Co-ordinated Design of PSS and TCSC Damping Controllers in Multi-machine Power System using PSO

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***Abstract*: This paper presents coordinated control tuning of power system stabilizer (PSS) with thyristor controlled series capacitor (TCSC). The design of proposed coordinated damping controller is formulated as an optimization problem and the controller gains are optimized instantaneously using particle swarm optimization (PSO). Here single machine infinite bus system and the multi-machine power system employed with PSS and TCSC is considered. The coordinated tuning among the damping controllers is performed on the non-linear power system dynamic model. Finally, the proposed coordinated controller performance is discussed with time domain simulations. Different loading conditions are employed on the test system to test the robustness of proposed coordinate controller and the simulation results are compared with different control schemes.**

***Keywords*: Particle swarm optimization, power system stability, PSS, TCSC.**

I. Introduction

During the recent years the demand for power has increased widely but the generation of power and transmission of power is limited due to resources and environmental condition. As a result due to high power demand few transmission lines are loaded heavily and the stability of the system become a power transfer limiting factor. The main purpose of using FACTS controller is to solve various power system and steady state control problems. During the recent studies it has been revealing that the power system can be used. The drive towards deregulated environment may result in simultaneous installation of different FACTS controllers in power system. These multiple FACTS controllers have the potential to interact with each other. This interaction may either deteriorate or enhance system stability depending upon the chosen controls and placement of FACTS controllers. Hence there is a need to study the interaction between the FACTS controllers. The various interactions can potentially occur between the different FACTS controllers, as well as between FACTS controllers and Power System Stabilizers (PSS) in a multi machine power system environment. These likely interactions have been classified into different frequency ranges and various interaction problems between FACTS controllers or FACTS to PSS's from voltage stability or small signal stability view point are presented. The PSS is a device that improves the damping of generator electromechanical oscillations. Stabilizers have been employed on large generators for several decades, permitting utilities to improve stability-constrained operating limits. In order to describe the application of the PSS, it is necessary to introduce general concepts of power-system stability and synchronous generator operation. An explanation regarding small-signal stability, high-impedance transmission lines, line loading, and high-gain fast-acting excitation systems is provided. Transient stability is discussed, including synchronizing and damping torques. The power angle curve is used to illustrate how fault-clearing time and high initial response excitation systems can affect transient stability. The term "power-system stability" has become increasingly popular in generation and transmission. The sudden requirement for power system stabilizers (PSSs) has created confusion about their applicability, purpose, and benefit to the system. This work discusses the fundamentals of the PSS and its effectiveness. The capability to return to stable condition and maintain its synchronism of a synchronous power system following a relatively large disturbance arising out of very ordinary situations such as switching 'on' and 'off' of circuit elements, or clearing of faults etc. is referred as the transient stability in power system of that system. More over the power generation systems are subjected to faults of this kind, and hence it is extremely important for any power engineers to be well-versed with the stability conditions of the system. In normal studies related to transient stability in power system are done for a very small period of time nearly equal to the time required for one swing, which approximates to around 1 sec or even less. If the system is found to be stable during this first swing, it is assumed that in the subsequent swings the disturbance will reduce, and the system will be stable thereafter as is generally the case. Now in order to mathematically determine whether a system is stable or not we need to derive the swing equation of power system Particle Swarm Optimization (PSO) algorithm appeared as a promising algorithm for handling the optimization problems.PSO shares many similarities with GA optimization technique, like initialization of population of random solutions and search for the optimal by updating generations. One of the most promising advantages of PSO over GA is its algorithmic simplicity as it uses a few parameters and easy to implement. In PSO, then potential solutions, called particle, fly through the problem space by following the current optimum particles. a PSO algorithm has been suggested for coordinated design of a TCSC controller and PSS in power systems for enhancing the power system stability. The design problem of PSS and TCSC based controllers is formulated as a time domain based optimization problem. PSO algorithm is employed to search for optimal controller parameters, by minimizing the time domain based objective function, in which the deviation in the oscillatory rotor speed of the generator is involved.

