Damping of Power Systems Oscillations by using Genetic Algorithm-Based Optimal Controller

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Abstract- In this paper, the power system stabilizer (PSS) and Thyristor controlled phase shifter(TCPS) interaction is investigated . The objective of this work is to study and design a controller capable of doing the task of damping in less economical control effort, and to globally link all controllers of national network in an optimal manner , toward smarter grids . This can be well done if a specific coordination between PSS and FACTS devices , is accomplished . Firstly, A genetic algorithm-based controller is used. Genetic Algorithm (GA) is utilized to search for optimum controller parameter settings that optimize a given eigenvalue based objective function.

Secondly, an optimal pole shifting, based on modern control theory for multi-input multi-output systems, is used. It requires solving first order or second order linear matrix Lyapunov equation for shifting dominant poles to much better location that guaranteed less overshoot and less settling time of system transient response following a disturbance.

Keywords-power system stability, PSS,FACTS,TCPS, Genetic Algorithms, Pole shifting.

I. INTRODUCTION

Power utilities are forced to rely on utilization of existing generating units and to load existing transmission lines close to their thermal limits.

However, stability has to be maintained at all times. Hence, in order to operate power systems effectively, without reduction in system security and quality of supply , even in the case of contingency conditions such as, loss of transmission lines and /or generating units , new control strategies need to be implemented .

The advances in the field of power electronic led to a new approach introduced by the Electric Power Research Institute (EPRI) called flexible AC transmission system or simply FACTS , which came as an answer to a call for more efficient use of already existing resources in present power systems while maintaining and even improving power system security [1-3].

The interconnection between distant located power systems is now a common practice, which gives rise to low frequency oscillations in the range of 0.1 – 3 Hz. If not well damped, these oscillations may keep growing in magnitude until loss of synchronism results [4].

In order to damp these power system oscillations and increase system stability, the installation of power system stabilizer (PSS) is both economical and effective. PSSs have been used for many years to add damping to electromechanical oscillation. To date, most major electric power system plants in many countries are equipped with PSS. However, PSSs suffer a drawback of being liable to cause great variations in the voltage profile and may not be able to suppress oscillations resulting from severe disturbances, especially those three – phase faults, which may occur at the generator terminals [5].

Recently, FACTS – based stabilizer has appeared offering an alternative way in damping power systems oscillations. Although , the damping ratio of FACTS controllers often is not their primary function , the capability of FACTS – based stabilizers to increase power system oscillations damping characteristics has been recognized.

However, possible interaction between PSSs and FACTS – based stabilizers, may deteriorate much of their contributions, and may even cause adverse effect on damping of system oscillations. Therefore, coordinated design of PSSs and FACTS – based stabilizers is a necessity, both to make use of the advantages of the different stabilizers and to avoid the demerits accompanied with their operation. Several approaches based on modern control theory have been applied to FACTS controller design .

Abid and Abdel – Magid , 2002 [6] demonstrated the effectiveness of FACTS based controllers (TCSC,SVC and TCPS) on damping local oscillation under different loading conditions, proposed a real coded genetic algorithm (RCGA) based method to tune the parameters of FACTS – based stabilizer, and introduced a singular value decomposition (SVD) to identify the most effective stabilizer . It was observed that the damping effect of TCPS is very robust with respect to load characteristics , while SVC is very dependent on load characteristics , and the dependence of load models on damping performance of a TCSC lies in between the dependence of the two other devices.

II. MATHEMATICAL MODEL

In previous article , the performance of TCSC interacted with PSS has been well simulated and tested[7]. The nonlinear dynamic model and linearised models of Single Machine connected to Infinite Bus bar SMIB equipped with FACTS devices: namely (TCPS) have been derived based on the liearised Phillips-Heffron model. This model includes: SMIB equipped with TCPS.

For simplicity, a conventional PSS is modeled by one phase compensation block connected with a washout circuit and gain block as shown in figure (1)[8].

