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POWER SYSTEM STABILITY ANALYSIS OF MULTIMACHINE SYSTEM USING JAYA ALGORITHM

Swati Rathore[1], Raunak Jangid[2], Kapil Parikh[3]
E-Mail id: raunak.ee85@gmail.com, swatirathore05@gmail.com
[1]M.Tech Student, [2,3]Assistant Professor, Electrical Engineering, SITE, Nathdwara (Rajasthan)

Abstract: Addressing the stability problem through Single machine infinite bus system is a quite simple and easy to understand. For a more practical approach Multi-machine system would be more beneficial giving the close insight of the real world situation of instability. In such a situation a power system must be able to maintain frequency and voltage level. SO is the case with presented work where a multi-machine system is considered under low frequency oscillations. If such an oscillation persists for a long period of time could lead to separation of a system in the absence of appropriate. It could be damped out by Power system Stabilizers (PSS) which is very effective and generally used controller in such a case. It enhances the stability limit and damping capability of the system. But it performance could further be optimized by the use of suitable optimization method. The method used here is the artificial intelligence (AI) based JAYA algorithm. The presented work uses the platform provided by MATLAB/SIMULINK to develop the multi machine system consisting 3 machines and 9 bus system, hence making it a 3 machine 9 bus system. This system in cooperates the JAYA based PSS which was analyzed under normal, light and heavy loading conditions respectively by applying three phase fault. The results are obtained in terms of speed deviation, change in generator speed and stabilizing signal deviation settling time. The results are compared with the results of system using Conventional PSS and system without any controller to verify its effectiveness and robustness.

1. INTRODUCTION

Power system stability is the most important aspects in system operations. It is defined whether or not the system can settle down to a new operating point after the occurrence of a disturbance. Power system stability is defined in as follows:

Power system stability is the state of equilibrium where systems regain its initial operating condition after intact with external disturbances, so the entire system remain uninterrupted and stable.

The electrical power system is a dynamic interconnected system which may include thousands of electric components and be spread over large geographical areas. There are many benefits of interconnected power systems:

- Provide many blocks of power and increase reliability of the electrical system.
- Reduce the number of machines which are required both for operation at peak load and required as spinning reserve to take care of a sudden change of load.
- Provide economical source of power to consumers.

1.1 Multi Machine Systems

It can be designed and modeled same as single machine system with following sets of assumptions.

- Every synchronous machine in the system is represented by its constant voltage E behind X_d. Here, saliency and flux has been neglected.
- Constant input power.
- Admittances to ground for all loads are equivalent via pre fault bus voltages.
- Ignoring asynchronous effect along with damping effect.
- $\delta_m=\delta$

All machines in a single station will swing simultaneously, hence called as coherent machine and can be taken as single machine.

1.2 Objective Function

Using the given optimization technique PSS parameters are tuned to get overall improved dynamic performance of the system. For the optimization problem the objective is shown as the multi objective function which is based on Integral Time Absolute Error (ITAE). It consists of the damping factor and damping ratio. The formulation of objective function J is shown below so as to minimize:

$$J = \int_0^{t_{sim}} t(|\Delta\omega_1| + |\Delta\omega_2| + |\Delta\omega_3|)dt$$

Here, ω_1, ω_2 and ω_3 are the speed of respective machines in 3 machine 9 bus system.
α=10
NP=total operating points
The aim is to minimize this objective function in order to better the system response.
Minimize J subjected to

$$K_i^{min} \ll K_i \ll K_i^{max}$$
$$T_{1i}^{min} \ll T_1 \ll T_{1i}^{max}$$
$$T_{3i}^{min} \ll T_{3i} \ll T_{3i}^{max}$$

2. MATHEMATICAL MODELING OF POWER SYSTEM & POWER SYSTEM STABILIZER

2.1 Classical Model of Multi Machine System

Fig. 2.1displays the multi machine system where n machines are assumed. Here, 0 is the reference node whereas the node numbered 1, 2. . . n are internal machine buses. Nodes are connected to each other and to the node 0 via passive impedances. In classical stability studies while transient E_i, i= 1, 2, ..., n are kept constant.
The passive electrical network described has n nodes with active sources. The admittance matrix of the n-port network from the terminals of the generators, is defined by
$\bar{I} = \bar{Y}\bar{E}$
$\bar{Y}$ has diagonal elements (Y_{ii}) and off-diagonal elements (Y_{ij}).
$\bar{Y}_{ii} = Y_{ii}\angle\theta_{ii} = G_{ii} + jB_{ii}$ driving point admittance for node i
$\bar{Y}_{ij} = Y_{ij}\angle\theta_{ij} = G_{ij} + jB_{ij}$ negative of the transfer admittance between nodes i and j
At node i power into the network (electrical power output of machine i), is given by $P_i = \mathcal{R}\varepsilon\bar{E}_i\bar{I}_i^*$

$$P_{ei} = E_i^2 G_{ii} + \sum_{j=1\ j\neq i}^{n} E_i E_j Y_{ij} cos(\theta_{ij} - \delta_i + \delta_j)$$

$$P_{ei} = E_i^2 G_{ii} + \sum_{j=1\ j\neq i}^{n} E_i E_j [B_{ij} sin(\delta_i - \delta_j) + G_{ij} cos(\delta_i - \delta_j)] \quad i=1,2,\dots n$$

The equations of motion are then given by

$$\frac{2H_i d\omega_i}{\omega_R dt} + D_i\omega_i = P_{mi} - E_i^2 G_{ii} + \sum_{j=1\ j\neq i}^{n} E_i E_j Y_{ij} cos(\theta_{ij} - \delta_i + \delta_j)$$

$$\frac{d\delta_i}{dt} = \omega_i - \omega_R \qquad i=1,2,\dots n$$

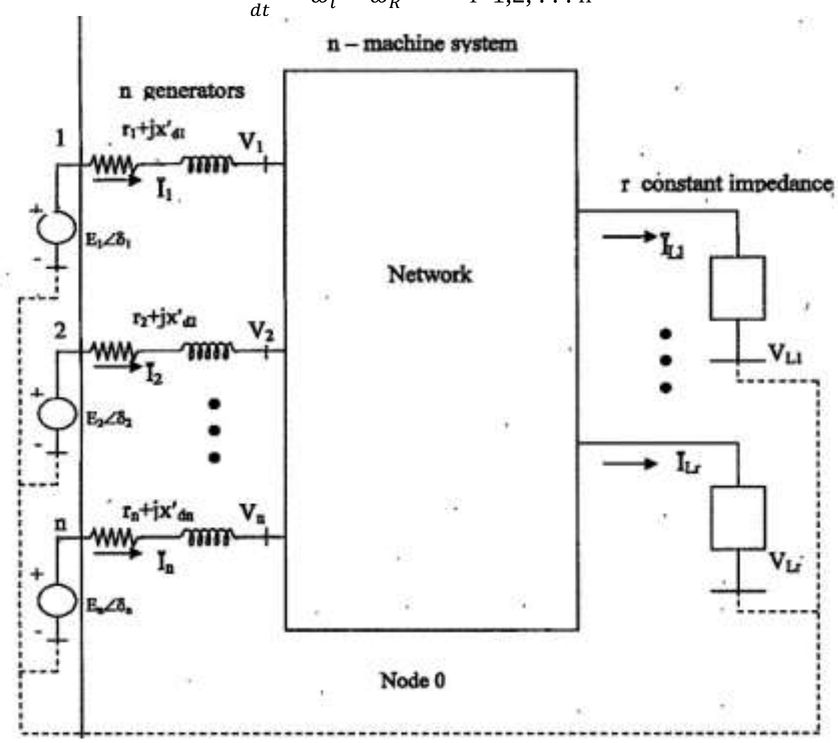


Fig. 2.1 Classical Model of Multi Machine System

It should be noted that prior to the disturbance i.e. at t =0

$$P_{ei0} = P_{mi0}$$

The subscript 0 is used to indicate the pre-fault conditions. This applies to all machine rotor angles and also to the network parameters, since the network changes due to switching during the fault.

