

## Dynamic Stability Improvement by Using STATCOM in a Multi Machine Environment

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**Abstract:** Static synchronous Compensator (STATCOM) is a commonly used FACTS devices and has been successfully applied in power systems. One of the most important functions of STATCOM is to improve power system stability. This purpose is obtained by application of a supplementary stabilizer on the STATCOM. In this way, a supplementary stabilizer is installed on the STATCOM and the function of this stabilizer is such as classical PSSs. In this study, Particle Swarm Optimization (PSO) is used to adjustment of STATCOM supplementary stabilizer. A multi machine power system with different loading conditions is considered as case study. Nonlinear time-domain simulations clearly show the ability of STATCOM in damping of power system oscillations and consequently stability improvement.

**Keywords:** Damping of power system oscillations, dynamic stability enhancement, flexible AC transmission systems, multi machine electric power system, static synchronous compensator

### INTRODUCTION

The rapid development of the high-power electronics industry has made Flexible AC Transmission System (FACTS) devices viable and attractive for utility applications. FACTS devices have been shown to be effective in controlling parameters of power system and also in damping power system oscillations. In recent years, new types of FACTS devices have been investigated that may be used to increase power system operation flexibility and controllability, to enhance system stability and to achieve better utilization of existing power systems (Hingorani and Gyugyi, 2000). The Static synchronous Compensator (STATCOM) is one of the most important FACTS devices and it is based on the principle that a voltage-source inverter generates a controllable AC voltage source behind a transformer-leakage reactance so that the voltage difference across the reactance produces active and reactive power exchange between the STATCOM and the transmission network. The can be used for dynamic compensation of power systems to provide voltage support (Aouzellag Lahaçani *et al.*, 2010; Antonio and Juan, 2010; Slepchenkov *et al.*, 2011). Also STATCOM can be used for transient stability improvement by damping of low frequency power system oscillations (Furini *et al.*, 2011; Hemmati *et al.*, 2011).

The objective of this study is to investigate the ability of STATCOM for dynamic stability improvement via damping of low frequency

oscillations. Intelligence optimization methods such as Particle Swarm Optimization (PSO) and Genetic Algorithms (GA) are considered for tuning the parameters of STATCOM supplementary stabilizer. A multi machine power system installed with a STATCOM is considered as case study. A classical Power System Stabilizer (PSS) is connected to STATCOM and the parameters of this STATCOM based stabilizer are adjusted using PSO and GA. The advantages of the proposed methods are their feasibility and simplicity. Different load conditions are considered to show effectiveness of STATCOM and also comparing the performance of PSO and GA. Simulation results show the validity of STATCOM in LFO damping and stability enhancement at large electric power systems.

### METHODOLOGY

**System under study:** Figure 1 shows a multi machine power system installed with STATCOM (Sauer and Pai, 1997). The static excitation system, model type IEEE-ST1A, has been considered. The STATCOM is assumed to be based on Pulse Width Modulation (PWM) converters. Detail of the system data are given in (Sauer and Pai, 1997). To assess the effectiveness and robustness of the proposed method over a wide range of loading conditions, three different cases as nominal, light and heavy loading are considered and listed in Table 1 (Shayeghi *et al.*, 2010). In this study, turbine-governor system is also modeled to eliminate steady state error of responses.

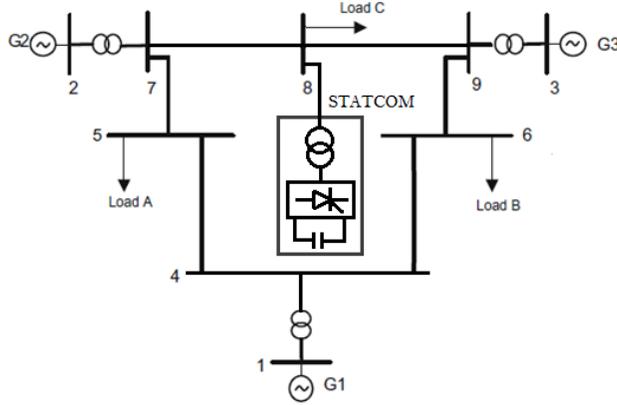


Fig. 1: Multi-machine electric power system

Table 1: System loading conditions

Loa	Light		Nominal		Heavy	
	P	Q	P	Q	P	Q
A	0.65	0.55	1.25	0.50	2.00	0.80
B	0.45	0.35	0.90	0.30	1.80	0.66
C	0.50	0.25	1.00	0.35	1.56	0.60