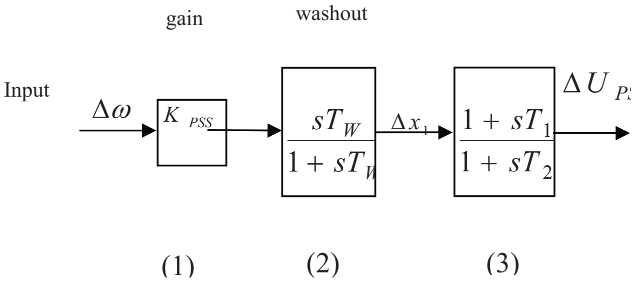


Figure (1): Block diagram of conventional PSS.

The phase compensation block provides the appropriate phase – lead characteristic to compensate for phase lag between the exciter input and the generator electric toque.

The basic function of a TCPS is to control transmission line power flow through the modulation of the phase angle difference between the two sides of the transmission line voltage. The phase shift is accomplished by adding or subtracting a variable voltage component that is in quadrature with the phase voltage of the line. This quadrature voltage component is obtained from a transformer connected between the other two phases. The configuration of TCPS is shown in figure (2).

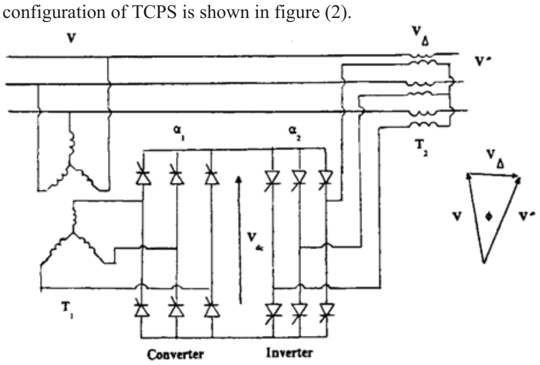


Figure (2):TCPS configuration

When the transmission line is equipped with TCPS, as shown in figure (3), the real power flow through a transmission line is obtained by:

$$P = \frac{V_i V_j}{X_{ij}} \sin(\delta_{ij} - \phi)$$

where ϕ is the phase shift in the voltage phase angle resulting from TCPS. Hence, the real power flow through the transmission line can be modulated by controlling the angle ϕ .

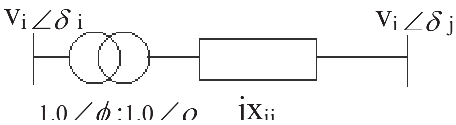


Figure (3): Transmission line equipped with TCPS

The SMIB power system with TCPS is shown in figure (4). The best location of the phase shifter is at generator terminal.

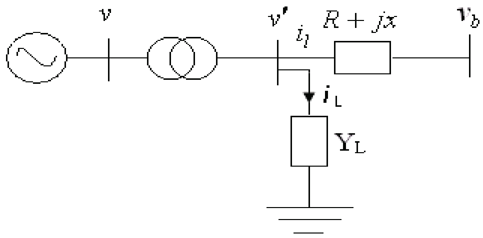


Figure (4) : Single machine infinite bus system with TCPS .

Figure (5) illustrates the block diagram of a TCPS with power oscillation damping (POD) controller. The phase shift angle, ϕ of the TCPS is expressed as:

$$\dot{\phi} = \frac{1}{T_S}\left[K_S\left(\phi_{ref} - U_{TCPS}\right) - \phi\right]$$

where ϕ_{ref} is the reference angle, and K_S and T_S are the gain and time constant of the TCPS respectively.

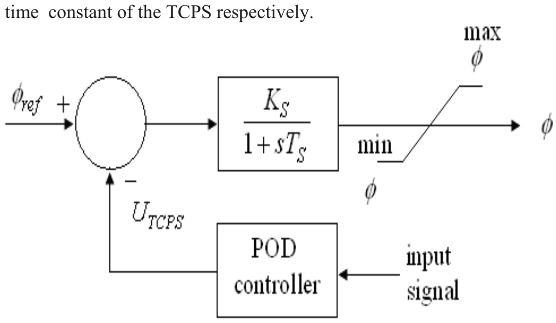


Figure (5): TCPS with POD controller .

