Application of series FACTS devices in power system

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Abstract: Flexible AC Transmission Systems (FACTS) are the well known and commonly used components in power system. These components are manly used to control of power system and also stability improvement. One of the benefits of FACTS devices is to damp out low frequency oscillations (LFO). One of the most important FACTS devices is Static Synchronous Series Compensator (SSSC) which is installed in series with line. In this paper SSSC is used to damp out LFO and a supplementary stabilizer based on SSSC is designed. Partial Swarm Optimization (PSO) is used to adjust the parameters of the proposed stabilizer.
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1. Introduction

With the practical applications of converter-based flexible AC transmission system (FACTS) controllers [1] such as the static synchronous compensator (STATCOM) [2], static synchronous series compensator (SSSC) [3] and unified power-flow controller (UPFC) [4], modeling and analysis of these FACTS controllers in power-system operation and control is of great interest. Power-flow calculations are fundamental to the operation, planning and control of power systems. In recent years, significant work has been done in the modeling of the FACTS controllers in power flow and optimal-power-flow studies [5–12].

SSSC is a voltage-sourced converter-based series compensator and was proposed within the concept of using converter-based technology uniformly for shunt and series compensation, as well as for transmission angle control. It has been successfully applied in power systems. In this paper, SSSC is used to increase power system stability. A supplementary stabilizer is equipped based on SSSC. The parameters of the proposed stabilizer are tuned by using PSO.

2. Static Synchronous Series Compensator (SSSC)

SSSC is one of the most important FACTS devices. It is installed in series with transmission line. This device has a voltage source converter serially connected to a transmission line through a transformer. It is necessary an energy source to provide a continuous voltage through a condenser and to compensate the losses of the VSC. A SSSC is able to exchange active and reactive power with the transmission system. But if our only aim is to balance the reactive power, the energy source could be quite small. The injected voltage can be controlled in phase and magnitude if we have an energy source that is big enough for the purpose. With reactive power compensation only the voltage is controllable, because the voltage vector forms 90º degrees with the line intensity. In this case the serial injected voltage can delay or advanced the line current. This means that the SSSC can be uniformly controlled in any value, in the VSC working slot.

The Static Synchronous Series Compensator (SSSC) uses a VSC interfaced in series to a transmission line, as shown in the Figure 1. Again, the active power exchanged with the line has to be maintained at zero hence, in steady state operation, SSSC is a functional equivalent of an infinitely variable series connected capacitor. The SSSC offers fast control and it is inherently neutral to sub-synchronous resonance.

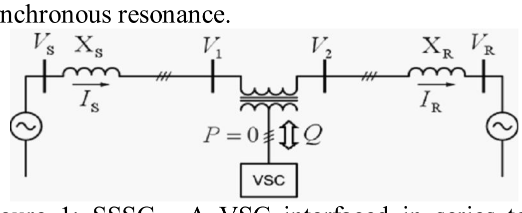

Figure 1: SSSC - A VSC interfaced in series to a transmission line

As mentioned, Static Synchronous Series Compensator (SSSC) is placed in the group of series connected FACTS devices. As shown in Figure 2, SSSC consists of a voltage source inverter connected in series through a coupling transformer to the transmission line. A source of energy is required for providing and maintaining the DC voltage across the DC capacitor and compensation of SSSC losses.

Figure 3 shows the model of SSSC which consists of a series connected voltage source in series with impedance. This impedance represents the impedance of coupling transformer. The SSSC when operated with an appropriate DC supply (an energy source and/or sink, or suitable energy storage) can inject a component of voltage in anti-phase with the voltage developed across the line resistance, to counteract the effect of the resistive voltage drop on the power transmission.

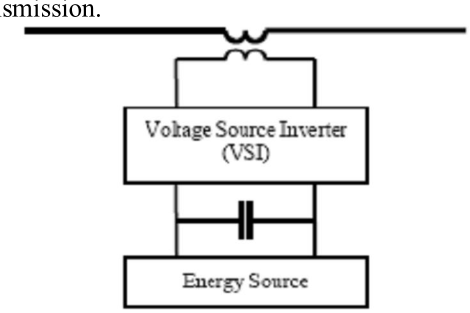

Figure 2: basic configuration of SSSC

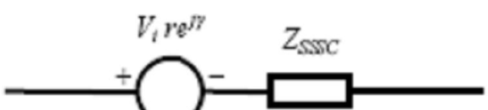

Figure 3: equivalent circuit of SSSC

3. Test system

A multi machine power system installed with SSSC is considered as case study. The proposed system is shown in figure 4. The SSSC is installed in line 4 and system data can be found in [13].

