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Design of GCSC Stabilizing Controller for Damping Low Frequency Oscillations

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Abstract— *This paper presents a systematic procedure for modeling and simulation of a power system equipped with FACTS type Gate Controlled Series Compensator (GCSC) based stabilizer controller. Single Machine Infinite Bus (SMIB) power system was investigated for evaluation of GCSC stabilizing controller for enhancing the overall dynamic system performance. PSO algorithm is employed to compute the optimal parameters of damping controller. Eigenvalues of system under various operating condition and nonlinear time domain simulation is employed to verify the effectiveness and robustness of GCSC stabilizing controller in damping low frequency oscillations (LFO) modes.*
Keywords—SMIB, GCSC, LFO, PSO, POD.

I. INTROUDUCTION

Nowadays, providing of electrical energy with high quality and reliability became more difficult than the past due to continuous growing of demand beside the environmental restrictions of building new generation plants and transmission lines and limited resources. As a result, transmission lines becomes heavily loaded, which in turns leads to system stability problem. In addition to that, operating of power system under this conditions lead to arising Low Frequency Oscillations (LFO), if not sufficiently damped leads to instability of power system. The LFOs can be divided into two major oscillatory modes. Local mode with the frequency range from 0.8-3 Hz and inter area mode has the frequency range of 0.1-0.8 Hz [1-3].

In recent years, a great efforts have been employed to full utilizing of existing power system facilities and operate it near to safe stability limits. Flexible AC Transmission System (FACTS) controllers are one of important emerging technology, which used recently for fixing many power system problems. Due to the operational features of FACTS devices, a number of improvements to power system became possible like power flow control, enhancement of power system stability (transient and dynamic) [3, 4]. Gate Controlled Series Capacitor (GCSC) is one of FACTS devices family, which installed in series with transmission lines as shown in Fig.2. A schematic diagram of GCSC shown in Fig.1 and a GCSC can control the series compensation percentage of lines by regulating the blocking angle (γ). Many features like ability to control, simple composition and flexibility in operation had made the GCSC one of candidate solutions for fixing the power system problems. As consequence, a GCSC can be considered as an effective alternative for damping the low frequency oscillations. FACTS devices may not add sufficient damping component for system oscillatory modes. Due to that, supplementary controllers with high flexibility and adjustable parameters are required for generated the needed damping component by FACTS [4-7].

In the last two decades, the heuristics methods have been mentioned as the robust methods for optimizing the engineering problems. Ease of use, wide application and ability to achieve close optimal results are including reasons for the increasing success of these techniques. The paper approaches focuses on study the capability of GSCS in providing a more robust stabilizer function for a Single Machine Infinite Bus (SMIB). So that, supplementary damping controller is assumed to be optimally designed in order to assist the GCSC for providing the damping component. The Particle Swarm Optimization algorithm (PSO) is assigned to compute the optimal parameters of damping controller through minimizing the eigenvalues of electromechanical mode of oscillations (EM) based objective function. In addition, the nonlinear time domain simulation is employed the verified the eigenvalues results [8, 10].

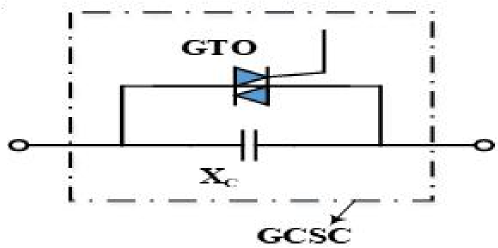

Fig.1: Schematic Diagram of GCSC.

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II. SINGLE MACHINE INFINITE BUS MODEL

SMIB is considered as investigated system as shown in Fig.2. The generator is connected to infinite bus via transmission lines while the GCSC is in series with transmission line. Machine is represented by third order model with including the excitation system. Equations from (1-4) represent the nonlinear equation of power system and excitation system while the other equations for algebraic and GCSC controller [4, 7].