From the state space equations of linearized model , the system matrix A is

$$A = \begin{bmatrix} 0 & \omega_b & 0 & 0 & 0 \\ \frac{-K_1}{M} & \frac{-D}{M} & \frac{-K_2}{M} & 0 & \frac{-K_{P\phi}}{M} \\ \frac{-K_4}{T'_{do}} & 0 & \frac{-K_3}{T'_{do}} & \frac{1}{T'_{do}} & \frac{-K_{q\phi}}{T'_{do}} \\ \frac{-K_5 K_A}{T_A} & 0 & \frac{-K_6 K_A}{T_A} & \frac{-1}{T_A} & \frac{-K_A K_{v\phi}}{T_A} \\ 0 & 0 & 0 & 0 & \frac{-1}{T_s} \end{bmatrix}$$

The parameters of the modified Phillips – Heffron model ($K_1 - K_6$, $K_{P\phi}$, $K_{q\phi}$ and $K_{v\phi}$) are computed for nominal operating condition .

Figure (4) shows the modified Phillips –Heffron transfer function model of the system including TCPS.. From this figure, it can be seen that the damping torque contribution by the FACTS devices can be considered to be in two parts. The first part directly applies to the electromechanical oscillation loop of the generator and its sensitivity is mainly measured by coefficient K_q , which is named the direct damping torque. The second part applies through the field channel of the generator and its sensitivity is related by the deviation of field voltage, which is referred to as the indirect damping torque.

III. GENETIC ALGORITM-BASED CONTROLLER

The control method is based on genetic algorithm (GA) to coordinate control of power system stabilizer (PSS) and FACTS – based stabilizer installed in single machine infinite – bus system (SMIB). The stabilizer design problem is transformed into an optimization problem where genetic algorithm (GA) will be applied to search for optimal parameter settings by maximizing the minimum damping ratio of all complex eigenvalues.

A supplementary lead – lag controller as an oscillation damping controller is proposed to be part of FACTS control system. The effectiveness of the proposed control in improving the power system dynamic stability is verified through eigenvalue analysis, time – domain simulations under different loading conditions, and practical verifications.

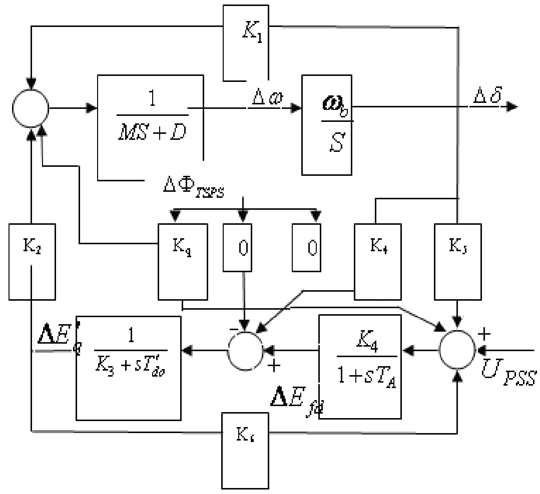


Figure (6): Modified Phillips – Heffron model of SIMB system with TCPS.

IV. POD CONTROLLER STRUCTURE

Supplementary control action applied to excitation or FACTS devices, to increase the system damping, is called power oscillation damping (POD).

Two POD controller structures are considered in this work. The first controller is lead/lag, and the second is state feedback controller (Optimal Pole Shifting), described in the next section .

The structure of FACTs POD controller has a similar structure to that of the PSS controllers. Speed change of the generator is used as an input signal for lead/lag controller. The washout time constant T_w and time constant T_{2i} are usually prespecified. In the present study, T_w =10sec. and T_{2i} =0.1sec. The controller parameters (K_i and T_{1i}) are optimized using GA techniques.

