

# Power System Transient Stability Enhancement by Tuning of SSSC and PSS Parameters Using PSO Technique

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## Abstract

In this paper, the tuning design of SSSC and PSS was examined in increasing the damping of system oscillations and improve the stability of the power system during disturbances. The design problem of the SSSC controller and PSS is designed as problem of optimization and the technique uses (PSO) technique to find for optimal control parameters. By minimizing the objective function based on the speed deviation and time domain, which deliberately deviates at the oscillation angle of the alternator rotor to improve performance of transient stability of the system. The proposed controllers are tested on the system of weak bonding ability exposed to severe disturbance. Nonlinear simulation results are presented to demonstrate the proposed controller's effectiveness and its ability to give efficient damping. It is also noted that the proposed controllers of SSSC and PSS greatly improves the power system stability.

**Keywords:-** Power System Stabilizer(PSS), Static Synchronous Series Compensator SSSC, Particle Swarm Optimization(PSO)

## الخلاصة

في هذه الورقة تم اختبار التصميم المتناغم بين SSSC و PSS في زيادة تخميد لتذبذبات و تحسين الاستقرار لمنظومة القدرة. تم تصميم مشكلة التصميم للمسيطر SSSC و مضبط منظومة القدرة PSS كمشكلة أمثلية وباستخدام تقنية أمثلية سرب الجسيمات PSO للبحث عن مقادير او معاملات التحكم الأمثل للمسيطرين من خلال التقليل من دالة الهدف التي بناؤها على أساس الانحراف في السرعة الزاوية لدوار المولد والمجال الزمني، المولد لتحسين أداء الاستقرار العابرة لمنظومة القدرة. تم اختبار المسيطرات المقترحة على منظومة قدرة ضعيفة الترابط تعرضت لاضطراب شديد. نتائج المحاكاة اللاخطية استخدمت لإظهار فعالية المسيطرات المقترحة وقدرتها على توفير كفاءة التخميد للتذبذبات المنظومة . ويلاحظ أيضا أن المسيطرين SSSC و يحسنان و إلى حد كبير استقرارية منظومة القدرة عند تعرضها الى اضطرابات شديدة.

**الكلمات المفتاحية :-** مضبط منظومة القدرة، معوض التوالي المتزامن الاستاتيكي، أمثلية سرب الجسيمات.

## 1-Introduction

Electric power systems have expanded rapidly and have been connected with weak transmission lines. Low frequency oscillations are increasing and the stability of the power system is declining. If the damping system is not sufficient in the power system, in the absence of control devices, these oscillations continue to grow until the system collapses. Power system stabilizers (PSS) are usually used in power systems to dampen oscillating oscillations (Kundur,1994). However, given the continuous increase in load on the transmission lines and the complexities of the network, it alone can not provide adequate system damping. However, other effective options must be provided from responsive electronic devices that have made possible the use of flexible systems

(FACTS) devices. FACTS controllers have the ability to quickly control the network mode in different operating conditions and have made it able to improve the stability of the power system (Sinha, 2011)

"The Static Synchronous Series Compensator(SSSC) Devices are one of the family of facts devices" that can be installed with "power system in series with transmission lines". A SSSC is an electrical device for providing fast-acting reactive power compensation on high voltage transmission networks(Abdel-Magid,2004; Castro M, 2007).The SSSC is electrical controller have the ability to control the energy flow effectively and can be inject series capacitive or inductive voltage to provide fast reaction compensation on transmission lines of high voltage and it can help to enhance in transient state (Jowder,2005; Falehi,2011). The A SSSC can be controlled by the design of the PSS which can enhance the steady and dynamic performance of the state of the power system on a large scale (Ali, 2013).The tuning between PSS and SSSC can be increase the damping in some oscillation modes.

In some previous studies FACTS proposes stability controllers based on artificial intelligence (Shayeghi, 2010). In this paper, this design was made using particle swarm optimization (PSO) to obtain full efficiency and safety in "the single and coordinated design of PSS and SSSC for damping control. A strong design problem of PSS and SSSC-based damping controller is converted to an optimal problem to adjust the controller parameters, PSO is employed in the present work to optimally tune the parameters of the PSS and SSSC controller" . The designed objective is to increase the oscillations damping and improve the stability of power system, to test performance of the proposed controllers ,its applied with a single-machine power system, subjected to severe disturbance under different operating conditions ,the results simulation is carried out by using MATLAB Simulink.

## 2. Power System Modeling

"The single-machine power system shown in Fig. 1 is considered in this study" .  
 ."The system includes a generator, transformer, SSSC and two parallel transmission lines"

