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# A Particle Swarm Optimization Based Approach For Power System Transient Stability Enhancement With TCSC

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**Abstract**

Power system engineers are currently facing challenges to increase the power transfer capabilities of existing transmission system. This led to the evolution of FACTS technology. FACTS controller helps in raising dynamic stability limit, provide better power flow control also provides improvement in asset utilization, system flexibility and system performance. Thyristor controlled series compensator (TCSC) is a series FACTS controller which can control the line impedance, improve network stability and damp the power system oscillations. This paper presents a procedure for modelling and optimal tuning the parameters of Thyristor controlled series compensator (TCSC) controller for the power system transient stability. For the simulation purpose, the model of Single Machine Infinite Bus (SMIB) power system with TCSC controller is developed in MATLAB. The design problem of TCSC controller is formulated as an optimization problem and particle swarm optimization (PSO) is applied to search for the optimal TCSC control parameters. The results obtained shows that the proposed TCSC controller is effective in damping small disturbance condition in the power system.



Keywords: FACTS; Particle Swarm Optimization (PSO);PSO algorithm; Genetic algorithm (GA) ;Thyristor controlled series compensator (TCSC); transient stability; Power System Stabilizer(PSS)

## 1. INTRODUCTION

The need for more efficient electricity systems management has given rise to innovative technologies in power generation and transmission. The combined cycle power station is a good example of a new

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development in power generation and flexible AC transmission systems, FACTS as they are generally known, are new devices that improve transmission systems. Worldwide transmission systems are undergoing continuous changes and restructuring. They are becoming more heavily loaded and are operated in ways not originally envisioned. Transmission systems must be flexible to react to more diverse generation and load. In addition, the economical utilization of transmission system asset is of vital importance to enable utilities in industrialized countries to remain competitive and to survive. In developing countries, the optimized use of transmission systems investments is also important to support industry, create employment and utilize efficiently scarce economic resources. Flexible AC Transmission Systems (FACTS) is a technology that responds to these needs. It significantly alters the way transmission systems are developed and controlled together with improvements in asset utilization, system flexibility and system performance. the main value of FACTS lies in improving transmission capability; increasing the flexibility of power flow control (e.g., for wheeling or for economic dispatch); for controlling voltage (and var flow); and possibly additional advantages in lower voltage systems (e.g., distribution systems).

Thyristor controlled series compensator (TCSC) is one of the important members of series FACTS family that is increasingly applied with long transmission lines by the utilities in modern power systems. It allows rapid change of the transmission line impedance. It can 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; damping the power oscillation and enhancing transient stability [1].

There are various stochastic search algorithms which have proved to be very efficient in solving complex power system problems. PSO is a novel population based method which utilizes the swarm intelligence generated by the cooperation and competition between the particle in a swarm and has emerged as a useful tool for engineering optimization. Unlike other heuristic techniques, it has a flexible and well balanced mechanism to enhance the global and local exploration abilities. Also, it suffices to specify the objective function and to place infinite bounds on the optimized parameters .This algorithm has also been found to be robust in solving problems featuring non-linearity, non-differentiability and high dimensionality[4-6]PSO technique combines social psychology principles in socio-cognition human agents and evolutionary computations PSO is inspired by the ability of flocks of birds, schools of fish, and herds of animals to adapt to their environment, find rich sources of food , and avoid predators by implementing an information sharing approach. In PSO a set of randomly generated solutions propagates in the design space towards the optimal solution over a number of iterations based on large amount of information about the design space that is assimilated and shared by all members of the swarm[7].

The reactance adjusting of TCSC is a complex dynamic process which calls for effective design and accurate evaluation of the TCSC control strategy which depends on the simulation accuracy of the process. In this paper, model of single machine infinite bus (SMIB) power system is installed with a TCSC where the parameters of the TCSC damping controller are optimized by a PSO optimization algorithms in MATLAB programming. The results show the advantage of using the modeling and tuning method when performing control and stability analysis in a power system involving a TCSC controller.