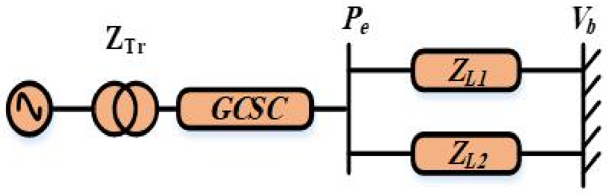

Fig.2: SMIB Equipped with GCSC.

$$\frac{d\delta}{dt} = \omega_b(\omega - \omega_s)(1)$$

$$\frac{d\omega}{dt} = \frac{1}{M}[P_m - P_t - D(\omega - \omega_s)](2)$$

$$\frac{dE'_q}{dt} = \frac{1}{T'_{do}}[-E_q - E'_q - (x_d - x'_d)i_d + E_{fd}](3)$$

$$\frac{dE_{fd}}{dt} = \frac{1}{T_A}[-E_{fd} + K_A(V_{ref} - V_t)](4)$$

Where:

$$P_t = \frac{E'_q V_b}{x'_{d\Sigma}}\sin\delta - \frac{V_b^2(x_q - x'_d)}{2x'_{d\Sigma}x_{q\Sigma}}\sin 2\delta(5)$$

$$E_q = \frac{E'_q x_{d\Sigma}}{x'_{d\Sigma}} - \frac{V_b(x_d - x'_d)}{x'_{d\Sigma}}\cos\delta(6)$$

$$V_t = \sqrt{V_{td}^2 + V_{tq}^2}(7)$$

$$X_{Gcsc}(\gamma) = X_C\left[1 - \frac{2\gamma}{\pi} + \frac{\sin 2\gamma}{\pi}\right](8)$$

Where the P_m, P_t, V_t, X_{Gcsc}, γ are the mechanical input power, electrical power, terminal voltage GCSC reactance and blocking angle of GCSC respectively. In state space representation the power system can modeled in form:

$$[\Delta\dot{X}] = [A][\Delta X] + [B][\Delta U](9)$$

Where the state vector;

$$[\Delta X] = [\Delta\delta \quad \Delta\omega \quad \Delta E'_q \quad \Delta E_{fd} \quad \Delta X_{Gcsc}]^T \ (10)$$

$$[\Delta U] = [u_{GCSC}](11)$$

$$[A] = \begin{bmatrix} 0 & \omega_S & 0 & 0 & 0 \\ \frac{-K_1}{M} & \frac{-K_D}{M} & \frac{-K_2}{M} & 0 & \frac{-K_P}{M} \\ \frac{-K_4}{T'_{do}} & 0 & \frac{-K_3}{T'_{do}} & \frac{1}{T'_{do}} & \frac{-K_q}{T'_{do}} \\ -\frac{K_5K_A}{T_A} & 0 & -\frac{K_6K_A}{T_A} & -\frac{1}{T_A} & -\frac{K_VK_A}{T_A} \\ 0 & 0 & 0 & 0 & \frac{-1}{T_{GCSC}} \end{bmatrix}$$

$$[B] = \left[0 \quad 0 \quad 0 \quad 0 \quad \frac{1}{T_{GCSC}}\right]^T (12)$$

III. GCSC DAMPING CONTROLLER

The aim of GCSC damping controller is providing sufficient damping component in power system through FACTS device to improve the system performance and stability. Due to the simplicity, adaptability and availability of conventional Lead-Lag controllers, they are still preferred by electrical utilities. Fig.3 shows the block diagram of GCSC damping controller which comprises washout signal, gain block and two stages of phase compensators block.Providing robust and sufficient damping (lead) component to face the lag component which arises between input and output signals of power system is the main role of damping controller. This implies optimal determination of K_s, τ_1, τ_2, τ_3 and τ_4. τ_w is time constant of washout which take values ranged from 1-20 s. in addition the lead lag compensator take values ranged from 0.1-1.5 s. Accelerating power (ΔP) or rotor speed deviation ($\Delta\omega$) is usually chosen as input to GCSC damping controller. Equation (13) represent the transfer function of GCSC supplementary controller [8, 9].