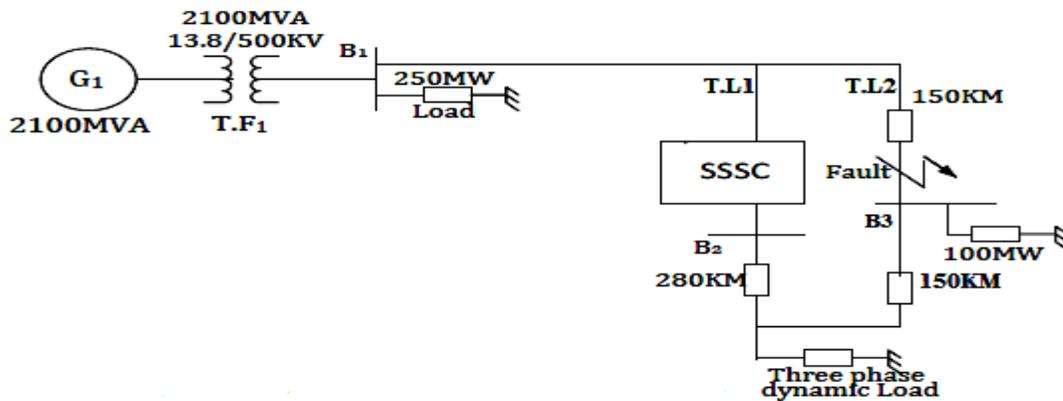


Fig. 1 Single-machine infinite bus power system with SSSC

## 2-1 Generator model

Synchronous machines are one of "the important components of any power system. There are three differential equations representing the dynamic behavior of a synchronous generator. These include mechanical, dynamic and electrical equations"(Jalilvand, 2011):

$$\dot{\delta} = \omega_b(\omega - 1) \quad (1)$$

$$\dot{\omega} = (P_m - P_e - D(\omega - 1))/M \quad (2)$$

$$\dot{E} = (E_{fd} - (x_d - x'_d)i_d - E'_d)/T'_{do} \quad (3)$$

Where,  $\delta$  is angle of rotor,  $\omega$  is speed of rotor,  $p_m$  is input power,  $p_e$  is output power;  $M$  is constant of inertia,  $D$  is damping coefficient,  $E_{fd}$  is the field voltage,  $T'_{do}$  is time constant of the open circuit field;  $i_q$  is q-axis armature current;  $i_d$  is d-axis armature current,  $x'_d$  is the transient reactance of d-axis,  $x_d$  is reactance of d-axis.

## 2-2 The Excitation System And PSS Model

The function of the excitation signal is complementary to increase torque damping rotation in the rotor generator. Increasing the gain of AVR with Exciter leads to increase probability of maintaining the generator synchronization during the occurrence of large disturbances. Therefore the PSS used to improved vibrations damping in the generator rotor during disturbances, the dynamic model of excitation and PSS system in figure 2 can be described as follows (Chow, 2004; Kamwa, 2005):

$$\dot{E}_{fd} = \frac{k_A(V_{ref} - v + u_{pss}) - E_{fd}}{T_A} \quad (4)$$

$$v = (v_d^2 + v_q^2)^{1/2} \quad (5)$$

The five parameters of PSSs are gain  $K_A$  and four time constants  $T_1$  to  $T_4$  must to be optimal values.

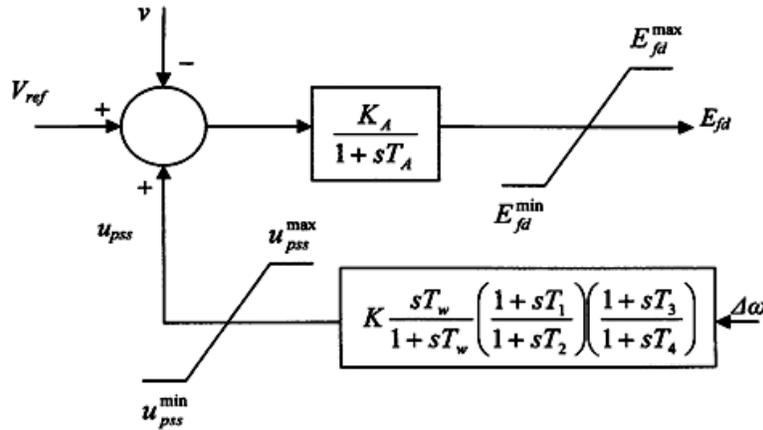


Fig. 2:IEEE type-ST1 excitation system with PSS

### 3.3 SSSC model

The SSSC "acts as a series compensator whose output voltage is fully controllable, independent of line current and kept in quadrature with it, with the aim of increasing or decreasing the voltage drop across the line, therefore controlling the power the basic voltage  $V_q$  is in quadrature with respect to line current, and can either provide capacitive compensation if  $V_q$  leads  $I$  by  $\pi/2$  rad or inductive compensation if  $V_q$  lags  $I$  by  $\pi/2$  rad". A relatively small active power exchange is required to compensate for coupling transformer and switching losses, and maintain the required DC voltage (Khadanga and Satapathy, 2015). Indeed, the SSSC can be controlled in two different operation modes: The SSSC relies on a dc capacitor fed voltage supply electrical converter that generates a three phase voltage at fundamental, that is then injected to a cable through a electrical device connected asynchronous with line . "The active and reactive power in transmission line are controlled by controlling the amplitude and the angle of  $V_q$  ,SSSC give the voltage  $V_q$  to the transmission line". The DC capacitor differential equation can be expressed as below (Shakarami , 2010):

$$\frac{dv_{dc}}{dt} = \frac{3}{2c} K_r M_r (I_q \cos\varphi + I_d \sin\varphi) - \frac{V_{dc}}{CR_p} \quad (6)$$

Where,  $C$  is the capacitor value,  $K_r$  is the ac to dc voltage ratio and  $M_r$  and the modulation ratio and,  $V_{dc}$  is the dc voltage, and  $I_d$  and  $I_q$  are d and q axis the line current , "The SSSC block diagram as shown in figure 3. "The lead-lag controller is preferred by power system utilities, due to the ease in its on-line training and the lack of guaranteed stability by some adaptive and variable structure approaches". "The input and output signals of the controller are  $\Delta\omega$  and  $V_q$ " , "During dynamic conditions the series injected voltage  $V_q$  is modulated to damp system oscillations". The effective value of  $V_q$  in dynamic conditions is:  $V_q = V_{qref} + \Delta V_q$ "