The set of equations (8) is a set of n- coupled nonlinear second order differential equations. These can be written in the form,

$$x = f(x, x_0, t)$$

Where x is a vector of dimension (2n x 1),

$$x' = [\omega_1, \delta_1, \omega_2, \delta_2, \dots., \omega_n, \delta_n]$$

And f is a set of nonlinear functions of the elements of the state vector x.

2.2 Stability of 3 Machine 9 Bus System

To study and understand the power system stability synchronous machine classical model can be utilized during the time where system response mostly relies on rotating masses stored kinetic energy. The time period is oft the order of 1 sec or less than it. It is a very simple model. It can be carried out within a short span of time at minimum cost and also it needs minimum data.

Furthermore, these studies can provide useful information. For example, they may be used as preliminary studies to identify problem areas that require further study with more detailed modeling. Thus, a large number of cases for which the system exhibits a definitely stable dynamic response to the disturbances under study are eliminated from further consideration. In the above single line diagram there are three generating units G1, G2 and G3.

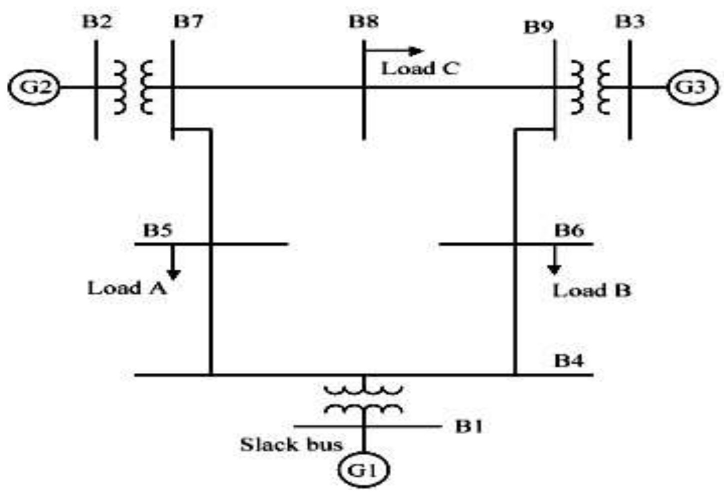


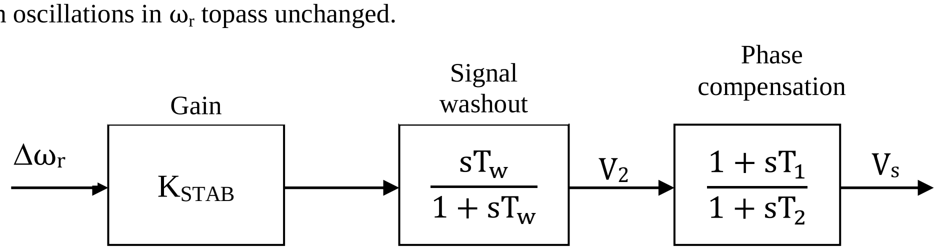
Fig. 2.2 Machine 9 Bus System Single Line Diagram

Also, there are 9 buses in the system (B1, B2, B3, B4, B5, B6, B7, B8 and B9). G1 is considered to be the largest unit out of the three which is connected to B1 and hence it is the slack bus. G2 and G3 are connected on bus B2 and B3 respectively. A, B and C are the loads connected on bus bar 5, 6 and 8. To understand the stability of present system some data is required. First of all it requires load flow study of the network so as to get P_m of the generators and then to have $E_i\angle\delta_{i0}$ for all the units. Load bus data is utilized to obtain loads equivalent impedances.

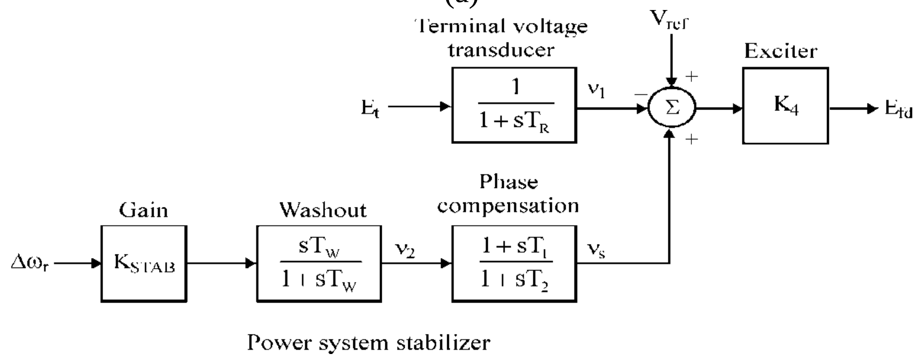
Then, to have system data which is H inertia constant and x_d' direct axis transient reactance. For initial network conditions transmission network impedances and sub transient switching. Also, to know the location and type of disturbance, its switching time and maximum time for the required solution.

2.3 Modeling of Power System Stabilizer (PSS)

The signal washout block serves as a high-pass filter, with the time constant T_w high enough to allow signals associated with oscillations in ω_r topass unchanged.



(a)



(b)

Fig. 2.3 (a) Basic Block Diagram of PSS (b) PSS With Exciter

Without it,steady changes in speed would modify the terminal voltage. It allows the PSS to respond only to changes in speed.

From the view point of the washout function, the T_w value is not critical which may be rangingfrom 1 to 20 seconds. The main consideration is that it should be long enough for passing Stabilizing signals at unaltered desired freequency, however, it should not be so long to cause undesirable generator voltage excursions while system is landing conditions. The stabilizer gain determines that how much PSS damping dampingmust introduce. The gain should ideally be set at a value which corresponds to maximum damping[5], however, it is often restricted by other considerations. The power system stabilizer with exciter basic block diagram is shown in fig. 2.4. The power system considered here for study receives control command from PSS via exciter. The excitation system with PSS taken here is IEEE type STI. Where,