$$u_{GCSC} = K_s\left(\frac{1+sT_1}{1+sT_2}\right)\left(\frac{1+sT_3}{1+sT_4}\right)\Delta\omega \quad (13)$$

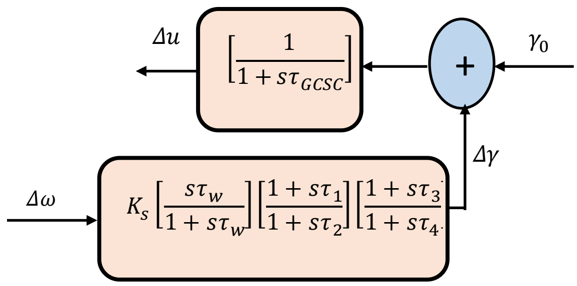

Fig.3: GCSC Supplementary Controller.

IV. OBJECTIVE FUNCTION

Determination of optimal parameters of GCSC damping controller depend on the selected objective function and approaches followed to compute controllers' parameters. In this paper, the proposed objective problem for the controllers design is based on eigenvalue and can be given as:

$$J_1 = Max\left(\frac{-\sigma}{\sqrt{\sigma^2 + \omega^2}}\right) \ (14)$$

It's aimed to maximize this objective to enhance the system damping. Design problem can be formulated as:

Optimize J_1, Subject to:

$$K_S^{min} \le K_s \le K_S^{max}$$
$$\tau_1^{min} \le \tau_1 \le \tau_1^{max}$$
$$\tau_2^{min} \le \tau_2 \le \tau_2^{max}$$
$$\tau_3^{min} \le \tau_3 \le \tau_3^{max}$$
$$\tau_4^{min} \le \tau_4 \le \tau_4^{max}$$

The Proposed approach employs PSO to search for the optimum parameters configurations of the given controllers:

