ISSN (Online) : 0974-5645
ISSN (Print) : 0974-6846
Indian Journal of Science and Technology, *Vol 8(3), 254–262, February 2015*
DOI : 0.17485/ijst/2015/v8i3/59595

Power System Stabilizers and Control of Reactive Power Compensator in Multi-Machine by Particle Swarm Optimization Algorithm

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Abstract

The purpose of this article is to increase the stability and synchronization of multi-machine power system through power system stabilizers 3 band (pss3b). This new stabilizer system indicates better performance by changes in operating conditions and on the other hand, by setting Flexible AC Transmission System device (FACTS) this system can play a key role in limiting fluctuations. All system variables including pss3b and svc are designed by PSO algorithm in the article. The designed stabilizer has been used in a grid of 11 bus bar with two areas and four machines, and the pss and pss3b performances on increase of low frequency oscillation damping have been compared by applying three-phase fault at different working conditions. Finally the comparison between responses obtained from simulations with the same reference system response can prove advantage of this stabilizer and the newly designed system over previous ones in damping vibrations and stability increase.

Keywords: Dynamic System, PSO (Particle Swarm Optimization), PSS (Power System Stabilizer), PSS3B (Power System Stability)

1. Introduction

A power system consists of generators, loads, transformers and transmission lines. Disturbances in power system lead to electromechanical oscillations and in result, the system variables will begin to swing. These variables can include system voltage, frequency, load and angle of the generator or other system parameters. These vibrations are known as Low Frequency Oscillations ranging from few tenths of Hz to several Hz[1]. On the other hand, by resettling the system poles, AVR feedback loop has a negative impact on the generator and low frequency oscillation. Stabilizing these parameters is so important in the system stability.

Electromechanical oscillations in transmission network are a fundamental problem for such systems. Two distinct dynamic vibrations have been identified which can be problematic for the power systems. One occurs when the producing units fluctuates unlike the rest of the system. Such fluctuations are known as local mode oscillations and their frequency characteristics depend on impedance of the transmission system. The second type called internal modes is complex; because they consist of numerous machines in one side of the system swinging from the machines in the other side of the system. The larger and more complex power system is, the more important will be its dynamic performance analysis. Synchronous generators have an important role in power

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system stability[2]. Several factors can cause such vibrations in the network including short circuit in the network, sudden load change or interrupt, and or loss of transmission lines. These fluctuations can also occur in normal operation. The worst low frequency fluctuations happen when the network has three-phase short circuit with the ground. Such that if the system is not able to sustain the entire network, security system would probably act[3].

To damp off these vibrations, it is necessary to control the system properly being done by controlling machine stimulation and/or power compensate reactive, etc. Controlling synchronous machine stimulation is possible in several ways. One of these methods is using an auxiliary control loop for the machine stimulation known as Power System Stabilizer (PSS)[4,5]. Up to now, various methods have been proposed for designing such stabilizers, but classic stabilizers has been taken into consideration due to its simplicity in implication. However, as these stabilizers are merely adjusted for certain performance and conditions and they get feedback only from one angular velocity variable or power changes variable and despite acceptable performance on nominal terms and conditions, they account for deficiency in changing conditions[6–8]. PSS3B is a type of power system stabilizer getting feedback from power changes and angular velocity simultaneously. This can lead to better control and better damping fluctuations in different working conditions[9]. Now, FACTS devices as wells as power system stabilizer can be used to improve power system stability (transient and dynamic), controllability, operation of the power system, and removing the limitations of power transmission. As FACTS devices are enabled to control both components of the real and reactive transitive powers on transmission lines, it is possible to correct transient and dynamic stability in power system by controlling these components on time. The purpose of this research is to obtain parameters related to power system stabilizer with two inputs as well as svc control parameters in a standard multi machine system by PSO algorithm. This is done through optimizing angular velocity changes of the reference sheen than other sheens by ISTSE cost function[10,11].

