International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:1, No:2, 2007

Genetically Optimized TCSC Controller for Transient Stability Improvement

Sidhartha Panda, N.P.Padhy, R.N.Patel

***Abstract*—**This paper presents a procedure for modeling and tuning the parameters of Thyristor Controlled Series Compensation (TCSC) controller in a multi-machine power system to improve transient stability. First a simple transfer function model of TCSC controller for stability improvement is developed and the parameters of the proposed controller are optimally tuned. Genetic algorithm (GA) is employed for the optimization of the parameter-constrained nonlinear optimization problem implemented in a simulation environment. By minimizing an objective function in which the oscillatory rotor angle deviations of the generators are involved, transient stability performance of the system is improved. The proposed TCSC controller is tested on a multi-machine system and the simulation results are presented. The nonlinear simulation results validate the effectiveness of proposed approach for transient stability improvement in a multimachine power system installed with a TCSC. The simulation results also show that the proposed TCSC controller is also effective in damping low frequency oscillations.

***Keywords*—**Genetic algorithm, TCSC, transient stability, multi-machine power system.

I. INTRODUCTION

RECENT development of power electronics introduces the use of Flexible AC transmission Systems (FACTS) controllers in power 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 a power system. The detailed explanations about the FACTS controllers are well documented in the literature and can be found in [1-3]. Thyristor Controlled Series Compensator (TCSC) is one of the important members of FACTS family that is increasingly applied with long transmission lines by the utilities in modern power systems. 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 subsynchronous resonance (SSR); damping the power oscillation; and enhancing transient stability [4]-[8].

Genetic Algorithm (GA) are becoming popular to solve the optimization problems in different fields of application mainly because of their robustness in finding an optimal solution and ability to provide a near optimal solution close to a global minimum. Unlike strict mathematical methods, the GA does not require the condition that the variables in the optimization problem be continuous and different; it only requires that the problem to be solved can be computed. GA employs search procedures based on the mechanics of natural selection and survival of the fittest. The GAs, which use a multiple point instead of a single point search and work with the coded structure of variables instead of the actual variables, require only the objective function thereby making searching for a global optimum simpler [9]. The advantage of using GA is evident as it finds its application in a number of papers for optimization problems [10-13]. So, the GA has an apparent benefit to adapt to irregular search spaces of an optimization problem. Therefore, in the present work GA is employed to simultaneously tune the parameters of the TCSC controllers.

The latest advances in the telecommunication industry have induced an increasing interest in technologies, such as phasor measurement unit (PMU) that would provide a reliable source of wide-area measurements of the dynamic state of power system. Many researchers are investigating the proper usage of this information in the various areas of power system dynamic performance. Although the local control signals are easy to get, they are not as highly controllable and observable as wide area signals for the inter-area oscillation modes. Due to restriction of local measurements, these controllers based on local signals tend to be difficult to offer satisfactory performance under various system operating conditions. With the rapid advancement in WAMS technology, fast communication networks and powerful information technology, the widely dispersed signals of power systems can be centralized, processed and distributed even in real time, which makes the wide area signal a good alternative for control input [14].

It is well known that the reactance adjusting of TCSC is a complex dynamic process. Effective design and accurate evaluation of the TCSC control strategy depend on the simulation accuracy of this process. This paper presents a simple transfer function model of the TCSC controller based on the speed deviation as the input signal. The model is developed in the MATLAB/SIMULINK environment. The GA based optimal tuning algorithm is used to tune the TCSC controller. The performance of the TCSC controller is evaluated over a 3-machine 9-bus power system. The location

Sidhartha Panda is a research scholar in the Department of Electrical Engineering, Indian Institute of Technology, Roorkee, Uttaranchal, 247667, India. (e-mail: speeddee@iitr.ernet.in).

N.P.Padhy is with Department of Electrical Engineering, IIT, Roorkee, and R.N.Patel is with Electrical Engineering Department of SSCET, Bhilai. India.(e-mail: nppeefee@iitr.ernet.in)

of the TCSC controller is so chosen that it improves the transient stability of the system for the most severe situation where the critical fault clearing time (CCT) is minimum.

The paper is organized as follows. Section 2 gives a brief introduction of the modeling the TCSC dynamics. The multi-machine power system under study, its modeling and most severe fault condition to determine the location of TCSC are presented in section 3. In section 4, the transfer function model of the TCSC controller is developed and the optimization problem is formulated. In section 5, a brief overview of GA and its application in the present optimization problem is presented. Finally, simulation results are given in section 6.

