GENETIC-BASED TCSC DAMPING CONTROLLER DESIGN FOR POWER SYSTEM STABILITY ENHANCEMENT

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ABSTRACT - A Genetic-based damping controller for a thyristor-Controlled Series Capacitor (GCSC) is presented in this paper. The design problem of TCSC based stabilizer is formulated as an optimization problem where the genetic algorithm (GA) is applied to search for the optimal setting of the stabilizer parameter. Minimizing the real part of the system eigenvalue associated with low frequency oscillation mode is proposed as the objective function of the design problem. The proposed controller has been examined on a weakly connected power system with different disturbances and loading conditions. Eigenvalue analysis and nonlinear simulation results show the effectiveness of the proposed GCSC based stabilizer and its ability to provide efficient damping of low frequency oscillations. In addition, the performance of the proposed GCSC outperforms that of conventional power system stabilizer (CPSS). It is also observed that the proposed GCSC improves greatly the voltage profile of the system under severe disturbances.

Keywords: thyristor controlled series capacitor, power system stabilizer, genetic algorithm.

1 INTRODUCTION

In the recent years, power demand increases substantially and, on the other hand, the expansion of power generation and transmission is limited due to limited resources and environmental restrictions. Therefore, the existing transmission systems should be utilized effectively by operating them closer to their thermal limits. This goal can be achieved by reliable and high-speed flexible AC transmission system (FACTS) devices [1-3] such as static VAR compensator (SVC), thyristor-controlled phase shifter (TCPS), and thyristor controlled series capacitor (TCSC). FACTS are designed to enhance power system stability by increasing the system damping in addition to their primary functions such as voltage and power flow control. One of the promising FACTS devices is TCSC, which is considered in this paper.

A considerable attention has been directed for investigating the effect of TCSC on power system stability [4-11]. Several approaches based on modern control theory have been applied to TCSC controller design. Chen et al [4] presented a state feedback controller for TCSC by using a pole placement technique. However, all system states were required by the controller that reduces its applicability. Chang and Chow [5] developed a time optimal control strategy for the TCSC where a performance index of time was minimized. A fuzzy logic controller for a TCSC was proposed in [6]. The impedance of the TCSC was adjusted based on machine rotor angle and the magnitude of the speed deviation. In addition, different control schemes for a TCSC were proposed such as variable structure controller [7-8], bilinear generalized predictive controller [9], H_∞-based controller [10], and neural network controller [11].

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Despite the potential of modern control techniques with different structures, power system utilities still prefer a conventional lead-lag controller structure [12-14]. The reasons behind that might be the ease of on-line tuning and the lack of assurance of the stability related to some adaptive or variable structure techniques. It is shown that the appropriate selection of conventional lead-lag stabilizer parameters results in effective damping to low frequency oscillations [14].

In the last few years, genetic algorithms (GA) [15-16] appeared as a promising algorithm for handling the combinatorial optimization problems. In most recent papers [17-20], GA has been applied to the problem of PSS and FACTS based stabilizer design. The results are promising and confirming the potential of GA to search for the optimal settings of CPSS parameters.

In this paper, design of TCSC based stabilizer using GA optimization algorithm is investigated. The proposed GCSC has been tested on a weakly connected power system. Based on eigenvalue analysis and simulation results, it was observed that the proposed GCSC provides good damping of electromechanical modes of oscillations, enhances power system stability, and improves the system voltage profile.

2 THYRISTOR CONTROLLED SERIES CAPACITOR

In this study, a single machine infinite bus system with a TCSC shown in Fig. 1 is considered. A TCSC has been placed in series with the transmission line to change the line flow. In this way, a TCSC can extend the power transfer capability and provide additional damping for low frequency oscillations. The configuration of a TCSC is shown in Fig. 2. It comprises a fixed capacitor in parallel with a thyristor-controlled reactor. Controlling the firing angle of the thyristors can regulate the TCSC reactance and its degree of compensation.