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V. PARTICLE SWARM OPTIMIZER

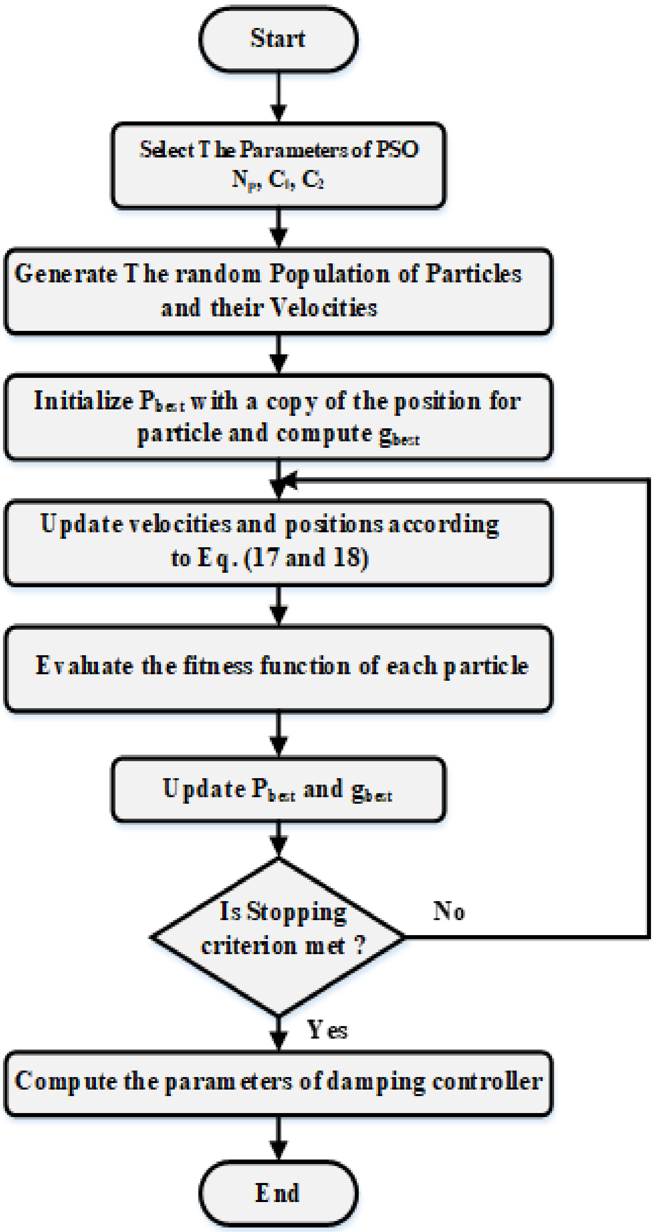

Fig.4: PSO Flow Chart.

In order to compute the optimum solution of GCSC supplementary controller, optimization tools play an important role access of arriving to global solution or at least near to it through formulating the problem in optimization form. Particle Swarm Optimization (PSO) algorithm considered one of optimization techniques, it models the behavior of food searching for birds flocking or fish schooling. PSO features comparing with the other algorithms, are easily programming, the required memory size and time consumed for computation are little and adaptable convergence with the potential to yield better quality of candidate solutions. PSO uses random real numbers and the global commutation among the swarm members called particles forming an initial population. In each iteration, population members are generate new members by the best values of itself and the group. Each particle is represented by $X_i = (x_{i1}, x_{i2}\dots x_{in})$ and keeps track of its coordinates in hyperspace, which are associated with the fittest solution it has achieved so far. The value of the fitness for particle i (P_{best}) is also stored as $P_i = (P_{i1}, P_{i2}\dots P_{in})$. While PSO have new update to improve the performance in computing the optimal solution by tracking the best solutions (g_{best}) and its positions for any member in population. Fig.4 demonstrates the process of PSO algorithm to find out the optimum solution of GCSC supplementary controller parameters [8-10].

$$v_i^{new} = wv_i^{old} + c_1 r_1 * \left(P_i^{Local\ best} - P_i^{old}\right) + c_2 r_{2*} (P_i^{global\ best} - P_i^{old}) \quad (15)$$

$$P_i^{new} = P_i^{old} + v_i^{new} \quad (16)$$

Where: c, r are learning factor and independent random uniform numbers respectively. PSO algorithm runs for several iterations and determines the optimal parameters of GCSC-POD controller. The optimized parameters are given in Table (1) and the Figure (5) represents the optimal fitness function of SMIB plus GCSC post 100 iterations.

Table 1. GCSC POD Controller Parameters.

Parameters	
K_s	5.0
τ_1	1.0
τ_2	0.3706
τ_3	1.0
τ_4	0.3706

VI. SIMULATION AND RESULTS

To assess effectiveness and robustness of the proposed controller and design approach, a severe disturbance is considered that is tripping a line for 5 cycles and the fault cleared and then returning the line in service. SMIB was tested system to evaluate the performance of GCSC based stabilizer controller in improvement the steady state and transient stability. In addition, eigenvalues of system under different operating conditions tabulated in tables (2-4) with consider the EM mode of oscillation and damping ratio highlighted by bold line.

Table.2: Eigenvalues Analysis (Normal Operating Condition).

	Eigenvalue	***Damping Ratio***
W.C	**-0.1479 ± j9.4457** -98.8179; -1.4764; -66.6667	**0.0157**

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GCSC	**-3.8471 ± j5.5924** -98.8019; -54.5678; -7.9460; -0.1001; -2.1696; -1.4738	**0.5668**

Table 3. Eigenvalues Analysis (Heavy Operating Condition).

