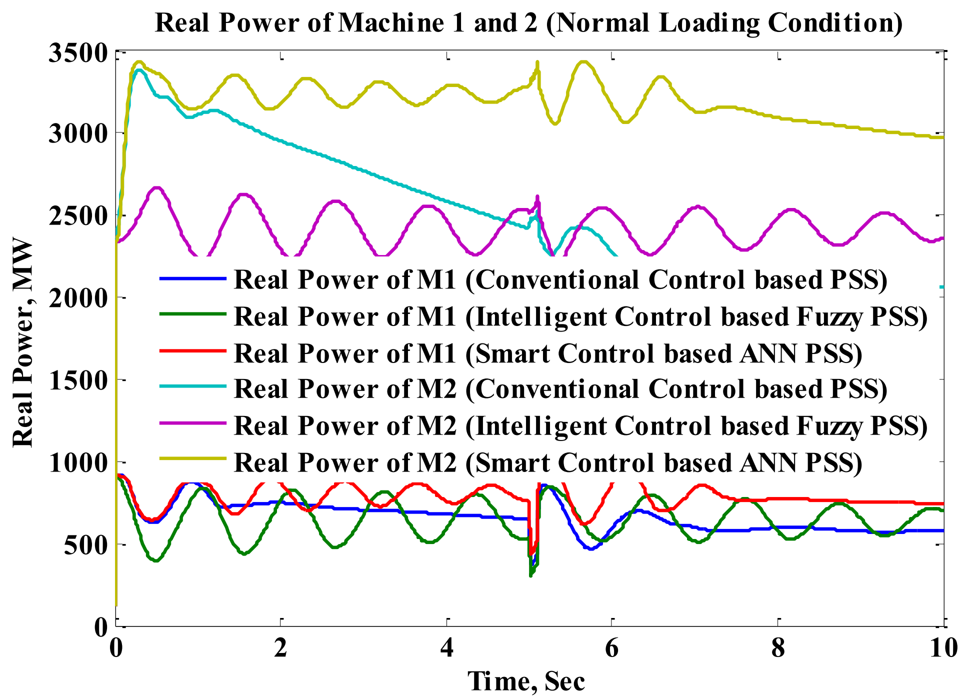


Fig. 4.27Real power comparisons for multimachine system (Normal Loading Condition)

