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Optimal Location and Design of TCSC controller For Improvement of Stability

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***Abstract* -** Power system stability improvement by a coordinate Design ofThyristor Controlled Series Compensator (TCSC) controller is addressed in this paper.Particle Swarm Optimization (PSO) technique is employed for optimization of the parameter-constrained nonlinear optimization problem implemented in a simulation environment. The proposed controllers are tested on a weakly connected power system. The non-linear simulation results are presented. The eigenvalue analysis and simulation results show the effectiveness and robustness of proposed controllers to improve the stability performance of power system by efficient damping of low frequency oscillations under various disturbances.

***Keywords* -** *Power system stability, PSS, TCSC, coordinated design, particle swarm optimization.*

I. INTRODUCTION

Low frequency oscillations are observed when large power systems are interconnected by relatively weak tie lines. These oscillations may sustain and grow to cause system separation if no adequate damping is available as a result stability has become a major concern in many power systems and many blackouts have been reported, where the reason has been instability i.e.rotor angle instability, voltage instability or frequency stability. Power system stabilizers (PSS) arenow routinely used in the industry to damp out power system oscillations. However, during some operating conditions, this device may not produce adequate damping, and other effective alternatives are needed in addition to PSS.

Recent development of powerelectronics introduces the use of Flexible AC Transmission System (FACTS) controllers inpower systems. FACTS controllers are capable of controlling the network condition in a very fast manner and this unique feature of FACTS can be exploited to improve the stability of powersystem.

Thyristor Controlled Series Compensator (TCSC) is one of the important members of FACTS family that is increasingly applied by the utilities in modern power systems with long transmission lines. Itcan have various roles in the operation and control of power systems, such as scheduling power flow, decreasing unsymmetrical components, reducing net loss, providing voltage support, limiting short-circuit currents, mitigating sub-synchronous resonance (SSR), damping the power Oscillation, and enhancing transient stability.

The objective of the paper is PSO based optimal tuning algorithm is used to TCSC controller . Rotor speed deviation is used as objective function . The proposed controllers have been applied and tested on a connected power system under wide range of loading conditions and severe disturbances.

II. MODELLING OF TCSC

A typical TCSC module consists of a fixed series capacitor(FC) in parallel with a thyristor controlled reactor(TCR).

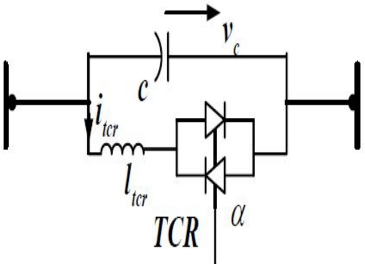

Fig. 1 : TCSC Model

The TCR is formed by a reactor in series with a bi-directional thyristor valve that is fired with a phase angle ranging between 90º and 180º with respect to the capacitor voltage [2].

$$X_{TCSC} = \frac{V_{CF}}{I} = X_C - \frac{X_C^2}{X - X}\frac{2\beta + \sin 2\beta}{\pi} + \frac{4X_C^2}{(X_C - X_L)}\frac{\cos^2\beta}{(k^2 - 1)}\frac{(k\tan k\beta - \tan\beta)}{\pi} \qquad (1)$$

WHERE

X_C = Nominal reactance of the fixed capacitor *C*

X_L= Inductive reactance of inductor L connected in parallel with C

K= $\sqrt{x_c/x_l}$ = Compensation ratio

The function of the external control is to operate the controller to accomplish specified compensation objectives; this control directly relies on measured systems variables to define the reference for the internal control, which is usually the value of the controller reactance.

The function of the internal control is to provide appropriate gate drive signals for the thyristor valve to produce the desired compensating reactance.

Thus, the external control is the one that defines The general block diagram of the TCSC model and external control structure used in this work is shown in Fig.2. In this figure, Xm is the stability control modulation reactance value, as determined by the stability or dynamic control loop, and Xeo denotes the TCSC steady state reactance or set point, whose value is provided by the power flow or steady state control loop. The sum of these two values yields X'm, which is the final value of the reactance ordered by the external control block.