II. MODELING THE POWER SYSTEM WITH TCSC AND PSS

In this, we focus our attention on single machine infinite bus (SMIB) power systems. Since a SMIB system qualitatively exhibits important aspects of the behavior of a multi machine system and is relatively simple to study, it is extremely useful in describing the general concepts of power systems stability, the influence of various factors upon stability, and alternative controller concepts. An infinite bus is a source of constant frequency and voltage either in magnitude and angle. We consider the particular SMIB power system arrangement shown in Fig.1. The actual dynamic response of a synchronous generator in a practical power system when a fault occurs is very complicated including much nonlinearity such as the magnetic saturation. However, the classical third order dynamic generator model has been commonly used for designing the excitation controller.

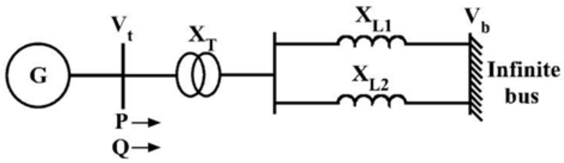

Fig..1 A single machine infinite bus power system.

The classical third-order dynamical model of a SMIB power system Fig..1 can be written as follows :

$$\frac{d\delta(t)}{dt} = \omega(t) - \omega_0$$

$$\frac{d\omega(t)}{dt} = -\frac{D}{2H}\left[\omega(t) - \omega_0\right] - \frac{\omega_0}{2H}\left[P_m - P_e(t)\right]$$

$$\frac{dE_q^1(t)}{dt} = \frac{1}{2H}\left[E_F(t) - (X_d - X_d^1)I_d(t) - E_q^1(t)\right]$$

Where

$$E_{fd}(t) = K_A E_F(t)$$

$$E_q(t) = \frac{X_{ds}}{X_{ds}^1}E_q^1(t) - \frac{X_d - X_d^1}{X_{ds}^1}V_b\cos(\delta(t))$$

$$P_e(t) = \frac{E_q(t)V_b}{X_{ds}}\sin(\delta(t))$$

$$X_{ds} = X_d + X_T + X_L$$

$$X_{ds}^1 = X_d^1 + X_T + X_L$$

δ (t) is the rotor angle of the generator (radians), ω(t) is the speed of the rotor of the generator (radian/sec), ωo is the synchronous machine speed (radian/sec), D is the damping constant (pu), H is the inertia constant , Pm is the mechanical input power of the generator (pu), Pe(t) is the active electrical power delivered by the generator (pu), Eq(t) is the EMF of the q-axis of the generator (pu), E1 q(t) the transient EMF in the q-axis of the generator (pu), E*fd*(t) is the equivalent EMF in the excitation winding of the generator (pu), T' do is the d-axis transient short circuit time constant (sec), KA is the gain of the excitation amplifier, Efd(t) is the control input of the excitation amplifier with gain KA, Xds is the total direct reactance of the system (pu), X'ds is the total transient reactance of the system (pu), Xd is the d-axis reactance of the generator (pu), X'd is the d-axis transient reactance of the generator (pu), XT is the reactance of the transformer (pu), XL is the reactance.

III. MODELLING OF POWER SYSTEM STABILIZER

Models for different types of excitation systems in use are described below. We will illustrate the method of incorporating these models into a transient stability program by considering the excitation system model shown in Fig.2. It represents a bus-fed thyristor excitation system (classified as type STIA1) with an automatic voltage regulator (AVR) and a power system stabilizer (PSS).

