ENHANCING POWER SYSTEM STABILITY BY USING Thyristor Controlled Series Compensator

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Abstract

Passivity- based controller is designed for the thyristor controlled series capacitor (TCSC) aimed at enhancing power system stability. The design problem formulated as optimization Problem and then particle swarm optimization (PSO) technique was used to search for optimal parameters. The proposed control 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, Eigen values analysis and nonlinear time-domain simulation implemented on SMIB equipped with TCSC. 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; Thyristor Controlled Series Compensator; particle swarm optimization*;*

I.INTRODUCTION

Modern interconnected power systems are large, complex and operated closer to security limits. Further more 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 where the reason has been instability i.e. rotor angle instability, voltage instability or frequency stability. Power system stabilizers (PSS) are now routinely used in the industry to damp out power system oscillations. How ever, during some operating conditions, this device may not produce adequate damping, observed which detract from the overall system performance and become unstable, and power input stabilizers were found to lead to large changes in the generator other effective alternatives are needed in addition to PSS. These problems are well known [1-4].

In order to meet the high demand for power transmission capacity, some power companies have installed series capacitors on power transmission lines. This allows the impedance of the line to be lowered, thus yielding increased transmission capability. The series capacitor makes sense because it's simple and could be installed for 15 to 30% of the cost of installing a new transmission line, and it can provide the benefits of increased system stability, reduced system losses, and better voltage regulation Protective distance relays, which make use of impedance measurements in order to determine the presence and location of faults, are "fooled" by installed series. Capacitance on the line when the presence or absence of the capacitor in the fault circuit is not known a priori. This is because the capacitance cancels or compensates some of the inductance of the line and therefore the relay may perceive a fault to be in its first zone when the fault is actually in the second or third zone of protection. Similarly, first zone faults can be perceived to be reverse faults! Clearly this can cause some costly operating errors. The conventional protections like distance, differential, and by using relays power controllers are very much in use nowadays.

Recent trend to overcome those problems is the application of FACTS technology, is being promoted as a means to extend 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 There have been significant activities and achievement research and application of flexible AC transmission systems (FACTS). Thyristor controlled series compensation (TCSC) is an important device in the FACTS family. It can have various roles in the operation and control of power systems, such as scheduling power flow; decreasing Unsymmetrical components and enhancing transient stability.

This was a very simple control; the maximum amount compensation was inserted at the same time that the faulted line was switched out advances in high-power electronics, high-efficiency power electronics have led to development of thyristor -controlled it can change its apparent reactance .

TCSC is able to directly schedule the real power flow control by 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 imp rove transient stability to 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 optimization (PSO) .Technique is used to find optimal parameters and then location of TCSC. The rotor speed deviation is used as objective function.

Section (II) of this paper discusses modeling of TCSC while sections (III) derive dynamic modeling of power system The rest of the sections are organized as follows: in section (IV) an over view of particle swarm optimization is presented Section (V) formulation problem and o objective function are derived. The simulation and results are presented in section VI). Finally conclusions are discussed in section (VII)

II. TCSC MODELLING

The basic TCSC configuration consists of a series capacitor bank C in parallel with a thyristor-controlled reactor and bypass inductor L as shown in Figure.1. This simple model utilizes the concept of a variable series reactance. The series reactance is adjusted automatically within limits to keep the specified amount of active power flow across the line. There are certain values of inductive and capacitive reactance which cause steady-state resonance.

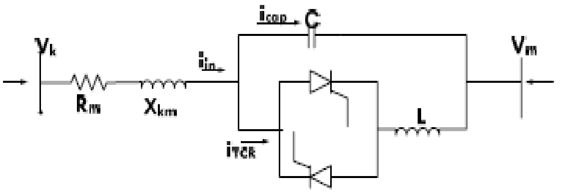


Fig .1 TCSC modules

The TCSC can be continuously controlled either in capacitive or in inductive area, avoiding the steady- state resonant region considering the three basic operating modes of the TCSC: Thyristor blocked, Thyristor bypassed and Vernier operation. The vernier mode is subdivided into two categories, namely: inductive vernier mode ($90^0 < \alpha < \alpha res$) and capacitive vernier mode ($\alpha res < \alpha < 180^0$) see Fig. 1.