II. MODELLING THE TCSC DYNAMICS

The main circuit of a TCSC is shown in Fig. 1. It consists of three components: capacitor banks C, bypass inductor L and bidirectional thyristors SCR$_1$ SCR$_2$. In the Fig. 1, i_C and i_L are the instantaneous values of the currents in the capacitor banks and inductor, respectively; i_S the instantaneous current of the controlled transmission line; v is the instantaneous voltage across the TCSC.

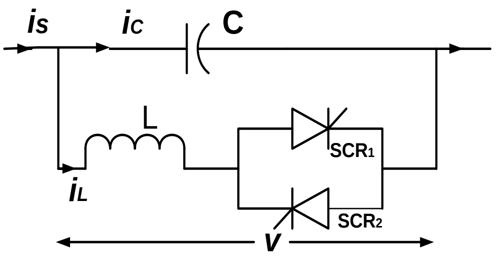

Fig. 1 Configuration of a TCSC

The control of the TCSC is achieved by the firing angle signal α, which changes the fundamental frequency reactance of the compensator. There exists a steady-state relationship between the firing angle α and the reactance $X_{TCSC}(\alpha)$. This relationship can be described in the following equation [3] :

$$X_{TCSC}(\alpha) = X_C - \frac{X_C^2}{(X_C - X_P)} \frac{\sigma + \sin\sigma}{\pi} + \frac{4X_C^2}{(X_C - X_P)} \frac{\cos^2(\sigma/2)}{(k^2-1)} \frac{(k\tan(k\sigma/2) - \tan(\sigma/2))}{\pi} \tag{1}$$

where

X_C = Nominal reactance of the fixed capacitor C

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

$\sigma = 2(\pi - \alpha)$ = Conduction angle of TCSC Controller

$k = \sqrt{\frac{X_C}{X_P}}$ = 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 modelled here as a variable capacitive reactance within the operating region defined by the limits imposed by α. Thus $X_{TCSC\ min} \le X_{TCSC}(\alpha) \le X_{TCSC\ max}$, with $X_{TCSC\ min} = X_{TCSC}(180^0)$ and $X_{TCSCmax} = X_{TCSC}(\alpha_{min})$. In this paper, the Controller is assumed to operate only in the capacitive region, i.e., $\alpha_{min} > \alpha_r$ where α_r corresponds to the resonant point, as the inductive region associated with $90^0 < \alpha < \alpha_r$ induces high harmonics that cannot be properly modelled in stability studies.

III. POWER SYSTEM UNDER STUDY

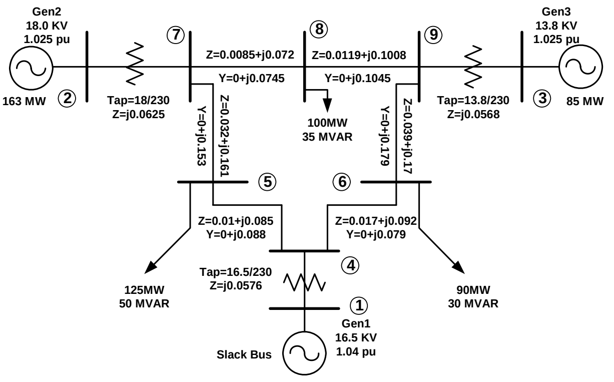

Fig. 2 WSCC 3-machine, 9-bus power system

The well known WSCC 3-machine 9-bus power system, shown in Fig. 2 is considered in the present study. The generators are represented by a flux-decay model suitable for simulation after neglecting the subtransient reactances and saturation. Also, the turbine governor dynamics is neglected resulting in T_{mi} being a constant. The differential-algebric equations for the *m* machiune, *n* bus system with IEEE-Type I excitors are [16]:

$$\frac{d\delta_i}{dt} = \omega_i - \omega_s \tag{2}$$

$$\frac{2Hi}{\omega_s}\frac{d\omega i}{dt} = T_{mi} - P_{ei} - D_i(\omega_i - \omega_s) \tag{3}$$

$$T'_{doi}\frac{dE'_{qi}}{dt} = -E'_{qi} - (X_{di} - X'_{di})I_{di} + E_{fdi} \tag{4}$$

In this model, the loads are assumed to be constant impedance and converted to admittances as:

$$\bar{y}_{Li} = \frac{-(P_{Li} - jQ_{Li})}{V_i^2} \tag{5}$$

where $i = 1,\ldots,m$.

