# Enhancement of Small Signal Stability Using optimized TCSC

**K.Sandeep, S.Ravindra**

*Abstract*— **This paper investigates the impact of Thyristor Controlled Series Compensator (TCSC) to enhance power system stability. The design problem of TCSC controller parameters is formulated as optimization problem, and then particle swarm optimization (PSO) technique was used to search for optimal parameters. The proposed controller and technique are employed on test system under different cases and location of TCSC. To validate the effectiveness of the TCSC on enhancing system stability, eigenvalues analysis and a nonlinear time-domain simulation implemented on SMIB equipped with TCSC. The simulation results show the effectiveness and robustness of proposed controller to enhance system stability by damping oscillations of different disturbances.**

*Index Terms*—**Power system stability, Thyristor Controlled Series Compensator, particle swarm optimization, eigen values analysis, damping oscillations**.

## I. INTRODUCTION

Modern interconnected power systems are large, complex and operated closer to security limits. Furthermore environmental constraints restrict the expansion of transmission network and the need for long distance power transfers has increased 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. Stability can be classified into two main categories: small signal stability or transient stability. A common approach to improve power system stability is the use of power system stabilizers (PSS), but in very large systems, few adverse interactions are observed which detract from the overall system performance. Early power system stabilizers, with speed as input, caused shaft torsional oscillations to become unstable, and power input stabilizers were found to lead to large changes in the generator voltage when the generator power was being ramped. But, solutions to both these problems are well known [1-4].

Recent trend to overcome those problems is the application of FACTS technology, is being promoted as a means to extend the capacity of existing power transmission networks to their limits without the necessity of adding new transmission lines [5-8]. Other potential advantages of FACTS lie in their ability to improve damping and to control the flow of power through selected corridors in a network [9-12]. TCSC is an important component of FACTS. With the firing control of the thyristors, it can change its apparent reactance smoothly and rapidly. The TCSC is able to directly schedule the real power flow through a typically selected line and allow the system to operate closer to the line limits. More importantly because of its rapid and flexible regulation ability, it can improve transient stability and dynamic performance of the power systems. [13]. The objective of this paper is to study the impact of TCSC on enhancing power system stability, when subjected to small or severe disturbances, as well as location of TCSC. To optimize the TCSC parameters particle swarm (PSO) optimization technique is used to find optimal parameters and then location of TCSC.the rotor speed deviation is used as objective function.

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## II. DYNAMIC MODELING OF POWER SYSTEM

In this paper, a simple single machine infinite bus (SMIB) system is used as shown in fig 1. The generator is represented by the third-order model. The dynamics of the machine, in classical model, can be represented by the following differential equations [16]:

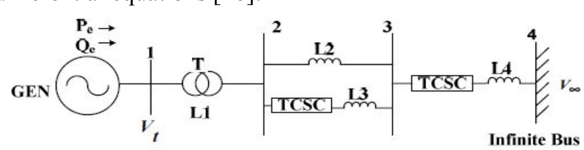


Fig 1 Single machine infinite-bus

**MECHANICAL EQUATIONS**

$$\dot{\delta} = \omega_B\left(\Delta\omega\right) \quad (1)$$

$$\dot{\omega} = \frac{\omega_B}{2H}\left[P_m - P_e\right] \quad (2)$$

Here, 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

### 2.1 GENERATOR ELECTRICAL DYNAMICS

The internal voltage, *E'q*; equation is

$$\dot{e}'_q = \frac{1}{T'_{do}}\left[E_{fd} - \left(x_d - x'_d\right)i_d - E'_q\right] \quad (3)$$

In this work a simplified IEEE type –ST1A is used, which can be represent by equation (4). The inputs are the terminal voltage (Vt) and reference voltage Vref. KA and TA are the gain and time constant of the excitation system.

$$E'_{fd} = \frac{K_A}{1+sT_A}\left(V_{ref} - V_t\right) \quad (4)$$

Where, $$P_e = \frac{E'_q V_\infty}{X'_{d\Sigma}} \sin\delta - \frac{V_\infty^2 \left(X_q - X'_d\right)}{2X'_{d\Sigma} X_{q\Sigma}} \sin 2\delta \quad (5)$$

$$P_e = V_q i_q + V_d i_d \quad (6)$$

$$v = \sqrt{v_d^2 + v_q^2} \quad (7)$$

$$v_d = x_q i_q \quad (8)$$

$$v_q = E'_q - x'_d i_d \quad (9)$$

For Small-signal stability analysis, the linearized incremental model around a nominal operating point is usually employed. The linearized power system model can be written as:

$$\begin{bmatrix} \Delta\dot{\delta} \\ \Delta\dot{\omega} \\ \Delta\dot{E}'_q \\ \Delta\dot{E}_{fd} \end{bmatrix} = \begin{bmatrix} 0 & 377 & 0 & 0 \\ -\frac{K_1}{2H} & -\frac{D}{2H} & -\frac{K_2}{2H} & 0 \\ -\frac{K_4}{T'_{do}} & 0 & -\frac{K_3}{T'_{do}} & \frac{1}{T'_{do}} \\ -\frac{K_A K_5}{T_A} & 0 & -\frac{K_A K_6}{T_A} & -\frac{1}{T_A} \end{bmatrix} \times \begin{bmatrix} \Delta\delta \\ \Delta\omega \\ \Delta E'_q \\ \Delta E_{fd} \end{bmatrix} + \begin{bmatrix} 0 \\ -\frac{K_p}{2H} \\ -\frac{K_q}{T'_{do}} \\ -\frac{K_A K_v}{T_A} \end{bmatrix} \Delta X_{TCSC} \quad (10)$$

$$\left.\begin{aligned} K_1 &= \frac{\partial P_e}{\partial \delta};\ K_2 = \frac{\partial P_e}{\partial E'_q};\ K_3 = \frac{\partial E_q}{\partial E'_q} \\ K_4 &= \frac{\partial E_q}{\partial \delta};\ K_5 = \frac{\partial V_t}{\partial \delta};\ K_6 = \frac{\partial V_t}{\partial E'_q} \\ K_p &= \frac{\partial P_e}{\partial \sigma};\ K_q = \frac{\partial E_q}{\partial \sigma};\ K_v = \frac{\partial V_t}{\partial \sigma} \end{aligned}\right\} \quad (11)$$

## III. PROBLEM FORMULATION

The structure of TCSC controller implemented in stability control loop was discussed earlier, fig.2 show TCSC with stability control loop

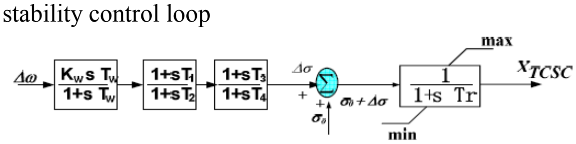


Fig 2 TCSC with stability control loop

In the above figure the the parameters Kw, T1 and T2 are to be determined, Tw is summed to 20, T1=T3 and T2=T4. The input signal to the controller is the speed deviation Δω and the output is the change in conduction angle $\sigma_0$. In steady state Δσ =0, and Xe =Xeq-XTCSC$_0$, while during dynamic period the series compensation is modulated for damping system oscillations, in this case Xe = Xeq - XTCSC. Where $\sigma = \sigma_0 + \Delta\sigma$ and ($\sigma = 2(\Pi-\alpha)$), where $\sigma_0$ is the initial value of firing angle, and Xeq is total reactance of the system.

### 3.1. 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 in the generator rotor speed (Δω). An integral time

$$J = \int_{t}^{t_{sim}} \left|\Delta\omega(t,x)\right|^2 dt \quad (12)$$

Where $\Delta\omega(t,x)$ is 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

Minimize J

subject to

$$\left.\begin{aligned} K_w^{min} &\le K_w \le K_w^{max} \\ T_1^{min} &\le T_1 \le K_1^{max} \\ T_2^{min} &\le T_2 \le K_2^{max} \end{aligned}\right\} \quad (13)$$

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

## IV. SIMULATION AND RESULTS

The objective function described by equation (12) is evaluated using PSO toolbox given in [21], for each individual by simulating SMIB , a three phase short at bus bar 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 .3 shows the flow chart of PSO algorithm used in this work and table (I) illustrates the parameters used for this algorithm. Table (II) shows the bounds for unknown parameters of gain and time constants as well as the optimal parameters obtained from PSO algorithm.

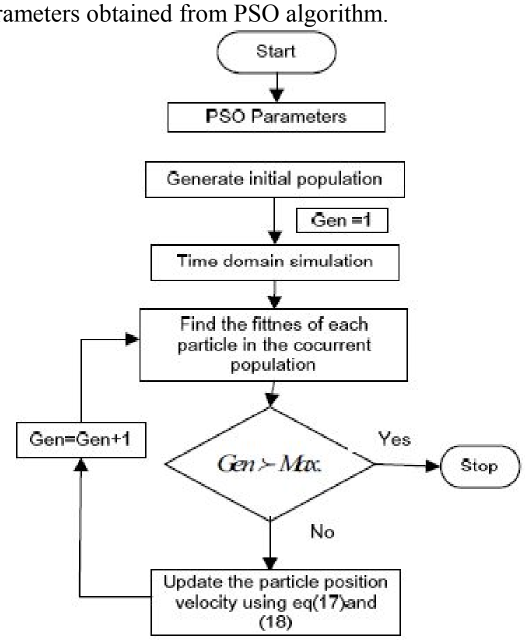


Fig .3 flow chart of PSO algorithm

| 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 (I): PSO 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 |

Table (II): Bounds & Optimized parameters

To assess the effectiveness of the proposed controller and best location the following cases are considered

1. Small disturbance assuming that line 2(L2) is tripped off. At t=0.5 sec
2. Severe disturbance assuming three phase short circuit occur at bus 2. in all case TCSC is connected first between bus(2-3) . And then between bus (3-4).