For the purposes of mathematical analysis a simplified TCSC circuit is shown in fig.2. Transmission-line current I assumed to be the independent-input variable and is modeled as an external current source, $i_s(t)$. It is further assumed that the line current is sinusoidal. Then the current through the fixed series capacitor, thyristor valve i_T (t), and the line current I_S(t),are expressed as

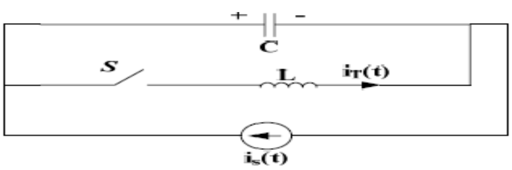


Fig .2 A simplified TCSC circuit

$$C\frac{dv_c}{dt}=i_s(t)-i_T(t)\,u \quad (1)$$

$$L\frac{di_T}{dt}=V_C\,u \quad (2)$$

$$i_s(t)=I_m\cos(wt) \quad (3)$$

In equation (1) the switching variable u= 1 when the thyristor valves are conducting (S is closed), and u= 0 when the thyristor are blocked(S is open) .

V_{CF} to I_M:

$$X_{TCSC}=\frac{V_{CF}}{I_M}=X_C-\frac{X_C^2}{X_C-X_L}\frac{2\beta+SIN2\beta}{\pi}+\frac{4X_C^2}{X_C-X_L}\frac{COS^2\beta}{(K^2-1)}\frac{(K\tan k\beta-\tan\beta)}{\pi} \quad (4)$$

Or

$$X_{TCSC}=\frac{V_{CF}}{I_M}=X_C-\frac{X_C^2}{X_C-X_L}\frac{\sigma+SIN\sigma}{\pi}+\frac{4X_C^2}{X_C-X_L}\frac{COS^2(\sigma/2)}{(K^2-1)}(K\tan(k\sigma/2)-\tan(\sigma/2))$$

Generally, in a TCSC, two main operational blocks can be clearly identified

A) An External control:

Control operates the controller 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. It may be comprised of different control loops depending on the control objectives. Typically the principal steady state function of a TCSC is power flow control, which is usually accomplished either automatically With a "slow" PI to guarantee steady-steady error – free control Obeying specified limits concerning reactance or the firing angle, or manually through direct operator intervention Additional functions for stability improvement, such as damping controls may be included in the external control.

The equivalent impedance X'_e Of the device is represented as a function of the firing angle based on the assumption of a sinusoidal steady-state controller current. In this model, it is Possible to directly represent some of the actual TCSC internal Control blocks associated with the firing angle control, as Opposed to just modeling them with a first order lag function.

B)An Internal control:

provide appropriate gate drive signals for the thyristor valve to produce the desired compensating reactance Fig .3 shown below illustrate block diagram of TCSC model used in this paper for both operation modes

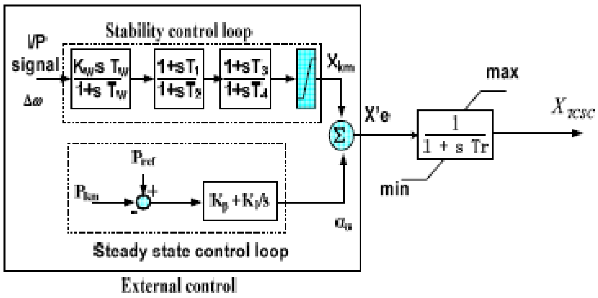


Fig .3 shown below illustrate block diagram of TCSC model used in this paper for both operation modes

The structure of the proposed stability control loop is depicted in Fig. 3. It consists of a washout filter to avoid a Controller response to the dc offset of the input signal, a Dynamic compensator and a limiter. The dynamic compensate or 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. DYNAMIC MODELING OF POWER SYSTEM

In this paper, a simple single machine in finite bus (SMIB) system is used as shown in fig .4. The generator is represented by the third-order model. The dynamics of the Machine in classical model, can be represented by the following.