There is a negative sign for $\bar{y}_{Li}$, since loads are assumed as injected quantities.

The network equations for the new augmented network can be written as:

$$\begin{bmatrix} \bar{I}_A \\ 0 \end{bmatrix} = \begin{pmatrix} \bar{Y}_A & \bar{Y}_B \\ \bar{Y}_C & \bar{Y}_D \end{pmatrix} \begin{bmatrix} \bar{E}_A \\ \bar{V}_B \end{bmatrix} \tag{6}$$

Since there is no current injection at the *n* network buses, theses buses can be eliminated resulting in:

$$\bar{I}_A = \left(\bar{Y}_A - \bar{Y}_B \, \bar{Y}_D^{-1} \, \bar{Y}_C \right) \bar{E}_A = \bar{Y}_{int} \, \bar{E}_A \tag{7}$$

Where the elements of the $\bar{I}_A$ and $\bar{E}_A$ are:

$$\bar{I}_i = \left(I_{di} + jI_{qi} \right) \, e^{j(\delta_i - \pi/2)} \tag{8}$$

$$\bar{E}_i = E_i \angle \delta_i \tag{9}$$

The elements of the $\bar{Y}_{int}$ are:

$$\bar{Y}_{ij} = G_{ij} + jB_{ij} \tag{10}$$

Since the network buses are eliminated, the internal nodes are renumbered as 1,…,*m* for ease of notation.

So the current equation becomes:

$$\bar{I}_i = \sum_{j=1}^{m} \bar{Y}_{ij} \, \bar{E}_j \tag{11}$$

The real power output of the internal node I can be written as:

$$P_{ei} = Re\left[\bar{E}_i \, \bar{I}_i^* \right] = \sum_{j=1}^{m} E_i E_j \left(G_{ij} \cos\delta_{ij} + B_{ij} \sin\delta_{ij} \right) \tag{12}$$

The 3-machine 9-bus power system shown in Fig. 2, is modeled in the MATLAB/SIMULINK environment using the above equations. Power system stabilizers are installed for the machines 2 and 3. For simplicity speed-governor dynamics are not modeled and generic power system stabilizer of the SimPowerSystems blockset, where the inputs to the stabilizer are the acceleration power of respective synchronous machines is used. Also a simplified exciter with one gain and one time constant is used for all the machines. As the network parameters change due to occurrence of the fault and subsequent tripping of line, the values of the variables are updated in the above equations.

The first stage in designing a FACTS-based controller in a multi-machine power system is the selection of the best location. In the present study to find the location of TCSC controller, a three phase fault is applied near a bus at the end of a line and the fault is cleared by tripping that line. The process is repeated for all the possible cases to find the most severe situation in terms of the critical clearing time (CCT). For the CCT calculation machine equations are expressed in state variable form. The voltage behind the transient reactance model is used for the generators and the phase angle difference of each machine with respect to the slack bus is determined [17]. The result in the form of CCT is gathered in the Table I.

TABLE I

CCT FOR FAULTS AT DIFFERENT LOCATIONS

Faulted Bus No.	Bus to bus No. of line to be removed		CCT
	From	To	Sec.
4	4	5	0.3
4	4	6	0.3
5	5	4	0.35
5	5	7	0.31
6	6	4	0.44
6	6	9	0.38
7	7	5	0.16
7	7	8	0.18
8	8	7	0.25
8	8	9	0.3
9	9	6	0.21
9	9	8	0.23

It is clear from the above Table I that, the most severe situation in terms of minimum CCT (0.16 sec) occurs where a three phase fault applied at bus 7 and cleared by tripping the line from bus 5 to bus 7. The variation of the power angle difference for the above most severe case is shown in Fig. 3.