2. PSO Algorithm Technique

Particle swarm algorithm first was suggested in 1995 by Aberhart and Kennedy to optimize nonlinear continuous functions. On one hand this algorithm is related to artificial life, particularly group theory, an on the other hand it is related to evolutionary processing algorithm and especially to evolutionary strategies and genetic algorithms. This method is inspired from groups of fishes and migrating birds. The algorithm was used for detecting the pattern of simultaneous birds' flight and the sudden change in their track. Since PSO works as a team and has fitness function, it is similar to evolutionary algorithms. But the main difference is that in PSO each person benefits from his/her own past data. In PSO, each member will change his/her position due to personal experiences and the experiences of the whole society. Sharing social information between members of a community has a series of evolutionary advantages. PSO algorithm is based on this hypothesis[12,13]. PSO simulates the social behavior of birds. Imagine a group of birds seeking food in an environment. None of them has information about location of the food, but they know their distance to the food. Accordingly, the best approach to find food is following the closest bird to the food. PSO simulates this behavior in optimization issues. In this algorithm, each bird is a possible answer in the search space called a particle. At first, PSO is initialized by a group of birds randomly generated in the atmosphere, and then a quest to reach the best answer begins. In each step of the algorithm repetition, the particle move towards better position. The following position of each particle will be obtained based on two values: the first one is the best position the particle has ever had (PBEST), and the second one is the best position the whole particles of that society have ever had, which is the best PBEST totally. This process repeats until the desired result is achieved (i.e. the birds velocity tends to zero) or we reach to the maximum considered iterations for the PSO algorithm[14,15].

According to PBEST and GBEST values, each bird uses the following correlations to determine next position[12–16].

In the mentioned correlations, C1 and C2 constants determine learning parameters (the effect) for GBEST and PBEST usually chosen equal to 2. r1 and r2 are random numbers ranging from 0 to 1; x (t) and v (t) are respectively current position and the velocity of the particles at that stage; j is a parameter that controls the inertial motion of particles. At the beginning of running the algorithm, it has greater velocity, and after a while we get closer to the answer, it decreases slowly. After each iteration, functions used for this purpose usually cause linear reduction.

- PSO algorithm with weight inertia.
- PSO algorithm with constriction factor.

Particle swarm algorithm with weight inertial.

In this method, equations for each particle are as follows:

$$v_{id}(t+1)=w\cdot v_{id}(t)+c_1\cdot r_1\cdot(p_{best_{id}}-x_{id}(t))+c_2\cdot r_2\cdot(g_{best_d}-x_{id}(t)) \quad (1)$$

$$v_{\min d}\le v_{id}\le v_{\max d}\ ,\ i=1,\ldots,n \quad (2)$$

$$x_{id}(t+1)=x_{id}(t)+v_{id}(t+1), \quad (3)$$

$$x_{\min d}\le x_{id}< x_{\max d}\ ,\ i=1,\ldots,n \quad (4)$$

$$v_{id}(t+1)=k[v_{id}(t)+c_1\cdot r_1\cdot(p_{best_{id}}-x_{id}(t))+c_2\cdot r_2\cdot(g_{best_{id}}-x_{id}(t))] \quad (5)$$

$$k=\frac{2}{\left|2-\phi-\sqrt{\phi^2-4\phi}\right|},\phi=c_1+c_2,\ \phi>4 \quad (6)$$

$$v_{\min d}\le v_{id}\le v_{\max d}\ ,\ i=1,\ldots,n \quad (7)$$

$$x_{id}(t+1)=x_{id}(t)+v_{id}(t+1) \quad (8)$$

$$x_{\min d}\le x_{id}\le x_{\max d},\ i=1,\ldots,n \quad (9)$$

2.1 Cost Function

Similar to any optimization issue, it is necessary to minimize the cost function to reach favorable answer at the output. In this paper, ISTSE criterion is used as the cost function.

$$ISTSE=\int(\Delta w\times t)^2\,dt \quad (10)$$

Here, Δw is difference between angular velocity generators' rotors and integral time is period of the simulation. The purpose of setting the optimal stabilizer parameters is increasing low-frequency oscillation damping as well as reducing settling time and maximum overshoot. The ISTSE criterion can be defined as cost function so that stabilizers' optimized parameters will be obtained by minimizing it.

