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Using Particle Swarm Optimization Method for Supplementary STATCOM Stabilizer Tuning in Electric Power System

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Abstract: In this study, the performance of supplementary stabilizer for static synchronous compensator (STATCOM) tuned based on particle swarm optimization method in order to improvement of dynamic stability is studied. Since STATCOM is usually used for damping Low Frequency Oscillations (LFO), a supplementary stabilizer is incorporated with STATCOM to reach the mentioned purpose. As a heuristic optimization technique, Particle Swarm Optimization (PSO) is used for tuning the parameters of the STATCOM supplementary stabilizer. The IEEE 14 bus test system is considered for achieving simulation results .In order to show the ability of GA-based STATCOM to damp LFO, the system responses in case with and without STATCOM are compared. Also two different operation conditions i.e. normal and heavy have been considered for better examination of PSO-based STATCOM performance. Several nonlinear time-domain simulation tests visibly show the ability of STATCOM in damping of power system oscillations and consequently stability enhancement.

Key words: Damping of power system oscillations, dynamic stability enhancement, flexible ac transmission systems, multi machine electric power system, particle swarm optimization, 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. It can be used for dynamic compensation of power systems to provide voltage support (Slepchenkov *et al*., 2011; Li *et al*., 2007; Singh *et al*., 2004; Lahaçani *et al*., 2010; Valderrábano and Ramirez, 2010). Also STATCOM can be used for transient stability improvement by damping of low frequency power system oscillations (Chatterjee and Ghosh, 2011; Padiyar and Prabhu, 2006; Furini *et al*., 2011; Hemmati *et al*., 2011). The objective of this study is to investigate the ability of STATCOM joined with a supplementary stabilizer for dynamic stability improvement via damping of low frequency oscillations. An auxiliary stabilizer is used to increase power system damping torque. Particle Swarm Optimization (PSO) is considered for tuning the parameters of the proposed STATCOM supplementary stabilizer. A multi machine power system is chosen as case study. Different load conditions are incorporated to show effectiveness of STATCOM. Simulation results show the validity of STATCOM in LFO damping and stability enhancement at large electric power systems.

System under study: In this study IEEE 14 bus test system is considered to evaluate the proposed method. The system data are completely given in IEEE standards. Figure 1 shows the considered system with a STATCOM installed in bus 14. Detail of the system data have been given in (University of Washington). To evaluate the effectiveness and robustness of the proposed method over a wide range of loading conditions, two different cases as nominal and heavy loading are considered. Where, in the

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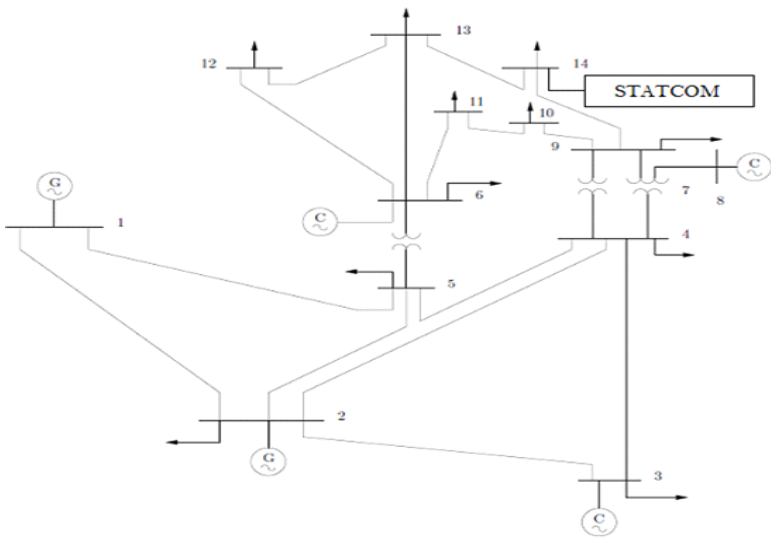