To optimize the stabilizer's parameters, an eigenvalue based objective function is considered . The objective function is formulated to increase the damping ratio of electromechanical mode eigenvalue. Therefore, the system response to disturbances will be improved. An eigenvalue –based objective function can be defined as

$$J = \min \ (\zeta_i)$$

where ζ_i is the damping ratio of electromechanical mode eigenvalue . It is clear that the objective function will identify the minimum value of the damping ratio among modes of all loading conditions considered in the design process. Hence, it is aimed to maximize J in order to increase the damping ratio of electromechanical modes. This will reduce the system response overshoots, settling time and enhance the system damping characteristics.

Controller Design

In this section, a procedure, for tuning multiple power system damping controllers(POD), will be described . The problem, of selecting the parameters for POD controllers that would assure maximum damping performance, is solved via a GA optimization procedure with an eigenvalue – based performance index. The objective function, which is maximized during the optimization, is derived in the following way.

Let $\lambda_j = \alpha_j \pm iB_j$ be the j-th eigenvalue (mode) of the closed loop matrix, then the damping coefficient (ζ_j) of the j-th eigenvalue is defined according to the following equation :

$$\zeta_j = \frac{-\alpha_j}{\sqrt{\alpha_j^2 + \beta_j^2}}$$

The goal of GAs - based optimization procedure is to achieve sufficient damping, for all modes , shifts the dominant poles to the desired position , and overall operating conditions under consideration ,by exploring the search space of admissible control parameters . Then, the design problem can be formulated as the following optimization problem:

Maximize J ,subject to

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

$$T_{1i}^{\min} \le T_{1i} \le T_{1i}^{\max}$$

where the K_i and T_{1i} are the parameters of i-th controller . The procedures involved in GA optimization are as follows:

Step 1: Set the initial population randomly.

Step 2: Evaluate performance index J.

Step 3: If the value of J obtained is maximum, then the optimum value of control parameters is equal to those obtained in the current generation, otherwise go to step 4.

Step 4: Based on the fitness, some individuals will be selected to populate the next generation. The selection is based on Roulette – wheel method. Selected individuals will be then recombined through crossover by exchanging genetic information between the pairs of the individuals contained in the current population. After that, each individual in the population will be mutated with a given probability, through a random process of replacing one allele with another to produce a new genetic structure.

The GA stops when a pre – defined maximum number of generations are achieved or when the value of J is maximum.

The eigenvalues of the system, without control, are calculated and given in table 1. It is clearly seen that the system is unstable.

Table 1:Eigenvalues of the system.

Eigenvalues of the system without control
$\lambda_{1,2} = +0.3 \mp j4.96$ $\lambda_{3,4} = -10.39 \mp j3.28$

Then, the proposed GA is applied to search for optimal settings of optimized parameters of the proposed control schemes . The final settings of the optimized parameters for the proposed stabilizers are calculated. To show effectiveness of GA method ,a classic lead – lag PSS controller is designed . The parameters of the classic PSS are obtained using the phase compensation technique . The detailed step – by – step procedure for computing the parameters of damping controllers using phase compensation technique is presented by YU [8].

The eigenvalues with CPSS and proposed stabilizers for nominal operating condition are given in table 2 . The first row represents the electromechanical model eigenvalue and their damping ratio , using participation factor to identify the eigenvalue associated with electromechanical model.

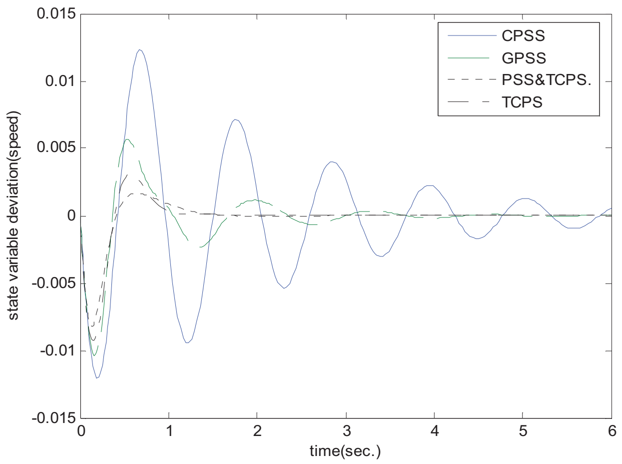
The system eigenvalues, with the proposed stabilizers for nominal loading condition, are given in table (2). The first row represent the electromechanical model eigenvalues and their damping ratio . It is shown that , the damping ratio of electromechanical mode of the proposed schemes (1) , (2) , (3) are 0.45,0.65,and0.816 respectively . It is quite clear that TCPS stabilizer greatly enhances the damping electromechanical mode of oscillation, however, better damping characteristics can be achieved with coordinated control of PSS and TCPS, as shown in proposed scheme (3).