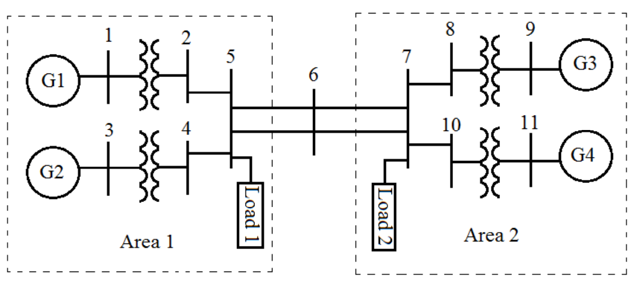

Figure 1. Multi-machine power system, IEEE.

3. Study System Modeling

The linear diagram block of four machines power system is figured in two areas, which has been used for studying and analyzing the issue. Each area includes two generators unit…, connected to main lines through transformers. The accurate information of buses, lines, generators and loads is mentioned in the Table 2.

4. IEEE Model of the PSS and PSS3B Stabilizers

Low damping of the system electromechanical modes causes low-frequency oscillations in interconnected power systems. When a generator uses automatic excitation system, it creates a negative damping to power system. Therefore, the system damping will be destroyed. Power system stabilizer is an electronic feedback control in stimulation system of the production unit and its function is damping oscillations and increasing the limit of stability of system rotor by modulating excitation voltage. For controlling damping, the stabilizer creates a component of electrical torque in phase with rotor speed

Table 1. Operating condition of tow area power system (pu).

Q_2	P_3	Q_3	P_1	Q_1	P_4	Q_3	P_2
Operating Condition		CASE 1		CASE 2		CASE 3	
0.1021	0.7777	0.1308	0.7989	0.0914	0.7778	0.7778	0.0918
0.1240	0.6022	0.0943	0.8333	0.0989	0.8889	0.8333	0.0955
0.0992	0.9624	0.2083	0.7778	0.0960	0.6667	0.6667	0.1036

deviation. Various types of IEEE are defined for power system stabilizers but we will discuss about PSS and PSS3B in this section. The method of such stabilizers is so that by creating the proper torque on the machine rotor, it compensates the offset phase between stimulation input and the machine electronic torque. However, due to excitement constant time, the amount of attenuation through these methods is limited. So FACT devices can establish better damping power along with the stabilizer. In this paper, we use svc device because of its major advantage, its appropriate cost. The following Figure 2 shows the IEEE model of a PSS stabilizer[17]. Its input is the signal of angular velocity changes.

The stabilizer contains a washout block, which reduces response of the power system unbearably during very large disturbances. Since PSS should build electronic torque in the phase by speed changes, lead and lag block will be used is PSS. The number of blocks depends on the nature of the system and the manner and quality of its setting. The block, eliminator of steady state effect, acts as high-pass filter (HPF) with Tw constant time and allows signals corresponding Wr oscillations to pass without any change. Stabilizer portion Ks determine the amount of attenuation caused by PSS. This stabilizer is sensitive to noise.

IEEE model of a two-input stabilizer is shown in the following Figure 3. PSS3B stabilizer uses two inputs for changes in the electrical power (ΔP) and changes in the angular velocity of the rotor (Δw)[18].

It can be cited that PSS3B is a modified version of PSS2B where the coil filter is removed.

In this stabilizer, T1 and T2 parameters represent converter time constants, and T2 and T4 depute washout time constants in two channels. The optimal use of the stabilizer occurs by setting K2 and K3 values. Limiting stabilizer of excitation voltage is used at output. tn1 and tn2 are compensatory coefficients of stabilizer's phase.

5. Static Compensator (SVC)

SVC is one of the most important FACTS elements, and because of its technical and economic advantage it has been used in solving voltage dynamic for many years. Its accuracy, availability and rapid response in comparison with other classical compensators made it a very effective tool in controlling the transient and steady voltage states. SVC's main task is to control the voltage in weak points rapidly by controlling the effective reactance properly[19,20].

SVC is composed of Thyristor Switched Capacitor (TSC) and Thyristor Controlled Reactor (TCR). TCR is a controllable self with thyristor and parallel with the network, and its effective reactance changes continuously by controlling partial directed of thyristor gate. TSC is a switching capacitor with thyristor, set parallel, and its effective reactance changes as a stage with the performance of the thyristor gate.

SVC Single-line diagram as well as simplified diagram block of the synchronous generator control system is shown in the following Figure 4.