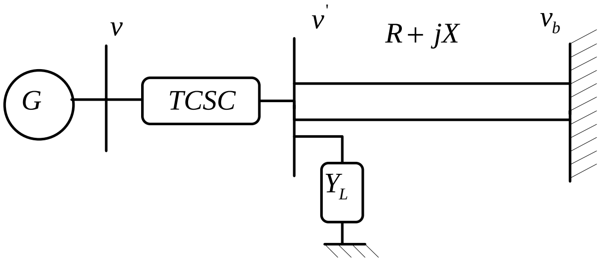


Fig. 1: Single machine infinite bus system with a TCSC

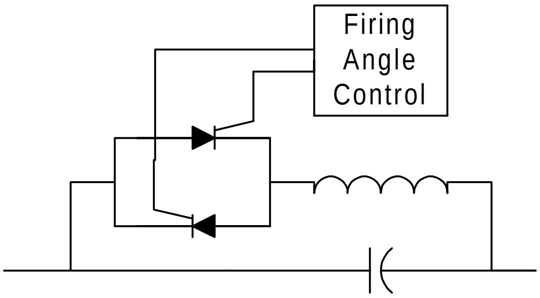


Fig. 2: The configuration of TCSC

3 LINEARIZED POWER SYSTEM MODEL

The generator is represented by the third-order model comprising of the electromechanical swing equation and the generator internal voltage equation. The swing equation is divided to the following equations

$$\rho\delta = \omega_b(\omega - 1) \tag{1}$$

$$\rho\omega = (P_m - P_e - D(\omega - 1))/M \tag{2}$$

P_m is assumed to be constant and P_e can be expressed as

$$P_e = v_d i_d + v_q i_q \tag{3}$$

The internal voltage, E'_q, equation is

$$\rho E'_q = (E_{fd} - (x_d - x'_d)i_d - E'_q)/T'_{do} \tag{4}$$

The IEEE Type-ST1 excitation system shown in Fig. 3 is considered in this study. It can be described as

$$\rho E_{fd} = (K_A(V_{ref} - v + u_{PSS}) - E_{fd})/T_A \tag{5}$$

where;

$$v = (v_d^2 + v_q^2)^{1/2} \tag{6}$$

$$v_d = x_q i_q \tag{7}$$

$$v_q = E'_q - x'_d i_d \tag{8}$$

Fig. 4 illustrates the block diagram of an TCSC stabilizer. The TCSC dynamics can be expressed as

$$\rho X_{CSC} = (K_c(X_{CSC}^{ref} + u_{CSC}) - X_{CSC})/T_c \tag{9}$$

where X_{CSC}^{ref} represents the desired degree of compensation.

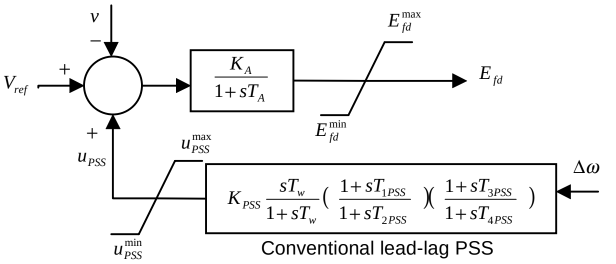


Fig. 3: IEEE Type-ST1 excitation system with conventional PSS

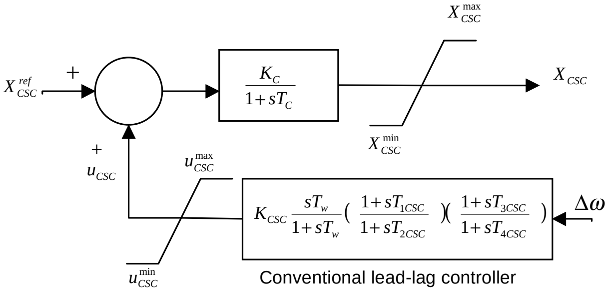


Fig. 4: TCSC with conventional lead-lag stabilizer

In the stabilizer design problem, the linearized incremental model around a nominal operating point is usually employed [12-14]. Generally, the linearized system model can be written as

$$\rho X = AX + BU \tag{10}$$

Here, the state vector X is $[\Delta\delta, \Delta\omega, \Delta E'_q, \Delta E_{fd}]^T$ and the control vector U is $[u_{PSS}, \Delta X_{CSC}]^T$.