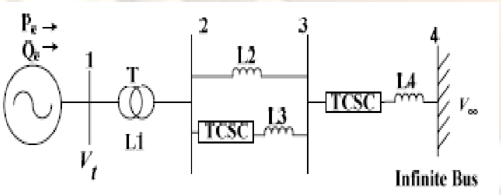


Fig:4 single machine infinite bus

A.MECHANICAL EQUATIONS

$$\delta = \theta e - w_s t \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$\dot{\delta} = w_B (\Delta w) \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Here *δ, w , H, D, P_M* and *P_e* are the angle, speed, moment Inertia , damping coefficient, input mechanical Power and output electrical power, respectively, of the machine .To measure the angular position of the rotor with respect to a synchronously rotating frame of reference.

δ =θe -w_st; rotor angular displacement from synchronously rotating frame called (torque angle/power angle). Where,

$$M \frac{d^2\delta}{dt^2} = P_M - P_E \ldots\ldots\ldots\ldots\ldots (7)$$

$$\frac{2GH}{} \frac{d^2\delta}{} = P_M - P_E \ldots\ldots\ldots\ldots\ldots (8)$$

$$W_S \quad dt^2$$

$$\frac{d^2\delta}{dt^2} = \frac{W_s}{2GH} (P_M - P_E) \ldots\ldots\ldots\ldots\ldots (9)$$

From equation 6 δ value can be substituted

$$\frac{d^2(\theta c - W_s t)}{dt^2} = \frac{W_s}{2GH} (P_M - P_E) \ldots\ldots\ldots\ldots (10)$$

$$\dot{W}_s = \frac{W_B}{2H} \{P_M - P_E - D(\Delta w)\} \ldots\ldots\ldots\ldots (11)$$

B.GENERATORELECTRICALDYNAMICS

The internal voltage, E_q; equation i

$$\dot{e}'_q = \frac{1}{T'_{do}}\left[E_{fd} - \left(x_d - x'_d\right) i_d - E'_q\right] \ldots\ldots (12)$$

In this work a simplified IEEE type –ST1A is used, which Can be representing by equation (15). The inputs are the terminal Voltage (V_t) and reference voltage V_{ref} . K_A and T_A are the gain and time constant of the excitation system

$$E'_{fd} = \frac{K_A}{1+sT_A}\left(V_{ref} - V_t\right) \ldots\ldots\ldots (13)$$

Where P_e,

$$P_e = \frac{E'_q V_\infty}{X_{d\Sigma}} \sin\delta - \frac{V_\infty^2 \left(X_q - X'_d\right)}{2X_{d\Sigma} X_{q\Sigma}} \sin 2\delta \ldots\ldots (14)$$

$$P_e = V_q I_q + V_d I_d \ldots\ldots\ldots\ldots\ldots (15)$$

$$v = \sqrt{v_d^2 + v_q^2} \ldots\ldots\ldots\ldots\ldots (16)$$

$$Vd = Xd\, I_d \ldots\ldots\ldots\ldots\ldots (17)$$

$$v_q = E'_q - x'_d i_d \ldots\ldots\ldots\ldots\ldots (18)$$

For Small-signal analysis, the lineraizedincremental model around a nominal operating point is usually employed. The lineraized power system model can bewrittenas:

$$\begin{bmatrix} \dot{\Delta\delta} \\ \dot{\Delta\omega} \\ \dot{\Delta E'_q} \\ \dot{\Delta E_{fd}} \end{bmatrix} = \begin{bmatrix} 0 & \omega_B & 0 & 0 \\ -\frac{K_1}{2H} & -\frac{D}{2H} & -\frac{K_2}{2H} & 0 \\ -\frac{K_4}{T'_{do}} & 0 & -\frac{K_3}{T'_{do}} & \frac{1}{T'_{do}} \\ -\frac{K_A K_5}{T_A} & 0 & -\frac{K_A K_6}{T_A} & -\frac{1}{T_A} \end{bmatrix} \times \begin{bmatrix} \Delta\delta \\ \Delta\omega \\ \Delta E'_q \\ \Delta E'_{fd} \end{bmatrix} + \begin{bmatrix} 0 \\ -\frac{K_p}{2H} \\ -\frac{K_q}{T'_{do}} \\ -\frac{K_A K_v}{T_A} \end{bmatrix} \Delta X_{TCSC} \ldots\ldots (19)$$