Fig. 1: Multi-machine electric power system installed with STATCOM

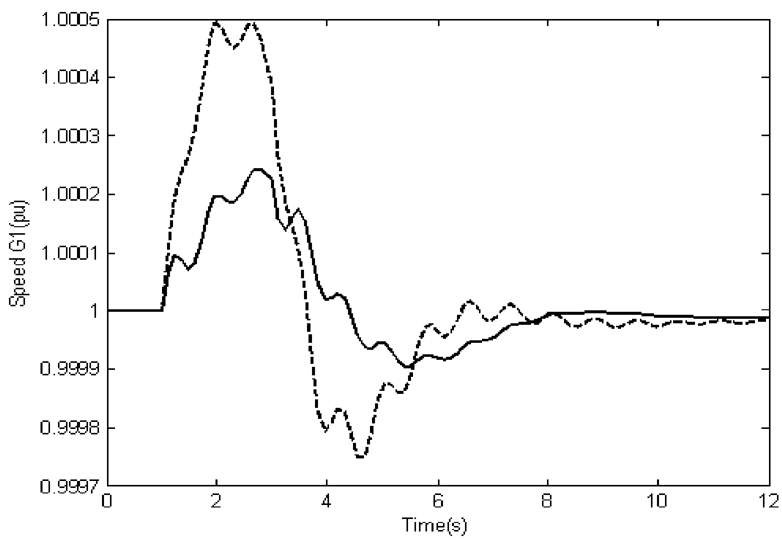

Fig. 2: Speed of generator 1 under fault scenario in the nominal operating condition solid (with STATCOM), dashed (without STATCOM)

Table 1: Optimal parameters of stabilizer using PSO

Parameter	K	T_1	T_2	T_3	T_4
Optimal value	0.92	0.83	0.019	0.83	0.019

heavy condition, the active and reactive powers of loads are considered by 30% increasing from the nominal vales. Also, in this paper, turbine-governor system is also modeled to eliminate steady state error of responses.

Dynamic model of the system with STATCOM: The nonlinear dynamic model of the system installed with STATCOM is given as (1). The detailed explanation is completely presented in (Wang, 1999).

$$\begin{cases} \dot{\omega} = (Om - Pe - D\omega)/M \\ \dot{\delta} = \omega 0(\omega - 1) \\ Eq' = \left(-E_q + \dot{E}_{fd}\right)/T'_{do} \\ \dot{E}'_f\, q = \left(-\dot{E}_{fd} + K_a\left(V_{ref} - V_t\right)\right) \\ b_{svc} = \left(Kr\left(\dot{V}_{ref} - V\right) - b_{svc}\right)/T_r \end{cases} \tag{1}$$

where, δ: Rotor angle; ω: Rotor speed (pu); P_m: Mechanical input power; P_e: Electrical output power (pu); M: System inertia (Mj/MVA); E'_q: Internal voltage behind x'_d (pu); E_{fd}: Equivalent excitation voltage (pu); T'_{do}: Time constant of excitation circuit (s); K_a: Regulator gain; T_a: Regulator time constant (s); V_{ref}: Reference voltage (pu); V_t: Terminal voltage (pu).By controlling m_E, the output voltage of the shunt converter is controlled. By controlling $_E$, 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

DC-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. In this paper the parameters of DC-voltage regulator are considered as K_{di} = 22.78 and K_{dp}= 8.21.

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). This type of stabilizer consists of a washout filter, a dynamic compensator. Where, U_{in} can be the speed deviation, active power of line, bus voltage or etc and the output signal U_{out} 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 paper the value of the time constant (Tw) 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, T1-T4. 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.

$$U_{out} = K\frac{ST_W}{1+ST_w}\frac{1+ST_3}{1+ST_4}U_{in} \tag{2}$$

In this study PSO is used for tuning the proposed stabilizer parameters. In the next section an introduction about PSO is presented.

Particle swarm optimization: PSO was formulated by Edward and Kennedy in 1995. The thought process behind the algorithm was inspired by the social behavior of animals, such as bird flocking or fish schooling. PSO begins with a random population matrix. It has no evolution operators such as crossover and mutation. The rows in the matrix are called particles. 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):

$$\begin{aligned} V_{m,n}^{new} = W \times V_{m,n}^{old} + \bar{1}_1 \times r_1 \times \left(P_{m,n}^{localbast} - P_{m,n}^{old}\right) \\ + \bar{1}_2 \times r_2 \times \left(P_{m,n}^{globalbast} - P_{m,n}^{old}\right) \end{aligned} \tag{3}$$

$$P_{,n}^{new} = P_{m,n}^{old} = \bar{1}v_{m,n}^{new} \tag{4}$$

where, $V_{m,n}$: Particle velocity; $P_{m,n}$: Particle variables; W: Inertia weight; r_1, r_2: Independent uniform random numbers; Γ_1, Γ_2: Learning factors; $P_{m,n}^{local\ best}$: Best local solution; $P_{m,n}^{global\ best}$: Best global solution.

