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A Study of Coordinated TCSC and PSS Damping Controller in a Multi Machine System using PSO To Improve Power System Stability

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***Abstract*— This paper investigates a robust simultaneous design technique of PSS and TCSC damping controller in order to mitigate the power system oscillations. The design problem is formulated as an optimization problem and an objective function is created. PSO algorithm is used to minimize the objective function and find out the optimal values of controller gains and the time constants. Time – domain simulations are carried out in MATLAB/ Simulink and the coordinated system is tested in multi machine system. Results reveal that the power system oscillations are damped out with coordinated control of PSS and TCSC in a multi machine system.**

***Keywords*— FACTS devices, Power system stabilizer, Power system stability, Particle swarm optimization, Thyristor controlled series capacitor .**

I INTRODUCTION

The power system is continuously is being subjected to a variety of disturbances. Large disturbances include severe lightning strokes, loss of transmission lines carrying bulk power due to overloading or voltage collapse due to heavy load or sudden increase in demand of reactive power. The power system must be capable of withstanding the disturbance either small or large and must operate satisfactorily under these conditions and thus meet the load demand. A variety of power electronics based devices known as flexible ac transmission system devices (FACTS) offer high speed, flexibility and reliability. TCSC is one of the FACTS devices that plays an impotant role in power systems such os optimal control of power flow, providing series compensation, removing sub-synchronous resonance (SSR), damping out oscillations thereby enhancing the power system stability. The main purpose of Power system stabilizer (PSS) is to sense changes in the generatot output power and by scheming the excitation value it reduces the power swings in the system. But PSS is not capable of damping out the oscillations in a multi machine power system alone, so in this work a robust coordinated design of PSS and TCSC damping controller has been proposed whose controller parameters are optimized using a population based algorithm known as Particle Swarm Optimization (PSO). A typical two machine system is considered for investigating the performance of PSS and TCSC. A MATLAB simulation is carried out to demonstrate the performance of PSS and TCSC in mitigating power system oscillations and thereby improving the transient stability of the power system.

II MODELING OF PSS AND TCSC

A. PSS Modeling [1], [6]

Fig 1. Shows the transfer-function model of lead-lag based controller structure of PSS. The stabilizing signal of PSS can be given as:

$$u_{PSS} = K_{PSS}\frac{sT_W}{1+sT_W}\left(\frac{1+sT_{1PSS}}{1+sT_{2PSS}}\right)\left(\frac{1+sT_{3PSS}}{1+sT_{4PSS}}\right)\Delta\omega \qquad (1)$$

Where,

K_{PSS}= Stabilizer gain,

T_W= Washout time constant,

$T_{1PSS}, T_{2PSS}, T_{3PSS}, T_{4PSS}$= Time constants of lead-lag network of PSS.

The washout block in the controller structure, is used to reduce the over-response of the damping during severe events. It is a high pass filter(HPF) with purpose to respond only to oscillations in speed and block the dc offsets. A washout time of 10 sec or less is recommended to quickly remove the low frequency oscillations.

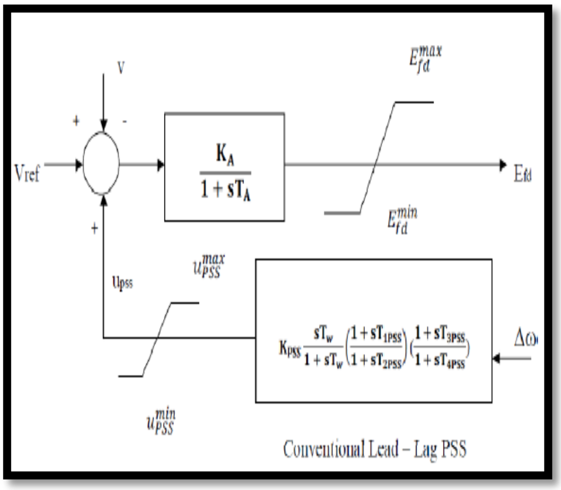

Fig 1 Excitation system model with AVR and PSS

B. TCSC Modeling [1], [9]

Fig 2. Shows the transfer-function model of lead-lag based controller structure of TCSC. The stabilizing signal of TCSC can be expressed as:

$$u_{TCSC} = K_{TCSC} \frac{sT_W}{1+sT_W} \left(\frac{1+sT_{1TCSC}}{1+sT_{2TCSC}}\right) \left(\frac{1+sT_{3TCSC}}{1+sT_{4TCSC}}\right) \Delta\omega \qquad (2)$$