The remainder of the paper is organized in eight major sections; Section II provides a brief review of TCSC. Section III presents power system modeling with the proposed TCSC controller structure. A short overview of PSS is presented in section IV.The PSO algorithm is discussed in Section V.The results are presented and discussed in Section VI. Section VII concludes this paper.Section VIII contains the appendix

## II THYRISTOR CONTROLLED SERIES COMPENSATOR

The basic thyristor controlled series capacitor scheme, proposed in 1986 by Vithayathil with others as a method of “rapid adjustment of network impedance”. It is a capacitive reactance compensator which consists of series capacitance bank shunted by thyristor controlled reactor in order to provide a smoothly variable series capacitive reactance[1]. TCSC is one of the most important and best known series FACTS controllers. It has been in use for many years to increase line power transfer as well as to enhance system stability. Basically a TCSC consists of three components: capacitor banks *C,* bypass inductor *L* and bidirectional thyristors as shown in fig 1.The firing angles of the thyristors are controlled to adjust the TCSC reactance in accordance with a system control algorithm , normally in response to some parameter variations[8].According to the variation of the thyristor firing angle (α) or conduction angle (σ) ,this process can be modelled as a fast switch between corresponding reactance offered to the power system.

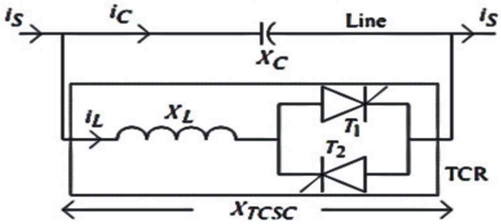


Fig:1 Basic Structure of a TCSC

Assuming that the total current passing through the TCSC is sinusoidal; the equivalent reactance at the fundamental frequency can be represented as a variable reactance $X_{TCSC.}$ There exists a steady state relationship between α and the reactance $X_{TCSC.}$ This relationship can be described by the following equation[9].

$$X_{TCSC}(\alpha) = X_C - \frac{X_C^2}{X_C - X_P}\frac{\sigma + sin\sigma}{\pi} + \frac{4X_C^2}{X_C - X_P}\frac{cos^2(\frac{\alpha}{2})}{K^2 - 1}\frac{(K\tan\left(\frac{K\sigma}{2}\right) - \tan\left(\frac{\sigma}{2}\right))}{\pi} \qquad (1)$$

Where $X_{C=}$ Nominal reactance of the fixed capacitor *C*

$X_{p\ =Inductive}$ reactance of inductor *L* connected in parallel with *C*

σ = 2(π- α),conduction angle of TCSC controller

$k = \sqrt{X_c/X_p}$ ,the compensation ratio

Since the relationship between α and the equivalent fundamental frequency reactance offered by TCSC , $X_{TCSC}(\alpha)$ is a unique valued function ,the TCSC is modeled here as a variable capacitive reactance within the operating region defined by the limits imposed by α. Thus $X_{TCSC,max} < X_{TCSC} < X_{TCSC,max}$ , with $X_{TCSC,max} = X_{TCSC}(\alpha min)$ and $X_{TCSC,min} = X_{TCSC}(\pi) = X_C$ . In this paper ,the controller is assumed to operate only in the capacitive region, i.e., $\alpha min > \alpha r$ where $\alpha r$ corresponds to the resonant point,as the inductive region associated with $(\pi/2) < \alpha < \alpha r$ induces high harmonics that cannot be properly modeled in stability studies.

## III. MODELING OF SINGLE MACHINE INFINITE BUS WITH TCSC

The single-machine infinite bus(SMIB) power system is considered in this study.The system has a TCSC installed in the transmission line between ‘vs’ and ‘vb’ with a generator which is equipped with a Power System Stabilizer(PSS).The generator has a local load of admittance Y=G+jB and the transmission line has impedance of *Z=R+jX.*In the figure ‘vt’ is the generator terminal voltage , ‘ vs’ is the bus voltage , ‘vb’ is the infinite bus voltage, ‘x1’ is the reactance between ‘vt’ and ‘vs’, ‘x2’is the reactance between ‘ vs’ and ‘vb’.A generator of third order model is taken into consideration with electromechanical swing equation and generator internal voltage equation.

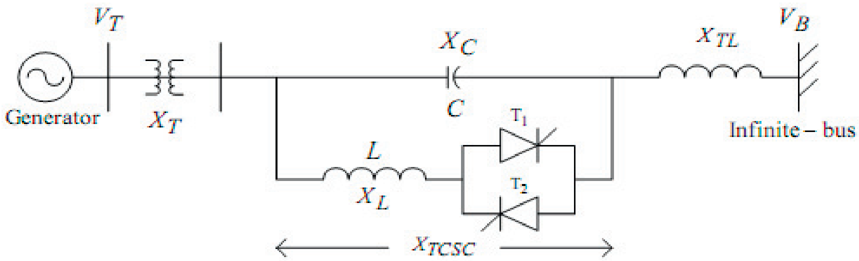



Fig:2 TCSC controller for SMIB

The nonlinear machine equations are[10]:

$$\frac{d\delta}{dt} = \omega_B (S_m - S_{mo}) \tag{2}$$

$$\frac{dS_m}{dt} = \frac{1}{2H}[-D(S_m - S_{mo}) + T_m - T_e] \tag{3}$$

$$\frac{dE_q'}{dt} = \frac{1}{T_{do}'}[-E_q' + (x_d - x_d')i_d + E_{fd}] \tag{4}$$

$$\frac{dE_d'}{dt} = \frac{1}{T_{do}'}[-E_q' + (x_q - x_q')i_q] \tag{5}$$

$$E_q' + x_d' i_d = v_q \tag{6}$$

$$E_d' - x_q' i_d = v_d \tag{7}$$

$$T_e = E_d' i_d + E_q' i_q + (x_d' - x_q') i_d i_q \tag{8}$$

$$v_q = -x_e i_d + E_b \cos\delta \tag{9}$$

$$v_q = x_e i_q - E_b \sin\delta \tag{10}$$

$$i_d = \frac{E_b \cos\delta - E_q'}{x_e - x_d'} \tag{11}$$

$$i_q = \frac{E_b \sin\delta - E_q'}{x_e - x_q'} \tag{12}$$

where, $\frac{d}{dt}$ : Differential operator

| | | |
|---|---|---|
| $\omega$ | : | rotor speed |
| M | : | effective inertia constant (H / πf, H is the inertia constant) |
| $P_m$ | : | mechanical power input to the generator |
| $\tau'_{d0}$ | : | equivalent transient rotor time constant |
| $x'_d$ | : | d-axis transient reactance of the generator |
| $x_q$ | : | q-axis reactance of the generator |
| $x_d$ | : | d-axis reactance of the generator |
| $E_{fd}$ | : | direct axis excitation voltage |
| $E_{fd0}$ | : | initial value of $E_{fd}$ |

**MODELLING THE TCSC CONTROLLER STRUCTURE**

TCSC provides a smoothly variable capacitive reactance to the system. For identifying and controlling the dynamics of a TCSC and the power system, a single-machine infinite-bus power system. The system shown in fig(2) comprises a synchronous generator connected to an infinite-bus through a double-circuit transmission line. The TCSC is located between the generator and the infinite-bus. The commonly used lead–lag structure is chosen in this study as a TCSC controller. The structure of the TCSC controller is shown in fig(3).It consists of a gain block with gain $K_P$, a signal washout block and two-stage phase compensation block. The phase compensation block provides the appropriate phase-lead characteristics to compensate for the phase lag between input and the output signals. The signal washout block serves as a high-pass filter, with the time constant $T_W$, high enough to allow signals associated with oscillations in input signal to pass unchanged. Without it steady changes in input would modify the output. From the viewpoint of the washout function the value of $T_W$ is not critical and may be in the range 1 to 20 seconds.$\sigma_0$ is the initial conduction angle as desired by the power flow control loop. The power flow control loop acts quit slowly in practice and hence $\sigma_0$ is assumed to remain constant during large-disturbance transient period.

The transfer function of the TCSC controller is:

$$u = K_P\left(\frac{sT_w}{1+sT_w}\right)\left(\frac{1+sT_1}{1+sT_2}\right)\left(\frac{1+sT_3}{1+sT_4}\right)y$$

where, $u$ and $y$ are the TCSC controller output and input signals respectively; $K_P$ is the stabilizer gain and $T_W$ is the washout time constant.

In this structure, $K_p$, $T_W$, $T_1$, $T_2$, $T_3$, $T_4$ ***and*** $T_{TCSC}$ are usually pre-specified for different conditions which values are given in appendix VII. In this study, the input signal of the proposed TCSC controller is the speed deviation $\Delta\omega$, and the output is change in conduction angle $\Delta\sigma$. The desired value of line reactance is obtained according to the change in the conduction angle. This signal is put through a first order lag representing the natural response of the controller and the delay introduced by the internal control which yields the reactance offered by the TCSC, $X_{TCSC}(\alpha)$. The effective reactance is given by:

$X_{eff}=X- X_{TCSC}(\alpha)$ , where, $X_{TCSC}(\alpha)$, is the reactance of TCSC at firing angle $\alpha$.

**IV POWER SYSTEM STABILIZER**

Low frequency oscillations are observed when large power system is interconnected by relatively weak tie lines which may sustain and grow to cause system separation if no adequate damping is available.PSS are used in the industry to damp out oscillations.. The action of a PSS is to extend the angular stability limits of a power system by providing supplemental damping to the oscillation of synchronous machine rotors through the generator excitation. This damping is provided by a electric torque applied to the rotor that is in phase with the speed variation. Once the oscillations are damped, the thermal limit of the tie-lines in the System may then be approached. This supplementary control is very beneficial during line outages and large power transfers.