Table (2): System eigenvalues with the proposed controllers.

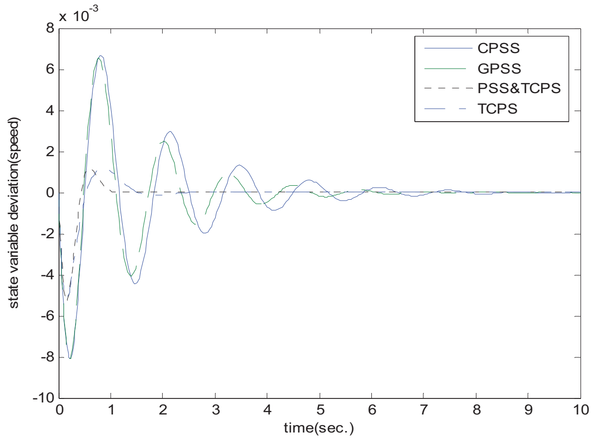
CPSS only	TCPS only	PSS & TCPS
-2.84 ± 5.6	$-3.05 \mp 3.56i$	$-3.52 \pm 2.49i$

To support the results of the eigenvalue analysis given in table (2) , time domain – simulation, based on differential equations of the system under disturbance 10 % step change in mechanical power input (ΔP_m), is preformed. The load angle $\Delta\delta$ and speed deviation $\Delta\omega$ responses, for the above disturbance at nominal loading condition, are shown in figure (7) . It is clear from the figures that the TCPS controller provides good damping of low frequency oscillation , however , better damping characteristic can be obtained by coordinated control of PSS and TCPS . This is consistent with eigenvalue analysis results .

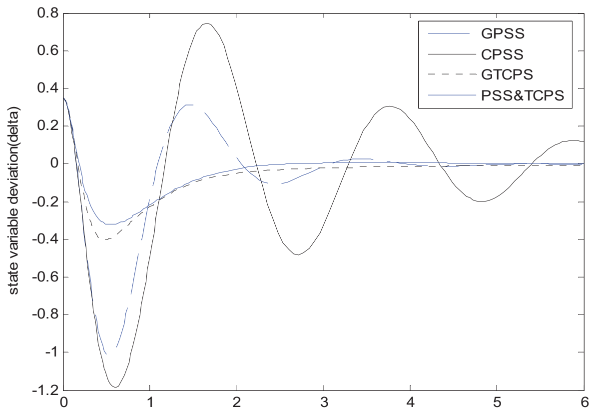
To assess the effectiveness of the proposed controllers , different loading conditions are considered . The response of the load angle and speed deviation for the 10 % step change in mechanical input power at the heavy and at light loading conditions are shown in figures (8) – (11) respectively . From the figures, it can be seen that the response with coordinated control of PSS and TCPS are much faster , with less over shoot and settling time compared to CPSS and the individual design .



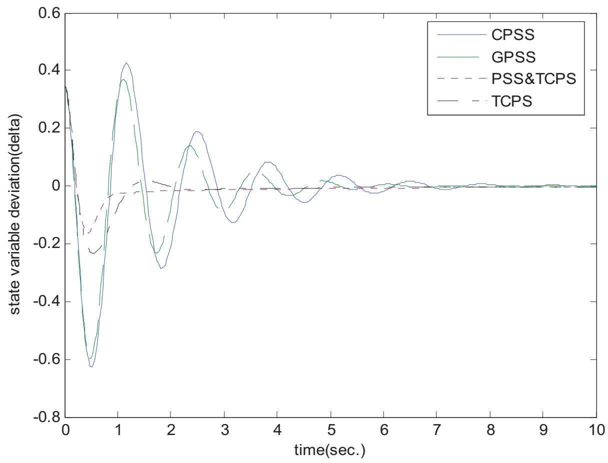
Figure(7): Dynamic responses for $\Delta\omega$ with different damping controllers (at nominal loading conditions)