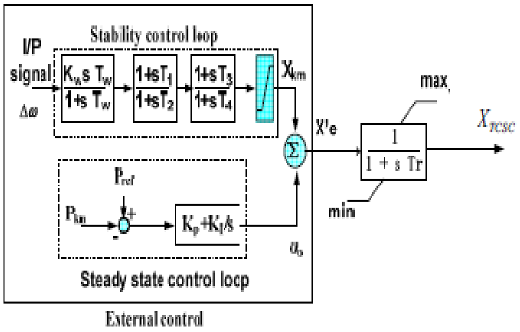

Fig. 2 : Block diagram of TCSC with steady state and stability control loops.

The general structure of the proposed stability controller is depicted in Fig. 2. It consists of a washout filter, a dynamic compensator, and a limiter.

The washout filter is needed to avoid a controller response to the dc offset of the input signal.The dynamic compensator consists of two (or more) lead-lag blocks to provide the necessary phase-lead characteristics.Finally, the limiter is used to improve controller response to large deviations in the input signal.

III. POWER SYSTEM UNDER STUDY

The SMIB power system with TCSC (shown in Figure 1), is considered in this study.The generator has a local load of admittance Y= G+*jB* and a double circuit transmission line of total impedance Z= R+ *jX*. In the figure *VT* and *VB* are the generator terminal and infinite bus voltage respectively and *XT* is the reactance of the transformer.

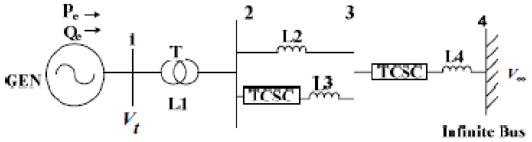

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Fig. 3 : Single machine infinite-bus

A. MECHANICAL EQUATIONS

$$\dot{\delta} = \omega_B (\Delta\omega) \qquad (2)$$

$$\dot{\omega} = \frac{\omega_B}{2H}[P_m - P_e] \qquad (3)$$

Here δ, ω, H, D, Pm and Pe are the angle, speed, moment of inertia, damping coefficient, input mechanical power and output electrical power, respectively, of the machine

B. GENERATOR ELECTRICAL DYNAMICS

The internal voltage, E'q; equation

$$\dot{e}'_q = \frac{1}{T'_{do}}\left[E_{fd} - (x_d - x'_d)i_d - E'_q\right] \qquad (4)$$

In this work a simplified IEEE type –ST1A is used, which can be represent by equation (9). The inputs are the terminal voltage (Vt) and reference voltage Vref. KA and TA are the gain and time constant of the excitation system.

$$E'_{fd} = \frac{K_A}{1+sT_A}\left(V_{ref} - V_t\right) \qquad (5)$$

$$P_e = \frac{E'_q V_\infty}{X'_{d\Sigma}} \sin\delta - \frac{V_\infty^2 \left(X_q - X'_d\right)}{2X'_{d\Sigma} X'_{q\Sigma}} \sin 2\delta \tag{6}$$

$$P_e = V_q i_q + V_d i_d \tag{7}$$

$$v = \sqrt{v_d^2 + v_q^2} \tag{8}$$

$$v_d = x_q i_q \tag{9}$$

$$v_q = E'_q - x'_d i_d \tag{10}$$

IV. OVERVIEW OF PARTICLE SWARM OPTIMIZATION

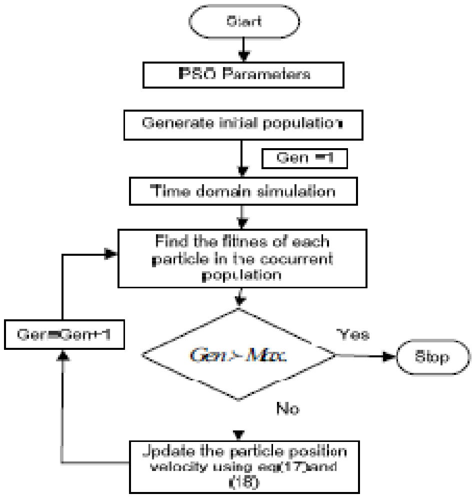
The PSO method is a member of wide category of swarm intelligence methods for solving the optimization problems. It is a population based search algorithm where each individual is referred to as particle and represents a candidate solution. Each particle in PSO flies through the search space with an adaptable velocity that is dynamically modified according to its own flying experience and also the flying experience of the other particles.