The system of four generators with two areas as well as SVS is shown here. The complete information of the network is mentioned in reference [?].

SVC is connected to the network in parallel, and as it is seen in the figure it can appear in two modes: inductive and capacitive reactive. In capacitive currents greater than SVC, Icmax converts to a capacitor and its reactive power changes as a function of the voltage. The slope of V-I diagram between Icmax and Irmax usually ranges from 2% to 5%.

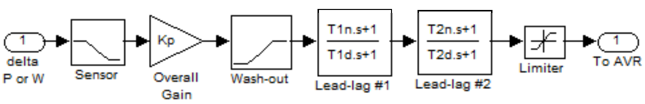

Figure 2. Block diagram of the PSS stabilizer.

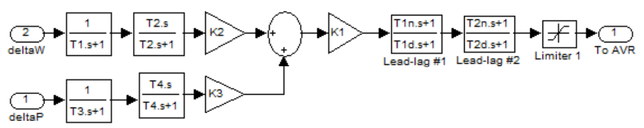

Figure 3. Block diagram of the PSS3B stabilizer.

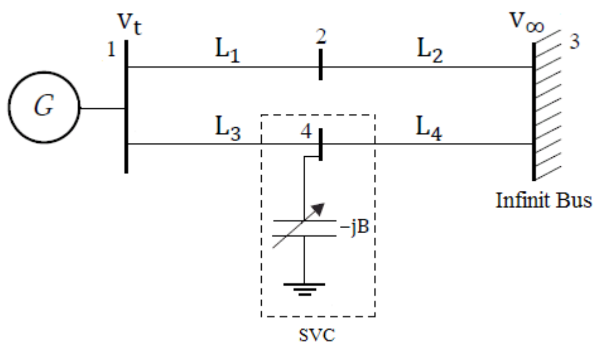

Figure 4. The structure of SVC.

6. Propose Objective Function

It is a difficult issue to optimize PSS3B parameters for the four generators of the network and two SVC parameters while they have proper attenuation ability in different working conditions. In this paper, PSO algorithm is used to determine the parameters which are an optimization matter with defined limitations.

Parameter limits of PSS3B used in optimization.

$$\begin{aligned} T_1^{\min} &\leq T_1 \leq T_1^{\max} \\ T_3^{\min} &\leq T_3 \leq T_3^{\max} \\ K_1^{\min} &\leq K_1 \leq K_1^{\max} \\ K_2^{\min} &\leq K_2 \leq K_2^{\max} \\ K_3^{\min} &\leq K_3 \leq K_3^{\max} \end{aligned} \quad (11)$$

Parameter limits of SVC.

$$\begin{aligned} K_p^{\min} &\leq K_p \leq K_p^{\max} \\ K_i^{\min} &\leq K_i \leq K_i^{\max} \end{aligned} \quad (12)$$

Parameter used in PSO.

Iteration = 40 (13)

Population = 40

7. Simulation Results

MATLAB software is used for simulating this system. The network model is designed in Simulink environment as () and PSS3B parameters used in four generators of the network as well as two SVC control parameters are set to coordinate with each other by PSO algorithm. By studying changes in the angular velocities of each generator than the first one, we can test performance capabilities of the system in transient conditions by applying three-phase fault lasting 200ms in the communication line between buses 5 and 6. The system should be capable of appropriate performance on various operating conditions and can cause necessary attenuation during disturbances. In order to evaluate the performance of the proposed stabilizer, its response has been compared with sustained response of designed PSS using PSO algorithm which has better performance than other optimization techniques[22]. In order to perform the test and a closer look at the function of each designed stabilizers, the system has been tested in various working conditions. The following Table 2 shows the Pu values of each unit's active and reactive power.

The first mode is considered as the basic situation and optimization process has been done in this condition. The second condition is related to the rise of active and reactive power of generators in two areas. Third condition links to a decrease in both the active and reactive power of the generator. The optimal values of parameters of the PSS stabilizers designed by PSO algorithm are given in the following Table 3.

The optimal values of parameters of SVC and PSS3B stabilizers designed by PSO algorithm incorporated are given in the following Table 4.

Following amounts are considered in PSS3B: 10 = T_2 = T_4, 0.02=T_1n, *0.01* =T_1d, *0.03*=T_2n, 0.01=T_2d.