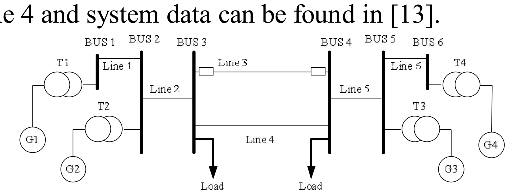

Figure 4: power system installed with SSSC in line 4

4. Power system stabilizer

An AVR (without supplementary control loops) can weaken the damping provided by the damper and field windings. This reduction in the damping torque is primarily due to the voltage regulation effects inducing additional currents in the rotor circuits that oppose the currents induced by the rotor speed deviation Δω. Adding supplementary control loops to the generator AVR or FACTS devices is one of the most common ways of enhancing both small-signal (steady-state) stability and large-signal (transient) stability. The Stabilizer can be used to add damping signal to the SSSC, where the output signal of the stabilizer is used as an additional input (v_{stab}) to the SSSC. The stabilizer input signal can be either the machine speed deviation, Δω, or its acceleration power. The stabilizer is modeled by the nonlinear system depicted in Figure 5.

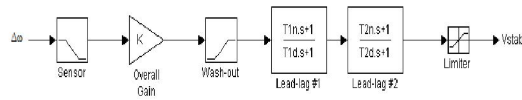

Figure 5: Conventional stabilizer

The model consists of a low-pass filter, a general gain, a washout high-pass filter, a phase-compensation system, and an output limiter. The general gain K determines the amount of damping produced by the stabilizer. The washout high-pass filter eliminates low frequencies that are present in the Δω signal and allows the stabilizer to respond only to speed changes. The phase-compensation system is represented by a cascade of two first-order lead-lag transfer functions used to compensate the phase lag between the excitation voltage and the electrical torque of the synchronous machine.

5. Partial Swarm Optimization

PSO was formulated by Edward and Kennedy in 1995 [14]. 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 (1-2):

$$V_{m,n}^{new} = w \times V_{m,n}^{old} + \Gamma_1 \times r_1 \times (P_{m,n}^{local\ best} - P_{m,n}^{old}) + \Gamma_2 \times r_2 \times (P_{m,n}^{global\ best} - P_{m,n}^{old}) \quad (1)$$

$$P_{m,n}^{new} = P_{m,n}^{old} + \Gamma\ V_{m,n}^{new} \quad (2)$$

Where:

$V_{m,n}$ = particle velocity

$P_{m,n}$ = particle variables

W= inertia weight

r_1, r_2 = independent uniform random numbers

$\Gamma_1 = \Gamma_2$ = 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.

6. Design methodology

The proposed supplementary stabilizer is designed based on the SSSC in the given test system. The stabilizer design by using PSO is presented in details by [15]. In this study the performance index is considered as (3). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (*ITAE*).

$$ITAE = \int_0^t t|\Delta\omega|dt \quad (3)$$

It is clear to understand that the controller with lower performance index is better than the other controllers. To compute the optimum parameters, different faults are assumed and then the best responses are chosen. In order to acquire better performance, number of particle, particle size, number of iteration, Γ_1, Γ_2, and Γ are chosen as 5, 12, 40, 2, 2 and 1, respectively. Also, the inertia weight, w, is linearly decreasing from 0.9 to 0.4. It should be noted that PSO algorithm is run several times and then optimal set of parameters is selected. The optimum values of the stabilizer parameters are obtained using PSO and summarized in the Table 1.

Table 1: Obtained parameters of stabilizer

parameter	K	T_{1n}	T_{1d}	T_{2n}	T_{2d}
value	9.11	0.44	0.01	0.35	0.01

7. Simulation result

The proposed stabilizer is evaluated based on the test system. Large disturbance is considered to show ability of the proposed stabilizer. The simulation results are depicted in figures 6-8. It is seen that the system without stabilizer contains insufficient damping and the responses are pendulous. But the stabilizer can greatly enhance power system stability and damp out the oscillations and the advantages of the proposed stabilizer are visibly seen.