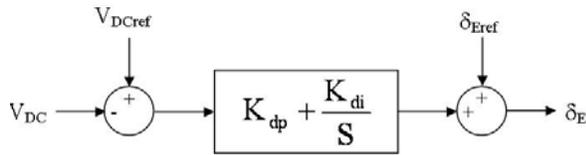


Fig. 2: DC-voltage regulator

**Dynamic model of the system with statcom:** The nonlinear dynamic model of the system installed with STATCOM is given as (1). The dynamic model of the system is completely presented by Sauer and Pai, (1997) and also dynamic model of the system installed with STATCOM is presented in Wang, (1999):

$$\begin{cases}
 \dot{\omega} = (P_m - P_e - D\omega) / M \\
 \dot{\delta} = \omega_b(\omega - 1) \\
 \dot{E}'_q = (-E'_q + E_{fd}) / T'_d \\
 \dot{E}'_{fd} = (-E'_{fd} + K_a(V_{ref} - V_t)) / T_a \\
 \dot{V}_{dc} = \frac{3m_E}{4C_{dc}} (\sin(\delta_E) I_{fd} + \cos(\delta_E) I_{fq})
 \end{cases} \quad (1)$$

By controlling  $m_E$ , the output voltage of the shunt converter is controlled. By controlling  $\delta_E$ , exchanging active power between the STATCOM and the power system is controlled.

**Statcom controllers:** In this study two control strategies are considered for STATCOM:

- DC-voltage regulator
- STATCOM supplementary stabilizer

**C-voltage regulator:** In STATCOM, The output real power of the shunt converter must be equal to the input real power or vice versa. In order to maintain the power balance, a DC-voltage regulator is incorporated. DC-voltage is regulated by modulating the phase angle of the shunt converter voltage. Figure 2 shows the structure of DC-voltage regulator. In this study the parameters of DC-voltage regulator are considered as  $K_{di} = 5.8$  and  $K_{dp} = 3.24$ .

**STATCOM supplementary stabilizer:** A stabilizer controller is provided to improve damping of power system oscillations. This controller is considered as a lead-lag compensator and it provides an electrical torque in phase with the speed deviation in order to improve damping of power system oscillations. The transfer function model of the classical stabilizer is as (2). Where,  $\Delta\omega$  is the deviation in speed from the synchronous speed. This type of stabilizer consists of a washout filter, a dynamic compensator. The output signal is fed as an auxiliary input signal to the STATCOM. The washout filter, which essentially is a high pass filter, is used to reset the steady state offset in the output of the PSS. In this study the value of the Time constant ( $T_w$ ) is fixed to 10 s. The dynamic compensator is made up to two lead-lag stages and an additional gain. The adjustable stabilizer parameters are the gain of the Stabilizer,  $K_{DC}$  and the time constants,  $T_1$ - $T_4$ . The lead-lag block present in the system provides phase lead compensation for the phase lag that

is introduced in the circuit between the STATCOM input and the electrical torque:

$$U = K \frac{ST_w}{1 + ST_w} \frac{1 + ST_1}{1 + ST_2} \frac{1 + ST_3}{1 + ST_4} \Delta\omega \quad (2)$$

**Stabilizer design:** Stabilizer controllers design themselves have been a topic of interest for decades, especially in form of classical Power System Stabilizers (PSS) which are connected to the excitation system of generator. But classical PSS cannot control power transmission and also can not support power system stability under large disturbances like 3-phase fault at terminals of generator (Mahran *et al.*, 1992). For these problems, in this study a stabilizer controller based on STATCOM is provided to mitigate power system oscillations. Two optimization methods such as PSO and GA are considered for tuning stabilizer parameters. In the next section an introduction about PSO is presented.