$$\left.\begin{array}{l} K_1 = \dfrac{\partial P_e}{\partial \delta}; K_2 = \dfrac{\partial P_e}{\partial E'_q}; K_3 = \dfrac{\partial E_q}{\partial E'_q} \\ K_4 = \dfrac{\partial E_q}{\partial \delta}; K_5 = \dfrac{\partial V_t}{\partial \delta}; K_6 = \dfrac{\partial V_t}{\partial E'_q} \\ K_p = \dfrac{\partial P_e}{\partial \sigma}; K_q = \dfrac{\partial E_q}{\partial \sigma}; K_v = \dfrac{\partial V_t}{\partial \sigma} \end{array}\right\}. \quad \ldots\ldots (20)$$

IV. OVERVIEW OF PARTICLE SWARM OPTIMIZATION [17–19]

Particle swarm optimization (PSO) method. It is one of the optimization techniques and a kind of evolutionary computation technique. The method has been found to be robust in solving problems featuring nonlinearity and non differentiability, multiple optima, and high dimensionality through adaptation, which is through adaptation, which is derived from social- psychological theory. It is a population based search algorithm

*The method is developed from research on swarm such as fish schooling and bird flocking.

*It can be easily implemented, and has stable convergence Characteristic with good computational efficiency.

The PSO method is a member of wide category of swarm intelligence methods for solving the optimization problems. It is 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 Particle.

The features of the searching procedure can be summarized as follows

1) Initial positions of p_{best} and g_{best} are different. However, using the different direction of p_{best} and g_{best}, all agents gradually get close to the global optimum.

2) The modified value of the agent position is continuous and the method can be applied to the continuous problem. How ever, the method can be applied to the discrete problem using grids for XY position and its velocity.

3) There are no inconsistency in searching procedures even if continuous and discrete state variables are utilized with continuous axes and grids for XY positions and velocities. Namely, the method can be applied to mixed integer nonlinear optimization problems with continuous and discrete state variables naturally and easily.

4) The above concept is explained using only XY axis (2dimensional space). However, the method can be easily applied to n dimensional problem.

Each particle keeps track of its coordinates in the problem space , which are associated with the best solution (evaluating value) it has achieved so far. This value is called p_{best}.

Another best value that is tracked by the global version of the particle swarm optimizer is the overall best value, and its location, obtained so far by any particle in the group, is called G_{best}.In PSO, each particle moves in the search space with a Velocity according to its own previous best solution and its Group's previous best solution. The velocity update in a PSO Consists of three parts ; namely momentum, cognitive and social parts. The balance among these parts determines the performance of a PSO algorithm.

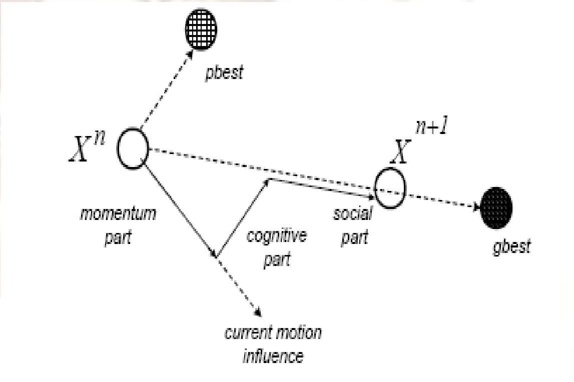


Fig:5 Position updates of particles in particle swarm optimization Technique

For example, the j^{th} Particle is represented as $x_j = (x_{j.1}, x_{j.2} \ldots.. x_{j.n})$ in the g-dimensional space. The best previous Position of the j^{th} Particle is recorded and represented as best $P_{best} = (P_{bestj.1}, P_{bestj.2} \ldots\ldots, P_{bestj.1})$ .The index of best among all of the particles in the group is represented by particle G_{bestg} The rate of the position change (velocity) for particle is represented as $V_j=(V_{j.1},V_{j.2},\ldots\ldots\ldots\ldots,V_{j.n})$. The modified velocity and position of each particle can be calculated using the current Velocity and the distance from $p_{best\, j.g}$ to $g_{best\, g}$