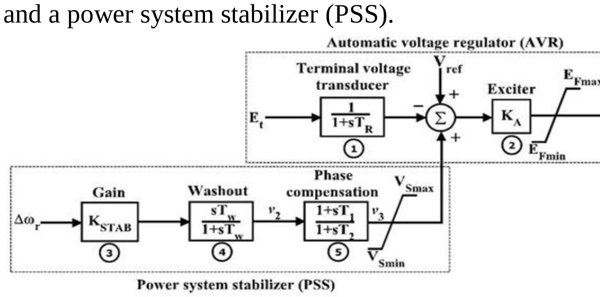

Fig. 2 Thyristor excitation system with AVR and PSS

The AVR regulator model (block 1) shown in Fig.2 has been simplified to include only those elements that are considered necessary for representing a specific system. Parameter *T*R represents the terminal voltage transducer time constant. A high exciter gain (block 2), without transient gain reduction or derivate feedback, is used. The nonlinearity associated with the model is that due to the ceiling on the exciter output voltage represented by (*E*Fmax, *E*Fmin*)* and PSS output voltage (*V*Smax, *V*Smin*)*.The PSS representation in Fig.2 consists of three blocks: a phase compensation block, a signal washout block, and again block. The phase compensation block (block 5) provides the appropriate phase-lead characteristic to compensate for the phase lag between the exciter input and the generator electrical (air-gap) torque. The signal washout block (block 4) serves as a high-pass filter, with the time constant *T* W high enough to allow signals association with oscillations in *w* to pass unchanged. Without it, steady changes in speed would modify the terminal voltage. The stabilizer gain *K*STAB(block3) determines the amount of damping introduced by the PSS. From block 1 of Fig.2, we may write:

$$pv_1 = \frac{1}{T_R}(E_t - v_1)$$

From blocks 3 and 4,

$$pv_2 = K_{STAB}\, p\Delta\omega_r - \frac{1}{T_W} v_2$$

$$pv_3 = \frac{1}{T_2}(T_1 pv_2 + v_2 - v_3)$$

The stabilizer output VS is

$$V_S = v_3$$

With

$$V_{S\max} \geq V_S \geq V_{S\min}$$

From block 2, the exciter output voltage is

$$E_{fd} = K_A[V_{ref} - v_1 + v_s]$$

With

$$E_{F\max} \geq E_{fd} \geq E_{F\min}$$

Initial value of excitation system variables

$v_1 = E_t$, $v_2 = 0$, $V_S = 0$

The AVR reference is

$$V_{ref} = \frac{E_{fd}}{K_A} + v_1$$

Thus Vref takes a value appropriate to the generator loading condition prior to the disturbance.

IV .MODELLINGN OF THYRISTOR CONTROLLED SERIES CAPACITOR (TCSC):

A TCSC Controller consists of a fixed series capacitor (FC) in parallel with a thyristor controlled reactor (TCR). The TCR is formed by a reactor in series with a bi-directional thyristor valve that is fired with a phase angle α ranging between 900 and 1800 with respect to the capacitor voltage. For the load flow and dynamic stability analysis studies, a TCSC can be modelled as a variable reactance. In this modelling approach, the effect of the FACTS devices on the power flow is represented as a variable current injection at the terminal buses of the lines. The use of thyristor control to provide variable series compensation makes it attractive to employ series capacitors in long lines. A major advantage is that the SSR problem (Torosional Interaction) is significantly reduced. The feasibility of fast control of thyristor valves enables the improvement of stability and damping of oscillations using appropriate control strategies. According to the variation of the conduction angle (σ) or the thyristor firing angle (α), the process can be modelled as a fast switch between corresponding reactance offered to the power system. There is a steady state relationship between α and the reactance XTCSC. This relationship can be described by the following equation:

$$X_{T\csc} = X_c - \frac{X_c^2(\sigma + \sin\sigma)}{(X_c - X_p)\pi} + \frac{4X_c^2\cos^2\left(\sigma/2\right)\left[k\tan\left(k\sigma/2\right) - \tan\left(k\sigma/2\right)\right]}{(X_c - X_p)(k^2-1)\pi}$$

Where

: *c X* Nominal reactance of the fixed capacitor C

: *p X* Inductive reactance of inductor L connected in parallel with C

σ : Conduction angle of TCSC

α : Firing angle of TCSC

k : Compensation ratio

A TCSC is modelled here as a variable capacitive reactance within the operating region defined by the limits imposed by α.