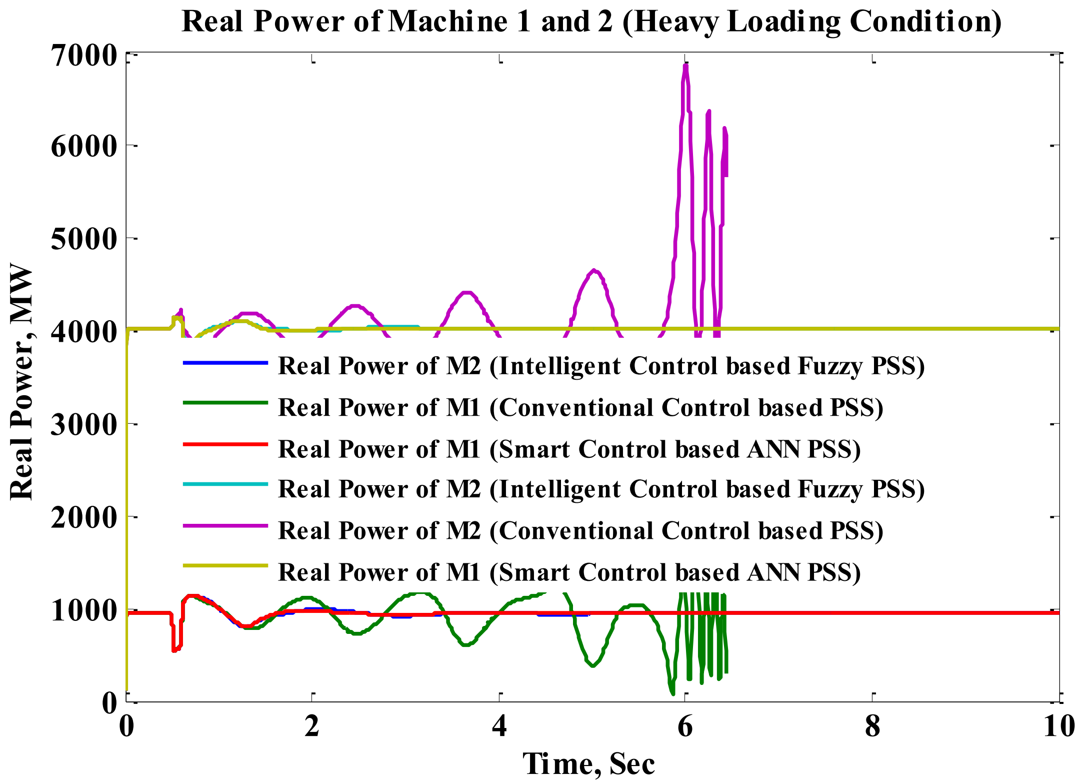


Fig. 4.28Real power comparisons for multimachine system(Heavy Loading Condition)

Table 4. 5 Real Power data

Load MW	Real Power MW					
	Conventional PSS	PSS with Intelligent Controller	PSS with Smart Controller	Conventional PSS	PSS with Intelligent Controller	PSS with Smart Controller
	P at M1	P at M1	P at M1	P at M2	P at M2	P at M2
5000	941	944.9	947.5	3752	3922	4022
3000	597.4	697.4	742.7	2063	2363	2968
1000	207.4	327	399.1	540	688.3	825.8

The conclusion drawn from the results of real power and reactive power that,

Complex power for AC power systems is defined to be

$$S = P + j\,Q \tag{4.1}$$

$$S = \sqrt{P^2 + Q^2} \tag{4.2}$$

Now consider two Machine M1 and M2

$$S = \sqrt{(P(G1) + P(G2))^2 + (Q(G1) + Q(G2))^2} \tag{4.3}$$

where, S is the apparent power [VA], P is the real power [watts] and jQ is the reactive power [vars] and j is the complex operator.

From the Result of Real power for Machine 1 and Machine 2shows that by using Smart controller with PSS gives better performance. As the increasing the loading conditions real power is also increased.

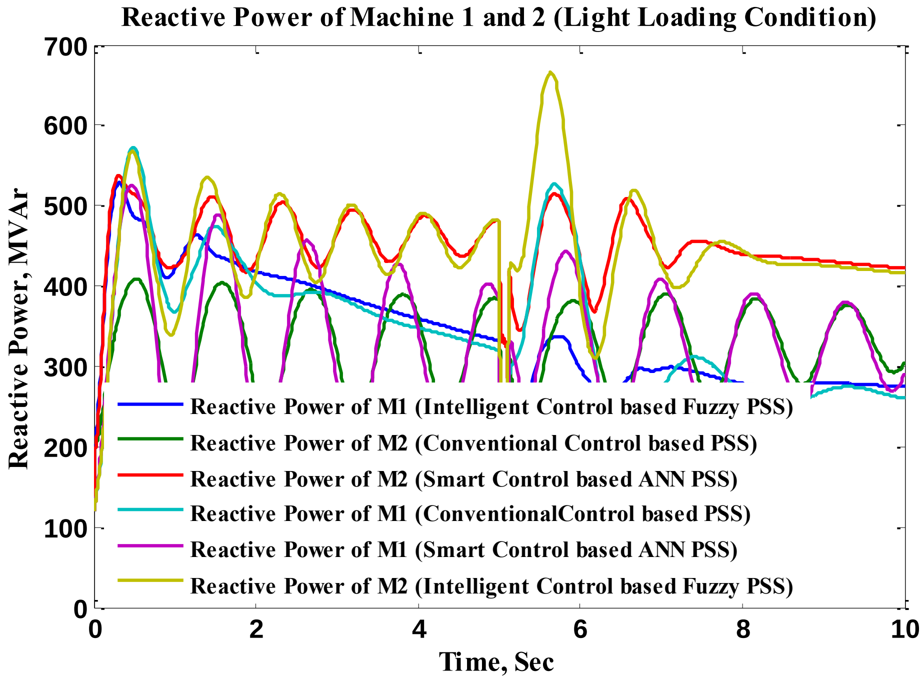


Fig. 4.29Reactive power comparisons for multimachine system(Light Loading Condition)