K_A= Amplifier gain of the excitation system,

T_A=Amplifier time constant of the excitation system

V_{ref}=Reference Voltage

V_t= Generator Terminal Voltage

$\Delta\omega_i$= Normalized speed deviation as ith PSS input signal

U_i=Supplementary stabilizing signal as output signal

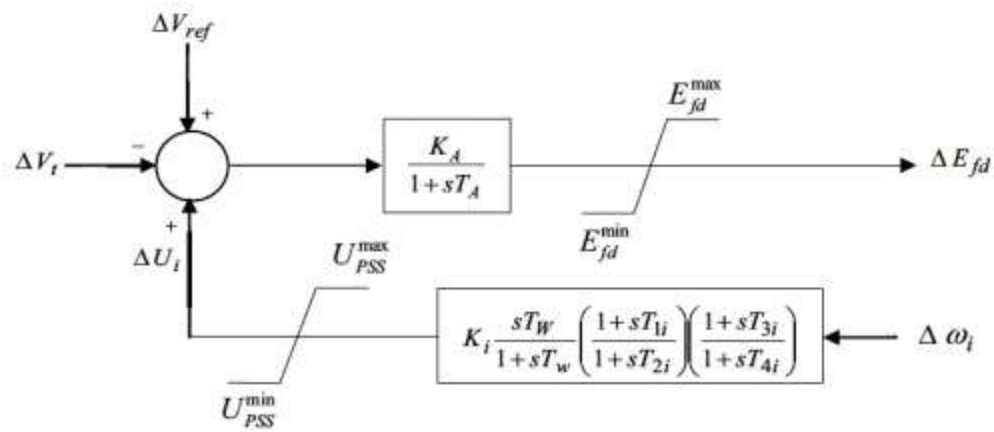


Fig. 2.4 Structure of Excitation System with PSS

PSS transfer function,

$$U_i = K_i \frac{sT_w}{1 + sT_w}\left[\frac{(1 + sT_1)(1 + sT_3)}{(1 + sT_2)(1 + sT_4}\right]$$

Previously, T_{wi} is used as a high pass filter so as to leave signals having range from 0.2 Hz to 2 Hz to pass without any change. These are associated with the oscillations of rotor. Generally the range is from 1s to 20s. The lead lag transfer function compensates for the phase lag existing between the PSS output and control action. The control action is the electrical torque. Hence, justifying the use of K_i, a wash out block with T_w and 2 blocks of lead lag.

2.4 Structure of PSS

The conventional lead–lag structure is picked in this study as a Conventional PSS (CPSS). The CPSS controller model structure is demonstrated in fig. 2.5.

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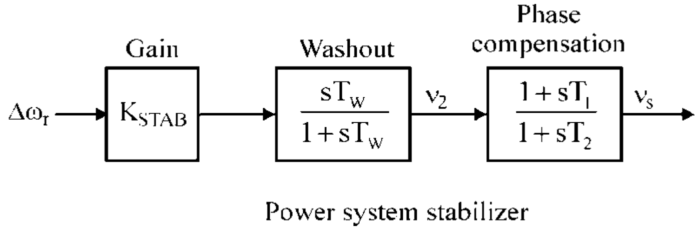

Fig. 2.5 Power system stabilizer (PSS) Structure

It has gain block (gain K_T), a signal washout block and phase compensation block of two-stage as displayed in figure. For the compensation of phase lag between input and the output signals for the appropriate phase-lead characteristics phase compensation block is employed here. The purpose of high gain filter is fulfilling by the signal washout block the purpose of high-pass filter having time constant T_w. This time constant is sufficiently high so as to permit signals corresponding to oscillations in passing input signal, unaltered.

2.5 Java Algorithm

This section illustrates the importance of the Jaya algorithm over the other algorithms. The detailed discussion presented in the Section I and II has concluded three main reasons are outlined here:

- The Jaya algorithm does need any algorithm specific parameters, which requires extensive tuning before conducting the actual computational experiments, if not done correctly, leads unavoidable and unwanted convergence.
- The controlling of the algorithm specific parameters is not as easy as it looks. Also, controlling the parameters in each iteration is most of the time difficult and time consuming. This entire process does not belong to the Jaya algorithm.
- The most important reason is the victorious nature of the Jaya algorithm makes it more powerful as compare to any other algorithms.

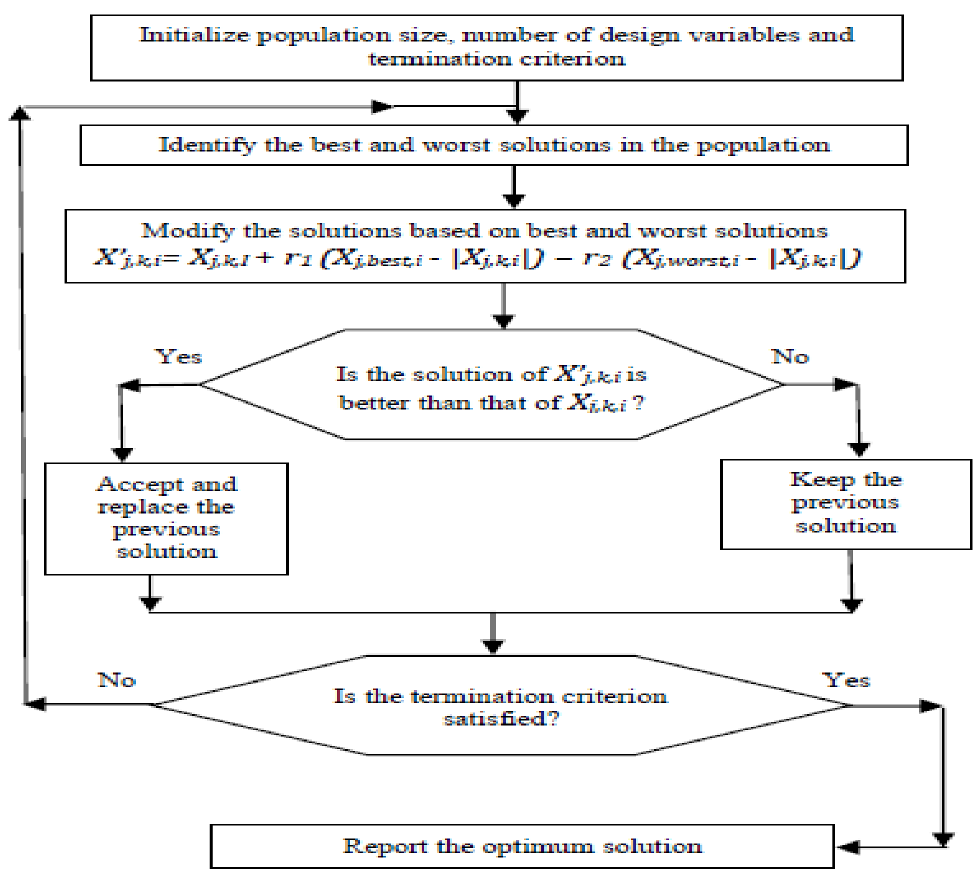

Fig. 2.6 Flow Chart of Jaya Algorithm

3. RESULT ANALYSIS & DISCUSSION OF JAYA TUNED PSS CONTROLLER IN MATLAB / SIMULINK

In this section the results of the developed simulation model under different contingencies are presented and discussed. The developed model is simulated without control and with CPSSs & with JAYAPSS controller. The responses without and with controller are accessed to test the effectiveness and toughness of the CPSS and JAYAPSS controller damping controller and its concert for a wide range of operating conditions for unlike faults.