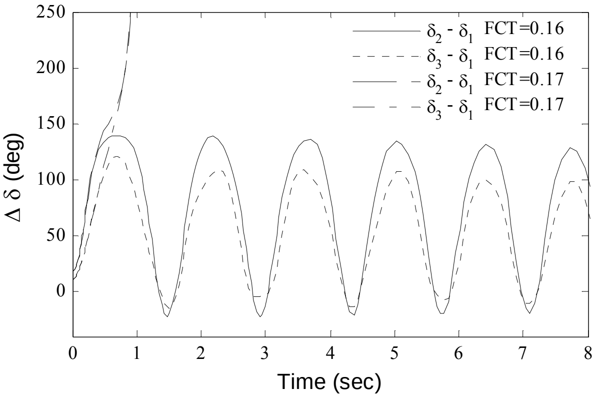

Fig. 3 Variation of power angle difference for different fault clearing

time.

IV. PROBLEM FORMULATION

A. TCSC Controller Structure

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. 4. It consists of a gain block with gain K_T, 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. From the viewpoint of the washout function, the value of T_W is not critical and may be in the range of 1 to 20 seconds [17]. In the Fig. 4, σ_0 is the initial conduction angle as desired by the power flow control loop. The power low control loop acts quit slowly in practice and hence σ_0 is assumed to remain constant during large-disturbance transient period.

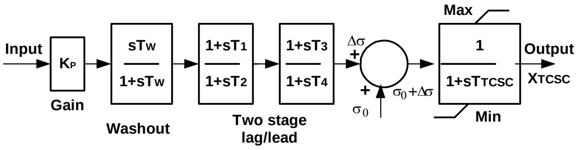

Fig. 4 Structure of the TCSC controller.

B. Optimization Problem

The transfer function of the TCSC controller is:

$$u = K_P\left(\frac{sT_W}{1+sT_W}\right)\left(\frac{1+sT_1}{1+sT_2}\right)\left(\frac{1+sT_3}{1+sT_4}\right) \tag{13}$$

Where, u and y are the TCSC controller output and input signals, respectively. In this structure, T_w is usually prespecified and is taken as 10 s. Also, two similar lag-lead compensators are assumed so that $T_1=T_3$ and $T_2=T_4$. The controller gain K_P and time constants T_1 and T_2 are to be determined. In this study, the input signal of the proposed TCSC controller is the speed deviation difference (ω_1- ω_2) and the output is change in conduction angle $\Delta\sigma$. The speed deviation of machine 2 w.r.t. slack bus is first converted to the pu value and the signal is passed through an integrator and applied as input to the TCSC controller. During steady state conditions $\Delta\sigma = 0$ and $X_{Eff} = X_T+X_L-X_{TCSC}(\alpha_0)$. During dynamic conditions the series compensation is modulated for damping system oscillations. The effective reactance in dynamic conditions is: $X_{Eff} = X_T+X_L-X_{TCSC}(\alpha)$, where $\sigma = \sigma_0+\Delta\sigma$ and $\sigma=2(\pi-\alpha)$, α_0 and σ_0 being initial value of firing & conduction angle respectively.

The objective function is defined as:

$$J = \sum \int_0^{t1} [\Delta\omega_2(t,x) - \Delta\omega_1(t,x)]^2\, dt \tag{14}$$

where $\Delta\omega_2$ (t, x) and $\Delta\omega_1$ (t, x) are the rotor speed deviations of machine 2 and machine 1 respectively for set of controller parameters x (note that here x represents K_P, T_1 and T_2, the parameters of TCSC controller), and t_1 is the time range of the simulation.

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 response in terms of the settling time and overshoots.The problem constraints are the TCSC Controller parameter bounds. Therefore, the design problem can be formulated as the following optimization problem:

Minimize J (15)

Subject to

$$K_{PT}^{min} \le K_P \le K_P^{max}$$

$$T_1^{min} \le T_1 \le T_1^{max}$$

$$T_2^{min} \le T_2 \le T_2^{max} \tag{16}$$

The proposed approach employs genetic algorithm to solve this optimization problem and search for optimal set of the TCSC controller parameters.

V. GENETIC ALGORITHM

A. Overview of GA

GA has been used as optimizing the parameters of control system that are complex and difficult to solve by conventional optimization methods. GA maintains a set of candidate solutions called population and repeatedly modifies them. At each step, the GA selects individuals from the current population to be parents and uses them produce the children for the next generation. Candidate solutions are usually represented as strings of fixed length, called chromosomes. A fitness or objective function is used to reflect the goodness of each member of population. Given a random initial population GA operates in cycles called generations, as follows [9]:

- Each member of the population is evaluated using a fitness function
- The population undergoes reproduction in a number of iterations. One or more parents are chosen stochastically, but strings with higher fitness values have higher probability of contributing an offspring.
- Genetic operators, such as crossover and mutation are

applied to parents to produce offspring.