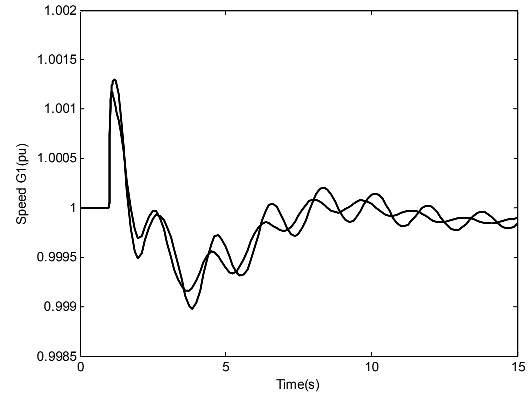

Figure 6: Speed G_1 following 10 cycle three phase short circuit in bus 8 (**Solid**: with stabilizer **dashed**: without stabilizer)

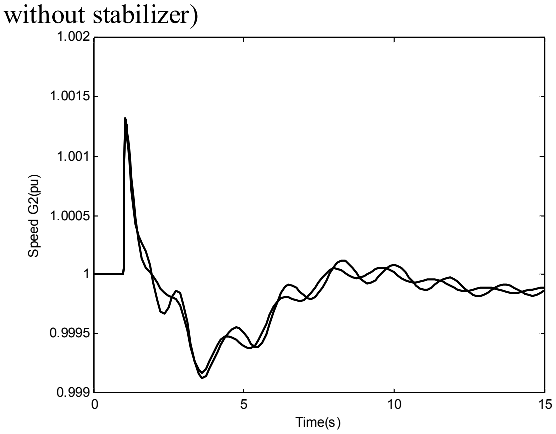

Figure 7: Speed G_2 following 10 cycle three phase short circuit in bus 8 (**Solid**: with stabilizer **dashed**: without stabilizer)

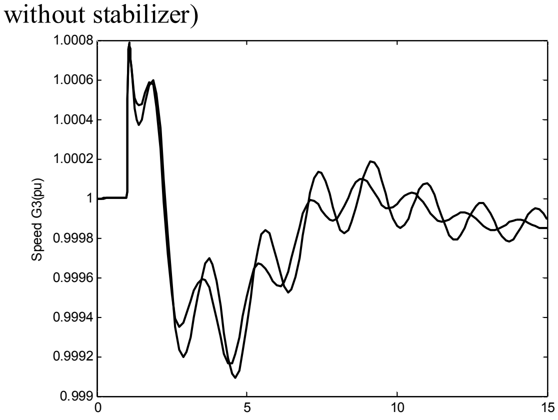

Figure 8: Speed G_3 following 10 cycle three phase short circuit in bus 8 (**Solid**: with stabilizer **dashed**: without stabilizer)

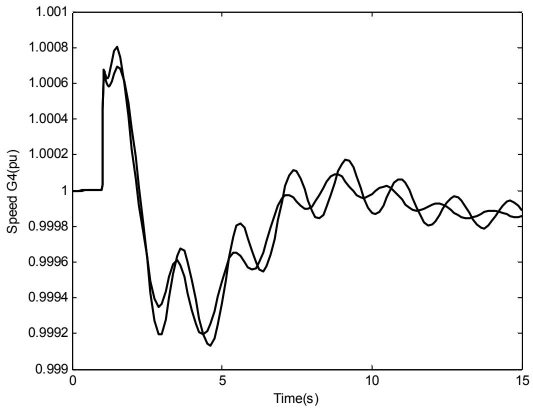

Figure 9: Speed G_4 following 10 cycle three phase short circuit in bus 8 (**Solid**: with stabilizer **dashed**: without stabilizer)

8. Conclusion

A supplementary stabilizer based on SSSC presented here. A two area power system assumed to show the ability of the proposed method. Non linear simulation results demonstrated that the designed stabilizer capable to guarantee the robust stability and robust performance under disturbances. Also, simulation results show that the PSO is a suitable tool to design stabilizer parameters.

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