4 PROBLEM FORMULATION

A TCSC based stabilizer and PSS as shown in Figs. 3 and 4 are considered in this study. In this structure, the washout time constant T_w and the time constants $T_{2\text{ CSC}}$, $T_{4\text{ CSC}}$, $T_{2\text{ PSS}}$, and $T_{4\text{ PSS}}$ are usually prespecified. In this study, T_w=5s and $T_{2\text{ CSC}}$=$T_{4\text{ CSC}}$= $T_{2\text{ PSS}}$=$T_{4\text{ PSS}}$=0.1s. The stabilizer gains K_{CSC} and K_{PSS}, and time constants $T_{1\text{ CSC}}$, $T_{3\text{ CSC}}$, $T_{1\text{ PSS}}$, and $T_{3\text{ PSS}}$ are remained to be determined. In this study, the tuning parameters of the proposed GCSC stabilizer are K_{CSC}, $T_{1\text{ CSC}}$, and $T_{3\text{ CSC}}$. For comparison purposes, a genetic-based power system stabilizer (GPSS) is also designed with the same objective function and procedure.

Participation factors method [21] is used to identify the eigenvalues of the system matrix A associated with the electromechanical modes. The following objective function J to increase the system damping is proposed.

J = real part of electromechanical mode eigenvalue (11)

The problem constraints are the optimized parameter bounds. Therefore, the design problem can be formulated as the following optimization problem.

$$\text{Minimize } J \tag{12}$$

Subject to

$$K_{CSC}^{\min} \leq K_{CSC} \leq K_{CSC}^{\max} \tag{13}$$
$$T_{1\,CSC}^{\min} \leq T_{1\,CSC} \leq T_{1\,CSC}^{\max} \tag{14}$$
$$T_{3\,CSC}^{\min} \leq T_{3\,CSC} \leq T_{3\,CSC}^{\max} \tag{15}$$

The proposed approach employs GA to solve this optimization problem and search for optimal or near optimal set of the optimized parameters.

5. GENETIC ALGORITHM

GA is an exploratory search and optimization procedure that was devised on the principles of natural evolution and population genetics. Unlike other optimization techniques, GA work with a population of individuals represented by bit strings and modifies the population with random search and competition. The advantages of GA over other traditional optimization techniques can be summarized as follows:

- GA works on a coding of the parameters to be optimized, rather than the parameters themselves.
- GA searches the problem space using a population of trials representing possible solutions to the problem, not a single point, i.e. GA has implicit parallelism. This property ensures GA to be less susceptible to getting trapped on local minima.
- GA uses a performance index assessment to guide the search in the problem space.
- GA uses probabilistic rules to make decisions.

Typically, the GA starts with little or no knowledge of the correct solution depending entirely on responses from interacting environment and their evolution operators to arrive at optimal or near optimal solutions. In general, GA includes operations such as *reproduction*, *crossover*, and *mutation* [15]. *Reproduction* is a process in which a new generation of population is formed by selecting the fittest individuals in the current population. *Crossover* is the most dominant operator in GA. It is responsible for producing new offsprings by selecting two strings and exchanging portions of their structures. The new offsprings may replace the weaker individuals in the population. *Mutation* is a local operator which is applied with a very low probability. Its function is to alter the value of a random position in a string.

6 GA APPLICATION TO THE PROPOSED DESIGN APPROACH

Generally, applying the GA to the problem of PSS design involves performing the following two steps.

1. The objective function value must be calculated for each of the strings in the current population. To do this, the optimized parameters must be decoded from each string in the population and the system is linearized to obtain the objective function value.
2. GA operations are applied to produce the next generation of the strings.

These two steps are repeated from generation to generation until the population converges producing an optimal or near optimal parameter set. The computational flow chart of the proposed design approach is shown in Fig. 5.