**Particle swarm optimization:** PSO was formulated by Edward and Kennedy (1995). The thought process behind the algorithm was inspired by the social behavior of animals, such as bird flocking or fish schooling. PSO is similar to the continuous GA in that it begins with a random population matrix. Unlike the GA, PSO has no evolution operators such as crossover and mutation. The rows in the matrix are called particles (same as the GA chromosome). They contain the variable values and are not binary encoded. Each particle moves about the cost surface with a velocity. The particles update their velocities and positions based on the local and global best solutions as shown in (3) and (4) (Randy and Sue, 2004):

$$V_{m,n}^{new} = w \times V_{m,n}^{old} + \Gamma_1 \times r_1 \times (P_{m,n}^{local\ best} - P_{m,n}^{old}) + \Gamma_2 \times r_2 \times (P_{m,n}^{global\ best} - P_{m,n}^{old}) \quad (3)$$

$$P_{m,n}^{new} = P_{m,n}^{old} + \Gamma V_{m,n}^{new} \quad (4)$$

The PSO algorithm updates the velocity vector for each particle then adds that velocity to the particle position or values. Velocity updates are influenced by both the best global solution associated with the lowest cost ever found by a particle and the best local solution associated with the lowest cost in the present population. If the best local solution has a cost less than the cost of the current global solution, then the best local solution replaces the best global solution. The particle velocity is reminiscent of local minimizes that use derivative information, because velocity is the derivative of position. The advantages of PSO are that it

is easy to implement and there are few parameters to adjust. The PSO is able to tackle tough cost functions with many local minima (Randy and Sue, 2004).

**PSO based stabilizer design:** In this section the parameters of the proposed stabilizer controller are tuned using PSO. Two control parameters of the STATCOM (mE, δE) can be modulated in order to produce the damping torque. The parameter mE is modulated to output of damping controller and speed deviation Δω is also considered as input of damping controller. The structure of supplementary stabilizer has been shown in (2). The optimum values of K and T1-T4 which minimize an array of different performance indexes are accurately computed using PSO. In optimization methods, the first step is to define a performance index for optimal search. In this study the performance index is considered as (5):

$$J = \left( \sum_{\sigma_i \geq \sigma_0} (\sigma_0 - \sigma_i) \right)^2 + a \times \left( \sum_{\xi_i \geq \xi_0} (\xi_0 - \xi_i) \right) \quad (5)$$

The parameter “a” is a weighting factor and is set as 10. Figure 3 shows σ0 and ξ0 and related region. This objective function reallocates the poles toward the dashed region. In this study the region parameters are considered as σ0 = -1.5 and ξ0 = 0.2.

To compute the optimum parameter values, a 10 cycle three phase fault is assumed in bus 3 and the performance index is minimized using PSO. In order to acquire better performance, number of particle, particle size, number of iteration, Γ1, Γ2 and Γ are chosen as 24, 5, 50, 2, 2 and 1, respectively. Also, the inertia weight, w, is linearly decreasing from 0.9 to 0.4. The optimum values of parameters, resulting from minimizing the performance index is presented in Table 2. Also in order to show effectiveness of PSO method, the parameters of stabilizer controller are tuned using the other optimization method, GA. In GA case, the performance index is considered as PSO case and the optimal parameters of stabilizer controller are obtained as shown in Table 2.

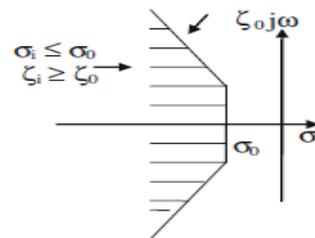
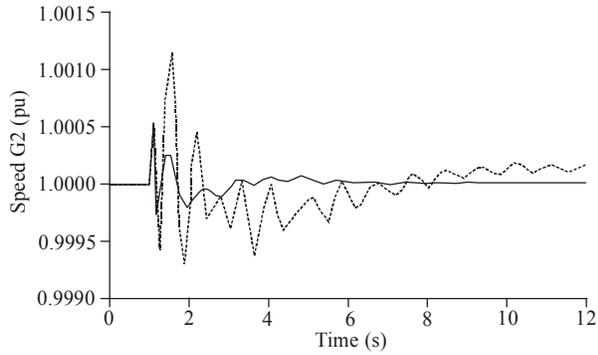