3.1 Proposed Model of 3 Machine 9 Bus System with CPSS and JAYAPSS Damping Controller

In this study, the three-machine nine-bus power system shown in Fig. 3.1 is considered. Detail of the system data are given in.

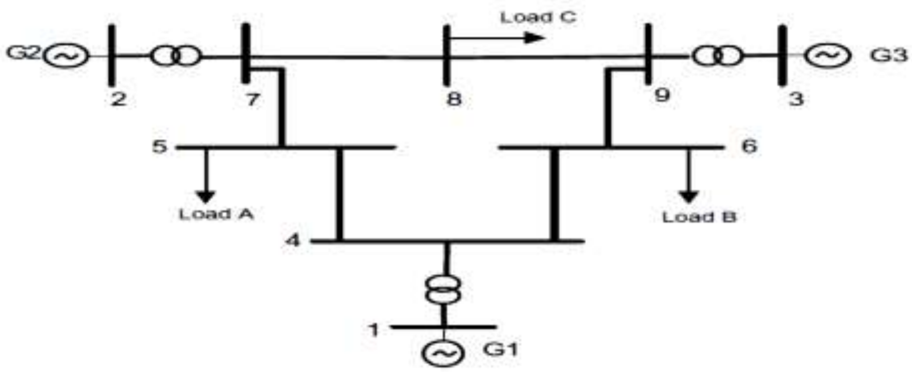

Fig. 3.1 Three Machine 9 Bus Power Systems

To assess the effectiveness and robustness of the proposed method over a wide range of loading conditions, three different cases designated as nominal, light and heavy loading are considered. WSCC 9-bus test system (also known as P.M Anderson 9-bus) represents a simple approximation of the Western System Coordinating Council (WSCC) to an equivalent system with 9 buses and 3 generators. This particular test case also includes 3 two-winding transformers, 6 lines and 3 loads.

3.2 MATLAB/SIMULINK Implementation of the no control and CPSS and JAYAPSS Damping Controller

Fig. 3.2 represents the MATLAB/SIMULINK model of Multi- Machine (3-Machine, 9-Bus) system incorporated with JAYAPSS and 6 cycles 3 phase fault disturbance at bus 7 at different loading conditions. WSCC system is widely used for transient stability study. The synchronous machines are equipped with voltage regulators combined with an exciter and comprehensive model of steam turbine and governors. System under examination is WSCC 3 generator G_1,G_2, G_3 and 3 two winding transformers connected at bus no. 1, 2 and 3. Three loads A, B, C connected at bus no. 5, 6 and 8.

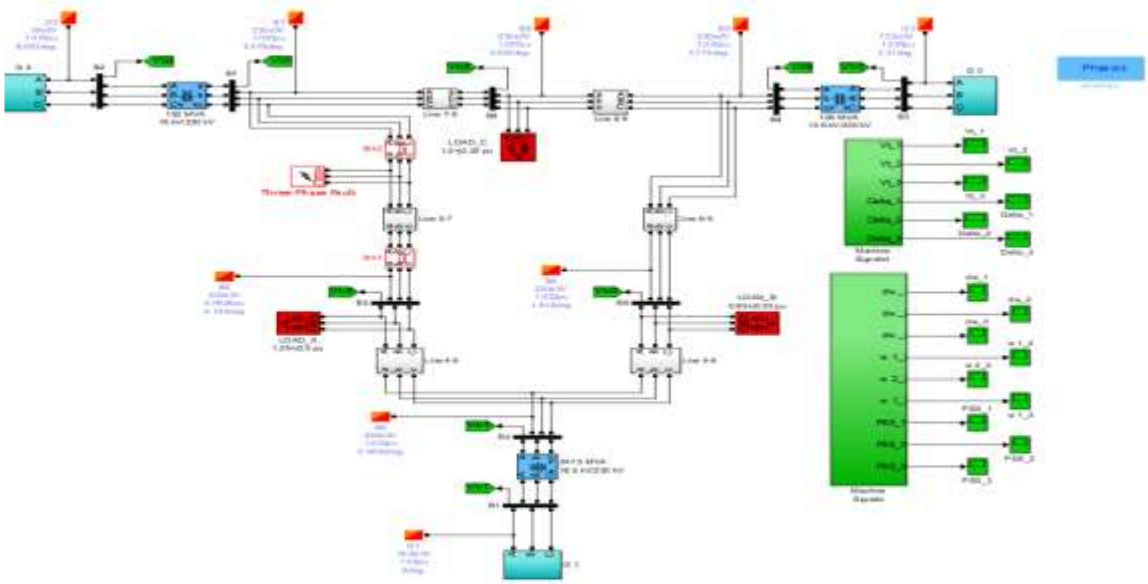

Fig. 3.2 MATLAB/SIMULINK Implementation of the 3 Machine 9 Bus Systems

3.3 Result Analysis & Discussion

In this study, the three-machine nine-bus power system shown in Fig. 3.1 is considered. Detail of the system data are given in. To assess the effectiveness and robustness of the proposed method over a wide range of loading conditions, three different cases designated as nominal, light and heavy loading are considered. The generator and system loading levels at these cases are given in Tables 3.1 and 3.2.

The Simulation studies are carried out is multi-machine power system 3 machine 9 bus system. The behavior of the no control, CPSS and JAYAPSS controller is tested under different effective conditions viz. nominal loading, light loading & heavy loading by applying of fault as three phase fault and obtain various graph as speed deviation of generator, change in speed of generator & Stabilizing signal deviation. Require better Simulation we use inlet i3 processer, 2 GB RAM computer, in MATLAB 7.13.0 environment. The best final solution obtained in the 50 runs is given in Table 3.1.

Table-3.1Generator Operating Conditions (in pu)

Gen.	Nominal		Heavy		Light	
	P	Q	P	Q	P	Q
G_1	0.72	0.27	2.21	1.09	0.36	0.16
G_2	1.63	0.07	1.92	0.56	0.80	-0.11
G_3	0.85	-0.11	1.28	0.36	0.45	-0.20

Table-3.2 Loading Conditions (in pu)

Load	Nominal		Heavy		Light	
	P	Q	P	Q	P	Q
A	1.25	0.5	2.0	0.80	0.65	0.55
B	0.90	0.30	1.80	0.60	0.45	0.35
C	1.0	0.35	1.50	0.60	0.50	0.25

3.4 Result of JAYA Optimization

In order to optimize the damping controller parameters, JAYA is used. Before using JAYA for optimization some parameters need to be provided like maximum number of iterations, population size, lower bound of scaling factor, upper bound of scaling factor, number of variable. The JAYA can work effectively only when these parameters are chosen carefully. The various parameters chose for JAYA are given in Table 3.3 below.