In PSO each particles strive to improve themselves by imitating traits from their successful peers. Further, each particle has a memory and hence it is capable of remembering the best position in the search space ever visited by it. The position corresponding to the best fitness is known as *pbest* and the overall best out of all the particles in the population is called *gbest* [14-18].

The modified velocity and position of each particle can be calculated using the currentvelocity and the distance from the *pbestj,g* to *gbestg* as shown in the following formulas[19]:

$$v_{j,g}^{(t+1)} = w.v_{j,g}^{t} + c_1^{*} rand()^{*} (pbest_{j,g} - x_{j,g}^{t}) + c_2^{*} Rand()^{*} (pbest_g - x_{j,g}^{t}) \tag{11}$$

$$\left.\begin{aligned} x_{j,g}^{(t+1)} &= x_{j,g}^{t} + v_{j,g}^{(t+1)} \\ j &= 1,2,\ldots\ldots,n \\ g &= 1,2,\ldots\ldots,m \end{aligned}\right\} \tag{12}$$



PROBLEM FORMULATION

The structure of TCSC controller implemented in stability control loop was discussed earlier, fig. 5 show TCSC with stability control loop

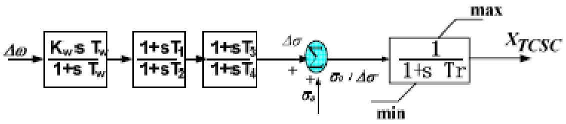


Fig . 5 : TCSC with stability control loop

In the above figure the parameters K_W, T_1 and T_2 to be determined, T_W is summed to 20,T_1=T_3 and T_2=T_4. The input signal to the controller is the speed deviation Δω and the output is the change in conduction angle σ. In steady state $\Delta\sigma=0$, and Xe =Xeq-X_{TCSC0} while during dynamic period the series compensation is modulated for damping system oscillations , in this case Where $\sigma = \sigma_n + \Delta\sigma$ and $(\sigma = 2(\pi-\alpha))$, where σ_0 is the initial value of firing angle, and Xeq is total reactance of the system

A. OBJECTIVE FUNCTION

TCSC controller is designed to minimize the power system oscillations after a small or lager disturbance so as to improve the stability. These oscillations are reflected in the deviation ithe generator rotor speed (Δω). An integral time absolute error of the speed deviations is taken as the objective function J, expressed as

$$J = \int_{t}^{t_{sim}} \left|\Delta\omega(t,x)\right|^2 dt \tag{13}$$

The absolute value of the speed deviation for a set of controller parameters x (Kw, T1, T2), and t is the time range of the simulation.With the variation of Kw, T1, T2, the TCSC based controller parameters, J will also be changed. For objective function calculation, the time-domain simulation of the power system model is carried out for the simulation period. It is aimed to minimize this objective function in order to improve the system stability. The problem constraints are TCSC controller parameter bounds; there the optimization problem can be written as

$$\text{MinimizeJ} \tag{14}$$

Subject to

$$\left.\begin{aligned} K_w^{min} &\le K_w \le K_w^{max} \\ T_1^{min} &\le T_1 \le K_1^{max} \\ T_2^{min} &\le T_2 \le K_2^{max} \end{aligned}\right\} \tag{15}$$

A particle swarm optimization is used to solve the optimization problem and then search for optimal parameters.

V. RESULTS AND DISCUSSION

Tuning a controller parameter can be viewed as an optimization problem in multi-modal space as many settings of the controller could be yielding good performance. Traditional method of tuning doesn't guarantee optimal parameters and in most cases the tuned parameters needs improvement through trial and error. In PSO based method, the tuning process is associated with an optimality concept through the defined objective function and the time domain simulation. Hence the PSO methods yield optimal parameters and the method is free from the curse of local optimality.

The objective function described by equation (13) is evaluated using PSO toolbox given in [13], for each individual by simulating SMIB shown in fig. 4. a three phase short at busbar 2 is considered and TCSC first is assumed to be connected between bus (2-3), and then between bus(3-4) to find the best location. Fig .6 shows the flow chart of PSO algorithm used in this work .Table (I) illustrates the parameters used for this algorithm..Table(II) shows the bound for unknown parameters of gain and time constants as well as the optimal parameters Obtained from PSO algorithm.