- The offspring are inserted into the population and the process is repeated

The designer has the freedom to explicitly specify the required performance objectives in terms of time domain bounds on the closed loop responses. The fitness function comes from time domain simulations, which is the power system stability program. Using each set of controllers' parameters the time domain simulation is performed and the fitness value is determined. Good solutions are selected and by means of the GA operators, new and better solutions are achieved. This procedure continues until a desired termination criterion is achieved. Although the chances of GA giving local optimal solution are very few but sometimes getting a suboptimal solution is also possible.

B. Application of GA

Tuning a controller parameter can be viewed as an optimisation 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 GA based method, the tuning process is associated with an optimality concept through the defined objective function and the time domain simulation. Hence this method yields optimal parameters and the method is free from the curse of local optimality. In GA optimisation technique, the designer has the freedom to explicitly specify the required performance objectives in terms of time domain bounds on the closed loop responses. In view of the above, the proposed approach employs GA to solve this optimisation problem and search for optimal TCSC controller parameters

In the present study GA is employed for the optimal tuning of TCSC controller parameters x so as to minimize the objective function *J.* While applying GA, a number of parameters are required to be specified. An appropriate choice of the parameters affects the speed of convergence of the algorithm. Table II shows the specified parameters for the GA algorithm. The normalized geometric ranking, which is one of the ranking methods, is used as selection function to select individuals in the population for the next generations. Also, arithmetic crossover as the crossover function and non-uniform mutation as mutation operators are adopted. The description of these operators and their properties can be found in reference [18]. The parameters of the controller are tuned for the most severe conditions. The critical fault clearing time (CCT) i.e. the maximum time duration for which the disturbance may act without the system losing its capability to recover a steady-state (i.e., stable) operation is used to tune the parameters. The computational flow chart of the proposed design approach is shown in Fig. 5. One more important point that affects the optimal solution more or less is the range for unknowns. For the very first execution of the program, a wider solution space can be given and after getting the solution one can shorten the solution space nearer to the values obtained in the previous iteration. Bounds for unknown parameters of gains and time constants used in the present study and the optimised parameters of the TCSC controller are shown in Table III.

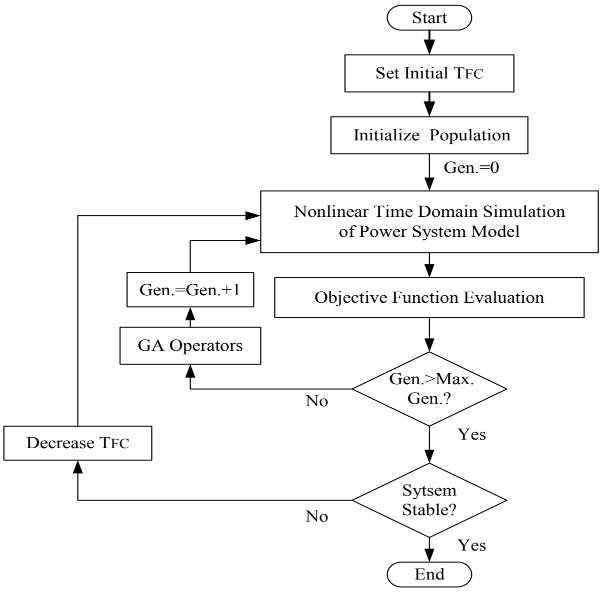

Fig. 5 Flowchart of the genetic algorithm approach

TABLE II
PARAMETERS USED IN GENETIC ALGORITHM

Parameter	Value/Type
Maximum generations	100
Population size	50
Type of selection	Normal geometric [0 0.08]
Type of crossover	Arithmetic [2]
Type of mutation	Nonuniform [2 100 3]
Termination method	Maximum generation

TABLE III
BOUNDS OF UNKNOWN VARIABLES AND OPTIMIZED PARAMETERS OBTAINED

Parameters	Gain K_P	Time constants T_1	 T_2
Minimum range	10	0.01	0.01
Maximum range	70	0.5	0.5
Obtained parameters	30.539	0.3861	0.1719

For a three phase fault applied at bus 7 and cleared by tripping of line between bus 5 to bus 7, the maximum value of fault clearing time T_{FC} as obtained by algorithm presented in Fig. 5 is found to 0.152 sec where as the CCT with out TCSC controller is found to be 0.134 sec. Note that the CCT without TCSC is less than that presented in Table I, as the results of

Table I are obtained using a simplified state variable approach, whereas for simulation purpose a more detailed model is developed using equations (1)-(12).