GA algorithm has been applied to search for optimal settings of the optimized parameters of the proposed GCSC and GPSS stabilizers. The final settings of the optimized parameters are given in Table 1. The convergence rate of the objective function J with the number of iterations is shown in Fig. 6.

It is worth mentioning that the optimization process has been carried out with the system operating at nominal loading condition given in Table 2.

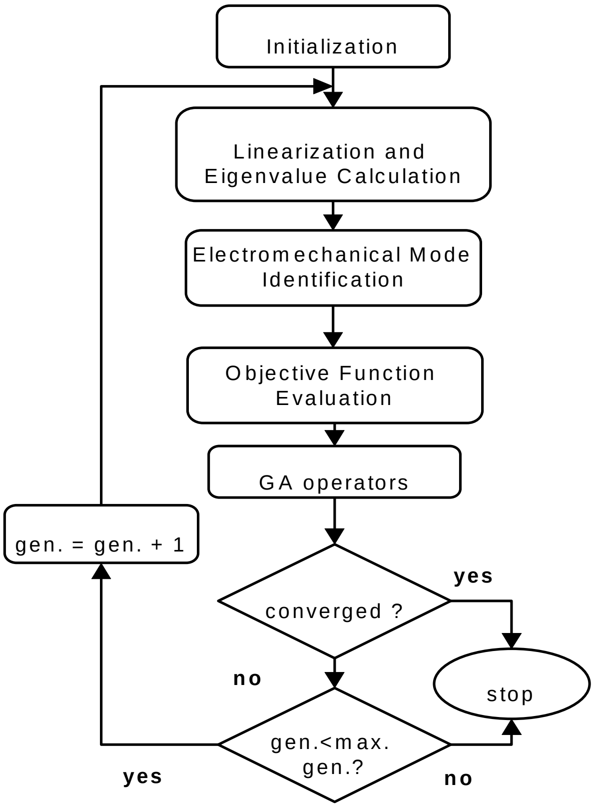


Fig. 5: Computational flow of the proposed approach

TABLE 1: THE OPTIMAL SETTINGS OF THE PROPOSED GCSC AND GPSS PARAMETERS

GCSC			*GPSS*		
K_{CSC}	$T_{1\,CSC}$	$T_{3\,CSC}$	K_{PSS}	$T_{1\,PSS}$	$T_{3\,PSS}$
98.8	0.072	0.068	25.2	0.176	0.152

TABLE 2: LOADING CONDITIONS

Loading	P (pu)	Q (pu)	X_{CSC}
Nominal	1.0	0.015	0.0
Leading PF	0.70	-0.30	0.2
Heavy	1.10	0.40	-0.2

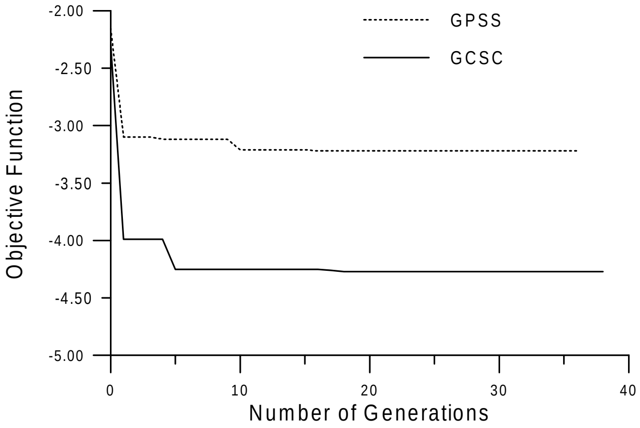


Fig. 6: Objective function variations of the proposed schemes

7 SIMULATION RESULTS

To assess the effectiveness and robustness of the proposed GCSC stabilizer, three different loading conditions given in Table 2 with different disturbances were considered. The performance of the proposed GCSC stabilizer is compared to that of CPSS given in [20] and GPSS designed in this study.

It is worth mentioning that all the time domain simulations were carried out using the nonlinear power system model. The system data is given in [20].