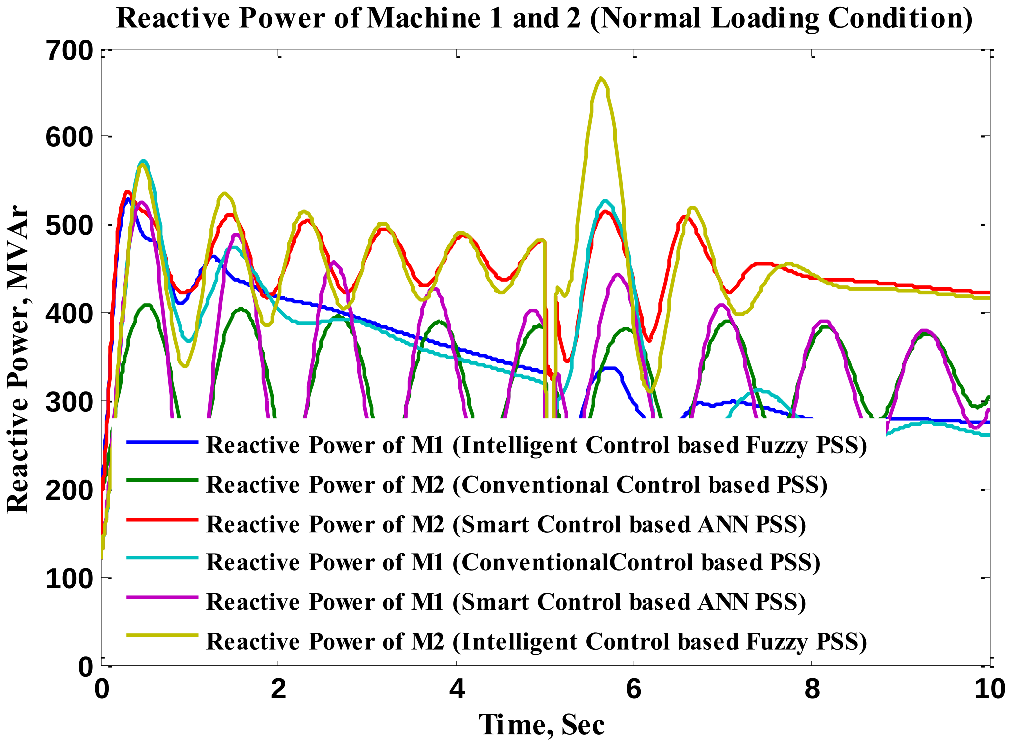


Fig. 4.30Reactive power comparisons for multimachine system (Normal Loading Condition)