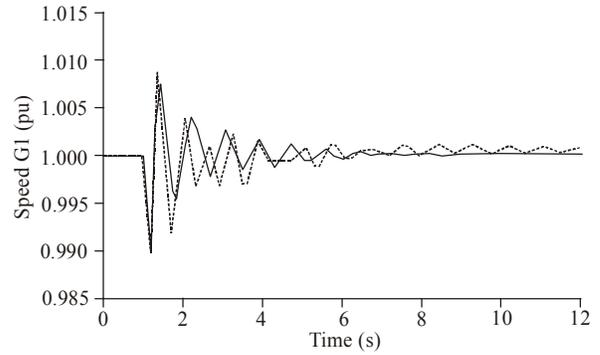
Fig. 3: Region of eigenvalue location for objective function

Table 2: Optimal parameters of stabilizer using PSO and GA

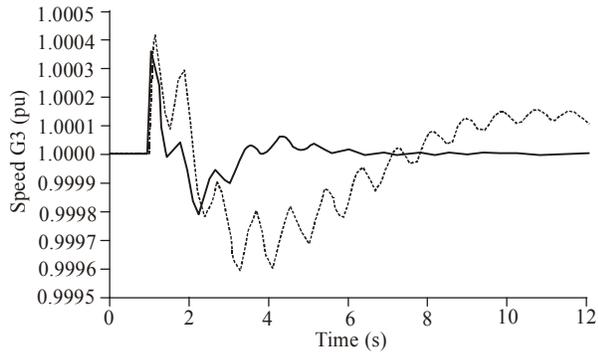
PSO					GA				
K	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>	K	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>
1.58	0.202	0.05	0.57	0.05	1.66	0.401	0.05	0.68	0.05



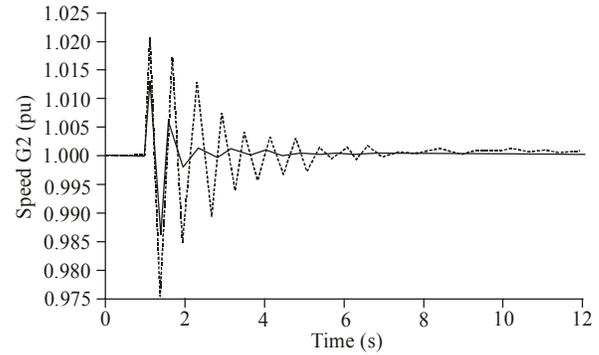
(a)



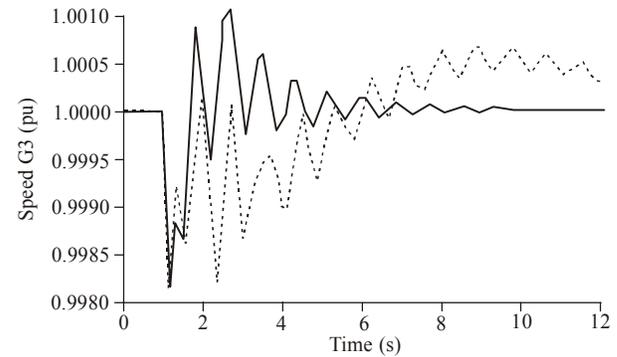
(a)



(b)



(b)



(c)

Fig. 4: System responses under scenario 1 with nominal loading condition solid (PSO-stabilizer), dashed (GA-stabilizer), dotted (without-stabilizer) a:  $\Delta\omega_1$  b:  $\Delta\omega_2$  c:  $\Delta\omega_3$

### RESULTS AND DISCUSSION

In this section, the designed PSO and GA based stabilizers are exerted to damping LFO in the under study system. In order to study and analysis system performance under different scenarios, two scenarios are considered as follows:

**Scenario 1:** 6 cycle three phase short circuit in bus 6

**Scenario 2:** 10 cycle three phase short circuit in bus 9

It should be noted that the PSO and GA based stabilizers have been designed for the nominal operating condition. The simulation results are presented in Fig. 4 to 5. Following cases have been considered and simulated:

Fig. 4: Simulation results under scenario 1 in the nominal operating condition

Fig. 5: System responses under scenario 2 with heavy loading conditionsolid (PSO-stabilizer), dashed (GA-stabilizer) a:  $\Delta\omega_1$  b:  $\Delta\omega_2$  c:  $\Delta\omega_3$