Table-3.3 Various Parameters of JAYA

S.N.	Parameter	Value
1.	Maximum Number of Iterations	50
2.	Population Size	05
3.	Lower Bound of Scaling Factor	[1e1 1e-2 1e-2 1e1 1e-2 1e-2 1e1 1e-2 1e-2]
4.	Upper Bound of Scaling Factor	[1e2 1e0 1e0 1e2 1e0 1e0 1e2 1e0 1e0]
5.	Number of Variable	09

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3.4.1 Condition-1: Nominal Loading

Fig. 3.3 the convergence rate of objective functions of 3 Machine 9 Bus MMPS system

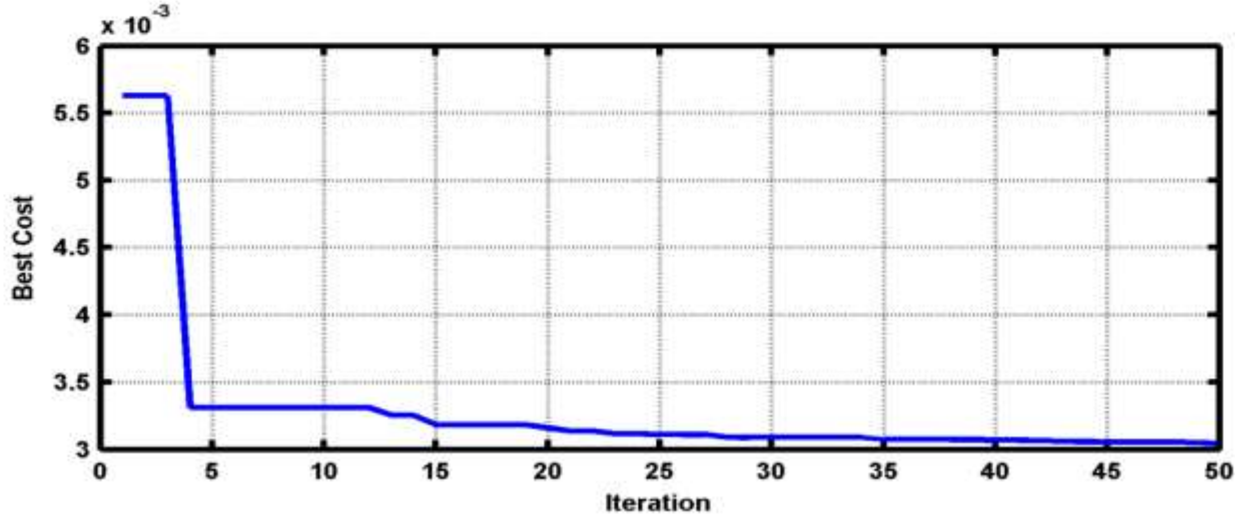

Fig. 3.3 Convergence of Objective Function for Best Cost in MMPS System

Table- 3.4 Optimal PSSs Parameters using JAYA at Nominal Condition

S.N.	System	JAYAPSS ITAE=0.0030		
		K	T_1	T_3
1.	G_1	67.3112	0.1849	0.9598
2	G_2	25.1227	0.0103	0.0183
3	G_3	10.0007	0.0183	0.2280

3.4.2 Non Linear Time-Domain Simulation at Nominal Condition

Fig. 3.4 to 3.9 shows various graph of nonlinear time domain simulation at nominal loading condition. To evaluate the system performance, we apply six-cycle three phase fault disturbance at bus 7 at the end of line 5–7 is measured. The various graphs are shows as speed deviation of different generator & change in speed. The different performance is defined as no control, with CPSSs & JAYAPSSs shown by blue, red, black line. The three performances compare with their settling time and finally we found JAYAPSSs shows superior response than other. So JAYAPSSs tuned system robust and damp the system very fast. The system is use objective function of Integral of the Time multiplied Absolute value of the Error (ITAE).The various control parameter & settling time of system shows in table 3.4 and 3.5 respectively.