VI. SIMULATION RESULTS

To assess the effectiveness of the proposed controllers, simulation studies are carried out for the most severe fault condition (a three phase fault applied at bus 7 and cleared by tripping of line between bus 5 to bus 7). The maximum fault clearing time ($T_{FC} = 0.152$ sec) is used in all simulations. The system power angle response under this severe disturbance is shown in Figs. 7 and 8. In the Figs., the response without TCSC controller is shown with dotted line and the response with TCSC controller is shown with solid lines. It is clear from the Figs. that, the system is unstable without control under this severe disturbance. The proposed TCSC controller maintains the stability and the power system oscillations are quickly damped out.

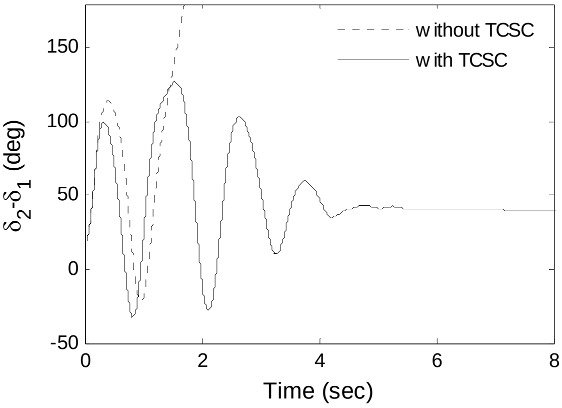

Fig. 6 Power angle response of machine 2 w.r.t. slack bus

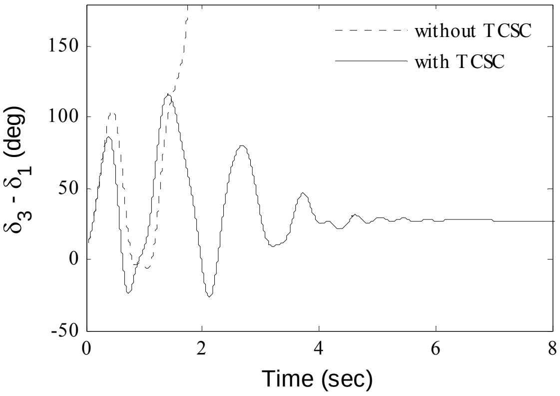

Fig. 7 Power angle response of machine 3 w.r.t. slack bus

The variations of the relative speed deviation of machines 2 and 3 w.r.t. slack bus are shown in Figs. 8-9. It is clear from the figures that genetically optimized TCSC controller not only maintains transient stability but also provides good damping characteristics to low frequency oscillations by stabilizing the system much faster. The percentage line compensation provided by the TCSC controller for the above disturbance is shown in Fig. 10, from which it is clear that the line reactance is appropriately modulated to improve system stability.