$V_{j,g}^{(t+1)}$ = W .v $_{j.g}$ +C*1rand()*(pbest $_{j.g}$-$x^t_{j.g}$)
C*2rand ()*(pbest j.g- $x^t_{j.g}$)
…………….(21)

$X^{(t+1)}_{j,g} = X^{(t)}_{j,g} + V^{(t+1)}_{j,g}$ ………………(22)
j = 1, 2... n
g = 1, 2... m

Where
n number of particles in a group
m number of member in a particles

t pointer of iteration (generations)
$V^{t}_{j,g}$ velocity of particle j at iteration t
$V_G^{MIN} \le V_{J..G}^{t} \le V_G^{MAX}$;
W inertia weight factor
C_1,C_2 acceleration constant
Rand () , rand() random number between 0 and 1
$X^{t}_{j,g}$ current position of particle j at iteration t ;
Pbest $_j$ Pbest o f particle j ;
gbest gbest of the group

In the above procedures, the parameter V^{max} determined the resolution, or fitness, with which regions be searched between the present position and the target position. If V^{max} is too high particles might fly past good solutions. If V^{max} is too small particles may not explore sufficiently beyond local solutions In many experiences with PSO V^{max} was often set at 10-20% of the dynamic range of the variable on each dimension.

The constants c_1 and c_2 represent the weighting of the stochastic acceleration terms that pull each particle Pbest and gbest positions. Low values allow particles to roam far from the target regions before being tugged back. On the other hand, high values result in abrupt movement toward, or past, target regions. Hence, the acceleration constants c_1 and c_2 were often set to be 2.0 according to past experiences Suitable selection of inertia weigh tin (19) provides a balance between global and local explorations, thus requiring less iteration on average to find a sufficiently optimal solution .As originally developed, often decreases linearly from about0.9 to 0.4 during a run. In general, the inertia weight is set according to the following equation:

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \quad \ldots\ldots\ldots (23)$$

Where $iter_{max}$ is the maximum number of iterations (generations), and iter is the current number of iterations.

V. PROBLEM FORMULATION

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

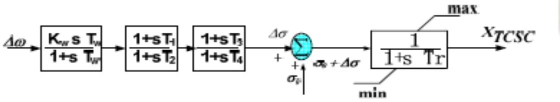


Fig:6 TCSC with stability control loop

It consists of a gain block with gain KT, a signal washout block and two-stage phase compensation block as shown in figure .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. The damping torque contributed by the TCSC can be considered to be in to two parts. The first part KP, which is referred as the direct damping torque, is directly applied to the electromechanical oscillation loop of the generator. The second part KQ and KV, named as the indirect damping torque, applies through the field channel of the generator

In the above figure the parameters K_w, T_1 and T_2 are 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 and the output is the change in conduction angle. In steady state $\Delta\sigma=0$, and $X_e = X_{eq} - X_{TCSC0}$ while during dynamic period the series compensation is modulated for damping system oscillations , in this case $X_e = X_{eq} - X_{TCSC}$.

Where $\sigma = \sigma + \Delta\sigma$ and ($\sigma = 2(\prod - \sigma)$), where σ_0 is the initial value of firing angle, and X_{eq} 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 in the generator rotor speed (Δw). An integral time absolute error of the speed deviations is taken as the objective Function J, expressed as

$$J = \int_{t}^{tsim} (t, x)\, dt \quad \ldots\ldots\ldots\ldots\ldots\ldots (24)$$

Where $|\Delta w\ (t, x)|$ is the absolute value of the speed deviation for a set of controller parameters x (K_w ,T_1, T_2) and t is the time range of the simulation. With the variation of K_w ,T_1,T_2 , 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 ……………...………….. (25)

Subject to

$$K^{min}_{w} \le K_{w} \le K^{max}_{w}$$
$$T^{min}_{1} \le T_{1} \le T^{max}_{1} \quad \ldots\ldots\ldots\ldots (26)$$
$$T^{min}_{2} \le T_{2} \le T^{max}_{2}$$

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

VI. SIMULATION AND RESULTS

The objective function described by equation (21) is evaluated using PSO toolbox given in [21], for each individual by simulating SMIB shown in fig. 4. 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 n. Fig .6 shows the flow chart o f 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 parameter obtained from PSO algorithm.