### V. Small disturbance

**Table (III) shows Eigen values of the tested system with and without TCSC as well as the different locations of TCSC**

| 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 |

Table (III): Eigenvalues analysis

It is clear from above table the system is stable in both cases, in other words the proposed TCSC controllers shift the electromechanical mode eigenvalue to the left of the line (s=-2.4,-0.42766).in S-plane which in turn enhances the system stability.

### 5.1 Severe disturbances

**Case (I):**

Now TCSC is supposed to be connected between bus (2-3). The value 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= 0.5 sec, figures(4,5,6) shows rotor angle and speed deviation, and active power respectively, with and without TCSC.

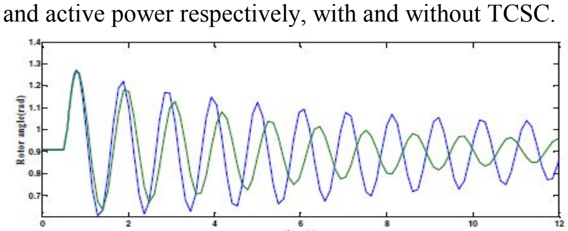

Fig.4 Rotor angle of machine with and without TCSC

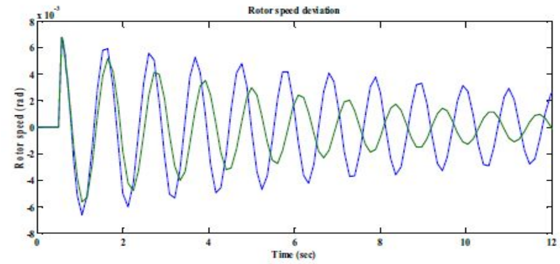

Fig.5 Rotor speed deviation of machine with and without TCSC

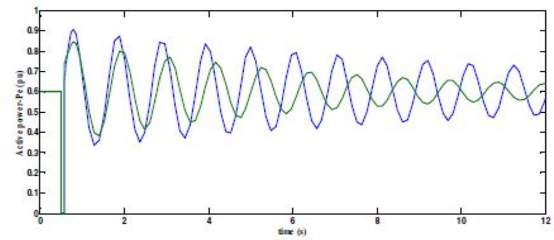

Fig.6 Active power of machine with and without TCSC

It is clear from above figures the proposed TCSC controller damp and suppresses the oscillations and provides good damping characteristics by stabilizing system much faster, which in turn enhances system stability.

**Case (II):**

Now TCSC is supposed to be connected between bus (3-4), he value 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(7,8,9) shows rotor angle and speed deviation, and active power respectively, with and without TCSC

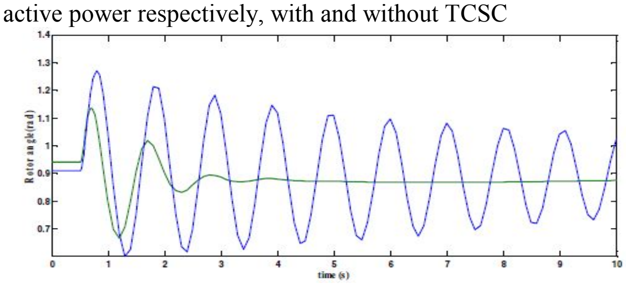

Fig .7 Rotor angle of machine with and without TCSC

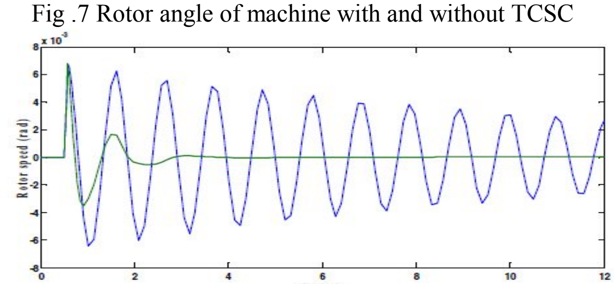

Fig .8 Rotor speed deviation of machine with and without TCSC

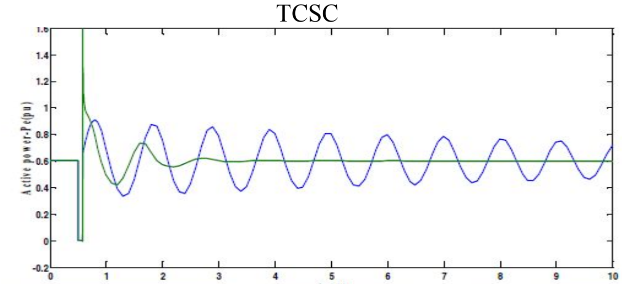

Fig .9 Active power of machine with and without TCSC

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 optimal parameters and allocation of TCSC, under different test cases. 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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