Fig. 5: Simulation results under scenario 2 in the heavy operating condition

Each figure contains three parameters as follows: PSO based stabilizer (solid line), GA based stabilizer (dashed line) and system without stabilizer (dotted line). The simulation results show that applying the supplementary stabilizer signal greatly enhances the

damping of the generator angle oscillations and therefore the system becomes more stable. The PSO stabilizer performs better than the GA stabilizer. With changing operating condition from the nominal to heavy, while the performance of GA supplementary stabilizer becomes poor, the PSO stabilizer has a stable and robust performance. It can be concluded that the PSO supplementary stabilizer have suitable parameter adaptation in comparison with the GA supplementary stabilizer when operating condition changes. Also in all figures, the system responses without any supplementary stabilizer have been shown. It is clear to see that the system without stabilizer does not have enough damping and the responses go to fluctuate after disturbance. The both stabilizers (GA and PSO) greatly enhanced power system damping, but in view of comparison the PSO based stabilizer can inject more stabilizing signal than GA.

The results clearly show that in large electric power systems, STATCOM can successfully increase damping of power system oscillations and the system with STATCOM based stabilizer is more robust and stable after disturbances. In this study, considering different types of disturbances short circuit helps to comprehensive study of STATCOM under real world disturbances.

### CONCLUSION

In this study Genetic Algorithms and Particle Swarm Optimization have been successfully exerted to adjust a supplementary stabilizer based on STATCOM. A multi machine electric power system installed with a STATCOM with various load conditions and disturbances has been assumed to demonstrate the ability of STATCOM in stability enhancement via LFO damping. Considering real world type disturbances such as three phase short circuit guarantee the results in order to implementation of controller in industry. Simulation results demonstrated that the designed STATCOM based stabilizers capable to guarantee the robust stability and robust performance under a different load conditions and disturbances. Also, simulation results show that the PSO technique has an excellent capability in comparison with GA method. Application to a multi machine electric power system which is near to practical systems can increase admission of the technique for real world applications.

### ACKNOWLEDGMENT

This study is a result of an approved research project in Islamic Azad University, Boroujen branch. Therefore we know necessary to thank this academic unit staunch for its most grateful support.

### REFERENCES

- Antonio, V. and M.R. Juan, 2010. DStatCom regulation by a fuzzy segmented PI controller. *Elect. Pow. Syst. Res.*, 80(6): 707-715.
- Aouzellag Lahaçani, N., D. Aouzellag and B. Mendil, 2010. Static compensator for maintaining voltage stability of wind farm integration to a distribution network. *Renew. Energ.*, 35(11): 2476-2482.
- Furini, M.A., A.L.S. Pereira and P.B. Araujo, 2011. Pole placement by coordinated tuning of Power System Stabilizers and FACTS-POD stabilizers. *Int. J. Elec. Power Energ. Syst.*, 33(3): 615-622.
- Hemmati, R., S.M. Shirvani Boroujeni, E. Behzadipour and H. Delafkar, 2011. Supplementary stabilizer design based on STATCOM. *Indian J. Sci. Technol.*, 4(5): 525-529.
- Hingorani, N.G. and L. Gyugyi, 2000. *Understanding FACTS*. IEEE Press, NJ.
- Mahran, A.R., B.W. Hogg and M.L. El-sayed, 1992. Co-ordinate control of synchronous generator excitation and static var compensator. *IEEE Trans. Energ. Conver.*, 7(4): 615-622.
- Randy, L.H. and E.H. Sue, 2004. *Practical Genetic Algorithms*, 2nd Edn., John Wiley and Sons, New Jersey.
- Sauer, P.W. and M.A. Pai, 1997. *Power System Dynamics and Stability*, Prentice Hall, Champaign, IL., Chapter 7, pp: 193-260.
- Shayeghi, H., H.A. Shayanfar, A. Safari and R.A. Aghmasheh, 2010. Robust PSSs design using PSO in a multi-machine environment. *Energ. Conver. Manage.*, 51: 696-702.
- Slepchenkov, M.N., K.M. Smedley, J. Wen, 2011. Hexagram-converter-based STATCOM for voltage support In fixed-speed wind turbine generation systems. *IEEE T. Ind. Electron.*, 58(4): 1120-1131.
- Wang, H.F., 1999. Phillips-Heffron model of power systems installed with STATCOM and applications. *IEE Proceeding Gen. Trans. Distr.* 146(5): 521-527.