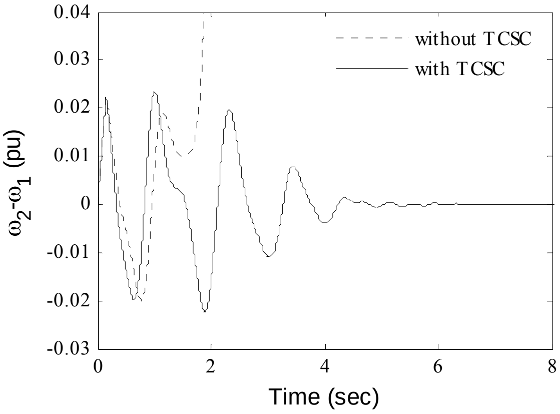

Fig. 8 Speed deviation response of machine 2 w.r.t. slack bus

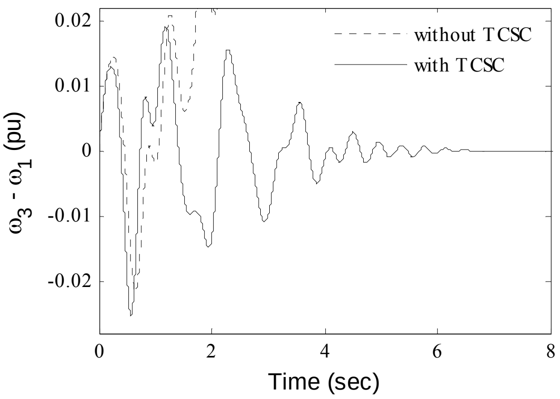

Fig. 9 Speed deviation response of machine 3 w.r.t. slack bus

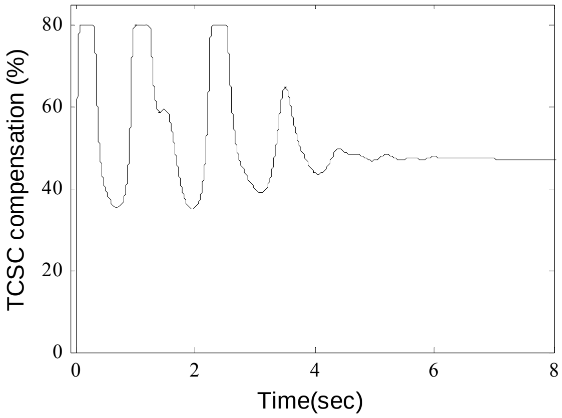

Fig. 10 Percentage line compensation provided by TCSC

To compare the damping performance of the TCSC controller for the cases of with and without controller, T_{FC} is decreased from 0.152 sec to 0.134 sec so that without TCSC controller also the system remains stable. The same contingency (a three phase fault applied at bus 7 and cleared by tripping of line between bus 5 to bus 7) is simulated. The system power angle response is shown in Fig. 11, which clearly depicts the advantage of the proposed TCSC controller to damp power system oscillations.

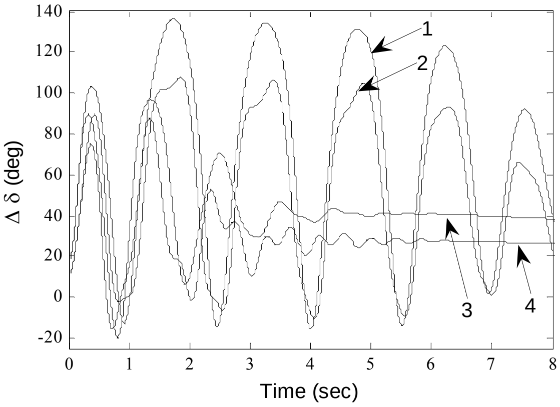

Fig. 11 Power angle responses of machines 2 & 3 w.r.t. slack bus for lower fault clearing time (T_{FC} = 0.134 sec)
1:$\delta_2 - \delta_1$; 2:$\delta_3 - \delta_1$:without TCSC controller
3:$\delta_2 - \delta_1$; 4:$\delta_3 - \delta_1$:with TCSC controller

VII. CONCLUSION

This paper presents the modeling and optimizing the parameters for a TCSC controller for transient stability improvement of a multi-machine power system. First, the location of the TCSC controller is obtained from the point of view of transient stability improvement. Then, a simple transfer function model of TCSC controller for stability improvement is developed and the parameters of the proposed controller are optimally tuned. The minimization of the rotor angle deviation following a severe disturbance is formulated as an optimization problem and the optimal TCSC controller parameters are obtained by means of genetic algorithm. The performance of the TCSC controller is tested over a 3-machins 9-bus power system, for the most severe situation in terms of critical fault clearing time. Nonlinear simulation results show the effectiveness of TCSC controller in enhancing the critical fault clearing time of the system and damping power system oscillations.

APPENDIX

Data for the studied 3-machine 9-bus power system. All data are in pu unless specified otherwise.