Table (I): PSO parameter

Parameters	**Value**
Swarm size	30
Max. Gen.	100
C_1,C_2	2.0,2.0
W_{start},W_{end}	0.9,0.4

Table (II): Bounds & Optimized parameters

Parameters	**K_w**	**T_1=T_3**	**T_2=T_4**
min	20	0.1	0.2
max	100	1	1
TCSC connected between bus (2-3)	66.5	0.1832	0.4018
TCSC connected between bus (3-4)	80.67	0.1124	0.2523

To access the proposed controller and best location of the following cases are considered.

Small disturbance assuming that line2 is tripped off.At t=0.5 sec .

Severe disturbance assuming three phase short circuit occurs at bus 2.

A. Small disturbance

Table (III): Eigenvalues analysis

states	**Without TCSC**	**TCSC between bus(2-3)**	**TCSC between bus(3-4)**
δ, ω	-0.08276±5.618	-2.400 ± 4.1713	-0.42766±5.5961
E'_q	-0.1671±0.39382	-0.1737±0.37346	-0.1682 ±0.38641

Tabe(iii) shows eigen values of tested system with or with out tcsc as well as different locations of tcsc.It is clear from above table the system is stable the tcsc controller shift the electromechanical eigen mode to the left of s-plane.

Fig (6,7,8) shows of load angle, rotor speed deviation and output active power .

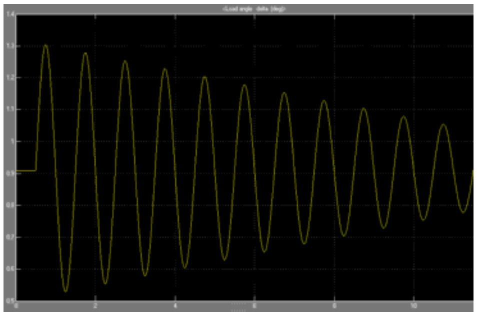


Fig. 6 : Load angle

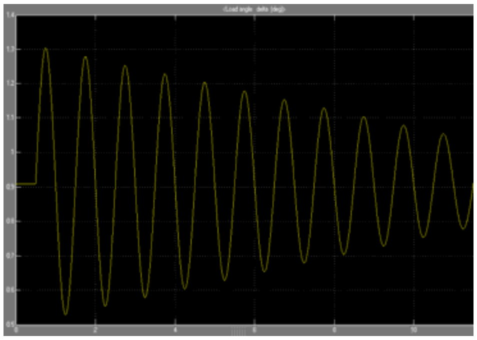


Fig.7 : Rotor speed deviation

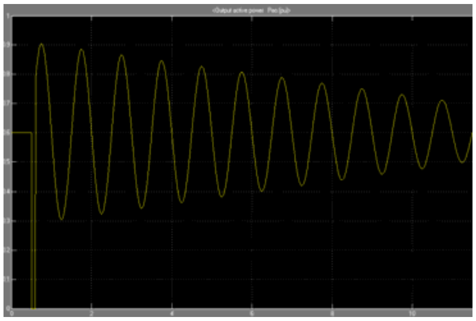


Fig.8.Output active power

B. Severe disturbance

Case(I):

Now TCSC is supposed to be connected between bus(2-3). The vaue of xL and xc was chosen as 0.203 and 0.102 pu.respectively. A three phase short circuit occur at bus 2 at t= 0.5sec , figures(9,10,11) shows rotor angle and speed deviation , and active power respectively.