The TCSC is designed to minimize the power system oscillations after a large disturbance so as to improve the power system stability. These oscillations are reflected in the deviations in power angle, rotor speed and line power. Minimization of any one or all of the above deviations could be chosen as objective. In the present study the two performance indices that reflect the settling time and overshoots are introduced as objective functions and evaluated. These indices are defined as:

$$\mathbf{PI_1} = \sum_{i=1}^{n} \int_{t=0}^{t=tsim} (t\Delta w).dt$$

$$\mathbf{PI_2} = \sum_{i=1}^{n} \int_{t=0}^{t=tsim} (\Delta w).dt\ ,$$

Where n = No of machines, and $t_{sim}$ is the simulation time.

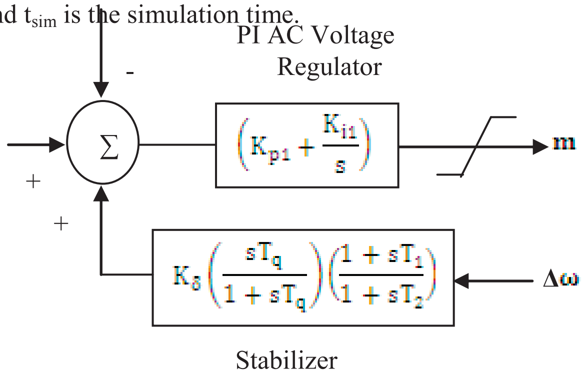



Fig:4.Lead Lag Power System Stabilizer

## V.PSO ALGORITHM

The PSO algorithm was first proposed by Kennedy and Eberhart[11,12] which is a novel evolutionary algorithm paradigm which imitates the movement of birds flocking or fish schooling looking for food.One major difference between particle swarm and traditional evolutionary computation method is that particles' velocities are adjusted, while evolutionary individuals' positions are acted upon; it is as if the "fate" is altered rather than the "state" of the particle swarm individuals[13].The system initially has a population of random solutions, called particle, is given a random velocity and is flown through the problem space. The particles have memory and each particle keeps track of previous best position and corresponding fitness. The previous best value is called as $p_{best}$ .Thus $p_{best}$ is related only to a particular particle. It also has another value called $g_{best}$ which is the best value of all the particles $p_{best}$ in the swarm. The basic concept of PSO technique lies in accelerating each particle towards its $p_{best}$ and the $g_{best}$ locations at each step. The best position ever attained by each particle of the swarm is communicated to all other particles. Acceleration has random weights for both $p_{best}$ and $g_{best}$ locations. The updating equations of the velocity and position are given as follows[14];

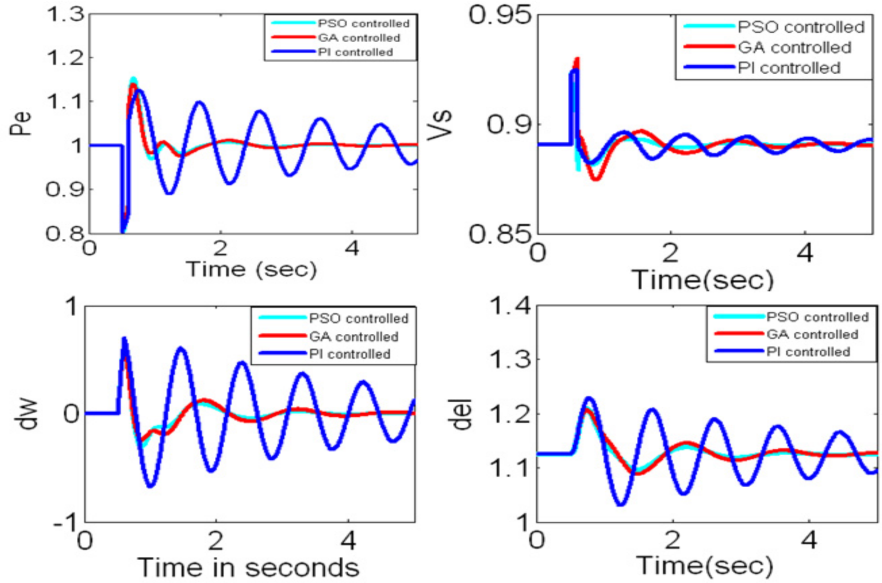
$$v_i(k+1) = w\, v_i(k) + r_1 c_1 [g_{best} - x_i(k)] + r_2 c_2 [p_{best} - x_i(k)] \quad (13)$$
$$x_i(k+1) = x_i(k) + v_i(k+1) \quad (14)$$

Where $v$ is the velocity and $x$ is the position of each particle. $c_1$ and $c_2$ are positive constants referred to as acceleration constants and must be $c_1+c_2 \leq 4$, usually $c_1=c_2=2$. $r_1$ *and* $r_2$ are random numbers between 0 and 1. $w$ is the inertia weight, $p_{best}$ refers to the best position found by the particle and $g_{best}$ refers to the best position found by its neighbour.