7.1 Case 1

In this case after optimization of the parameters, 200ms three-phase fault is applied to the system. Angular velocity variations of each generator than the first one are shown in Figures (5–8).

ISTSE, ITAE, OV and US criterion is presented in the Table 1.

7.2 Case 2

At this point, increasing the amount of active and reactive power of each generator and put it based on Table 6 and by applying three-phase fault to the ground durable 200ms, angular velocity variations of each generator than the first on has been studied in Figures (9–12). ISTSE, ITAE, OV and US criterion is presented in the Table 2.

Table 2. Operating condition of two area power system (pu)

Q_2	P_3	Q_3	P_1	Q_1	P_4	Q_3	P_2
Operating		CASE 1		CASE 2		CASE 3	
0.1021	0.7777	0.1308	0.7989	0.0914	0.7778	0.7778	0.0918
0.1240	0.6022	0.0943	0.8333	0.0989	0.8889	0.8333	0.0955
0.0992	0.9624	0.2083	0.7778	0.0960	0.6667	0.6667	0.1036

Table 3. PSO parameters.

	PSO Parameters			
–	PSS1	PSS2	PSS3	PSS4
K_p	17.0513	25	23.1502	20.7828
T_{1n}	0.3304	0.1879	0.2857	0.9652
T_{1d}	0.3366	1	0.1537	0.7395
T_{2n}	0.7840	0.4671	0.4711	0.4279
T_{2d}	0.4735	0.5430	0.5993	0.9218

Table 4. PSO parameters and SVC

		PSO Parameters				
SVC		PSS3B 4	PSS3B 3	PSS3B 2	PSS3B 1	–
1.45	K_p	20.7828	23.1502	15	13.46	K_1
283	K_i	18.568	21.58	24.7	23.73	K_2
-	-	0.736	0.689	1	0.742	K_3
-	-	0.463	0.386	0.741	0.234	T_1
-	-	0.168	0.174	0.193	0.180	T_3

Table 5. Description case1

Type of Methods	CASE 1			
	ISTSE	ITAE	OV%	%US
PSS design by PSO in case 1	0.0041	2.0	0.16	-0.17
PSS3B design by PSO in case 1	0.0022	1.4	0.12	-0.13
PSS3B and SVC design in case 1	0.0017	1.1	0.11	-0.11

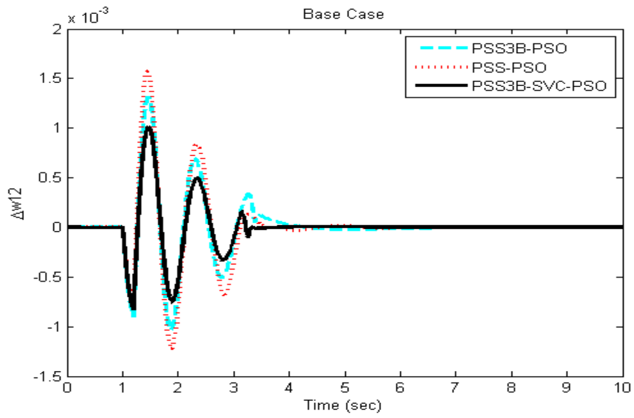

Figure 5. Local mode (W_1-W_2) of oscillation for case 1.

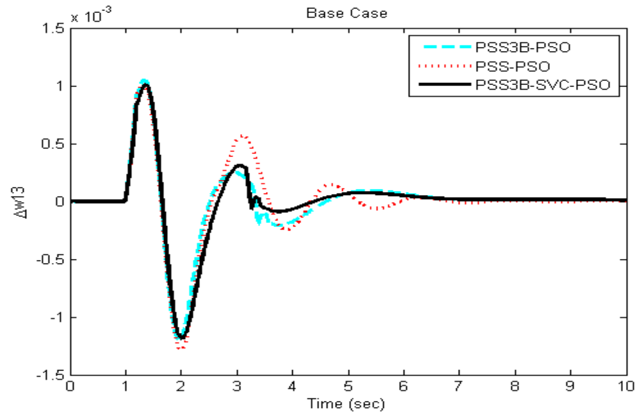

Figure 6. Inter-area mode (W_1–W_3) of oscillation for case 1.