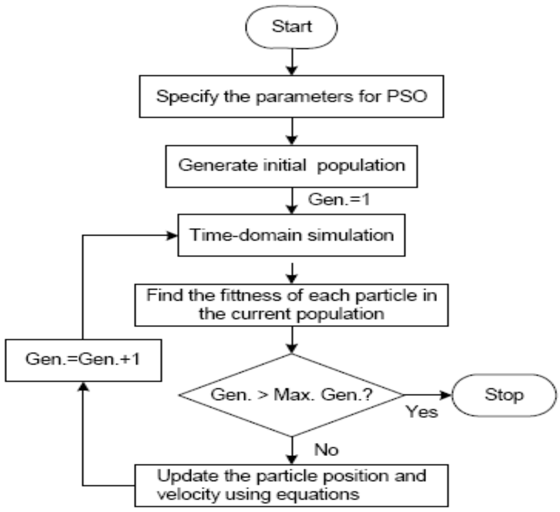


Fig: 7 flow chart of PSO algorithms

Table (I): PSO parameters

parameter	Value
Swarm size	30
Max.gen	100
$C_1 C_2$	2.0,2.0
W_{strat}, W_{end}	0.9,0.4

Table (II):Bounds &optimized parameters

parameter	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 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).

A. small disturbance

Table (III) shows Eigen values of the tested system with and with out TCSC as well as the different locations of TCSC

Table (III): Eigen values analysis

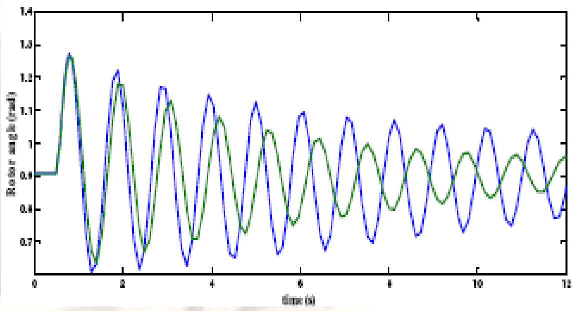
states	Without TCSC	TCSC Between bus(2-3)	TCSC Between bus(3-4)
δ ,w	-0.087±5.618	-2.4±4.1713	-0.4276±5.596
E_q	-0.167±0.393	-0.1737±0.373	-0.1682±0.396

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

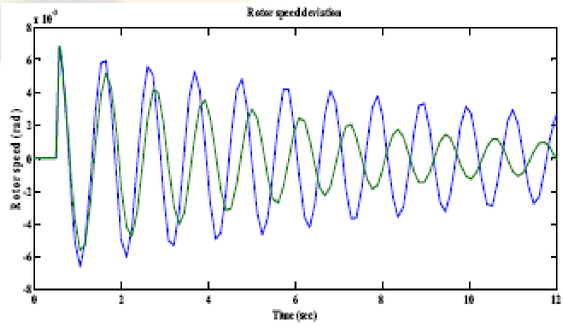
B. severe disturbance

Case (I):

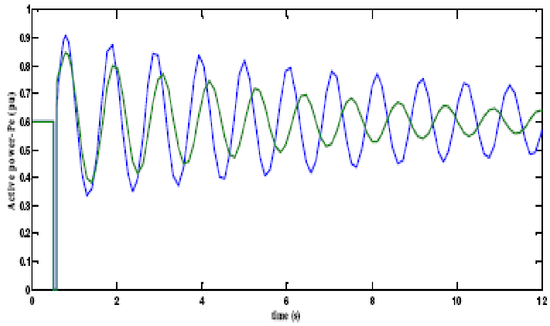
Now TCSC is supposed to be connected between bus (2-3).The value of x_L and x_C was chosen as 0.068 and 0.034 pu respectively. A three phase short circuit occur at t= 0.5 sec figures (8,9,10) shows rotor angle and speed deviation and active power respectively with and without TCSC.