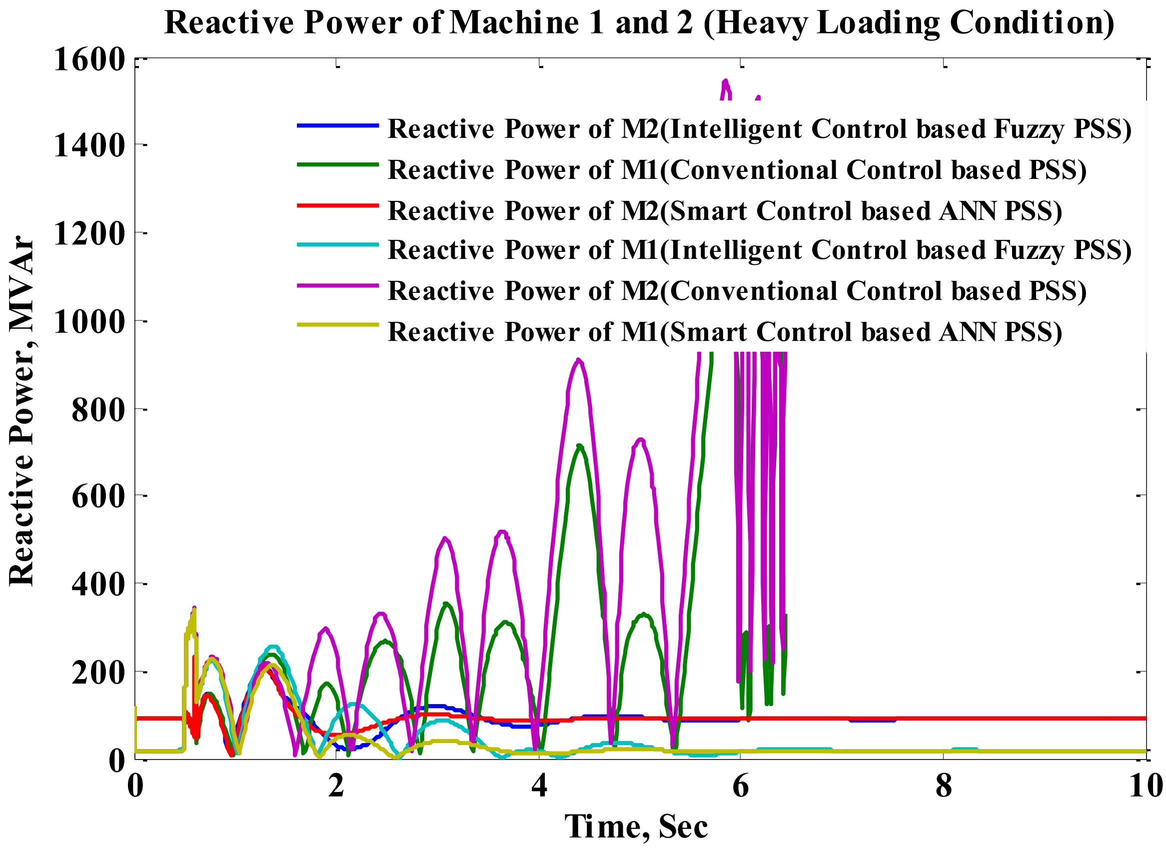
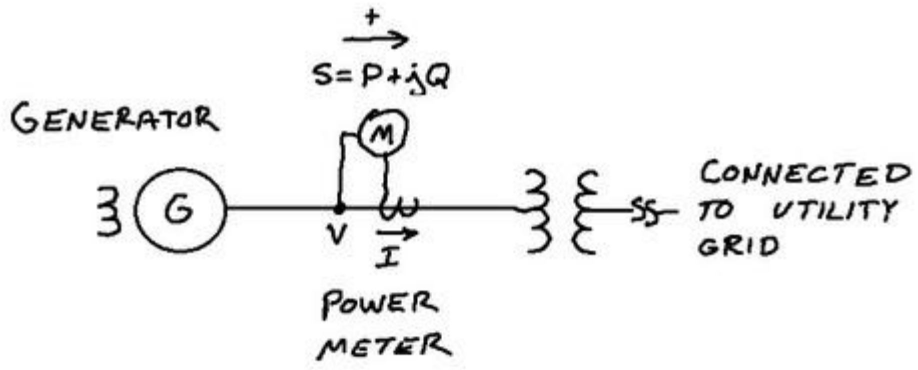


Fig. 4.31Reactive power comparisons for multimachine system (Heavy Loading Condition)

Table 4. 6Reactive power data

Load MW	Reactive Power MVAr					
	Conventional PSS	PSS with Intelligent Controller	PSS with Smart Controller	Conventional PSS	PSS with Intelligent Controller	PSS with Smart Controller
	Q at M1	Q at M1	Q at M1	Q at M2	Q at M2	Q at M2
5000	350.6	85.54	89.28	619	9.36	17.53
3000	303.8	303.8	422	289.5	289.5	415.9
1000	253.4	465.1	504.8	290.9	351	445.2

Negative reactive power –jQoccurs in quadrants (3) and (4). For a generator application, only quadrant (4) applies since the real power P must be positive. Negative reactive power generated means that reactive power is flowing from the utility grid (source) to the generator.