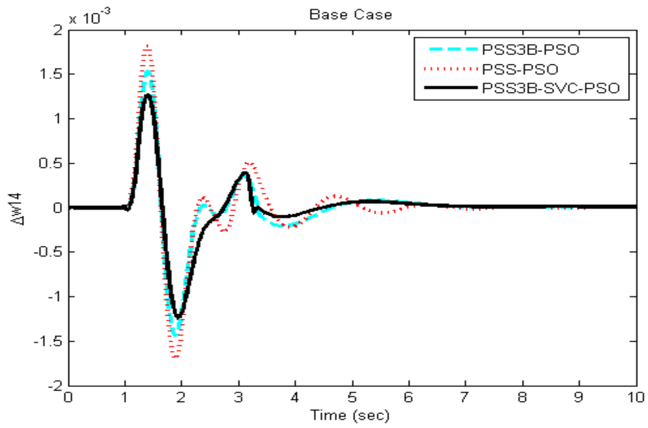

Figure 7. Inter-area mode (W_1–W_4) of oscillation for case 1.

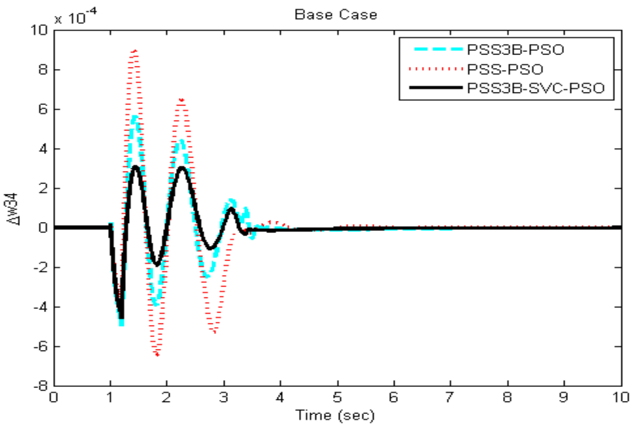

Figure 8. Local mode (W_3–W_4) of oscillation for case 1.

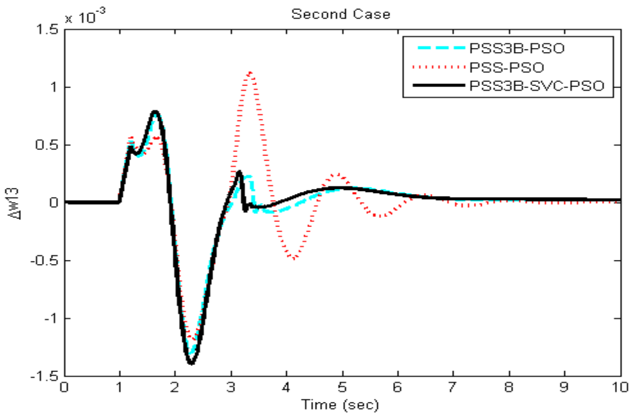

Figure 10. Inter-area mode (W_1–W_3) of oscillation for case 2.

Table 6. Description case 2

Type of Methods	CASE 2			
	ISTSE	ITAE	OV%	%US
PSS design by PSO in case 1	0.0043	1.6	0.14	-0.14
PSS3B design by PSO in case 1	0.0022	1.0	0.09	-0.11
PSS3B and SVC design in case 1	0.0019	0.9	0.08	-0.10

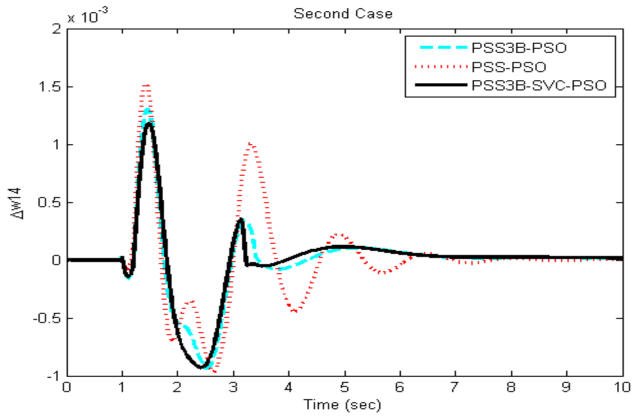

Figure 11. Inter-area mode (W_1–W_4) of oscillation for case 2.