7.1 Nominal Loading

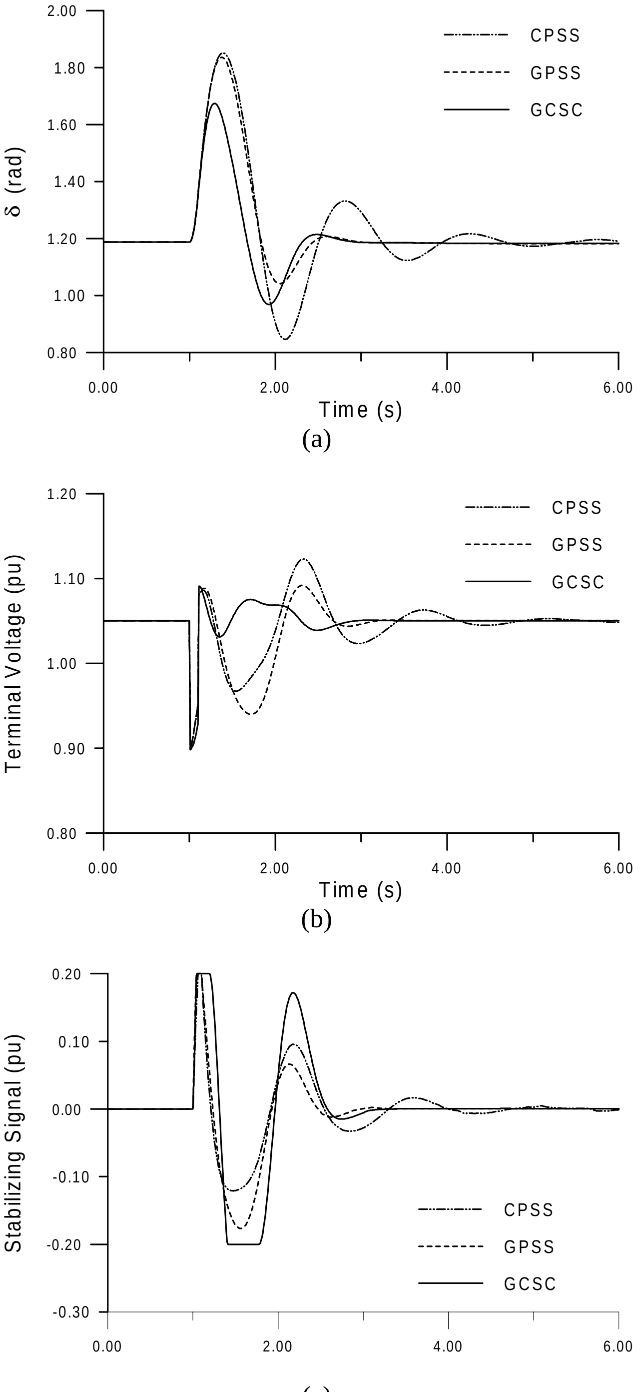
At this loading condition, the system eigenvalues with and without the proposed control schemes are given in Table 3. It is shown that the open loop system is unstable because of the negative damping of electromechanical mode. It is quite clear that the proposed GCSC stabilizer outperforms the GPSS and CPSS and shifts substantially the electromechanical mode eigenvalue to the left in the *s*-plane. This enhances greatly the system stability and improves the damping characteristics of electromechanical mode.

TABLE 3: SYSTEM EIGENVALUES WITH AND WITHOUT CONTROL

No Control	*CPSS*	*GPSS*	*GCSC*
$+0.3\pm j5.0^{*}$	$-1.2\pm j4.4^{*}$	$-3.2\pm j4.4^{*}$	$-4.3\pm j3.9^{*}$
$-10.4\pm j3.3$	$-4.6\pm j7.4$	$-3.2\pm j7.3$	$-4.3\pm j6.5$
---------	-0.2, -18.7	-19.9, -7.3	$-11.9\pm j1.5$
--------	-------	-0.2	-19.3, -0.2