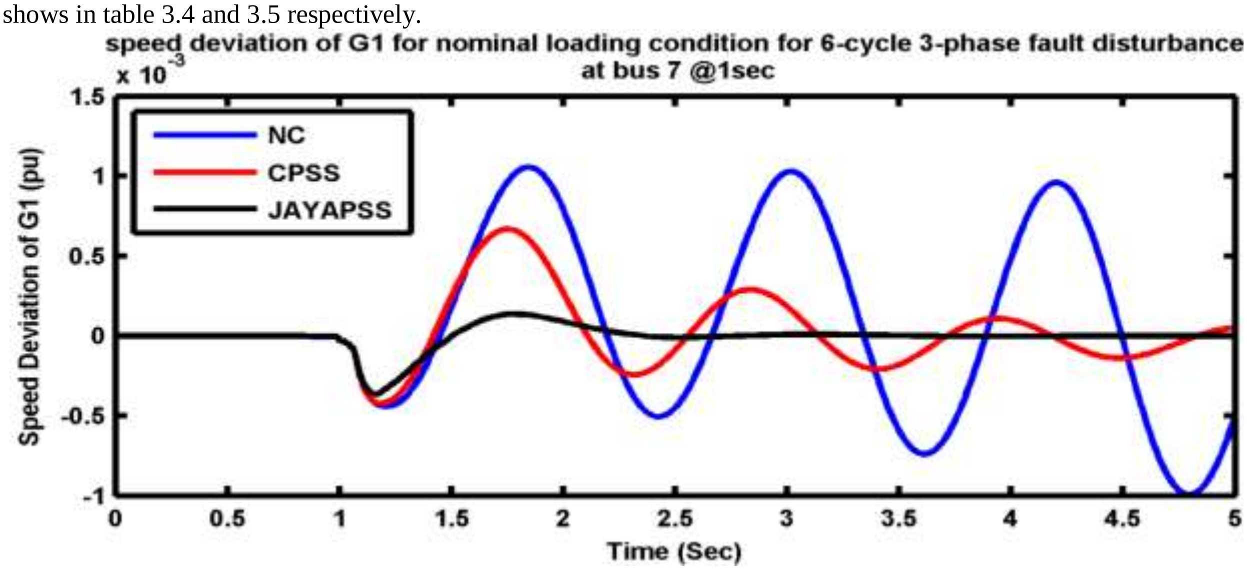

Fig. 3.4 Speed deviation of G_1 for Nominal Loading for 3-phase Fault

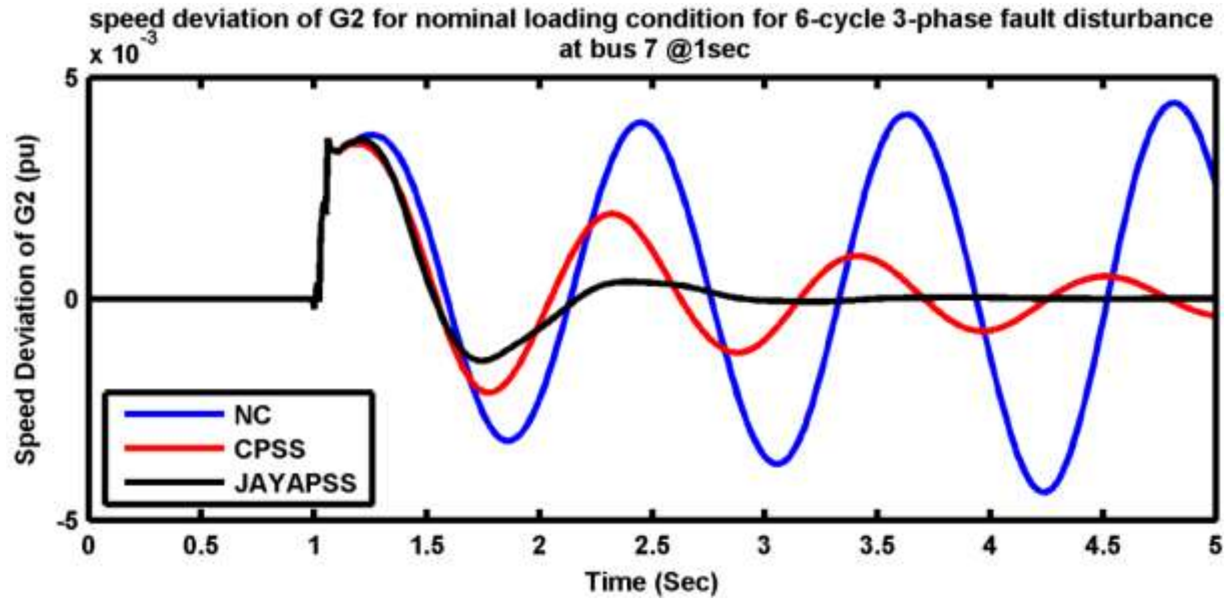

Fig. 3.5 Speed deviation of G_2 for Nominal Loading for 3-phase Fault

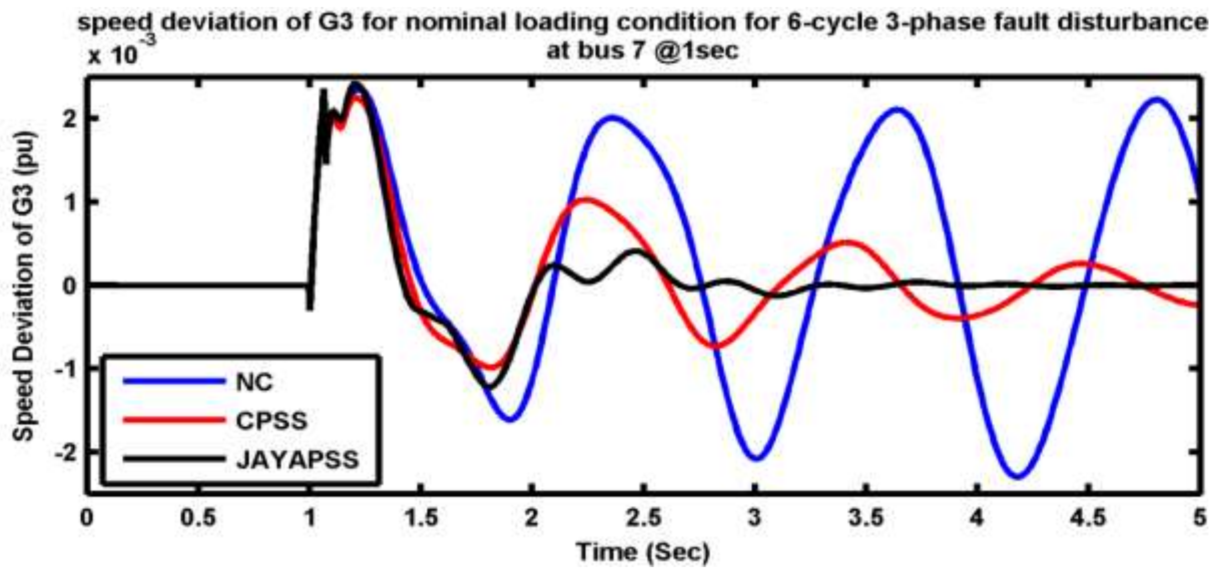

Fig. 3.6 Speed deviation of G_3 for Nominal Loading for 3-phase Fault

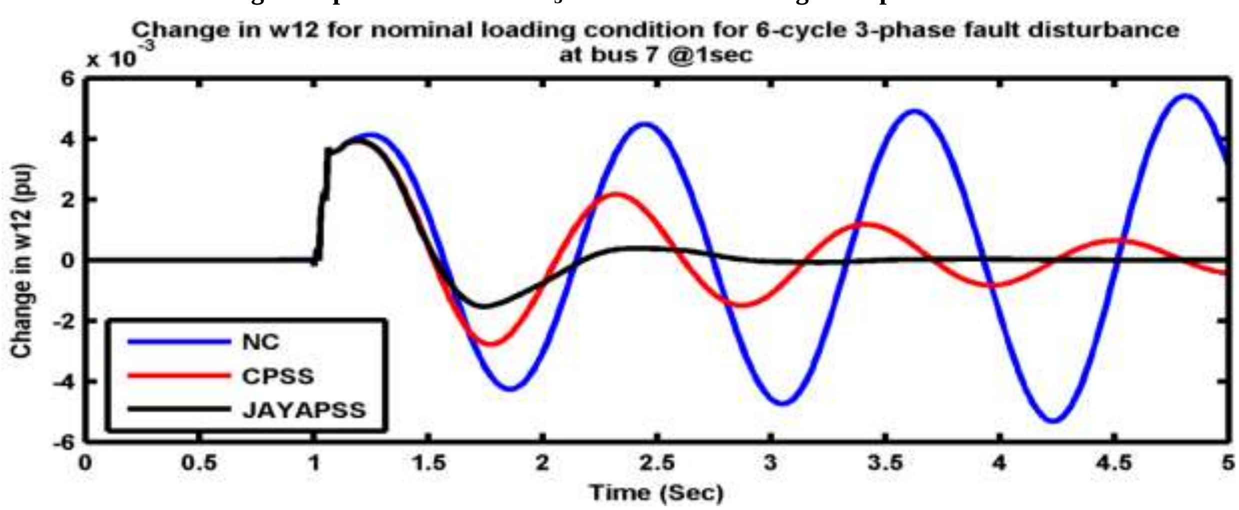

Fig. 3.7 Change in w_{12} for Nominal Loading for 3-phase Fault

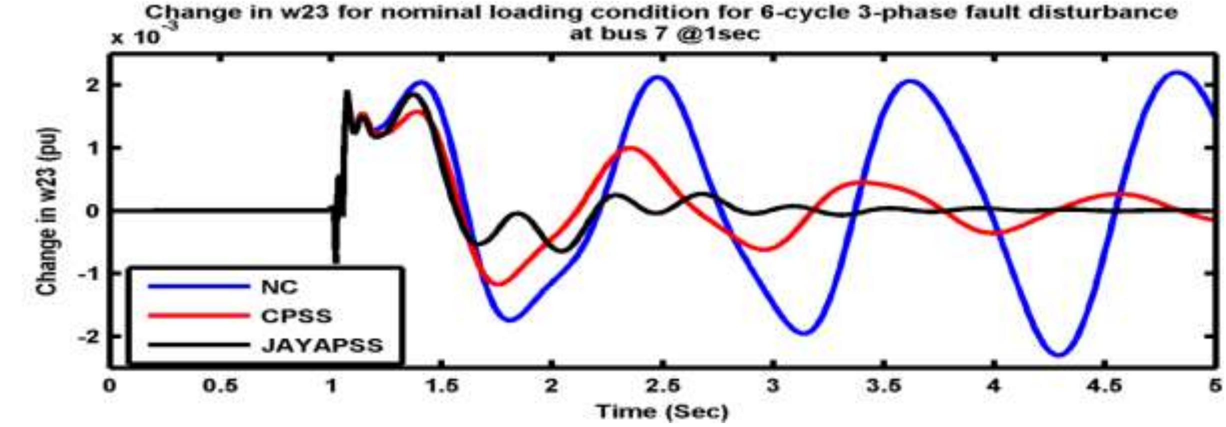

Fig. 3.8 Change in w_{23} for Nominal Loading for 3-Phase Fault