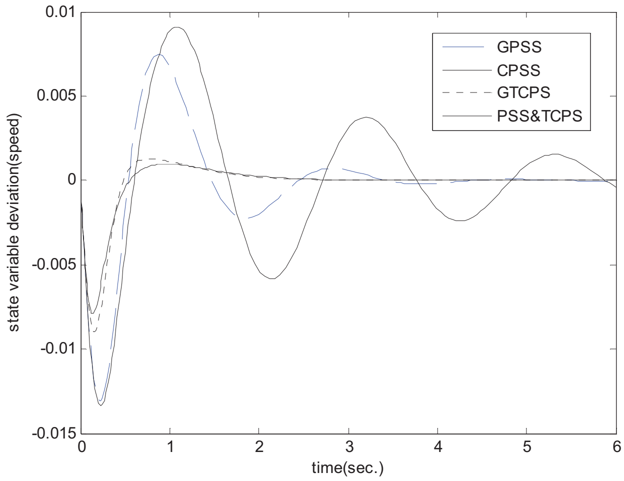
Figure(8): Dynamic responses for $\Delta\delta$ with different damping controllers (at heavy loading conditions)



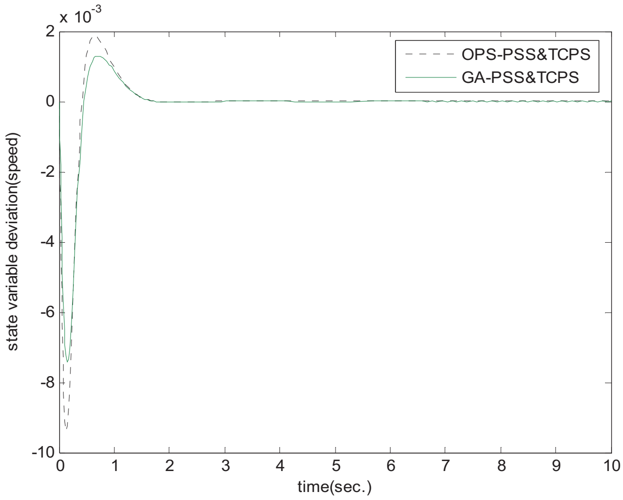
Figure(9): Dynamic responses for $\Delta\omega$ with different damping controllers (at heavy loading conditions)



Figure(10): Dynamic responses for $\Delta\delta$ with different damping controllers (at light loading conditions)



Figure(11): Dynamic responses for $\Delta\omega$ with different damping controllers (at light loading conditions)



Figure(12): Dynamic response for $\Delta\omega$ with coordinated control of PSS and TCPS

VI.CONCLUSIONS

This work concerned with the damping of power systems oscillations by using the coordinated control of PSS and FACTS devices : namely (TCPS) . Based on the analysis and results presented in this work the following conclusions are drawn: The results show that the TCPS – based controllers have good effect in improving the system damping ,

The optimal pole shifting technique overcomes the difficulty of choosing suitable values for the performance index parameters often-encountered in practical applications of optimal control theory. Furthermore, this method does not require the solution of the non linear matrix Riccati equation and it is thus computationally very fast and the possibility to directly impose damping constraints in controller design, the benefits are to achieve a simple structure in the damping controller obtained and avoid time-consumption.

IX. References

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Appendix: system parameters

B=0.262, G=0.249, R=0.034, X=0.997, X_d=0.937, X'_d=0.19, X_q=0.55, M=9.26, D=0, T'_{do}=7.76 sec., K_A=50, T_A=0.05 sec., t_w=10 sec, K_s=1, T_s=0.05 sec, T_1=0.1 sec.