[*] Eigenvalues associated with the electromechanical mode

The behavior of the proposed stabilizer under transient conditions was verified by applying a three phase fault at the infinite bus at *t*=1s. The fault duration was 0.1s. The system response is shown in Fig. 7. It can be seen that the first swing in the torque angle is significantly suppressed with the proposed GCSC stabilizer. Thus, GCSC stabilizer has better damping of the first swing than that of CPSS and GPSS. This feature increases power system stability margin. In Fig. 7(b), the voltage profile is greatly improved with the proposed GCSC stabilizer. The stabilizing signals are also shown in Fig. 7(c). It can be seen that the proposed GCSC stabilizer utilizes properly and efficiently the controller for fast damping of the oscillations



(a)

(b)

(c)

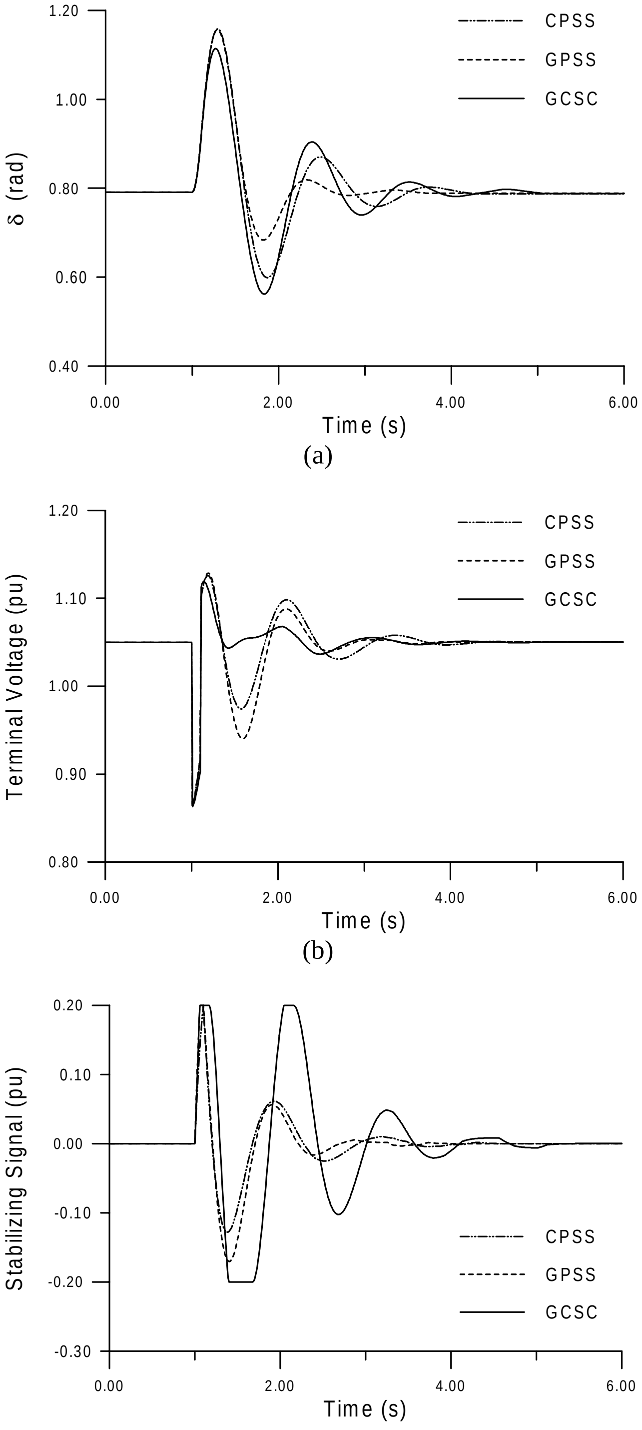
Fig. 7: System response to the fault test with nominal loading

7.2 Leading PF Loading

A three-phase fault test has been applied at the infinite bus for 0.1s. The system response is shown in Fig. 8. It is shown that the system damping characteristics and voltage profile are significantly enhanced with the proposed GCSC stabilizer.