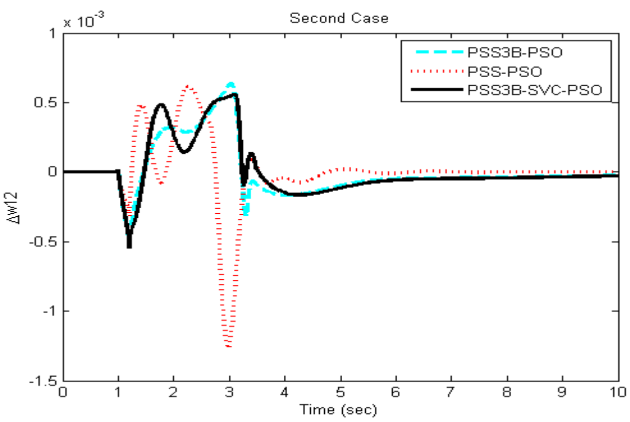

Figure 9. Local mode (W_1–W_2) of oscillation for case 2.

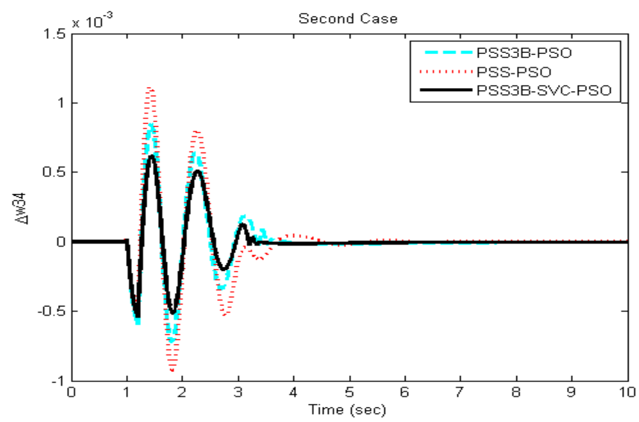

Figure 12. Local mode (W_3–W_4) of oscillation for case 2.

7.3 Case 3

In this phase, the active and reactive power of generators is reduced to test the performance of the designed stabilizers in new situation. To do this, active and reactive power of each generator is set in accordance with Table 7 and a three-phase fault to the ground durable 200ms is applied. Figures (13–16) shows changes in angular velocity during decrease in output power of the generators. ISTSE, ITAE, OV and US criterion is presented in the Table 3.

8. Conclusion

The result show that PSS3B+PSO have better result from pass for all cases.

In the Figures 17, 18 show that indexes of dynamic system are better than conventional methods.

Table 7. Description case 3

Type of Methods	CASE 3			
	ISTSE	ITAE	OV%	%US
PSS design by PSO in case 1	0.0120	6.2	0.25	-0.25
PSS3B design by PSO in case 1	0.0059	3.0	0.17	-0.23
PSS3B and SVC design in case 1	0.0049	2.9	0.15	-0.20

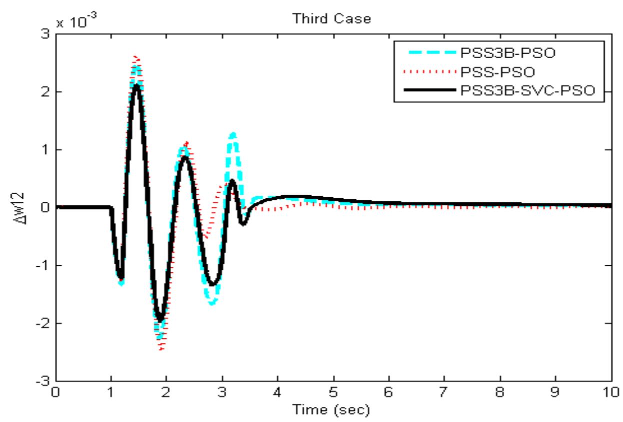

Figure 13. Local mode (W_1–W_2) of oscillation for case 3.