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 are tuned using PSO. Two control parameters of the STATCOM (m_E, δ_E) can be modulated in order to produce the damping torque. The parameter m_E is modulated to output of damping controller and power of line between bus 13 and bus 14 is also considered as input of damping controller. The optimum values of K and T_1-T_4 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). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (ITAE).

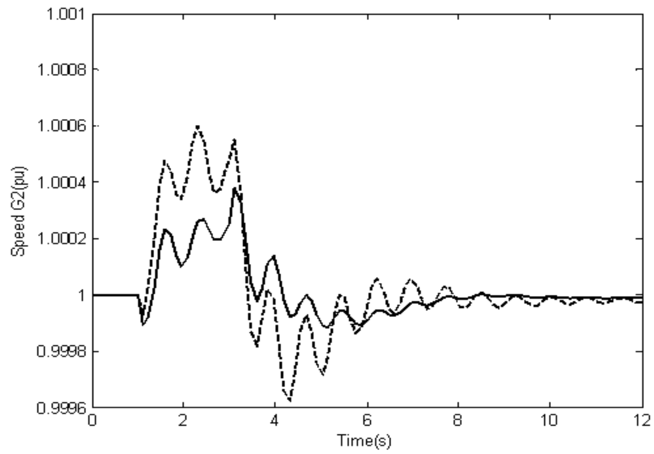

Fig. 3: Speed of generator 2 under fault scenario in the nominal operating condition solid (with STATCOM), dashed (without STATCOM)

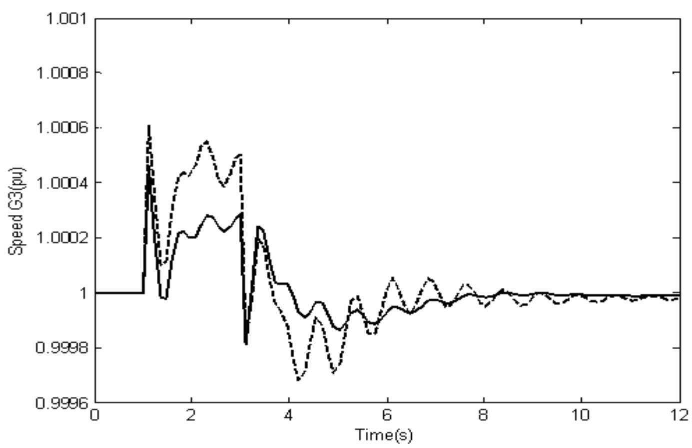

Fig. 4: Speed of generator 3 under fault scenario in the nominal operating condition solid (with STATCOM), dashed (without STATCOM)

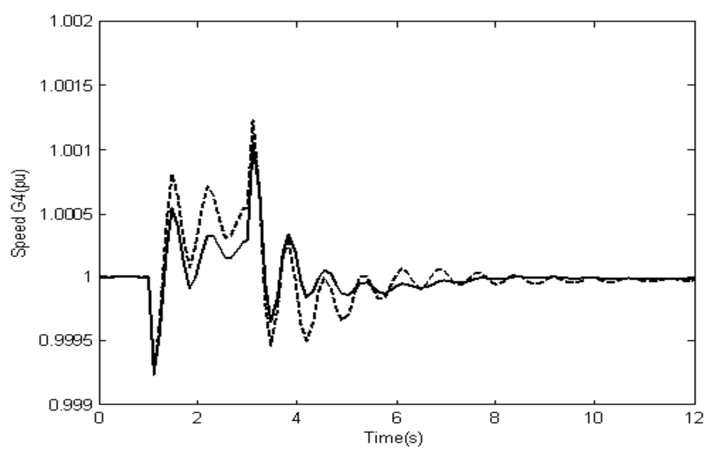

Fig. 5: Speed of generator 4 under fault scenario in the nominal operating condition solid (with STATCOM), dashed (without STATCOM)