Where,

K_{TCSC} = Gain of TCSC

T_W = Washout time contant

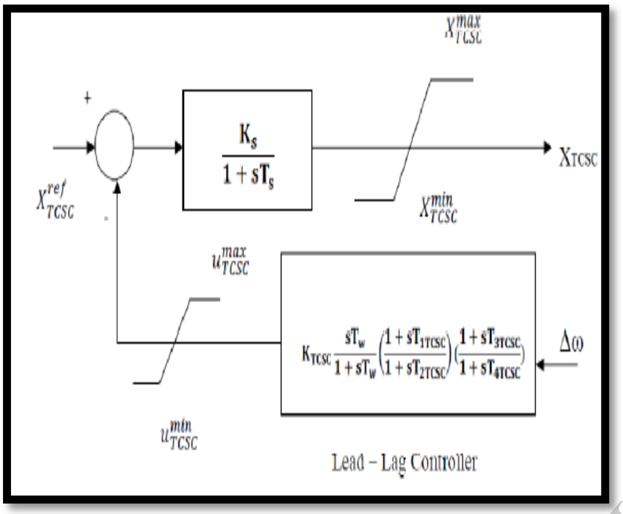

Fig 2 Structure of Lead-Lag based TCSC Controller

III PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) is an efficient, robust and simple optimization technique developed by Kennedy and Eberhart and is used in solving various problems in power systems. PSO is a stochastic population based optimization technique that is derived from socio-psychological theory. This technique is inspired by flock of birds circling over an area where they can smell their source of food. The bird who is closest to the food chirps the loudest and other birds tend to move in his direction. It is a computational method that tries to improve a candidate solution iteratively with a given measure of quality. The position and velocity vectors og the ith particle in D-dimensional space can be given as $X_i = (x_{i1}, x_{i2}, \ldots\ldots . x_{id})$ and $V_i = (v_{i1}, v_{i2}, \ldots\ldots v_{id})$ respectively. In each iteration particles will update their velocities and positions by using following quation:

$$V_{i,iter+1} = wV_{i,iter+1} + c_1 r_1 (P^{best}{}_{i,iter} - X_{i,iter}) + c_2 r_2 (G^{best}{}_{i,iter} - X_{i,iter}) \qquad (3)$$

$$X_{i,iter+1} = X_{i,iter+1} + V_{i,iter+1} \qquad (4)$$

Where, $V_{i,iter+1}$ and $X_{i,iter+1}$ represent the velocity vector and the position vector of the ith particle at iteration 'iter', $P^{best}{}_{i,iter}$ and $G^{best}{}_{i,iter}$ are the personal best position of the ith particle and global best position of swarm at iteration 'iter'. The constants c_1 and c_2 are the positive cognitive and social components that are held for varying the particle velocity towards pbest and gbest respectively, r_1 and r_2 are random numbers generated in range of [0-1]. The inertia weight is responsible for adjusting the velocity of the particles and is updated by following equation:

$$w = (w_{max} - w_{min}) * \left[\frac{iter_{max} - iter}{iter_{max}}\right] + w_{min} \qquad (5)$$

Where, $iter_{max}$ is maximum no. of iterations and iter is present no. of iteration. [3]