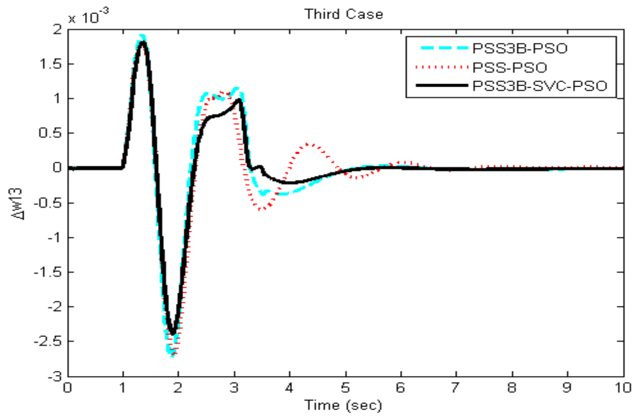

Figure 14. Inter-area mode (W_1–W_3) of oscillation for case 3.

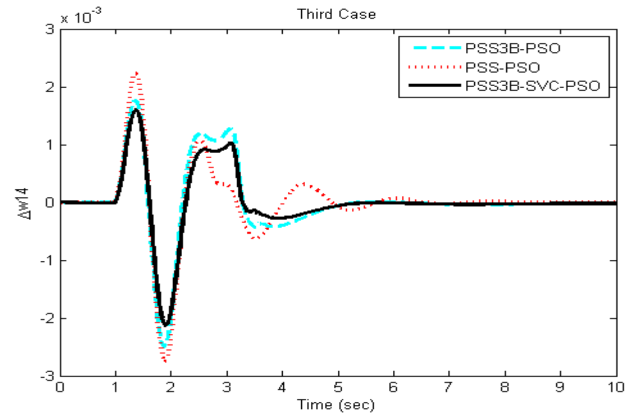

Figure 15. Inter-area mode (W_1–W_4) of oscillation for case 3.

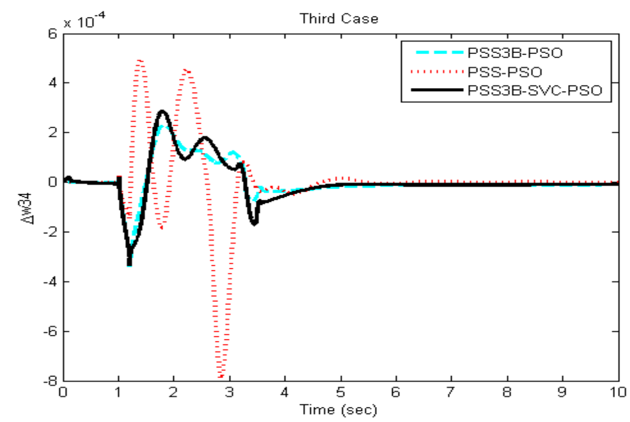

Figure 16. Local mode (W_3–W_4) of oscillation for case 3.

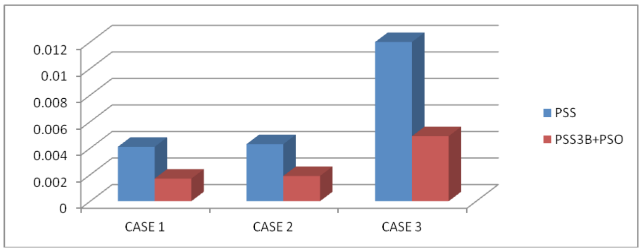

Figure 17. Value of performance index ISTSE for different case study.

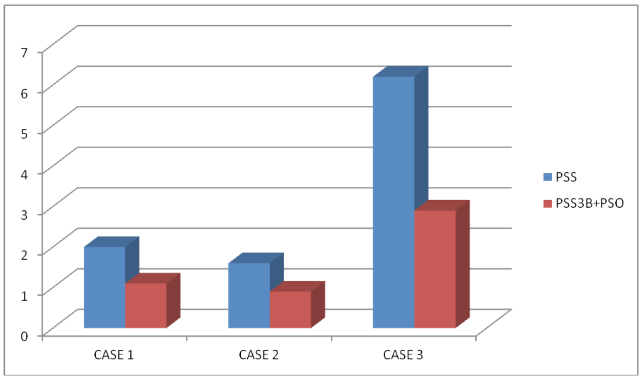

Figure 18. Value of performance index ITAE for different case study.

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