7.3 Heavy Loading

A three phase fault disturbance at the infinite bus for 0.05s was applied. The results are shown in Fig. 9. It can be seen that the proposed control schemes suppress the first swing in torque angle and extend the system stability limit. In addition, the voltage profile is greatly improved with the proposed GCSC stabilizer in terms of overshoots and settling time.



(a)

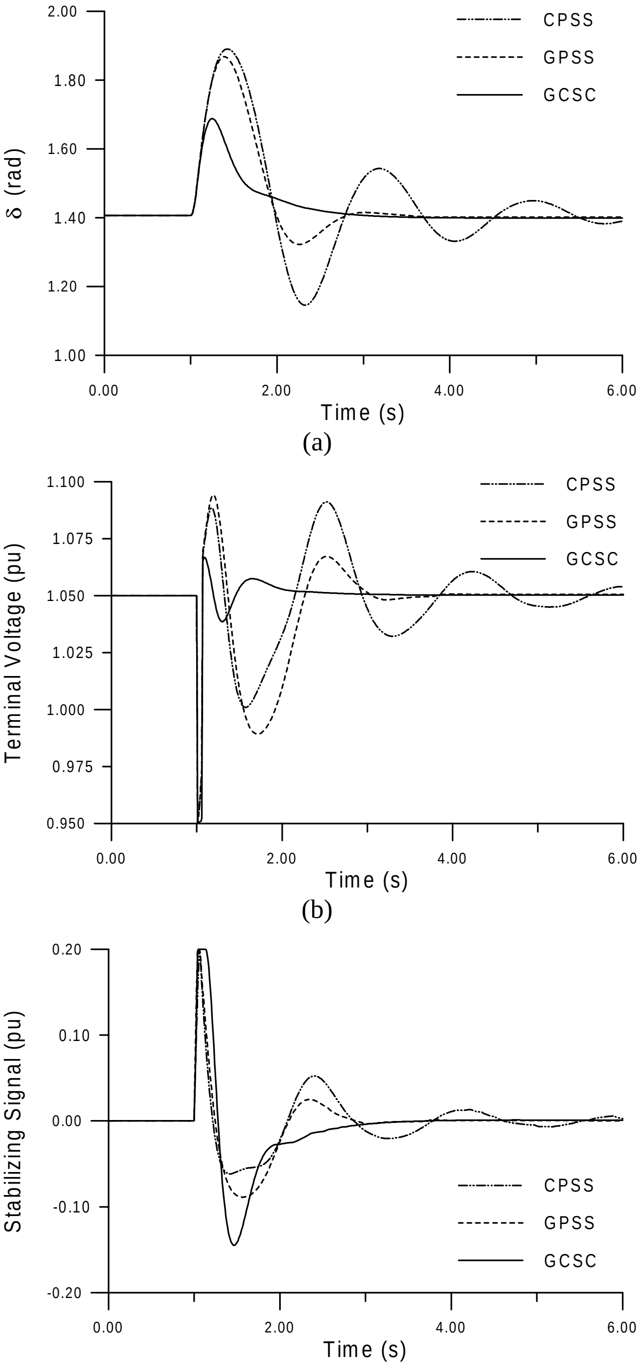
(b)

(c)

Fig. 8: System response to the fault test with leading PF loading

8 CONCLUSIONS

In this study, a genetic-based TCSC stabilizer is presented. The proposed GCSC stabilizer design problem is formulated as an optimization problem where GA has been employed to search for optimal settings of stabilizer parameters. The proposed stabilizer has been tested on a weakly connected power system under different disturbances and loading conditions. The eigenvalue analysis and the nonlinear simulation results show that the proposed GCSC stabilizer provides good damping of low frequency oscillations and improves greatly the voltage profile.



(a)

(b)

(c)

Fig. 9: System response to the fault test with heavy loading

9 ACKNOWLEDGEMENT

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11. BIOGRAPHY

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His research interests are power system planning, operation and stability, FACTS, system identification, optimization techniques applied to power systems, and intelligent control.