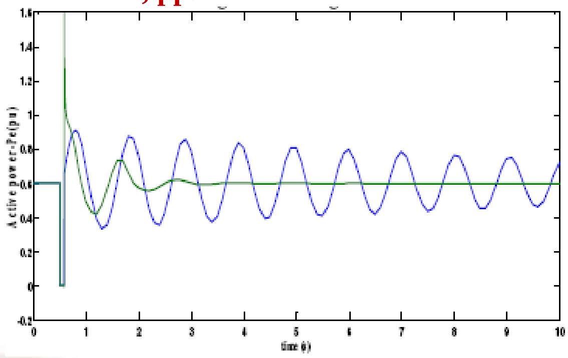
Rotor angle (rad) Vs Time(sec)
Fig .8 Rotor angle



Rotor speed (rad) Vs Time(sec)
Fig .9 Rotor speed deviation



Active power P_e (PU) Vs Time (sec)
Fig 10. Active power



Active power P_e (PU) Vs Time(sec)
Fig 13. Active power

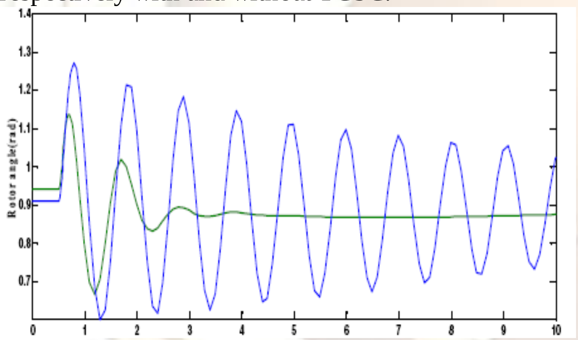
No TCSC with TCSC

No TCSC with TCSC

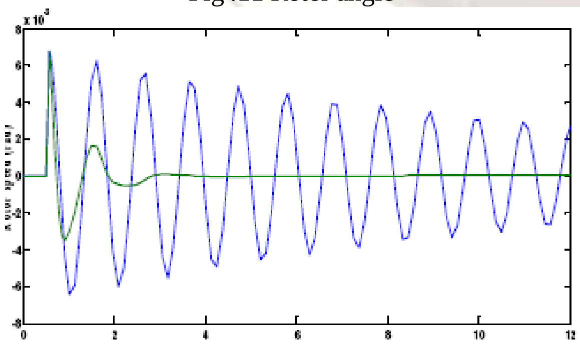
It is clear from above figures the proposed TCSC controller damp and suppresses the oscillations and provides good damping characteristics by stabilizing system much faster, which in turn enhances system stability.

Case (II):

Now TCSC is supposed to be connected between bus (3-4),the value of x_L and x_C was chosen as 0.068 and 0.034 pu respectively . A three phase short circuit occur at t= 0.5 sec figures (11, 12,13) shows rotor angle and speed deviation , and power respectively with and without TCSC.



Rotor angle (rad) Vs Time (sec)
Fig .11 Rotor angle



Rotor speed (rad) Vs Time(sec)
Fig .12 Rotor speed deviation

It is obvious from above figures damping and suppressing .The oscillation in between when TCSC is connected between Bus (3-4).

VII. 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 were evaluated. The problem is formulated as optimization problem to minimize the rotor angle deviation and PSO (particle swarm optimization) techniques employed to find out 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 eigenvalue analysis results show effectiveness of the proposed controller to enhance power system stability and best allocation n of TCSC.

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Appendix

Single-machine infinite bus system data;
(On a 100 MVA base- 400 KV base)
P_e=0.6; $V_{T=}$1.03; $V\infty$ =1.0 (slack)

Generator:
r_a=0.00327; X_d=1.7572; X_q=1.5845; X'_d=0.4245; T'_{do}=6.66;H=3.542; f=50

Transformer:
r_t =0.0; X_t=0.1364

Transmission line:(per circuit)
r_{L2}=r_{L3}=0.0;X_{L2}= X_{L3}= 0.40625; B_c=0.059; X_{L4}=0.13636

Excitation system (Exc):
E_{fd}= ± 6.0; K_a= 400; T_a= 0.025; K_f =0.45; T_f=1.0; Td= 1.0; T_r=0.001;

TCSC:
T_r= 0.5; K_p= 5; K_i=1.0;α_{max}= pi; α_{min}=pi/2;