Thus,

$$X_{TCSC_{\min}} \leq X_{TCSC} \leq X_{TCSC_{\max}},$$

$$X_{TCSC_{\min}} = X_{TCSC}(\alpha_{\max}) = X_c$$

$$X_{TCSC_{\max}} = X_{TCSC}(\alpha_{\min})$$

V. PARTICAL SWARM OPTIMIZATION (PSO):

The conventional technique can be used to design a robust controller but the designed controller by this method is usually complicated with high order and the control parameters values are difficult to select. To solve this problem we propose a new design technique called "Particle swarm optimization". Particle Swarm Optimization (PSO) technique, developed by Kennedy and Eberhart, is found applicability and has been used extensively in solving various problems in power systems. Introduction of PSO to search for optimal settings of rule based PSS have been discussed in below. Multi-objective design of multi-machine power system stabilizers using particle swarm optimization (PSO) is proposed in following. Power system stability enhancement via excitation and FACTS-based stabilizers is thoroughly investigated. Here, eigenvalue-based objective function to increase the system damping and improve the system response is developed and it is optimized using real-coded genetic algorithm. However, from an evolutionary point of view, the performance of the PSO is better than that of GA and the authors claimed that PSO arrives at its final parameter values in fewer generations than the GA. Moreover the authors tested several stabilizers like PSS, SVC, TCSC and TCPS individually to enhance system stability. PSO has a flexible and well balanced mechanism to enhance the global and local exploration abilities. Compare to GA, PSO is easy to implement and it consists of only few Parameters to adjust. The position and velocity vectors of the ith particle in the D-dimensional space can be represented as *Xi* (*xi*1, *xi*2, ..., *xid*) and *Vi* (*vi*1, *vi*2, ..., *vid*) respectively. The particles in the optimization problem share their information with each other and run towards the best trajectory to find optimum solution in iterative process. In each iteration particles will update their velocities and positions by using the following equations:

$$V_{i,\,iter+1} = wV_{i,\,iter} + c_1 r_1 (P_{i,\,iter}^{best} - X_{i,\,iter}) + c_2 r_2 (G_{i,\,iter}^{best} - X_{i,\,iter})$$

$$X_{i,\,iter+1} = X_{i,\,iter} + V_{i,\,iter+1}$$

Where *Vi*, *iter* and *Xi*, *iter* represent the velocity vector and the position vector of ith particle at iteration 'iter', The constants *c1* and *c2* are the positive cognitive and social components that are responsible for varying the particle velocity towards the pbest and gbest, respectively, *r1* and *r2* are two random numbers in the range [0-1]. The inertia weight *w* is responsible for dynamically adjusting the velocity of the particles. To enhance the efficiency of PSO, one can adjust the inertia weight *w* to linearly reduce during the iterations. The inertia weight is updated by the following equation is:

$$w = (w_{\max} - w_{\min}) \times \left(\frac{iter_{\max} - iter}{iter_{\max}}\right) + w_{\min}$$

where *iter*max is the maximum number of iterations and iter is the current number of iteration. *w*max and *w*min are maximum and minimum values of inertia weight respectively. The typical range of *w* from 0.9 at the beginning of the search to 0.4 at the end of the search

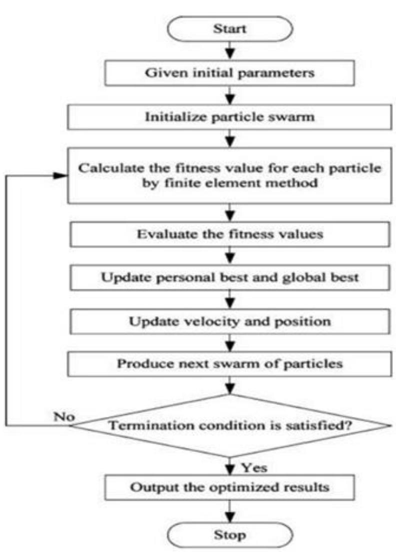

Fig.3.Flowchart of the proposed PSO technique

Hence, the particles in the swarm can update their velocities and positions by using the following equations:

$$V_{i,\,iter+1} = K\,[wV_{i,\,iter} + c_1 r_1 (P_{i,\,iter}^{best} - X_{i,\,iter}) + c_2 r_2 (G_{i,\,iter}^{best} - X_{i,\,iter})]$$

$$X_{i,\,iter+1} = X_{i,\,iter} + V_{i,\,iter+1}$$

$$\text{where } K = \frac{2}{\left|2 - \varphi - \sqrt{\varphi^2 - 4\varphi}\right|},\ \varphi = c_1 + c_2, \varphi > 4$$

Usually c1 and c2 are selected in the range of 0 to 4.