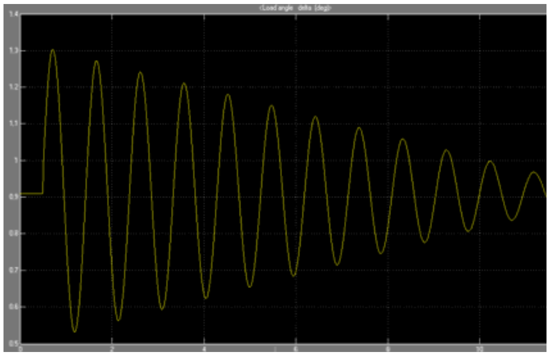


Fig.9. Load angle

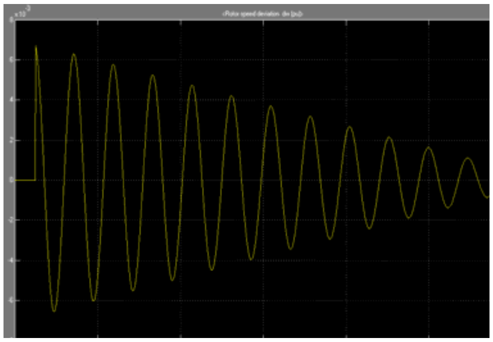


Fig.10.Rotor speed deviation

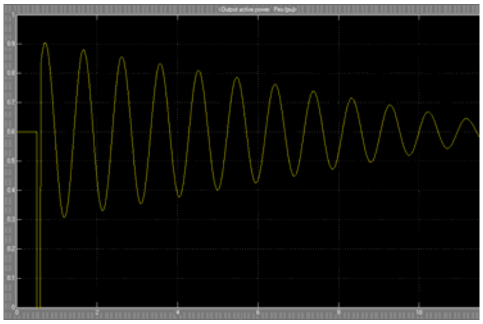


Fig.11.Output active power

It is clear from above figures the proposed TCSC controller damp and suppresses the oscillations and provide good damping characteristics by stabilizing system much faster.

Case(II):

Now TCSC is supposed to be connected between bus (3-4),the vaue of xL and xc was chosen as 0.068 and 0.034 pu respectively. A three phase short circuit occur at t= 0.5 sec , figures(12,13,14) shows rotor angle and speed deviation , an active power respectively

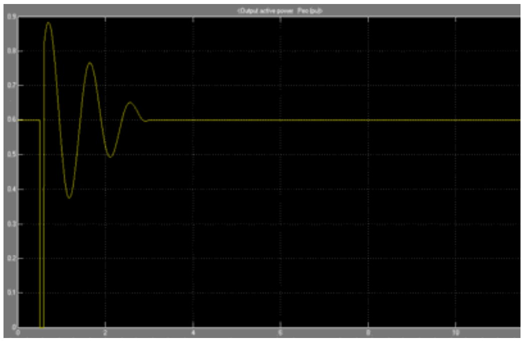


Fig.12.Load angle

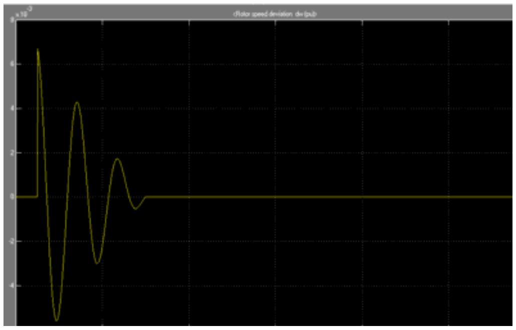


Fig.13.Rotor speed deviation

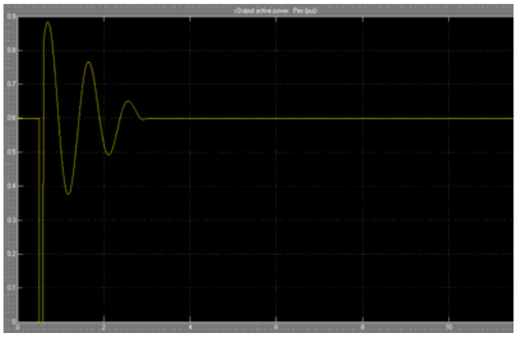


Fig.14.Output active power

It is obvious from above figures damping and suppressing the oscillations is better when TCSC is connected between bus (3-4)

CONCLUSION:

In this paper the impact of TCSC on enhancing power system stability was investigated for small and severe disturbances. Optimal parameters and different locations of TCSC was evaluated. The problem is formulated as optimization problem to minimize the rotor angle deviation and particle swarm optimization techniques employed to find The proposed controller and design approach testes on SIMB using MATLAB environment.The non-linear simulation and eigenvalues analysis results show the effectiveness of the proposed controller to enhance power system stability and best allocation of TCSC.

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