	Eigenvalue	***Damping Ratio***
W.C	**0.1203 ±j9.9481** -98.8015; -1.5479; -66.6667	**0.0121**
GCSC	**-3.8791 ± j4.7804** -98.7571; -50.9364; -11.4867; -0.1002; -2.1739; -1.5410	**0.6301**

Table 4. Eigenvalues Analysis (Light Operating Condition).

	Eigenvalue	***Damping Ratio***
W.C	**-0.0869 ± j7.9460** -98.7304; -1.6859; -66.6667	**0.1019**
GCSC	**-1.3732 ± j7.3179** -98.7272; -63.3977; -3.8040; -0.1001; -2.2949; -1.6833	**0.1844**

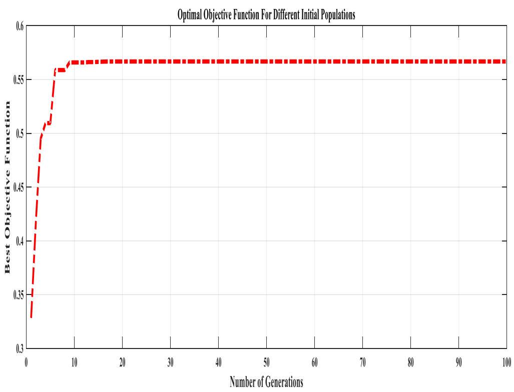

Fig. 5: Optimal Objective Function Graph.

In order to verify the robustness of optimized controller tables (2-4) shows the eigenvalues of system at various operating points beside the damping ratio of electromechanical (EM) mode of oscillations. It's clear the damping ratio of EM of system without any supplementary controllers is low comparing when added the FACTS controller type GCSC which led to increase the damping ratio and also decreasing the settling time of system oscillation and overshoot of system. Figures (6-10) shows the system response when subjected to large disturbance before and after adding the supplementary controllers.

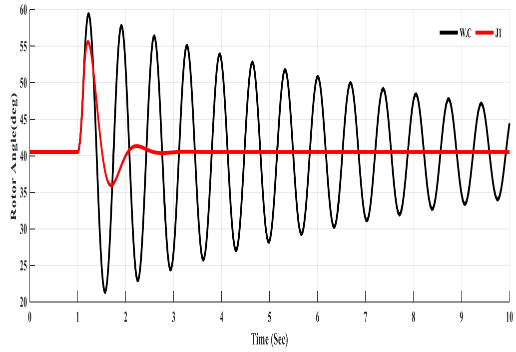

Fig.6: Rotor Angle.

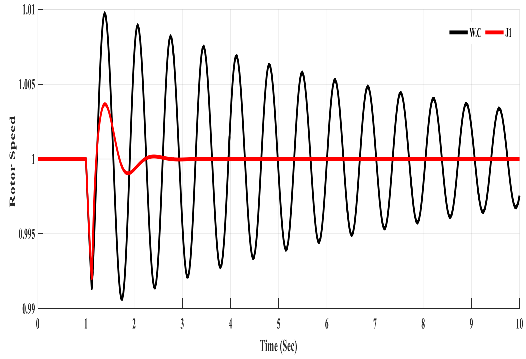

Fig.7: Rotor Speed.

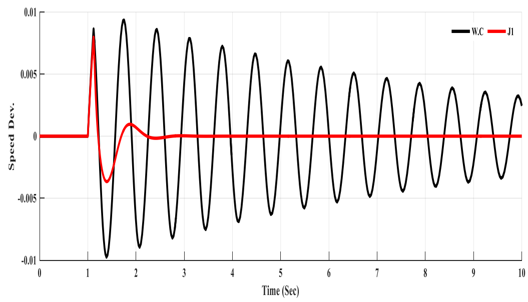

Fig. 8: Speed Deviation.