In population based optimization methods, the policy is to encourage the individuals to roam through the entire search space without clustering around local optima during the initial stages. However, during latter stages to find the optimum solution efficiently convergence towards the global optima should be encouraged. The concept of time-varying acceleration coefficients (TVAC) c1 and c2 in addition to time-varying inertia weight factor is introduced in advanced adaptive PSO technique such that AAPSO can efficiently control the local search and provide adequate convergence towards the global optimum solution. During initial stages a large c1 and small c2 allows the particles to move around search space instead of moving the population best prematurely. At latter stages a small c1 and large c2 allows the particles to converge towards the global optima. Acceleration coefficients are adaptively changed as follows:

$$c_1 = c_1^f \left(\frac{iter}{iter_{\max}}\right) + c_1^i \left(\frac{iter_{\max} - iter}{iter_{\max}}\right), c_1^f < c_1^i$$

$$c_2 = c_2^f \left(\frac{iter}{iter_{\max}}\right) + c_2^i \left(\frac{iter_{\max} - iter}{iter_{\max}}\right), c_2^f > c_2^i$$

SMIB with PSS and TCSC:

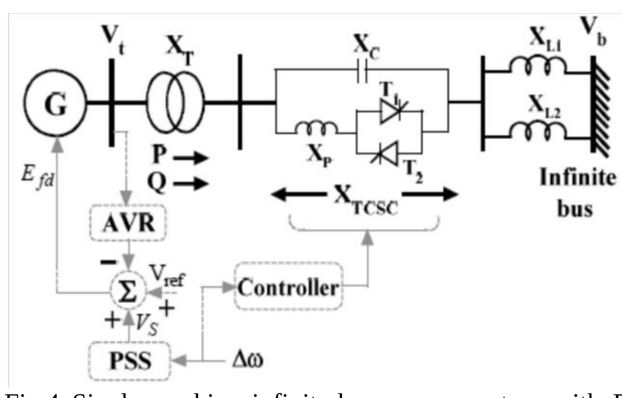

Fig.4 Single-machine infinite-bus power system with PSS and TCSC controller.

Simultaneous Coordinated Design using Particle Swarm Optimization

The proposed controller must be able to work well under all operating conditions, while the improvement for the damping of the critical modes is necessary. Since the select

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ion of the TCSC damping controller and PSS parameters is a complex optimization problem. Thus, to acquire an optimal combination and to improve the optimization synthesis and find the global optimum value an PSO algorithm has been employed. A performance index based on the system dynamics after an impulse disturbance alternately occurs in the system is organized and used as the objective function for the design problem. In this study, an ITAE is taken as the objective function. Since the operating conditions in the power systems are often varied, a performance index for an operating point (Nominal loading) is defined as follows:

Objective function:

$$ITAE = \int_0^{t_{sim}} t|\omega_1(t) - \omega_0(t)|dt$$

Where ω 1(t) , ω0 *(t)* are measured speeds and reference speeds and sim t is the time range of simulation In order to improve the system response in terms of the settling time and overshoots we have to minimize this objective function. The design problem can be formulated as the following constrained optimization problem, where the constraints are the POD (power oscillation damping) controller parameter bounds.

Power Flow Solution by Newton-Rapshon Method:

Here, Load flow analysis is carried out for three machine nine bus system using Newton-Raphson approach. From this analysis we will know the amount of power flowing from one bus to another bus and we will know line losses and total losses occurred in the lines and in the system. The Newton-Raphson (NR) method is a powerful method of solving non-linear algebraic equations. Because of its quadratic convergence, Newton's method is mathematically superior to the Gauss-Seidel method and is less prone to divergence with ill conditioned problems. It works faster, and is sure to converge in most cases as compared to the Gauss-Siedel (GS) method. It is indeed the practical method of load flow solution of large power networks. Its only drawback is the large requirement of computer memory, which can be overcome through a compact storage scheme. One of the main strengths of the Newton- Raphson method is its reliability towards convergence. Contrary to non Newton-Raphson solutions, convergence is independent of the size of the network being solved and the number and kinds of control equipment present in the system.