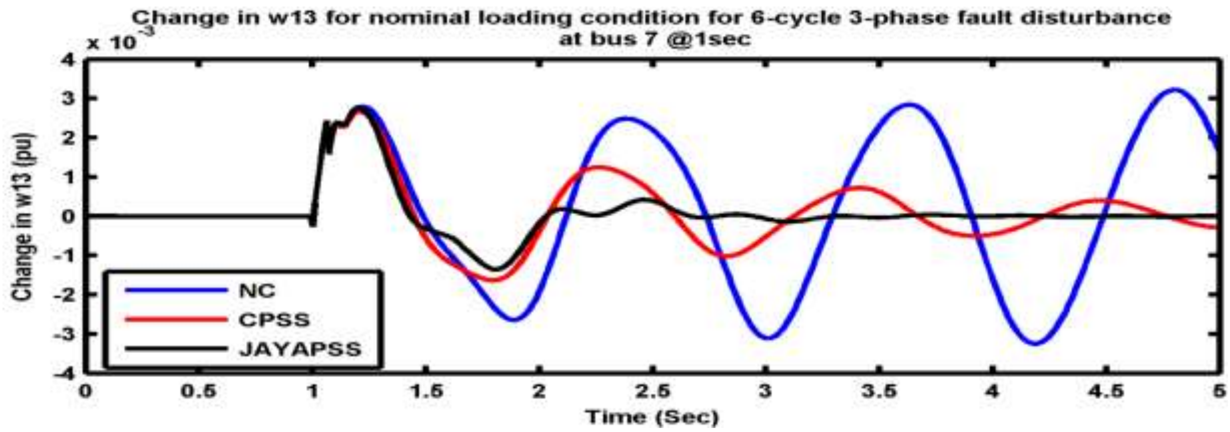

Fig. 3.9 Change in w_{13} for Nominal Loading for 3-phase Fault

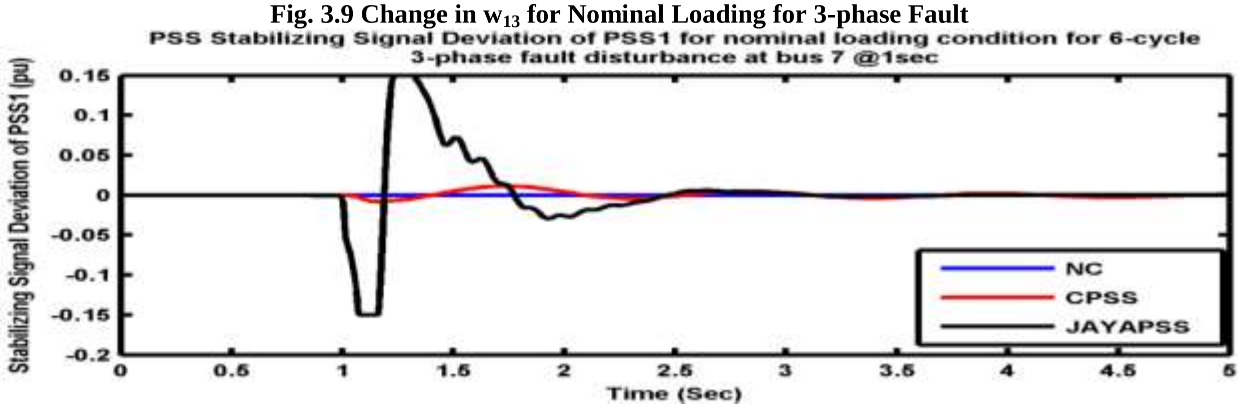

Fig. 3.10 Stabilizing Signal Deviation of PSS_1 of Generator 1 for Nominal Loading for 3-phase Fault

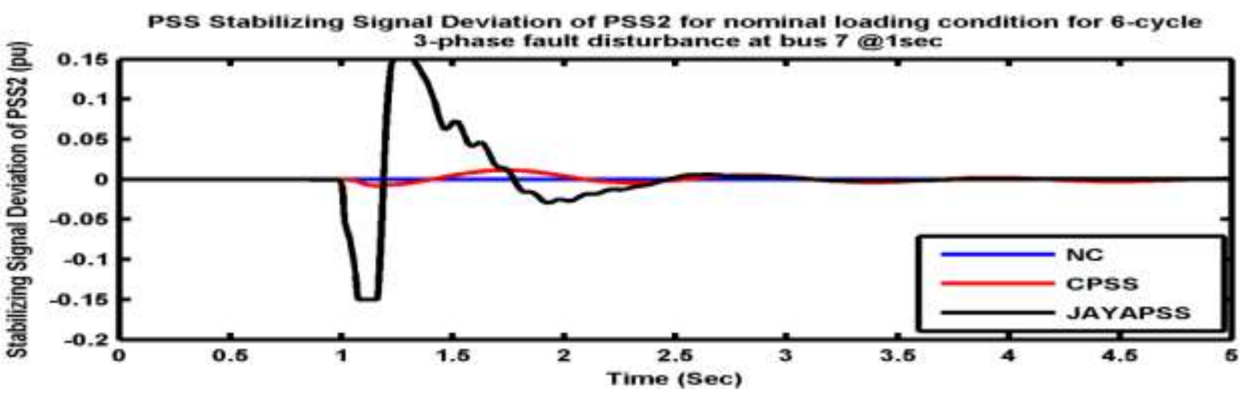

Fig. 3.11 Stabilizing Signal Deviation of PSS_2 of Generator 2 for Nominal Loading for 3-phase Faul

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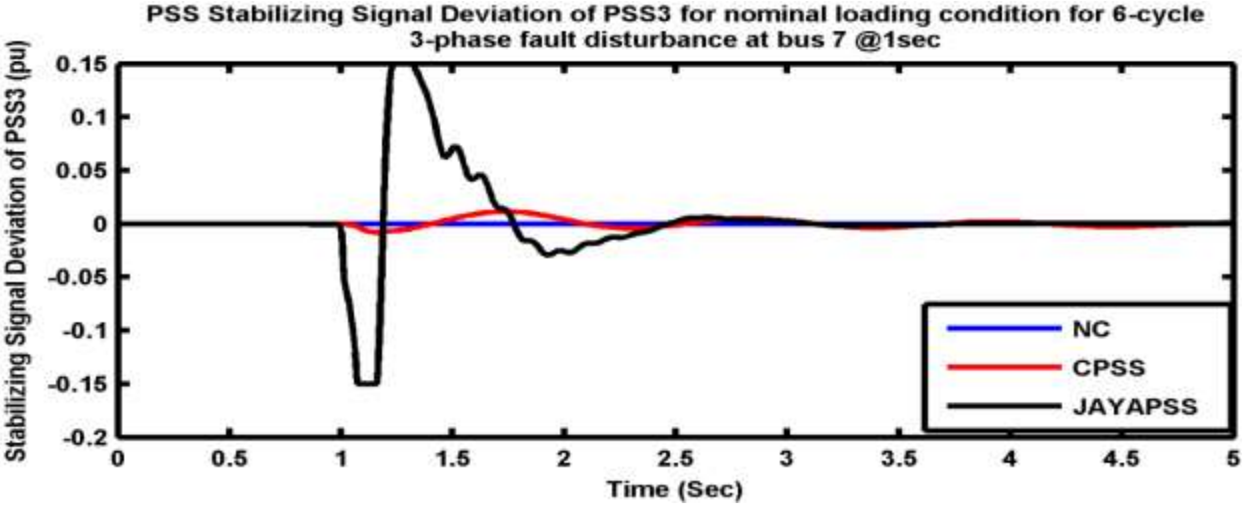