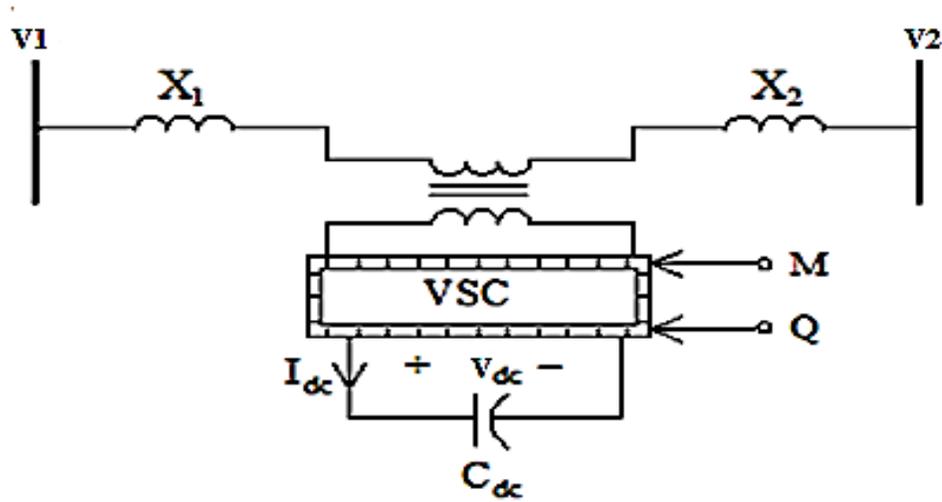


Fig. 3: A SSSC Structure

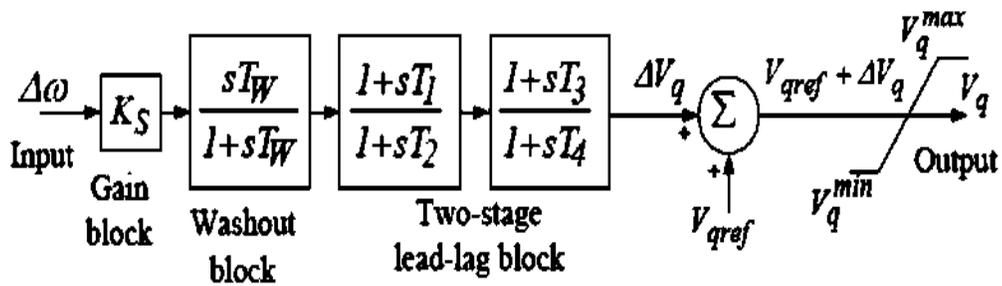


Fig.4: A SSSC Block Diagram

### 3. Problem Formulation

#### 3.1 Stabilizers Structure

The Transfer function of PSS and SSSC-based controllers will be:

$$u = k \frac{ST_w}{1+ST_w} \left( \frac{1+ST_1}{1+ST_2} \right) \left( \frac{1+ST_3}{1+ST_4} \right) \Delta\omega \quad (7)$$

In structure of controller,  $T_w$  is usually predetermined. Searching will done for optimal set of the stabilizer parameters are  $K, T_1, T_2, T_3$  and  $T_4$

#### 3.2 Objective Function and Problem Optimization

The power system and improve transient performance of the power system after subjected to a large disturbance, during large disturbance the deviations in rotor speed  $\Delta\omega$  and power angle  $\delta$  is happen, to minimize deviations we will use the objective function below:

$$J = \int_0^{t_1} |\Delta\omega(X, t)| t dt \tag{8}$$

X represents the controllers parameters and t1 is a range of time

The design problem of SSSC and PSS can be framed as follows: Minimize J

Subject to

$$K^{\min} \leq K \leq K^{\max}$$

$$T_i^{\min} \leq T_i \leq T_i^{\max} \quad i=1, \dots, 4$$

### 3-2 Application of PSO

Application the technique of Particle Swarm Optimization (PSO) for optimization the objective function of equation (8), can be used routines from PSO toolbox [Birge B.]. For calculation of objective function, we can calculate "the modified velocity and position of each particle by calculating the current velocity and the distance from the  $p_{best}$ , to  $g_{best}$  by using equations (9) and (10) (Soliman, 2008; Valle, 2008):

$$v_i(t+1) = w * v_i(t) + c_1 * r_1 * rand(f_i(t) - x_i(t)) + c_2 * r_2 * rand(f_{gd}(t) - x_i(t)) \tag{9}$$

$$x_i(t+1) = x_i + v_i(t+1) \tag{10}$$

Where

$f_i = f_{best}$ ,  $f_{gd} = g_{best}$ , W is weight of inertia,  $c_1$  is cognitive factor and,  $c_2$  "social acceleration factors  $r_1$  and  $r_2$  are random numbers the value of them between 0 and 1.

The flow chart of PSO algorithm" as shown in figure. 5.