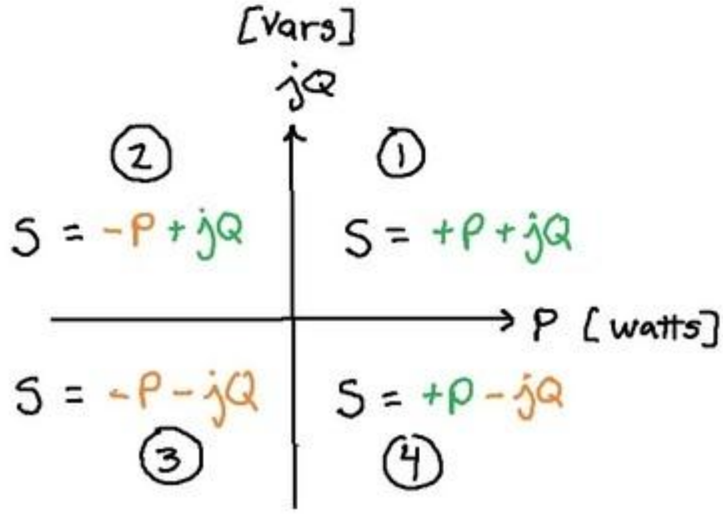


Fig. 4. 32four quadrants operation of power meter connected to register positive power

This occurs whenever the generator field is under-excited or if an induction generator is being used.To develop a magnetic field in motor/generator system needs a reactive power support. The reading itself suggest that when intelligent control based PSS is applied, it gives reactive power support and hence voltage reading is also increase. To transmit a power at a larger distance these voltage support will be beneficial. As both the generators interfaced with the intelligent control based PSS are delivering more real power i.e. also an advantage.

So the below Fig. 4.29 to Fig. 4.31 shows the performance comparisons for the reactive power measurements for different loading conditions at Machine M1 and Machine M2.

Above Calculation shows that load is nearly equal to the generation. i.e.

$$\sqrt{(PL)^2 + (QL)^2} = \sqrt{(P(G1) + P(G2))^2 + (Q(G1) + Q(G2))^2} \qquad (4.4)$$

Calculation of Apparent Power is shown in below Table.

Table 4. 7 Apparent power data

Load MW	**Apparent Power**		
	Conventional Control based PSS	**Intelligent Control based PSS**	**Smart Control based PSS**
5000	**3958**	**4132**	**4989**
3000	**2450**	**2780**	**2960**
1000	**940**	**967**	**986**

4.5.4 Comparison of control parameters of Multimachine system

From Table 4.9 which shows Rise Time, Peak Time and Settling Time comparisons. The response of thesystem for the given disturbance is growing in oscillations, so that the settling time is more than 7 seconds. So a controller must be designed to make the system stable and also to improve the damping. When PSS is connected to the system it improves the stability of the system and the oscillations are reduced. The settling time is reduced less than 3seconds. Among the different PSS used for in SMIB system the Real Time PSS performs better in reducing the settling time and maximum overshoot of rotor speed, torque variations and Angular Position is reduced while satisfying the time domain specifications (8).

(9) Paper under preparation entitled,"Multiobjective optimization of Single machine infinite bus system for power system stabilization", IEEE International conference on communications, ICC 2017, May 21-25, 2017

Table 4. 8Comparison of control parameters of Multimachine system

System	Performance parameters	Controller Techniques	tr	tp	Ts
Multimachine System	Torque variation	Conventional control	1.16 s	1.36 s	7.1 s
		Intelligent control	1.11 s	1.24 s	3.2 s
		Smart control	1.10 s	1.25 s	2.0 s
	Rotor angle	Conventional control	1.36 s	1.35 s	6.5 s
		Intelligent control	1.28 s	1.25 s	3.0 s
		Smart control	1.24s	1.24 s	2.2 s
	Change in speed	Conventional control	1.04 s	1.13 s	7.4 s
		Intelligent control	1.01 s	1.2 s	3.15 s
		Smart control	1.0 s	1.12 s	2.1 s

From the above comparison table, it is observed that control parameters such as rise time, peak time and settling time can be reduced by using Smart control techniques compared to Conventional control and intelligent control for SMIB & Multimachine system.

4.6 Concluding Remarks

In this chapter, new techniques for control performance assessment are developed for power system stabilization considering Single machine Infinite bus system and Multimachine system. Intelligent control and Smart control are used to identify the best control algorithm for complex system.