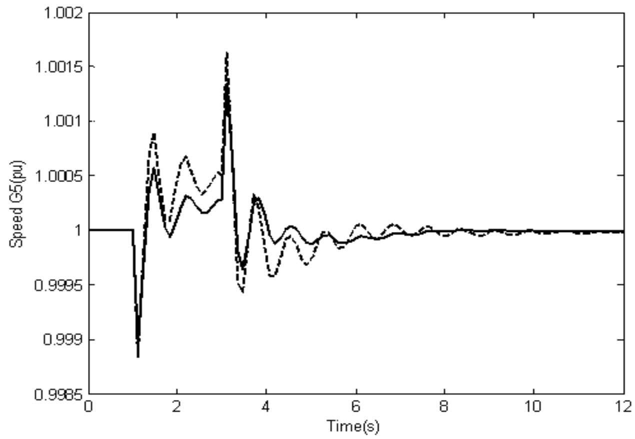

Fig. 6: Speed of generator 5 under fault scenario in the nominal operating condition solid (with STATCOM), dashed (without STATCOM)

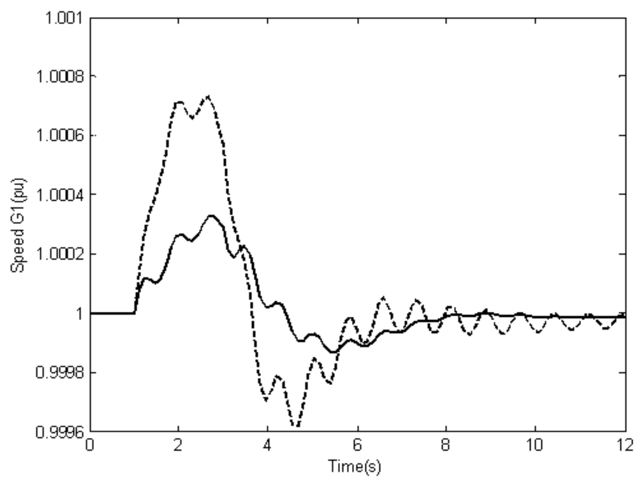

Fig. 7: Speed of generator 1 under fault scenario in the heavy operating condition solid (with STATCOM), dashed (without STATCOM)

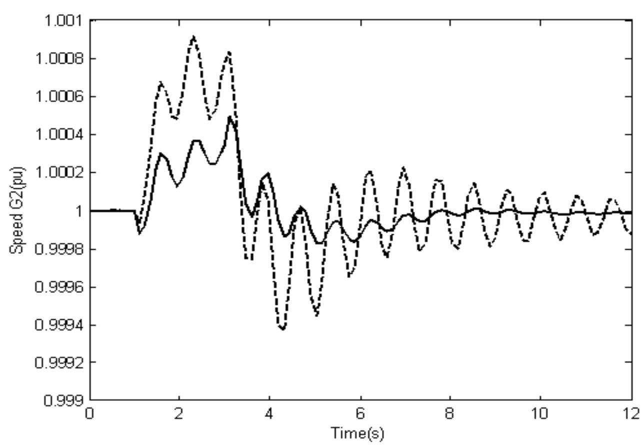

Fig. 8: Speed of generator 2 under fault scenario in the heavy operating condition solid (with STATCOM), dashed (without STATCOM)

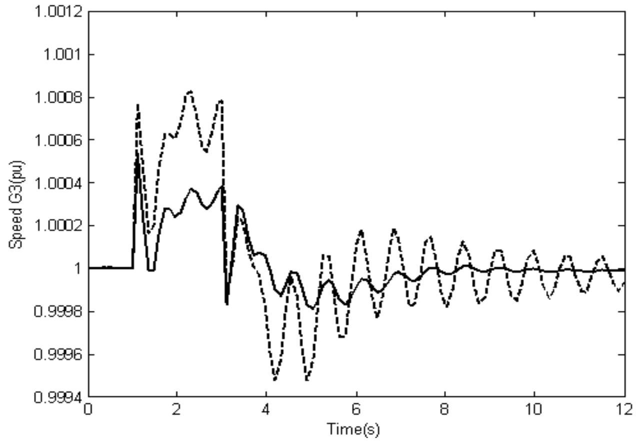

Fig. 9: Speed of generator 3 under fault scenario in the heavy operating condition solid (with STATCOM), dashed (without STATCOM)