Three-machine nine-bus system:

A classical study will be presented here on nine bus power systems that have three generators and three loads as shown in fig.5. The classical model of synchronous machine is used to study the stability of a power system for a period of time during which the system dynamic response is dependent largely on the stored kinetic energy in the rotating masses. The classical model is the simplest model is used in studies of a power system dynamics and requires minimum amount of data. A classical study will be presented here on nine bus power systems that have three generators and three loads as shown in above. The input bus data for the considered system are given in Table1 and input transmission line data given in Table 2 . The transmission line impedances and line charging admittances are in per unit.

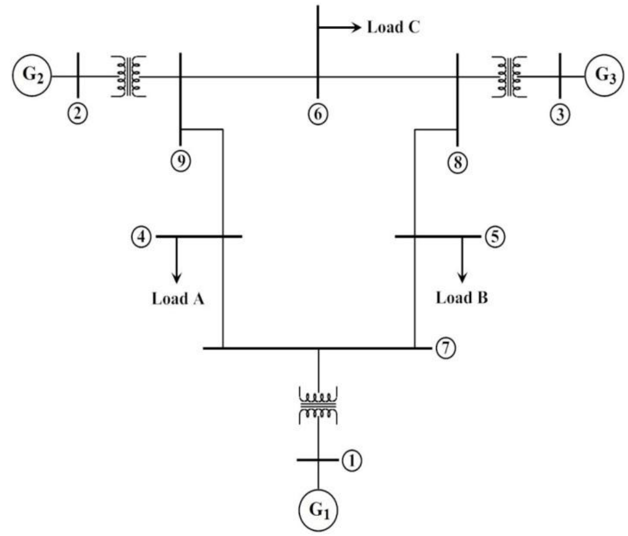

Fig.5. Single line diagram of Three-machine nine-bus system

Table 1: Input Bus Data for Three Machine Nine Bus System

Bus no	Type	Voltage		Generation		load	
		|v|	θ	P	Q	P	Q
1	slack	1.040	0.000	0.000	0.000	0.000	0.000
2	P-V	1.025	0.000	1.63	0.000	0.000	0.000
3	P-V	1.025	0.000	0.85	0.000	0.000	0.000
4	P-Q	0.000	0.000	0.000	0.000	1.25	0.5
5	P-Q	0.000	0.000	0.000	0.000	0.90	0.30
6	P-Q	0.000	0.000	0.000	0.000	1.00	0.35
7	P-Q	0.000	0.000	0.000	0.000	0.000	0.000
8	P-Q	0.000	0.0 00	0.000	0.000	0.000	0.000
9	P-Q	0.000	0.000	0.000	0.000	0.000	0.000

Assuming base quantity of 100MVA and 100KV

Table 2. Input Transmission Line Data (p.u.)

Bus no	Line Code	Impedance (R+jX)	Line charging admittance
1	1-7	0+j0.0576	0.000
2	7-4	0.01+j0.085	0+j0.088
3	7-5	0.017+j0.092	0+j0.079
4	4-9	0.032+j0.061	0+j0.153
5	5-8	0.039+j0.17	0+j0.179
6	2-9	0+j0.0625	0.000
7	9-6	0.0085+j0.07	0+j0.0745
8	6-8	0.0119+j0.10	0+j0.1045
9	3-8	0+j0.0586	0.000

Table 3 Bus data after TCSC included in the system

Bus no	Type	Voltage		Generation		Load	
		|v|	θ	P	Q	P	Q
1	slack	1.040	0.000	0.732	0.243	0.000	0.000
2	P-V	1.025	5.574	1.63	0.021	0.000	0.000
3	P-V	1.025	2.405	0.85	-0.12	0.000	0.000
4	P-Q	0.998	-3.397	0.000	0.000	1.25	0.5
5	P-Q	1.015	-4.510	0.000	0.000	0.90	0.30
6	P-Q	1.018	-2.364	0.000	0.000	1.00	0.35
7	P-Q	1.027	-2.264	0.000	0.000	0.000	0.000
8	P-Q	1.033	-0.291	0.000	0.000	0.000	0.000
9	P-Q	1.029	0.029	0.000	0.000	0.000	0.000