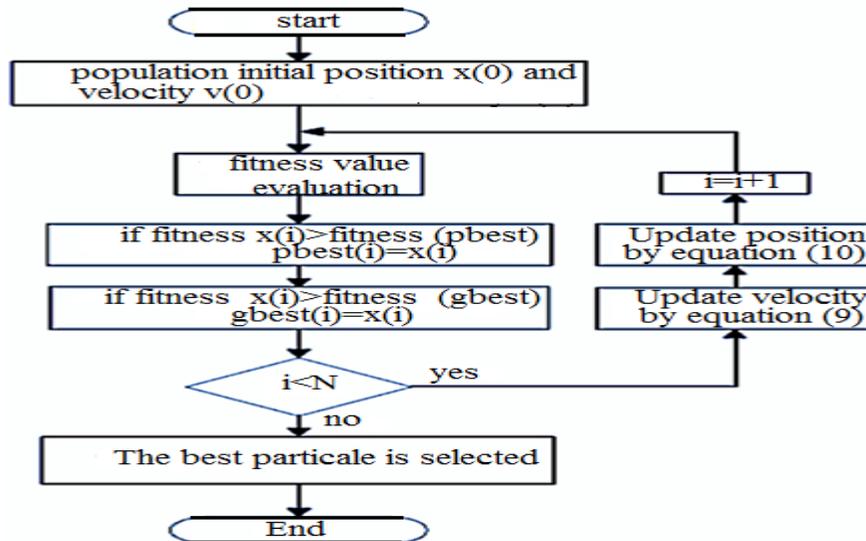


Fig.5: Flowchart of PSO

## 4.The Tuning Of SSSC And PSS

The parameters of PSS and SSSC-based stabilizer can be coordinated tuned individually together to get the best performance of system . The tuning of PSS and SSSC-based stabilizer is addressed at the normal loading point. By using equations (9) and(10) PSO tune the parameters of the two controllers individually in order to minimize the objective function and also PSS and SSSC parameters are tuned at the same time using ( PSO) applying to the problem of optimization above to find the optimum settings for the proposed controllers .

In this study, the parameters of SSSC and PSS are tuned at nominal loading (P=1 pu ,Q=0.15pu) to study the effect of the proposed controllers, it is considered three different load conditions as shown in table (1),values of PSO algorithm parameters are set as shown in table (2) the ranges of the typical parameters that will optimize for PSS and SSSC-based controllers set as shown in table(3) for the tuning and the simulation.

**Table 1:Loading conditions**

Loading condition	values
(P, Q) Light	(0.2, 0.025) p.u
(P, Q) Nominal	(1, 0. 15) pu.
(P, Q)Heavy	(1.25, 0.3) pu.

**Table(2): A specified parameters of PSO algorithm**

Parameters	values
C1	2.0
C1	2.0
W1	0.9
W2	0.4
Swarm Size	30
Generations number	40

**Table(3):typical parameters of SSSC and PSS**

Parameters	SSSC	PSS
Ki	0.01 – 100 s	0.01 – 100 s
T1,T2,T3,T4	0.01 – 2 s	0.01 – 2 s
Tw	a predetermined amount (15s)	a predetermined amount(15s )

## 4- The Tuning Results And Simulation

### 4.1The Optimal Parameters of SSSC And PSS

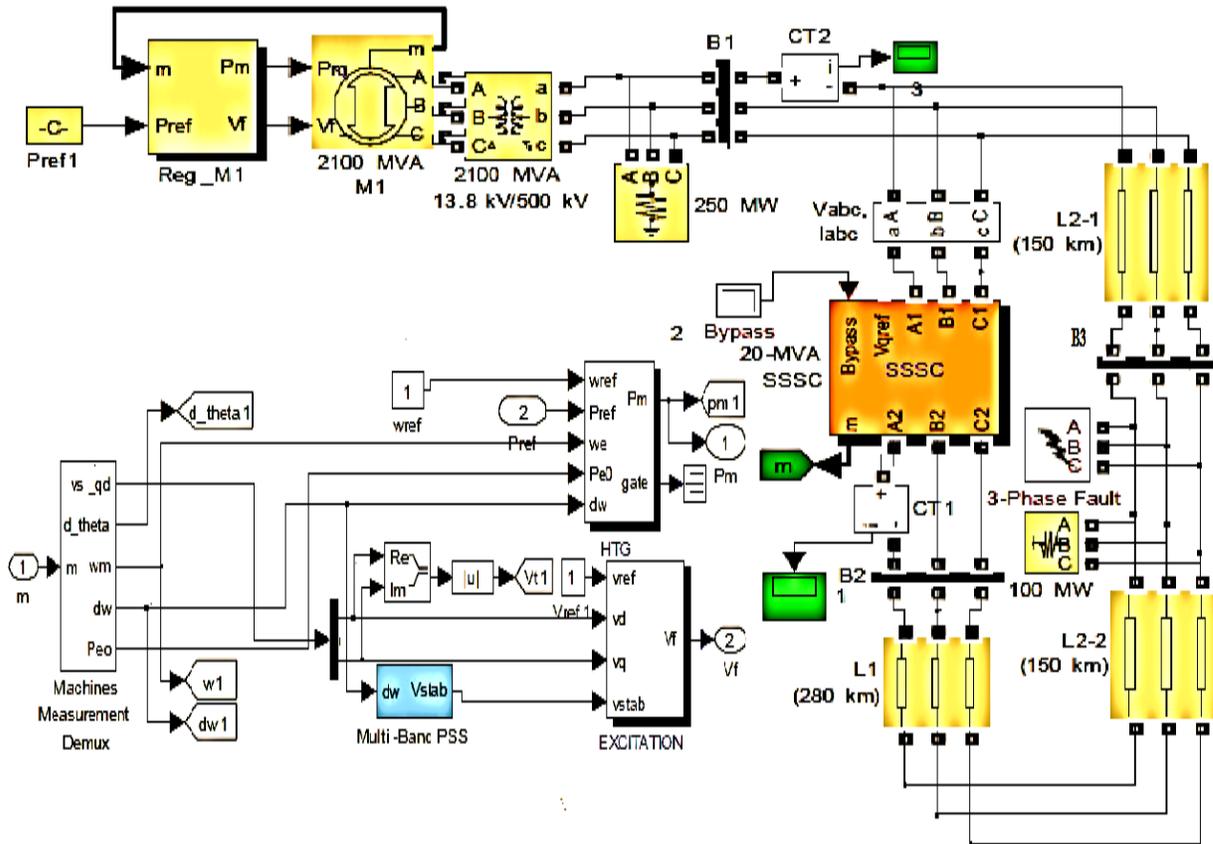
The final optimum parameters for single and coordinated design of the two controllers are given in table (4) below :