Fig. 3.12 Stabilizing Signal Deviation of PSS_3 of Generator 3 for Nominal Loading for 3-Phase Fault

Figs. 3.10 –3.12 shows Stabilizing signal deviation of (PSS_1,PSS_2 ,PSS_3) for nominal condition for six-cycle three phase fault disturbance at bus 7 at the end of line 5–7.It can be concluded that the proposed JAYAPSSs provides greatly suitable control signals than CPSSs & no control.

Table- 3.5: Three Machine 9 Bus System at without Controller and with CPSS and JAYAPSS Controller at Nominal Loading at 3 phase Fault

S.N.	Types of Deviation	Without Controller (Settling Time) Seconds	With CPSS Controller (Settling Time) Seconds	With Coordinated (JAYA PSS) Tuned (Settling Time) Seconds
1	Speed deviation G_1	Highly Oscillatory	4.9351	3.2014
2	Speed deviation G_2	Highly Oscillatory	4.9303	2.8160
3	Speed deviation G_3	Highly Oscillatory	4.9021	3.2210
4	Change in w_{12}	Highly Oscillatory	4.9341	2.8110
5	Change in w_{23}	Highly Oscillatory	4.9399	3.9630
6	Change in w_{13}	Highly Oscillatory	4.9156	3.2213
7	Stabilizing Signal Deviation PSS1	Highly Oscillatory	4.9255	2.93330
8	Stabilizing Signal Deviation PSS2	Highly Oscillatory	4.9255	2.93330
9	Stabilizing Signal Deviation PSS3	Highly Oscillatory	4.9255	2.93330

Table -3.6 Optimal PSSs Parameters Using JAYA at Light Loading Condition

S. N.	System	JAYAPSS ITAE=9.4569e-4		
		K	T_1	T_3
1.	G_1	92.7733	0.0100	0.9614
2	G_2	58.8576	0.5973	0.0100
3	G_3	66.7612	0.3953	0.1403

Table- 3.7 Three Machine 9 Bus System at Without Controller and With CPSS and JAYAPSS Controller at Light Loading at 3 Phase Fault

S.N.	Types of Fault	Without Controller (Settling Time) Sec	With CPSS Controller (Settling Time) seconds	With Coordinated (JAYA PSS) Tuned (Settling Time) Seconds
1	Speed deviation G_1	Highly Oscillatory	4.9233	3.0968
2	Speed deviation G_2	Highly Oscillatory	4.8959	2.8021
3	Speed deviation G_3	Highly Oscillatory	4.8835	3.0337
4	Change in w_{12}	Highly Oscillatory	4.9060	2.6257
5	Change in w_{23}	Highly Oscillatory	4.8820	2.3796
6	Change in w_{13}	Highly Oscillatory	4.9015	2.7303
7	Stablizing Signal Deviation PSS1	Highly Oscillatory	4.9167	2.1840
8	Stablizing Signal Deviation PSS1	Highly Oscillatory	4.9167	2.1840
9	Stablizing Signal Deviation PSS3	Highly Oscillatory	4.9167	2.1840

Table-3.8 Optimal PSSs Parameters using JAYA at Heavy Loading Condition

S.N.	System	JAYAPSS ITAE=0.0062		
		K	T_1	T_3
1.	**G_1**	99.9785	0.0106	0.0266
2	**G_2**	99.6161	0.1730	0.0985
3	**G_3**	10.0230	0.0270	0.3741

Table- 3.9 3 Machine 9 Bus System at Without Controller and with CPSS and JAYAPSS Controller at Heavy Loading at 3 phase Fault

S.N.	Types of Fault	Without Controller (Settling Time) Seconds	With CPSS Controller (Settling Time) Seconds	With Coordinated (JAYA PSS) Tuned (Settling Time) Seconds
1	Speed deviation G_1	Highly Oscillatory	4.8767	3.1298
2	Speed deviation G_2	Highly Oscillatory	4.9031	2.2066
3	Speed deviation G_3	Highly Oscillatory	4.7727	2.8684
4	Change in w_{12}	Highly Oscillatory	4.9024	2.5649
5	Change in w_{23}	Highly Oscillatory	4.9461	2.8852
6	Change in w_{13}	Highly Oscillatory	4.7955	2.3595
7	Stabilizing Signal Deviation PSS1	Highly Oscillatory	4.8487	2.7986
8	Stabilizing Signal Deviation PSS1	Highly Oscillatory	4.8487	2.7986
9	Stabilizing Signal Deviation PSS3	Highly Oscillatory	4.8487	2.7986

It is concluding that Table 3.5, 3.7, 3.9 shows various comparison table of different loading condition. The various graph shows at condition of three phase fault at system 3 machine nine bus systems. The system tested at various graph at time domain simulation at each condition JAYAPSSs shows better response than other controller. The system settles very quickly and improves system stability.

CONCLUSION

- Successful implementation of JAYA algorithm based PSS in 3machine 9 bus system has been done and then compared with CPSS system.
- The system was simulated and tested under nominal loading, light loading & heavy loading. In all the loading conditions, three phase fault was applied. At last for each loading conditions speed deviation of generator (G_1, G_2, G_3), change in speed of generator (w_{12},w_{23},w_{13}) & Stabilizing signal deviation of (PSS_1,PSS_2,PSS_3) graphs were plotted and presented.
- Any loading conditions, system is highly oscillatory without any kind of controller.
- In nominal loading, settling time when deviation of speed and Stabilizing signal is considered is highly oscillating. However, on application CPSS settling time reduces. On including JAYA PSS it further improves by 35% to 45%.
- In Light loading conditions, JAYA PSS performs well as compared to CPSS. Its settling time 30% to 40% less than the letter.
- In heavy loading conditions, for all the three generating units results are still the same. JAYA PSS performs better than CPSS.
- The system tested at various graph at time domain simulation at each condition JAYAPSSs shows better response than other controller. The system settles very quickly and improves system stability.

FUTURE SCOPE

- The optimal ANN controller will be designed for the damping the low frequency local as well as inter-area oscillations of the large power system. In the design a two multilayer-perceptron neural networks can be used in the identifier/model network. This is used to identify the dynamics of the power system. The controller network will provide optimal damping.
- The fuzzy sets will provide additional degree of freedom that will made it possible to directly model & handle uncertainties. The proposed fuzzy controller will be more effective than GA based damping controller.

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