## VI SIMULATION AND RESULT ANALYSIS

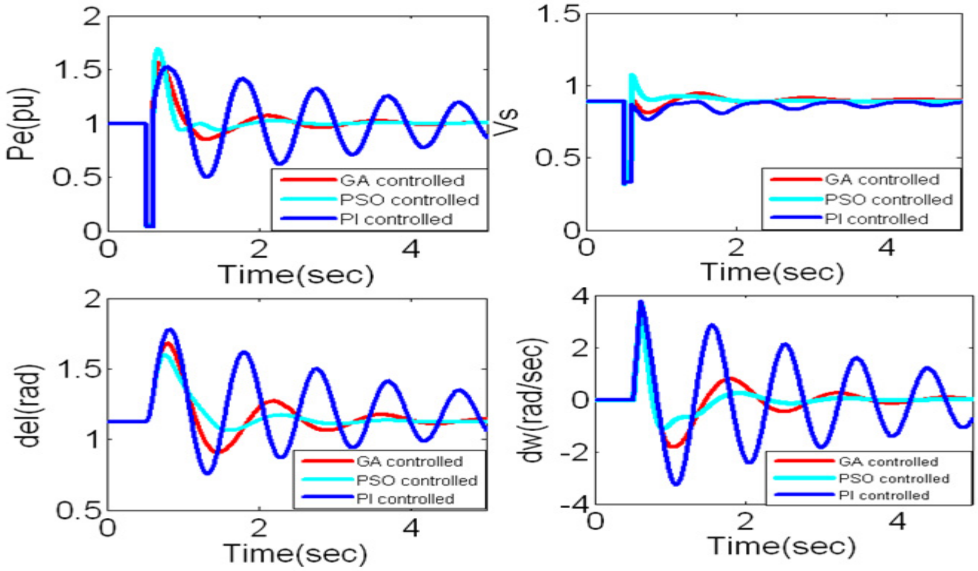
### Case1:Line reactance increased

The performance of the optimized TCSC controller by Particle Swarm Optimization (PSO) Technique is tested to sudden variation of line reactance. The variations of parameters are shown in Fig6.1 (a) to 6.1 (d) under this severe disturbance with the comparison with GA based PI controller and conventional PI controller. The system is restored to original condition after some few cycles. It is clear from the figures that PSO tuned TCSC controller improves stability performance and damp power system oscillations effectively as compared to GA tuned controller and conventional PI controller




**Case-2:Short circuit fault**

The performance also is tested subjected to a three phase short circuit fault for duration of 0.1 sec(5 cycles/sec). The variations of all the parameters are shown in the Fig.6.2 (a)-6. 2(d) under this condition. The graphs clearly indicate the effectiveness of the PSO tuned TCSC controller is a very efficient method for restoration of power system stability and damping power system oscillations for various conditions as compared to GA based PI controller and conventional PI controller.



## VII CONCLUSION

In this chapter Particle Swarm Optimization(PSO) is used to search the optimal parameters of the TCSC controller so that the oscillation due to change in mechanical power to the generator and short circuit fault will be damped out suddenly. From the results as shown in the figure it is clearly inferred that the optimized TCSC controller by PSO damped the frequency oscillation, rotor angle deviation quickly as compared to GA based PI controller and conventional PI controller

## VIII APPENDIX

| | $K_p$ | $T_w$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_{tcsc}$ |
|---|---|---|---|---|---|---|---|
| Short circuit fault | 0.5 | 0.9985 | 0.3646 | 1 | 1 | 1 | 0.216 |
| Pm decreases to 0.8 | 0.4298 | 1.459 | 0.5438 | 0.9606 | 0.6803 | 0.7524 | 0.0112 |

$X_{tcsc}$=0.2 $P_e = 1$ $Q_e = 0.608$
$R_1 = R_2 = 0.0$ $X_1 = 0.2$ $X_2 = 0.4$ , Local load=10% 0f generator output

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