**Table (4): optimal parameters of PSS and SSSC**

parameters	Single controller		Coordination between the two controllers	
	PSS	TCPS	PSS	TCPS
$T_1$	0.896	0.524	0.402	0.476
$T_2$	0.312	0.635	0.132	0.185
$T_3$	0.435	0.812	0.249	0.189
$T_4$	0.497	0.511	0.22	0.129
K	53.462	81.31	13.124	87.357

**4.2 Simulation of Non Linear Time Domain**

The proposed designs for the SSSC and the PSS controllers have been simulated with power system in Figure 1. The 6-cycle 3-ph fault at midpoint one of parallel transmission lines (TL2) of the power system considered for studies of non-linear simulation with three operating conditions are shown in Table 1, for the study effect of the two optimal controllers SSSC and PSS when using individually and coordinated design with the power system. Figures 8-11 shows the response of the rotor angle and the rotor speed deviation with above mentioned fault at conditions of nominal, light and heavy loading a MATLAB version 13 SimPowerSystems toolbox [http://www.mathworks.com/products/simpower] used in Complete simulink of power system with PSS and SSSC as in figure(6)



**Fig.6: complete simulink of power system**

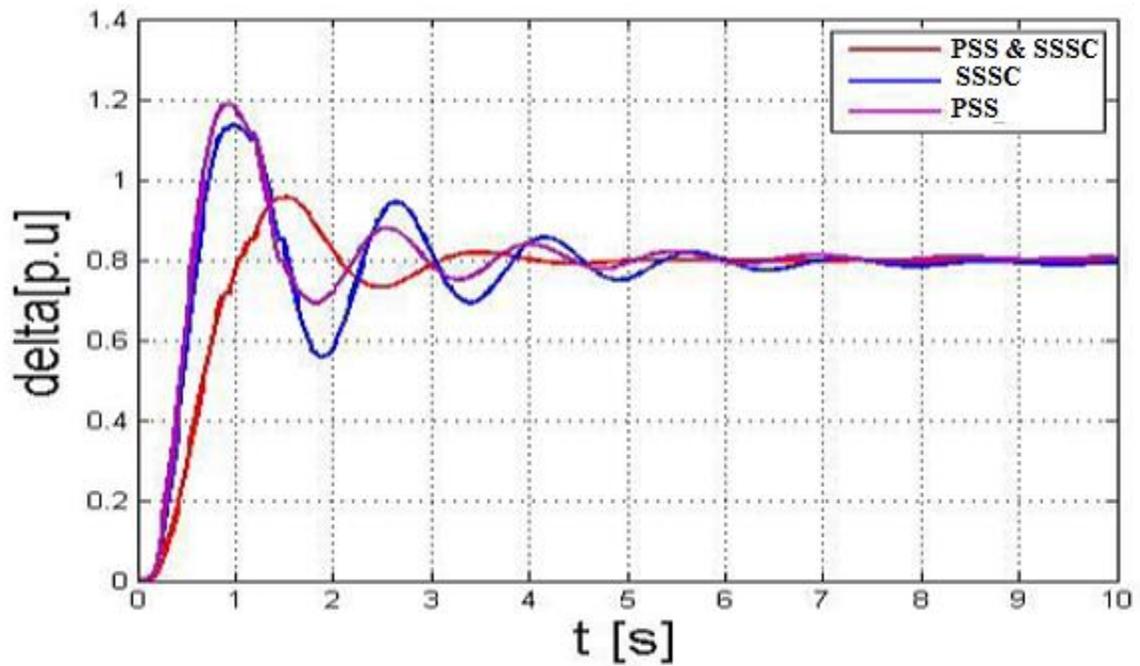


Fig.7:response of generator rotor angle at nominal loading