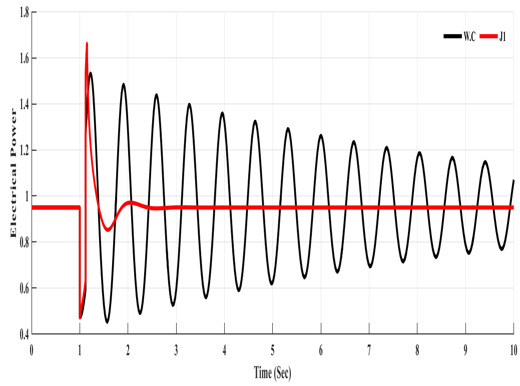

Fig.9: Electrical Power.

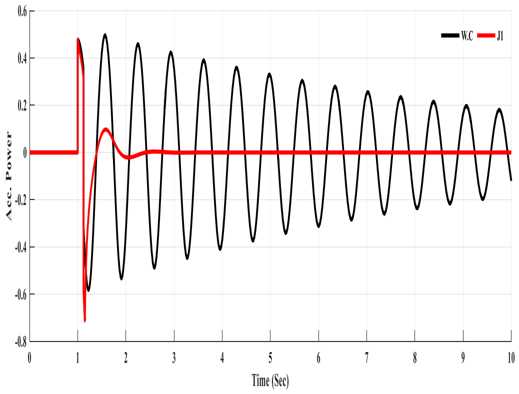

Fig.10: Acceleration Power.

VII. CONCLUSION

In this paper, GCSC damping controller is deigned based on PSO algorithm. Maximization of damping ratio of EM mode of oscillation is selected as objective function to be optimized. The GCSC supplementary controller has succeeded in increasing the damping ratio and then improve the system overall performance. Different loading conditions and a severe disturbance is employed to reveal the efficiency of damping controller. Assessment the nonlinear time domain simulation results and analyzing the eigen-proporties of system supported the robustness of the designed damping controller besides showing the superior performance of the eigenvalue based objective function in enhancing the steady state stability of system.

REFERENCES

[1] P.Kundur, Power system stability and control, 1st ed., McGraw-Hill, Inc., 1994.
[2] P.W.Sauer, M.A.Pai, Power system dynamics and stability, Prentice Hall, 1998.
[3] H.Wang, W.Du, Analysis and damping control of power system low frequency oscillations, Springer, 2016.
[4] E.Acha, V.G.Agelidies, O.Anaya-Lara, T.J.E. Miller, "*Power Electronics Control in Electrical Systems*", Newnes Power Engineering Series, first publish 2002.
[5] Narian.G.Hingorani, Laszlo.Gyugyi, Understanding Facts, Wiley Interscience, 2000.
[6] Swakshar Ray, Ganesh Kumar, Edson H. Watanabe, A Computational approach to optimal damping controller design for a GCSC, IEEE Transactions on power delivery , Vol.23, No.3, July 2008.
[7] D.Mondal, A.Chakrabarti, Power system small signal stability analysis and control, Elsevier, 2014.
[8] N.Rezaei, A.Safari, H.A.Shayanfar,"A Particle Swarm Optimizer to Design A GCSC Based Damping Controller of Power System", International Journal on Technical and Physical problems of power system, Sept. 2011-issue – volume-number 3- page 17-24.
[9] M.Abido, "Power System Stability Enhancement Using FACTS Controllers: A Review", The Arabian Journal for Science and Engineering, Sept. 2008, Volume 34.
[10] Randy L.Haupt, Sue Ellen Haupt, Practical Genetic Algorithm, 2nd ed, Wiley Interscience, 2004.

APPENDIX

The investigated system parameters are:
Machine: $x_d = 1, x_q = 0.8, \acute{x}_d = 0.15, M = 6\,s, f = 50\,Hz, \acute{T}_{do} = 5.044\,s,$
$V_b = 1$, P_b=0.95.
Exciter: $K_A = 10$, $T_A = 0.05\,s.$
Transmission line:
$x_{L1} = x_{L2} = 0.7$, $R_e = 0$
GCSC: X_c=0.7, T_{GCSC}=15 msec.

BIOGRAPHIES

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