IV OBJECTIVE FUNCTION

The selection of TCSC damping controller and PSS parameters is a complex optimization problem. A performance index based on system dynamics is formulated and is used as an objective function for the design problem. In this study, the main work is to minimize an objective function given by :

$$J = \int_{t=0}^{t=t_{sim}} t|\omega_1(t) - \omega_2(t)|\, dt \qquad (6)$$

Where, $\omega_1(t)$ and $\omega_2(t)$ are the measured speed and the reference speed and t_{sim} is the time range of the simulation. The design problem can be formulated as following optimization problem: [1], [5]

$$K^{min}{}_{PSS} \le K_{PSS} \le K^{max}{}_{PSS}$$
$$K^{min}{}_{TCSC} \le K_{TCSC} \le K^{max}{}_{TCSC}$$

$$T^{min}{}_{1PSS} \le T_{1PSS} \le T^{max}{}_{1PSS}$$

$$T^{min}{}_{2PSS} \le T_{2PSS} \le T^{max}{}_{2PSS}$$

$$T^{min}{}_{3PSS} \le T_{3PSS} \le T^{max}{}_{3PSS}$$

$$T^{min}{}_{4PSS} \le T_{4PSS} \le T^{max}{}_{4pss}$$

$$T^{min}{}_{1TCSC} \le T_{1TCSC} \le T^{max}{}_{1TCSC}$$

$$T^{min}{}_{2TCSC} \le T_{2TCSC} \le T^{max}{}_{2TCSC}$$

$$T^{min}{}_{3TCSC} \le T_{3TCSC} \le T^{max}{}_{3TCSC}$$

$$T^{min}{}_{4TCSC} \le T_{4TCSC} \le T^{max}{}_{4TCSC}$$

Where, K_{PSS} and K_{TCSC} are the gains of PSS and TCSC respectively.

The optimization of the TCSC controller parameters is carried out by evaluating the objective cost function.

V SIMULATION RESULTS

Two-machine five-bus system is taken as the test system to analyze the dynamic performance of the power system. The analysis of power system transient stability has been done using PSS and TCSC. The model of a 2-machine 5-bus system has been designed in Simpower System Toolbox of MATLAB. A three phase fault has been applied on the phase A of the transmission line between bys 1 and bus 2 at t= 1sec and cleared after 5 cycles.

The values of the optimized controller parameters are shown in the following tables:

TABLE I Optimized values for Time constants of PSS after using PSO

Time constants	Optimized values using PSO
T_{1PSS}	0.638913
T_{2PSS}	0.730822
T_{3PSS}	0.796387
T_{4PSS}	1.000000

TABLE II Optimized values for Time constants of TCSC after using PSO

Time constants	Optimized value after using PSO
T_{1TCSC}	1.000000
T_{2TCSC}	0.507435
T_{3TCSC}	0.656678
T_{4TCSC}	0.774714

TABLE III Optimized values for Heffron Phillips constants of PSS after using PSO

Heffron Philips constants	Optimized values using PSO
K_1	1.000000
K_2	0.622492
K_3	0.754874
K_4	0.764878
K_5	0.680309
K_6	1.337227

TABLE IV Optimized values for Gains of PSS and TCSC after using PSO

Gain of PSS and TCSC	Optimized values after using PSO
K_A (K_{PSS})	4.751178
K_T (K_{TCSC})	35.119349

It has been observed that when no compensation is provided, then on occurrence of fault, the system becomes unstable and amplitude of waveform keeps on increasing. When the compensation is provided to the system in terms of PSS and TCSC, it has been observed that the oscillations decrease in amplitude with time and the system becomes stable.