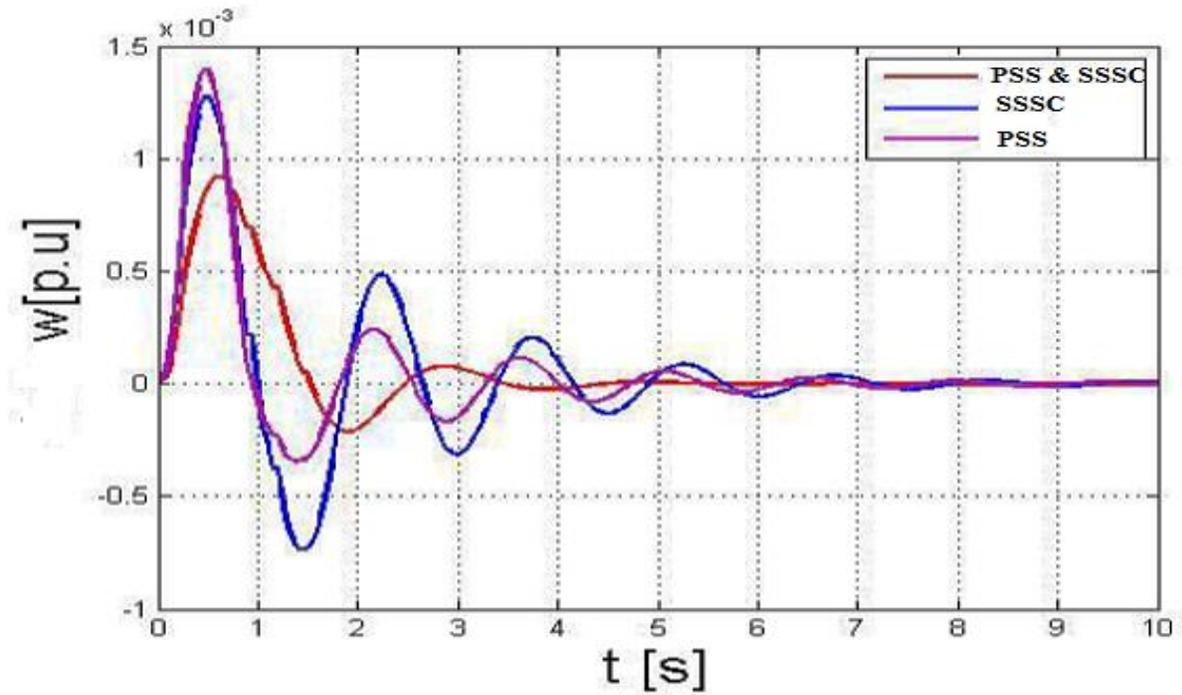


Fig 8: response of generator rotor speed at nominal loading

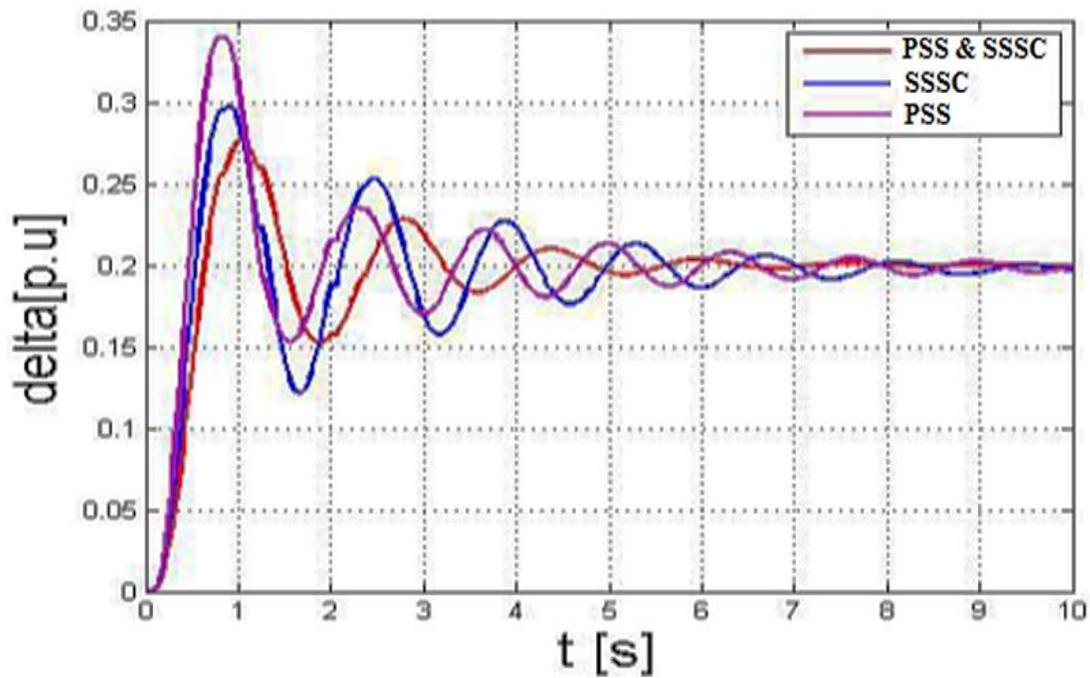


Fig 9: response of generator rotor angle at light loading

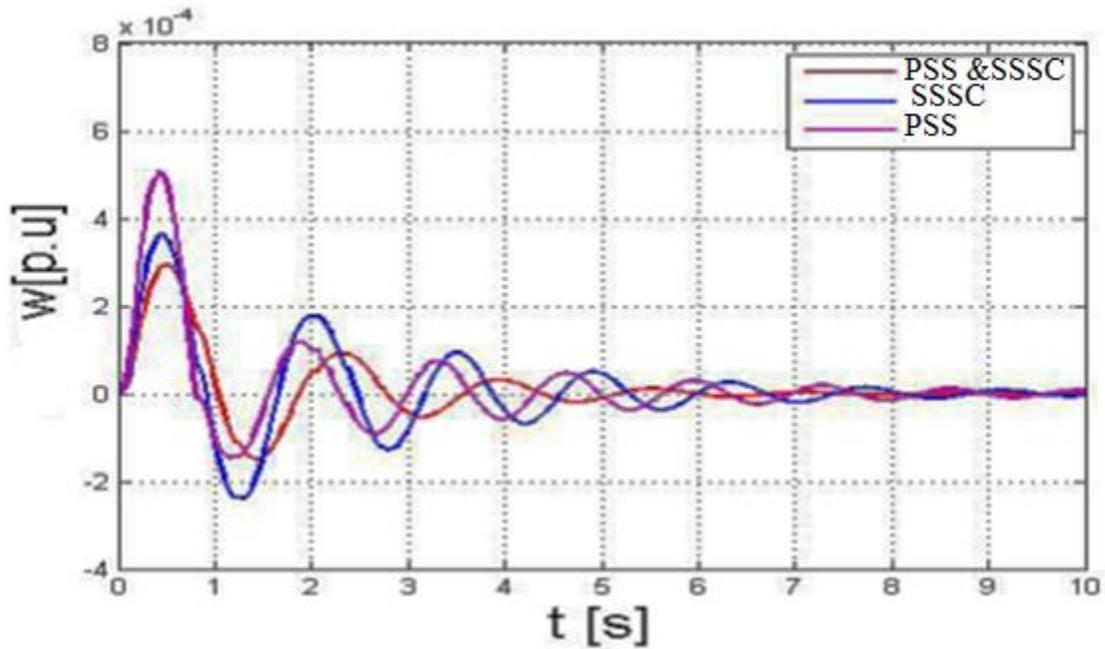


Fig 10: response of generator rotor speed at light loading

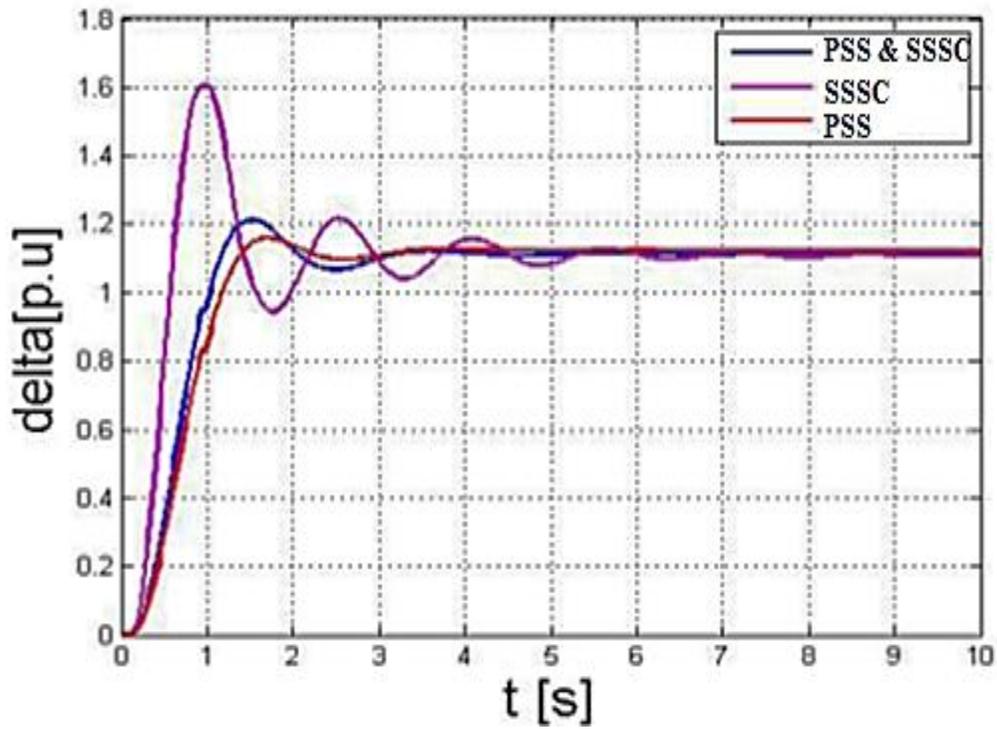


Fig 11: response of generator rotor angle at heavy loading

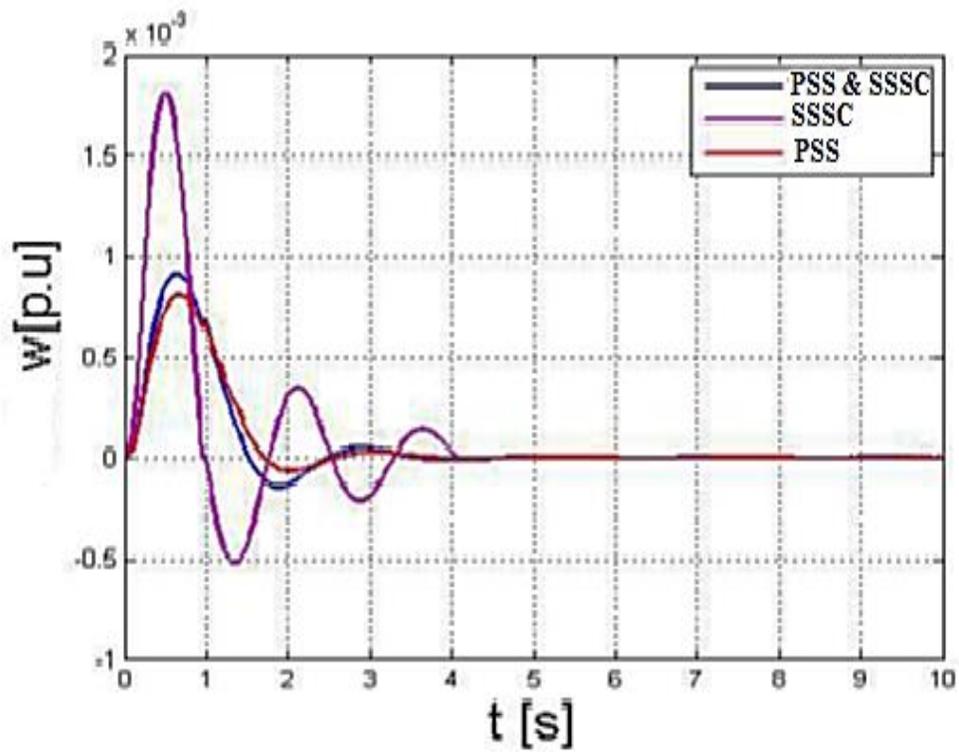


Fig.12: response of generator rotor speed at heavy loading

## 5- Conclusion

When the disturbance is happening in power system, the parameters of this power system (V,P,Q) become unstable even with PSS operating, if a SSSC is connected to a power system, then parameters of system can be stable but if the parameters of PSS and SSSC are tuned by using PSO Algorithm, then parameters of system which make it stable in a quick way. For the design problem of proposed controllers, the objective function was developed to increase damping the power system. The PSO technique used to find the optimal parameters of two controller. Then, the parameters of SSSC with PSS controllers are tuned in the same time make them more effective to increase the oscillations damping and improve the stability of power system. A non-linear