Table 4. Power Flow Results with TCSC Controller

Power flow		Power at bus & Line flow			Line Loss	
From	To	MW	Mvar	MVA	MW	Mvar
1	7	0.73264	0.247	0.771	0.000	0.035
2	9	1.63	0.021	1.634	0.000	0.158
3	8	0.85	-0.125	0.858	0.000	0.043
4	7	-0.27	-0.39	0.489	0.0017	-0.164
	9	-0.98	-0.102	0.986	0.03	-0.256
5	7	-0.452	-0.128	0.473	0.00342	-0.143
	8	-0.451	-0.173	0.486	0.00771	-0.3474
6	9	-0.617	-0.142	0.632	0.00313	-0.129
	8	-0.389	-0.209	0.442	0.00186	-0.0207
7	1	-0.732	-0.211	0.768	0.000	0.035
	4	0.276	0.235	0.362	0.00172	-0.164
	5	0.451	-0.018	0.459	0.00342	-0.143
8	5	0.459	-0.163	0.489	0.00771	-0.344
	6	0.391	0.0005	0.394	0.00186	-0.207
	3	-0.85	0.016	0.866	0.000	0.043
9	4	1.01	-0.144	1.021	0.031	-0.256
	2	-1.63	0.137	1.631	0.000	0.158
	6	0.614	0.017	0.617	0.0031	-0.124
	Total loss				0.0488	-1.013

Dynamic Modelling Of Three Machine Nine Bus System:

TCSC Based Damping Controller

The TCSC damping controller can be modelled as a variable reactance for the load flow and dynamic stability studies. The controller structure of TCSC is shown in Fig.3. The dynamic equation for reactance of TCSC is given by

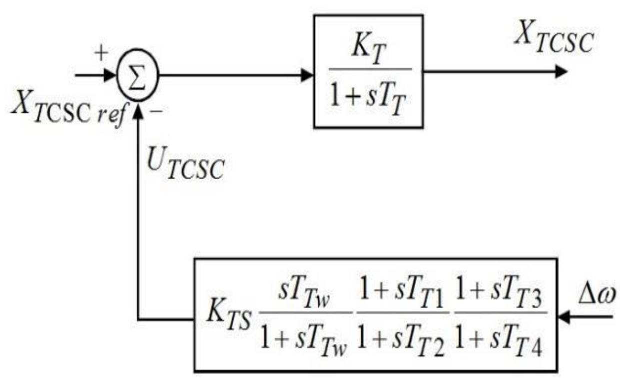

Fig.5. Structure of the TCSC damping controller

$$\dot{X}_{TCSC} = \frac{1}{T_T}\left[K_T(X_{TCSCref} - U_{TCSC}) - X_{TCSC}\right]$$

Where, *XTCSCref* is the reference reactance of TCSC, KT and TT are the gain and time constant of the TCSC. *UTCSC* is the output of conventional lead-lag TCSC damping stabilizer.

V1. SIMULATION RESULTS

The power system stabilizer (PSS) and thyristor controlled series compensator (TCSC) are employed in single machine infinite bus system to damp out low frequency oscillations occurred in the system when severe disturbance taken place at any one of the transmission lines. The employment of these controllers will improve the transient stability of in single machine infinite bus system. In this chapter we will go through the results of single machine infinite bus system equipped with PSS and TCSC damping controllers without coordination and with coordination using particle swarm optimization. Similarly we will go through the results coordination of PSS and TCSC damping controllers in Three machine Nine bus multi machine power system using particle swarm optimization. The close-loop behaviour of the system with different control schemes is simulated using MATLAB programming. A three phase fault is applied at one of the transmission line is considered for analysis of SMIB system with TCSC. The performance of the system is:

Analysed under following different loading conditions:
a) Heavy loading: Pe=1.2p.u. and Qe=0.35p.u.
b) Lightly loading: Pe= 0.8p.u. and Qe=0.15p.u.
The fault that we consider here is a symmetrical three-phase short circuit fault on one of the parallel lines at a point which is very nearer to the generator bus bar, occurs at a time t=1sec, and it is cleared at t=1.1sec (i.e. the fault is applied for 6 cycles).Here frequency considered is 60 Hz. The results of time responses computed with the alternative controllers for nominal loading, heavy loading and lightly loading respectively are shown in Fig. 7 to 9 The responses of rotor angle variation, rotor speed variation are shown in figures7 (a) and 7(b) respectively.