Generators: H1 = 23.64, H2=6.4, H3=3.01; D1/M1=0.1, D2/M2=0.2, D3/M3=0.3; X_{d1}=0.146, X_{d2}=0.8958, X_{d3}=1.3125; X_{d1}'=0.0608, X_{d2}'=0.1198, X_{d3}'=0.1813; X_{q1}=0.0969, X_{q2}=0.8645, X_{q3}=1.2578; T_{do1}'=8.96, T_{do2}'= 6.0, T_{do1}'=5.89;

Exciter: (Simplified exciter): K_{A1}= K_{A2}= K_{A3}=20, T_{A1}= T_{A2}= T_{A3}=0.2s,

PSS: (Machines 2&3): Generic power system stabilizer; Sensor time constant T_S=0.03, K=20, T_W=2s, T_{1S}=0.05s, T_{2S} =0.02s, T_{3S}=3.0s, T_{4S} =5.4s, V_{SMAX} = 0.15, V_{SMIN} = -0.15

TCSC controller: T_{TCSC} = 15 ms, X_C = 0.02376, k=2, T_1 = T_3, T_2 = T_4, T_{WS}=10 s, $X_{TCSCMAX}$ = 0.576 (80% of line), $X_{TCSCMIN}$ = 0.

REFERENCES

1) N.G.Hingorani and L.Gyugyi, *Understanding FACTS: Concepts and Technology of Flexible AC Transmission System*. IEEE Press. 2000.
2) Y.H.Song and T.A.Johns, *Flexible AC Transmission Systems (FACTS).* IEE. London. 2000.
3) R.M Mathur and R. K.Verma, *Thyristor-based FACTS Controllers for Electrical Transmission Systems.* IEEE press. Piscataway. 2002.
4) P.Mattavelli, G.C.Verghese and A. M. Stankovitctt, "Phasor dynamics of Thyristor-Controlled series capacitor systems," *IEEE Trans. Power Systs.,* vol-12, pp. 1259–1267, 1997.
5) B. H Li, Q. H. Wu, D. R. Turner, P. Y. Wang and X.X Zhou, "Modeling of TCSC dynamics for control and analysis of power system stability," *Electrical Power & Energy Systs*., Vol-22, pp. 43–49, 2000.
6) L Fan, A. Feliachi and K. Schoder, "Selection and design of A TCSC control signal in damping power system inter-area oscillations for multiple operating conditions." *Electrical Power & Energy Systs.,* Vol-62, pp. 127-137, 2002.
7) A. D Del Rosso, C. A Canizares and V.M. Dona, "A study of TCSC controller design for power system stability improvement," *IEEE Trans. Power Systs*., vol-18, pp. 1487-1496, 2003.
8) S.Panda, R.N.Patel and N.P.Padhy, "Power system stability improvement by TCSC controller employing a multi-objective genetic algorithm approach, *International Journal of Intelligent Technology,* Vol. 1, No. 4, pp. 266-273, 2006.
9) D. E. Goldberg, *Genetic Algorithms in Search, Optimization and Machine Learning*. Addison-Wesley, 1989.
10) S.Mishra, P.K. Dash, P.K.Hota and M.Tripathy, "Genetically optimized neuro-fuzzy IPFC for damping modal oscillations of power system." *IEEE Trans. Power Systs.,* vol-17, pp. 1140–1147, 2002.
11) T.K.Mok, H.Liu, Y.Ni, F.F.Wu and R.Hui, "Tuning the fuzzy damping controller for UPFC through genetic algorithm with comparison to the gradient descent training," *Electric Power Systs. Research*. Vol-27, pp. 275–283, 2005.
12) M.A.Abido, "Analysis and assessment of STATCOM-based damping stabilizers for power system stability enhancement." *Electric Power Systs. Research*. Vol-73, pp. 177–185, 2005.
13) S. Panda and R.N.Patel, "Optimal location of shunt FACTS controllers for transient stability improvement employing genetic algorithm", *Electric Power Components and Systems,* Vol. 35, No. 2, pp. 189-203, 2007.
14) Yong Chang and Zheng Xu, "A novel SVC supplementary controller based on wide area signals", *Electric Power Syst. Research,* Article in Press.
15) P.W.Sauer and M.A.Pai, *Power System Dynamics and Stability.* Pearson education (Singapore) Pte. Ltd. 2002.
16) H.Saadat, *Power System Analysis*. Tata McGraw-Hill, New Delhi, 2002.
17) P. Kundur, *Power System Stability and Control*. New York: McGraw-Hill, 1994.
18) C.Houck, J.Joines and M.Kay, *A genetic algorithm for function optimization: A MTLAM implementation*. NCSU-IE, TR 95–09. 1995. Available: http://www.ise.ncsu.edu/mirage/GAToolBox/gaot