simulation achieved by using a MATLAB version 13 SimPowerSystems toolbox for power system with optimal design of SSSC and PSS when the system subjected to 3-phase fault in one of transmission lines. The obtained results of simulation show that the tuning of two controller in same time more effectiveness to increase damping of system oscillations and their ability in improving power stability under severe disturbance with different conditions loading especially at large loading. It can be concluded that the stability of power system is improved when parameters of two controllers are tuned individually but with tuning design of PSS and PSS the oscillations damping of power system more increased and power transient stability is enhanced.

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## APPENDIX

The data of power system in figure 1 are:

### 1) Generator

" $S_B = 2100$  MVA,  $H = 3.7$  s,  $V = 13.8$  kV,  $f = 60$  Hz,  $P_{e0} = 0.75$ ,  $V_{to} = 1.0$ ,  $\delta_o = 41.510$ ,  $R_S = 2.8544 \times 10^{-3}$ ,  $X_d = 1.305$ ,  $X'_d = 0.296$ ,  $X''_d = 0.252$ ,  $X_q = 0.474$ ,  $X'_q = 0.243$ ,  $X_{e0} = 0.18$ ",

$T_d = 1.01$  s,  $T'_d = 0.053$  s,  $T''_{d0} = 0.1$  s.

### 2) Hydraulic Turbine and Governor

" $K_a = 3.33$ ,  $T_a = 0.07$ ,  $G_{min} = 0.01$ ,  $G_{max} = 0.97518$ ,  $V_{gmin} = 0.1$  pu/s,  $V_{gmax} = 0.1$  pu/s,  $R_p = 0.05$ ,  $K_p = 1.163$ ,  $K_i = 0.105$ ,  $K_d = 0$ ,  $T_d = 0.01$  s,  $\beta = 0$ ,  $T_w = 2.67$  s"

### 3) Excitation System and PSS

" $T_{LP} = 0.02$  s,  $K_a = 200$ ,  $T_a = 0.001$  s,  $K_e = 1$ ,  $T_e = 0$ ,  $T_b = 0$ ,  $T_c = 0$ ,  $K_f = 0.001$ ,  $T_f = 0.1$  s,  $E_{fmin} = 0$ ,  $E_{fmax} = 7$ ,  $K_p = 0$ ,  $|\text{upss}| \leq 0.2$  pu";

### 4) Transformer

"2100 MVA, 13.8/500 kV, 60 Hz,  $R_1 = 0.002$ ,  $L_1 = 0$ , D1/Yg connection,  $R_m = 500$ ,  $L_m = 500$ "

### 5) Transmission line

"3-Ph, 60 Hz, Length  $TL_1 = 280$  km,  $TL_2 = 300$  km,  $R_1 = 0.02546$   $\Omega$ / km,  $R_2 = 0.3864$   $\Omega$ / km,  $L_1 = 0.9337 \times 10^{-3}$  H/km,  $L_2 = 1.1264 \times 10^{-3}$  H/ km,  $C_1 = 12.74 \times 10^{-9}$  F/ km,  $C_2 = 7.751 \times 10^{-9}$  F/ km"

### 6) SSSC

" $S_{nom} = 100$  MVA,  $V_{nom} = 500$  kV,  $f = 60$  Hz,  $V_{qmax} = 0.2$ , Max rate of change of  $V_{qref} = 3$ /s,  $R_{cnv} = 0.00533$ ,  $L_{cnv} = 0.16$ ,  $V_{DC} = 40$  kV,  $C_{DC} = 375 \times 10^{-6}$  F,  $KP_{IVR} = 0.00375$ ,  $KI_{IVR} = 0.1875$ ,  $KP_{VdcR} = 0.1 \times 10^{-3}$ ,  $KP_{VdcR} = 20 \times 10^{-3}$ "