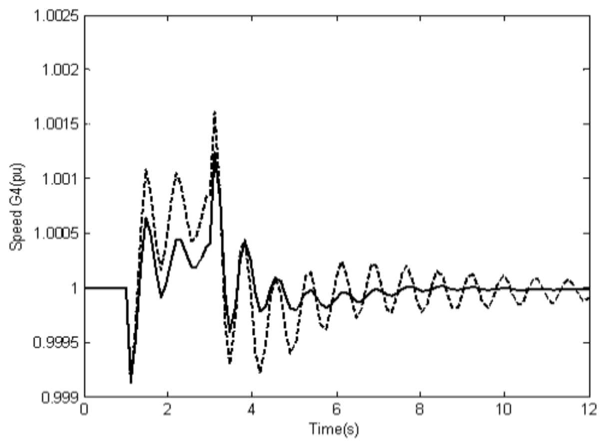

Fig. 10: Speed of generator 4 under fault scenario in the heavy operating condition solid (with STATCOM), dashed (without STATCOM)

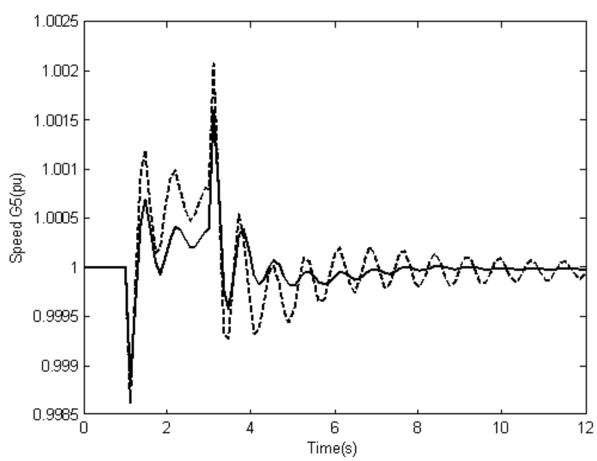

Fig. 11: Speed of generator 5 under fault scenario in the heavy operating condition solid (with STATCOM), dashed (without STATCOM)

$$ITAE = \int_0^t t|\nabla\omega_1|\,dt + \int_0^t t|\nabla\omega_2|\,dt + \int_0^t t|\nabla\omega_3|\,dt + \int_0^t t|\nabla\omega_4|\,dt + \int_0^t t|\nabla\omega_5|\,dt \quad (5)$$

where, shows the frequency deviations. It is clear to understand that the controller with lower ITAE is better than the other controllers. To compute the optimum parameter values, a 8 cycle three phase fault is assumed in bus 2 and the performance index is minimized using PSO. The optimum values of parameters, resulting from minimizing the performance index is presented in Table 1.

RESULTS AND DISCUSSION

In this section, the tuned supplementary stabilizer is incorporated with STATCOM. In order to study and analysis system performance under different scenarios, fault scenario is considered as follows:

Fault Scenario: Disconnection of the line between bus 2 and bus 4 by breaker

It is worth to mention that in the fault scenario, the line is disconnected by breaker and after one second the line is connected again.

The simulation results are presented in Fig. 2-11. Each figure contains two plots; solid line which indicates on the system installed with STATCOM and dashed line for system without STATCOM.

As it is clear in Fig. 2-6, in normal operation condition, STATCOM could damp the generator angle oscillations faster in comparison with the case of the lack of STATCOM. It means that by applying the supplementary stabilizer signal the system becomes more stable.With changing operating condition from nominal to heavy, looking to Fig 7-11, the performance of system without STATCOM becomes poor, but the system with STATCOM has a stable and robust performance. The results clearly show that in large electric power systems, STATCOM can successfully increase damping of power system oscillations and the system with STATCOM is more robust and stable after disturbances, either in normal or heavy operation conditions.

CONCLUSION

In this study Particle Swarm Optimization (PSO) method has been successfully exerted to adjust supplementary STATCOM parameters. 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 damping of power system oscillations. Considering real world type disturbances such as line disconnection guarantee the results in order to implementation of controller in industry. Simulation results demonstrated that the designed STATCOM 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 STATCOM parameters tuning. Application to a multi-machine electric power system which is near to practical systems can increase admission of the technique for real world applications.

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