(a). Heavy Loading Condition

To test the robustness of proposed coordinated controller the test system is operated even in heavy loading condition. The Fig.7(a),(b),(c),(d) represents the rotor angle change of Generator 2 and Generator 3 with respect to Generator 1 and rotor speed change of Generator 2 and Generator 3 with respect to Generator 1.From the results the test system without any controller unstable and the generators are loses their synchronism. However the test system with coordinated controller shows better damping as well as adequate settling time compared with individual controllers. In heavy loading condition also the proposed controller performs well in all accepts.

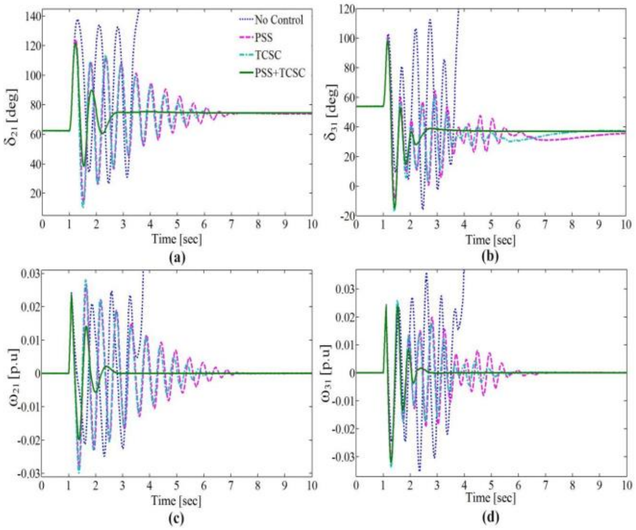

Fig.7.System dynamic response for Heavy loading (a) Rotor angle change of δ21(b) Rotor angle change of δ 31(c) Rotor speed change of ω21 (d) Rotor speed change of ω31

(b) Lightly Loading (Pe= 0.8p.u. and Qe=0.15p.u.)

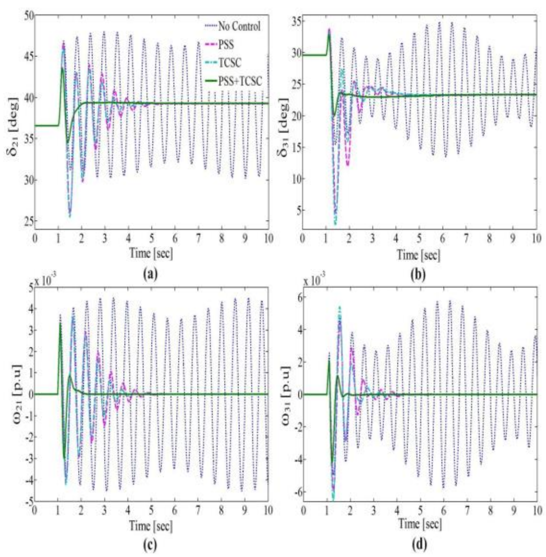

Fig8 System dynamic response for Lightly loading (a)Rotor angle change of δ21(b) Rotor angle change of δ31 (c) Rotor speed change of ω21(d) Rotor speed change of ω31

CONCLUSIONS:

In this paper, An optimized coordinated control of a power system stabilizer (PSS) with TCSC based damping controller is discussed. An objective function is minimized using PSO for finding the optimal control parameters of coordinated controller. Different control schemes are employed on the test system to investigate the performance of the proposed controller. The time domain simulation of a non-linear system is carried out in MATLAB software package. The robustness of the proposed coordinated controller is investigated by testing its performance under different loading conditions. The simulation results show that the test system dynamic performance and overall damping effect are enhanced by simultaneous tuning of PSS and TCSC damping controllers. Therefore, coordinated control of PSS and TCSC based damping controller provides better damping of power oscillations.

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