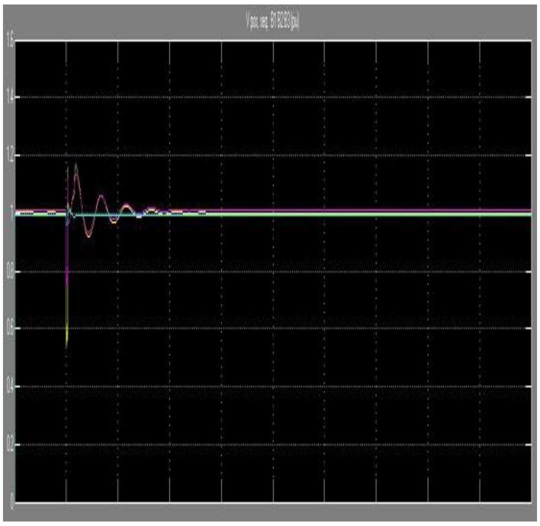

Fig.3 Variation of output voltage with PSS and TCSC

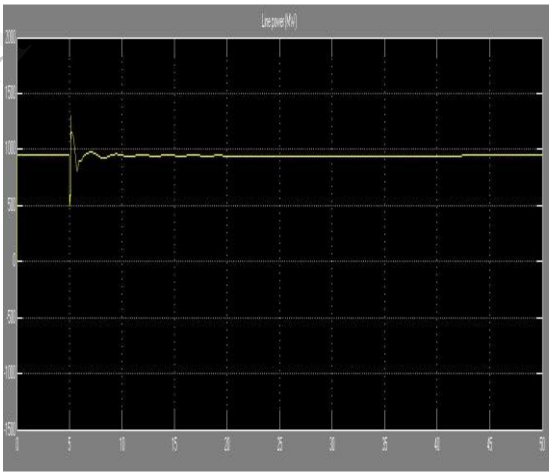

Fig. 4 Variation of Line power with PSS and TCSC

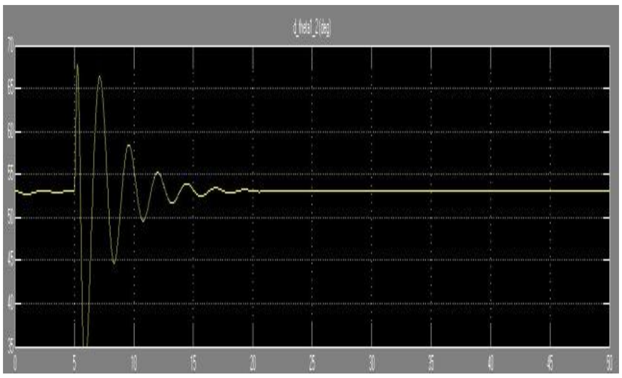

Fig 5 Rotor Angle deviation with PSS and TCSC

VI CONCLUSIONS

In this thesis, a vigorous design technique for coordinated control of Power System Stabilizer (PSS) and Thyristor Controlled Series Capacitor (TCSC) has been discussed. The PSSs and TCSC design problem is formulated as an Optimization problem and thus an Objective function is minimized using Particle Swarm Optimization (PSO) in order to find the optimal controller parameters. The robustness of proposed scheme is carried out in a multi machine power system. The simulation analysis and from different waveforms give us result that the test system dynamic performance is improved and the system employing PSS and TCSC exhibits lower oscillations and thus enhance power system stability.

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APPENDIX

The Heffron Phillips constants are given by:

K_1= change in electrical power at constant flux, with change in load angle.

$$K_1 = \frac{\partial P_e}{\partial \delta} = \frac{x_q - x'_d}{X_{eff} + x'_d} i_{q0} V_b \sin \delta_0 + \frac{E_{q0} V_b \cos \delta_0}{x_{eff} + x_q}$$

K_2= change in electrical power at constant load angle with change in field flux.

$$K_2 = \frac{\partial P_e}{\partial E'_q} = \frac{V_b}{x_{eff} + x'_d} \sin \delta_0$$

K_3= impedance factor

$$K_3 = \frac{\partial E_q}{\partial E'_q} = \frac{x_d + x_{eff}}{x'_d + x_{eff}}$$

K_4= demagnetizing effect of the armature reaction

$$K_4 = \frac{\partial E_q}{\partial \delta} = \frac{x_d - x'_d}{x_{eff} + x'_d} V_b \sin \delta_0$$

K_5= change in terminal voltage at constant load angle, with change in field flux.

$$K_5 = \frac{\partial V_T}{\partial E'_q} = \frac{X_q}{x_{eff} + x_q} \frac{V_{d0}}{V_{to}} V_b \cos \delta_0 - \frac{x'_d}{x_{eff} + x'_d} \frac{V_{qo}}{V_{to}} V_b \sin \delta_0$$

K_6= change in terminal voltage at constant flux, with change in load angle.

$$K_6 = \frac{\partial V_T}{\partial \delta} = \frac{x_{eff}}{x_{eff} + x'_d} \frac{V_{qo}}{V_{to}}$$